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Influence of Aldicarb on the Growth and Yield of Tobacco[1]

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Abstract: Microplot and field experiments were used to examine the plant-growth stimulation frequently associated with the use of aldicarb on tobacco in the absence of major pests. Aldicarb rates of 1.5–4.5 kg a.i./ha enhanced tobacco growth and yield in most experiments, but higher rates (≥ 4.5 kg) usually resulted in a neutral to negative effect. Tobacco cultivars NC 82 and Speight G-28 were more responsive than McNair 944 to the pesticide in microplots. Supplemental irrigation enhanced the responsiveness of Speight G-70 tobacco and McNair 944 to aldicarb, but excessive moisture (ca. 7–8 cm/week) limited cured-leaf yields. Aldicarb also resulted in the greatest mean tobacco yields in 35 field experiments involving *Meloidogyne* spp. over 3 years, relative to ethoprop, 1,3-dichloropropene (1,3-D), 1,3-D + chloropicrin, and nontreated controls. Thus, aldicarb generally enhanced tobacco growth and yield in the presence or absence of nematodes, but its impact is dependent on other variables, including cultivar, soil moisture, and soil type.
Key words: aldicarb, growth regulation, *Meloidogyne* spp., nematicide, *Nicotiana tabacum*, Temik.

The secondary effects of certain insecticide–nematicides, including aldicarb (Temik, Union Carbide Agricultural Products Co., now Rhône-Poulenc), on plant growth and yield have received much attention but remain poorly documented and not well understood (1,4,6). The numerous parameters that may impact directly on plant-growth responses to aldicarb have been reviewed (1) and will not be discussed in detail here.

Application of technical or formulated aldicarb enhanced soybean growth and yield, under certain conditions (1). Similar treatments resulted in oat-coleoptile elongation (R. V. Miller et al., unpubl.) and delayed senescence of tobacco-callus cells (J.-S. Huang et al., unpubl.) possibly because of ethylene inhibition (4). One study has shown that aldicarb suppresses ethylene synthesis in green soybean leaf tissue (4). Certain treatments with this compound, however, may be phytotoxic on cotton grown in the absence of pests in the greenhouse (6).

Research in this laboratory has focused on the impact of cultivar, growth media, and temperature on the responses of soybean to aldicarb (1). The present study concerned the differential growth and yield responses of tobacco (*Nicotiana tabacum* L.) cultivars to various rates of aldicarb, related effects of irrigation rates and soil types on growth responses of this crop to aldicarb in microplots, and comparative efficacy and effects of responses of tobacco to selected nematicides on tobacco yields in fields infested with *Meloidogyne* spp.

MATERIALS AND METHODS

Microplot studies: Unless indicated otherwise all microplots were treated with approximately 73 g a.i. of methyl bromide (Brozone 68% a.i.) per square meter 6 weeks before establishing a given crop. The polyethylene cover used to retain the fumigant was removed 5–7 days after treatment. All soil was tilled two or three times during the remaining 5 weeks to facilitate the release of any residual fumigant. To partially re-establish beneficial microflora, the mycorrhizal fungus *Glomus macrocarpus* Tul. and Tul. was added to each microplot at planting by pouring a suspension of ca. 1,000 chlamydospores broadcast over the soil followed by immediate incorporation to a soil depth of ca. 15 cm.

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The experimental design was a randomized complete block. Statistical evaluations included analysis of variance, Waller–Duncan K-ratio *t*-test, linear and orthogonal polynomial contrasts, and (or) regression analyses.

The first microplot study involved a 2 × 4 factorially arranged experiment with five replicates conducted with two tobacco cultivars, NC 82 and McNair 944, and four broadcast rates, ranging from low to greater than recommended rates, of granular (15%) aldicarb (0, 2.24, 4.48, 6.72 kg a.i./ha). The chemical was incorporated to a soil depth of 5–10 cm. This test was established on 9 April 1984 at the Central Crops Research Station (CCRS), Clayton, North Carolina. The NC-82 cultivar was selected because of its high responsiveness to aldicarb observed in previous field research (F. A. Todd, N. T. Powell, unpubl.) McNair 944 was included because it currently is one of the most widely used tobacco cultivars in the southeastern United States. The soil type was Fuquay sand (91% sand, 6.5% silt, 2.5% clay, pH 6.1, 0.6% OM). Fertilizer was applied as needed, based on soil analysis. Standard sucker, insect control, and harvesting practices were followed (5). Sucker control consisted of 14 liters (21.7% potassium salt) maleic hydrazide in 450 liters water/ha after most plants had flowered. A commercial formulation of *Bacillus thuringiensis* Berliner and Acephate (1 kg/ha) were used as needed for foliage insect control. Supplemental irrigation (1.2–2.5 cm/week) was provided when plants were exposed to severe moisture stress.

In addition to dry leaf weights, quality, and value, the length and width of selected green leaves were determined. General growth–vigor indices (0 = poorest growth; 10 = optimum growth) were recorded on 5 July and 31 July 1984. Roots were removed and evaluated for possible infection by nematodes and other pathogens following final harvest. A few plants were infected with *Meloidogyne incognita* (Kofoid and White) Chitwood or *M. arenaria* (Neal) Chitwood, and data from these were excluded from data analysis. Selected treatment effects were evaluated using orthogonal contrasts (Table 1).

The second experiment included four slightly lower rates of granular aldicarb (0, 1.5, 3.0, 4.5 kg a.i./ha) than those for experiment 1, two tobacco cultivars (Speight G-70 and McNair 944), and three irrigation levels on a Fuquay sand (water-holding capacity at 0.1 bar = 5.5%). The Speight G-70 cultivar had been observed to give positive growth responses to aldicarb in the field (N. T. Powell, unpubl.). The lower aldicarb rates were selected because of the growth suppression of the 6.72 kg a.i/ha in the first experiment. The irrigation rates were low = no supplemental water (ca. 2–5.5% or 0–15 bars), medium = soil kept moist with 2–3 cm water/week but not wet, and high = soil kept near field capacity with 7–8 cm water/week (ca. 4–5.5% or ca. 0–5 bars). The supplemental water was delivered through a low volume automatic emitter system.

The management and harvesting practices used in the first experiment were followed for experiment 2. Growth indices and market values per plot also were obtained, but only leaf weight yield data are included herein as all response parameters followed similar patterns.

In the third experiment (1985) four levels of aldicarb were tested on Speight G-28 tobacco growing in six soils in microplots at a common site (CCRS). The texture and other physical characteristics for these soils (Table 2) have been published previously (2). The plots were fertilized as needed according to soil analyses. Other management practices followed those described for experiment 2. Data collected included plant growth indices, yield and quality, and value. Statistical analyses similar to those for the earlier tests were utilized.

Field studies: The 35 field tests analyzed as a part of this study were conducted over a 3-year period (1981–83). All fields were infested with *Meloidogyne* spp.—*M. incognita*, primarily, and some with *M. arenaria* and (or) *M. javanica* (Treub) Chitwood. A 4-row plot (1/156 ha) was used in all tests

TABLE 1. Growth responses of tobacco to aldicarb in microplots, 1984.

Cultivar	Application rate of aldicarb (kg a.i./ha)	Plot dry weight (g)†	Plot value ($)†	Measurements of leaf no. 5		Growth index (0–10)†	Color index (0–10)†
				Width (cm)	Length (cm)		
NC-82	0	473‡	1.83‡	30.0	51.0‡	8.2‡	9.0
	2.24	529	2.06	31.5	56.5	8.0	9.2
	4.48	559§	2.21§	32.7	56.3	9.2§	9.2
	6.72	496	1.91	31.8	54.8	8.0	9.0
Overall means		513	1.99	31.4	54.4	8.4	9.1
CV		9.4	10.7	8.0	6.0	7.3	7.6
McNair 944	0	576	2.21	32.5	53.3‡	8.0	10.0
	2.24	636‖	2.49‖	32.0	52.8	8.7	10.0
	4.48	593	2.27	30.5	51.1	7.8	9.5
	6.72	596	2.31	31.0	50.1	8.0	9.6
Overall means		601	2.32	31.3	51.4	8.4	9.7
CV		5.8	6.8	8.6	5.1	7.6	4.8
Means of both cultivars	0	507‡	1.96‡	30.8	51.8	8.2‡	9.3
	2.24	575	2.24	31.8	54.7	8.3	9.6
	4.48	575	2.24	31.4	53.4	8.5	9.4
	6.72	546	2.11	31.3	52.2	8.4	9.3

† Significant ($P = 0.05$) cultivar interactions by orthogonal contrasts; growth and color responses with 0 = minimum and 10 = maximum.
‡ Control (0 aldicarb) vs. means of aldicarb treatment is significantly different ($P = 0.05$) by orthogonal contrasts.
‖ The 2.24 vs. 4.48 and 6.72 kg aldicarb/ha is significantly different ($P = 0.05$) by orthogonal contrasts.
§ The 4.48 vs. 6.72 kg aldicarb/ha is significantly different ($P = 0.05$) by orthogonal contrasts.

with four replicates per treatment. Row width was 1.05–1.20 m, and length was adjusted accordingly (13.5–15.6 m). Two rows of each plot contained a variety resistant to races 1 and 3 of *M. incognita,* and two rows were planted with a susceptible cultivar. Recommended fertilizers, based on soil analyses, were applied during transplanting and (or) at the first cultivation. Where possible a 3-week waiting period for the fumigants was observed before transplanting.

The chemical soil treatments analyzed for this study included 1) control (no treatment); 2) ethoprop (Mocap) usually 6 EC 8.9–13.4 kg a.i./ha (broadcast over soil surface of the row and incorporated into the upper 7.5–10 cm with a disc, followed by preparation of a high, wide bed (ca. 25 cm high × 60 cm wide) and an aeration period of 5 days in most instances; 3) 1,3-D Telone II) at 56.1 liters/ha; 4) 1,3-D + chloropicrin (Telone C-17) at 98.2 liters/ha (both telone fumigants were injected about 26 cm below the soil surface of a high, wide bed 3 weeks before transplanting); and 5) aldicarb (Temik 15 G) applied at 3.4 kg a.i./ha following the procedure used for ethoprop. Standard management practices were followed in all experiments (5).

Nematode population densities were determined by elutriation and centrifugation for juveniles and elutriation plus the NaOCl procedure for eggs at midseason (10–14 weeks after transplanting) and at the final harvest (2).

Data for each experiment were analyzed for each cultivar at each site using the Duncan's new multiple-range test ($P = 0.05$). The means for the 35 tests across 3 years were not analyzed statistically because of site-to-site variation.

RESULTS AND DISCUSSION

The four chemical treatments of two tobacco cultivars, in experiment 1 produced a striking positive plant-growth response to aldicarb. Cultivar NC 82 was very responsive, as previously noted in field studies where nematodes were present in varying numbers (F. A. Todd, N. T. Powell, unpubl.). The aldicarb rates of 2.24 and 4.48 kg a.i./ha gave a 12 and 18% increase in yield, respectively, over the untreated controls (Table 1). The 6.72-kg aldicarb rate appeared to be slightly phytotoxic early in the growing season, as reflected by the growth indices (Table 1), but the treatment still resulted in slightly higher yields than those obtained for the untreated control. This type of negative impact on growth has been observed in other plants (6). Cultivar McNair 944 proved to be less responsive to aldicarb than NC 82. Nevertheless, treatment of McNair 944 with 2.24 kg aldicarb gave 10% increase in yield; treatments of 4.48 or 6.72 kg aldicarb had only slightly positive effects on yield of this cultivar (Table 1). The increases in yield with aldicarb treatments were generally related to an increase in leaf size.

The overall yield (Y) responses of cultivar NC 82 to aldicarb dosage was adequately described by a quadratic regression: $Y = 463.5 + 46.4X - 6.18/X^2$; $R^2 = 0.70$ where X = kg a.i/ha. There was not a significant regression for these parameters for McNair 944. The dollar values of the tobacco receiving different rates of aldicarb closely paralleled the respective yields (Table 1).

Supplemental irrigation and aldicarb rates (experiment 2) had significant effects on the growth and yield of both tobacco cultivars (Fig. 1). Because these plots were open and exposed to considerable natural rainfall, the greatest yields of tobacco generally occurred in plots that received no supplemental irrigation. Speight G-70 had a positive growth response to aldicarb treatments (1.5–4.5 kg a.i./ha) at all moisture levels (Fig. 1A); however, the higher rates (3.0–4.5 kg a.i./ha) inhibited McNair 944 growth at the low and high moisture levels (Fig. 1B). In contrast, the medium moisture levels resulted in both cultivars responding positively to 1.5 and 3.0 kg aldicarb. Nevertheless, 4.5 kg resulted in minor to significant negative growth response depending on moisture and cultivar. This type of growth suppression with aldicarb, especially at high rates, has been observed

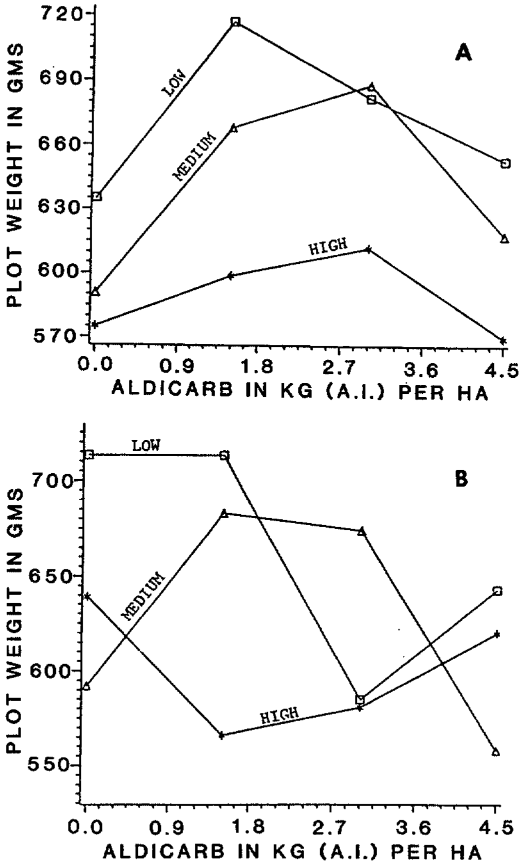

FIG. 1. Growth responses of two tobacco cultivars to aldicarb under three moisture regimes in microplots. High moisture = soil kept near field capacity; moderate moisture = soil kept moist but not wet; low moisture = no supplemental water. A) Speight G-70 cultivar. Quadratic regression for medium moisture: $Y = 589.49 + 80.3X - 16.4X^2$; $R^2 = 0.99$. The R^2 for low and high moistures were 0.80 and 0.92 (NS), respectively. B) McNair 944 cultivar. Quadratic regression for medium moisture: $Y = 591.79 + 96.1X - 23.0X^2$; $R^2 = 0.99$; R^2 for high, −0.94, and low, 0.57, were NS.

on soybean (1) and cotton (6). Much of the poor plant growth under the high moisture level probably was due to leaching of soil nutrients, especially nitrogen, through this Fuquay sand. Apparently, much of the aldicarb also was leached from these plots.

Although the growth responses of Speight G-28 tobacco in the 1985 soil type experiments showed few significant differences, there were some interesting trends. First, response to the aldicarb generally was positive, as tobacco dry weight was in-

TABLE 2. Growth and yield responses of aldicarb-treated Speight G-28 tobacco in six soil types, 1985.

Application rate (kg a.i./ha)	Cecil clay	Cecil loam	Fuquay	Muck	Norfolk	Portsmouth
			Growth indices†			
0	5.6	6.0	6.0	6.8	7.2	7.0
1.5	6.0	5.6	6.0	6.4	6.8	6.4
3.0	6.4	6.6	6.4	6.0	7.0	7.4
4.5	6.4	6.0	6.2	7.0	5.8	7.0
Soil means‡	6.1 c	6.0 c	6.2 bc	6.6 ab	6.7 a	7.0 a
			Plot weight (g/plot)			
0	566	513	524	480	494	493
1.5	511	480	538	456	499	531
3.0	540	541	540	412	568	529
4.5	538	543	531	448	543	553
Soil means†	539 A	519 A	533 A	449 A	526 A	526 A
			Plot value ($/plot)			
0	2.21	2.04	1.97	1.77	1.91	1.85
1.5	1.98	1.88	2.10	1.78	1.90	2.00
3.0	2.14	2.10	2.06	1.55	2.20	2.01
4.5	2.12	2.12	2.02	1.68	2.07	2.11
Soil means†	2.11 A	2.04 A	2.04 A	1.69 B	2.02 A	1.99 A

Different letters indicate significantly differing means; capital letters indicate significance at $P = 0.01$, and lower case letters indicate significance at $P = 0.05$ according to Waller–Duncan K-ratio t-test.
† Growth indices based on scale of 1–10 with 10 being maximum and 1 being poorest growth.
‡ Soil variable is significant at $P = 0.01$; effects of aldicarb were not significant compared to respective controls.

creased from 3 to 15% over the respective controls (Table 2). The soils that tended to retain aldicarb best, including the organic soil (muck), cecil clay, and cecil loam, gave slight or negative yield responses to aldicarb. Thus, based on our earlier experiments with tobacco cultivars and different rates of aldicarb, as well as the effects of supplemental irrigation rates, the impact of aldicarb on the yield responses of tobacco may be influenced by cultivar, rainfall, and rate of aldicarb, as well as soil type.

The mean data for 35 field experiments over 3 years indicated that aldicarb treatments resulted in the greatest average tobacco yields among treatments compared (Fig. 2). This response occurred even though aldicarb resulted in the third overall lowest level of nematode control.

The specific yield responses and nematode control due to the chemical soil treatments being compared varied with location (Fig. 3). In a Guilford County test, aldicarb gave excellent nematode control and a striking positive yield differential over other treatments (Fig. 3A). In contrast, all nematicides (ethoprop, 1,3-D, 1,3-D + chloropicrin, and aldicarb) gave excellent nematode control in some tests, such as in Lenoir County in 1983, with the fumigants resulting in slightly better yields than the nonfumigants (Fig. 3B).

The growth and yield responses of tobacco to aldicarb in these microplot and field experiments may involve more than its effects on microflora or microfauna. The close agreement of the yield responses of tobacco in microplot and field tests indicates that some cultivars are more responsive to aldicarb than others. Furthermore, high rates of aldicarb may suppress growth of tobacco cultivars in some instances.

Although there may have been small benefits derived from minor insect-pest control on the tobacco in microplots, the differential dosage responses of the two cultivars (G-70 and McNair 944) across the moisture levels indicate that aldicarb directly affects plant growth. The high rate of 6.72 kg a.i./ha (experiment 1) was slightly phytotoxic or suppressive, whereas

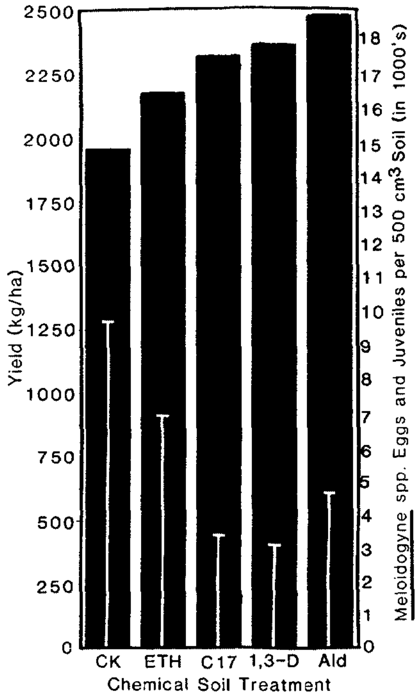

FIG. 2. Mean yield responses of tobacco and relative nematode control with selected nematicides for 3 years (means of *Meloidogyne incognita*-resistant and susceptible cultivars of some 35 experiments in six counties). Single lines represent nematode numbers in late July or August of each year. CK = check; ETH = ethoprop; C17 = Telone C-17; 1,3-D = 1,3-dichloropropene or Telone II; Ald = aldicarb. Different letters at top of each line indicate significantly differing means (P = 0.05), based on Duncan's new multiple-range test.

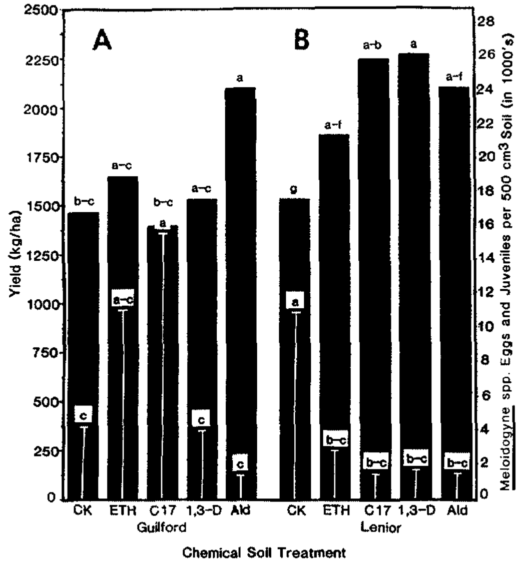

FIG. 3. Comparative yield responses of NC-82 tobacco (*Meloidogyne incognita*-susceptible) and control of *Meloidogyne* spp. with selected chemical soil treatments in 1983. A) Guilford County (*M. arenaria*). B) Lenoir County (*M. incognita* and *M. arenaria*). Single lines represent nematode numbers in early August. CK = check; ETH = ethoprop; C17 = Telone C-17; 1,3-D = 1,3-dichloropropene or Telone II; Ald = aldicarb.

1.5 or 3.0 kg (experiment 2) stimulated both cultivars under moderate moisture conditions. These two rates enhanced the growth and yield of responsive cultivars such as NC 82 and Speight G-70 in most tests.

Slow release formulations (3) possibly could minimize any phytotoxic effects that were observed with higher rates of this pesticide. This formulation also could result in an extension of the often-observed short-term growth stimulation of soybean and other crops, but problems of lower pest control could be encountered. Slow-release technology for nematicides to date, however, is not very promising (A. R. Ayers, pers. comm.). The prolonged presence of an ethylene inhibitor such as aldicarb (4) could result in undesirable growth patterns with a slow-release material. Still the differential sensitivity of crop cultivars also could be diminished by the use of improved slow-release technology. For example, moderate irrigation of McNair 944 tobacco shifted this plant from being slightly stunted by 1.5 or 3.0 kg a.i./ha of aldicarb under low moisture to its growth being enhanced by these treatments. Should this hypothesis be correct, the growth and yield of many crop cultivars could be increased as is the case with nematode-resistant compared with susceptible tobacco cultivar McNair 944. This or a similar approach could facilitate maximum exploitation of this secondary benefit of aldicarb and certain other pesticides that tend to enhance plant growth and yield (1).

Failure to consider the stimulatory and (or) inhibitory dosage effects of nematicides such as aldicarb may result in erroneous conclusions concerning nematode-damage thresholds and related yield returns. In addition, independent, dichotomous schemes of evaluating nematicide effectiveness possibly should be instituted—one for efficacy and one for growth or yield. This concern is particularly important because levels of nematicide control and corresponding yields often differ greatly, as shown in Figures 2 and 3. Thus, greater understanding of direct effects of nematicides on plant growth should lead to the development of more precise nematode-damage thresholds and more useful management systems.

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