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Growth and Yield Responses of Soybean to Aldicarb[1]

K. R. Barker,[2] S. R. Koenning,[3] A. L. Bostian,[3] and A. R. Ayers[3]

Abstract: A series of greenhouse, phytotron, field, and microplot experiments evaluated factors that influenced plant-growth stimulation associated with the use of the pesticide aldicarb. A phytotron experiment showed that aldicarb increased growth of Ransom soybean at all temperatures but was somewhat phytotoxic to Coker 156 soybean at 30 C. Soybean gave the greatest response to this nematicide at 22 C in a commercially available medium, Metromix 220. Soybean cultivars Ransom and Coker 156 exhibited increased growth in response to aldicarb or, to a lesser extent aldicarb sulfone treatments under greenhouse and microplot conditions. Enhanced soybean growth, however, did not always result in significantly greater soybean seed yield. Soil type affected soybean sensitivity to aldicarb, with the greatest growth and yield increases generally occurring in fine-textured soils or those with high organic matter. Plant-growth stimulation by aldicarb occurs in the absence of pests but is dependent upon concentration and edaphic and other environmental factors.
Key words: aldicarb, aldicarb sulfone, *Glycine max*, growth regulation, nematicide, Temik.

Numerous investigators have observed crop growth enhancement associated with the use of aldicarb and other pesticides in the apparent absence of pests (7,11,20,21). Aldicarb (2-methyl-2-[methylthio]propionaldehyde *o*-[methylcarbamoyl]oxime), a carbamate insecticide–nematicide, generally increases the number of flowers on potato, cotton, peas, and other plants, as well as enhancing the uptake of nitrogen (33,35). This compound promotes shoot growth of apple even though it suppresses photosynthesis and transpiration (14). Although aldicarb may inhibit ethylene synthesis in green leaf tissue (16), the mechanism(s) by which it influences plant growth is (are) not clearly understood. In addition to direct alterations of the plant hormonal system, changes in composition of nontarget soil microflora and microfauna could affect crop performance.

Most of the published reports on aldicarb affecting growth of cotton (11,16,23, 24,33), pecans (22,29), sugarbeet (6), soybean (10), and wheat (18,26) do not delineate the possible benefits of pest control as opposed to direct growth stimulation. A recent greenhouse study showed that sequential applications of the carbamates aldicarb and oxamyl enhanced root and shoot growth of a number of plants (15). An extensive investigation indicated that aldicarb increased ion uptake by cotton and subsequently affected plant growth and development (11), whereas other researchers concluded that this compound suppresses growth of this plant (36).

Plant growth regulator effects of aldicarb may depend on environmental conditions. Conflicting results may be caused by soil type, plant pests, or various soil microflora and microfauna. Circumstantial evidence suggests that interactions of micro-organisms with aldicarb could result in increased plant growth. Several species of fungi degrade aldicarb (17). Numbers of cellulose-decomposing microflora may increase shortly after application of aldicarb to soil (1). The microbivorous nematode *Panagrellus redivivus* (L.) Goodey accumulates aldicarb more readily than do stylet-bearing nematodes but metabolizes this compound very rapidly (4). A rate of 2 mg

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[2] Professor, Plant Pathology Department, North Carolina State University, Raleigh, NC 27695-7616.
[3] Former Research Associates, Plant Pathology Department, North Carolina State University. Currently, Research Analyst, Department of Plant Pathology, North Carolina State University, Raleigh, NC 27695-7616; Product Issues Manager and Product Specialist; Rhône-Poulenc Inc., Research Triangle Park, NC 27709.
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aldicarb/ml water may increase the multiplication of *Bradyrhizobium japonicum* (Buchanan) Jordan and its synthesis of indoleacetic acid (2,3,26), but higher levels of aldicarb inhibit this bacterium.

Plant responses to aldicarb may be influenced by its effects on pathogenic microflora (4,7,8,17). Aldicarb failed to give direct bactericidal or fungicidal activity in vitro, although it did give moderate powdery mildew control on cucumber (31). Compared with the control plants, aldicarb-treated cucumbers also exhibited greater plant vigor. Damping-off of sugarbeet seedlings, caused by *Rhizoctonia solani* Kühn (*Thanatephorus cucumeris* (Frank) Donk), can increase in aldicarb-treated soil (34). This material has little impact on the growth of several soil-inhabiting fungi (13,32). In contrast, aldicarb, as well as fensulfothion and fenamiphos, may suppress the growth of *Pseudomonas solanacearum* E. F. Smith and certain other bacteria (13). Sugarbeet germination may be suppressed or inhibited, depending on aldicarb rate and placement and soil type (6). Similarly, decomposition of aldicarb varies with soil type and pH, temperature, moisture, and organic matter (7,8,25,30).

The present research was initiated to characterize plant growth responses to aldicarb under various conditions. Specific objectives included determination of 1) the effects of greenhouse, phytotron, and field conditions on soybean growth responses to aldicarb in the absence of plant pests; 2) relative sensitivity of selected soybean cultivars to aldicarb; and 3) plant dosage responses to aldicarb.

Materials and Methods

Greenhouse studies: Preliminary greenhouse experiments were conducted to determine the responsiveness of two soybean (*Glycine max* (L.) Merr.) cultivars, Coker 156 and Ransom, to aldicarb in different growing media. Clay pots (15-cm-d) were used, and plants were watered twice daily. All plants were grown under a multivapor supplemental lighting regime to give a 12–15-hour photoperiod. Greenhouse temperatures ranged from 25 to 30 C.

Sequential aldicarb and aldicarb sulfone application to two soybean cultivars: Ransom and Coker 156 soybean cultivars were treated with technical grade aldicarb and aldicarb sulfone (Table 1). Both soybean cultivars were also treated with commercial aldicarb (Temik 15-G) applied either as dry granules or as a drench of a solution obtained by soaking granules in tap water for 24 hours. Controls included plants without treatments and plants treated with gypsum, the inert carrier in Temik 15-G. All technical aldicarb and aldicarb sulfone treatments were applied at 1 $\mu g/cm^3$ soil in tap water at planting and every 2 weeks thereafter for a total of 4 $\mu g/cm^3$ soil. Single seeds inoculated with a commercial preparation of *B. japonicum* were placed in the center of each pot containing 1,500 cm^3 Metromix 220 (W. R. Grace Company, Cambridge, MA). Seeds were covered with 2.5 cm Metromix 220, and aldicarb was applied as a drench of 40 ml/pot.

A randomized complete block design was used with eight replications per treatment. Dry weights of shoots and roots were recorded after 8 weeks. Statistical analyses included analysis of variance (ANOVA) and the Waller–Duncan K-ratio *t*-test.

Impact of temperature: A factorial experiment was designed to evaluate the influence of temperature on the aldicarb–plant growth stimulation phenomenon in the Southeastern Plant Environment Laboratories (phytotron), North Carolina State University. Growth rooms were maintained at 22, 26, and 30 C. Metromix 220 was used as the growing medium for the soybean cultivars Ransom and Coker 156 in 15-cm-d clay pots. Treatments included untreated control and technical aldicarb applied at a rate of 1 $\mu g/cm^3$ soil at planting and every 2 weeks thereafter. Plants were grown under a combination of fluorescent and incandescent light with a 12-hour photoperiod. Plants were fertilized using standard phytotron nutrient solution (12). Eight replicates were harvested per treatment at 4 and 8 weeks after planting.

Analyses were the same as in the previous experiment.

Effects of pH and test media: A series of four greenhouse experiments was conducted to determine the impact of the addition of lime or sulfur in adjusting the pH of media. Dehydrated lime was added at rates of 0, 2.5, 5, 10, and 20 g per 15-cm-d pot of either Metromix 220 or a 1:1 soil–sand mixture. Sulfur was added at rates of 0.25, 0.50, 0.75, and 1.0 g per 15-cm-d pot of soil. Initial pH of soil and Metromix 220 were 6.6 and 6.8, respectively. In most of these tests, soybeans were grown for 6 weeks after lime or sulfur amendments to allow the pH to stabilize before conducting the experiments. Coker 156 soybean was used to evaluate growth responses to aldicarb in these experiments.

Aldicarb was added in split applications to the growth media in which 3-day-old Coker 156 soybean seedlings had been established. Five days after transplanting, all aldicarb treatments received 1 $\mu g/cm^3$ soil of technical material; 3 weeks later the 2-μg and 3-$\mu g/cm^3$ soil treatments received an additional 1 $\mu g/cm^3$ soil aldicarb; and at 5 weeks the 3-$\mu g/cm^3$ soil treatment plants received the final 1 $\mu g/cm^3$ soil aldicarb. There were six replicates arranged in a randomized complete block design. Statistical analyses involved ANOVA and orthogonal polynomial contrasts.

Microplot and field studies: Unless indicated otherwise, all microplots were treated with approximately 73 g a.i. methyl bromide (mb) (Brozone, 68% a.i.) per square meter 6 weeks before soybean planting. The polyethylene cover used to retain the fumigant was removed 5–7 days after treatment. The soil was tilled two or three times during the 5 weeks before planting to facilitate the release of residual fumigant. Still, considerable chemical injury to soybean was observed, especially in soils with high organic matter. The mycorrhizal fungus *Glomus macrocarpus* Tul. and Tul. was added to each microplot at planting by pouring a suspension containing ca. 1,000 chlamydospores into the seed furrow. Soybean seeds were inoculated with a commercial preparation of *B. japonicum* at planting.

Standard management practices were followed for experiments unless specified differently. Supplemental irrigation was provided when plants were exposed to severe moisture stress in 1984.

Effects of soil type: The first series of microplot experiments in 1983 involved a factorial experiment with five soil types and five locations (Clayton, Grifton, Raleigh, Whiteville, Wenona) in North Carolina, chemical treatments of 0, 2.24, and 6.72 kg a.i./ha aldicarb, and the soybean cultivars Ransom and Coker 156. At the Whiteville and Clayton locations there were two additional chemical treatments of 2.24 and 6.72 kg a.i./ha aldicarb sulfone (Standak, a breakdown product of Temik). The granular chemicals were broadcast (2.24 and 6.72 kg a.i./ha) on the soil surface and incorporated to a depth of 5–10 cm. Soil textures (percentages of sand, silt, clay, and organic material, respectively) and pH for each site were Clayton—Fuquay sand: 93, 4, 3, 0.6, pH 6.1; Grifton—Lakeland sand: 93, 3, 4, 0.3, pH 5.8; Whiteville—Goldsboro sandy loam: 69, 27, 4, 0.9, pH 5.6; Raleigh—Appling sand clay loam: 53, 17, 30, 0.4, pH 6.0; and Wenona—Belhaven muck: 71, 22, 7, > 35, pH 4.5.

Data collection for each plot at all sites included plant height, total seed weight (adjusted for moisture), weight per 100 seeds, soybean mosaic virus infection (%), and purple seed stain (%). In addition, plots at Raleigh and Clayton were rated for defoliation 1–2 weeks before harvest. Plants at Whiteville were mostly defoliated at this time and were rated on the basis of amount of green stem tissue. The number of pods per plant was determined for three plants from each plot from Whiteville, Raleigh, and Wenona. The average number of nodes on the main stem was determined for each plot at all locations except Grifton. There were four replications in a randomized complete block design. Data were subjected to analysis of variance, Waller–Duncan K-ratio *t*-test, and regression analysis.

Microplot experiments were conducted

TABLE 1. Growth of soybean cultivars Ransom and Coker 156 as affected by aldicarb treatments in the greenhouse 8 weeks after planting in Metromix 220.

Treatment†	Dry weight (g)	
	Shoot	Root
Untreated control	17.4 b	4.4 b
Gypsum carrier	18.9 b	4.2 bc
Solution from granules	21.7 a	5.5 ab
Granules (dry)	15.3 c	3.7 c
Technical aldicarb	22.9 a	5.8 a
Technical aldicarb sulfone	22.2 a	5.7 a

Combined mean weight of two cultivars for 16 replicates; Waller–Duncan K-ratio *t*-test ($P \leq 0.05$). Means followed by the same letter not significantly different.

† Aldicarb treatments were applied at 1 μg/cm³ soil biweekly for a total of 4 μg/cm³ soil.

TABLE 2. Dry weights of soybean treated with aldicarb grown in Metromix 220 at three temperatures 8 weeks after planting in the phytotron.

Treatment		Dry weight (g)	
Temperature	Aldicarb†	Shoot	Root
		Coker 156	
22 C	0	7.5 f	2.0 d
	1†	12.0 e	3.0 cd
26 C	0	20.0 a	3.5 abc
	1	17.8 abc	4.6 a
30 C	0	17.3 abc	4.3 ab
	1	12.5 de	3.5 abc
		Ransom	
22 C	0	10.2 ef	3.7 abc
	1	12.0 e	3.4 bc
26 C	0	16.5 bc	3.0 cd
	1	18.8 ab	3.4 abc
30 C	0	3.0 g	0.9 e
	1	15.0 cd	2.9 cd

Means with the same letter are not significantly different according to the Waller–Duncan K-ratio *t*-test ($P \leq 0.05$). Data are means of eight replicates. Soybean response to temperature was quadratic ($P \leq 0.05$).

† Aldicarb applied biweekly at 1 μg/cm³ soil for a total of 4 μg/cm³ soil.

in 1984 at Clayton with six soils at a common site. Soil textures (percentages of sand, silt, clay, and organic material) and pH for these soils were Fuquay sand: 91, 6, 3, 0.6, pH 6.1; Norfolk sandy loam: 84, 12, 4, 1.4, pH 6.3; Portsmouth loamy sand: 72, 18, 10, 3.8, pH 5.9; muck: 58, 33, 9, > 30, pH 5.0; Cecil sandy clay loam: 53, 18, 29, 2.2, pH 6.7; and Cecil sandy clay: 48, 13, 39, 0.9, pH 6.7. The soils were fumigated using methyl bromide as described earlier. The experiment was a 6 × 4 factorial with six soil types, and aldicarb treatments of 0, 2.24, 4.48, and 6.72 kg a.i./ha were arranged as a randomized complete block design with five replications. Soybean cultivar Coker 156 was used in this experiment. Plant height and canopy width, yield, and weight per 100 seeds were recorded for each plot. Plant height was multiplied by canopy width for an estimate of total plot biomass. Analysis of variance and linear contrasts were used to interpret data collected.

Response of Coker 156 soybean to selected aldicarb rates in field plots: A field plot at the Central Crops Research Station (CCRS) at Clayton was fumigated with 33 g a.i. methyl bromide per square meter (Brozone, 68% mb). The soil was a Fuquay sand (93% sand, 5% silt, 2% clay, 0.6% organic material, pH 6.1). Plots were four 9-m-long rows with 95-cm row spacing. Seeds of Coker 156 soybean were dusted with a commercial preparation of *B. japonicum* at planting on 26 June 1984. Aldicarb (Temik 15-G) was applied at planting in a 33-cm-wide band and incorporated with rolling tines. Rates used were 0, 1.12, 2.24, 3.36, 4.48, and 5.6 kg a.i./ha, calculated on a broadcast basis for 15 cm deep. The experiment consisted of a randomized complete block design with orthogonal polynomial contrasts for equally spaced treatments and six replicates.

RESULTS

Effects of sequential application of aldicarb and aldicarb sulfone on the growth of two soybean cultivars: Both Ransom and Coker 156 soybean plants exhibited increased shoot and total growth in response to applications of technical aldicarb, technical aldicarb sulfone, and aldicarb derived from soaked Temik 15-G (Table 1). Shoot growth of plants treated with aldicarb was up to 30% greater than that of the controls, and aldicarb sulfone was slightly less stimulatory. Gypsum carrier granules did not affect soybean growth. Dry aldicarb gran-

TABLE 3. Effects of sequential aldicarb treatments and prior lime amendments on Coker 156 soybean growth in Metromix 220.

Aldicarb (μg a.i./ cm^3 soil)	Lime (g/pot)	pH	Shoot wt. (g)		Y/Aldicarb (g shoot wt.)	
			Fresh	Dry	Fresh	Dry
0	0	6.8	43.7	7.7	**	**
	2.5	7.9	58.8	10.3		
	5	8.2	52.7	10.0		
	10	8.5	49.8	7.8		
	20	8.7	19.8	2.3	45.0	7.6
1	0		55.8	11.3		
	2.5		63.5	13.0		
	5		55.3	9.3		
	10		48.2	8.3		
	20		30.8	4.3	50.7	9.3
2	0		63.2	12.8		
	2.5		75.8	15.7		
	5		61.8	11.3		
	10		43.5	7.3		
	20		29.6	4.8	54.8	10.4
3	0		74.3	15.8		
	2.5		67.6	14.8		
	5		58.8	12.5		
	10		66.2	13.0		
	20		28.7	4.3	59.1	12.1
	Orthogonal contrasts†				1	1
	Y/Lime		**	**		
	0		59.2	11.9		
	2.5		64.4	13.4		
	5		57.2	10.8		
	10		51.9	9.1		
	20		27.2	4.0		
	Orthogonal contrasts†		(1), 2	(1), 2		

Significance of aldicarb and lime variables: ** = significant differences ($P \leq 0.01$). Data are means of six replicates. Aldicarb applied sequentially: 1 μg/cm^3 soil 5 days after transplanting 3-day-old Coker 156 soybean seedling; the 2-μg treatment received another 1 μg 10 days later; and the 3-μg treatment received an additional 1 μg another 14 days later. Plants were harvested after 11 weeks growth.

† Orthogonal contrasts: number without "( )" indicate significance at $P \leq 0.01$; numbers with "( )" indicate significance at $P \leq 0.10$. Contrasts are defined as follows: 1 = linear; 2 = quadratic.

ules (Temik 15-G) inhibited both seed germination and plant growth. Root growth response was generally similar to shoot growth, but treatment effects were less striking.

Impact of temperature: Soybean growth differences among treatments after 4 weeks in the phytotron were not significantly different. Coker 156 root growth was increased somewhat by aldicarb treatments at 22 C but suppressed at 30 C (data not included). No differences were evident with Ransom at the 4-week harvest.

At 8 weeks aldicarb again enhanced shoot growth of Coker 156 at 22 C, gave no response at 26 C, and suppressed growth at 30 C (Table 2). By contrast, aldicarb treatments stimulated Ransom soybean growth at 30 C. Ransom generally responded positively to aldicarb at all three temperatures (Table 2), and the interaction of aldicarb × cultivar × temperature was significant ($P \leq 0.01$).

Aldicarb improved germination of Ransom soybean at 26 and 30 C by 28.6 and 26.4%, respectively, over the untreated control. Germination of Coker 156 was not affected by any treatment.

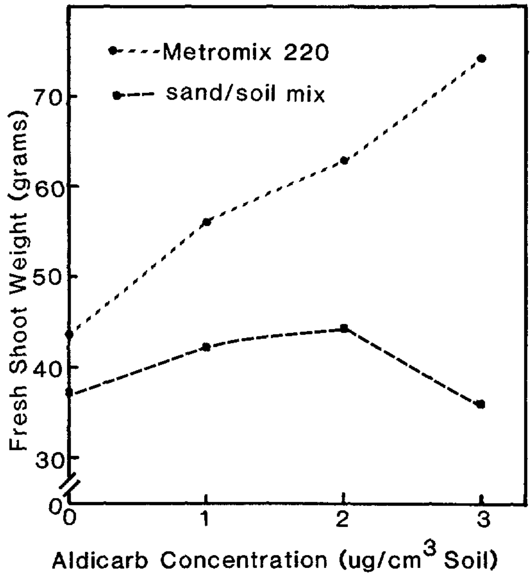

FIG. 1. Growth response to sequential applications of aldicarb to Metromix 220 and a soil–sand mixture (1 μg a.i./cm^3 soil) applied 5, 10, and 14 days after transplanting 3-day-old Coker 156 soybean seedlings. Orthogonal contrasts showed the soybean response to aldicarb to be significantly different from the control in Metromix, whereas the growth differences in the soil–sand mix were not significant.

Effects of pH and test media: The addition of lime, particularly at low rates, to Metromix 220 enhanced the growth of soybean plants but contributed only slightly positive effects to their responsiveness to aldicarb (Table 3). No aldicarb treatment × lime interaction was detected in Metromix 220 or the soil–sand mixture (data for latter not included). The three split aldicarb applications of 1 μg/cm^3 soil (3 μg/cm^3 soil total) without any pH adjustment (pH 6.8) gave an almost twofold increase ($P \leq 0.01$) in shoot growth over the untreated control in the Metromix 220 (Fig. 1). This response was much less pronounced in the soil–sand mixture. Overall, lime or sulfur amendments tended to result in a less uniform growth response to aldicarb. Sulfur amendments enhanced soybean growth but had little impact on aldicarb responsiveness of this plant (data not included).

Effects of soil types at different locations: Combined analyses of all locations demonstrated that aldicarb treatments increased soybean yield ($P \leq 0.01$). The location × aldicarb interaction was significant ($P \leq 0.06$) for soybean yield. Treatments with aldicarb sulfone were not significantly different from controls at the Clayton and Whiteville locations, although they tended to parallel results of aldicarb treatments (Table 4).

The aldicarb treated plots yielded more ($P \leq 0.05$) than the controls at Clayton (Table 4). Aldicarb at 6.72 kg a.i./ha increased yield of Ransom soybean over 2.24 kg aldicarb and untreated control. Seed yield of Coker 156 was enhanced by aldicarb at 6.72 kg ($P = 0.05$) but not at 2.24 kg. Both cultivars responded to high concentrations of aldicarb at this location. There was a trend toward enhanced soybean yield as a result of treatment with 2.24 kg aldicarb for both cultivars (Table 4). There was a positive relationship between soybean yield and seed weight and aldicarb concentration ($P = 0.02, R^2 = 0.22$, and $P = 0.05, R^2 = 0.18$, respectively). Soybean yields and seed weights were not related to aldicarb sulfone concentration. Defoliation was delayed by chemical treatment, indicating delayed senescence.

Analyses of the combined data for both cultivars at Grifton demonstrated enhanced soybean growth as measured by plant height ($P \leq 0.05$, data not included) and seed yield ($P \leq 0.05$) in response to aldicarb treatments (Table 4). Mean seed weight was unaffected by aldicarb. Coker 156 had a greater ($P \leq 0.05$) yield at both 2.24 and 6.72 kg a.i./ha aldicarb rates. Yield of Coker 156 was related to aldicarb concentration ($P = 0.01, R^2 = 0.44$), whereas average seed weight was not. Yield and seed weight of Ransom soybean were not affected by aldicarb concentration.

Chemical treatments (2.24 or 6.72 kg aldicarb and aldicarb sulfone) increased soybean yield ($P \leq 0.05$) and plant height ($P \leq 0.05$) at Whiteville (Table 4, plant height not included) when combined analyses of the two cultivars were performed. The percentage of green stem tissue (a measure of delayed senescence) was also increased by chemical treatments ($P \leq 0.05$). Yield of Ransom soybean was in-

TABLE 4. Yields of Ransom and Coker 156 soybean treated with aldicarb and (or) aldicarb sulfone at five locations in North Carolina in 1983.

Location and soil type	Treatment: Compound	Treatment: Rate (kg a.i./ha)	Seed yield (g/microplot): Ransom	Seed yield (g/microplot): Coker 156
Clayton (Fuquay sand)	Control	0	274 b	245 bc
	Aldicarb	2.24	304 ab	275 ab
		6.72	345 a	306 a
	Aldicarb sulfone	2.24	304 ab	210 c
		6.72	281 ab	263 ab
Grifton (Lakeland sand)	Control	0	138 a	90 b
	Aldicarb	2.24	181 a	160 a
		6.72	174 a	173 a
Whiteville (Goldsboro sandy loam)	Control	0	362 b	297 a
	Aldicarb	2.24	440 ab	392 a
		6.72	568 a	437 a
	Aldicarb sulfone	2.24	414 ab	340 a
		6.72	463 ab	397 a
Raleigh (applying sandy clay loam)	Control	0	62 b	23 c
	Aldicarb	2.24	106 ab	54 b
		6.72	134 a	96 a
Wenona (Belhaven muck)	Control	0	195 a	189 a
	Aldicarb	2.24	230 a	266 a
		6.72	252 b	175 a

Waller–Duncan k-ratio *t*-test results ($P \leq 0.05$). Means with the same letter are not significantly different. Analyses performed individually, by location and cultivar. All data means of four replicates.

creased by 6.72 kg aldicarb ($P \leq 0.05$) (Table 4) when analysis was performed for this cultivar separately. Other trends toward enhanced growth of Ransom soybean in response to aldicarb or aldicarb sulfone treatments were not statistically significant.

Coker 156 at Whiteville showed trends toward yield and growth enhancement by both aldicarb and aldicarb sulfone treatments, but the differences usually were not statistically significant (Table 4). There was an increase in numbers of nodes on the main stem of soybean and delayed senescence in response to high concentrations of aldicarb (data not included). The average seed weight of Coker 156 was positively regressed ($P = 0.04, R^2 = 0.35$) against aldicarb concentration.

The yield of aldicarb treated soybeans, combined for both cultivars, at Raleigh was higher than that of the controls ($P \leq 0.01$) (Table 4). The number of pods and the mean seed weight were also greatest ($P \leq 0.01$) for aldicarb treated plots (data not included). Untreated controls defoliated and reached harvest maturity at least 1 week earlier than plants treated with either 2.24 or 6.72 kg aldicarb. There was a twofold increase in seed yield for Ransom and a fourfold increase for Coker 156 treated with 6.72 kg aldicarb (Table 4). Seed yield and average seed weight were both positively related to aldicarb concentration ($P \leq 0.01$, $R^2 = 0.48$, and $P \leq 0.01$, $R^2 = 0.45$, respectively).

Combined analyses of the two cultivars at Wenona in the muck soil type showed no significant differences. Yield and mean seed weight (mean seed weight not included) of Ransom soybean treated with 6.72 kg aldicarb were greater than those of the controls (Table 4), but this was significant only when analyzed separately. The number of pods per plant on Ransom soybean increased when treated with 2.24 kg aldicarb. There was no significant relationship between any of the growth parameters or soybean yield and aldicarb concentration for the cultivar Coker 156 (Table 4).

Six soil types at a common location: Analyses of all plots as a factorial with orthogonal

TABLE 5. Soybean growth and seed weights in response to different soil types and aldicarb concentrations of 0, 2.24, 4.48, and 6.72 kg a.i./ha at the Central Crops Research Station, Clayton, North Carolina.

Soil types	Biomass†					Seed weight (g)						Control vs. aldicarb contrasts§
	0	2.24	4.48	6.72	Contrasts‡	0	2.24	4.48	6.72	Contrasts‡	Means	
Cecil sandy clay	51.5	59.5	63.8	60.3	a	606	634	636	651	NS	632	NS
Cecil sandy clay loam	66.4	78.3	76.4	72.7	NS	734	823	725	776	NS	765	NS
Fuquay sand	64.2	80.0	81.5	74.5	A, (c)	639	598	647	643	NS	632	NS
Muck	25.0	34.2	43.0	31.8	a, (c)	298	394	413	361	a	355	b
Norfolk loamy sand	76.4	94.5	94.7	97.6	(a)	754	813	813	833	NS	803	NS
Portsmouth loamy sand	35.6	38.2	63.1	52.5	a, b	447	452	652	606	a, b	539	B, c
Means	53.2	64.1	70.4	64.9	A	580	612	648	645	A	621	b, c

Soil types significantly different ($P \leq 0.01$). Data are means of five replications.

† Biomass estimated by plant height cm × canopy width cm = $cm^2 \times 10^{-4}$.

‡ Capital letters indicate significance at $P \leq 0.01$, lower case indicate $P \leq 0.05$, and "()" indicate $P < 0.10$. Contrasts are A, a = 0 vs. others; B, b = 2.24 vs. 4.48 and 6.72 kg; and C, c = 4.48 vs. 6.72 kg.

§ Contrasts were made between the control and each of the aldicarb treatments. Capital letters indicate significance at $P \leq 0.01$, lower case indicate $P \leq 0.05$ and "()" indicate $P \leq 0.10$. Contrasts are A, a = 0 vs. 2.24 kg; B, b = 0 vs. 4.48 kg; and C, c = 0 vs. 6.72 kg.

contrasts revealed a positive linear response to aldicarb dosage ($P \leq 0.01$). The aldicarb × soil type interaction was not significant, but analyses of individual soil types still proved useful (Table 5). For example, plant biomass was increased ($P \leq 0.05$) by aldicarb treatments in all soils with the exception of the Cecil sandy clay loam. In contrast, soybean yield was increased ($P \leq 0.05$) by aldicarb treatments only in the Portsmouth sandy loam and muck soils. Aldicarb at 4.48 kg a.i./ha resulted in a 46% increase in yield over the control in the Portsmouth loamy sand, whereas 2.24 kg had little effect on yield and 6.72 kg increased yield somewhat less than that observed with 4.48 kg. Similar results were obtained with the muck (organic) soil where overall yields were somewhat lower than those noted in the Portsmouth soil. Cecil sandy clay and Cecil sandy clay loam supported 10–12% increases in soybean yield in response to aldicarb, although these increases were not significant. The relative differences in seed yield were paralleled by relative plant size (biomass) (Table 5). Similarly, increased plant biomass in the sandy Norfolk and Fuquay soils did not translate into a significant yield increase. Seed size (data not included) was greater ($P \leq 0.05$) with aldicarb treatments in combined analyses over soil types but not when soil types were analyzed individually.

Response of Coker 156 soybean in field plots: All five rates of aldicarb gave similar increases in yield of Coker 156 over the untreated control. The control yielded 5,152 g/plot as opposed to a mean of 5,574 g/plot for aldicarb treatments ($P \leq 0.01$). Surprisingly, 1.12 kg a.i./ha resulted in seed yield about 10% higher than the control, similar to results obtained with the higher aldicarb rates. Overall, aldicarb treatments again resulted in larger soybean seed, ~ 15 g/100 seeds with aldicarb concentration ≥ 3.36 kg soil versus 14.6 g/100 seeds from control or 1.12 kg a.i./ha aldicarb treated plots ($P \leq 0.01$).

DISCUSSION

Greenhouse, phytotron, microplot, and field experiments showed that aldicarb may enhance soybean growth in the absence of known pests, especially in soil or media with high organic matter. The high water-holding capacity of these high organic materials such as Metromix 220 undoubtedly slowed the leaching of aldicarb and probably made it available more slowly than did sandy soils. Other factors influencing the growth response of soybean to aldicarb included dosage and application sequence, temperature, soil texture, and cultivar. In addition to these parameters, other investigations indicate that soil microflora and moisture affect plant responses to aldicarb (1,2,13, 15,23,24,30,34). Soil pH, in contrast, had no significant impact on soybean response to aldicarb.

Our results show that some of the inconsistencies in previous research with aldicarb probably are related to dosage and differential cultivar and temperature effects. The range of aldicarb dosages that enhance plant growth and yield is relatively narrow. A single level of aldicarb also may have a positive or a negative effect, depending on environmental conditions. Maximum response in greenhouse experiments occurred with split or sequential applications. Higher rates ($\geq 1\ \mu g/cm^3$ soil) in single applications tended to suppress plant growth, compared with lower rates. Low moisture probably resulted in higher effective concentrations that suppressed plant growth.

Soybean growth stimulation by aldicarb occurred in most microplot experiments. This increased growth, however, did not always result in a significant yield increase as was true in other studies with tobacco (K. R. Barker, unpubl.). The increased growth in tobacco is translated directly into yield, since tobacco is grown for its foliage. Soybean, however, is primarily a seed crop, and increased plant height and foliage may not be as readily translated into yield increases. Late drought stress may restrict pod set and pod fill and place an upper limit on soybean yield. Stimulation of soybean growth, and perhaps other grain crops, by pesticides in the absence of pests may not occur unless other limiting factors can be controlled.

Aldicarb treatments generally increased the average soybean seed weight. Delayed senescence associated with aldicarb treatments may account for increased seed size. Increased seed size accounts for only a small portion of the increased yield since the number of pods per plant also was increased. Larger seed may be beneficial to seed producers, since seed size is often related to seedling vigor.

The environmental conditions for the 2 years during which microplot–soil location experiments were conducted were very different. In 1983, experiments at five sites were subjected to an unfavorable growing season, initially cool and wet followed by hot drought conditions that persisted throughout the summer. The only pest problem encountered was a severe spider mite infestation at the Raleigh location, which may have biased these data somewhat. The poor soybean response to aldicarb in the Fuquay sand and Norfolk loamy sands at Clayton in 1984, compared with 1983, may have been caused by very high rainfall (approximately 30 cm) shortly after planting which may have leached much of the aldicarb from the soil profile. Conversely, soybeans were generally not responsive to aldicarb in the muck soil at Wenona in 1983 under dry conditions, whereas Coker 156 responded favorably to aldicarb in both the Portsmouth sandy loam (3.8% O.M.) and in the Bellhaven muck at Clayton in 1984. These observations agree with greenhouse results showing a better response to aldicarb in Metromix 220 than in soil and sand mixtures. Ransom soybean, although more responsive to aldicarb than Coker 156, was dropped from the later tests because of its high variability.

Soybean responses to aldicarb sulfone at Whiteville and Clayton in 1983 generally paralleled those obtained with aldicarb but were not significant. Aldicarb sulfone tended to be phytotoxic at high concentrations and did not stimulate soybean growth as much as aldicarb at lower concentrations (aldicarb sulfone is a breakdown product of aldicarb). These results suggest that aldicarb sulfone and (or) aldicarb sulfoxide may be the actual stimulant. Aldicarb may give better growth stimulation because as it degrades the aldicarb sulfone is released more slowly, preventing growth inhibition.

The development of effective slow release formulations (9) could favor the growth enhancement phenomenon associated with certain pesticides and possibly decrease some of the adverse effects observed for aldicarb. A prolonged exposure to aldicarb, however, may alter ethylene synthesis (18), possibly causing undesirable growth patterns. Still, the high sensitivity of some crop cultivars could be diminished by the use of slow-release formulations. For example, moderate irrigation of McNair-944 tobacco changed this plant from being slightly stunted by 3.0 kg a.i./ha aldicarb under low moisture to its growth being enhanced by this treatment (K. R. Barker, unpubl.). Should this hypothesis be correct, the growth and yield of many crop cultivars may be increased, as is the case with nematode-resistant tobacco cultivars, compared with certain susceptible cultivars. Slow release formulations and irrigation techniques could facilitate maximum exploitation of the secondary benefit of aldicarb and certain other pesticides that tend to enhance plant growth and yield (7,11, 15,32).

The growth responses to aldicarb described here have important economic and theoretical implications. Economic yield responses to such compounds may be partly due to direct growth stimulation effects rather than simple nematode control. Special care also must be given in using this type of nematicide in developing nematode-damage thresholds. Finally, the general importance of this phenomenon with nonfumigant nematicides and other pesticides warrants further investigation.

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