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Response of Soybean Cultivars to Aldicarb in *Heterodera glycines*-infested Soils in Missouri[1]

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Abstract: Soybean cultivars in maturity groups III, IV, and V that were resistant or susceptible to *Heterodera glycines* were evaluated for their response to in-furrow applications (5.43 kg a.i./ha) of aldicarb. Tests were conducted over three years (1988–1990) in various *H. glycines*-infested locations in Missouri for a total of 16 environments. In 7 environments, overall yields were higher ($P \leq 0.05$) in aldicarb-treated than in nontreated plots. In one environment, soybean yields in aldicarb-treated plots were lower ($P \leq 0.05$) than in nontreated plots. Cultivar × aldicarb interactions were detected in only one environment. Resistant cultivars yielded higher than susceptible cultivars in 13 of 15 environments. Final populations (Pf) of *H. glycines* were generally unaffected by aldicarb treatment; however, in 3 environments Pf were significantly higher, whereas in 2 other environments Pf were significantly lower in aldicarb-treated plots than in nontreated plots.

Key words: aldicarb, chemical control, *Heterodera glycines,* management, nematicide, nematode, soybean cyst nematode.

Soybean cyst nematode, *Heterodera glycines* Ichinohe, emerged as the major soybean (*Glycine max* L. (Merr.)) pest in the Midwest in the 1980s. Most major soybean-producing counties in Iowa, central and northern Illinois, north Missouri, eastern Kansas, and eastern Nebraska confirmed *H. glycines* infestations in the 1980s and early 1990s (11,12). In Missouri, losses due to *H. glycines* were estimated at $34 to $100 million (Niblack and Smith, unpubl.).

Soybean, the major agronomic crop in north Missouri, was planted on an estimated 1.6 million hectares annually from 1988 to 1990 (19). Approximately 30% of this hectarage was planted continuously to soybean or rotated infrequently to other crops. Few *H. glycines*-resistant cultivars were available, and these were planted on less than 1% of the total hectarage (19). Soybean producers were reluctant to plant these cultivars because they considered them inferior to susceptible cultivars in yield and other agronomic characteristics. Thus, widespread use of susceptible cultivars probably contributed to the spread of *H. glycines* throughout the Midwest and to resulting yield losses.

We initiated studies on the effectiveness of aldicarb in reducing yield losses due to *H. glycines.* Aldicarb is a systemic, soil-applied, nonfumigant nematicide/insecticide that may increase growth and yield of soybean in *H. glycines*-infested and noninfested soil (2,5). Its current registration status in Missouri permits rates up to 5.43 kg a.i./ha applied in-furrow for nematode control on soybean. The objectives of this study were to determine the responses of resistant and susceptible cultivars to aldicarb in *H. glycines*-infested soils and to determine the effect of aldicarb treatments on *H. glycines* egg densities.

Materials and Methods

Soybean variety trials were conducted at 14 locations from 1988 through 1990 in *H. glycines*-infested fields (Table 1). Soil texture and fertility (Table 1) were determined by the University of Missouri Regional Soil Test Lab. Soybean cultivars (*H. glycines*-resistant [R] or susceptible [S]) and maturity group grown at each location were as follows: in 1988 at Laddonia, 'Asgrow 3307' (R,III), 'Asgrow 3415' (R,III), 'Cartter' (R,III), 'Fayette' (R,III), 'JMS 3609' (R,III), 'Lewis 351' (R,III), 'Americana Jackson' (R,IV), 'Asgrow 4009' (R,IV), 'Egyptian' (R,IV), 'JMS 4109' (R,IV), 'Pioneer 9402' (R,IV), 'Pyramid' (R,IV), 'Williams 82' (S,III), and 'Stine 3790' (S,III);

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TABLE 1. Site information on experiment locations in Missouri from 1988 to 1990.

Location	Soil texture and fertility†							Date of planting	*H. glycines*	
	Sand	Clay	Silt	OM	pH	P	K		Pi‡	Race
					1988					
Sikeston	74	10	16	1.0	6.5	48	255	26 May	14,113	6
Laddonia	22	30	48	2.1	7.1	29	177	10 May	4,625	3
Shelbina	12	28	60	1.4	6.9	47	152	12 May	26,250	6
					1989					
Baring	22	54	25	2.2	6.9	24	241	11 May	28,000	6
Brunswick	62	10	28	0.9	7.2	32	209	8 May	30,000	3
Centralia	12	56	32	2.5	6.6	82	366	17 May	3,000	3
Laddonia	12	60	28	1.5	7.0	67	348	17 May	15,900	3
Henrietta	42	22	36	1.3	7.3	14	401	5 May	3,225	5
St. Charles	50	24	26	3.4	5.5	241	1,025	10 May	3,880	1
					1990					
Baring	22	54	25	2.0	7.0	65	348	5 June	18,370	6
Benton City	16	28	56	1.8	6.6	69	451	18 June	10,900	3
Brunswick	38	16	46	1.5	7.2	65	484	4 June	5,400	3
Centralia	12	56	32	1.4	6.8	49	233	21 June	4,600	3
Henrietta	40	30	30	1.4	7.5	60	492	4 June	3,100	5

† Sand, clay, silt, and organic matter expressed as percentages. P and K values are kg/ha.
‡ Pi = *H. glycines* eggs/250 cm^3 soil.

at Shelbina, 'Lewis 351' (R,III), 'Lewis 411' (R,IV), 'Williams 82' (S,III), and 'Stine 3790' (S,III); and at Sikeston, 'Avery' (R,V), 'Asgrow 5474' (R,V), 'Bedford' (R,V), 'Coker 355' (R,V), 'Coker 485' (R,V), 'Coker 6995' (R,V), 'Forrest' (R,V), 'Hartz 5370' (R,V), 'Pioneer 9531' (R,V), and 'Essex' (S,V). In 1989, 'Fayette', 'Egyptian', 'Ripley' (S,IV), 'Pioneer 9391' (S,III), 'Asgrow 3733' (S,III), 'Williams 82', and 'Stine 3790' were grown at all locations except Brunswick, where only 'Williams 82' was grown. In 1990, 'Fayette', 'Williams 82', 'Caldwell' (S,IV), and 'Resnik' (S,3) were grown at all locations. At each location, there were four or six replications of each cultivar and two treatments: aldicarb and an untreated control. Two separate experiments were conducted in the same field at the Centralia and Baring locations in 1989, giving a total of 16 experiments.

Aldicarb was applied in-furrow at planting at 5.43 kg/ha with Gandy insecticide boxes (Gandy Co., Inc., Owatonna, MN) mounted on the planter. In the separate experiments conducted at Centralia and Baring in 1989, aldicarb was applied in-furrow at rates of 2.72 and 5.43 kg a.i./ha. Plots were four rows by 7.6 m, with rows spaced 75 cm apart. Seeds were planted in a conventionally tilled seedbed with a four-row planter at 24 seeds/m.

Each location received a preemergence or preplant incorporated herbicide treatment at recommended rates followed by a cultivation approximately 45 days after planting. In 1990, imazaquin was applied for broadleaf weed control at all sites except Centralia, where metribuzin was applied. For grass control, pendimethalin was applied at all sites except Henrietta and Centralia in 1989, where trifluralin was applied, and Benton City in 1990, where alachlor was applied. Plots were hand weeded when needed. At harvest, plot rows were trimmed to 6 m, the middle two rows were harvested with a plot combine, and seed yields were adjusted to 13% moisture.

Densities of *H. glycines* were determined at planting (Pi) and harvest (Pf). In each plot sampled, six to eight 2.5-cm-diam cores 20-cm-deep were taken from the center two rows of the plot. The cores were combined and a 100-cm^3 subsample (determined by water displacement) was removed for processing (3).

Cysts and vermiform nematodes were extracted from the soil by elutriation (6) and counted at 40× magnification before extraction of eggs from cysts. Eggs were extracted by grinding the cysts against a polypropylene tube with a motorized stainless steel bit with 1-mm helical ridges (4). Eggs were stained with acid fuchsin and counted at 60× magnification (7). Race determinations were made according to the method of Riggs and Schmitt (14) using *H. glycines* eggs extracted from preplant composite samples from each site.

Field experiments were randomized complete blocks with four or six replications, except for a split plot at Centralia in 1989 where two rates of aldicarb were evaluated. Egg data and Pf/Pi ratios were $\log_{10}$ (x + 1) transformed before analysis. Year and location (field plots) were combined into a classification variable called "environment" and treated as a random variable in the analysis of variance. Differences among means were investigated by planned single degree of freedom orthogonal contrasts and by least squares means comparisons. Regression analysis was used to determine relationships between Pf/Pi and Pi.

TABLE 2. Effect of aldicarb† on soybean yields and *Heterodera glycines* egg densities (Pf) at harvest in Missouri.

Location	Seed yield (kg/ha) + aldicarb	Seed yield (kg/ha) − aldicarb	*H. glycines* Pf‡ + aldicarb	*H. glycines* Pf‡ − aldicarb
	1988			
Laddonia	2,052*	1,707	21,994*	10,493
Shelbina	813	704	39,737*	59,292
Sikeston	2,072	2,159	ND	20,518
	1989			
Baring	1,104	1,023	44,711	33,163
Baring	1,155*	1,008	ND	ND
Brunswick	2,047*	1,556	ND	ND
Centralia	2,704	2,841	33,031*	18,230
Centralia	3,393*	2,889	ND	ND
Henrietta	2,236*	2,037	11,091	11,832
Laddonia	2,201*	1,756	15,857*	21,600
St. Charles	3,264	3,426	3,674	3,057
	1990			
Baring	1,460*	1,209	36,840*	24,740
Benton City	2,407	2,348	24,593	22,688
Brunswick	3,067*	3,242	13,666	9,083
Centralia	1,875	1,789	22,762	27,087
Henrietta	2,216	2,089	6,769	7,712

† Applied in-furrow at planting at 5.43 kg a.i./ha.
‡ Eggs per 250 cm^3 soil. ND = not determined.
* Significant difference ($P \le 0.05$) between treated and nontreated plots.

RESULTS

Aldicarb effects on soybean yields: The effects of in-furrow applications of 5.43 kg a.i./ha aldicarb on yields of *H. glycines*-resistant and *H. glycines*-susceptible cultivars and egg densities were inconsistent in the 16 environments (Table 2). Overall yields in aldicarb-treated plots compared to nontreated plots were higher ($P \le 0.05$) in 7 environments, unaffected by aldicarb treatment in 8 environments, and lower in 1 environment (Brunswick, 1990). Differences in soybean yield related to aldicarb treatment were not consistently associated with soil texture, organic matter, pH, P or K levels, *H. glycines* Pi, or *H. glycines* race.

The effect of the labeled aldicarb rate (5.43 kg a.i./ha) and a one-half rate (2.72 kg a.i./ha) on yields of five susceptible and one resistant cultivars differed by location (Table 3). The Centralia location, a silty clay loam soil, had a mean *H. glycines* Pi of 3,000 eggs/250 cm^3 soil of a race 3 population, whereas the Baring location, a silt loam soil, had a mean *H. glycines* Pi of 28,000 eggs/250 cm^3 soil of a race 6 population. Mean yields at the Centralia and Baring locations were 3,075 kg/ha and 1,124 kg/ha, respectively. There was a significant cultivar × aldicarb interaction at Centralia. The cultivar main effect was significant only at the highest aldicarb rate at Centralia, whereas significant yield increases were obtained with both aldicarb rates at Baring. Fayette, the resistant cultivar, yielded more than any susceptible cultivar without aldicarb treatment. Averaged over all aldicarb treatments, Fayette yielded 307 kg/ha and 864 kg/ha higher than the combined yields of the five susceptible cultivars at Centralia and Baring, respectively.

TABLE 3. Yields of soybean cultivars in response to two aldicarb rates at two locations in Missouri, 1989.

	Seed yield (kg/ha)			
	Aldicarb (kg a.i./ha)			
Cultivar†	0	2.72	5.43	Mean‡
	Centralia			
Asgrow 3733	2,882	2,936	3,292	3,036 bc
Pioneer 9391	2,936	3,097	3,561	3,251 ab
Ripley	2,298	2,849	3,615	2,921 c
Stine 3790	2,936	2,802	3,447	3,062 bc
Williams 82	2,755	2,714	3,239	2,905 c
Fayette	3,554	3,272	3,198	3,342 a
Mean‡	2,889 a	2,943 a	3,393 b	
	Baring			
Asgrow 3733	996	935	970	967 c
Pioneer 9391	1,113	1,292	1,301	1,242 b
Ripley	437	918	717	691 d
Stine 3790	804	1,076	1,199	1,027 c
Williams 82	873	1,136	908	972 c
Fayette	1,801	1,891	1,837	1,844 a
Mean‡	1,008 a	1,208 b	1,155 b	

† All cultivars susceptible to *H. glycines* except Fayette.
‡ Main effect least squares means followed by the same letter are not significantly different ($P \leq 0.05$). Cultivar × aldicarb interaction significant ($P \leq 0.001$) at Centralia.

Aldicarb effects on H. glycines egg densities: Heterodera glycines Pf (Table 2) and Pf/Pi ratios were determined at 12 of the 16 environments. There was no consistent effect on Pf from aldicarb applications; Pf were significantly higher with aldicarb treatment in 3 environments but significantly lower in 2 environments.

For 1989 and 1990 egg data, Pf/Pi ratios and Pi were combined from all cultivars and locations and subjected to separate regression analyses for aldicarb-treated and nontreated plots. There were significant ($P \leq 0.05$) linear relationships between (Pf/Pi) and Pi, but only 16 to 42% of the variation was accounted for by the regression. Differences in slopes and intercepts between regressions from aldicarb-treated and nontreated plots were significant ($P = 0.02$) in 1989 but not in 1990 ($P = 0.09$). The magnitude of egg increase (Pf/Pi) relative to Pi was less in aldicarb-treated plots compared with nontreated plots in both years.

DISCUSSION

Soybean and nematode responses to aldicarb may be influenced by genotypic differences in phytotoxicity, soil type and texture, aldicarb dosage and application sequence, temperature, moisture, herbicide, and soil microflora (2,10,11,15–18). In our studies, cultivar, soil texture, organic matter, pH, P or K levels, *H. glycines* Pi, and race had no apparent effect on host or pathogen responses to aldicarb. Although all locations were infested with *H. glycines* egg densities above damage thresholds for Missouri (Niblack, unpubl.), significant yield increases from aldicarb on resistant and susceptible cultivars were obtained in only 7 of 16 environments.

Late season drought stress in 1988 and 1990 and severe phytotoxicity on seedlings in 1989 were the most probable factors influencing the inconsistent responses to aldicarb in our experiments. Precipitation in 1988 was one-third to one-half normal levels in the Midwest; consequently, north Missouri soybean yields were severely affected by drought. In 1988 and 1990, soybean vegetative growth was visibly greater in aldicarb-treated plots from early to mid-season, but the increase was not reflected in yields, except at Laddonia in 1988 and Baring in 1990. Laddonia received over 10 cm of precipitation in mid-August 1988 that allowed near normal yields (pers. obs.). Baring, in 1990, had the highest *H. glycines* Pi of all locations, so higher yields in aldicarb-treated plots may have been determined more by Pi than by environmental factors. Precipitation in 1989 was normal throughout the growing season, but severe seedling phytotoxicity symptoms (stunting, leaf crinkling, leaf chlorosis or necrosis, or reduced stands) were observed in aldicarb-treated plots at all locations. Significant yield responses to aldicarb, however, were obtained at five of the eight locations in 1989.

Heterodera glycines egg or cyst counts at harvest have been reported to increase following aldicarb treatment (15). In our experiments, however, *H. glycines* Pf were not consistently higher or lower in aldicarb-treated plots compared with nontreated plots. In addition, Pf/Pi ratios were reduced relative to Pi in aldicarb-treated plots. This was probably due to the aldicarb-induced mortality of infective juveniles.

Aldicarb applications did not consistently produce predictable yield increases on *H. glycines* resistant or susceptible cultivars adapted to Missouri. In environments where yields were higher with aldicarb treatment, mean yield increases on susceptible cultivars treated with aldicarb ranged from 199 to 670 kg/ha. Yields of the resistant cultivars, however, were equivalent to or significantly higher than yields of the susceptible cultivars treated with aldicarb. Similar results have been reported from other states (8,11). In Illinois, 'Fayette' yields were equivalent to or significantly higher than the aldicarb-treated, susceptible cultivar over 3 years (11). In Alabama, soybean yields were higher on aldicarb-treated susceptible cultivars in only 2 of 5 field locations in 1986, and yields of the resistant cultivars were equivalent to aldicarb-treated, susceptible cultivars in all locations (8). Soybean response to aldicarb in North Carolina varied with aldicarb rate, soil type, and *H. glycines* Pi (2,17). Excessive or deficient precipitation was cited also as an important factor influencing the efficacy of aldicarb on soybeans in these states.

Resistant cultivars, crop rotations, and nematicides have been recommended as *H. glycines* management strategies in soybean producing states (13). Based on results from our studies, however, we cannot recommend aldicarb for *H. glycines* management in Missouri. Soybean producers should grow resistant cultivars and implement effective crop rotations in *H. glycines*-infested fields.

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