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Irrigation of Soybean Cultivars Susceptible and Resistant to Soybean Cyst Nematode

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ABSTRACT

Soybean cyst nematode (SCN) (*Heterodera glycines* Ichinohe) infests soils throughout the mid and lower Mississippi River Valley and the southeastern Coastal Plain in the USA, a region where irrigation is widely practiced. This study was conducted to determine the effect of irrigation on number of SCN cysts and seed yield of three soybean [*Glycine max* (L.) Merr.] cultivars that have varying levels of SCN resistance when grown in monoculture on SCN-infested Dundee silt loam (fine-silty, mixed, thermic, Aeric Ochraqualf) that has a perched water table. Cultivars (all Maturity Group V) were Forrest (resistant to SCN Race 3), A5474 (resistant to SCN Races 3 and 4), and Bay (susceptible to SCN). Bay was grown with and without nematicide applied after planting. Irrigation treatment was either with or without supplemental water during reproductive development of soybean. Neither seed yield nor number of SCN cysts at planting or harvest were significantly (P = 0.05) affected by irrigation on this soil. Application of nematicide to Bay plots reduced the number of SCN cysts at harvest, but did not significantly affect seed yield. Number of SCN cysts was lowest in A5474 plots, and seed yield of A5474 was highest in the second and third year of the study. Irrigation did not significantly interact with cultivar or nematicide to affect cyst number or seed yield. We conclude that irrigation during reproductive development of soybean did not affect (i) cultivar response to infection with SCN, (ii) the capability of SCN to maintain cysts on any cultivar, or (iii) the yield-limiting effect of SCN on susceptible cultivars. This suggests that SCN effects on soybean are more complex than simply restricting water uptake by roots.

SOYBEAN CYST NEMATODE infests soils throughout the mid and lower Mississippi River Valley and the southeastern Coastal Plain in the USA (Riggs and Schmitt, 1987). Yield losses in soybean due to SCN can be significant. Effective management of SCN and consequent higher yields have been achieved using resistance (Reese et al., 1988; Young and Hartwig, 1988; Young et al., 1986), various rotations of resistant and susceptible soybean cultivars (Francl and Wrather, 1987; Young et al., 1986), and rotations with nonhost crops (Francl and Dropkin, 1986; Young et al., 1986). Nematicides have provided erratic economic benefit (Epps et al., 1981; Reese et al., 1988; Weaver et al., 1985).

Drought and SCN stress often occur simultaneously. Current hypotheses about the influence of soil moisture on the soybean–SCN interaction are (i) SCN may reduce soybean yield less in seasons with adequate soil moisture (Heatherly et al., 1982; Young et al., 1986), (ii) SCN may reduce yield of soybean less in years when soil moisture is deficient (Francl and Dropkin, 1986; Francl and Wrather, 1987), or (iii) soil moisture content and SCN infestation interact to affect soybean yield (Heatherly and Young, 1991). At this time, the impact of soil water on SCN behavior and soybean response is not clear. Soybean cyst nematode reduced vegatative growth of soybean grown on soil with little drought stress (Heatherly et al., 1982) and number of SCN cysts decreased with declining soil water potential. Seed yield was greatest in wet, noninfested soil, and seed yield was independently affected by soil water content and SCN infestation level in microplot studies (Young and Heatherly, 1988). In greenhouse studies (Heatherly and Young, 1991; Young and Heatherly, 1988), both seed yield and SCN cyst number were lower when a susceptible cultivar was grown in silt loam soil with low soil water potential than in soil with high water potential. In these studies, a significant interaction between soil water content and SCN infestation level resulted in percentage yield reduction caused by SCN being greater in the drier soil. The relative contribution of soil moisture and SCN stresses to decreased seed yield of soybean in field plantings has not been determined.

Use of nematicides has been proposed to alleviate stress in soybean caused by SCN. However, environmental concerns over their use (Weaver et al., 1985) and the fact that their use has not resulted in stress alleviation that surpasses that provided from use of resistant cultivars (Reese et al., 1988; Epps et al., 1981) have reduced their use and perceived effectiveness. Nevertheless, a nematicide × irrigation test is worthy of investigation from a practical and scientific perspective.

The objectives of this study involving a monoculture cropping system were to determine the effect of irrigation of an SCN-infested soil with a perched water table on (i) SCN reproduction and seed yield of soybean cultivars having varying levels of SCN resistance, and (ii) a susceptible cultivar grown with and without a nematicide.

MATERIALS AND METHODS

In the fall of 1985, after harvest of Forrest soybean, the intended study area (Dundee silt loam) was sampled to confirm infestation with SCN. Fifteen to 20 cores that were 15-cm deep were removed from each of 28 plot locations that comprised a 1984-1985 study. Cores collected from each plot were mixed thoroughly and a 300-cm^3 composite subsample was removed. Nematodes were extracted with a semiautomatic elutriator with cysts collected on a 250-μm-pore sieve and juveniles on a 38-μm-pore sieve. The juvenile fraction was further processed by centrifugal flotation (Barker et al., 1986). After cysts were counted, they were placed on Baermann funnels, and emerging juveniles were collected and counted after 7 d. This process determined that the entire study site was infested with viable

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Abbreviations: I, irrigated; NI, nonirrigated; SCN, soybean cyst nematode.

cysts. In November 1985, more samples were taken to form a composite for race determination. In January 1986, soybean was planted in this soil in pots in a greenhouse, with soybean harvest one month later. From this typing, soybean cultivars were selected for the experiment.

A field experiment was conducted from 1986 through 1988 on an area that had been planted with Forrest soybean in 1984 and 1985. Experimental design was a randomized complete block with a split-plot arrangement of treatments in four replicates. Treatments were irrigation level (main unit) and cultivar (subunit). Irrigation level was either nonirrigated or irrigated whenever soil water potential as measured by tensiometers at the 15-cm depth dropped below −50 kPa between beginning bloom (R1) and near full seed stage (R6). Irrigation of the randomized main units was accomplished with an overhead lateral-move irrigation system. Cultivar (all Maturity Group V) plots (randomized within each main unit) were Forrest (resistant to SCN race 3), A5474 (resistant to SCN races 3 and 4), Bay (susceptible to SCN) with nematicide applied after planting, and Bay without nematicide. Each subplot unit was 46 m long and 12 m wide (12 1-m wide rows). All irrigation level–cultivar combinations were repeated in the same location for the duration of the experiment.

In autumn of each year, the entire study area was subsoiled to ≈45-cm depth. Each spring, the area was disk-harrowed and bedded into 1-m wide rows with a disk bedder. In 1986, fertilizer was not applied, while in 1987, 84 kg ha^{-1} of K was applied immediately in the formed bed. In 1988, 53 kg ha^{-1} of P and 100 kg ha^{-1} of K were broadcast and disk-incorporated just prior to bedding. All fertility amendments were applied according to requirements established by soil tests.

The test site was planted on 7 May 1986, 30 Apr. 1987, and 9 June 1988. Seeding rate was ≈33 seed m^{-1} of row. Immediately after planting in 1986 and 1987, a tank-mix of metribuzin [4-amino-6-(1,1-dimethylethyl)-3-(methylthio)-1,2,4-triazin-5(4*H*)-one] at 0.23 kg a.i. ha^{-1} plus metolachlor [2-chloro-*N*-(2-ethyl-6-methylphenyl)-*N*-(2-methoxy-1-methylethyl)acetamide] at 2.25 kg a.i. ha^{-1} was broadcast for weed control. In 1988, 0.56 kg a.i. ha^{-1} of trifluralin [2,6-dinitro-*N*,*N*-dipropyl-4-(trifluoromethyl)benzenamine] plus 0.14 kg a.i. ha^{-1} of metribuzin were applied just prior to disking and bedding, and metribuzin at 0.14 kg a.i. ha^{-1} was applied broadcast immediately after planting. During the growing season, plots were cultivated two or three times for additional weed control. A tank-mix of 2,4-DB [4-(2,4-dichlorophenoxy)butanoic acid] plus linuron [*N'*-(3,4-dichlorophenyl)-*N*-methoxy-*N*-methylurea] was directed under the canopy on a 50-cm band for control of late-season weed infestations in the row.

Soil samples to determine population density of SCN were collected as previously described immediately after planting and harvest each year from the interior 31 m adjacent to a row in the middle of each plot. The post-harvest sample was lost in 1987. Samples were processed as previously described. After nematode samples were taken following planting each year, aldicarb [2-methyl-2-(methylthio)propionaldehyde-*O*-(methylcarbamoyl)oxime] at 2.0 kg a.i. ha^{-1} was applied to the designated Bay plots within 1 week of planting. All of the granular material was placed in a 5- to 7-cm-deep chisel slit ≈18 cm from one side of each of the 12 rows.

Height of mature soybean (measured from ground surface to terminal node) was recorded just prior to harvest each year. A field combine modified for in-field weighing of harvested seed was used to harvest the four center rows of each subplot unit. Harvest dates were 16 Oct. 1986, 23 Sept. 1987, and 11 Oct. 1988. Seed yields were adjusted to 130 g kg^{-1} moisture concentration. Weights of two random 100-seed samples per plot were also recorded and adjusted to the same moisture content. Calculations of number of seed per square meter were made from the seed weight and yield data.

Analysis of variance was used to evaluate the significance of treatment effects on measured traits. A significant *F*-test was used to determine difference between irrigation treatment means, while an LSD (0.05) value was used to determine differences among cultivar means. The two error mean squares in the analysis of variance model were pooled whenever they were not significantly different.

RESULTS AND DISCUSSION

Weather and Irrigation

Average maximum and minimum temperatures, rainfall, and pan evaporation during the soybean vegetative growth periods in 1986 and 1987 were similar and more favorable than in 1988, probably because of the later planting in 1988 (Table 1). Planting was delayed in 1988 because the soil from late April to early June was too dry for seed germination. A total of 51 mm of irrigation water was applied on 2 and 6 June to provide soil moisture sufficient for germination and emergence. Average temperatures during the R1 to R6 periods (Fehr and Caviness, 1977) of each year were similar. Rainfall during reproductive phase varied among years, and irrigation water applied varied as a result. In 1988, pan evaporation was considerably lower than in 1986 and 1987, and less irrigation water was applied than in the other 2 yr.

Number of Soybean Cyst Nematodes

The irrigation level × cultivar interaction was never significant ($P = 0.05$). Number of SCN cysts at planting and harvest of soybean was not significantly ($P = 0.05$) affected by irrigation (Table 2). Apparently soil moisture during the reproductive stage of soybean was not detrimental to SCN development. This finding is contrary to results reported by Heatherly and Young (1991) and Young and Heatherly (1988) from greenhouse and microplot studies where soil water potential, which was maintained at constant wet or dry levels from planting to maturity, significantly influenced cyst number.

As expected, there was no significant difference in number of cysts among the four cultivar subplots at planting in 1986. The residue nematicide in Bay plots did not significantly affect number of cysts at planting in subsequent seasons (1987 and 1988) (Table 2). However, number of cysts in treated Bay plots at harvest in 1986 and 1988 was fewer than in untreated plots, but the difference was significant only in 1986. Among all cultivars at harvest, number of cysts was fewest in plots of A5474, while Bay and Forrest were equally susceptible. Thus, irrigation did not affect cultivar response to infection by SCN, nor did it affect the reproductive capability of SCN on any cultivar, even when a nematicide was used.

Seed Yield and Yield Components

Irrigation did not significantly affect height at maturity, seed yield, seed weight, or number of seed of soybean in any year of the study (Table 3). The reason for this lack of response to irrigation is not apparent,

Table 1. Average maximum (max.) and minimum (min.) air temperatures (temp.) and total rainfall, irrigation (irrig.), and pan evaporation (evap.) amounts during vegetative and reproductive periods of Maturity Group V soybean in 1986, 1987, and 1988 at Stoneville, MS.

Period		Avg. temp.†				
Stages	Dates	Max.	Min.	Rain†	Pan evap.†	Irrig.
		°C		mm		
		1986				
Planting–R1	7 May–25 June	31	20	215	295	0
R1–R6	26 June–1 Sept.	34	22	87	482	203
		1987				
Planting–R1	30 Apr.–17 June	30	19	257	293	0
R1–R6	18 June–30 Aug.	33	22	174	469	102
		1988				
Planting–R1	9 June–26 July	33	21	63	350	0‡
R1–R6	27 July–10 Sept.	32	21	153	293	25

† Observations made by NOAA, Mid-South Agric. Weather Service Center, Stoneville, MS.
‡ Total of 51 mm applied preplant on 2 and 6 June.

especially when weather conditions (Table 1) are considered. Yield response of soybean to irrigation on clay and silt loam soils at this location in the absence of SCN has usually been significant and large (Heatherly, 1983, 1984, 1988; Heatherly and Pringle, 1991; Wesley et al., 1988). Heatherly et al. (1982), using vegetative measurements of shoot dry weight and leaf area index, proposed that high populations of SCN in wet soil offset an expected increase in plant productivity which had been achieved previously in the absence of SCN in greenhouse studies (Heatherly, 1980).

Water table observation wells were used to verify the existence of a perched water table at this site in 1989 and 1990. Water level was 1.6 m below the surface on 25 July 1989 (June–August rainfall = 564 mm) and 2.2 m below the surface on 27 July 1990 (June–August rainfall = 180 mm). If we assume that the perched water table existed at this site during 1986 (June–August rainfall = 163 mm), 1987 (June–August rainfall = 239 mm), and 1988 (June–August rainfall = 219 mm), the lack of yield response to irrigation in these years could have been due to the readily available water from the perched water table.

A5474 yielded more than Forrest and Bay each year. Difference between A5474 or Forrest and Bay with and without nematicide in 1986 was significant at *P*

Table 2. Number of cysts of soybean cyst nematode in irrigated (I) and nonirrigated (NI) plots of three soybean cultivars at planting and harvest, 1986 to 1988, Stoneville, MS.

	Sampled at					
	Planting			Harvest		
Cultivar	I	NI	Avg.	I	NI	Avg.
	cysts L^{-1} soil					
			1986			
Forrest	106	97	102a†	623	560	592a
A 5474	209	150	180a	38	32	35c
Bay −‡	125	72	98a	612	549	580a
Bay +	196	125	160a	549	306	428b
Avg.	159a	111a		456a	362a	
			1987			
Forrest	393	142	268ab	—§	—	
A 5474	78	63	70b	—	—	
Bay −	416	462	439a	—	—	
Bay +	401	275	338a	—	—	
Avg.	322a	236a				
			1988			
Forrest	72	46	59a	328	431	380a
A 5474	38	13	26a	78	72	75b
Bay −	53	97	75a	431	444	438a
Bay +	53	59	56a	256	431	344a
Avg.	54a	54a		273a	344a	

† Within years, columns, and rows, means followed by the same letter are not significantly different according to LSD (0.05) mean separation test; cultivar means × irrigation interaction never significant.
‡ Minus sign indicates no nematicide applied at planting; plus sign indicates nematicide applied at planting.
§ Harvest samples in 1987 inadvertently not counted.

Table 3. Mature plant height, seed yield, seed weight, and number of seed of irrigated (I) and nonirrigated (NI) soybean cultivars grown on a soybean cyst nematode (SCN) infested soil at Stoneville, MS.

	Plant height			Seed yield			Seed weight			Number of seed		
Cultivar	I	NI	Avg.	I	NI	Avg.	I	NI	Avg.	I	NI	Avg.
	cm			$kg\ ha^{-1}$			$mg\ seed^{-1}$			m^{-2}		
						1986						
Forrest	53	53	53a†	2809	2911	2860a	130	140	135b	2141	2084	2113a
A5474	59	53	56a	3062	2665	2864a	136	131	134b	2250	2041	2146a
Bay −‡	49	48	48a	2618	2553	2586a	167	174	170a	1569	1475	1522b
Bay +	54	50	52a	2541	2497	2519a	167	171	169a	1529	1482	1506b
Avg.	54a	51a		2758a	2656a		150a	154a		1872a	1771a	
						1987						
Forrest	55	58	56b	2213	2318	2266b	86	90	88c	2552	2585	2569b
A5474	66	66	66a	2916	2858	2887a	105	102	104b	2786	2805	2796a
Bay −	47	54	50b	2440	2483	2462b	117	121	119a	2087	2061	2074c
Bay +	52	52	52b	2451	2468	2460b	116	120	118a	2112	2056	2084c
Avg.	55a	58a		2505a	2532a		106a	108a		2384a	2377a	
						1988						
Forrest	92	89	90a	2822	2862	2842b	128	133	130c	2197	2152	2174a
A5474	88	88	88a	3142	3169	3156a	149	155	152b	2104	2047	2076a
Bay −	88	86	87a	2655	2729	2692c	178	175	176a	1495	1562	1528b
Bay +	88	84	86a	2608	2632	2620c	173	176	174a	1507	1493	1500b
Avg.	89a	87a		2807a	2848a		157a	160a		1826a	1814a	

† Within variables, years, and columns or rows, means followed by the same letter are not significantly different according to LSD (0.05) mean separation test.
‡ Minus and plus signs indicate that preemergence nematicide was not or was applied, respectively.

= 0.10, and at $P = 0.05$ in 1987 and 1988. This coincided with plots of A5474 having the lowest infestation of SCN. Obviously, its resistance to SCN contributed to the higher seed yield. However, the yield potential of this site is greater than the resistant A5474 produced in the presence of SCN, since irrigated Forrest grown on an adjacent site of this soil series yielded 3820 kg ha^{-1} in 1984 (Wesley et al., 1988).

Use of nematicide on susceptible Bay did not increase seed yield (Table 3), even though number of cysts at harvest was reduced by the nematicide (Table 2). Irrigation did not affect response to nematicide. Epps et al. (1981) measured an increase in seed yield and a decrease in number of cysts when aldicarb was applied to SCN race 4 susceptible Forrest. However, yield of Forrest from nematicide-treated soil did not equal yield of SCN Race 4 resistant 'Bedford' in their study. Reese et al. (1988) determined that nematicide-treated susceptible cultivars yielded no more than a resistant cultivar that was not treated with nematicide. They did find, however, that nematicide application at planting and flowering improved yield of susceptible cultivars grown on sandy loam soils in the field.

Irrigation level and cultivar did not interact significantly to affect soybean yield or yield components. Thus, the susceptibility of a cultivar to SCN was manifested in lower seed yield even with supplemental water. This is similar to results reported from microplot studies (Young and Heatherly, 1988). Evidently, plant injury or reduction in yield associated with SCN infestation in the field was not overcome with irrigation; otherwise, Forrest and Bay with irrigation should have produced yields comparable with those of A5474, or at the very least, produced higher yields than NI Forrest and Bay. Perhaps other factors such as reduced mineral uptake and dinitrogen fixation associated with *Heterodera* infection (Dropkin, 1989) contributed to the lack of response to irrigation.

These results indicate that SCN infection of soybean will reduce seed yield of susceptible cultivars, and irrigation in the presence of a perched water table apparently will not overcome this SCN stress. Unanswered questions arising from these results are: (i) will irrigation influence SCN-soybean interaction on soils that experience severe drought, and (ii) would a susceptible or resistant cultivar growing in SCN-free soil under conditions otherwise identical to those of this study have yielded the same as or more than A5474 growing in the presence of SCN? Further research is needed to answer these questions.

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