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Tolerance of Soybean to *Heterodera glycines*[1]

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Abstract: Seven soybeans were selected from 200 entries evaluated for tolerance to soybean cyst nematode (SCN), *Heterodera glycines.* Tolerance to SCN was measured by comparing the seed yield from aldicarb-treated vs. nontreated plots. A yield response index (YRI) was calculated for each entry: YRI = (seed yield from nontreated plot/seed yield from treated plot) × 100. The soybean entries Coker 156, PI 97100, and S79-8059 exhibited high tolerance (YRI) to SCN when compared to Essex even though they became heavily infected with SCN. Tolerance in soybeans to SCN may be useful in pest management programs designed to stabilize soybean yield.
Key words: Glycine max, Heterodera glycines, pest management, resistance, SCN, soybean, soybean cyst nematode, tolerance.

Soybean cyst nematode (SCN) *Heterodera glycines* Ichinohe is a serious pest of soybean in the United States. Resistant cultivars, crop rotation, and nematicides are utilized to reduce soybean yield suppression caused by this pest. These management measures have been used with varying degrees of success. Nematicides require additional expenditure by growers, crop rotation may require additional grower expertise, and the use of resistant cultivars has resulted in selection of SCN pathotypes that may damage resistant cultivars (5,9,16). Grower acceptance of programs to alleviate yield suppression caused by SCN may ultimately depend on the number of available options. The complexities of the SCN–soybean pathosystem (a pathologic system consisting of a parasite and host influenc-

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ing each other at a particular integration level [17]) and the seriousness of the problem require that we explore alternate methods of managing this pest.

Tolerance to cereal leaf rust was described by Caldwell et al. (3). Young (15) reported satisfactory yield performance of wheat cultivars tolerant to leaf rust. Potato cultivars tolerant to late blight are commonly grown in many countries (11). Yield differences among potato cultivars in the presence of *Globodera rostochiensis* have been reported (4,12). Heijbrock et al. (6) discussed techniques to breed for tolerance to *Heterodera schachtii* in sugar beets. Nyczepir and Lewis (8) observed differences among soybean cultivars for tolerance to *Hoplolaimus columbus*. Methods for screening soybean cultivars for tolerance to *Phytophthora megasperma* have been described (14). Boerma and Hussey (2) measured tolerance to *H. glycines* in soybeans by comparing yields from DBCP treated plots with yields from nontreated plots. Our objectives were to identify additional soybean cultivars with tolerance to *H. glycines* and study their reaction to different races of SCN.

Materials and Methods

The experiment was conducted at the Rhodes Farm of the University of Missouri, near Clarkton, Missouri, in Broseley loamy sand (86% sand, 11% silt, 3% clay, < 1% O.M., pH 5.4) heavily infected with a combination of SCN races 3 and 4 (1). Initially, 200 soybean entries were included in the test. Most of these entries were picked from USDA Preliminary and Advance Uniform Tests in maturity groups IV, V, and VI. Several relatively high yielding PI (plant introductions) lines were also included. Seven of the 200 entries were selected for further evaluation and experimentation on the basis of yield potential and perceived level of tolerance to SCN. The cultivars Bedford, with resistance to races 3 and 4; Forrest, with resistance to races 1 and 3; and Essex, susceptible to all races, were used as standards.

The 10 soybean entries were evaluated by planting in nontreated soil or soil treated with aldicarb in 1983 and 1984. Aldicarb was applied over the row in a 15-cm band at a rate of 2.24 kg a.i./ha and incorporated. Subplots were 6 m long and contained four rows each 0.97 m apart. The two middle rows were trimmed to 5 m prior to harvest. Yield and nematode data were collected from the two middle rows of each plot. The experiment had four replications in a split-plot design with soybean entries in the main plot and nematicide treatments in the subplot. Plots were irrigated four times in 1983 and twice in 1984. A yield response index (YRI) was calculated for each soybean entry where YRI = (yield without nematicide/yield with nematicide) × 100. The data were analyzed by analysis of variance techniques. In 1984, sixteen 2.3-cm-d soil cores were taken to a depth of 20 cm from the middle two rows of each plot for nematode analyses. Each composite sample was thoroughly mixed, and two 100-g subsamples were processed by elutriation and recovered cysts enumerated. Soil samples were collected before planting and at harvest.

Each soybean entry was tested for its reaction to race 3 of SCN reared on Essex, race 4 reared on PI 90763, and the Clarkton population reared on Essex. One thousand eggs of each nematode race or population were added to soil containing one 10-day-old seedling in an 8-cm-d clay pot. Each entry had eight pots. Thirty days after inoculation, soil was gently removed from the roots, SCN females were removed from the roots with a water jet, and the females were counted. The number of eggs per plant was calculated for the Clarkton population by counting eggs in 10 cysts selected at random from each entry tested.

Results and Discussion

Soybean seed yields were higher in both 1983 and 1984 in aldicarb-treated than nontreated plots (Table 1). The magnitude of the yield response to aldicarb by the different soybean entries as measured by the YRI varied significantly ($P < 0.01$), ranging from 63 to 98 in 1983 and from 66 to 104 in 1984. Soybean cultivars Essex and Forrest generally responded more positively to aldicarb treatment (low YRI) than did other entries in both years. The response between years was similar for most of the entries.

Aldicarb-treated soil generally con-

TABLE 1. Yield and yield response index (YRI) of soybean entries with (+) and without (−) aldicarb in a field infested with *Heterodera glycines*.

Entry	1983 Yield in kg/ha +	1983 Yield in kg/ha −	1983 YRI	1984 Yield in kg/ha +	1984 Yield in kg/ha −	1984 YRI
Bedford	2,239	2,124	96 de	1,926	1,940	101 cd
Forrest	2,084*	1,590	76 ac	1,917*	1,501	78 ab
Essex	1,222*	748	63 a	1,182*	794	66 a
GA76-113	1,663	1,451	87 bc	1,092	875	79 ac
N77-432	1,617	1,303	81 bd	1,069	920	89 bd
GA77-603	1,140	979	86 be	1,589	1,450	91 bd
R77-320	2,111*	1,492	72 ab	921	769	82 ab
PI 97100	1,141	1,048	91 ce	869	872	104 d
Coker 156	2,188	1,919	87 ce	1,641	1,477	90 bd
S77-8059	1,321	1,284	98 ce	1,017	950	93 bc
Mean	1,673	1,394		1,161	1,014	

LSD (0.05) to compare means with and without aldicarb, 93 for 1983 and 105 for 1984; to compare between two means with and without aldicarb for the same soybean cultivar, 384 for 1983 and 310 for 1984.
Values in columns with the same letter are not significantly different ($P = 0.05$).
* Yield of aldicarb treated plots significantly greater than without aldicarb ($P = 0.05$).

tained higher population densities of SCN at soybean harvest than did nontreated soil (Table 2). This result was not unexpected since nematicides protect plant roots for limited periods. Such protection increases root biomass which allows high nematode reproduction.

The greenhouse test revealed that Bedford, Forrest, GA76-113, and N77-432 possessed high resistance to SCN race 3 (Table 3). Roots of GA77-603 and R77-320 yielded cyst numbers intermediate between those on Essex and Bedford when inoculated with race 3. Coker 156, Essex, PI 97100, and S77-8059 all had large numbers of females on the roots, indicating high susceptibility to race 3. The Clarkton population and race 4 showed high reproduction on all entries except Bedford, indicating that race 4 predominated in this field.

Tolerance of Bedford to SCN could not be evaluated in this study, since it exhibited high resistance to the Clarkton population. Tolerance of Forrest, GA76-113, and N77-432, with high resistance to race 3 (Table 3), and GA77-603 and R77-320, with moderate resistance to race 3, must be considered separately from Bedford or entries susceptible to all races. Entries with some resistance may mask tolerance, since the genes for resistance will still be effective against some portion of the SCN population at Clarkton. Thus, partial resistance may be perceived as tolerance when the entry is actually intolerant. Forrest, therefore, with a YRI of 77, may actually be as intolerant as Essex, with a YRI of 63. GA76-113 and GA77-603, with YRI of 84 and 87, respectively, may possess higher levels of tolerance to SCN than either Forrest or Essex. Comparisons demonstrated that some susceptible entries possess a high level of tolerance to SCN (Table 1). PI 97100, Coker 156, and S76-8059 have YRI of 100, 88, and 95, respectively, significantly greater than the 63 YRI of Essex (Table 1).

Previous research (2) has shown that PI 97100 and Coker 156 are tolerant to SCN race 3. Our work indicates that these entries are also tolerant to race 4, as is S79-8059. The high level of tolerance exhibited by these three entries to both SCN races 3 and 4 indicates that tolerance, like horizontal resistance (13), may be effective against all races of SCN. More research is necessary to validate such a conclusion with regard to the soybean–SCN pathosystem. Tolerance to race 1 of SCN may be a special case, since race 1 severely inhibits nodulation of soybean by *Rhizobium japonicum* (7).

Tolerance of soybean entries to SCN should be evaluated not only against different races but also under varying environmental conditions. Under stressful environments, such as low soil moisture or

TABLE 2. Number of cysts of *Heterodera glycines* per 100 g soil at planting and after soybean harvest in 1984 with (+) and without (−) aldicarb.

Entry	Preplant	Post-harvest +	Post-harvest −
Bedford	29	87	86
Forrest	39	180	99
Essex	25	80	71
GA76-113	27	128	121
N77-432	24	126	97
GA77-603	36	197	162
R77-320	37	140	86
PI 97100	36	151	141
Coker 156	38	122	137
S77-8059	27	163	142
Mean	30	137	114

LSD (0.05) preplant NS, with and without aldicarb 18, between cultivars at the same or different level of aldicarb 58.

TABLE 3. Numbers of white females recovered per soybean plant inoculated with races 3 and 4, and the numbers of females and eggs per plant of the Clarkton population of *Heterodera glycines* in pots in the greenhouse after 30 days.

Entry	Race 3	Race 4	Clarkton population: Females	Clarkton population: Total eggs per plant
Bedford	1	14	21	2,000
Forrest	2	127	226	47,400
Essex	128	162	263	57,000
GA76-113	3	189	246	57,900
N77-432	5	175	182	34,600
GA77-603	79	124	259	42,100
R77-320	70	166	224	48,600
PI 97100	119	120	237	47,800
Coker 156	128	189	165	30,500
S77-8059	134	112	252	32,000
LSD (0.05)	30	48	22	

low fertility, tolerance may be inadequate to alleviate damage caused by SCN. Hussey and Boerma (2) indicated that low damage by SCN under high rainfall reduced the tolerance index (lower YRI) although the ranking of tolerant entries remained the same. Irrigation used in our experiments may have masked environmental influences on tolerance. The influence of environment on tolerance in soybeans to SCN must be better understood before tolerance is recommended as a tactic for managing yield suppression by SCN.

The use of nematicides in evaluating tolerance to plant-parasitic nematodes has limitations. Our results using aldicarb are similar to the results obtained by Boerma and Hussey (2) using DBCP. Nematicide application, therefore, can be justified in that it allows for the comparisons of many plant genotypes in one environment. The different modes of actions, biological spectra, environmental influences on efficacy, and nontarget effects of nematicides must be considered when selecting a nematicide. Additionally, one must remember that nematicides provide plant protection for only a limited time period.

Another approach to evaluating tolerance involves mathematical models for the relationship between nematode soil population density and damage to plants as proposed by Seinhorst (10). This model proposes a tolerance limit, a nematode population density below which plants are not damaged. If tolerance is related to the inoculum density at planting, then it should be evaluated on the basis of nematode population density rather than on the presence or absence of nematodes. The implications are that soybean tolerance may be dependent on the population density of SCN. Tolerance may be adequate when nematode pressure is moderate, but additional management tactics may be required if the nematode population density is high.

Soybean cultivars with resistance to individual SCN races are being developed at present. Planting resistant cultivars places selection pressure on the nematode population. This increases the frequency of genes for the ability to parasitize resistant cultivars. Continued selection pressure eventually renders the cultivar susceptible. Tolerant cultivars allow unrestricted development of all races of the pathogen. Thus there is lessened likelihood of the emergence of a pathotype that will damage the cultivar. Tolerance should effectively manage all races of the pathogen. Tolerant plants would be little damaged if a new race or pathotype were to become more prevalent.

Tolerance to SCN should be incorporated into soybean cultivars whenever possible. However, reliance on tolerance as the sole tactic to reduce yield suppression caused by SCN is inadvisable at present. Tolerance must be integrated into a management program that utilizes crop rotation, resistance, cultural practices, and possibly biological control. These tactics should be deployed in such a way that they complement each other.

In conclusion, tolerance to SCN is available in soybeans. Tolerance appears to be independent of the race of SCN, although more research is necessary to validate this concept. The mechanisms by which tolerance alleviates damage to soybean caused by SCN, however, are not understood. A critical evaluation of tolerance under different environmental conditions is required before tolerance can be recommended as a tactic to manage SCN over large geographic areas.

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