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Field Response of Soybean in Maturity Groups III–V to *Heterodera glycines* in Kansas[1]

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Abstract: Soybean cultivars from maturity groups III–V were grown in *Heterodera glycines*-infested locations in northeastern and southeastern Kansas from 1991 through 1994. Yield performance and nematode reproduction were significantly ($P < 0.01$) affected by host response to *H. glycines* and year, whereas effects of cultivars within host response categories and cultivar × year interactions were generally negligible. In northeastern Kansas, *H. glycines*-susceptible cultivars from maturity groups III–IV yielded 8% less than resistant cultivars across years, whereas in southeastern Kansas, susceptible cultivars from maturity groups IV–V yielded 38% less than resistant cultivars across years. Analyses of yield components suggested that number of pods per plant accounted for most of the differences in seed yields. *Heterodera glycines* reproduction rates (final population density/initial population density) averaged 0.7 and 1.3 for resistant cultivars and 8.7 and 15.9 for susceptible cultivars in northeastern and southeastern locations, respectively. Results indicated that the relative performance of resistant and susceptible cultivars can be reliably predicted based on preplant egg densities across most environments in eastern Kansas.

Key words: cultivar, *Glycine max*, *Heterodera glycines*, management, nematode, resistance, soybean, soybean cyst nematode.

Resistant soybean (*Glycine max*) cultivars, along with crop rotation, continue to be the most effective options for management of the soybean cyst nematode, *Heterodera glycines*, in Kansas and other states (6,7). Several recent field evaluations have included *H. glycines*-resistant and -susceptible soybean cultivars from maturity groups III–V, which are commonly grown in Kansas (4,6,7,9). Resistant cultivar yields were higher than susceptible cultivar yields across most environments in these studies, but the percentage yield difference varied with preplant egg densities in Missouri (6) and with soil texture in Illinois (4). Resistant cultivars are also effective in reducing *H. glycines* populations but, again, the effect is variable (3,4).

In northeastern Kansas, the yield benefit associated with resistant cultivars from maturity groups III–IV is usually small, whereas in southeastern Kansas, large yield increases are often observed with resistant cultivars from maturity groups IV–V (7–9). In addition to length of growing season, numerous differences between these two regions exist, including average *H. glycines* population densities, soil type, soil fertility, and precipitation. *Heterodera glycines* infestations in northeastern Kansas typically occur in sandy flood plains, whereas infestations in southeastern Kansas are more widely distributed across the shallow silt loams common to the area. Higher *H. glycines* population densities, warmer temperatures, and lower precipitation during the months of July and August are all characteristic of southeastern compared with northeastern Kansas. The objective of this study was to compare the yield performance of selected resistant and susceptible soybean cultivars and the associated *H. glycines* reproduction over multiple years at representative locations in these two diverse environments in Kansas.

Materials and Methods

Soybean performance trials were conducted in *H. glycines*-infested fields at two locations per year from 1991 to 1994. Resistant (R) and susceptible (S) cultivars from maturity groups III–IV and IV–V

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were grown at separate locations in northeastern and southeastern Kansas, respectively, each year of the study. Soils at southeastern locations were silt loams; soils at northeastern locations were variable across years (Table 1). Populations of *H. glycines* at all locations were race 3 with the exception of Rossville, which was infested with a race 14 population. Soybean cultivars, response to *H. glycines* race 3, and maturity group were as follows: in northeastern Kansas, Asgrow 3431 (R,III), Asgrow 4138 (R,IV), Asgrow 4715 (R,IV), Cartter (R,III), Delsoy 4210 (R,IV), Delsoy 4500 (R,IV), Delsoy 4710 (R,IV), Fayette (R,III), Flyer (S,IV), Jack (R,III), NC+ 3A63 (R,III), Neco 1051N (R,III), Northrup King (NK) S42-32 (R, IV), NK S46-44 (R,IV), Resnik (S,III), Spencer (S,IV), Williams 82 (S,III); and in southeastern Kansas, Asgrow 4715 (R,IV), Asgrow 5112 (R,V), Avery (R,V), Bay (S,V), Delsoy 4710 (R,IV), Delsoy 4900 (R,IV), Essex (S,V), Flyer (S,IV), Forrest (R,V), Hartwig (R,V), Hutcheson (S,V), Hyperformer HCS 501 (R,V), KS4895 (S,IV), KS5292 (R,V), Manokin (R,V), NC+ 5A15 (R,V), Pioneer 9521 (R,V), Pioneer 9531 (R,V), Rhodes (R,V), Stafford (S,V), Terra E4792 (R,IV). All race 3-resistant cultivars planted at Rossville in 1993 were also resistant to race 14.

The experimental design at all locations was a randomized complete block with four replications. Plots were four rows, 6.1 m long with 75-cm row spacing. Seeds were planted with a two- or four-row planter at a rate of 24 seeds/m. Each location received a preemergence herbicide treatment of alachlor (2.67 kg a.i./ha) and trifluralin (0.56 kg a.i./ha) or imazaquin (0.14 kg a.i./ha) and pendimethalin (0.84 kg a.i./ha). Plots were hand-weeded as necessary. Soybeans were harvested from 4.5 m of each of the two middle rows with a plot combine. Soybean pods were collected by hand from 0.6 m of plots of Asgrow 4715, Avery, Essex, Flyer, Forrest, Hutcheson, KS5292, and Stafford from 1992 through 1994 for analysis of yield components, including number of pods per plant, number of seeds per pod, and weights of individual seeds.

Soil population densities of *H. glycines* were determined at planting (Pi) and harvest (Pf) from a composite sample of four 5-cm-d cores collected to a depth of 15 cm from the middle two rows of each plot. Cysts from 100-cm^3 subsamples were collected on a 150-µm-pore sieve and mechanically ground to release eggs and second-stage juveniles (J2) (2). Eggs and J2 were counted at ×40 magnification.

All data were subjected to analysis of variance with the General Linear Models procedure of SAS (SAS Institute, Cary, NC) software. Data from field plots in northeastern and southeastern Kansas were analyzed separately, with year treated as a random variable. Egg counts and Pf/Pi ratios were transformed to $\log_{10}(x + 1)$ values before analysis. In addition to actual

TABLE 1. Site information on *Heterodera glycines* field trial locations in Kansas, 1991–94.

Location	Year	Date of planting	Soil texture and fertility: Sand %	Silt %	Clay %	OM %	pH	P kg/ha	K kg/ha	*H. glycines* Pi[a]
					Northeast					
Wathena	1992	28 May	54	33	13	1.6	8.1	70	468	1,624
Rossville	1993	20 May	72	20	8	1.3	5.4	62	418	2,497
Severance	1994	13 May	19	56	23	2.4	6.5	122	462	427
					Southeast					
Columbus	1991	29 May	34	46	20	1.5	6.9	29	147	2,080
Columbus	1992	25 June	36	40	24	1.4	7.2	32	226	6,214
Pittsburgh	1993	15 June	30	58	12	1.8	7.2	36	217	5,467
Columbus	1994	10 June	37	46	17	1.5	7.0	43	198	2,367

[a] Pi = number of eggs and J2 per 100 cm^3 soil at planting.

soybean seed yields, the relative yield performance of each cultivar was expressed as a percentage of the average yield for each field trial to facilitate comparisons of resistant and susceptible cultivars. Correlation and regression analyses were used to examine relationships between soybean seed yields and nematode populations and between seed yields and yield components.

Results

Seed yields: Soybean seed yields among maturity group III–IV cultivars in northeastern Kansas did not differ during the years 1992 (the field location in northeastern Kansas for 1991 was lost due to drought) through 1994 ($P \leq 0.05$) (Tables 2, 3). Differences in soybean yields were observed among years ($P < 0.001$), but cultivar × year interactions were not significant. Susceptible cultivars averaged 8% lower relative yields than resistant cultivars across years ($P < 0.01$) (Table 3).

Maturity group IV–V cultivars in southeastern Kansas exhibited large differences between host response categories for both actual and relative seed yields during 1991 through 1994 ($P < 0.001$) (Tables 2,4). The year and cultivar × year interaction effects were significant for actual seed yield, but these effects were small compared to the overall effect of host response. Average actual and relative seed yields for susceptible cultivars were 38% lower than average resistant cultivar yields ($P < 0.001$) (Table 4), with annual yield reductions ranging from 22% to 46%.

Yield components: Number of seed pods per plant differed between resistant and susceptible cultivars but not among cultivars within host response categories ($P < 0.05$) (Table 5). Susceptible cultivars pro-

TABLE 3. Seed yields and *Heterodera glycines* reproductive rates for resistant and susceptible cultivars in maturity groups III–IV soybean grown in northeastern Kansas, 1992–94.

Cultivar	Seed yield (kg/ha)	Yield as % of test average	Pf/Pi[a]
		Resistant	
Asgrow 3431	2,901 a[b]	114 a	2.2 b
Asgrow 4138	2,881 a	112 a	1.9 b
Delsoy 4500	2,794 a	110 a	1.1 b
NC+ 3A63	2,707 a	110 a	2.6 b
NK 42-32	2,848 a	109 a	2.0 b
NK 46-44	2,700 a	105 a	0.1 b
Asgrow 4715	2,660 a	103 a	0.1 b
Delsoy 4210	2,546 a	98 a	1.1 b
Neco 1051N	2,586 a	97 a	0.9 b
Jack	2,526 a	95 a	0.8 b
Delsoy 4710	2,466 a	95 a	1.7 b
Fayette	2,365 a	94 a	2.5 b
Cartter	2,271 a	90 a	1.9 b
Averages	2,620 A[b]	102 A	1.3 B
		Susceptible	
Spencer	2,760 a	105 b	10.8 a
Flyer	2,479 a	90 b	22.8 a
Williams 82	2,385 a	90 b	18.4 a
Resnik	2,338 a	89 b	11.4 a
Averages	2,492 A	94 B	15.9 A
CV (%)	9.2	8.4	58.0

[a] Pi = number of eggs and J2 per 100 cm^3 soil at planting; Pf = number of eggs and J2 per 100 cm^3 soil at harvest.
[b] Means followed by the same letter for host response (A-B) or cultivar within host response (a-b) are not significantly different according to Fisher's LSD ($P = 0.05$).

TABLE 2. Analyses of variance in soybean seed yields and *Heterodera glycines* reproductive rates on resistant and susceptible cultivars in northeastern and southeastern Kansas, 1991–94.

	Mean squares			
	Northeastern Kansas		Southeastern Kansas	
Source of variation	Seed yield	Pf/Pi[a]	Seed yield	Pf/Pi
Year	7,808.3**	0.93	2,766.4**	0.54**
Host response	104.8	10.88**	7,347.7**	21.03**
Cultivar (within host response category)	63.8	0.15	42.4	0.04
Year × Cultivar	42.2	0.20**	29.9**	0.08
Error	25.7	0.07	10.9	0.06

* $P \leq 0.05$, ** $P \leq 0.01$.
[a] Pi = number of eggs and J2 per 100 cm^3 soil at planting; Pf = number of eggs and J2 per 100 cm^3 soil at harvest.

TABLE 4. Seed yields and *Heterodera glycines* reproductive rates for resistant and susceptible cultivars in maturity groups IV–V soybean grown in southeastern Kansas, 1991–94.

Cultivar	Seed yield (kg/ha)	Yield as % of test average	Pf/Pi[a]
		Resistant	
Rhodes	2,204 a[b]	127 a	0.9 b
Manokin	2,291 a	121 a	0.2 b
Pioneer 9521	2,258 a	120 a	0.4 b
KS5292	2,245 a	119 a	1.1 b
Delsoy 4710	2,231 a	118 a	0.4 b
Forrest	2,111 a	118 a	1.1 b
Hartwig	2,171 a	115 a	0.0 b
Avery	2,064 a	115 a	0.8 b
Asgrow 5112	2,157 a	115 a	0.5 b
HSC 501	2,184 a	114 a	0.1 b
Delsoy 4900	2,064 a	113 a	0.5 b
Asgrow 4715	2,084 a	111 a	1.5 b
Pioneer 9531	2,023 a	110 a	1.3 b
NC+ 5A15	2,030 a	109 a	0.4 b
Terra E4792	2,003 a	107 a	0.4 b
Averages	2,114 A[b]	116 A	0.7 B
		Susceptible	
Hutcheson	1,582 b	82 b	9.8 a
Bay	1,347 b	75 b	8.2 a
KS4895	1,494 b	75 b	8.4 a
Stafford	1,340 b	71 b	7.3 a
Essex	1,340 b	69 b	10.1 a
Flyer	978 b	60 b	8.3 a
Averages	1,340 B	72 B	8.7 A
CV (%)	9.4	10.5	57.9

[a] Pi = number of eggs and J2 per 100 cm^3 soil at planting; Pf = number of eggs and J2 per 100 cm^3 soil at harvest.
[b] Means followed by the same letter for host response (A-B) or cultivar within host responses (a-b) are not significantly different according to Fisher's LSD (P = 0.05).

duced 28% fewer pods per plant than resistant cultivars. Number of seeds per pod varied slightly with cultivar response, but was primarily affected by cultivar, whereas individual seed weight was not affected by host response or cultivar. Regression analysis indicated that, of the yield components examined, only the number of pods per plant explained a significant amount of the variation in relative seed yields for all cultivars over all years (R^2 = 0.35, P = 0.003).

Nematode reproduction: Heterodera glycines Pf/Pi ratios were affected by cultivar response at both locations over all years (P < 0.001), but did not differ among cultivars within response categories (Table 2). Average Pf/Pi ratios ranged from 0.1 to 2.6 for individual resistant cultivars and from 7.3 to 22.8 for individual susceptible cultivars (Tables 3,4). A significant cultivar × year interaction occurred for Pf/Pi ratios from northeastern Kansas due to abnormally low reproduction on susceptible cultivars in 1993. Although Pf/Pi were still higher on susceptible cultivars than on resistant cultivars in 1993, differences were of smaller magnitude (data not shown).

Relationships among soybean yield, H. glycines Pi, and Pf/Pi ratios: Relative soybean seed yield was negatively correlated (r = −0.59, P < 0.001) with *H. glycines* Pi across all environments for susceptible, but not resistant, cultivars. Regression analysis indicated that nearly half of the variation in relative seed yields for all cultivars across all environments was explained by the multiplicative effects of Pi and Pf/Pi ratios (R^2 = 0.45, P < 0.001). Reproduction (Pf/Pi) was negatively correlated with Pi across environments for both resistant (r = −0.24, P = 0.05) and susceptible (r = −0.46, P = 0.01) cultivars.

DISCUSSION

Differences in seed yields between resistant and susceptible cultivars were consis-

TABLE 5. Yield components for *Heterodera glycines*-resistant and susceptible cultivars in maturity groups IV-V soybean grown in southeastern Kansas, 1992–94.

Cultivar	Pods/plant	Seeds/pod	Individual seed weight (g)
		Resistant	
Forrest	45.3 a[a]	2.0 b	0.13 a
KS5292	40.7 a	2.0 b	0.13 a
Avery	33.1 a	2.2 a	0.16 a
Asgrow 4715	34.2 a	2.4 a	0.15 a
Averages	38.3 A[a]	2.1 A	0.14 A
		Susceptible	
Hutcheson	28.9 b	2.2 c	0.15 a
Essex	29.7 b	2.0 d	0.13 a
Stafford	26.1 b	2.2 cd	0.13 a
Flyer	25.7 b	1.7 e	0.14 a
Averages	27.6 B	2.0 B	0.14 A
CV (%)	25.5	11.8	17.1

[a] Means followed by the same letter for host response (A-B) or cultivar within host responses (a-b) are not significantly different according to Fisher's LSD (P = 0.05).

tently small for northeastern Kansas, despite a wide range in soil texture and *H. glycines* egg densities across locations. This result can be explained largely by the excessive amounts of precipitation and below-average temperatures at Rossville in 1993, which severely limited *H. glycines* reproduction and damage to susceptible cultivars. Under average climatic conditions, yield loss would be expected to be high at this location due to the high sand content (4) and relatively high egg density. In contrast to observations in northeastern Kansas, differences in performance between resistant and susceptible cultivars in the southeastern region of the state were consistently large, varying slightly with egg density. Average soybean seed yields for both areas were strongly affected by year, and this effect was primarily related to precipitation; however, environmental conditions did not appear to strongly affect the relative performance of resistant vs. susceptible cultivars in Kansas during 1991–94.

Relative losses in seed yield initially appeared to be lower for the maturity group III–IV susceptible cultivars grown in northeastern Kansas (8% per 1,500 eggs/100 cm^3 soil) than for the maturity group IV-V susceptible cultivars grown in southeastern Kansas (38% per 4,000 eggs/100 cm^3 soil), even when differences in *H. glycines* Pi are considered. Susceptible cultivars in the former group, however, exhibited a 6% yield advantage over resistant cultivars when grown in uninfested fields during the same 3-year period; this difference was not observed for cultivars in the latter group (Schapaugh, *unpubl.*). When this incongruity is removed, and when Pi is standardized at 1,000 eggs/100 cm^3 soil, susceptible cultivars produced 9% lower seed yields on average than resistant cultivars at both locations. This level of yield loss is consistent with previous yield loss estimates of 12% for preplant egg densities of 1,400/100 cm^3 soil in northeastern Kansas (8) and 38%–39% for preplant egg densities of approximately 4,000/100 cm^3 soil in southeastern Kansas (7,9).

Analysis of yield components indicated that *H. glycines*-induced yield reductions in susceptible cultivars resulted primarily from reduced numbers of pods. Numbers of seed per pod also differed between host response categories but reductions in this yield component were restricted essentially to the early-maturing cultivar Flyer. Early-maturing cultivars have been shown to exhibit proportionately more yield loss from *H. glycines* and other diseases than long-season cultivars in southeastern Kansas (5,7).

Reproduction of *H. glycines* on resistant cultivars, as determined by Pf/Pi ratios, averaged only 8% of that observed on susceptible cultivars across locations and years. Nematode reproduction was higher on both resistant and susceptible cultivars in northeastern than in southeastern Kansas, despite shorter host maturities at the former location. Correlation and regression analyses from this and other studies (6) suggest that a significant portion of the variation in Pf/Pi ratios across environments is associated with Pi for resistant as well as susceptible cultivars. Because Pi were lower on average at locations in northeastern compared to southeastern Kansas, higher levels of reproduction would be expected for the northeastern locations in this study. The influence of Pi on reproduction is particularly notable for resistant cultivars, because at low Pi, reductions in nematode populations will likely be small and increases may actually occur. Thus, although resistant cultivars may still provide yield increases over susceptible cultivars because relative differences in rates of reproduction appear constant, they will probably not further reduce already low population levels of the nematode. The exception to this premise would be resistant cultivars with the PI 437654 source of resistance, such as Hartwig (1), because they do not appear to support any nematode reproduction.

The results of this study indicate that the yield benefit obtained from planting a high-yielding resistant cultivar is directly proportional to preplant *H. glycines* egg densities, and can be predicted with sufficient accuracy for most environmental conditions in eastern Kansas. The causes of the commonly observed differences in egg densities between northeastern and southeastern areas of the state need further examination.

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