Journal of Nematology 29(2):173–179. 1997.

Distribution of Races of *Heterodera glycines* in the Central United States[1]

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Abstract: A total of 62 populations of *Heterodera glycines* were collected in 10 states along the Mississippi and Missouri rivers, and 206 populations were collected in Arkansas. Among the 62 populations, races 2, 3, 4, 5, 6, 9, and 14 were found south of 37°N latitude, and races 1 and 3 were found north of 37°N latitude. In Arkansas samples, races 2, 4, 5, 6, 9, and 14 comprised 87% of the populations. In both groups of samples, *H. glycines* populations with genes that enabled the population to parasitize cv. Pickett occurred the most frequently, followed by those with genes for parasitism of cv. Peking, then PI88.788, and the fewest with genes for parasitism of PI90.763. The diversity of races in this study raises questions about the effectiveness of race-specific cultivars for the management of soybean cyst nematodes. The greater diversity of races of *H. glycines* in the southern United States may be because of a longer history of planting resistant cultivars.

Key words: breeding, geographic distribution, *Glycine max, Heterodera glycines,* race, resistance, soybean, soybean cyst nematode.

Soybean cyst nematode, *Heterodera glycines* Ichinohe, is one of the most damaging pests of soybean, *Glycine max* (L.) Merr., causing more yield reduction than most other diseases (Doupnik, 1993; Sciumbato, 1993). Although nematicides have been used to some extent, inclusion of nematode-resistant soybean cultivars in rotations with non-host crops is the principal method for limiting yield losses (Epps et al., 1981).

The variability in *H. glycines* populations (Sipes, 1992), however, complicates the use of resistant cultivars for *H. glycines* management. Continuous planting of resistant cultivars may result in the selection of *H. glycines* genotypes that are able to develop and reproduce on those cultivars. Several races are known to occur in soybean fields in the United States (Anand et al., 1994), but the distribution of races is not well documented. Information on the distribution of races in different soybean production areas would facilitate the development of strategies for future breeding programs for *H. glycines* resistance and for management of the nematode.

To examine the race distribution pattern in soybean fields in the central United States, 62 populations of *H. glycines* from randomly selected soybean fields in 10 states along the Mississippi and Missouri rivers and 206 populations from Arkansas were classified as to race based on the 16-race scheme (Riggs and Schmitt, 1988).

Materials and Methods

Races of H. glycines in Arkansas: Heterodera glycines isolates were collected from soybean fields in 31 counties in Arkansas from 1988 to 1994. A total of 206 isolates of *H. glycines* were classified as to race (Riggs and Schmitt, 1988). The method used for race tests was similar to that reported previously (Riggs and Schmitt, 1991). Briefly, seeds of the differential soybean genotypes Pickett, Peking, PI88.788, PI90.763, and Lee 74 (susceptible check) were germinated in vermiculite and transplanted at the cotyledon stage into 7.5-cm-diam. clay pots containing *H. glycines*-infested field soil. Each genotype was replicated three times. The greenhouse was maintained at 24 ± 4°C, and plants were watered as needed.

After 30 to 40 days, females were separated from the roots and soil and counted with a stereomicroscope. The number of females and cysts on 'Lee 74' was considered to have a Female Index (FI) of 100. The

Received for publication 26 April 1996.
[1] Published with the approval of the Director, Arkansas Agricultural Experiment Station, manuscript #96021. This research was supported in part by a grant from the Alternative Pest Control program, USDA-CSRS.
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term FI was defined as the number of females and cysts (hereafter called cysts) that developed on a test soybean cultivar expressed as a percent of the number that developed on the susceptible cultivar, Lee 74. A race designation was given to each *H. glycines* isolate that produced more than 50 cysts total in the three pots planted to 'Lee 74'.

Races of H. glycines in the Central United States: A total of 62 *H. glycines* isolates were collected from 30 counties in 10 states (Table 1) along the Mississippi and Missouri rivers during fall 1992 and 1993 and were classified as to race (Riggs and Schmitt, 1988; 1991). The method used for race tests was similar to that described for Arkansas populations except that pots were filled with steam-sterilized fine river sand infested with 5,000 to 20,000 eggs each of the 62 isolates cultured on 'Lee 74' soybean. To obtain eggs, susceptible 'Lee 74' soybean was planted in soil infested with each of the *H. glycines* isolates, all of which were maintained in a greenhouse for 2 to 4 months. Each differential genotype was replicated three times. In addition to the FI, any *H. glycines* isolate that produced at least one cyst on a given differential was considered to have at least one gene for parasitism on that soybean genotype (Anand et al., 1994).

TABLE 1. Race distribution of 206 soybean cyst nematode (*Heterodera glycines*) populations in Arkansas samples and the differentials for which that race has genes for parasitism: none (0), 'Pickett' (Pi), PI88.788 (88), 'Peking' (Pe), or PI90.763 (90).

Race[a]	% of population	Differentials parasitized
1	1	88
2	13	Pi, Pe, 88
3	4	0
4	11	Pi, Pe, 88, 90
5	15	Pi, 88
6	22	Pi
8	1	90
9	18	Pi, Pe
10	3	Pi, 90
12	1	Pe, 90
14	8	Pi, Pe, 90
15	3	Pi, Pe, 88

[a] Races as designated by Riggs and Schmitt (1988).

RESULTS

Races of H. glycines in Arkansas: Twelve races of *H. glycines* were found in soybean fields in Arkansas (Table 1). Races 6 (22%), 9 (18%), 5 (15%), 2 (13%), 4 (11%), and 14 (8%) comprised 87% of the *H. glycines* populations. The occurrence of races 1, 3, 8, 10, 12, and 15 was less than 4% each. Races 7, 11, 13, and 16 were not found.

About 91% of *H. glycines* populations had genes for parasitism on 'Pickett' (FI ≥ 10) followed by 'Peking' (51%), PI88.788 (43%), and PI90.763 (26%) (Table 1). About 11% of *H. glycines* populations had genes for parasitism on all four differentials, whereas less than 4% of the populations did not parasitize any of the genotypes.

Races of H. glycines in the Central United States: Eight races were found in soybean fields in 10 states along the Mississippi and Missouri rivers (Table 2). Races 2, 3, 4, 5, 6, 9, and 14 were found south of 37°N latitude, and only races 1 and 3 were found north of 37°N latitude. Races 2, 6, and 9 were the dominant races in southern states, and race 3 was the dominant race in northern states.

About 66% of the *H. glycines* populations had genes for parasitism on 'Pickett', followed by 'Peking' (56%), PI88.788 (29%), and PI90.763 (9%). About 3% of the *H. glycines* populations had genes for parasitism on all four resistant differentials, and 27% of the populations did not parasitize any of the genotypes.

DISCUSSION

A survey of soybean fields in the central United States revealed that at least 12 races of *H. glycines* occurred in soybean fields in this region. The race distribution pattern clearly differed between northern (north of 37°N latitude) and southern (south of 37°N latitude) states. This survey, which admittedly was limited, included fields selected at random, and only two races were found in 21 fields sampled in northern states, whereas seven races were found in 41 fields sampled in southern states other than Arkansas. The survey in Arkansas was much more extensive, and five races were found in

TABLE 2. Numbers of cysts on Lee 74, female indices on soybean cyst nematode differentials, and the resulting race designations of 62 soybean cyst nematode isolates collected from 10 states.

Source (State and county)	Cysts on Lee 74[b]	Female index[a]				Race[c]
		Pickett	Peking	PI88788	PI90763	
Isolates collected north of 37°N latitude						
Minnesota						
Martin	18–201	0–3	+	0	0	3
Mower	720–1200	0–1	+	0	0	3
Illinois						
Alexander	240–344	0–1	0	+	0	3
Alexander	51–372	0–1	0	0	0	3
Iowa						
Des Moines	140–360	0	0	0	0	3
Humboldt	294–432	2–2	+	9–14	0	1
Kossuth	636–1944	1–6	+	0	0	3
Lee	1,020–1,710	0	0	0	0	3
Lee	6–214	+	0	+	0	3
Kansas						
Doniphan	16–108	0–0	0	0	0	3
Doniphan	180–1,200	1–8	+	17–31	+	1
Doniphan	468–588	1–3	+	3–8	0	3
Nebraska						
Burt	810–1,800	1–15	0–1	3–9	+	3
Burt	216–468	0–2	+	23–35	0	1
Cass	38–74	0	0	0	0	3
Cass	870–1,950	0	0	3–74	+	1
Richardson	174–174	1–10	+	0	0	3
Richardson	720–1,230	2–3	+	0–1	0	3
Missouri						
Clark	240–2,160	0–5	+	5–9	0	3
Lewis	23–138	0–3	0	0–1	0	3
Warren	69–324	0	0	0–1	0	3
Isolates collected south of 37°N latitude						
Kentucky						
Ballard	756–1,320	21–36	3–4	2–4	0–1	6
Fulton	264–612	24–81	2–3	2–4	0–1	6
Fulton	2,448–3,240	9–29	0–2	2–13	+	6
Fulton	70–104	1–32	0–1	0–22	0	5
Fulton	33–132	7–77	0–12	0–4	0–1	9
Fulton	228–750	21–56	0–1	62–73	0	5
McCraken	264–558	8–49	11–31	5–17	5–23	4
Tennessee						
Dyer	390–540	57–222	0–2	7–23	0–1	5
Dyer	870–1,740	52–82	1–5	13–50	+	5
Dyer	150–360	20–193	3–140	6–39	0–7	2
Lake	186–210	77–103	3–6	11–18	0–2	5
Lake	138–444	37–86	2–5	5–36	0–1	5
Lake	228–450	24–139	12–30	4–5	5–10	9
Lake	2,376–4,500	24–107	1–2	8–28	1–1	5
Lake	318–426	36–122	6–16	4–13	3–9	2
Lake	450–528	37–205	10–37	6–7	5–19	14
Lake	210–318	80–128	5–6	4–8	6–8	6
Lauderdale	330–990	2–70	0–6	0–3	0	6
Lauderdale	213–690	36–136	1–1	4–35	+	5
Lauderdale	102–276	49–94	0–10	24–36	0–1	5
Lauderdale	1,512–2,520	106–130	2–3	2–3	2–5	6
Obion	63–300	35–56	0–1	0–11	0–4	6
Mississippi						
DeSoto	1,080–2,220	15–74	17–22	0–9	2–7	9
Lee	336–492	33–85	18–26	5–15	6–24	4

TABLE 2. *Continued*

Source (State and county)	Cysts on Lee 74[b]	Female index[a]				Race[c]
		Pickett	Peking	PI88788	PI90763	
Lee	66–297	44–117	7–35	4–6	2–20	14
Desoto	396–1,260	13–67	9–21	3–22	0–1	2
Grenada	276–660	46–341	0–1	0	0–12	6
Panola	162–588	52–109	2–8	3–11	1–12	6
Panola	45–129	53–157	7–12	1–4	7–12	9
Pontotoc	810–1,350	16–103	0–3	+	0–3	6
Pontotoc	492–798	44–114	0–2	0–2	2–3	6
Tate	105–267	32–94	1–10	3–3	1–2	6
Tate	720–936	82–135	7–11	1–2	1–7	6
Louisiana						
Avoyelles	168–300	19–55	0–10	6–12	0–2	6
Avoyelles	240–720	38–95	0–6	0	0	6
Avoyelles	72–306	4–10	2–8	1–3	3–6	3
Avoyelles	60–204	63–101	4–6	1–5	2–8	6
Pointe C.	306–648	1–101	7–80	1–2	5–9	9
Rapides	690–1,470	36–119	1–4	0–8	0–1	6
Rapides	336–510	58–162	10–18	10–23	3–5	2
Rapides	312–1,050	26–70	2–7	0–1	0–1	6

[a] Female index on the resistant genotypes was measured as percentage of cysts that developed on susceptible cultivar Lee 74. Each value in the range is from one replication and represents the mean of three plants. 0 = No cysts produced; + = Cysts produced and the isolate considered to have genes for parasitism on that differential, but level of parasitism less than 1.0% of that on Lee 74.

[b] Number of cysts produced on Lee 74 after 30 days.

[c] Race as designated by Riggs and Schmitt (1988).

Arkansas fields that were not found in other southern states.

Races other than 1 and 3 have been reported to occur in northern states (Niblack, et al., 1993; Sikora and Noel, 1991; G. L. Tylka, pers. comm.). For example, in a survey of race distribution in 43 fields in Illinois, 12 were infested with race 1, 1 was race 2, 27 were race 3, 1 was race 4, and 2 were race 5. A survey of race distribution in Missouri included 285 samples, of which 68 were race 1, 15 were race 2, 131 were race 3, 18 were race 4, 22 were race 5, 23 were race 6, and 8 were race 14. Obviously, races of *H. glycines* other than races 1 and 3 occur in the northern states. However, in the Illinois survey 91% of the fields sampled had either race 1 or race 3. In the Missouri survey, which was the most extensive, 70% were races 1 or 3. Three other races were found in Illinois and five in Missouri, but races 1 and 3 were the predominant races. A related report indicated that all five isolates from five different counties in Indiana were race 3 (Faghihi et al., 1986). Though limited, this report supports the predominance of race 3 in northern soybean-growing areas.

Other surveys from southern soybean-growing areas also support the more frequent occurrence of races with broad parasitic capabilities in southern states (Lehman and Dunn, 1987; Lewis et al., 1993; Schmitt and Barker, 1987; Young, 1990b). The survey in North Carolina revealed that in 156 fields infested with *H. glycines*, 18% were infested with race 1, 21% with race 2, 15% with race 3, 7% with race 4 and 23% with other races (Schmitt and Barker, 1987). In a 1995 survey of 32 North Carolina fields in 10 counties, 3% of the fields had race 1, 59% race 2, 22% race 4, 9% race 5, and 6% race 9 (S. R. Koenning, pers. comm.). Although the 1995 survey was more limited than the 1987 survey, the results indicate a further shift toward races that parasitize cultivars that carry genes for resistance to *H. glycines*. Ninety percent of the populations parasitize cultivars that carry genes for parasitism of both Pickett and PI88.788. A South Carolina survey included 39 *H. glycines*-infested fields, of which 11 (28%) were race 3, 2 (5%) were race 6, 5 (13%) were race 9, 1 (3%) was race 10, and 20 (51%) were race 14 (Lewis et al., 1993). In Florida, isolates from 20 fields infested with *H. glycines* were tested, and 8 (40%) were race 3, 1 (5%) was race 4, 2 (10%) were race 6, 7 (35%) were race 9, and 2 (10%) were race 14 (Lehman and Dunn, 1987).

The differences in frequency of occurrence of different races of *H. glycines* in different areas may be related to the source of resistance to *H. glycines* that has been planted and the length of time resistance has been used extensively in the areas. A number of researchers have shown that continuous planting of a resistant cultivar or line results in the selection of genotypes that infect and damage the formerly resistant line (Young, 1994a,b). An isolate of *H. glycines* that was selectively cultured for 20 generations on cv. Forrest soybean reproduced well on Forrest and fairly well on Peking but very poorly on cv. Bedford and PI88.788 (Young, 1984). When the same isolate was cultured for 20 generations on 'Bedford' soybean, the resulting isolate reproduced only fairly well on 'Forrest' and poorly on 'Peking' but reproduced very well on 'Bedford' and PI88.788. An isolate of *H. glycines* that reproduced well on 'Pickett', PI88.788, and 'Bedford' and poorly on 'Peking', PI90.763, and 'Cordell' soybean plants, when cultured on 'Cordell' for 10 to 14 generations, reproduced poorly on PI88.788 and 'Bedford' but fairly well on 'Peking', PI90.763, and 'Cordell' (Young, 1994a). When a field was planted in a number of different cropping sequences, including continuous 'Forrest' and continuous 'Bedford', the resulting population following 'Forrest' reproduced well on Peking (the source of resistance for 'Forrest') but not on 'Bedford'; the 'Bedford' population reproduced well on 'Bedford' but poorly on 'Peking' (Young, 1994a). These results demonstrate the effects of different sources of resistance in the selection of populations that reproduce on different resistant cultivars.

'Pickett', released in 1967 (Brim and Ross, 1966), was the first cultivar with resistance to *H. glycines* that was planted widely in the southern United States. 'Forrest' was released several years later (Hartwig and Epps, 1973) and, because of its high yields, was planted even more extensively. Both of these cultivars derived their resistance from 'Peking'.

In the past, either 'Pickett' or 'Forrest' often was grown in monoculture in the South, and usually in 3 to 4 years populations of *H. glycines* that reproduced on these cultivars were the predominant populations in the fields. In most cases the populations that developed were race 14 (Riggs and Schmitt, 1988). To counteract the damage by these newly selected populations of *H. glycines*, resistance from PI88.788 was incorporated into 'Bedford' (Hartwig and Epps, 1978) and other cultivars.

Because changes in the race within a field appeared to depend on the host cultivar planted and the frequency of its planting (Anand, 1992), extensive planting of various resistant cultivars in southern states may have contributed to the occurrence of the complexity of races found in this study.

'Custer' soybean (Luedders et al., 1968) was released in northern areas about the same time that 'Pickett' was released in southern areas, both with 'Peking' as their source of resistance to *H. glycines*. However, 'Custer' apparently was not as widely planted as was 'Pickett', either because damage by *H. glycines* was not as great in northern areas as in southern areas or because its yield was so low that susceptible cultivars yielded as well or better when *H. glycines* was present. 'Forrest' followed 'Pickett' in southern areas and was planted even more extensively because of its high yield. 'Franklin', with resistance from 'Peking', was released in 1976 (Bernard and Shannon, 1980) but still was not planted as widely in the North as was 'Forrest' in the South. Fayette, with resistance from PI88.788, was released in 1981 (Bernard et al., 1988) and was planted more extensively than either 'Custer' or 'Franklin' because it either produced higher yields or *H. glycines* had become more of a problem.

In our survey and those of Sikora and Noel (1991) and Niblack et al. (1993), race

1, which reproduces only on PI88.788 (FI > 9%), was the predominant resistance-breaking race found in northern states. 'Bedford' was the first cultivar released in the South with resistance derived from PI88.788 and also derived some resistance genes from 'Peking' (Hartwig and Epps, 1978). The extensive planting of 'Bedford' probably contributed to further diversification of *H. glycines* in southern soybean-growing areas.

Races 7, 11, 13, and 16 of *H. glycines* were not detected in this survey. Races 11, 12, 13, and 16 are characterized by a higher FI (>9%) rating on 'Peking' and a lower FI (<10%) rating on 'Pickett'. Because 'Pickett' was derived from 'Peking' (Brim and Ross, 1966) and did not retain all of the genes for resistance present in the donor parent (Luedders, 1989), races 11, 12, 13, and 16 may not occur in nature (Niblack et al., 1993). A population of race 12 found in Lee County, Arkansas, in 1988 (R. T. Robbins, pers. comm.) requires additional study. However, a soybean cultivar has been reported to be susceptible to *H. glycines* race 3 and resistant to race 5 (Young, 1990a). Based on the fact that race 5 reproduces on 'Pickett' and PI88.788, susceptibility to race 3 of a cultivar resistant to race 5 would seem unlikely. Therefore, populations may occur that reproduce on 'Peking' but not on 'Pickett'.

This study also shows that genes for parasitism on 'Pickett' and 'Peking' are widespread among the *H. glycines* populations in Arkansas and probably other southern states. Soybean cultivars with resistance genes derived from 'Peking', a source of resistance to *H. glycines* used extensively in the southern states in the past (Caviness, 1992), are likely to be less effective in reducing damage caused by *H. glycines*. Use of cultivars with resistance genes derived from other resistance sources such as PI90.763, PI209.332, and PI437.654 should be encouraged (Anand, 1992; Anand et al., 1994).

In both northern and southern states, a soybean cultivar that possesses a broad spectrum of genes for *H. glycines* resistance derived from many resistance sources would seem to be of great benefit because it would be resistant to most, if not all, races of *H. glycines*. Soybean-breeding programs must consider the possibility that numerous races may occur in southern states, whereas resistance to fewer races may be necessary for northern states. For example, in Maturity Groups I–III, grown primarily in northern states, resistance to races 1 and 3 of *H. glycines* are of primary concern even though other races are being found where those maturity groups are planted. On the other hand, in the production area where Maturity Groups IV–VII are grown, resistance may be needed for races 2, 4, 5, 6, 9, and 14.

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