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Breeding Productive Soybean Cultivars Resistant to the Soybean Cyst Nematode for the Southern United States

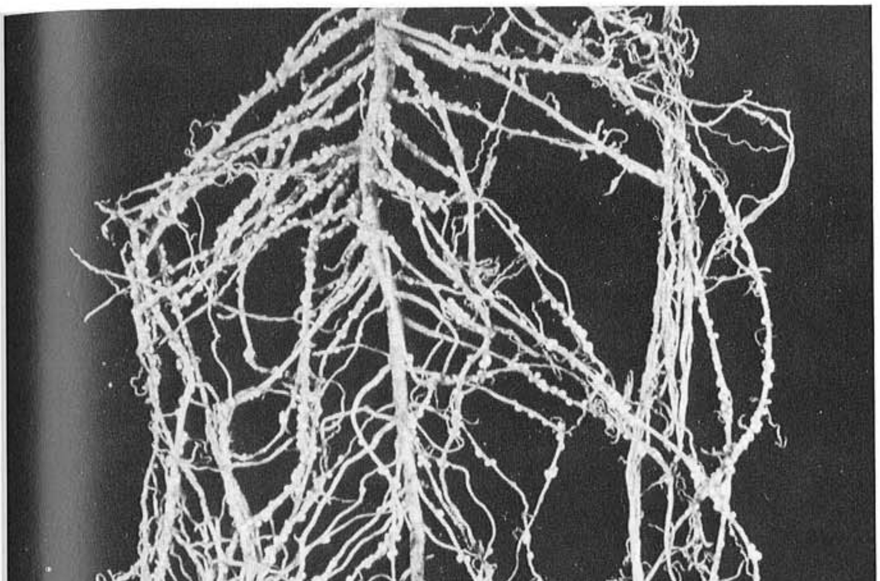

Fig. 1. Cyst nematode development on soybean roots.

Recognition of the soybean cyst nematode (*Heterodera glycines* Ichinohe) (Fig. 1) added another dimension to the breeding of productive soybean (*Glycine max* [L.] Merr.) cultivars for the southern United States. A major consideration in the cultivar development program is to retain resistance to other pests, including bacterial pustule (*Xanthomonas phaseoli* [E. F. Sm.] Dows. var. *sojensis* [Hedges] Starr & Burkh.), target spot (*Corynespora cassiicola* [Berk. & Curt.] Wei), Phytophthora rot (*Phytophthora megasperma* [Drechs.] var. *sojae* A. A. Hildeb.), and root-knot nematode (*Meloidogyne incognita* [Kofoid & White] Chitwood and *M. arenaria* [Neal] Chitwood).

Cultivars resistant to the soybean cyst nematode (SCN) should also be highly productive when grown on soils free from the nematode. The cultivar Forrest, which is resistant to SCN races 1 and 3 as well as the two root-knot species *M. incognita* and *M. arenaria* and the reniform nematode *Rotylenchulus reniformis* (Linford & Oliveira), had a 9-year average seed yield of 3,435 kg/ha on a sandy loam soil at Stoneville, Mississippi, where nematodes are not a yield-limiting factor (5). The highest yielding cultivar (3,840 kg/ha) in the 1979 trials at the same location was Bedford, selected for resistance to SCN race 4. I consider growing resistant cultivars even where pest problems do not exist to be excellent protection against a problem developing.

First Recognition of SCN in the United States

SCN was first described in 1915 in Japan by Hori (12). In 1954, the nematode was recognized as causing injury to soybeans in southeastern North Carolina, and 2 years later it was identified in western Tennessee. In North Carolina, the assumption was that SCN was recently introduced from Japan, but the nematode's widespread distribution leads one to believe that it has a longer history in the United States. The annual lespedezas are now known to be susceptible to SCN. In greenhouse plantings at Jackson, Tennessee, cyst counts after 60 days were as high in three annual lespedeza cultivars as in the susceptible soybean cultivar Lee 68 (Table 1). The areas of the United States where the nematode is most widely distributed are those where the annual lespedezas were grown most extensively. Economic injury from SCN has been observed the first year soybeans are grown after more than 20 years of small grain and lespedeza production.

Genetics of Resistance and Designation of Races

Breeding for pest resistance can proceed most efficiently when the breeder understands the genetic basis of the host plant's resistance and the life history of the pest. Information on the relationship of SCN populations to the degree of soybean injury is limited. Genetic studies indicate that the inheritance of resistance is complex. Caldwell et al (2), using the black-seeded cultivar Peking as a source of resistance to what was later described

Table 1. Reproduction of SCN races 3 and 4 on annual lespedeza and soybean 60 days after plants were infested with 250 cysts per pot in a greenhouse[a]

Crop / Cultivar	Cyst count per 800 cc of soil: Race 3	Race 4
Annual lespedeza		
Kobe	1,050	1,054
Yadkin	1,740	1,225
Rowan	925	875
Soybean		
Lee 68	1,930	1,050

[a] Three pots per treatment.

Fig. 2. Comparative growth of Bedford (J74-46) and Forrest soybeans in soil infested with SCN race 4.

Fig. 3. Microplots for evaluating cyst nematode reproduction in soybean strains with differing reactions to SCN race 4.

Table 2. Seed yield and cyst count for soybean cultivars grown in fields with soil infested with SCN race 3 or 4[a]

	Seed yield (kg/ha)[b]		Cyst count per 250 cc of soil[c]	
Cultivar	Race 3	Race 4	Race 3	Race 4
Forrest	3,425	1,340	0	840
Pickett 71	2,900	1,480	5	740
Centennial	3,300	1,815	0	1,010
Tracy[d]	2,080	1,615	410	550
LSD (0.05)	436	362		
CV	9%	12%		
Forrest	3,220	1,210	0	870
Bedford	2,960	2,360	0	27
LSD (0.05)	540	490		
CV	7%	25%		

[a]Cultivars grown in four-row plots 6 m long; plots replicated three times.
[b]Determined by harvesting 5 m of two center rows of plots.
[c]Determined from soil samples taken approximately 3 weeks before soybean maturity.
[d]Susceptible to SCN races 3 and 4.

as SCN race 1, considered three recessive gene pairs to be controlling resistance. Progeny of yellow-seeded resistant plants, however, continued to segregate for seed coat color. Matson and Williams (15) later determined that an additional dominant gene, closely linked to a gene controlling seed coat color, was necessary for resistance. The difference between an F_2 ratio of 63:1 and 253:3 is very slight. Hartwig and Epps (7), using PI 90763 as a source of resistance to a SCN isolate from Virginia later described as race 2, determined that an additional gene was necessary for resistance. Thomas et al (16) reported on the genetics of resistance to SCN race 4. PI 88788 was considered to carry one more gene than Peking.

The first SCN-resistant cultivars released were Pickett (1) in 1967 and Dyer (6) and Custer (14) in 1968. Each yielded less in uninfested areas than other adapted cultivars of similar maturity but did provide growers with cultivars of moderate productivity covering a range in maturity for known SCN-infested areas. Second-cycle cultivars included Pickett 71 (11), Forrest (8), Mack (3), and Centennial (9). These are highly productive in uninfested areas and are resistant to several other pests; all have Peking as a source of resistance to SCN.

In 1969, the second year of commercial production of Pickett, SCN-damaged areas were found in fields in Arkansas and Missouri, and the next year similar areas were recognized in Tennessee. The recognition of a high level of SCN reproduction on Pickett led to re-evaluation of the breeding program and to race designation for the nematode (4): race 1 for the original isolate from North Carolina; race 2 for the isolate from southeastern Virginia; race 3 for the original isolate from Arkansas, Tennessee, and Missouri; and race 4 for the newly recognized isolate from Arkansas, Missouri, and Tennessee. The damage to Pickett in widely separated fields the first or second year of production suggests that SCN race 4 was in the fields, possibly on annual lespedeza, before resistant soybean cultivars were grown.

The cultivar Bedford (10), with resistance to SCN race 4 from PI 88788, was released in 1977 for seed production in 1978. A modified backcrossing program was used to retain resistance to races 1 and 3 and the other pest resistance and production qualities of Forrest. The seed yield and cyst count for Bedford and other adapted cultivars grown on soils infested with SCN race 3 or 4 are shown in Table 2, and growth of Bedford and Forrest on soil infested with SCN race 4 is compared in Figure 2.

Greenhouse Studies

Greenhouse studies were conducted at Jackson, Tennessee, to evaluate reproduction of SCN race 4 on several soybean strains (Table 3). Reproduction of SCN race 4 on the cultivars resistant to race 3, Forrest and Pickett 71, was similar to that on the susceptible cultivar Lee. The germ plasm strains PI 87631-1, PI 88788, and PI 89772 had low reproduction rates, and each has been used in breeding programs.

Of particular interest was the much lower cyst count on Peking than on Pickett 71 or Forrest (Table 3), indicating that Peking carries an additional gene or genes for SCN resistance that protect against SCN race 4. This level may be adequate under field conditions and may broaden the range of protection.

Greenhouse plantings were made to determine if Peking's level of resistance might be associated with seed coat color, since one gene for resistance was closely linked with a gene that controlled seed coat color. NC55, a black-seeded line incorporating many of the agronomic qualities of the Lee parent, was considered equal to Peking in resistance to the original SCN isolates from North Carolina and Tennessee. NC55 had a cyst count similar to that of Lee 68 or Pickett 71 (Table 4), providing evidence that the extra level of resistance carried by Peking was not associated with seed coat color.

Field and Microplot Studies

Field studies of soil infested with SCN race 3 using such cultivars as Forrest showed cyst counts to be very low (Table 2). In breeding lines evaluated for resistance to SCN race 4, a range in reproduction levels was observed. Microplots 120 × 120 cm (Fig. 3) were established to determine nematode reproduction on strains ranging from susceptible to highly resistant to SCN race 4. After 5 years of continuous planting, cyst counts were extremely low even on the susceptible cultivar. Cysts appeared to be diseased. Kerry (13) reported a disease on the oat cyst nematode in England that permitted near normal production of susceptible cultivars on cyst-infested soil.

Field studies have been conducted at Verona, Mississippi, on soil infested with SCN race 3, using plots 32 × 16 m. A resistant cultivar (Centennial) and a susceptible cultivar (Tracy) have been grown continuously for 5 years. Cyst counts on the susceptible cultivar have decreased after each year of production,

Table 3. Reproduction of SCN race 4 on soybean strains 60 days after plants were infested with 475 cysts per pot in a greenhouse[a]

Strain	Cyst count per 800 cc of soil
Lee	7,800
Pickett 71	5,400
Forrest	7,000
Peking	400
PI 90763	425
PI 87631-1	83
PI 88788	33
PI 89772	50

[a] Four pots per strain.

Table 4. Reproduction of SCN race 4 on soybean strains 60 days after plants were infested with 250 cysts per pot in a greenhouse[a]

Seed coat color Strain	Cyst count per 800 cc of soil
Yellow	
Lee 68	2,500
Pickett 71	2,300
Black	
NC55	3,300
Peking	325

[a] Four pots per strain.

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Fig. 4. Potash deficiency is evident in SCN-susceptible Tracy soybeans (right) but not in SCN-resistant Pickett 71 soybeans (left).

Table 5. Reproduction of SCN race 4 on soybean strains grown on soil heavily infested with race 4 the previous year[a]

Strain	Parentage[b]	Cyst count per 250 cc of soil
Bedford	Forrest (2) × (D68-18 × PI 88788)	10
Forrest	Dyer × Bragg	210
D72-8927	D66-12392 × (Hill[2] × PI 90763)	70
Peking	Introduction from China	80
Essex	Lee × S5-7075	325

[a]Strains grown in 16-row plots 16 m × 24 m; plots replicated three times.
[b]Forrest, D68-18, Dyer, and D66-12392 resistant to SCN races 1 and 3 from Peking.

the count after the fifth year being approximately 15% of that after the first year. These results also suggest that a pathogen may be attacking the nematode.

Large field plots, 16 × 24 m, were established in northwestern Tennessee on a field heavily infested with SCN race 4. Cultivars and strains vary in reaction to SCN race 4 and include different sources of resistance. Cyst counts for some of the strains after the first year are reported in Table 5. Plans are to continue these plots for 5 years. Finding out if a strain such as D72-8927 maintains a cyst population at an uneconomic level will aid in determining the level of resistance necessary. Strains such as D72-8927 and Peking may also have a broader range of resistance should additional biotypes be identified that produce an economic level of injury on types such as Bedford.

Occasionally, soybean producers are advised not to grow a SCN-resistant cultivar continuously to circumvent the possible buildup of a SCN isolate that might cause an economic level of injury to the cultivar. Bedford has now been grown continuously for 4 years on some fields originally heavily infested with SCN race 4. Several hundred acres where Bedford has been grown for 4 years and several thousand acres where it has been grown for 3 years have been monitored, and no evidence of SCN injury has been observed. Soil samples taken after the 1980 crop show a very low cyst count. Since low fertility is frequently confused with SCN damage (Fig. 4), adequate fertilization of these fields is considered important.

Parent Cultivars and Strains Used in Breeding Programs

The cultivar Forrest, of group V maturity, has a broad range of disease and nematode resistance and is highly productive in the absence of nematodes. To develop cultivars with resistance to SCN race 4, Forrest and other productive cultivars and strains resistant to SCN race 3 were used as recurrent parents in a modified backcrossing program. In the development of Bedford, approximately 40,000 F_2 seedlings were screened in three cycles of breeding to obtain 125 agronomically suitable types for advancing to replicated yield trials. Several other strains were retained for use as parental material, including J74-87, having PI 87631-1 as a parent, and J74-88, having PI 89772 as a parent.

Considerable effort is being directed toward developing highly productive breeding lines in maturity groups V, VI, and VII having the Bedford-type resistance to SCN along with resistance to Phytophthora rot, the root-knot nematodes *M. incognita* and *M. arenaria*, the reniform nematode, foliar-feeding insects, bacterial pustule, and target spot. Several somewhat independent programs and large plant populations are needed to achieve the final combination for developing the multiple pest-resistant types.

Earlier results showed PI 88788 and PI 89772 to have similar reactions to SCN race 4. Greenhouse studies, using a recently isolated biotype of the nematode, permit differentiation. J74-88 gives a reaction similar to that of PI 89772, its parent. Although J74-88 is not high yielding and shatters, it is superior to PI 89772. J74-88 has been used as a parent with other strains resistant to SCN race 4, but with better agronomic qualities, to develop strains with a broader range of SCN resistance. Using J74-88 as a parent rather than PI 89772 considerably increases the likelihood of recovering a highly productive strain.

D72-8927, a selection from D66-12392 × an F_5 selection from Hill (2) × PI 90763, is another breeding line that has been used as a parent. D66-12392 has resistance to SCN races 1 and 3, and PI 90763 has good resistance to race 2 and moderate resistance to race 4. D72-8927 has good resistance to SCN races 1, 2, and 3 and moderate resistance to race 4 (Table 5). A greenhouse screening technique identifies strains with the combination of resistance from strains such as Bedford and resistance from D72-8927. D72-8927 is a good yielding strain but is susceptible to injury by *M. incognita*. The time and effort involved in developing strains illustrate the problems in utilizing resistance from poor agronomic parents.

Other material is being developed in which the extra level of resistance to SCN race 4 carried by Peking will be added to cultivars resistant to race 3, such as Forrest and Centennial, and to race 4, such as Bedford. This program requires special greenhouse screening procedures.

Adding genes for resistance from lines such as J74-88, D72-8927, and Peking is a precaution against additional biotypes that might cause economic injury to Bedford. At present, no effective means for field evaluation of this additional resistance is recognized.

The screening of germ plasm lines for resistance to SCN identified other strains with levels of resistance lower than those of Peking, PI 90763, PI 89772, PI 88788, and PI 87631-1. All were used as parents, but as more information was gathered, breeding programs concentrated on using the strains with the highest levels of resistance. Bulk populations developed from double crosses using plant introductions with low levels of resistance offer possibilities of new genetic combinations if additional economically injurious biotypes are recognized.

Major Problem, Major Caution

In the years since it was recognized as causing injury, SCN has attracted more attention than any other pest problem of soybeans. I consider SCN a major problem, but no more serious than several other problems for which productive, resistant cultivars have successfully minimized crop injury. Building in resistance to SCN will continue to be a part of the program to develop highly productive, pest-resistant soybean cultivars for the South. Hopefully, field studies will give us further information on whether the nematode has disease problems that can aid management. Field studies in other regions will give information on the range of biotypes, and screening of soybean germ plasm for additional sources of SCN resistance will be continued. A major caution in the breeding program is to have sufficient field evaluation under a wide range of conditions to insure that the lines developed and released as cultivars resistant to SCN are not susceptible to the diseases, nematodes, shattering, and lodging to which present cultivars are adequately resistant. We do not make progress by substituting yield-limiting factors.

Acknowledgment

All cyst nematode studies were conducted in cooperation with James M. Epps, nematologist (retired), USDA/SEA-AR, West Tennessee Experiment Station, Jackson. All field and greenhouse evaluations of breeding material were conducted under his supervision.

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