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Management of *Heterodera glycines* by Cropping and Cultural Practices[1]

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Abstract: *Heterodera glycines* was identified in North Carolina in 1954, although symptoms of the disease were noted in the state at least 8 years earlier. Crop rotation experiments designed to develop management systems were initiated in 1956. Two or more years in production of a nonhost crop resulted in decreases of the nematode to low or undetectable levels with acceptable subsequent yields of soybean (*Glycine max*). Because of almost complete dependence on resistant cultivars and (or) nematicides for nematode control, crop rotation experiments were not conducted from 1962 to 1980. Research on control of *H. glycines*, beginning in 1981, emphasized biological and ecological aspects of the nematode in order to determine cropping systems that restrict the nematode to nondamaging levels. Mortality during embryogenesis was high at temperatures above 30 C. Hatching of eggs occurs readily in May and June. Postinfection development takes 2–3 weeks at weekly mean temperatures of 22–29 C and is slow above and below those temperatures. Egg production is high during the late growing season. Some cultural practices such as planting early maturing cultivars in mid-to-late June and rotation with a nonhost effectively keeps populations at low levels.

Key words: crop rotation, cropping system, *Glycine max*, *Heterodera glycines*, soybean, soybean cyst nematode.

Patches of chlorotic soybean (*Glycine max*) were noted by North Carolina growers in the mid-to-late 1940s. The problem initially was believed to be a nutrient deficiency (Winstead, pers. comm.). Nutrient application, however, did not correct the problem. In 1954 cysts were observed on the roots of plants from affected areas of the field (17). These cysts were identified as soybean cyst nematode, *Heterodera glycines* Ichinohe. Through surveys by quarantine agency personnel, *H. glycines* was confirmed in other fields throughout the state in 1955.

Early research on crop rotations in North Carolina: The first crop rotation experiments directed toward managing *H. glycines* in North Carolina were established in 1956 by Ross (9), who justified the need for this type of research on the premise that "since the host range of *H. glycines* is limited, crop rotation should provide a promising method of practical control." Chemical soil treatments were considered to be uneconomical, and commercially suited soybean cultivars resistant to *H. glycines* were not available at that time. Nonhost crops used in various rotations with soybean were cowpea, corn, and cotton. The period of nonhost culture ranged from 0 to 4 years on a crop rotation experiment (9). The second-stage juvenile population densities decreased to low or undetectable levels on nonhosts and increased to high levels on 'Lee' soybean (Table 1). Even after 3 years of growing a nonhost, *H. glycines* population density increased rapidly on soybean in a single season. The longer nonhosts were grown, the greater were the subsequent soybean yields (Table 2).

A second rotation study in North Carolina was conducted from 1960 to 1962 (10,11). Yields were 518 kg/ha in continuous soybean (cultivar name not given), 1,258 kg/ha with a soybean–corn–soybean rotation, and 1,634 kg/ha with soybean following 2 years of corn.

De-emphasis of crop rotations: Crop rotation research was de-emphasized in the early 1960s as priorities shifted to the development of resistant cultivars and the evaluation of nematicides. Resistant lines of soybean, developed and released in 1965 by Brim and Ross (4,5), performed well in

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TABLE 1. Average postseason levels (no./473 cm^3 soil) *Heterodera glycines* second-stage juvenile (J2) populations in crop rotation plots.

1956	1957		1958		1959		1960	
Crop	Crop	J2	Crop	J2	Crop	J2	Crop	J2
SB	SB	145	SB	140	SB	490	SB	37
CP	SB	1,009	CP	67	SB	568	CP	1
CP	SB	1,141	CR	40	SB	944	CR	36
CP	SB	420	CT	38	SB	802	CT	4
SB	CP	65	SB	1,469	CP	25	SB	580
SB	CP	8	SB	959	CR	9	SB	735
CP	CP	0	SB	8	CT	0	SB	25
CP	CP	1	SB	32	CP	1	CP	1
SB	CP	6	CP	1	SB	628	CP	1
CP	SB	1,232	CP	15	CP	1	SB	371
SB	CP	6	CP	1	CP	0	SB	15
CP	CP	1	CP	0	CP	0	SB	1
CP	CP	0	CP	0	SB	3	SB	293
CP	CP	1	SB	22	SB	781	—	—
LSD 5%		6		56		4		9
1%		9		9		8		22
Coefficient of variation		37%		35%		26%		53%

SB = soybean 'Lee'; CP = cowpea 'Iron'; CR = corn 'NC82'; CT = cotton 'Coker 100'. Numbers were $\log_{10}(x + 1)$ transformed for analysis. (After Ross [9].)

cyst-infested fields and gave the maximum yield potential for the environment in which they were grown. Yields of soybean produced in *H. glycines*-infested fields treated with nematicides also were satisfactory (Sasser, pers. comm.; Wells, pers. comm.).

Resistant cultivars controlled *H. glycines* in most fields for more than a decade, but then new races of this nematode began to appear. The first resistant cultivar, Pickett released in 1965 (4,5), had good resistance to races 1 and 3. Cultivars Forrest and Centennial, also resistant to races 1 and 3, were released in 1972 and 1977, respectively. Both cultivars had excellent agronomic characteristics and produced high yields in the presence of *H. glycines*. Because of these advantages, these cultivars became widely grown, often in monoculture. The consequence was a major shift in race composition (Table 3) (12). For example, in 1976, race 1 comprised 80% of the *H. glycines* populations in North Carolina. That year, 54% of the hectarage was planted to the susceptible cultivar Ransom. By 1980, only 50% of the infested fields contained race 1. This decrease in race 1 continued over the next several years so that only ca. 18% of the fields were infested with it in 1986 (12). Consequently, the use of resistant cultivars as a management tool is now limited

TABLE 2. Yield of soybean harvested from *Heterodera glycines* crop rotation plots.

Crops				Yield (kg/ha)	
1956	1957	1958	1959	1958	1959
SB	SB	SB	SB	87	128
CP	SB	CP	SB		390
CP	SB	CR	SB		363
CP	SB	CT	SB		430
SB	CP	SB		451	
CP	CP	SB		861	
SB	CP	CP	SB		942
CP	CP	CP	SB		1,116
CP	CP	SB	SB		229
			LSD 5%	282	195
			1%	444	269

SB = soybean 'Lee'; CP = cowpea 'Iron'; CR = corn 'NC82'; CT = cotton 'Coker 100'. (After Ross [9].)

TABLE 3. Race distribution (%) of *Heterodera glycines* in North Carolina from 1976 to 1986.

Year	1	2	3	4	5	Other†
1976	80	15	5	0	0	0
1980	50	30	0	8	0	12
1986	18	21	15	7	16	23

† Races other than 1–5. Most of those races classified as other in 1986 were race 6 or 9.

because of these shifts in *H. glycines* race composition.

More prudent utilization of resistant cultivars in a rotation with nonhosts would increase their longevity in fields infested with races 1, 3, or 4. A rotation of nonhost–resistant cultivar–nonhost–susceptible cultivar has been recommended in North Carolina and other states for nearly 20 years and still appears to be effective where growers follow it carefully. The key requirement is to use the resistant cultivar as infrequently as possible. Utilization of several crop species and cultivars within crop species encourages nematode species diversity and generally a lower population density of all species (unpubl. data).

The most cost-effective nematicides cannot be used legally in the United States for soybean. Fumigant nematicides (DBCP, EDB) that controlled *H. glycines* were withdrawn from the market, leaving relatively high-cost nonfumigants that perform inconsistently. Currently registered nematicides often provide inadequate control of *H. glycines* even at rates greater than those labeled for use (15). At a very high population for North Carolina (ca. 100,000 eggs/500 cm^3 soil) (Fig. 1, curve 1), aldicarb fails to reduce the population to nondamaging levels. Consequently, any application rate results in a net economic loss. If the nematode population is low to moderate, certain dosages of aldicarb will give a net return on the investment. For example, at an initial population of 10,000 eggs/500 cm^3 soil, which frequently occurs in North Carolina (Fig. 1, curve 2), sufficient control is obtained so return is greater than investment. However, soybean yields in chemically treated infested soil are low relative to those from uninfested fields.

Population dynamics of Heterodera glycines: Effective management of *H. glycines* on soybean, a low cash value crop, depends on cropping systems that exploit weaknesses in the nematode's biology and (or) population dynamics. Nematode development, which is closely regulated by environmental conditions, can be manipulated with altered cultural practices.

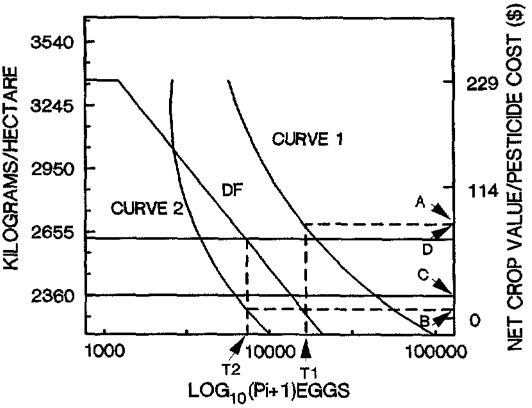

FIG. 1. Dosage-response curves for determining effects of aldicarb on damage function of *Heterodera glycines.* Curve DF is the damage function. Curves 1 and 2 are cost of control function for population densities of 100,000 and 10,000 eggs/500 cm^3 soil. Points A and B are costs for optimal dosages for curves 1 and 2. Points C and D are crop values at which losses are minimized for curves 2 and 1. T1 and T2 denote points to which populations are effectively reduced (15).

The rate of embryogenesis from a two-celled egg to the second-stage juvenile is directly related to increases in temperature between 15 and 30 C (2). Mortality of the embryo is relatively low at temperatures between 5 and 30 C but high when temperatures exceed 30 C. Activity from hatching to postinfection development is restricted to a narrower temperature range than embryonic development. Hatching of *H. glycines* eggs occurs readily in May and June after winter dormancy has been broken (8). Upon penetration of soybean roots, the nematode's postinfection development occurs over a wide temperature range (16). The most rapid development occurs from 24 to 28 C (16). Postinfection development does not occur below 10 or above 35 C (6). Females can mature in 2–3 weeks at weekly mean temperatures of 22–29 C, and in 3–4 weeks at weekly mean temperatures of 17–22 C (2).

Numbers of cysts and eggs gradually increase on soybean during the growing season and slowly diminish during periods when a host is absent. Egg numbers begin to increase when the first generation is completed in the spring, but their numbers change little until late in the growing season (3,14), probably largely because of hot (>30 C), dry soil conditions that commonly occur in midsummer (2). Egg numbers increase rapidly and to a large magnitude in the fall when the crop is maturing (7).

Date of planting and cultivar maturity characteristics are major factors affecting population growth of *H. glycines* (7). A late maturing cultivar planted early provides a food substrate for *H. glycines* up to 6 months. In contrast, early maturing cultivars planted late, a common practice with soybeans doublecropped after wheat or barley, can be grown within 3 months. This latter situation results in relatively low end-of-season populations (13).

Managing H. glycines with cropping systems: Biological and ecological aspects of the nematodes were used as test parameters to determine if cropping systems could be developed that restrict *H. glycines* to nondamaging levels. The relatively poor control of *H. glycines* with current nematicides and the decreasing number of fields infested with races controllable with available resistant cultivars result in a situation similar to that of 1956 (9). Therefore, several cropping systems in combination with various cultural practices were evaluated throughout the 1980s as means of managing this nematode.

Experiments initiated in 1981 focused on shifting the predominant genotypes of the nematode from race 2 to race 1 in the field so the available resistance could be employed again. This strategy was based on greenhouse research conducted in Arkansas by R. D. Riggs, who mixed *H. glycines* race 1 with race 2 (1:1) and race 3 with race 4 (1:1) genotypes (Riggs, pers. comm.). Growing a susceptible cultivar in the race 1 and 2 mixture or 3 and 4 mixture resulted in populations ultimately shifting so that race 1 or race 3 genotypes predominated (Riggs, pers. comm.). Regardless of rotation with susceptible soybean or nonhosts or treatment in North Carolina field tests, gene frequencies of *H. glycines* fluctuated from year to year but did not shift the race composition significantly (Schmitt and Sipes, unpubl. data). Thus, the shift toward race 2 genotypes occurs rapidly when selection pressure is exerted by resistant cultivars, but the reverse shift is difficult to achieve under field conditions. Although the ultimate objective was not achieved, aspects of the study provided data necessary for the development of more effective rotations that restrict the population density of the nematode to low numbers.

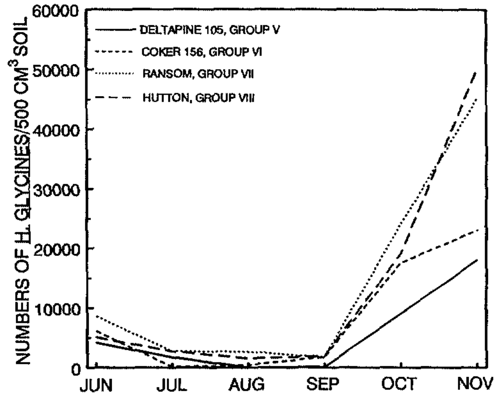

FIG. 2. Numbers of *Heterodera glycines* eggs/500 cm^3 soil developing on four soybean cultivars of different maturity groups.

The seasonal behavior of *H. glycines* provides additional options for management. Nematode eggs hatch readily in May in North Carolina. Temperature conditions of early to midsummer and the absence of a host are fatal to the resulting juveniles (1). These aspects of the nematode's biology were used to design cropping systems experiments involving planting dates and cultivar maturity. The planting of soybean in late June resulted in as much as 50% reduction in population numbers relative to the populations present in May. In addition, early maturing cultivars prevented populations of *H. glycines* from increasing to high levels typically found on later maturing cultivars (Fig. 2).

In conclusion, *H. glycines* population densities can be restricted to nondamaging levels with relatively short cycle rotations. A 2-year rotation of corn–wheat–soybean, commonly used in North Carolina, has the additional benefit of eliminating the need for nematicides and resistant cultivars. The greatest benefit is the long-term restriction of *H. glycines* to very low levels.

Future outlook: Managing *H. glycines* at low population levels can be achieved with cropping systems. Improving these systems will require additional research on the nematode's biology and ecology, particularly survival mechanisms. If dormancy of the nematode could be reduced or broken during the periods with nonhosts, resulting mortality of the nematode should reduce the length of crop rotating involving a nonhost. Research on the population genetics of *H. glycines* should enhance our understanding of this nematode's biology and survival mechanisms, especially in the absence of susceptible hosts.

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