BIOLOGY AND MANAGEMENT OF SOYBEAN CYST NEMATODE

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CROPPING SYSTEMS AND CROP MANAGEMENT PRACTICES

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For the past 50 years, North American researchers have attempted to define specific management practices that can be used to optimize soybean yields in soybean cyst nematode-infested fields (Niblack *et al.*, 2003; Schmitt, 1991; Schmitt and Riggs, 1989). Some adaptations by the nematode that have made management challenging include its ability to survive for long periods without a host, to adapt to resistant cultivars and perpetuate itself under a wide range of crop management systems. Among all the management options that have been hypothesized and tested, there is consensus on only two. The two options are: nonhost crops reduce soybean cyst nematode population densities and soybean cyst nematode-resistant cultivars yield more than susceptible ones if soybean cyst nematode population densities are high. Other options are still a matter of research and debate.

Regardless of the management tactic or tactics, the first step in managing soybean cyst nematode is periodic sampling (Young, 1998c) (See Chapter 6). This is necessary in order to optimize selection of the management strategy related to the site-specific nature of control tactics and/or to verify efficacy of the tactic or tactics being employed. Sampling is especially crucial because infected plants are often symptomless (Noel, 1992; Noel and Edwards, 1996; Young, 1996; Wang *et al.*, 2003).

The basic management tactics for controlling population densities of soybean cyst nematode are crop rotation and resistant cultivars. Biological control (See Chapter 11) and selected crop management (cultural) practices may augment these two tactics. Cultural methods that might reduce population densities of soybean cyst nematode are trap crops, water management, tillage, cover crops, soybean planting date, selection of soybean cultivar maturity group, soil fertility, herbicides and row spacing. Some of these practices have the potential to affect the soil environment and are likely to affect soybean cyst nematode, as well as, natural biological control.

The primary subject of this chapter is management of soybean cyst nematode with cropping systems employing crop rotations, cultivar rotations and resistant cultivars. Some aspects of selected crop management practices, such as planting date, growing period, tillage, soil fertility and water management are summarized to illustrate their impact on soybean cyst nematode populations.

CROPPING SYSTEMS

Rotation with nonhosts

The rate of reduction in the population density of soybean cyst nematode with nonhosts varies with nonhost plant species, climate and edaphic factors. The number of eggs and juveniles initially decline relatively rapidly without a host. In some situations, several years may be required to reduce the populations below damaging levels (Francl and Dropkin, 1986; Koenning *et al.*, 1993). The remaining eggs may be in host-mediated and/or time-mediated dormancy (Yen *et al.*, 1995). These dormant eggs will hatch when a host is planted and the females that develop produce large numbers of progeny during the first year on the susceptible host. Consequently, susceptible cultivars will be damaged after one year following 10 or more years absence of a host (Porter *et al.*, 2001; R. D. Riggs, personal communication).

The goal of reducing numbers of soybean cyst nematode is to increase yields. In North Carolina, soybean yields were 10% to 40% greater following nonhosts crops grown for one to two years compared to soybean monoculture (Koenning *et al.*, 1993). In earlier studies, growing nonhosts for two to three years was required to reduce the number of nematodes to desired levels (Francl and Dropkin, 1986; Ross, 1962). The shorter duration of rotations with nonhosts may be related to increased populations of soybean cyst nematode predators, pathogens and parasites (Chen and Reese, 1999; Chen *et al.*, 1996; Koenning *et al.*, 1993; Niblack *et al.*, 1992; Noel and Edwards, 1996) (See Chapter 11).

Most species of nonhosts have a similar influence on mortality of soybean cyst nematode, but there are a few that affect mortality more than others. The decline in numbers of soybean cyst nematode in Missouri was similar on the nonhosts cotton, corn and grain sorghum (Francl and Dropkin, 1986). Annual ryegrass was more effective than other nonhosts tested in Ontario, Canada in reducing infectivity of soybean by soybean cyst nematode (Riga *et al.*, 2001).

Winter wheat in double crop production sequences may enhance mortality of the nematode in some systems, but not in others (Baird and Bernard, 1984; Hershman and Bachi, 1995; Koenning and Anand, 1991; Long and Todd, 2001). Second-stage juvenile population densities were lower in soybean following winter wheat in Tennessee than in other treatments without wheat (Baird and Bernard, 1984). This reduction was attributed to substances released from wheat that were assumed to be toxic to the nematode. Likewise, in Kentucky (Hershman and Bachi, 1995) and Kansas (Long and Todd, 2001), fewer cysts were present in plots with wheat residue than plots without residue. In contrast, winter wheat did not affect soybean cyst nematode numbers in southeastern Missouri (Koenning and Anand, 1991).

Planting nonhosts in soybean cyst nematode infested fields has other advantages for managing this pathogen. Rotation with non-host crops increases the amount of time required for a soybean cyst nematode population to become established and increase to yield-reducing levels (Noel and Edwards, 1996). Likewise, parasites and predators will have more time to become established before the nematode reaches large population densities.

Rotation with resistant cultivars

Rotating resistant cultivars within the cropping system, as with nonhosts, is effective for reducing soybean cyst nematode population densities and increasing subsequent soybean yields (Anand and Brar, 1983; Luedders and Dropkin, 1983; McCann *et al.*, 1982; Young, 1984a; Young, 1984b). However, the level of resistance varies among cultivars (Fig. 1) and populations of soybean cyst nematode vary in their ability to attack resistant cultivars (See Chapter 4). Unbiased information about levels of resistance is available through cultivar testing programs (Iowa Crop Improvement Association, 2003; University of Illinois Crop Testing, 2003).

Identification of the HG Type (race) is an important part of selecting cultivars in order to match resistance with the virulence profile of the nematode population in a particular field (Young, 1998c). Such testing has had limited acceptance by producers. Time constraints and cost appear to be reasons for the limited adoption. Nevertheless, an economic analysis would demonstrate that matching the cultivar to the HG Type (race) is likely to increase the probability of an economic gain on the investment.

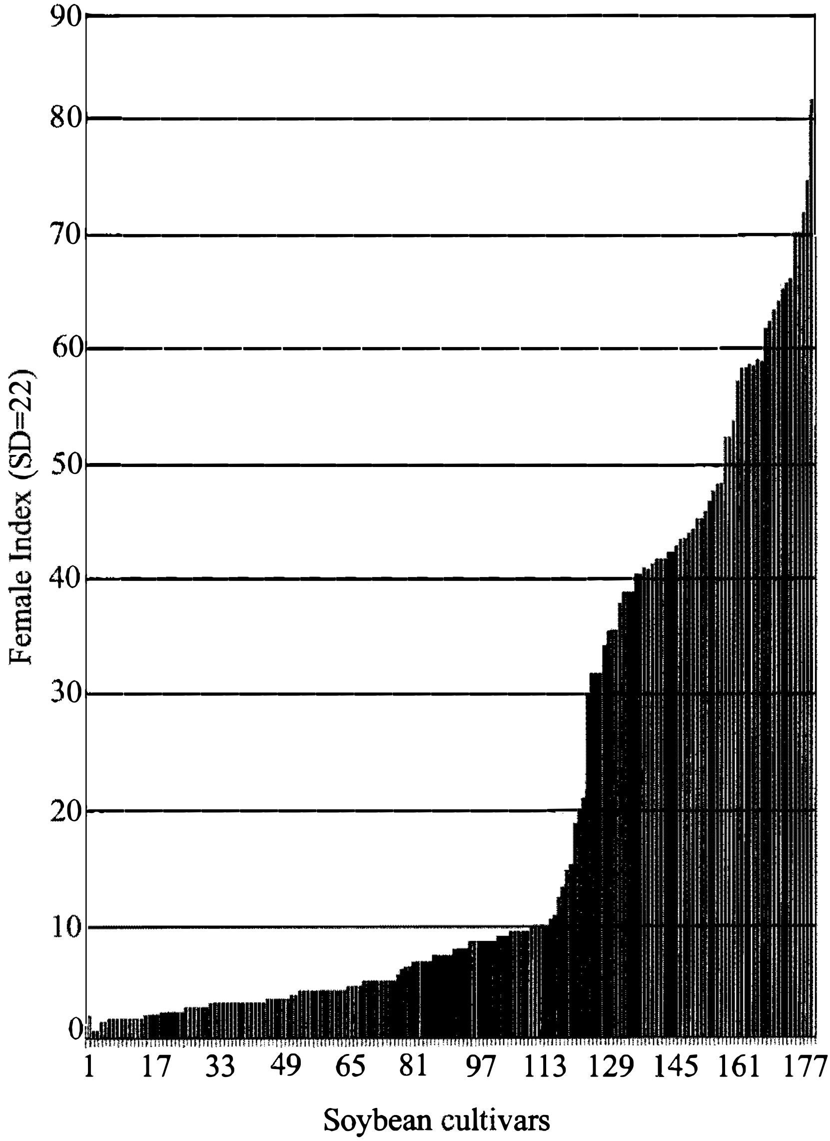

Figure 1. Levels of resistance of soybean cultivars labeled as "resistant" and reported by the seed companies that derive their resistance from PI 88788. (1 = PI 88788; SD = standard deviation). Resistance is measured according to the Female Index.

Rotation of resistant cultivars

Rotation of resistant cultivars signifies rotating soybean cyst nematode resistant cultivars derived from different sources of resistance or changing cultivars regardless of pedigree (Young, 1992; Young, 1998c). The Female Index of soybean cyst nematode can be increased experimentally on soybean cyst nematode resistant soybean lines (Anand and Brar, 1983; Francl and Wrather, 1987; Luedders and Anand, 1989; McCann *et al.*, 1982; Riggs *et al.*, 1977; Triantaphyllou, 1975; Young, 1982; Young, 1984b; Young and Hartwig, 1988; Young and Hartwig, 1992; Young *et al.*, 1986) (See Chapter 4). Therefore, selection pressure should theoretically be reduced by changing sources of resistance. The result should be the maintenance of specific (target) nematode genotypes at low levels. It is important to keep the population density of the nematode low because of the inverse relationship of soybean yield to nematode population density (See Chapter 6). As soon as the Female Index value begins to increase on a resistant line, yield losses will usually increase.

Considering the practical application of cultivar rotation strategies, designing rotations to minimize soybean cyst nematode adaptation to resistance genes should be possible. For example, cultivars deriving their resistance from PI 90763 or PI 89772 could be rotated since soybean cyst nematode lines selected on one of these resistance sources reproduce poorly on the other resistant source (Anand and Brar, 1983). This type of rotation, termed "reciprocal changes" in Female Index (Luedders and Dropkin, 1983; McCann *et al.*, 1982; Young, 1984b) or "mutual incompatibility" (Francl and Wrather, 1987) has been tested in the field with inconsistent results (Anand *et al.*, 1995a; Francl and Wrather, 1987; Noel and Edwards, 1996; Young, 1994; Young, 1998a; Young and Hartwig, 1992). Whatever the reasons for the inconsistent results, rotating resistance genes (i.e., rotating cultivars with different sources of resistance) is a viable management option if soybean cyst nematode populations are low and if frequencies of alleles for virulence are not high (Noel and Edwards, 1996).

Assessments of soybean cyst nematode populations over time are essential if this tactic is included in a soybean management strategy for reducing yield loss due to damage from this nematode. Further success of this management option will depend on increasing the diversity in resistance, that is, increasing the number of sources because soybean cyst nematode populations adapt to resistance by gaining the ability to reproduce on all the other commonly used sources of resistance (Niblack, unpublished). Therefore, the need to identify and incorporate new sources of resistance in adapted soybean cultivars should still have priority.

Cropping sequences

Within a cropping system, recommendations for the sequence of growing crops for managing soybean cyst nematode vary by region. Perhaps the most commonly used sequence in North America is a 4-year rotation consisting of: 1) nonhost, 2) soybean cyst nematode resistant cultivar, 3) nonhost and 4) soybean cyst nematode susceptible cultivar (Schmitt, 1991). In Arkansas, a 3-year rotation is suggested and consists of: 1) nonhost, 2) resistant cultivar and 3) susceptible cultivar (Slack *et al.*, 1981). A 6-year rotation plan recommended in Iowa includes: 1) nonhost, 2) resistant soybean cultivar, 3) nonhost, 4) resistant soybean cultivar different from that used in the second year, 5) nonhost and 6) susceptible soybean cultivar (Tylka, 1995). The susceptible cultivar is recommended only if soybean cyst nematode population densities are low. A resistant soybean cultivar should not follow a susceptible cultivar unless the resistant cultivar has a moderate to high level of resistance to the soybean cyst nematode population (HG Type) present (Anand *et al.*, 1995a).

The common aspect of all the proposed cropping sequence recommendations is the inclusion of a susceptible cultivar for the purpose of preventing “race shifts”. Early research (Hartwig *et al.*, 1982; Hartwig *et al.*, 1987; Young and Hartwig, 1988; Young *et al.*, 1986) did not demonstrate that the inclusion of susceptible cultivars prevented the development of resistance-breaking populations of soybean cyst nematode (Anand *et al.*, 1995a; Young *et al.*, 1986). However, more recent evidence shows that cropping sequences including susceptible cultivars slow the adaptation of soybean cyst nematode populations to resistant cultivars (Noel and Edwards, 1996; Young, 1998b). In the absence of selection pressure, the frequency of virulence genes was not maintained in the nematode population in one trial (Francl and Wrather, 1987); but in other experiments, there was no indication that selection in soybean cyst nematode populations was stabilized by growing susceptible cultivars (Anand *et al.*, 1995a; Colgrove *et al.*, 2002; Sipes *et al.*, 1992; Young and Hartwig, 1988).

Soybean yield responses vary in cropping sequences alternating resistant and susceptible cultivars. Higher yields were obtained in Tennessee (Young, 1998b) and Illinois (Noel and Edwards, 1996) with cropping sequences including susceptible soybean cultivars. In Minnesota, the yield of a susceptible cultivar was greater following a resistant cultivar compared to continual planting of susceptible cultivars (Chen *et al.*, 2001b). A sequence with continuous cropping of a resistant cultivar or a sequence of more than one cultivar resulted in higher overall yields at the end of four years than in any sequence with a susceptible cultivar (Chen *et al.*, 2001b).

Two difficulties must be mentioned in interpreting cropping sequence data. Both of them relate to PI 88788, the source of soybean cyst nematode resistance used most commonly today. First, the resistance conferred by PI 88788 (at least in highly resistant cultivars) may not be HG Type specific, at least in terms of soybean yield. For example, the Female Index of a population increased steadily on Bedford (resistance derived from PI 88788) cropped continuously for 11 years without any notable detrimental affect on yield (Young and Hartwig, 1992; Young *et al.*, 1986). Similar results were noted in Illinois with the cultivars Linford

(Noel and Wax, 2003) and Fayette (Noel and Edwards, 1996) (resistance in both cultivars is derived from PI 88788). This lack of yield suppression exhibited by these cultivars might indicate that the plants are tolerant and/or the population of soybean cyst nematode developing on the PI 88788 source of resistance may be less virulent than those that develop on other sources.

The second difficulty with interpretation of cropping sequence data is that much of the research involved assessment of soybean cyst nematode population densities based on cyst numbers. More cysts develop on PI 88788 and cultivars derived from it than on other resistant lines or cultivars, but the number of eggs/cyst are lower than those from other resistance sources (Wallace *et al.*, 1995). In spite of differences and inconsistencies in research results, most soybean researchers are in agreement that the inclusion of susceptible cultivars in the cropping sequence will at least slow the adaptation of soybean cyst nematode populations to resistant cultivars and thereby preserve their effectiveness.

Blends

Another potential tactic in cropping sequences for soybean cyst nematode management is using blends of resistant and susceptible cultivars. The concept for using specific blends is to slow the adaptation of soybean cyst nematode populations to resistant cultivars (Wallace *et al.*, 1995; Young and Hartwig, 1992). Determining the validity of this concept is difficult because data concerning blends are contrasting. In some cases, the blends were not superior to resistant cultivars in terms of their yield response and their affect on nematode reproduction (Hartwig *et al.*, 1987; Young and Hartwig, 1988). In one study, the Female Index values on PI 88788 were higher in soybean cyst nematode populations from pure soybean stands than in those from blends, but yields were similar between pure stands and blends (Anand *et al.*, 1995b). To resolve this issue, additional research is recommended on blending tolerant cultivars and those with different sources of resistance (Hartwig *et al.*, 1987; Young and Hartwig, 1988).

Trap crops

Trap crops (crops used to encourage nematode infection of selected or managed to prevent maturation of the nematode) have been evaluated as a means of managing nematodes (Heijbroek, 1996; Kerr, 1994; Koch and Gray, 1997; LaMondia, 1996; Whitehead, 1977; Whitehead and Turner, 1998). Resistant cultivars that prevent the completion of a nematode's life cycle are effective as trap crops (Koch and Gray, 1997). Susceptible host plants can also be used as trap crops if the plants are destroyed or removed from the field before the nematode has completed its life cycle (LaMondia and Brodie, 1986; Mugniery and Balandras, 1984). Trapping soybean cyst nematode with resistant and susceptible soybean or pea during the corn cycle of a corn-soybean rotation did not reduce the nematode population to the desired level in Minnesota (Chen *et al.*, 2001a). Conversely, population densities of this nematode in North Carolina were reduced to low levels by killing susceptible soybean seedlings just before the first trifoliate leaves developed (D. P. Schmitt, personal communication).

Intercropping

Anecdotal evidence exists for benefits from intercropping resistant soybean with corn. One approach is to grow highly resistant cultivars under the corn canopy. Another option is to plant susceptible cultivars in the corn crop and then kill them with herbicides two weeks after planting in order to arrest development of juveniles. These approaches, though not proven (Niblack and Wiebold, unpublished), are receiving attention in the northern region of the midwestern USA.

Impact of weeds

The effectiveness of nonhosts and/or resistant cultivars will be greatly reduced if weed hosts are present in the field. For example, hemp sesbania growing in fields of resistant soybean or flooded rice in Arkansas enabled the population density of soybean cyst nematode to be maintained or even increase (R. D. Riggs, personal communication). Mechanical means can be used to control weeds, but generally a greater proportion of the weed population can be controlled with herbicides (Bradley *et al.*, 2003). Herbicides have been recommended for control of weeds that serve as hosts of soybean cyst nematode (Venkatesh *et al.*, 2000).

CROP MANAGEMENT (CULTURAL) PRACTICES

Planting date and growing period

Delayed planting and the use of early-maturing cultivars have been recommended as means of managing soybean cyst nematode (Schmitt, 1991). The logic for delaying planting is to avoid the high population densities of infective soybean cyst nematode juveniles that hatch early in the season (Koenning and Anand, 1991). The theory behind using early maturity soybean is that by shortening the growing period, there is a reduction in the number of soybean cyst nematode generations that can be produced in a single season.

Delaying soybean planting for a few weeks after the eggs have hatched results in substantial mortality of soybean cyst nematode juveniles since diapause is broken in early spring (Koenning and Anand, 1991; Koenning *et al.*, 1996). If the emerging juveniles do not find a host, their numbers decrease substantially within 30-60 days. Consequently, fewer infective juveniles are available to attack the plant. Furthermore, since high soil temperatures are detrimental to the survival and development of soybean cyst nematode (Ross, 1964; Slack and Hamblen, 1961; Slack *et al.*, 1972), less infection and damage would be expected in soybean planted in June in southern states in the USA, such as Georgia (Hussey and Boerma, 1983). Although population density at planting was usually lowered, delayed planting generally resulted in higher population densities by harvest, but variability existed among fields and years (Epps and Chambers, 1963; Hussey and Boerma, 1983; Koenning *et al.*, 1996). Nevertheless, soybean damage still occurs with delayed planting at these lower population densities of soybean cyst nematode (Todd, 1993). Additionally, yields are compromised as a consequence of a shorter growing season (Koenning and Anand, 1991). In addition, seed quality in early maturing cultivars may be more adversely affected than cultivars that mature later (P. Donald, personal communication).

The results of research to test the hypotheses about planting date and cultivar maturity are variable (Koenning *et al.*, 1996). In North Carolina, the effects of planting date on soybean cyst nematode population densities at harvest varied from year to year and location to location (Koenning *et al.*, 1993). This seasonal and geographical variation may explain why planting date effects reported in the literature are different. For example, planting date had no effect on soybean cyst nematode population densities in Georgia (Hussey and Boerma, 1983), whereas late-maturing cultivars in one North Carolina study supported a higher soybean cyst nematode population density than the early-maturing cultivars within Maturity Groups V through VIII (Hill and Schmitt, 1989). In Missouri, higher populations were recovered from early maturing cultivars than later maturing ones (Koenning and Anand, 1991; Koenning *et al.*, 1992). In Kansas, fewer eggs were recovered from soybean when planting was delayed compared to those planted early (Todd, 1993). In a follow-up study in Kansas using near-isogenic soybean lines differing for determinacy in two maturity groups, maturity date and determinacy of cultivars did not affect reproduction of soybean cyst nematode (Todd *et al.*, 2000).

In spite of the contradictory results among planting date studies, shortening the growing period of soybean with determinant cultivars reduces the amount of time that soybean cyst nematode has to produce progeny. Therefore, a delay in planting of early-maturing determinant cultivars may be useful (Schmitt, 1991) because final population densities were generally lower on them than on later maturity determinate cultivars (Hill and Schmitt, 1989; Koenning *et al.*, 1996; Riggs *et al.*, 2000). This concept may not work with indeterminate cultivars since soybean maturity group within the indeterminate cultivars did not affect the final population densities of soybean cyst nematode (Todd, 1993; Todd *et al.*, 2000). In the indeterminate groups, the prolonged flowering period may enhance nematode reproduction, offsetting the soybean maturity date effect (Todd *et al.*, 2000). Further study is needed to test this hypothesis.

Planting date and soybean maturity date influence seed yield. In Kansas where soybean cyst nematode caused an average loss of 35% over several maturity groups, less loss was incurred on the later-maturing cultivars than on the earlier-maturing ones (Todd, 1993). In Georgia, yield loss increased with late planting (Hussey and Boerma, 1983). To maximize the yield potential of cultivars of different maturity groups planted at different times, row spacing needs to be adjusted to assure a full canopy by the time the plant begins to flower (Koenning *et al.*, 1993).

Some damage to soybean may also be avoided by planting earlier than normal. By planting as much as six weeks earlier than recommended, soybean seed yields were higher in Alabama, Arkansas and Missouri than they were at normal planting dates (Pacumbaba and Tadesse, 1991; Riggs *et al.*, 2000). At these earlier planting dates, soil temperatures were too low for soybean cyst nematode to infect the roots and the nematode still may have been in diapause. Then, when the nematode became active, a root system was in sufficiently established in order to tolerate infection.

Straightforward experiments to test maturity and planting date effects are not easy to devise because of large planting date-environment interactions and the confounding effects of genetic backgrounds of cultivars in different maturity groups. In a study involving 20 environments (five locations over four years), Riggs *et al.* (2000) concluded that factors other than planting date or maturity group contributed to the effect of soybean cyst nematode on soybean yield and on the effect of soybean on soybean cyst nematode population densities. Over all, neither manipulation of planting dates nor cultivar maturity is predictable in soybean management for the control of yield losses due to soybean cyst nematode.

Cover crops

Cover crops are used to reduce soil erosion, improve soil fertility, increase biological diversity, reduce disease and reduce pest pressures. These crops can be planted in rotation or inter-seeded with primary crops for managing a number of plant-parasitic nematodes (Duncan and Noling, 1998). An ideal cover crop should have multiple modes of action for suppressing or reducing nematode populations. Cover crop species can reduce population densities of nematodes because they: 1) either are non-hosts or poor hosts, 2) produce allelochemicals that are toxic or inhibitory, 3) provide niches for antagonistic organisms and/or 4) function to trap nematodes (Kloepper *et al.*, 1992; Wang and McSorley, 2002; Wang *et al.*, 2002).

A number of crop species have properties that reduce populations of soybean cyst nematode and fulfill the criteria to function as a cover crop. Studies performed in the greenhouse to evaluate host range (Davis *et al.*, 1996; Mosjidis *et al.*, 1994; Riggs, 1980; Riggs, 1992; Valle *et al.*, 1995), effect of plants on hatch and development (Schmitt and Riggs, 1991; Sortland and MacDonald, 1987) and nematicidal effect of crop residues (Riga *et al.*, 2001) provide useful information for selecting cover crops for field use to manage this pathogen. Bahiagrass, American jointvetch and hairy indigo grown in rotation with soybean reduced the population density of soybean cyst nematode and increased soybean yield compared to soybean in monoculture (Rodríguez-Kábana *et al.*, 1989; Rodríguez-Kábana *et al.*, 1990; Rodríguez-Kábana *et al.*, 1991; Weaver *et al.*, 1998). Annual ryegrass, grown as a winter cover crop, reduced the numbers of soybean cyst nematode more than fallow, but soybean yield was lower following the cover crop than following fallow (Pedersen and Rodríguez-Kábana, 1991).

Tillage

The influence of soil disturbance on population densities of soybean cyst nematode is quite variable. No generalizations can be made, other than the effects of tillage appear to be site- or region-specific based on comprehensive summaries of 20 years of research (Chen *et al.*, 2001b; Noel and Wax, 2003). Based on a regional survey (Workneh *et al.*, 1999), the soils with high clay content that were tilled had higher population densities of soybean cyst nematode than those that were not tilled. In these no-till fields, population densities of soybean cyst nematode were inversely related to clay content, whereas they were not related to clay content in tilled fields (Workneh *et al.*, 1999). Population densities of this nematode in the southern USA were lower in no-till plots than in conventional or minimum tillage plots (Edwards *et al.*, 1988; Hershman and Bachi, 1995; Koenning *et al.*, 1995; Tyler *et al.*, 1983; Tyler *et al.*, 1987). On the other hand, the type of tillage did not affect the number of soybean cyst nematode in Minnesota (Chen *et al.*, 2001b). In Missouri and Illinois, population densities of soybean cyst nematode, in response to tillage intensity, varied by location and year within a state (Niblack *et al.*, 1999; Noel and Wax, 1997). This inconsistency of the nematode response to tillage practice was confirmed in an extensive study conducted from 1997 to 2000 in nine states in the North Central region of the USA and in Ontario, Canada (Atibalentja *et al.*, 2001).

Tillage effects on soybean cyst nematode population density, although inconsistent, may be important for the rate of spread of the nematode. For example, fewer no-till fields than tilled fields in the North Central region of the USA were infested with this nematode and the numbers were also lower in no-till fields (Workneh *et al.*, 1999). Reduction of spread in no-till soils was confirmed in a plot experiment (Gavassoni *et al.*, 2001).

The effect of tillage on soybean cyst nematode is probably indirect and influenced by factors such as soil compaction. Whatever the factors, several years may be required before the effect is manifested (Edwards *et al.*, 1988; Tyler *et al.*, 1983). Compaction of soil can occur with no-till and is a process that progresses over several years (Denton and Cassel, 1989; Koenning *et al.*, 1995). The soil in a North Carolina tillage trial was considerably more compacted under no-tillage than under conventional tillage (Koenning *et al.*, 1995). Over time, the number of cysts declined under no-till in this trial. Disturbing compacted soil in no-till plots resulted in increased reproduction of soybean cyst nematode (Young, 1987).

Water management

Soil water management might be useful in fields under irrigation as a means of enabling the crop to compensate for loss of uptake efficiency in soybean cyst nematode damaged roots. Certain soil water conditions negatively affect soybean cyst nematode behavior (See Chapter 6). Penetration of susceptible soybean roots by soybean cyst nematode was reduced by increasing soil water potential (Johnson *et al.*, 1993a; Johnson *et al.*, 1993b). In most soil materials tested, irrigation to increase the soil water content was associated with a lower nematode population density than at drier conditions, presumably with soil water potential near -30 to -40 kPa (Heatherly and Young, 1991; Heatherly *et al.*, 1982; Heatherly *et al.*, 1992; Johnson *et al.*, 1993b; Koenning and

Barker, 1995). There were some exceptions (Heatherly and Young, 1991; Young and Heatherly, 1988). Although response of nematode populations to irrigation varied in different studies, soybean growth and yield were generally greater in irrigated soil than in the drier soils (See Chapter 6). In most cases, the increase is probably due to less water stress rather than reduced nematode damage (Young and Heatherly, 1988).

Soil fertility

Nutrient partitioning in plants may be affected by nematode infection, especially with endoparasites such as soybean cyst nematode that induce major morphological and physiological changes in the plant (See Chapter 8). P, K, Mg and Ca are some of the nutrients that might be altered in the plant by soybean cyst nematode infection. Addition of these nutrients to soil infested with soybean cyst nematode had variable affects on soybean yield and nematode reproduction. Soybean cyst nematode population densities increased on soybean seedlings growing in soil with moderate concentrations of K, but the numbers decreased when K rates were higher (Luedders *et al.*, 1979). Likewise, soybean cyst nematode population densities were highest when soils were treated with low rates of P and K, but were lowest at high rates of P and K (Howard *et al.*, 1998). Conversely, Hanson *et al.* (1988) reported no affect on yields or soybean cyst nematode population densities when K was added to soil with moderate levels of extractable K. The application of Mg + B did not result in a yield increase of infected plants (Smith *et al.*, 2000) even though concentrations of Mg are known to be reduced in infected plants (Blevins *et al.*, 1995). Likewise, application of four different fertilizer formulations to an Alabama soil low in N and P, but with adequate K, did not influence soybean cyst nematode population densities (Pacumbaba *et al.*, 1997).

ROLE OF CROPPING SYSTEMS IN THE FUTURE

Much progress has been made during the past 50 years in the understanding of the biology of soybean cyst nematode. Nonetheless, convincing producers to keep this nematode in mind when making soybean management decisions is still a major challenge. Clearly, rotation systems employing nonhost crops and soybean cyst nematode resistant cultivars will sustain the soybean production system well into the future. The heterogeneity of soybean cyst nematode populations (Niblack *et al.*, 2003) and the variation in recommendations across the growing regions cause growers to be concerned and maybe even question management recommendations. The additional factors associated with regional differences in experimental results lead Koenning *et al.* (1996) to emphasize the need for regionalized research efforts on soybean cyst nematode-soybean interactions.

A key to utilizing cropping systems effectively for managing soybean cyst nematode is to renew the emphasis on the necessity for monitoring soybean cyst nematode populations because of the site-specific effects of soybean management practices. The data from assays enables growers to make sound choices for selecting nonhosts in the rotation sequence and also for selecting appropriate cultivars with resistance to the HG Types present in the specific fields.

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