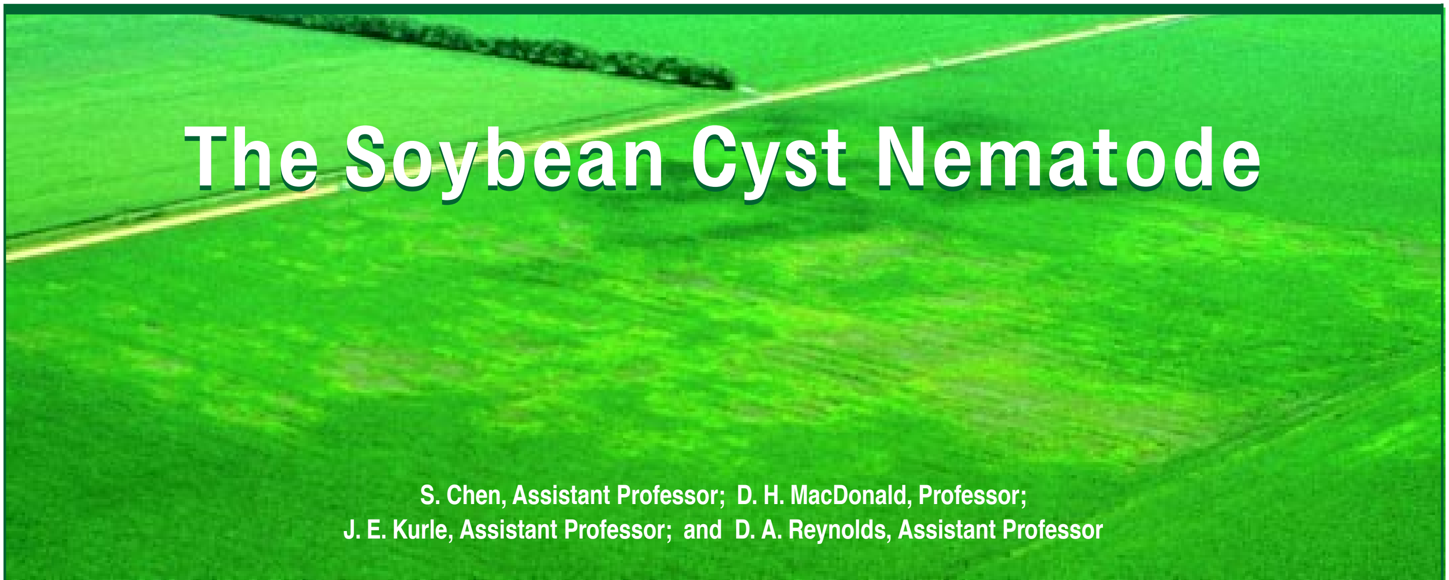

The Soybean Cyst Nematode

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Extensive SCN damage in soybean field.

Significance

The soybean cyst nematode (SCN), *Heterodera glycines*, is one of the most destructive pests affecting soybeans in the United States as well as in the other top ten soybean-producing countries of the world. Annual yield losses in soybeans due to SCN have been estimated at about $1.5 billion in the U.S. alone. SCN was first reported in North America in North Carolina in 1954, and since then has spread to 28 soybean-producing states and Canada. In Minnesota, SCN was first detected in 1978 near Frost in Faribault County. By 2000, its presence had been detected in 52 counties in the state **(Figure 1)**.

The soybean cyst nematode infects soybean, dry edible bean, and snap bean, and not rotation crops such as corn, small grains, and alfalfa (**Table 1**). Because the nematode can be present in fields without causing obvious above-ground symptoms, yield losses caused by SCN are often under-estimated. Yield losses incurred by susceptible crops growing in SCN infested fields can be expected to vary from year to year. In heavily infested fields of fertile silt loam soil, SCN can cause yield losses of more than 30%. In Minnesota, crop failures during warm and droughty growing seasons have occurred with soybean planted in non-irrigated, heavily-infested, sandy soils on the Anoka Sand Plain.

Figure 1. Minnesota Map showing known distribution of the soybean cyst nematode by county and the decade in which it was discovered.

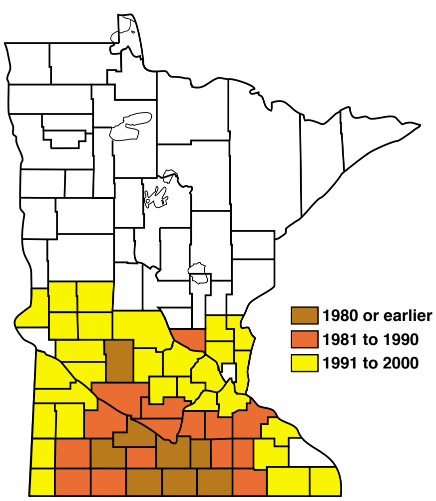

Table 1. Some Hosts and Non-hosts of the Soybean Cyst Nematode.

Non-host crops	Host Crops	Host weeds
alfalfa	common & hairy vetch	common chickweed
barley	cowpea	common mullein
corn	crimson clover	henbit
oat	dry edible bean	hop clovers
potato	snap bean	milk & wood vetch
sorghum	soybean	mouse-ear chickweed
sugar beet	pea (poor host)	
sunflower	sweet clover	
wheat	white & yellow lupine	

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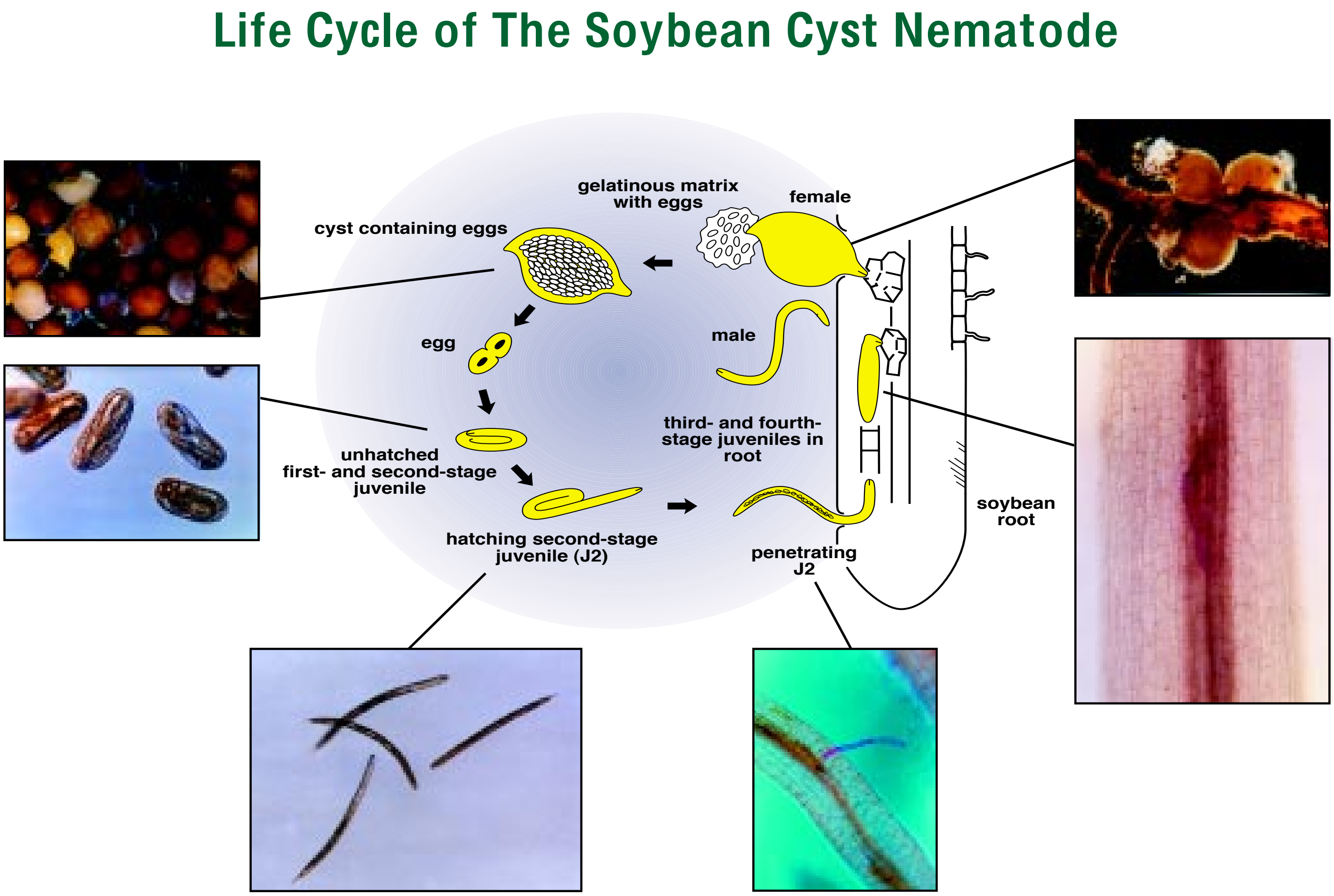
Figure 2. Life cycle of the soybean cyst nematode. (Sketch by Dirk Charlson, Iowa State University.)



Development and Life Cycle

SCN is a microscopic roundworm that attacks roots of soybean and a limited number of other host plants (**Table 1**). Developmental stages of the nematode include the egg and four juvenile stages **(Figure 2)**. The first-stage juvenile develops within the egg and molts to form a second-stage juvenile (J2). The J2 hatches from the egg, moves through soil pores in the film of water surrounding soil particles, is attracted to actively growing roots, and infects by penetrating host plant roots usually near the root tip. After penetrating the root, the nematode establishes a feeding site in the vascular tissue where it becomes sedentary, enlarges to become sausage-shaped, and molts three more times before becoming an adult. The adult female is lemon-shaped and, when fully developed, is visible on the root surface without magnification. The adult male undergoes a metamorphosis during the last molt to become a slender, motile worm. The male stops feeding and exits the root.

A pheromone released by the female attracts the male for mating. The female exudes a gelatinous matrix from the posterior portion of its body into which it deposits a small portion of the total eggs that it will produce. The gelatinous matrix containing eggs is referred to as an egg mass. Eggs in the egg mass hatch and the resulting larvae infect soybean roots the same year they are produced **(Figure 2)**. Several hundred additional eggs are retained inside the female body. As the female matures, its lemon-shaped body changes color from white to yellow. When the female dies the body (now referred to as the cyst), becomes dislodged from the root and undergoes a tanning process during which the cyst changes color to a dark brown. The cyst protects the eggs from damage by environmental stresses and serves as the over-wintering and long-term survival structure for the nematode eggs. In addition to the protection afforded by the cyst, the egg itself is durable and resistant. Some eggs within the cyst have been shown, under laboratory conditions, to be able to survive for more than 9 years before hatching.

The life cycle for SCN typically takes 3 to 4 weeks depending on geographic location, soil temperature, and nutritional conditions. Optimal soil temperatures for the various phases of the SCN life cycle are 75º F for egg hatch, 82º F for root penetration, and 82-89º F for juvenile and adult development. Little or no development takes place below 59º F or above 95º F. In southern Minnesota, SCN can complete three to four generations during a soybean-growing season. In central Minnesota, the nematode probably can complete only two to three generations.

Races

SCN field populations vary in their abilities to successfully develop and reproduce on a set of four differential soybean lines that differ genetically in their resistance to SCN. These different populations are referred to as SCN races and are given number designations. There are currently 16 possible reaction combinations and, thus, 16 potential SCN races. To date 12 different races have been reported in the United States. Although race 3 is the most common in Minnesota, races 1, 4, 5, 6, and 14 have been detected, also.

Most, if not all, SCN resistant soybean varieties available in the state are resistant to race 3 and some may be resistant to other races. Resistant soybeans are not immune to SCN. Some nematodes can be expected to develop to maturity and reproduce on a resistant variety. The current race scheme for SCN classification may have limited practicality in a production field since all SCN in a field are unlikely to be genetically similar. Some individuals in the field will overcome the particular source of resistance planted. These individuals will be selected for and will increase in percentage of the total SCN population with continued use of the same source of resistance in a field. If varieties with a specific source of resistance are used continually in the same field, that source of resistance will eventually become ineffective at preventing yield loss due to the nematode.

Dissemination

Healthy, newly hatched SCN J2 can move only a few inches in the soil. However, soil with cysts containing eggs can move long distances within a field or between fields by any means that moves soil. Soil movement in runoff or flood water, on wildlife, and as windborne dust are examples of natural mechanisms that spread SCN. Since eggs enclosed within the nematode cyst can survive passage through a bird's digestive system, migrating birds may spread SCN over long distances. Human activities that move soil between fields on equipment, tools, and vehicles are the primary means by which SCN spreads. Seed lots contaminated with soil peds infested with SCN are another way SCN can move long distances.

In Minnesota, SCN has been reported throughout soybean-producing areas in the southern and central regions of the state **(Figure 1)**. It appears that colder climatic conditions will not prevent the establishment of the nematode in the Red River Valley where soybean production is increasing.

Symptoms and Signs

"Yellow dwarf" is an appropriate description for symptoms that are commonly caused by SCN. When soybean plants are severely infected, they become stunted, canopy closure doesn't occur, and leaves may become chlorotic **(Figure 3)**. Unfortunately, these symptoms are not unique to the disease caused by SCN and may be confused with symptoms caused by other crop stresses such as nutrient deficiencies, injury from agricultural chemicals, feeding of the soybean aphid, and

Figure 3. Stunting and chlorosis induced by soybean cyst nematode infection on soybean roots.

infection by other plant pathogens. SCN populations are not evenly distributed throughout fields. Areas of severely affected and symptomatic soybean plants are often round or elliptical in shape. Those heavily infested areas are often elongated in the direction of tillage due to localized mechanical spread of cysts by tillage equipment (see aerial photograph on front cover). SCN infection may limit nodulation by nitrogen-fixing bacteria. Because SCN damages roots and limits nutrient uptake by the soybean plant, iron and potassium deficiencies may increase in severity. Severely infected plants may die before flowering, especially during dry years and in soils with poor water holding capacity. Good soil fertility and adequate moisture increase tolerance of soybean plants to SCN and reduce the severity of aboveground symptoms in fields. Producers may not realize that the cyst nematode is present in such fertile fields until environmental stresses accentuate the effects of the large SCN populations that have developed over the previous several growing seasons and significant yield loss has occurred.

Belowground symptoms include dark-colored roots, poorly developed root systems, and reduced nodule formation. Several important diseases of soybean caused by fungi are associated with or increased in severity by the presence of SCN. The causes of those diseases most likely enter the plant through wounds in the soybean root made by enlarging SCN females **(Figure 2)** and then find the nematode-altered root especially suitable for infection and colonization. These pathogens may also enter the young root where the J2 penetrate behind the root cap **(Figure. 2)**.

Figure 4. White to light yellow soybean cyst nematode females on soybean roots.

In-Field Diagnosis:

Detecting the Presence of the Female SCN

The unique, diagnostic sign of SCN infection is the living female nematodes attached to infected roots **(Figure 4)**. These tiny, lemon-shaped, white to yellow females usually can be seen on the roots from 4 to 5 weeks after planting, are usually abundant in July and August, and then decline in numbers as roots senesce. Early season development of the female SCN on the soybean root is very much temperature dependent. In a cool growing season in Southern Minnesota female development may be delayed until as late as July. The female's body is attached to the root by only its head and neck. Plant roots to be examined for the presence of females, need to be gently dug rather than pulled from the soil. Gentle rinsing of soil from the roots in a bucket of water will help reveal their presence. Females and cysts are about $^{1}/_{40}$ inch long and $^{1}/_{60}$ inch wide and are large enough to be seen with the unaided eye. They are easily distinguished from the much larger bacterial nodules on the roots.

Females may be difficult to find on roots if the SCN density is low, when sampling is done too early or too late in the growing season, or when the SCN population density is extremely high. Soybean roots that are severely damaged due to the actions of the nematode and associated microorganisms will be no longer capable of supporting SCN. Under such circumstances, analysis of soil samples from suspect fields by a professional laboratory may be necessary to detect the presence of SCN.

Soil Sampling-Detecting SCN

The purpose of this type of sampling is to detect the presence of SCN before it can become numerous enough to cause economic loss. Declining seed yield from a field or portion of a field is usually the first clue that some type of soil sampling should be done. This type of sampling can actually be done at any time of the year when the physical condition of the soil will permit use of a sampling tube or, less desirably, a shovel.

A sample consisting of 10 to 20 one-inch diameter by 6-8 inch long cores should be collected from each of several localized "most likely" sites in a field. "Most likely" sites are locations where SCN was first introduced into a property and has had access to a sufficient number of susceptible crops in order to build up to detectable levels. The cores should be collected from in-row locations rather than from between crop rows that are 15 inches or more apart. The reason for sampling in the row is the fact that all plant nematodes including SCN can only develop on plant roots.

Nematode populations are much more likely to be larger in soybean rows than they are between the rows where plant roots are scarce. One such "most likely" site would be a short distance into the field opposite each entrance point where tillage equipment enters the field. Sampling is done at such locations because contaminated equipment is the number one method by which SCN is introduced into a property. Infested soil scoured from equipment at such locations allows SCN buildup to begin there. Another "most likely" site would be on the lee-side of a small hill or knoll, or along a fence or tree line. Wind-blown soil containing cysts tends to settle out at such locations much like wind-driven snow will accumulate behind a snow fence or similar obstacle. A third "most likely" sampling site would be low areas that flood when streams overflow. Egg-filled cysts can be carried and spread by moving water.

Soil samples enclosed in individual sealed plastic bags should be submitted to a commercial or university laboratory for processing. Although the dark brown cysts can be seen with the unaided eye, they are very inconspicuous when mixed with soil. The laboratory will use a procedure to "float" any cysts out of a soil sample. If cysts are found, then the laboratory will rupture them to release any eggs that they contain. The lab's report will typically report SCN-positive samples in terms of number of eggs per 100 cm^3 (approximately one-half cup) of soil. If SCN is found, then managing it through the use of resistance and rotation as an on-going farming practice is required. If the reported egg number is very low, the infestation needs to be confirmed by bioassay of the soil or by sampling again in the next soybean crop.

Although the laboratory procedure described above "is the norm", producers who feel that their other rotation crops (which are not affected by SCN) are not as productive as they should be may want to consult the laboratory about having a "broad spectrum" plant nematode assay performed with each of the soil samples. This type of assay procedure can detect the presence of cyst as well as other (e.g., corn or lesion) nematodes that may be numerous enough to be adversely affecting plant growth. Native nematodes such as the lesion were present before the introduction of SCN and are a normal biological component of all natural soils in which plants can grow.

Soil Sampling-Deciding on Management Strategies

Representative sampling is used to estimate average SCN populations in a field and is most effectively used when nematodes are known to already exist in a field. A representative sample is important in determining the appropriate management plans for SCN.

Because SCN are usually distributed in an aggregated (spotty or patchy) pattern in most fields, arbitrarily collecting samples while crossing the field in a zigzag pattern is the best sampling pattern. Divide a field into 10-acre areas. Within each 10-acre area collect a soil core, or $^1/_4$ cup of soil, to a depth of 6 to 8 inches from about 20 different locations using a soil probe. The soil cores should be broken and thoroughly mixed, placed in a plastic bag, labeled with field identification using a water-resistant marker, and sent to a professional laboratory for analysis. Nematode egg numbers may vary significantly with sampling techniques, so it is very important to use recommended sampling procedures.

Analysis of two representative soil samples collected from the same field may have widely varying egg population densities. Even utilizing the recommended zigzag pattern for collecting soil samples does not insure that two samples from the same field will result in similar population densities. Since the spatial distribution of SCN in most fields typically is an aggregated pattern there are hot spots and non-infested areas. During sampling, soil cores may come from areas with egg population densities that are significantly higher or lower than the actual average field egg population density. Also, the efficiency of extracting SCN from the soil is dependent on soil characteristics such as soil texture and soil moisture content at the time of sampling. Some error may be associated with the actual laboratory processing of the sample. This error is usually not a concern unless the sample is reported to have a very low population density.

An effective management program can still be planned, however, using the rough estimate of the average SCN population in a field. Increasing the number of soil cores collected in each 10 acre area or reducing the size of the area for each sample can increase the precision of the sample. If the hot spots in the field cannot be managed separately from the rest of the field the best option is to manage the entire field according to the higher population density.

There are other reasons why SCN population densities may vary in two soil samples taken from the same field. SCN egg counts will be highest if samples are collected in the soybean row at the end of the growing season. Egg counts may be lower when samples are collected in a soybean field within the first 4 to 6 weeks after soybean planting because a significant portion of the eggs will have hatched. Since SCN egg population densities are reduced during a year when a non-host crop is grown, SCN egg counts from samples taken after corn harvest but before soybean planting are the most useful in estimating potential soybean yield loss. Sampling in the fall also allows more time for the soybean producer to develop an appropriate SCN management plan.

Management Strategies

Resistant varieties:

Resistant varieties are being successfully used in SCN management. A number of SCN–resistant varieties in Maturity Groups I and II have been developed and are available for planting by Minnesota soybean producers. One SCN–resistant variety, 'MN00902CN', is available for Maturity Group 0 production areas. In the past, resistant varieties produced 5-10% less yield than susceptible varieties when both were grown in the absence of the nematode. Although current elite, high-yielding susceptible varieties may still outperform current resistant varieties in fields where there are no soybean cyst nematodes, the yield potential of resistant varieties continues to be improved. There is one main source of information about varietal characteristics as well as how well various public and private varieties yield when grown at SCN-infested sites. It is available as part of the University of Minnesota's Soybean Breeding Project's contribution to the annual publication titled "Minnesota Variety Trials Results" that most producers routinely receive or from the Web site at http://www.maes.umn.edu/maespubs/vartrial/cropages/soybean.html.

Information about SCN population development on individual soybean varieties is available at http://sroc.coafes.umn.edu/Nematology/nematology.htm.

Performance of a resistant variety in an SCN infested field depends on the genetics of both the soybean and the nematode. The three sources of SCN resistance genes that have been incorporated into soybean varieties suitable for growth in Minnesota are PI 88788, 'Peking', and PI 209332. The source of SCN resistance in over 90% of the commercial and public varieties in Maturity Groups I and II is currently (2001) PI 88788. A small percentage of SCN resistant varieties were developed from Peking. 'Faribault', a Maturity Group I variety, was developed at the University of Minnesota with resistance derived from PI 209332. As indicated earlier, the available soybean varieties are resistant to race 3. This race typically predominates until SCN-resistant varieties are commonly planted. Some varieties have resistance to more than just race 3. Planting SCN resistant varieties imposes a selection pressure on the population of SCN present in an infested field and can cause a change in the SCN race present. Resistant varieties are not resistant to all potential SCN races and they are not immune. SCN at a high density of 10,000 or more eggs/100 cm^3 of soil can cause a significant yield loss (> 2 bu/A) even to a resistant variety **(Figure 5)**. Repeated use of the same resistant variety or the continuous use of varieties with the same resistance source may eventually result in a reduction in the ability of those varieties to manage the nematode and produce maximum yields.

Crop Rotation:

Several crops are not hosts for SCN **(Table 1)** and could be included in the crop rotation to reduce SCN populations. The number of years of a non-host crop needed to effectively lower

Figure 5. The effect of two soybean cyst nematode population densities on the resistant soybean variety 'Freeborn.' Plant growth was significantly suppressed in the two left rows where SCN egg population densities prior to planting were 35,500 eggs/100 cm^3 of soil. The two rows on the right were planted into soil with 3,500 eggs/100 cm^3 of soil.

SCN population density depends on many factors, including nematode density before planting the non-host crop, the species of non-host crop, and soil biotic and abiotic factors that affect nematode mortality. In the southern U.S., planting 2-3 years of non-host crops can effectively reduce high densities of SCN eggs to below the damage threshold. However, the survival potential of SCN in Minnesota is greater than it is in the South and more seasons with a non-host crop are needed here to reduce the number of viable SCN eggs to the level that will allow a susceptible soybean to be grown. In Minnesota, the percentage reduction of SCN eggs in the soil after a season of corn ranges from 20% to 80% depending on environmental conditions. If the fall egg density in a soybean field is about 10,000 eggs/100 cm^3 of soil, it may take as long as 5 years of non-host crops to reduce the SCN population below a density that will not damage a susceptible soybean variety.

Chemical control:

Some nematicides are registered for use to control SCN. The performance of any nematicide depends on many soil and environmental factors including soil type, rainfall, soil moisture, soil temperatures, and soil microbial activity. Use of nematicides adds significantly to production costs and does not guarantee increased yields. Economics as well as environmental and personal health concerns should be considered before using nematicides. For these reasons, nematicides are not recommended for SCN management.

Biological control:

Biological control of the SCN appears to have some potential and is an area of research that is currently receiving much attention. Fungal and bacterial parasites of SCN eggs, juveniles, and adults have been isolated. These parasites may increase the effectiveness of resistant varieties and crop rotations by limiting or reducing SCN populations. Although their effectiveness is being tested in greenhouse and field trials, no commercial biological agents for use against SCN had been developed by the time of publication of this fact sheet.

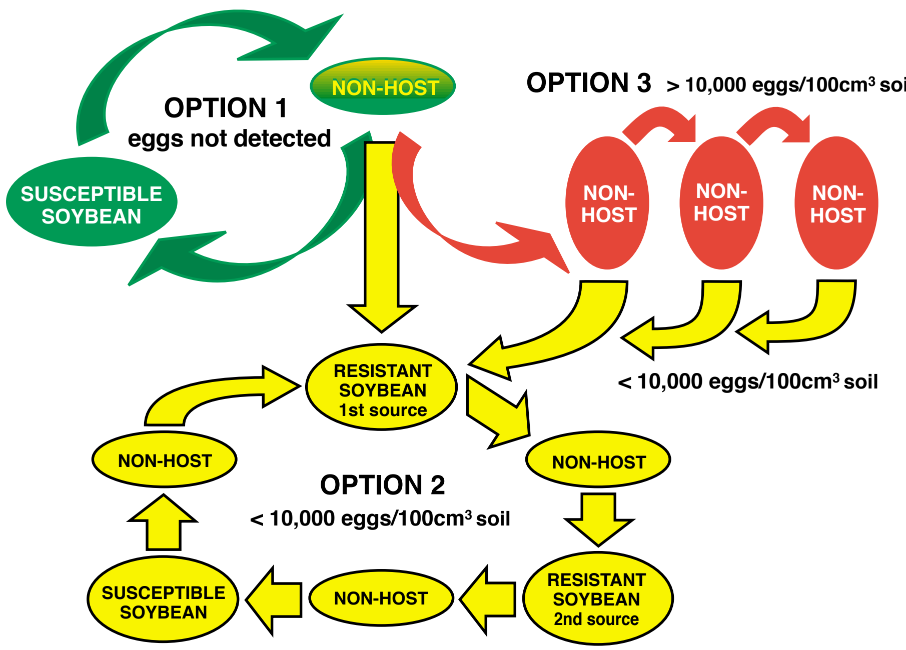


Figure 6. SCN management scheme utilizing non-host crops and resistant and susceptible soybean varieties. The initial SCN egg densities used to determine the appropriate option to use is based on soil sample taken after a year of non-host.

Long-term Management of the Soybean Cyst Nematode

There is no way to eliminate SCN once it is present in a field. Instead the goals of SCN management are to minimize soybean yield losses and reduce SCN populations. Currently, the most effective SCN management practices are use of resistant varieties and rotation to non-host crops. Yearly yield monitoring, scouting for symptoms, and soil sampling to determine SCN egg densities provide the information necessary for making SCN management decisions. **Figure 6** provides guidelines for SCN management strategies that are based upon nematode egg numbers.

Option #1: Despite the contagious nature of SCN, fields still exist even in Southern Minnesota that are apparently not infested with the nematode. If sampling the "Most Likely Sites" in a field fails to detect the presence of SCN, then a traditional 2-year rotation with one year of non-host crop and the second year with susceptible soybean can still be utilized. The grower, however, will want to do everything that is feasible to delay the introduction of SCN into the field. This will require that only seed free of infested soil peds is planted, and equipment used in infested fields will be pressure-washed prior to entering the non-infested field. The grower may want to consider using no-till or conservation till practices in the field to further minimize chances of SCN introduction on equipment. Although the type of tillage did not affect SCN density in a study conducted in Southern Minnesota, work done elsewhere indicated that conservation tillage may be less favorable for build-up of the nematode compared to conventional tillage. Vigilance in terms of monitoring soybean yields and soil sampling for SCN prior to every third planting of soybean are additional inputs required with use of Option #1.

Option #2: If, as the result of a soil sampling program, SCN is determined to be present at population levels of up to 10,000 eggs/100 cm^3 of soil, then a 6-year rotation consisting of non-host crop, resistant soybean, non-host crop, resistant soybean, non-host crop, and susceptible soybean is recommended. Although there probably is merit in selecting two resistant soybean varieties that have different sources of resistance (i.e. PI 88788 and 'Peking'), there currently are so few varieties available with resistance derived from some source other than PI 88788 that the use of varieties with two different sources of resistance is not a particularly feasible option. The next best choice of resistant varieties would be two different varieties with the PI 88788 source of resistance selected from different parental crosses.

Option #3: If SCN populations are above 10,000 eggs/100 cm^3 of soil, then even the best adapted resistant soybean variety is likely to be damaged and yields reduced. If the soybean plants are likely to be stressed at some point during the growing season, then that stress will magnify the potential for stunting caused by the nematode-infected soybean's necrotic root system and significant yield loss can occur. This situation is likely to prevail in most fields and several years of non-host crops will be necessary to reduce egg densities below 10,000/100 cm^3 of soil and Option #2 can be utilized safely. If the field is irrigated and plant stresses other than SCN can be minimized, then Option #2 will provide satisfactory results and resistant varieties can be used to reduce SCN density without limiting cropping options to corn or other non-host crops.

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