

CHECK OUT
KEY CHECKOFF-
FUNDED ARTICLES
STARTING ON
PAGE 20.

70 YEARS OF PROGRESS

FIGHTING SOYBEAN
CYST NEMATODE
IN NORTH AMERICA



SOYBEAN CYST NEMATODE: A COSTLY CHALLENGE

Soybean cyst nematode, or SCN, is the top yield-robbing pest for soybeans, reducing yields by up to 5 bushels per acre in infected fields. Estimates over the last 25 years show SCN has cost soybean growers more than \$27 billion dollars in lost yield — and it continues to rob U.S. growers of more than \$1 billion per year.¹ Yield increases due to improved soybean genetics and management has likely masked the true extent of yield loss to SCN over time.

The nematodes are microscopic, plant-parasitic roundworms. As juveniles, the pests damage soybeans and other host plants by feeding on

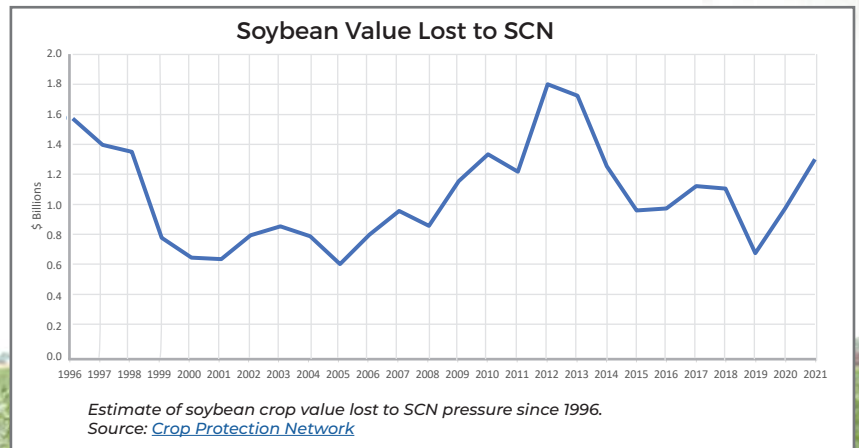
roots, inhibiting plant growth and root function. Feeding allows adult females to become cysts containing up to 400 eggs, which can remain dormant in the soil for up to 10 years.² Once they are in the soil they can be suppressed, but never completely eliminated.

SCN was first reported in Asia in 1915.³ In North America, it was initially discovered in 1954 on six North Carolina farms covering 200 to 300 acres.⁴ Researchers speculated that it came from Asia on lily bulbs used as a cover crop. Since then, SCN has spread. It is currently found in almost every soybean growing county in the U.S. and Canada.

Farmer-funded research plays

a critical role in fighting SCN. The soy checkoff has funded many research trials, scientific papers and presentations about SCN at national and state levels.⁵ For example, trials demonstrate that SCN-resistant soybean varieties continue to be the most effective and cost-efficient means to reduce yield loss from this pest.

Researchers began identifying and developing useful varieties almost immediately after SCN was first detected. During the past 70 years, this work, funded in part by the soy checkoff, has been instrumental in preventing even greater yield losses and helping farmers profitably raise soybeans despite the threat.



THE SOYBEAN CYST NEMATODE LIFE CYCLE

The SCN life cycle can be completed in as few as 24 days during the growing season. There can be from three to six generations per year.

What's your number?

Take the test.  Beat the pest.

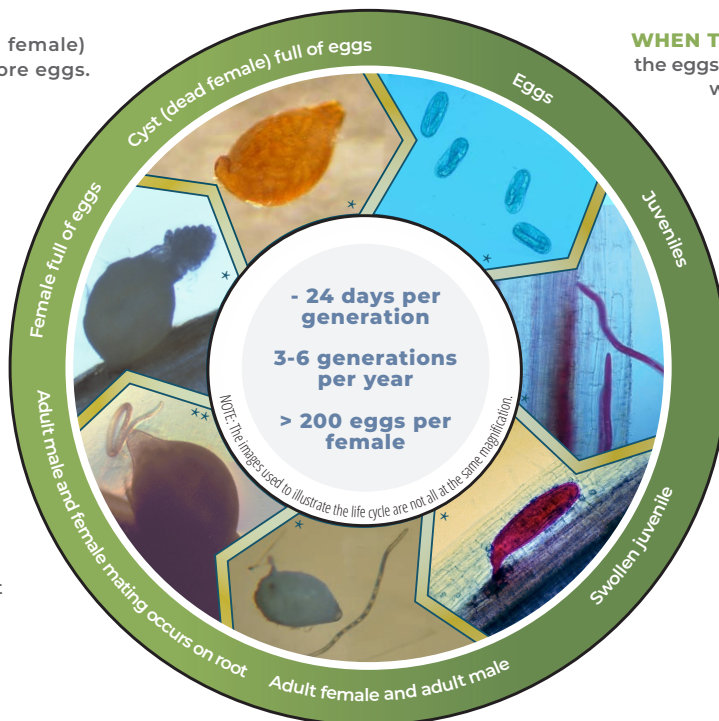
The SCN Coalition™

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EACH CYST (dead female) contains 200 or more eggs.

AFTER MATING, she makes about 50 eggs outside her body and fills up with another 200+ internally. Then she dies and her body wall hardens to form the cyst.

THE FEMALE GETS SO LARGE that she ruptures out of the root onto the root surface and sends out a chemical signal to attract mates. There's no such thing as nematode monogamy. Females mate with many males, and males mate with many females. There's a lot of genetic mixing.



WHEN THE CYST BREAKS, half of the eggs will become male and half will become female.

JUVENILE WORMS hatch from eggs and burrow into soybean roots to feed and develop. There's no way to tell whether a juvenile is male or female at this stage.

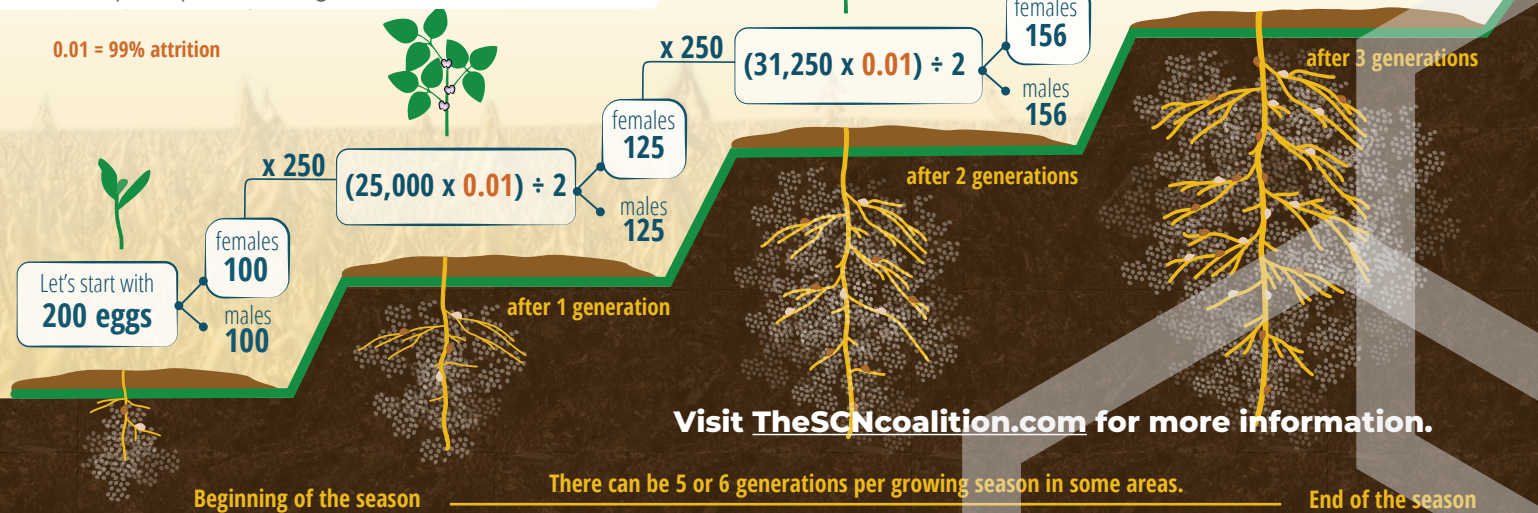
THIS JUVENILE IS SWOLLEN from feeding in the root for several days. If this juvenile is female, she'll stay in the soybean root and keep feeding.

* Tylka, Iowa State University
** Chitwood, USDA

IF THE JUVENILE IS MALE, it will revert back to a worm shape and leave the root.

WHY YOU NEED TO TEST YOUR FIELDS to know your numbers.

Even with an attrition rate of 99% – meaning only 1% of eggs survive each generation – this is how quickly SCN egg populations can build up on a plant in three generations.



SPREAD. GROWTH. SOLUTIONS.

SPREAD OF SOYBEAN CYST NEMATODE AND GROWTH OF RESEARCH FOR SOLUTIONS

Though SCN has been in North America for at least 70 years, the story of the pest and its management solutions began decades earlier. Thanks to USDA research, a soybean variety with native resistance to SCN was collected in China in 1906, before SCN was identified in Asia and soybeans became a common U.S. crop.

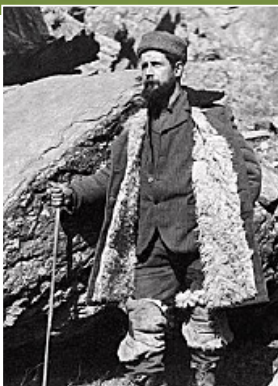
In the following years, the foresight of farmers, agronomists and scientists enabled development of research infrastructure to tackle complex challenges. Because of these efforts, work on SCN solutions started and ramped up quickly as the problem became clear. In fact, the foundation to build solutions was already available in the soybean germplasm collection.

This timeline shows that as SCN has spread, so have research efforts.

1900s

1906 – USDA researcher Frank Meyer collects the black-seeded Peking soybean variety in China

Frank N. Meyer on a plant collection trip to China for the USDA Office of Seed and Plant Introduction



USDA researchers Palemon Dorsett and William Morse on a plant collection trip in China

1930s

1906 – USDA researcher Frank Meyer collects the black-seeded Peking soybean variety in China

1915 – SCN is first reported in Japan

1920 – The American Soybean Association is founded by soybean farmers, agriculture extension specialists and breeders

1930 – William Morse, USDA soybean specialist, collects PI88788 variety in China

- 1936** – SCN is discovered in Korea
- 1936** – Uniform soybean variety testing begins in Illinois, Indiana, Iowa, Missouri and Ohio
- 1938** – SCN is documented in Manchuria
- 1943** – Uniform soybean variety testing extends to 12 southern states
- 1944** – Congress funds soybean disease research through the USDA Bureau of Plant Industry, thanks to lobbying efforts of soybean farmers and crushers
- 1944** – The Southern States Soybean Planning conference includes growers who helped direct breeder efforts
- 1949** – USDA formally establishes the soybean germplasm collection



New Nematode In Carolina

A CYST-FORMING nematode has been found infesting soybeans in the Castle Hayne area, New Hanover County, N. C., according to North Carolina Experiment Station and U. S. Department of Agriculture workers in the area. Six or more farms have been found to be infested with this nematode, or a total area of 200 to 300 acres. So far it has not been found elsewhere.

The Experiment Station and USDA are studying the problem and conducting a survey to learn if the nematode is widespread in North Carolina.

Examination of soybean roots from small areas where the plants were severely stunted and chlorotic revealed the presence of numerous lemon-shaped female nematodes attached to the roots. Soil from infested areas contained several hundred to a pint of several hundred female nematodes per acre in 1954. However, injury farther west, and other states have not to recommend it.

"Alanap 3 has the advantage that it does not injure the roots of soybeans as readily and so can be applied at a date of planting more than DNEP can. Alanap is a serious pest in much of the South where soybeans are grown. It is an important limitation.

"Isopropyl-N-(3-chlorophenyl)phosphoramidate (CIPC) has again given excellent results on soybeans again recommended at six to ten pounds per acre by the North Carolina Weed Control Conference. It controls smartweed, but does not control ragweed.

"All of these materials are much more expensive than 2,4-D. However, in fields where specific serious weed problems are known to exist, and especially for early planting, these are the three herbicides most worth trying."

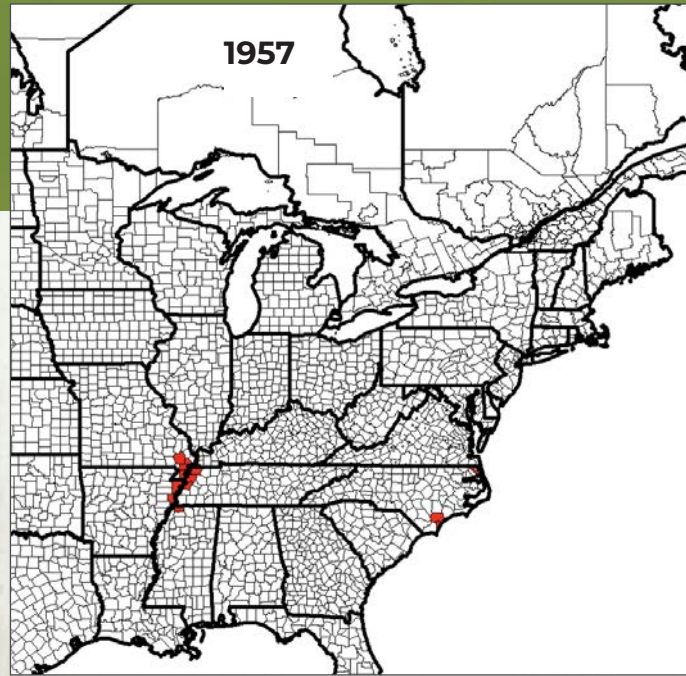
Weeds Cut Yields
MODERATE infestations such as reproduction and size of plants.

1940s



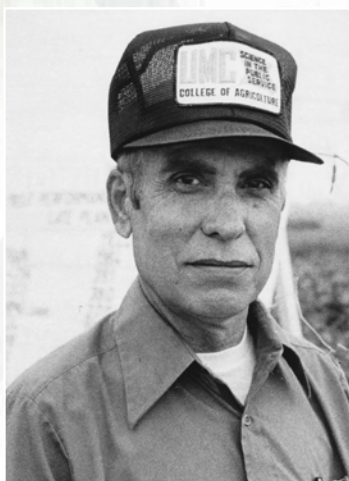
June 1955 Soybean Digest

Rapid expansion in soybean production begins



1950s

- 1954** – Initial discovery of SCN on 6 farms covering 200 to 300 acres in New Hanover County, North Carolina
- 1955** – First mention of SCN in Soybean Digest
- 1956** – Quarantine is established in North Carolina
- 1956** – To begin screening for genetic resistance, a wide range of germplasm is planted in one of the North Carolina fields where SCN was first found
- 1957** – Researchers plant 3,500 strains originally from eastern Asia in an SCN-infested field near Wilmington, North Carolina



1960s

1960s – Farmers begin to form voluntary state associations affiliated with ASA, and checkoff legislation starts passing on a state-by-state basis; state checkoff boards often fund ASA research with state checkoff funds



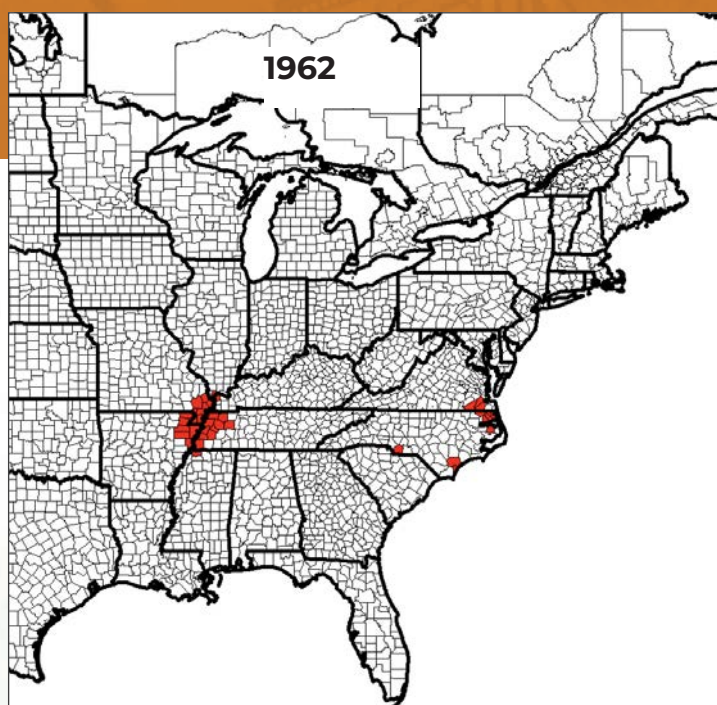
1961 – USDA identifies SCN in 37 counties in 8 states

1963 – Three breeding programs in North Carolina, Missouri and Mississippi/Tennessee almost simultaneously obtain SCN resistance in yellow-colored soybeans

1965 – A group of Midwestern seed companies establish the Soybean Research Foundation to develop soybean varieties

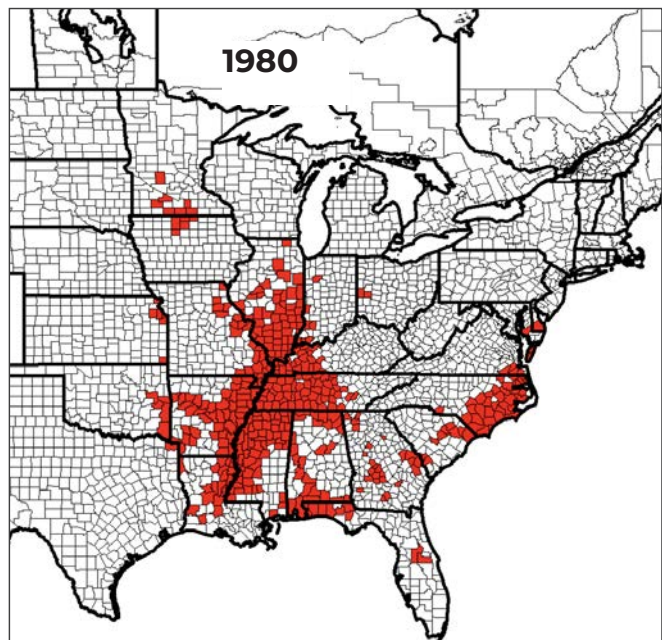
1965 – The Pickett breeding line containing SCN resistance is released

1967 – Dywer and Custer genetic lines with SCN resistance are released



“We monitor the number of soybean cyst nematode by soil sampling every field, every year. We also send in root samples throughout the year, and then we keep track of the numbers. If they start to get too high, we will rotate with corn-on-corn or alfalfa.”

– TOM FRISCH, FARMER, DUMONT, MINNESOTA



1981 – Fayette line with PI88788 resistance is released

1987 – SCN is discovered in Kent County, Ontario, Canada

PI88788
SoPI88788

› 1980s

1970 – The Plant Variety Protection Act passes, resulting in soybean breeding expansion to the commercial sector

› 1970s



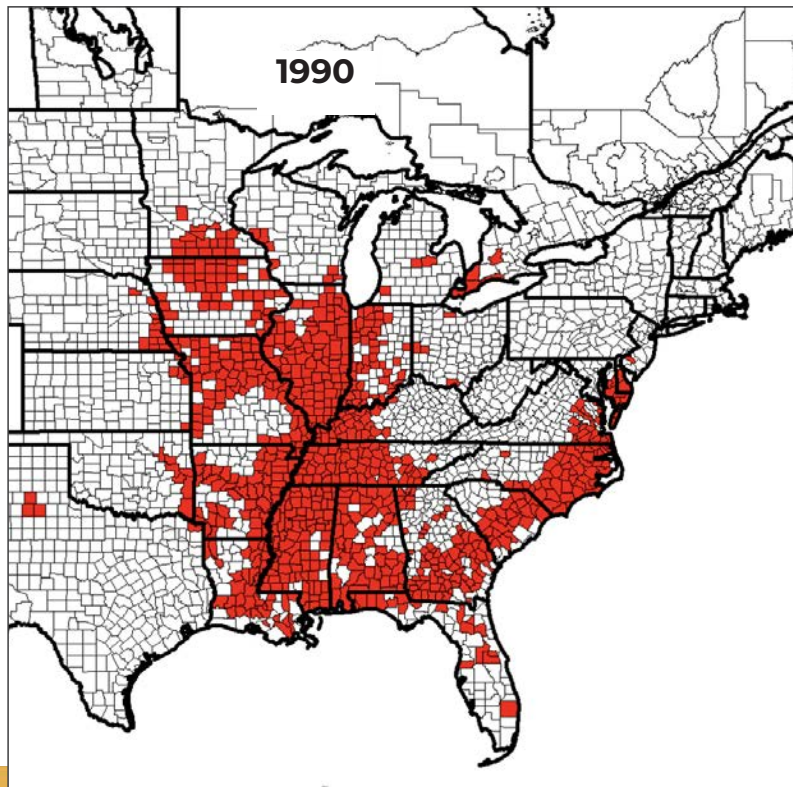
1972 – SCN quarantine is declared ineffective and lifted; southern breeders begin including PI88788 in breeding programs

1974 – SCN becomes the most damaging soybean pathogen in the country

1979 – Northern Region SCN tests coordinated at the University of Illinois

PI88788





1991 – Hartwig variety with PI437654 resistance is released

1992 – A collaboration of states found the North Central Soybean Research Program, or NCSRP

1992 – Iowa State University starts an ongoing regional SCN education and research program

1993 – The soy checkoff begins providing support to the Northern Region SCN Tests at the University of Illinois

1994 – Release of Faribault variety, which contains PI209332 resistance

1995 – First national SCN conference is held in Ames, Iowa

> 1990s

1991 – The national checkoff program is enacted, and the United Soybean Board forms



Edgar Hartwig became curator of the southern soybean germplasm collection



1997 – The first SCN Coalition is created with soybean checkoff funding through NCSRP and tasked with encouraging farmers to sample soil for SCN

1998 – The Agriculture Research, Extension, and Education Reform Act increases funding for agriculture research and crop insurance

1999 – Second national SCN conference is held in Orlando, Florida

The SCN Coalition™

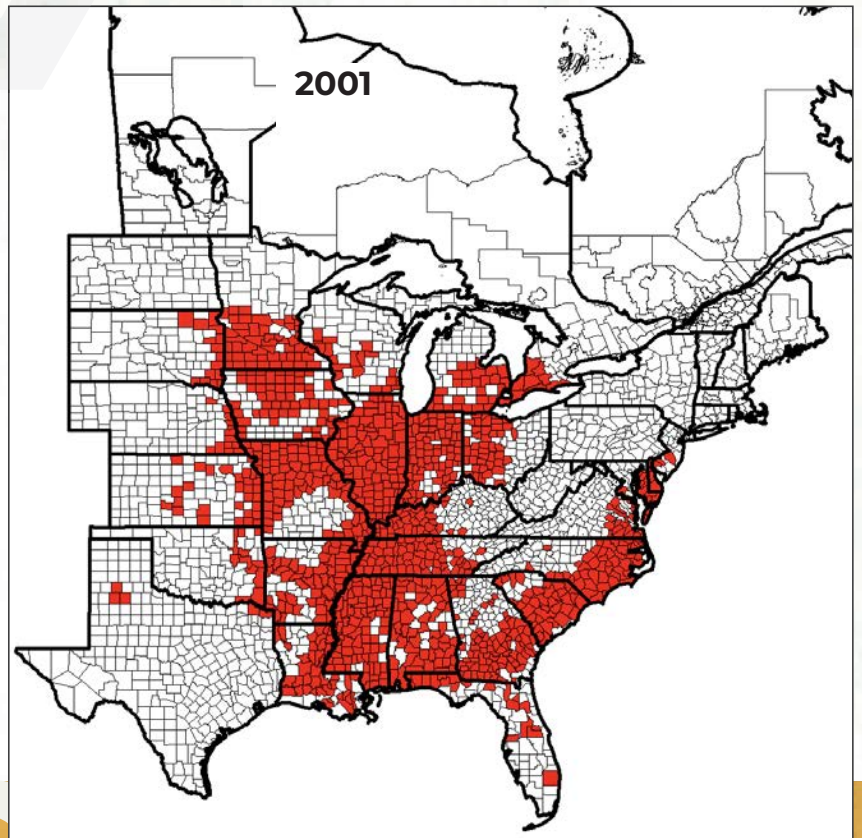
Funded by the soybean checkoff



2002 – Third national SCN conference is held in St. Louis, Missouri

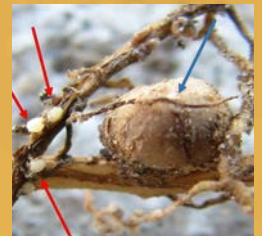
2008 – Soybean genome sequencing, funded in part by the soy checkoff, is completed

2008 – Fourth national SCN conference is held in Tampa, Florida



2000s

2001 – Indiana CystX germplasm, derived from PI437654, launches following its discovery by checkoff-funded researchers



2010s

2014 – SCN spreads to an additional 57 counties in 13 states since 2008, including the last county in Illinois

2015 – Nearly 90% of SCN-resistant soybean varieties in the upper Midwest use PI88788 as the source of resistance

2016 – Fifth national SCN conference is held in Coral Gables, Florida

2017 – SCN infests an additional 37 counties in 17 states since 2014, including the first observation in New York, and the final county in Iowa

2018 – A revitalized SCN Coalition is launched to prevent a resistance crisis, with the goal to increase testing for nematodes, determining the soil population density and actively managing for SCN across the country

2018 – The first National SCN Strategic Plan releases as a framework to prioritize, guide and synergize research efforts across the U.S. and Canada

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2020 –SCN is found in every soybean-producing state in the U.S. except West Virginia, spreading to an additional 55 counties in 11 states and 24 Canadian counties since 2017, which is 1.5 times as many new counties as in the previous 3-year period; states with newly discovered SCN-infested counties include Kansas, Kentucky, Michigan, Minnesota, Nebraska, New York, North Carolina, North Dakota, South Dakota, Virginia and Wisconsin

2020 – Syngenta releases two soybean varieties with PI89772 resistance, the first of their kind

2022 – SCN reproduction on PI88788 reaches all-time high in Iowa, with female indices exceeding 75% in 3 fields; a female index greater than 10% is considered to be overcoming resistance

2022 – Sixth national SCN conference is held in Savanna, Georgia

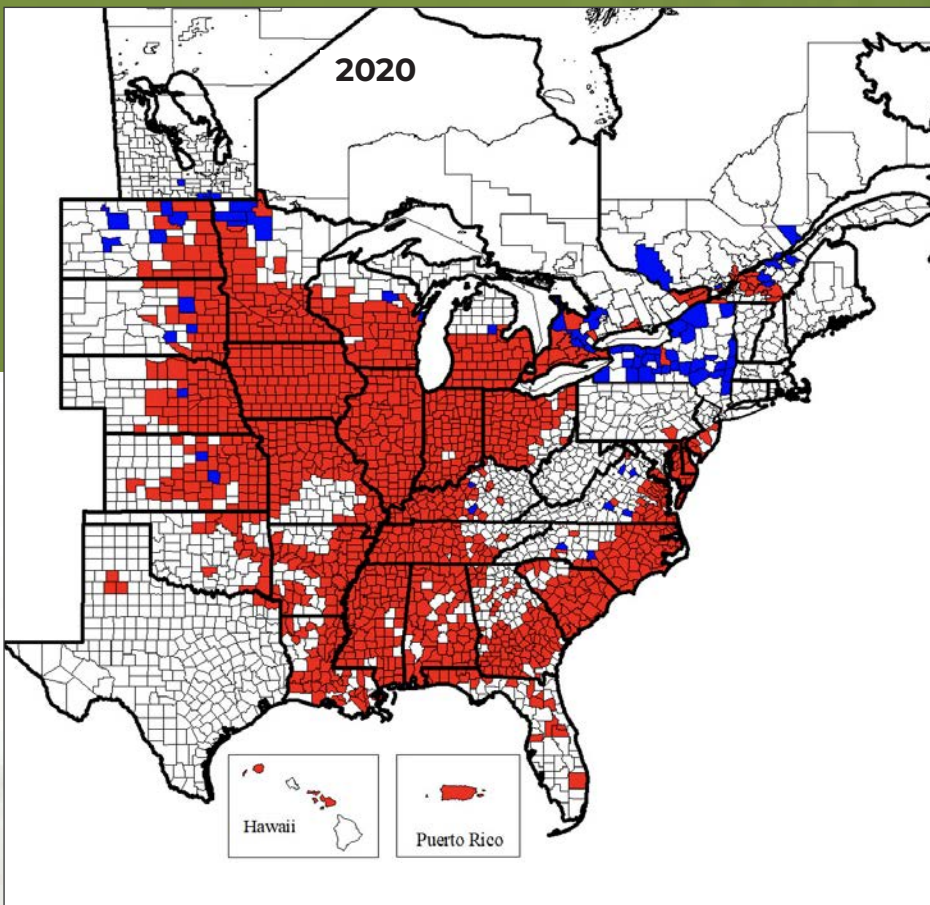
2023 – SCN remains the most economically damaging pest to soybeans, with an estimated yield loss exceeding \$1 billion annually

2023 – To date, SCN has not been discovered and reported in West Virginia or Prince Edward Island, Canada

“Each time we figured out the gene and protein responsible for a particular SCN resistance trait it has created opportunities for cheaper and more accurate breeding.”

– ANDREW BENT, PLANT PATHOLOGY PROFESSOR, UNIVERSITY OF WISCONSIN

›2020s



Map shows the known distribution of the soybean cyst nematode, *Heterodera glycines*, in counties and rural municipalities in the United States and Canada in 2020. Those reported as infested since 2017 are shown in blue; those known to be infested in 2017 or before are indicated in red. ¹³

[see maps](#)



“We will consistently battle against this stubborn and aggressive pest until we can be confident that we have won the fight.”

— MARK SEAMON, RESEARCH DIRECTOR, MICHIGAN SOYBEAN COMMITTEE





FARMERS INVEST IN SOYBEAN CYST NEMATODE SOLUTIONS

Like many pests, SCN exists in an environment where complex interactions between genetics, biology, weather, soils and cultural practices demand sustained investments to successfully combat the problem. SCN steals yield, quality, profit and sustainability.

Soybean farmers and checkoff boards at state, regional and national levels understand that a challenge like this requires sustained commitments to and investments in basic and applied research. Such research develops integrated pest management solutions and systems that help farmers manage SCN. For publicly funded soybean research, especially related to SCN, the soy checkoff takes the unique position of representing the needs and interests of growers to funding agencies and researchers.

Starting in the 1990s, the national soy checkoff and NCSRP built on past research efforts and provided a steady supply of funding for regional

and national research on important soybean issues. Due to its large economic impact and the work already accomplished, SCN became one of those critical research topics. Along with research, soybean farmers have invested checkoff dollars into sharing research information and helping farmers understand the problem. These investments have paid dividends in several ways.

FOUNDATION FOR KNOWLEDGE: LEVERAGING CHECKOFF RESOURCES

Checkoff investments in research frequently provide early discovery and proof of concept results and data. This necessary background research then attracts national competitive grant funding and private company investments into more studies. Checkoff success in research is multiplied by supplemental funding and support from other organizations.

Key sources for additional research funding include the USDA's Agricultural Research

“Checkoff investments frequently provide early discovery and proof-of-concept results necessary to attract national competitive grant funding and private company investments.”

— ED ANDERSON, EXECUTIVE DIRECTOR, NCSRP

Service, which is committed to finding scientific solutions to agricultural problems. Other federal funding agencies, like the National Science Foundation or NSF, the National Institute of Food and Agriculture or NIFA, and the Department of Energy Joint Genome Institute or JGI, frequently fund foundational research. Over the years, these institutions have supported and expanded SCN research that began as checkoff-funded projects. For example, the recent sequencing of the SCN

genome was supported by NCSRP, JGI and NSF.⁶

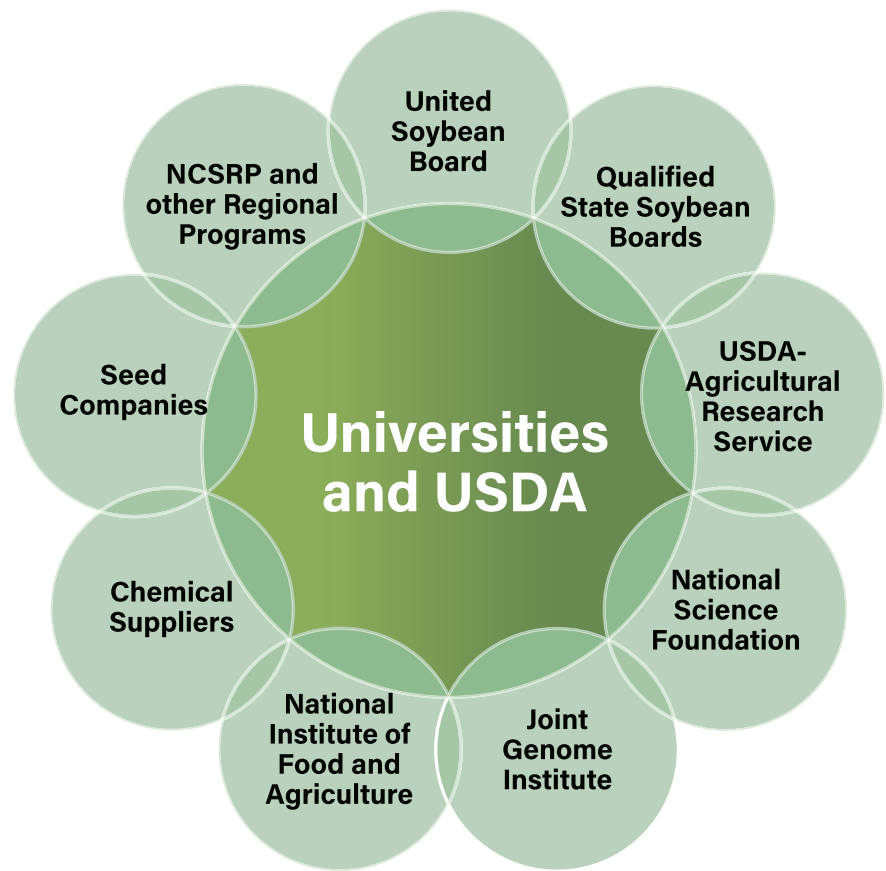
Research funded by the soy checkoff also generates agribusiness investments that lead to robust evaluation and commercialization of SCN management options. Seed and chemical companies have become important research partners. Agribusiness focus on SCN has resulted in more licensed germplasm and breeding to incorporate resistant traits and genes in varieties, as well as tools like nematicides, biological controls, chemicals, and other technologies. Company participation in The SCN Coalition exemplifies the value of leveraged checkoff investments with industry.

UNCOVERING SOLUTIONS: BASIC AND APPLIED RESEARCH

Industry-leading research investments from the soybean checkoff at state, regional and national levels have uncovered valuable insight to manage SCN. These investments have funded countless research projects, and more than 2,400 academic publications.

As researchers began to tackle the problem of SCN infestation, they needed a deep understanding of the pest to test for resistance and to develop management practices, new tools and resources to combat yield losses. This basic research continues to create knowledge to find effective solutions.

For example, with soy checkoff



Funding sources for scientific research and extension activities focused on SCN

support, researchers identified novel genetics and mechanisms of interaction between plant hosts and SCN. This work led to the discovery of both native and biotech genes and traits to provide soybeans with tolerance or resistance.

SCN-resistant soybean varieties have been and remain the [most effective, cost-efficient](#) means of reducing yield losses to SCN. Identification and development of useful resistant varieties began shortly after SCN was first detected in the U.S. The first major discoveries

of native SCN resistance — Peking and PI88788 — remain the best sources available today. In fact, the dip in yield loss to SCN in the late 1990s corresponds to the increasing availability of soybean varieties with resistant PI88788 genetics.

Researchers [continue](#) to uncover new data about complex genetics and mechanisms of action with these two resistance sources. With the increasing knowledge of genetics, molecular technology can enhance natural resistance or create novel mechanisms of SCN tolerance.

“Funding from the soybean checkoff has resulted in the discovery of SCN resistance sources and the incorporation of this resistance into elite breeding material. Most SCN resistance in private and public cultivars can be traced to this checkoff funded research.”

— BRIAN DIERS, CROP SCIENCE PROFESSOR, RETIRED, UNIVERSITY OF ILLINOIS

Applied checkoff-funded research has provided data and information about combining genetic resistance with other management solutions. Since the beginning of the SCN infestation in the U.S., recommended best management practices remain consistent.

- [Test soil in fields](#) to understand SCN pressure
- [Rotate sources of resistance](#) in soybean varieties
- Rotate to non-host crops
- Consider nematode-protectant seed treatments
- Manage weeds, moisture and fertility to reduce plant stress

Scientific studies, often partially funded by the soy checkoff, demonstrate the efficacy of each practice. For example, thanks to the heavy focus on SCN, nematicides and nematode-protectant seed treatments have become more widely available in recent years. They can effectively reduce SCN population density, but their

success depends on many soil and environmental factors.

Economic studies help growers make informed decisions to manage SCN while increasing profits and productivity. Checkoff-funded research provides long-term support to measure changes over time.

SHARING KNOWLEDGE AND SOLUTIONS: COLLABORATION

Regional and national soy checkoff programs support researchers, extension personnel, industry representatives, farmers and others as they share research results and data. Grower field days, meetings, trade show exhibits and published guides educate farmers about SCN biology and management. A variety of small workshops and six national conferences promote a sense of community among researchers and provide opportunities for them to work together and build on the findings of their colleagues.

[The SCN Coalition](#), a public/checkoff/private partnership, exemplifies how the soy checkoff works with public universities and agribusinesses to provide [information and resources](#) directly to soybean farmers

What's your number?

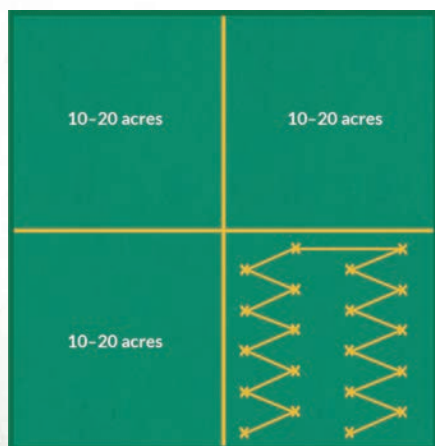
Take the test.  Beat the pest.

The SCN Coalition™

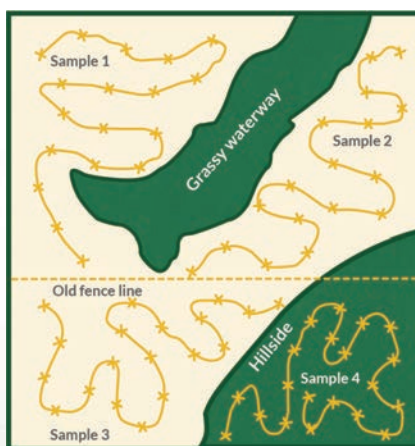
Funded by the soybean checkoff

for active SCN management. NCSRP initiated the first iteration of the coalition in 1998, with a focus on encouraging soil tests for SCN. The partnership was revived in 2018 to address reduced performance of SCN-resistant varieties. The SCN Coalition includes university researchers from 28 states and Ontario, Canada, state, regional and national soy checkoff organizations and corporate agribusiness partners. [The SCN Coalition website](#) provides general management information, state-specific

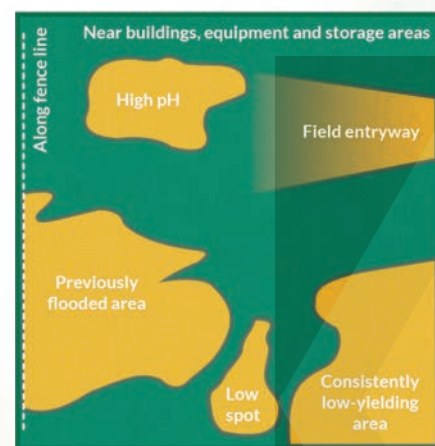
THREE APPROACHES TO COLLECTING SOIL SAMPLES.



1 Collect soil cores using a zigzag pattern.



2 Collect soil cores from logical areas or management zones in the field.



3 Collect soil cores from high-risk areas in the field where SCN might first be discovered.

recommendations and contact information for area pathologists and nematologists.

GAINING IN-FIELD KNOWLEDGE: SOIL TESTING

Continual refinement of SCN surveys within and across states and soil sampling processes helps researchers and growers understand SCN population shifts. Many states have provided free soil sampling and SCN testing to farmers. Most often, state soy checkoffs, extension nematologists and agronomists at land grant universities [work together](#) to provide this service. Both iterations of The SCN Coalition encouraged soil sampling, using the slogan, “Take the test. Beat the pest.”

Farmers need to know what SCN pressure exists in their fields before they decide how to manage it. As SCN population increases, soybean yield decreases.

COORDINATING FUTURE RESEARCH: STRATEGIC PLANNING

Like any major crop stress, successful long-term SCN management depends on sustained investments in basic and applied research. The development of long-range strategic plans and short-term tactics and objectives sets the stage for well-coordinated, collaborative, multidisciplinary research and teaching. Extension programs deliver that research in the form of tangible and meaningful solutions, with a sense of urgency and accountability.

The soy checkoff at the national, regional and state levels worked together to develop the long-range strategic plan for SCN research. The first strategic plan, released in 2018, synergizes research efforts and funding to ensure ongoing progress.

NATIONAL SOYBEAN NEMATODE STRATEGIC PLAN 2018-2022

The United Soybean Board (USB) and the North Central Soybean Research Program (NCSRP) have joined forces on a national research, education and outreach effort on nematodes affecting soybeans. Their ultimate goal is to maximize farmer profitability and sustainability in the face of increasing nematode threats.

The National Soybean Nematode Strategic Plan was developed by a team of scientists from throughout the soybean-producing regions of the US and Canada to guide current and future nematode research, after a USB/NCSRP review identified gaps, needs and opportunities. The objective is to coordinate and support complementary projects and programs to develop short- and long-range solutions for parasitic nematode control. These encompass the spectrum of basic and applied research and Extension aimed at increasing and applying molecular, genetic, biological and agronomic understanding of the host, pest, environment and cropping systems for durable integrated nematode management. The USB and NCSRP have established six goals and anticipated benefits for soybean farmers.



GOAL 1: Develop genomic and genetic tools, resources and data. (Nematode focus)



Goal 2: Discover, leverage and enhance native nematode resistance in soybean. (Soybean focus)



GOAL 3: Engineer resistance using molecular tools to generate or improve nematode resistance in soybean. (Transgenic focus)



GOAL 4: Assess the impacts of new management practices on nematode population dynamics. (Management focus)



GOAL 5: Conduct nematode surveys for improved diagnostics and economic impact. (Information focus)



GOAL 6: Foster Extension education and outreach. (Audience focus)

For further information and progress updates on the USB/NCSRP National Soybean Nematode Strategic Plan, visit www.soybeanresearchinfo.com or www.soybeanresearchdata.com.

SOYBEAN CYST NEMATODE ADAPTS TO MANAGEMENT

As researchers and farmers have learned during the past 70 years, the complexity of SCN makes the pest virtually impossible to eradicate. In fact, likely due in part to better scouting and more testing, the rate of spread appears to be increasing. But, the extent of soybean yield loss to SCN has been decreasing over time as farmers have learned to actively manage for it.

UNDERGROUND LIFE CYCLE

Nematodes live their entire lives underground, on the roots of host plants. They are tiny and very hard to see, even by the trained eye. Because of this, SCN often goes unnoticed until

infestation levels are severe.

NONSPECIFIC DAMAGE

Juveniles damage soybean plants by feeding on roots, inhibiting plant growth and reducing root function. Above the ground, this damage is not distinctive and may not appear until infestations reach extremely high levels. In fact, yield losses of up to 40% can occur without any visible symptoms.²

LONG-LIVED AND PROLIFIC

Adult female SCN become cysts typically carrying about 250 eggs — but as many as 400.² These robust eggs can withstand drought, waterlogging, heat, cold and more, which is why they can

remain dormant in the soil for up to 10 years, until a host plant becomes available. After just four generations, SCN can produce more than 48,000 eggs. And SCN can cycle through five or six generations in a single season. In addition to soybeans, at least 97 other legumes and 63 other plants can support SCN.²

LIMITED GENETIC RESISTANCE IN SOYBEANS

The strong infrastructure for agricultural research meant that researchers collected sources of genetic resistance to SCN long before the pest arrived in North America. Breeders identified that resistance, found in Peking and PI88788, shortly



SCN-resistant soybean varieties

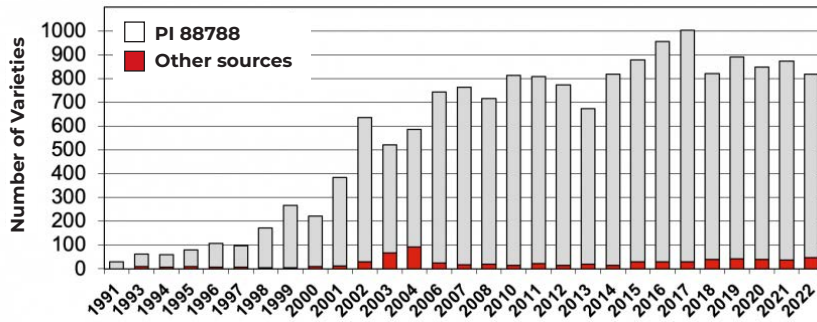


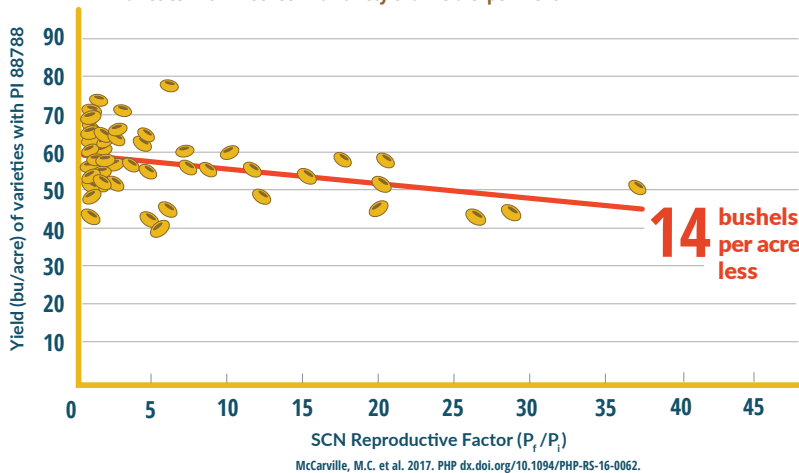
Figure 1. SCN-resistant soybean varieties in maturity groups 0, 1, 2, and 3; since 2006, the Peking source of resistance comprises almost 100% of percent of varieties from other genetic sources. Source: [Iowa State University](http://lowa State University)

AS SCN REPRODUCTION INCREASES, yields decrease by as much as 14 bushels per acre.

Each data point represents the MEAN yield of all resistant varieties with PI 88788 in a variety trial field experiment

$$R^2 = 0.14294$$

$$Y = 59.726 - 0.3798X$$



McCarville, M.C. et al. 2017. PHP dx.doi.org/10.1094/PHP-RS-16-0062.

Research shows [yield loss as SCN populations increase](#) on varieties with the PI 88788 resistance source. This data is from 25 years of variety trial experiments in farmers' fields in Iowa.

after SCN became an issue. However, despite extensive searching, relatively few additional soybean germplasm lines with native resistance to SCN have been identified. Even fewer of those are available as high yielding varieties to growers today.

BECOMING RESISTANT TO THE RESISTANCE

Genetic variability within SCN populations allows the pest to adapt to farm management practices. For example, continuously planting varieties derived from the same SCN resistance genetics shifts field populations by selecting for the most virulent SCN populations that can naturally reproduce on those roots. For more than 20 years, more than 95% of all SCN-resistant soybean varieties included resistance from the PI88788 plant introduction.

Just as weeds overcome herbicide active ingredients when used exclusively and continuously for a long time, SCN is overcoming the PI88788 SCN resistance genetics. When SCN-resistant soybean varieties first became available for use in the field, they allowed less than 10% SCN reproduction, or they provided more than 90% control. Today, research shows that in some fields planted with varieties containing PI88788 genetics, SCN reproduction levels are reaching 75 to 90%, which is just 10 to 25% control.⁷ (See Figure 1.)

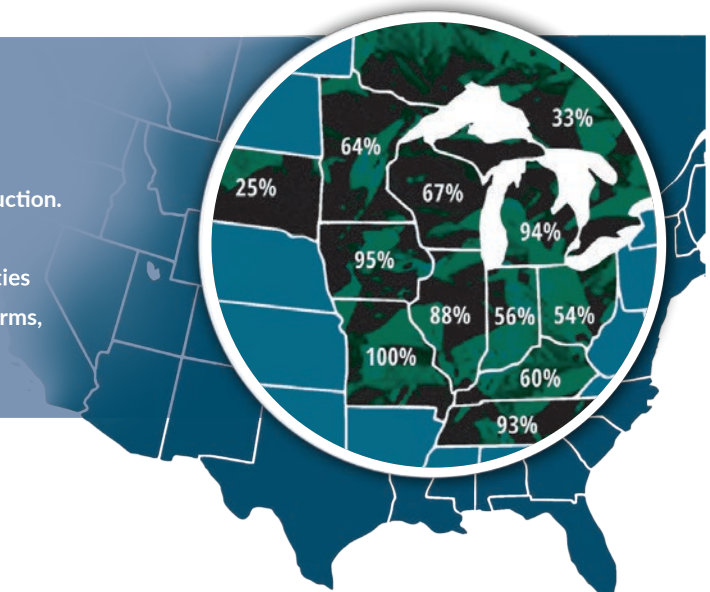
HOW THE SCN PROBLEM EVOLVED.

For more than 20 years, greater than 95 percent of all SCN-resistant soybean varieties have included resistance from the PI 88788 breeding line. The percentage of SCN populations in a state/province with elevated reproduction (>10%) on PI 88788

Nematodes are becoming “resistant to the resistance.”

A resistant variety should allow less than 10 percent reproduction. In other words, a resistant variety should stop 90 percent of the SCN in a field from reproducing. Across the region, varieties with PI 88788 resistance aren't hitting the mark. On some farms, one out of every two nematodes can reproduce.

SCN populations with reproduction higher than 10% on PI88788
Source: The SCN Coalition





ONGOING ADVANCES IN THE SOYBEAN CYST NEMATODE FIGHT

Because of the complexity and adaptability of SCN, more basic and applied research is required to continue reducing yield losses to this pest. Thanks to the long-term commitment of soybean farmers, much of this research is planned or underway.

STRENGTHENING BASIC UNDERSTANDING OF SCN

Researchers have produced several high-quality SCN reference genomes. However, they still need to capture the full complexity and genetic variation of SCN populations. This will be explored by sequencing new genomes, developing techniques to sequence single nematodes, creating gene expression atlases that detail differences in gene expression between SCN populations at different points in their life cycle, or other methods yet to be identified.

Recently, researchers have made several advances in the development of DNA-

based tests to detect SCN in soil samples. Analyses can now distinguish between nematode species and provide a quantitative measure of eggs in the soil.⁸ Further work can develop tests that distinguish between resistant and non-resistant SCN and create a rapid test for use directly in the field.

EXPANDING SCN-RESISTANT GENETICS

Almost all of the 21,000 accessions in the USDA soybean germplasm collection have now been screened for SCN resistance. This has revealed over 200 SCN resistance markers spread over 19 of the 20 soybean chromosomes.⁹ A new major resistance gene, called *rhg2*, was identified in PI90763. Researchers are currently developing methods to incorporate and combine this gene with other known resistances.¹⁰ Overexpression studies are starting to impart resistance in previously susceptible cultivars.

Scientists are beginning to

understand other resistance mechanisms, such as those involving epigenetics, or the impact of the environment or behaviors that can change how genes work.

Others are working on engineering SCN resistance using molecular tools. For example, BASF researchers have incorporated a *Bacillus thuringiensis*, or Bt, toxin called Cry14Ab into soybeans as a transgenic solution. Both greenhouse and field trials demonstrate decreases in SCN and increases in yield.¹¹ Growers can expect soybean varieties with this technology by 2030.

DEVELOPING BETTER BEST MANAGEMENT PRACTICES

Current and planned SCN management studies focus on the effect of cover crops on SCN, biological control with soil fungi or microbes and incorporation of digital agriculture solutions. Researchers expect a new generation of nematicides and seed coatings to be more

robust. Success in these areas will provide new options to effectively manage SCN.

INCREASING ACTIVE MANAGEMENT

Continued investment in SCN surveys across states, combined with field history data, provides information critical to long-term management. Many state extension researchers and nematologists are developing new or improved state SCN management and education plans.

Surveys conducted by The SCN Coalition show that more growers are actively

managing SCN, resulting in estimated economic gains of more than \$100 million.¹² Ongoing coordinated communication disseminates updated active management recommendations to keep SCN top-of-mind for growers.

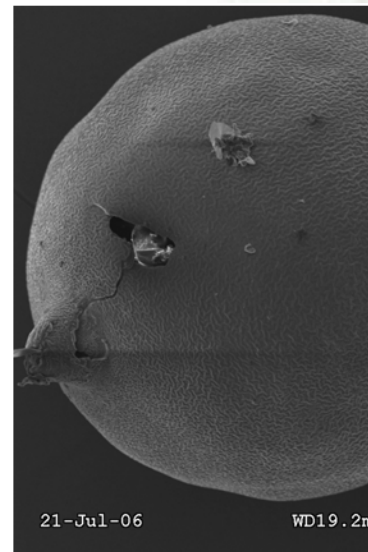
Additional surveys assessing the presence of other parasitic nematodes in soybeans indicate a trend that they are spreading throughout the U.S. This indicates that future research and surveys should focus on other nematodes species that feed on and damage soybeans.

“On our really tough nematode fields, we’ve gone to planting more corn-on-corn, instead of raising soybeans every other year. We’ll extend our rotation to every third or fourth year before we bring soybeans back to that field to break the cycle of nematode production.”

– GENE STOEL, FARMER,
LAKE WILSON, MINNESOTA

“The SCN genome is enabling population and comparative genomics studies paving the way to develop novel resistance strategies and rapid molecular diagnostic technologies to advance SCN management for the future.”

– MELISSA MITCHUM, PROFESSOR OF PLANT NEMATOLOGY, UNIVERSITY OF GEORGIA



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Check out key checkoff-funded studies:

SCN research funded by the soy checkoff ranges from understanding the life cycle to detailing how the genetics of soybean resistance work, and from using soil surveys to understand where SCN lives to practical management guidelines to reduce yield losses. Check out examples of research highlights shared at www.SoybeanResearchInfo.com

Basic Research

- [Fighting the 'Invasion of the Body Snatchers' in Soybeans](#)
- [Finding New Soybean Breeding Prospects to Manage SCN Resistance](#)
- [Making Advancements for Soybean Cyst Nematode through Plant Breeding](#)
- [NCSRP Research Team Unravels Genome of the Soybean Cyst Nematode, Revealing Genes Involved in Parasitism](#)
- [Nematologists Eager to Study a New Soybean Variety with SCN Resistance](#)

Applied Research

- [An Integrated Approach to Enhance Durability of SCN Resistance for Long-Term Strategic SCN Management](#)
- [Cover Crops May Help to Reduce SCN Populations](#)
- [Exploring Sudden Death Syndrome Pathogens and SCN Connections](#)
- [Evaluating Resistant Varieties and Seed Treatments in SCN Infested Fields](#)
- [Farmers Can Improve the Effectiveness and Yield of SCN Soybean Varieties](#)
- [Finding Biopesticides and Seed Treatments for SCN and SDS Control](#)
- [Improving Profitability, Reducing SCN with a Double-Crop System](#)
- [Know Your SCN Risks Before Planting Soybeans Back-to-Back](#)
- [Proactive SCN Monitoring and Management](#)

Impactful Academic Soybean Cyst Nematode Research Articles

Farmers have been supporting peer-reviewed scientific research on soybean cyst nematode, or SCN, for decades through the soy checkoff at state, regional and national levels. That research has generated more than 2,400 articles.

This lists samples some key articles that have advanced the understanding of SCN and management solutions. New research almost always builds on and extends prior work. Listed from most recent to oldest, these published articles demonstrate how the soy checkoff has allowed SCN researchers to build on previous work.

The number of citations included with many academic articles refers to subsequent research journal articles that reference the work listed. It is often used as a measure of the importance of an article, or how much

others valued the work. Older articles typically have more citations than more recent ones.

[2022 Evaluation of Iowa Soybean Varieties Resistant to Soybean Cyst Nematode](#)

Tylka, G., et al., Iowa State University, 2022

- On-farm variety trials measure SCN resistance levels of cultivars available to growers
- These types of studies have been done in many states, though Iowa may be the leader in terms of the longevity of this work, going back to the 1990s
- Funded by the Iowa Soybean Association

[Summary of Soybean Cyst Nematode Survey: 2013-2021](#)

Markell, Sam, North Dakota State University, May 19, 2022

- Statewide nematode surveys in North Dakota over nine years assessed approximately 4,700 samples
- Growers can access data on the presence of SCN, as well as the number of eggs per 100 cubic centimeters of soil
- Funded by the North Dakota Soybean Council

[W112Rhg1 Interacts with DELLAs and Mediates Soybean Cyst Nematode Resistance through Hormone Pathways](#)

Dong, Jia, and Matthew E. Hudson, Plant Biotechnology Journal 20.2 (2022): 283-296

- One of many studies that investigate the molecular mechanisms of Rhg1 proteins found in PI88788
- Funded by the United Soybean Board
- 9 citations

[A Chromosomal Assembly of the Soybean Cyst Nematode Genome](#)

Masonbrink, Rick E., et al., Molecular Ecology Resources 21.7 (2021): 2407-2422

- A high-quality, publicly available SCN genome with data analysis tools
- Funded by the North Central Soybean Research Program
- 7 citations

[Growth Chamber and Greenhouse Screening of Promising in vitro Fungal Biological Control Candidates for the Soybean Cyst Nematode \(Heterodera glycines\)](#)

Haarith, Deepak, et al., Biological Control 160 (2021): 104635

- Explores biological control agents and their effect on nematodes
- Funded by the Minnesota Soybean Research and Production Council
- 9 citations

[Resistance Gene Pyramiding and Rotation to Combat Widespread Soybean Cyst Nematode Virulence](#)

Meinhardt, Clinton, et al., Plant Disease 105.10 (2021): 3238-3243

- Evaluation of rotating soybean with novel combinations of known resistance genes to

- develop new management strategies for SCN
- Funded in part by the North Central Soybean Research Program and the Missouri Soybean Merchandising Council
- 6 citations

[A Pathogenesis-Related Protein GmPRO8-Bet VI Promotes a Molecular Interaction between the GmSHMT08 and GmSNAP18 in Resistance to *Heterodera glycines*](#)

Lakhssassi, Naoufal, et al., Plant Biotechnology Journal 18.8 (2020): 1810-1829

- Study to investigate the molecular interaction of the proteins expressed in Peking type resistance after infection with SCN
- Funded in part by the United Soybean Board and the Tennessee Soybean Promotion Board
- 29 citations

[Managing Soybean Cyst Nematode by Utilizing Cover Crops and Resistant Sources from Early Maturing Soybean Accessions](#)

Acharya, Krishna, North Dakota State University, 2020

- A study on cover crops that are not potential hosts for SCN
- Funded by the North Dakota Soybean Council

[t-SNAREs Bind the Rhg1 \$\square\$ -SNAP and Mediate Soybean Cyst Nematode Resistance](#)

Dong, Jia, Raymond E. Zielinski, and Matthew E. Hudson, The Plant Journal 104.2 (2020): 318-331

- One of many studies that investigate the molecular mechanisms of Rhg1 proteins found in PI88788
- Funded by the United Soybean Board
- 18 citations

[Variety Rotation as a Strategy for Managing Soybean Cyst Nematode](#)

Chen S., University of Minnesota Extension, 2020

- This 12-year rotation study and others of this type provide insight into the long-term effect on SCN populations when different resistant varieties are grown in rotation with non-host crops
- Funded by the Minnesota Soybean Research and Promotion Council

[Genome-Wide Association Analysis Pinpoints Additional Major Genomic Regions Conferring Resistance to Soybean Cyst Nematode \(*Heterodera glycines* Ichinohe\)](#)

Tran, Dung T., et al., Frontiers in Plant Science 10 (2019): 401

- Use of modern molecular tools and statistical models to find soybeans with new sources of resistance
- This study identified 58 lines that were resistant to SCN but did not carry PI88788 or Peking resistance
- Funded in part by the United Soybean Board
- 29 citations

[Host-Derived Gene Silencing of Parasite Fitness Genes Improves Resistance to Soybean Cyst Nematodes in Stable Transgenic Soybean](#)

Tian, Bin, et al., Theoretical and Applied Genetics 132.9 (2019): 2651-2662

- Attempts to increase SCN resistance by employing RNA interference and overexpressing key plant genes, which is the beginning of developing new types of resistance
- Funding by the Kansas Soybean Commission and the North Central Soybean Research Program
- 14 citations

[The Genome of the Soybean Cyst Nematode \(*Heterodera glycines*\) Reveals Complex Patterns of Duplications Involved in the Evolution of Parasitism Genes](#)

Masonbrink, Rick, et al., BMC Genomics 20.1 (2019): 1-14

- Just like having a good soybean genome, a good SCN genome sequence helps to accelerate research
- Funded in part by the North Central Soybean Research Program
- Federal support from the Joint Genomics Institute and others
- 63 citations

[Increase in Soybean Cyst Nematode Virulence and Reproduction on Resistant Soybean Varieties in Iowa from 2001 to 2015 and the Effects on Soybean Yields](#)

McCarville, Michael T., et al., Plant Health Progress 18.3 (2017): 146-155

- Retrospective analysis of 15 years of data spanning more than 25,000 experimental SCN testing plots
- Assesses yield potential loss as PI88788 resistance increased over the time span
- Funded in part by the Iowa Soybean Association
- 69 citations

[Advancements in Breeding, Genetics, and Genomics for Resistance to Three Nematode Species in Soybean](#)

Kim, Ki-Seung, et al., Theoretical and Applied Genetics 129.12 (2016): 2295-2311

- Breeding for resistance to multiple species of nematodes
- Combining resistant traits is particularly important for growers in the South
- Funded by the United Soybean Board and the Missouri Soybean Merchandising Council
- 43 citations

[Soybean Resistance to the Soybean Cyst Nematode *Heterodera glycines*: An Update](#)

Mitchum, Melissa G., Phytopathology 106.12 (2016): 1444-1450

- This review article discusses several aspects of creating novel resistance, including a section on strategies to combine native resistances, such as Peking and PI88788 in a single soybean line.
- Funded in part by the Missouri Soybean Merchandising Council, the United Soybean Board and the North Central Soybean Research Program
- 116 citations

[Targeted Genome Modifications in Soybean with CRISPR/Cas9](#)

Jacobs, Thomas B., et al., BMC Biotechnology 15.1 (2015): 1-10

- This foundational work demonstrated the ability to use CRISPR/Cas9 gene editing for the first time in soybean, conducted to support SCN research
- Funded by the United Soybean Board
- 543 citations

[Engineered Resistance and Hyper Susceptibility through Functional Metabolic Studies of 100 Genes in Soybean to its Major Pathogen, the Soybean Cyst Nematode](#)

Matthews, Benjamin F., et al., *Planta* 237.5 (2013): 1337-1357

- Soybean genes were overexpressed in soybean roots to assess their impact on SCN infection, and to test them as potential targets for resistance improvement
- Funded in part by the United Soybean Board
- 85 citations

[A Soybean Cyst Nematode Resistance Gene Points to a New Mechanism of Plant Resistance to Pathogens](#)

Liu, Shiming, et al., *Nature* 492.7428 (2012): 256-260

- Cloning of the essential gene for the Peking resistance revealed a novel resistance mechanism not previously seen in plants
- Funded in part by the United Soybean Board, Missouri Soybean Merchandising Council, Illinois Soybean Association, North Central Soybean Research Program and Iowa Soybean Association
- 385 citations

[Copy Number Variation of Multiple Genes at Rhg1 Mediates Nematode Resistance in Soybean](#)

Cook, David E., et al., *Science* 338.6111 (2012): 1206-1209

- Proof that resistance in PI88788 is due to four genes that are repeated up to 10 times. This was a significant finding, not only for the SCN research community, but it revealed a new type of plant pest resistance never before discovered.
- Funded in part by the United Soybean Board and the Illinois Soybean Association
- 575 citations

[Novel Quantitative Trait Loci for Broad-Based Resistance to Soybean Cyst Nematode \(*Heterodera glycines* Ichinohe\) in Soybean PI 567516C](#)

Vuong, Tri D., et al., *Theoretical and Applied Genetics* 121.7 (2010): 1253-1266

- Mapping resistance in PI567516C, a soybean introduction with resistance to multiple Hg-types of SCN
- Funded in part by the United Soybean Board and the Missouri Soybean Merchandising Council
- 121 citations

[A Standard Greenhouse Method for Assessing Soybean Cyst Nematode Resistance in Soybean: SCE08 \(Standardized Cyst Evaluation 2008\)](#)

Niblack, T. L., et al., *Plant Health Progress* 10.1 (2009): 33

- Uniform soil testing methods were developed so comparisons can be made across fields and across soybean varieties, and resistance ratings for soybean cultivars are standardized
- Meeting support to develop protocol was provided by the United Soybean Board
- Additional support from the North Central Soybean Research Program, Illinois Soybean Program

Operating Board, Missouri Soybean Merchandising Council and industry

- 62 citations

[Effects of Crop Rotation of Soybean with Corn on Severity of Sudden Death Syndrome and Population Densities of *Heterodera glycines* in Naturally Infested Soil](#)

Xing, Lijuan, and Andreas Westphal, *Field Crops Research* 112.1 (2009): 107-117

- Funded by the Indiana Soybean Board, the North Central Soybean Research Program and the United Soybean Board

[Laser Capture Microdissection \(LCM\) and Comparative Microarray Expression Analysis of Syncytial Cells Isolated from Incompatible and Compatible Soybean \(*Glycine max*\) Roots Infected by the Soybean Cyst Nematode \(*Heterodera glycines*\)](#)

Klink, Vincent P., et al., *Planta* 226.6 (2007): 1389-1409

- Genes expressed by resistant and susceptible soybean roots when they are infected by SCN
- Identifying differences between resistant and susceptible soybeans can help to identify targets for intervention
- Funded in part by the United Soybean Board
- 200 citations

[Soybean Cyst Nematode Management Reconsidered](#)

Niblack, T. L., *Plant Disease* 89.10 (2005): 1020-1026

- SCN best management practices based on scientific research, with a focus on using resistant varieties in a responsible manner
- Funded in part by the Iowa Soybean Association, Illinois Soybean Program Operating Board, Missouri Soybean Merchandising Council, the North Central Soybean Research Program and the United Soybean Board
- 194 citations

[A Chorismate Mutase from the Soybean Cyst Nematode *Heterodera glycines* Shows Polymorphisms that Correlate with Virulence](#)

Bekal, Sadia, Terry L. Niblack, and Kris N. Lambert, *Molecular Plant-Microbe Interactions* 16.5 (2003): 439-446

- Funded in part by the Illinois Soybean Program Operating Board
- 166 citations

[A Revised Classification Scheme for Genetically Diverse Populations of *Heterodera glycines*](#)

Niblack, T. L., et al., *Journal of Nematology* 34.4 (2002): 279

- Focus on generating a classification system to describe different SCN populations and their ability to overcome native soybean resistance
- Funded in part by the United Soybean Board
- 432 citations

[Identification of Putative Parasitism Genes Expressed in the Esophageal Gland Cells of the Soybean Cyst Nematode *Heterodera glycines*](#)

Gao, Bingli, et al., *Molecular Plant-Microbe Interactions* 14.10 (2001): 1247-1254

- Funded in part by the United Soybean Board and Iowa Soybean Promotion Board
- 159 citations

[A DNA Hybridization Probe for Detection of Soybean Cyst Nematode](#)

Besal, E. A., et al., *Phytopathology* 78.9 (1988): 1136-1139

- An early study developing a molecular method to detect SCN in the soil
- Funded in part by the American Soybean Association
- 17 citations

List updated March 2023.

[Loci Underlying Resistance to Race 3 of Soybean Cyst Nematode in Glycine Soja Plant Introduction 468916](#)

Wang, D., et al., *Theoretical and Applied Genetics* 103.4 (2001): 561-566

- Discovery of SCN resistance in Glycine soja, a wild relative of domesticated soybean
- Funded in part by the United Soybean Board and Illinois Soybean Program Operating Board
- 121 citations

[Weed Hosts of Soybean Cyst Nematode \(*Heterodera glycines*\) in Ohio](#)

Venkatesh, Ramarao, S. Kent Harrison, and Richard M. Riedel, *Weed Technology* 14.1 (2000): 156-160

- A study on weeds that are potential hosts for SCN
- Funded by the Ohio Soybean Council
- 100 citations

[Effect of Soybean Cyst Nematode \(*Heterodera glycines*\) on Yield of Resistant and Susceptible Soybean Cultivars Grown in Ohio](#)

Wheeler, T. A., et al., *Journal of Nematology* 29.4S (1997): 703

- Yield benefits of using resistant cultivars in different soil types in Ohio, at a time when few producers were using SCN resistant soybean
- Funded in part by the Ohio Soybean Council
- 25 citations

[Genetic Analysis of Parasitism in the Soybean Cyst Nematode *Heterodera glycines*](#)

Dong, Ke, and Charles H. Opperman, *Genetics* 146.4 (1997): 1311-1318

- Provided identification of nematode genes required to establish parasitic association with soybean, and evaluation of their utility for resistance targets
- Funded in part by North Carolina Soybean Producers Association
- 62 citations

[Genome Mapping of Soybean Cyst Nematode Resistance Genes in 'Peking', PI 90763, and PI 88788 using DNA Markers](#)

Concibido, Vergel C., et al., *Crop Science* 37.1 (1997): 258-264

- Developing DNA markers that enable breeders to more rapidly incorporate SCN resistance into new breeding lines
- Funded in part by Minnesota Soybean Research and Promotion Council
- 243 citations

[Sudden Death Syndrome of Soybean: *Fusarium solani* as Incitant and Relation of *Heterodera glycines* to Disease Severity](#)

Lawrence, G. W., et al., *Phytopathology* 79 (1989): 191-197

- SCN is often associated with the presence and increased severity of sudden death syndrome
- Assesses the relationship between the two diseases
- Funded in part by Mississippi Soybean Promotion Board
- 183 citations

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¹ [Soybean Disease Loss Calculator](#): Soybean Cyst Nematode, Crop Protection Network, 2023

² Cyst Nematodes, edited by Roland N. Perry, Ph.D., Maurice Moens and John T. Jones, CABI, May 15, 2018

³ [Worldwide Distribution of Soybean-Cyst Nematode](#) and Its Economic Importance, R. D. Diggs, National Center for Biotechnology Information, 1977

⁴ [New Nematode in Carolina](#), Soybean Digest, June 1955

⁵ United Soybean Board, National Soybean Checkoff Research Database, The SCN Coalition

⁶ The genome of the soybean cyst nematode (*Heterodera glycines*) reveals complex patterns of duplications involved in the evolution of parasitism genes, BMC Genomics, February 2019

⁷ [High Reproduction of SCN Populations on PI 88788](#). Resistance is Frightening, Iowa State University, October 28, 2022

⁸ Developing a real-time PCR assay for direct identification and quantification of soybean cyst nematode, *Heterodera glycines*, in soil and its discrimination from sugar beet cyst nematode, *Heterodera schachtii*, Baidoo, Richard, and Guiping Yan, Plant Disease 105.12 (2021): 3848-3857

⁹ Progress in controlling soybean cyst nematode through genetic resistance, Diers, Brian, 2022 National Soybean Nematode Conference and SoyBase, accessed December 2022

¹⁰ Epistatic interaction between Rhg1-a and Rhg2 in PI 90763 confers resistance to virulent soybean cyst nematode populations, Basnet, Pawan, et al., Theoretical and Applied Genetics (2022): 1-15

¹¹ A *Bacillus thuringiensis* Cry protein controls soybean cyst nematode in transgenic soybean plants, Kahn, Theodore W., et al., Nature communications 12.1 (2021): 1-12

¹² New Study: Up to 18% more soybean growers are now actively managing SCN resistance, The SCN Coalition, June 2021 and NDSU-led Coalition Advances Fight Against Soybean Cyst Nematode, North Dakota State University, August 2022

¹³ Published in: Gregory L. Tylka; Christopher C. Maret; Plant Health Progress. Copyright The authors retain the copyright for the map (Figure 1) and the animated series of maps (supplementary material). All other content is in the public domain and not copyrightable. It may be freely reprinted with customary crediting of the source. The American Phytopathological Society, 2021. • DOI: 10.1094/PHP-10-20-0094-BR

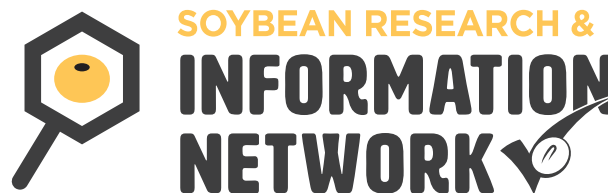
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