Project/Activity Number: NC1197
Project/Activity Title: Practical Management of Nematodes on Corn, Soybeans and Other Crops of Regional Importance
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Brief summary of minutes of annual meeting: Uploaded separately

Accomplishments: Plant-parasitic nematodes (PPNs) continue to be a major constraint to crop production in the north-central region and beyond. The NC1197 multistate group is assessing strategies for the control of PPNs. Special attention is given to plant-parasitic nematodes of corn and soybean.

Objective 1. Develop, evaluate, improve, and integrate management techniques for plant-parasitic nematodes in the north-central region to increase grower profitability.

A. Evaluate interactions of plant-parasitic nematodes with germplasm of economically important plants.

B. Assess intraspecific variability in nematode virulence and pathogenicity.

C. Evaluate new commercial products and innovative strategies for the control of SCN, root-lesion and other plant-parasitic nematodes.

D. Develop innovative methods to detect and quantify plant-parasitic nematodes

In Iowa, Kansas, and North Dakota, soybean lines were evaluated versus SCN populations for their reactions. In Iowa, SCN-resistant varieties were evaluated in experiments with 191 different SCN-resistant soybean varieties (70 resistant and 2 susceptible) at each of 9 locations; 29 varieties had the Peking source of resistance, all others were PI 88788. In the Kansas Soybean Performance Tests (KSVPT), soybean resistance to SCN was evaluated in replicated screening trials for 67 entries. Evaluations involved SCN populations that varied in their virulence to the common resistance source PI 88788. Only ~40% of KSVPT entries could be classified as resistant to moderately resistant to the HG Type 7 population, while only 9% (six entries) could be classified as resistant to moderately resistant to the HG Type 2 populations. Female indices for the HG Type 7 population were reasonably predictive of FI for the HG Type 2 populations,i confirming that most KSVPT entries shared a common source of resistance (PI 88788). In addition, soybean resistance to SCN was evaluated in replicated screening trials for 245 breeding lines in 2021. Approximately 40% of 2021 lines were rated as resistant or moderately resistant to the HG Type 7 SCN screening population, while 7%-9% were rated as resistant or moderately resistant to the HG Type 2 SCN screening populations. In North Dakota, 149 early maturity soybean accessions were tested for resistance to SCN HG type 2.5.7, one of the common virulent SCN populations in North Dakota. SCN white females were extracted from individual plants of each accession after 35 days of growth in greenhouse conditions. The females were counted to determine a female index [FI = (average number of females on a tested accession/average number of females in Barnes, a susceptible soybean check) x 100]. The resistance response of each soybean accession was categorized as resistant, moderately resistant, moderately susceptible, and susceptible. Out of the soybean 149 accessions tested, only 13 were resistant in both runs of the experiments. The majority of screened soybean accessions were susceptible or moderately susceptible to the SCN HG type 2.5.7. The resistant soybean accessions identified in this study have the potential to be used in breeding SCN-resistant cultivars. In addition, 47 soybean seed samples (commercial cultivars) were obtained from growers and tested against HG type 0, and 44 seed samples were assessed against HG type 2.5.7. Out of the 47 soybean seed samples tested for SCN HG type 0, 13% of them showed resistant reaction, 19% were moderately resistant, 45% were moderately susceptible, and 23% of them were susceptible. Out of the 44 soybean seed samples for SCN HG type 2.5.7, 9% of them showed resistant reaction, 11% of them showed moderately resistant, 30% had moderately susceptible reaction, and 50% had susceptible reaction. Microplot tests in Iowa were also conducted to study the effects of 5 novel resistant soybean genotypes grown continuously and in rotation in two field experiments.

State nematode surveys were also conducted during the last year. The results of a statewide survey of soybean fields in Kansas during 2020-2021 indicated that SCN prevalence had increased from 15% to 35% during the past decade. Increases were observed across multiple crop reporting districts, with the largest increase occurring in South Central Kansas. In addition, a survey of alfalfa nematode was also conducted. Soil and roots were collected from 71 alfalfa production fields across 28 counties in Kansas during 2021. *Heterodera medicaginis* was recovered from a single field in southwestern Kansas near the site of the original find. *Meloidogyne hapla* was recovered from three fields in the same area. All four of these fields were in the Arkansas River flood plain. Additionally, root-lesion nematodes, predominantly *Pratylenchus neglectus*, were recovered from 57% of fields.

In Indiana, SCN HG type tests were conducted on select populations collected from soybean fields in Indiana. Here a revised HG type test was devised by including one additional soybean line (PI 567516C), in the consideration that this PI line has a different SCN resistance and has been used by a couple of soybean breeding pipelines. The PI 567516C line is assigned as #8 of soybean indicator line. The Zhang lab conducted the re-designed SCN virulence type test on 23 SCN populations until this report was written. The results showed that all the 23 SCN populations tested are able to overcome the PI 88788-type resistance in soybean, indicating that virulent SCN populations are commonly present on soybean fields in Indiana. According to the results, the HG type 2.5.7 is the major virulence type found, accounting for 56.5% of population tested, and HG type 1.2.5.7 is 13%. Two populations are found to be HG 2.3.5.7 and three populations are shown to be HG 2.5. Most interestingly, we have found two SCN populations which are virulent on the PI 567516C, with HG type 2.5.7.8. We plan to test between 45 and 50 SCN populations in total.

A soybean cyst nematode (SCN) survey is ongoing in Kentucky that was initiated in the Fall of 2018. Currently, a total of ~300 soil samples have been tested for SCN. SCN is present in 84% of the fields tested. Figure 1 shows the break-out of SCN densities (eggs/100 cc soil). This project was funded through the Kentucky Soybean Promotion Board and the United Soybean Board.

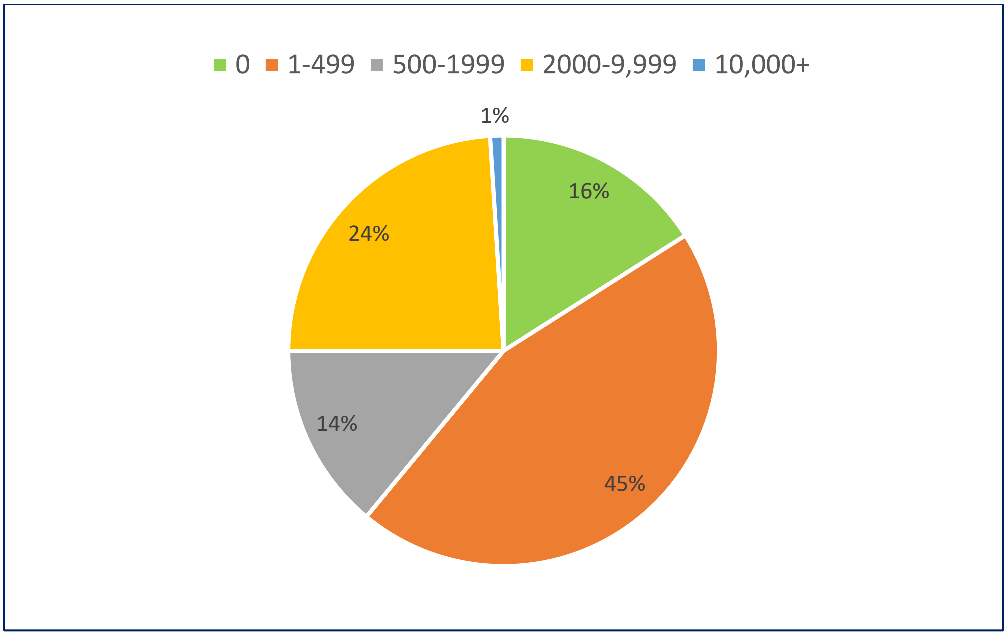

Figure 1. Percentage of Kentucky fields with different SCN egg population categories (eggs/100 cc soil).

A separate field survey was conducted to test for other plant-parasitic nematodes in soybean. This survey was initiated in the Fall of 2020 and continued in the Fall of 2021. Results from the 2020 survey revealed that 7% of the fields were infested with dagger nematodes (range of 0-8 per 100 cc soil), 27% were infested with lance nematodes (0-85 per 100 cc soil), 33% were infested with lesion nematodes (0-69 per 100 cc soil), 98% were infested with spiral nematodes (0-731 per 100 cc soil), and 2% were infested with stunt nematodes (0-15 per 100 cc soil). No samples revealed the presence of reniform, root-knot, sheath, or stubby root nematodes. Many samples collected from the 2021 survey were lost when a F-4 tornado destroyed the UK-Research & Education Center in Princeton on December 10, 2021. Samples that were salvaged are currently in cold storage and have not been submitted for nematode extraction and counting. This survey was funded by the United Soybean Board.

The Wisconsin Soybean Marketing Board continued the free nematode testing program for Wisconsin growers. In 2021, 547 soil samples were submitted with the majority arriving after September 1st. The two most important nematode pests of soybean in Wisconsin, SCN and Root Lesion (RL), were not detected in 14% of the samples. SCN, but not RL, were detected in 7% of the samples. RL, but not SCN, were detected in 60% of the samples. Both SCN and RL were detected in 19% of the samples. For samples infested with both SCN and RL, population densities of RL were inversely related to population densities of SCN (nonlinear). The maximum number of RL in 100 cm3 soil was 1598 in the absence of SCN and 1508 in the presence of SCN. The maximum number of SCN eggs in 100 cm^3 soil was 24,572 in the absence of SCN and 47,705 in the presence of SCN. All samples were processed by a commercial laboratory so we have no information on the putative species represented in the data. All cysts were assumed to be SCN, but this is probably not the case as *H. trifolii* and *Cactodera* spp. are fairly common in Wisconsin.

Other projects on plant-parasitic nematodes in corn include surveying Kentucky counties for presence and distribution of plant-parasitic nematodes and examining in-season methods for managing corn nematodes. Planned projects for 2022, included expanding survey work into counties not previously sampled and conducting field trials to examine efficacy of seed treatment and in-furrow products on plant-parasitic corn nematode management. Survey work and field trials are on hold after an F4 tornado destroyed the facilities at the University of Kentucky Research and Education Center in Princeton, KY. The loss of cold storage for sample storage, and the loss of equipment needed to conduct field trials will limit progress in 2022. Trials and sampling will resume in 2023.

In Michigan, work under this objective is focused on understanding parasitic variability (PV) and adaptation of soybean cyst (SCN) and northern root-knot nematode (NKRN) in Michigan cropping systems. A major emphasis on NRKN has been to understand the relationship between PV and the soil conditions where it exists. Last year, we reported that NRKN was distributed in mineral and muck soils with disturbed and degraded soil health conditions. A follow up study has shown that NRKN populations from degraded mineral soils have significantly higher PV than populations from disturbed mineral and disturbed and degraded muck soils (Lartey *et al*. under revision). The results support a hypothesis that the conditions where PV exists are likely to be variable within or across soil groups. On-going are analyses to establish the relationship between PV and soil biophysicochemical conditions.

Others in Iowa, Kentucky, Nebraska, and South Dakota are testing the efficacy of commercially available nematicides. In South Dakota, seven nematicide seed treatments were evaluated for their efficacy in reducing SCN infection and prevent yield loss in 2021 on a susceptible cultivar at one location in South Dakota. Non-treated seed (naked) was the check. The experiments were laid out in a complete randomized complete block design with four replications. Plots were 15 feet long and four rows wide spaced 30 inches apart. Beginning SCN population densities in test plots were determined by collecting soil samples at planting while end of season SCN population density was determined from soil samples collected after soybean harvest. No significant differences in yield were observed between nematicide seed treatments and the non-treated. However, there were numerical yield differences that could be impactful on a larger scale with Aveo+base and untreated check producing the lowest yield. The soybean nematicides Ilevo and Saltro versus their bases were also tested in field experiments in 9 locations in Iowa.

In 2021, as part of a multi-state trial, nematode-protectant seed treatments were evaluated in soybean field trials infested with soybean cyst nematode at two locations in Kentucky. No significant differences were observed between of the nematode-protectant seed treatments and a “base” treatment that included only fungicides and an insecticide (no nematicide). This trial was funded by BASF Corp. and the Kentucky Soybean Promotion Board. Data from this project were provided to Dr. Kaitlyn Bissonnette for draft of a manuscript summarizing the multi-state results of this project. In Nebraska, the effects of Averland and Counter were compared to a standard base treatment on nematodes in a commercial corn field. Inconsistent treatment effects were observed on nematode reproduction factors between the planting and V6 sample dates. In addition, there were inconsistent treatment effects on yield that may have been impacted by an earlier hail event in 2022. Additional pre-labeled seed treatments were tested for their effects on SCN in field and greenhouse trials.

New commercial products were also evaluated in Missouri, as well as innovative strategies for the control of SCN, root-lesion and other plant-parasitic nematodes. Greenhouse testing of nematode-protectant seed treatment products evaluated in Obj 2b were conducted for multiple SCN HG types (HG 0, 2.5.7, and 1.2.5.7). These HG types were selected to represent the most prevalent SCN field populations where soybeans are grown. Results of these evaluations shared some consistency with field evaluations when SCN females were extracted after 30 days, but not among all treatments. Trial results are in manuscript preparation. Researchers at the University of Missouri also led a multi-state study evaluating the impacts of nematode protectant seed treatments on SCN and SDS from 2019-2021. The third and final year of data were collected and analyzed evaluating nematode-protectant seed treatments since the last report culminating in 51 site-years of data. No one seed treatment was found to be the silver bullet in this multi-state trial. Data from this trial are being prepared for publication in Plant Disease. Additionally, sites in Missouri are being evaluated for microbial interactions and relationships with these seed treatments and soils.

Trials conducted in California seek to identify nematode pathogenic effectors with computation prediction based on N-terminal signal domain and lack of transmembrane domain. Additional criteria are also in use for identifying effectors in nematodes, such as RXLR motifs in oomycetes and are needed because of the lack of tools for use managing some nematodes. Host proteomics are also in use to identify effectors including 99 putative secretory proteins that possess signal peptides but lack TM. Twenty-six effectors have unknown functions, with no domain except signal peptides and are conserved across all cyst nematodes, but absent in other nematodes. Structural analyses are also underway. Other work is underway on the functional genomic tools using techniques that are widely used to understand the gene and protein function. Examples include RNA interference (RNAi), soaking of PPNs in dsRNA, CRISPR (limited to few model organisms). Some of challenges include the lack of effective toolbox options for determining the function of genes and the gene products in PPNs. The aim of the project was to develop genome editing tools for PPNs with in-depth mechanistic studies of biological pathways to dissect associated phenotypes, visualize gene expression patterns, and protein localization using fluorescent markers.

In North Dakota, corky ringspot disease (CRS) on potato is caused by *Tobacco rattle virus* vectored by stubby-root nematodes. In May 2021, a field where CRS and stubby-root nematode were present was used to test the efficacy of eight experimental chemical treatments from Bayer CropScience on Yukon Gold potatoes. Overall, treatments with Vydate showed consistently significant reductions in disease incidence and severity, which is similar to the results observed in previous years.

SCN continues to be a major threat to soybean production. Morphological discrimination between SCN and other nematodes of the *H. schachtii sensu stricto* group is not only difficult and time-consuming, but also requires high expertise in nematode taxonomy. Molecular assays were developed to differentiate SCN from sugar beet cyst nematode (SBCN) and other nematodes; and to quantify SCN directly from DNA extracts of field soils. SCN and SBCN-specific quantitative real-time PCR (qPCR) primers were designed from a nematode-secreted CLAVATA gene and used for these assays. The primers were evaluated based on specificity, efficiency, and target specificity to SCN or SBCN using DNA from 20 isolates of SCN and 32 isolates of other plant-parasitic nematodes. A standard curve relating threshold cycle and log values of nematode numbers was generated from artificially infested soils and was used to quantify SCN in naturally infested field soils. There was a high correlation between the SCN numbers estimated from naturally infested field soils by conventional methods, and the numbers quantified using the SYBR Green I-based qPCR assay. Species-specific conventional PCR assays were also developed each for SCN and SBCN, alongside a qPCR assay that simultaneously discriminates SCN from SBCN.

Work conducted in North Dakota focused on the root-lesion nematode, *Pratylenchus scribneri* a migratory endo-parasitic nematode which impacts potato production. Typically, the nematode population estimates are made from infested soil, however, considering the endo-migratory lifestyle of this nematode, it also is crucial to determine the nematode population residing inside the host roots. a SYBR green-based quantitative real-time PCR (qPCR) assay was developed for detection and quantification of *P. scribneri* in potato roots. The assay used a previously reported primer pair (ITS-2F/ITS-2R) and it proved to be specific and sensitive, detecting as low as $1/128^{th}$ equivalents of a *P. scribneri* individual per 0.2 g of potato roots. The assay had high correlation observed between the *P. scribneri* densities determined microscopically and the densities detected by qPCR in artificially inoculated and naturally infected root samples. A time-course experiment conducted in the greenhouse using qPCR detected *P. scribneri* in potato roots as early as five days after planting. The results correlated well with the microscopic observations and were complemented further with root-staining.

In Wisconsin, edaphic field factors were used to predict *Pratylenchus penetrans***.** A global ordinal regression model was developed to predict the distribution of six categories of *P. penetrans* initial population densities (Pi) across a field. The model was developed from a data set representing 322 sampling locations in eight commercial fields. More than 20 edaphic variables and their 2-way interactions were evaluated for inclusion in the model. Factors essential for the model were % sand, Zn, Mg, N, K, Mn, Fe, Mo, pH, EC_a and the interactions % sand x pH, % sand x Zn, % sand x K, % sand x Mo, N x Cu, and altitude x Fe. Factors that contributed most to the model were % sand (estimate = 12.27 (p = 0.01)), Zn (estimate = -4.65 (p = 0.00)), and Mg (estimate = 2.58 (p = 0.02)). For simplicity, the six categories were collapsed into low / medium / and high with a 70% correct prediction for the low category and a 75% correct prediction for the high category. Samples were then collected from two new fields for model validation. The model was correct for 71% of the areas with the lowest Pi and highest Pi in one field and for 50% of the areas with the lowest Pi and highest Pi in the other. *The model was developed by Dr. Gary Pack.*

Objective 2. Determine interactions of nematodes with other pests and pathogens and the impact of nematodes on plant and soil health.

Work underway in Michigan emphasizes this objective to understand the effects of tillage, cropping systems, and soil amendments affect nematode, nutrient and soil health management. Soil has biological, physiochemical, structural, nutritional and water holding integrity components that need to be aligned simultaneously and deliver the desired ecosystem services.

We use the Soil Food Wed (SFW, Ferris *et al*.) model to assess agroecosystem suitability of the outcomes, and the Fertilizer Use Efficiency (FUE) model to assess the potential sustainability of the outcomes (https://doi.org/10.3390/soilsystems5020032). The SFW accounts for nematodes functions, but the FUE model treats nematodes as either harmful or beneficial trophic groups. Our latest model, Integrated Productivity Efficiency (IPE), accounts for nematode functions and identifies sustainable soil health outcomes using the same principles as the FUE model (https://doi.org/10.3390/soilsystems6020035). In addition to identifying sustainable soil health outcomes, the IPE model, for the first time, relates nematode numbers to soil health values. The three models are decision-making tools that provide foundations towards step-by-step integration and alignment of different ecosystem services and soil health indicators needed for developing sustainable soil health management strategies.

In South Dakota, a study was undertaken by Chowdhury et al. (2022) to study the interaction between *Phytophthora sojae* and Soybean Cyst Nematode on Soybean (*Glycine max*). The study suggests that "On all soybean cultivars with different types of incomplete resistance, the complex pathotype (PS-15-TF3) influenced the lesion length (mm) in the presence of SCN. However, the SCN population was reduced by both complex and simple pathotypes of *P. sojae*. This suggests that use of both SCN and *P. sojae* resistance cultivars, can manage the disease complex and reduce soybean yield loss"

Models were developed to quantify the yield impact of *Pratylenchus penetrans* on the early season growth and yield of soybean in field and greenhouse environments and to estimate yield loss due to *P. penetrans* in Wisconsin. There was a negative linear relationship between initial nematode population densities (P_i) and shoot and total plant weight at V2 and yield, pod number, seed number, and seed mass at harvest in the field. Relative yield loss, modeled for the second year of the field experiment, suggested a loss of 4.5% for yield and between 2.4% to 2.8% for yield components at the mean field P_i. Negative linear relationships were demonstrated for the relative loss in those variables as well as for harvest index and shoot, root, and total plant weight at harvest in the greenhouse. Stress imposed by *P. penetrans* began within two weeks after planting and continued through harvest. Estimates of the percent loss attributed to each nematode P_i were 0.020% for yield, 0.015% for pod number, and 0.017% for seed number. *Pratylenchus* spp. was the most widely prevalent pest nematode among samples submitted to a statewide nematode testing program Molecular identification of a subset of 63 samples suggested 15% were infested with *P. penetrans* at a mean P_i of 197 *P. penetrans* per 100 cm^3 soil. Yield loss due to *P. penetrans*, estimated from prevalence data and our empirical greenhouse model, ranged from 0.23% to 2.76% among Wisconsin's agricultural districts. The cumulative impact for all *Pratylenchus* spp. is likely much greater given this loss estimate does not account for the monoecious species present in 79% of the samples. *This research was conducted by Dr. Kanan Saikai.*

A multi-state survey of crown rot disease of corn is being led by the University of Nebraska with support from Bayer CropScience. Plant parasitic nematode genera are being extracted and population densities compared from roots and soil associated with plant samples with and without symptoms of crown rot.

Objective 3. Develop and disseminate research-based information on the biology and management of plant-parasitic nematodes of economically important crops in the NCR.

There is a considerable body of basic and applied knowledge on all components of soil health, but intra- and cross-disciplinary gaps and barriers make it difficult to: **i)** relate specific soil health indicators and soil health values and **ii)** integrate and develop sustainable soil health management strategies. As part of bridging the intra-disciplinary gaps, we had a successful workshop on the SFW, FUE and IPE models at NC 1197 Report for 2021-22 Melakeberhan et al. 2 (Michigan).

An SCN survey was conducted in 2021 throughout the state of North Dakota using a 'free' sampling program. Succinctly, growers received SCN sample bags at the Extension county offices, sampled fields, and submitted samples to a partner lab. Data were mailed to growers directly, data was sent to NDSU and density maps with egg counts were developed.

Dr. Sam Markell and others are currently developing and expanding the SCN Coalition. Succinctly, the SCN Coalition is a national effort to mitigate yield loss caused by SCN, address the loss of effective resistance conferred by PI88788, and advance management for SCN.

Information generated from objective one and from other research efforts in the region was availed to soybean growers, agronomists, crop consultants and other stakeholders in the state via extension articles, extension talks, social media, and research field days. The main message was SCN soil testing (which is free of charge in South Dakota- paid by a grant from SD Soybean Council), awareness of SCN resistance to PI88788 and usefulness of nematicide seed treatments.

Information on the level of resistance in commercial soybean cultivars to Kansas SCN populations is published annually at http://www.agronomy.k-state.edu/services/crop-performance-tests/soybean/. The results obtained from this project have been used in classroom training for crop diseases and for training of certified crop advisors. Iowa State University also annually compiles an updated list of SCN-resistant soybean varieties in maturity groups 1, 2, and 3.

Drs. Bissonnette, Bish and Mr. Barizon from the University of Missouri and regional Extension specialists presented information about SCN and plant parasitic nematodes in their outreach activities. Free SCN testing for Missouri farmers has been offered in the 2020 and 2021 season and Free PPN testing offered in 2021 which are both continuing into the 2022 season. These results are being analyzed to be distributed at field days and Scouting Schools. Information about SCN biology and management were distributed with the nematode testing results and at the Missouri State Fair.

Similarly, the University of Nebraska Plant & Pest Diagnostic Clinic (P&PDC) continues to process and report results from soil samples submitted for SCN analysis. These analyses are conducted at no charge to producers and the program is supported by the Nebraska Soybean Board. The P&PDC continues to offer processing and reporting of plant parasitic nematodes from corn field samples, as well.

SCN information, including SCN Coalition content and other research based information was shared at most winter Extension programs across the state, including Crop Production Clinics, Midwest Soybean Production Clinics, Crop Scout Trainings, and Soybean Management Field Days, among others.

Output Summary:

The group reported 18 peer-reviewed articles and 10 meeting presentation abstracts were published, as well as 22 Extension articles, and two book chapters produced on the biology and management of PPNs were reported.

Impact Statements

- Information on resistance levels of commercial soybean cultivars to Kansas populations of SCN provides growers with information necessary to increase profitability of soybean production in SCN-infested environments. Knowledge of the prevalence of SCN and HG Types in Kansas is guiding soybean breeding efforts and providing soybean producers with information vital to variety selection.
- Characterization of SCN virulence patterns in Kansas and results of research on resistance-based management practices and durability of resistance sources is being used to improve management recommendations.
- The studies provide quantitative and integrated data base that are critical to understanding nematode parasitic variability cropping systems and soil health management decision-making to benefit growers and the environment.
- The research and outreach efforts have created awareness of SCN in South Dakota. Soybean growers continue to test their soils for SCN and growers with SCN in their fields are using SCN resistant varieties. The nematicide demonstration trials have showed limited benefit using nematicide seed treatment when the SCN population levels at the start of the season are low. The effectiveness of using SCN resistant varieties for increased grain yield in SCN infested soils has been demonstrated.
- As a result of a survey in North Dakota, growers are able to assess their likelihood of SCN in existing in their growing region. Additionally, they are much more likely to sample for SCN proactively. The information of soybean cultivars and germplasm for resistance to SCN is included in an annual research report and available to growers.
- In North Dakota, new molecular detection and identification methods provide rapid and sensitive diagnostic methods, improve nematode species detection efficiency, and are essential for nematode management.
- Information on the distribution and host range of RLN species in Kansas will be used to improve recommendations for reducing nematode losses in corn and wheat through crop rotation and cover crop selection.
- Current information on the efficacy of nematode control products is disseminated at Kansas grower meetings and field days to improve knowledge-based management decisions.
- The presence of *Pratylenchus* smolikii in Wisconsin was documented in a research publication.

- A damage function representing the relationship between soybean yield loss and initial population densities of *P. penetrans* was published for Wisconsin.
- An estimate was published for the prevalence of *P. penetrans*, as well as estimated impacts on soybean yield loss in Wisconsin were published.
- SCN biology and management information was presented at up to 7 locations of the annual Nebraska Extension Crop Production Clinics in January 2022 to up to 763 attendees for >$8 million value of knowledge gained over more than 30 million acres.

Refereed Publications:

1. Acharya, K. and Yan, G. P**.** 2022. Screening of early maturing soybean accessions for resistance against HG Type 2.5.7 of soybean cyst nematode, *Heterodera glycines*. Plant Health Progress 23:166-173. https://doi.org/10.1094/PHP-07-21-0105-RS.
2. Arora, D. and Yan, G. P. 2022. Early detection and temporal dynamics of *Pratylenchus scribneri* infection in potato roots determined using quantitative PCR and root staining. Phytopathology (in press), https://doi.org/10.1094/PHYTO-10-21-0412-R.
3. Baidoo, R. and Yan, G. P. 2021. 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*. Plant Disease 105:3848-3857. https://doi.org/10.1094/PDIS-01-21-0129-RE.
4. Bali,S., Hu,S., Vining,K., Brown,C., Majtahedi,H., **Zhang,L**., Gleason,C. and Sathuvalli,V. (2021) Nematode Genome Announcement: Draft genome of Meloidogyne chitwoodi, an economically important pest of potato in the Pacific Northwest. *Molecular Plant-Microbe Interactions* doi.org/10.1094/MPMI-12-20-0337-A
5. Bali,S*., **Zhang,L***., Franco,J and Gleason,C.(2021) Biotechnological advances with applicability in potatoes for resistance against root-knot nematodes. *Current Opinion in Biotechnology* 70, 226-233
6. **Bissonnette, K.M.***, Barizon, J.*, Adee, E., Ames, K.A., Becker, T., Biggs, M., Bradley, C.A., Brown, M., Byamukama, E., Chilvers, M.I., Faske, T.R., Harbach, C.J., Jackson-Ziems, T.A., Kandel, Y.R., Kleczewski, N.M., Koehler, A.M., Markell, S.G., Mueller, D.S., Sjarpe, D.A., Smith, D.L., Telenko, D.E.P., and Tenuta, A.U. 20XX. Management of SCN and SDS with nematode-protectant seed treatments across multiple environments. Plant Disease. *In Preparation.* *co-first authors
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9. Chowdhury, I. A., Yan, G. P., Plaisance, A., and Markell, S. 2021. Characterization of virulence phenotypes of soybean cyst nematode (*Heterodera glycines*) populations in North Dakota. Phytopathology 111:2100-2109. https://doi.org/10.1094/PHYTO-01-21-0031-R.
10. Davis, E.L. and G.L. Tylka. 2021. Soybean cyst nematode disease. The Plant Health Instructor. DOI: https://doi.org/10.1094/PHI-I-2000-0725-02

11. Habteweld, A., A. N. Kravchenko, P. S. Parwinder, and **H. Melakeberhan** (2022). A nematode community-based integrated productivity efficiency (IPE) model that identifies sustainable soil health outcomes: A case of compost application in carrot production. *Soil Systems* 6, 35. https://doi.org/10.3390/soilsystems6020035
12. Harbach, C.J. and G.L Tylka. 2022. Assessing direct and residual effects of cover crops on the soybean cyst nematode, *Heterodera glycines*. Plant Disease 106:1486-1491. https://doi.org/10.1094/PDIS-12-20-2581-RE
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14. Melakeberhan, H. and A. Habteweld (2022). Expanding indicator qualities of nematodes to identify sustainable soil health: Workshop #1. International Congress of Nematology, Antibes, France. ICN 2022 - Relive Monday 2 May 2022 (alphavisa.com)
15. Powers, T. P., Todd, T., Harris, T., Higgins, R., MacGuidwin, A., Mullin, P., Ozbayrak, M., Powers, K., and Saikai, K. 2021. Pratylenchus smoliki, a new nematode species (Pratylenchidae: Tylenchomorpha) from the Great Plains region of North America. Journal of Nematology. Volume 53, Pages 1-23, DOI: https://doi.org/10.21307/jofnem-2021-100
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Extension Publications

1. Bish. 2022. Soybean Cyst Nematode Out of Site, Out of Mind. IPCM Newsletter. May 2022. University of Missouri.
2. Bish and Barizon. 2022. The Enemy Lives Among Us! Test Your Garden for "Bad" Nematodes IPCM Newsletter. May 2022. University of Missouri.
3. Bissonnette and Barizon. 2022. Harvest is the perfect time for checking your fields for SCN. Know your number! IPCM Newsletter. October 2021. University of Missouri.

4. **Byamukama, E., Strunk, C.,** Clark, J., and Bly, A. 2021. What is causing soybeans to yellow at this time? SDSU Extension; Published July 2021.
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6. Corn & Soybean Field Guide 2022 Edition. (South Dakota)
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14. *IV. ISU Extension Integrated Crop Management News articles (www.extension.iastate.edu/cropnews)*
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Extension/Outreach Programs and Other Media

1. Extension specialists Drs. Damon Smith and Shawn Conley presented information about SCN in their outreach activities in Wisconsin. Information about SCN biology and management were distributed with the nematode testing results.
2. The University of Nebraska Plant and Pest Diagnostic Clinic provides free SCN testing for Nebraska samples (led by Kyle Broderick, Coordinator, supported by the Nebraska Soybean Board)
3. In South Dakota, radio interviews which focused on SCN were held in late September/early October (SCN Radio interview with Dakota Farm Talk) and February 22, 2022 (SCN Radio interview with Brownfield Ag News for America). SCN educational content was presented to 895 attendees at winter meetings, including Crop Hour, Agronomy Road Show and Ag CAT programs in 8 locations.