PROPOSAL TITLE:	**Site-specific Soybean Cyst Nematodes Detection Using EC Mapping**
INSTITUTION/ORGANIZATION:	**South Dakota State University**
PRINCIPLE INVESTIGATOR:	**Ali Nafchi, Assistant Professor, Precision Ag. Agronomy, Horticulture, & Plant Science**
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CO – INVESTIGATOR/S:	**Christopher Graham, Cheryl Reese, Sutie Xu**
CONTRACT SIGNER:	
NAME:	**Dr. Dianne Nagy**
EMAIL ADDRESS:	**grants.contracts@sdstate.edu**

TOTAL FUNDING REQUESTED: (Total requested fund for this three project)

Nematodes cause hundreds of millions of dollars in yield losses annually to USA agricultural products (Molinari, 2011 and Allen et al., 2017). Soil sampling is an efficient way to determine if Soybean Cyst Nematodes (SCN) are present in a field. From a practical standpoint, nematode detection and characterization based on the physical collection of soil samples is labor-intensive and time-consuming. The population of cyst nematodes in the infected area depends on soil and climate conditions and existing of the host plant. Therefore, accurate detection and quantifying spatially aggregated nematodes, especially in a large production field, is challenging. In addition, early detection is important to manage SCN and minimize yield loss.

More importantly, soil sampling from different locations in a zigzag pattern and mixing them before sending them to the lab may provide unreal nematode counts (mixing the low counts with high counts samples results in averaging down the threshold).

PROPOSAL GOAL/S & OBJECTIVE STATEMENTS:

This is a three-year project, with the overarching goal of assisting Minnesota and South Dakota soybean producers in adopting advanced technologies, including site-specific detection strategies and Precision Cover Cropping System (PCCS) as robust mitigation, in improving the SCN management in infested fields. We will develop and test concepts and technologies for site-specific detection and control of plant-parasitic nematodes to increase yield and farm profit and reduce the chemical use.

OBJECTIVES

The objectives of this project are to; a) Define and quantify the significant environmental and soil factors (the physical, chemical, and biological properties) that impact or regulate the spatial relationships, population dynamics, and survival of SCN in soybean fields in MN and SD; b) Establish three "Prototype Fields" to train producers; c) Demonstrate and evaluate the effects of the Site-specific SCN detection on crop yield and farm profits; d) Implement an intensive training program in Minnesota and South Dakota for crop consultants, technology providers, and agronomists to become the primary providers of the Site-specific SCN.

COMPLIANCE: (The following MUST be answered**)**

Is your organization involved in influencing any unit of government?	**NO**
Do you employ a registered lobbyist?	**NO**
Will any of the funds requested be used to lobby or as donations to an elected official?	**NO**
Is your project designed or planned to enhance the image or desirability of soybean or soybean products in domestic/foreign markets?	**YES**
Will your project communicate to consumers, importers, processors, wholesalers, retailer, government officials, or others information relating to the positive attributes of soybeans or soybean products and their importation or use?	**YES**

If so, who is your target audience and how will you accomplish this goal?

We will improve the SCN biological control to improve the yield and product quality and reduce the chemical used.

Is your project or plan any type of study to advance the image, desirability, marketability, production, product development, quality, or functional or nutritional value of soybeans or soybean products? **NO**

If so, which aspect of soybean and soybean products listed above do you propose to study?

How will the results of your study further the goals of increasing the image or desirability of soybean and soybean products?

Adopting advanced technologies, including site-specific detection strategies and Precision Cover Cropping System (PCCS) as robust mitigation, results in improving the SCN management in infested fields leading to a higher yield and chemical control.

Will requested funds be used to purchase depreciable capital equipment (property worth $2,000.00 or more) or physical property? **NO**

Will any preference be given to a brand or trade name of any soybean product as a result of your project? **NO**

If so, please provide the brand or trade name:

What percentage of the total budget is being requested from the MSR&PC? **100 %**

Are any portions of the requested funding under your proposal a general sponsorship, endowment, scholarship fund, foundation donation, or for use in humanitarian relief? **NO**

PROPOSAL SUBMITTED BY: Ali M Nafchi

Printed Name

SIGNATURE: ______________________________ **DATE:**__02/24/2024_______________

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Project Title: **Site-specific Soybean Cyst Nematodes Detection Using EC Mapping**

Project year: One

Principal Investigator (PI): Ali Nafchi, Assistant Professor, Precision Ag, Agronomy, Horticulture, & Plant Science, and ABE Departments. ali.nafchi@sdstate.edu, (863-325-6434).

Co-PIs and collaborators: Christopher Graham, Cheryl Reese, and Xu, Sutie, all from SDSU.

Co-PIs email: christopher.graham@sdstate.edu, cheryl.reese@sdstate.edu, and sutie.xu@sdstate.edu

Project Budget and Funding request: the requested fund for the **year 2 is $34,852** and the total requested fund for this three years project is as follows (Proposed detailed budget attached). Year 1: **$44,018** Year 2: $34,852 Year 3: $37,986 **Total: $116,856**

Project Summary:

Nematodes cause hundreds of millions of dollars in yield losses annually to USA agricultural products (Molinari, 2011 and Allen et al., 2017). Soil sampling is an efficient way to determine if Soybean Cyst Nematodes (SCN) are present in a field. From a practical standpoint, nematode detection and characterization based on the physical collection of soil samples is labor-intensive and time-consuming. The population of cyst nematodes in the infected area depends on soil and climate conditions and existing of the host plant. Therefore, accurate detection and quantifying spatially aggregated nematodes, especially in a large production field, is challenging. In addition, early detection is important to manage SCN and minimize yield loss. More importantly, soil sampling from different locations in a zigzag pattern and mixing them before sending them to the lab may provide unreal nematode counts (mixing the low counts with high counts samples results in averaging down the threshold).

This is a **three-year** project, with **the overarching goal** of assisting Minnesota and South Dakota soybean producers in adopting advanced technologies, including site-specific detection strategies and Precision Cover Cropping System (PCCS) as robust mitigation, in improving the SCN management in infested fields. The **overall objective of** this work is to develop and test concepts and technologies for site-specific detection and control of plant-parasitic nematodes to increase farm profit.

In Minnesota and South Dakota, Soybean Cyst Nematode (*Heterodera glycines Ichinolie*) is the most damaging soybean pest. Therefore, it needs to be managed to minimize yield loss. Considerable research evidence supports a significant correlation between nematode populations and soil texture properties (Overstreet et al., 2014; Noe and Barker, 1985; Wyse-Pester et al., 2002; Avendaño et al., 2004; Monfort et al., 2007). Research has suggested that the variation in soil properties has a significant correlation between SCN populations and soil texture, adequate for site-specific management (Avendano et al., 2004). The cyst population density was consistently higher in loamy sand than in sandy clay loam. Sand, clay, and silt in the soil were spatially structured and strongly correlated with SCN population density (Avendano et al., 2004). According to other studies, the percent of clay or sand in the soil is strongly correlated with EC data and a significant correlation with SCN populations and adequate site-specific management (Overstreet et al., 2014; Khalilian et al., 2001).

Project Objectives:

The objectives of this project are to; a) Define and quantify the significant environmental and soil factors (the physical, chemical, and biological properties) that impact or regulate the spatial relationships, population dynamics, and survival of SCN in soybean fields in MN and SD; b) Establish three "Prototype Fields" to train producers; c) Demonstrate and evaluate the effects of the Site-specific SCN detection on crop yield and farm profits; d) Implement an intensive training program in Minnesota and South Dakota for crop consultants, technology providers, and agronomists to become the primary providers of the Site-specific SCN.

A positive SCN detection requires adopting an integrated management approach, including planting resistant cultivars, non-SCN hosts or poor SCN host crop rotation, or the use of nematicide seed treatments (Niblack, 2005). A periodic SCN soil test is also needed to monitor the SCN population changes in the field. An increase in SCN populations would call for tactics or management methods (Strunk and Byamukama,https://extension.sdstate.edu/cover-crop-considerations-when-dealing-soybean-cyst-nematode). The cysts can remain viable for more than ten years and continue to reproduce and accumulate in the soil if an SCN host is included in the crop rotation. The cover crop significantly reduced population densities of nematodes without nematicides application (Marshall et al., 2016). According to a study (2016-2017) at South Dakota State University (SDSU), several weed species are hosts for SCN in South Dakota (Basnet et al., 2020). Similarly, some cover crops can be hosts for SCN (Acharya et al. 2020); therefore, selecting cover crops is very important for soybean producers dealing with SCN in their fields. The effects of non-host cover crops on reducing the soybean cyst nematode population compared to the initial population density reported being from 44 to 67%. At the same time, the natural reductions in fallow were from 4 to 24% (Acharya et al. 2021). This study suggested that cover crops can reduce the SCN populations. Consequently, it is recommended to select non-SCN hosts or poor SCN hosts in cover cropping systems in crop rotation, especially for the suspected area or a positive SCN detected area.

Project Methodology and Work Plan:

We propose to evaluate and demonstrate soil property maps value as indicators of where SCN can be expected in an infested field. This study provides the basis of how site-specific soil texture data can improve the spatial prediction of SCN. We will collect soil samples in a geostatistical sampling design based on soil properties variation. Soil electrical conductivity correlates strongly to soil particle size and texture (William and Hoey, 1987, Khalilian et al., 2010). Sands have a low conductivity, silts have a medium conductivity, and clays have a high conductivity. In addition to texture, electric conductivity has been proven to relate closely to other soil properties, such as organic carbon, CEC, and topsoil depth (Kitchen and Sudduth, 1996; and Doolittle et al. 1994). The EM-38 equipment is now available at SDSU, measures equivalent soil electrical conductivity across a field for a rapid and accurate determination of various soil physical properties. The implement can be operated at speeds from 5-20 mph and can measure a 40-60 ft swath in most fields. This equipment would allow a 100-acre field to be mapped for the soil type in a few hours, rather than the several days required for manual grid sampling and standard laboratory texture analyses. Soil texture maps allow producers to selectively focus nematode sampling efforts only in the parts of the field with a high probability of having a nematode problem.

On the other hand, the technology for remote plant vegetative stress is developing rapidly. Images taken using sophisticated space-borne or air-borne sensors are commercially available. While these images can detect crop vigor across a field, they do not necessarily indicate the specific cause of the stress. Since nematodes cause numerous growth problems in soybean, detecting nematode-induced plant stress in aerial images may be possible. Vellidis et al. (1999) reported a very good correlation between crop yield and aerial images taken within the first ten weeks of crop growth. This project will develop actual nematode distribution and population density maps of individual prototype fields based on small-grid (1.0 acre or less) sampling. Fields will be selected that represent soybean production fields with the presence of SCN. We will process the soil texture maps by grid sampling and using the EM-38 soil conductivity apparatus.

In addition, soil information (chemical, physical, and biological properties) will be collected from each grid to determine the factors highly correlated with the presence, spatial distribution, and population density of SCN in each field and region. Once these data have been collected, crop performance and yield will be monitored with the yield monitors. We believe that site-specific management and precision cover cropping system (PCCS) will help control and mitigate the SCN.

<u>Project Deliverables, Outcomes, and Benefits to soybean producers:</u>

The immediate target beneficiaries for this research project are Minnesota and South Dakota soybean producers. We will implement a training program for crop consultants, technology providers, and Extension personnel to become the primary providers of this technology.

We will Integrate research-based precision approaches to nematode problem site detection and site-specific control for small and mid-sized producers in the midwestern region. These workshops will be conducted in cooperation with the appropriate extension field specialists and will be focused primarily on training local crop consultants, farm advisors, and producers in the concepts and utility of site-specific nematode management in soybean in their areas. Producers' demonstration sites will be expanded to include site-specific nematode management technology. Project findings will be published by appropriate means to meet the target audience. The Web will be utilized for information providing (electronic publishing) and the development of distance education tools focusing upon precision agriculture.

Performance Metrics, Action Plan, and the Timeline:

Event	Year 1				Year 2				Year 3			
Identifying fields with nematode presence (Milestones 1)	*	*			*	*			*	*		
Soil sampling / EC mapping (Milestones 2)	*	*			*	*			*	*		
Finalize sites selection and establish protype fields (Milestones 3)	*	*	*		*	*	*		*	*	*	
Data collection at-planting and in-season aerial imagery (Milestones 4)		*	*			*	*			*	*	
Data collection at harvest (Milestones 5)			*	*			*	*			*	*
Data analysis and producing reports (Milestones 6)			*	*			*	*			*	*
Workshops, field days, and training for the trainers (Milestones 7)			*	*			*	*			*	*
Semiannual progress and final reports (Milestones 8)		*		*		*		*		*		*

<u>Keywords</u>: Soybean Cyst Nematodes, Precision Cover Cropping System, Management, Biological Control, Site-specific, Electrical Conductivity, Precision Agriculture

MSR&PC PROPOSAL BUDGET EXPENSES TEMPLATE

Title: Site-specific Soybean Cyst Nematodes Detection Using EC Mapping

Amount Year 1	Cost Description	Year 2	Year 3	Total Project
	COMPENSATION			
$0.00	PI Senior Personnel Compensation	$0	$0	$0
$28,776.00	Student Compensation	$28,322	$29,241	$86,339
$28,776.00	**Total Compensation**			$86,339
	CONSULTING/PROFESSIONAL SERVICE			
$0.00	**Total Consulting/Professional Service**			$0
	TRAVEL			
$3,252.00	Specific details in attached budget justification.	$1,240	$1,225	$5,717
$3,252.00	**Total Travel**			$3,252
	SUPPLIES			
$10,740.00	Specific details in attached budget justificatio	$4,040	$5,270	$20,050
$10,740.00	**Total Supplies**			$10,740
	OTHER DIRECT COSTS			
$1,250.00	Publication	$1,250	$2,250	$4,750
				$0
				$0
$1,250.00	**Total Other Direct Costs**			$1,250
$44,018.00	**GRAND TOTAL FUNDING REQUEST**	$34,852	$37,986	$116,856

Budget-- Site-specific Soybean Cyst Nematodes Detection Using EC Mapping

Project Budget: (Total requested fund for this project)
Year 1: $44,018 Year 2: $34,852 Year 3: $37,986 **Total: $116,856**

BUDGET AND BUDGET NARRATIVE
Salaries & Wages
Faculty Salaries: Year 1: $0.00 Year 2: $0.00 Year 3: $0.00 Total: $0.00

Student Salary and Wages:
Graduate Students: Year 1: $26,051 Year 2: $25,515 Year 3: $26,350 **Total: $77,916**
One graduate student will be working with the team on the project's tasks, including lab data collections, analyzing results, and project evaluation tasks. Funds are requested for one master student to support the objectives of this proposal. This student will assist senior scientists and technicians in fabrication, collecting data, and analyzing of the data.

Pre-baccalaureate Student: Year 1: $2,520 Year 2: $2,596 Year 3: $2,673 **Total: $7,789**

Funds are requested to pay two hourly student workers to support the objectives of this proposal. These students will assist senior scientists in all tasks during the life of the project. They will assist in (but not limited to) fabrication, plot maintenance, collect soil, plant, and other data as deemed necessary. These students will work 10 hours/week for 1.5 months (an estimated 60 hours/each) during the summer. Average pay rate = $14.00/hr based on education level and experience.

Fringe Benefits: Year 1: $205 Year 2: $211 Year 3: $218 **Total: $634**
Salaries and Fringe Benefits: Year 1: $20,714 Year 2: $21,336 Year 3: $21,976 **Total: $64,026**

Materials, and Supplies: Year 1: $10,740 Year 2: $4,040 Year 3: $5,270 **Total: $20,050**

- Funds are requested for moisture sensors/data loggers/controller for monitoring dynamic soil moisture contents and the soil Cone penetrometer sensors, wire & cable, power supply, cable ties, circuit breakers, field and shop supplies and environmental monitoring ($6,320 - first year, $2,340 - second year and $2,700 for the year 3).
- Supplies for collecting soil and plant samples and laboratory fees for soil health assay, supplies used for plot such as stakes, flags, etc. ($4,420, first year, $1,700, second year, and $1,570 for the year 3).

Other: Workshop/Training Supplies: (Year 1: $0.00, Year 2: $0.00, Year 3: $1,000)
Funds necessary to conduct training workshops, develop training and educational material, develop web-based training and educational material, and develop/mail workshop announcements. This will cover facilities (building and/or tent) rental, specific meeting materials, web development costs, mailings, etc.

Travel: Year 1: $3,252 Year 2: $1,240 Year 3: $1,225 **Total: $5,717**

Travel is estimated based on mileage, lodging, and per diem. Funds will be used to support travel by the project coordinator, students, and summer workers to grower sites for data collection, transporting equipment to demonstration sites, and presenting results to growers/stakeholders at production field days. This includes an updated presentation at the SD and MN State Technical Committee meeting. Any travel to additional conferences will be covered by other funds available to the Project Director.

available to the Project Director.

Year one estimated annual travel totals are based on:

- 2,823 miles - $1,440 ($.51/mi).

- 12 nights lodging - $1000 ($75/night + tax = $83.38/night)
- 14 days full perdiem - $560 ($40/day)
- 18 Lunches for closer trips -$252 ($14/lunch)

Publications: Year 1: $1,250 Year 2: $1,250 Year 3: $2,250 **Total: $4,750**
Funding is requested to cover publishing costs of creating an 11x17 folded brochure/factsheet (~$0.60/piece x 950pgs = $570), and meeting handouts and postcards ($0.25/pg. x 1,520pgs = $380). Funding is requested to cover publishing costs of $100 per 8.5 by 11-inch published page in Journal of Agronomy, Transactions of the ASABE and Applied Engineering in Agriculture, and $50 per 6 by 9 inch published page in the Journal of Agricultural Safety and Health, based on ASABE website (2 x ~$100/pg. x 19pgs = $3,800).

Request for No-cost extension; **Site-specific Soybean Cyst Nematodes Detection Using EC Mapping**; *PI – Ali Nafchi*

Work Completed

In phase one of this project, our research provides valuable insights into the relationship between nematode counts and soil properties. Understanding these interactions will enhance our ability to implement targeted management strategies for nematode control, contributing to improved soybean crop health and productivity. The soybean harvest has been successfully completed, and while the sampling and initial data collection phase is finished, we are currently awaiting the receipt of detailed harvest data. For a thorough analysis, it's crucial to obtain more specific information about the agricultural practices employed in the field, particularly regarding fertilizer and herbicide applications. This additional data will be instrumental in enriching our understanding and facilitating a comprehensive evaluation of the field conditions and their impact on the crop yield and health. We have collected the after-harvest soil samples sent to the AGVISE Laboratories in Benson, Minnesota.

Recruiting the students

Two graduate students will work with the team on the project's tasks, including field and lab data collection, analysis of results, and project evaluation tasks. We recruited the second students in June and Jully 2023; however, due to visa status, the starting date was delayed. Only one student started working on this project, and another student is waiting to change his status to be able to participate in this project.

Work Remaining and Timeline

In phase two of this project, we are seeking collaborative partners for the future phase of this project. We need to work and collaborate with growers in their fields to get more precise insights and gather additional data from different fields and disseminate and share the results of this study with them and we will provide training and support to ensure proper use of the system). We will assist MN and SD collaborators to consider the complexity of field conditions and the need for further investigations to establish more robust correlations. We have added one scope of using drone to do the early detection and scouting for the infested area.

Budget Carryover

Due to the delay in starting date for the students, a small amount of salary has gone to a graduate student and summer help to support the project, reaching out to producers, helping set up visits, taking farm visits, and sampling. Due to the delay in the starting date for the students, despite meeting the project's milestones, we need to map as many as fields we can to strengthen our model and protocol. However, since it is a new project with a significant impact, we have expedited the process and will address the expectations in the coming year. For this reason, the remained of the funds awarded for Year 1, as a "Carryover" to the next year, is requested to cover the salaries of the graduate students and summer help. Also, additional equipment, materials, and supplies funds are requested to carry over to support the project's objectives.

Appendix

Soybean Cyst Nematode Site-specific Distribution and EC Mapping Correlation

Yashar Askarzadeh, Ahmed Abdalla, Christopher Graham, Cheryl Reese, Sutie Xu, and Ali M Nafchi
College of Agriculture, Food and Environmental Sciences/Departments of Agronomy, Horticulture, & Plant Science (Corresponding author: ali.nafchi@sdstste.edu)
South Dakota State University

Introduction

The Soybean Cyst Nematode (SCN) represents a significant global threat to soybean yields, particularly in the U.S., leading to considerable economic losses. The complex interplay between soil properties and SCN distribution, combined by the nematode's genetic variability and lack of visible symptoms, complicates management efforts. However, advancements in precision agriculture, such as electrical conductivity sensors (EM-38), provide new strategies for SCN detection and control. These approaches leverage the necessary link between soil characteristics and nematode presence to effectively mitigate SCN's adverse effects in crops.

Purpose of the study: to find correlation between SCN population with soil properties.

Objectives

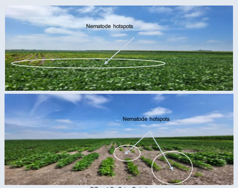
1. Evaluating soil conductivity of Soybean field using an EM-38.
2. Defining management zones and site-specific management zones.
3. Determining correlation between SCN egg counts with soil variation and the interaction between different soil variation.
4. Suggesting non-host cover crops for improving soil properties and managing nematode distribution.

Materials & Methods

- EC data collection using an EM-38 device to create management zones prior to planting Soybeans.
- Targeted soil samples collected prior to planting, mid-season and post harvest .
- Analyzing soil core samples for SCN egg counts and soil variations including physical and chemical characteristics.
- Data will be integrated in agriculture spatial programs such as GIS and SMS for better understandings of variations in the field.

Studied area: Southeast South Dakota Research Farm near Beresford, SD (43° 02′ 36.76″ N, 96° 54′ 15.58″ W). The following picture shows the locations of sampling points within the 11-acre area outlined by the red border.

Dragging EM-38 Through The Field



Different On-Going Project

Testing Soil Strength Using Cone Penetrometer

Collecting soil samples from the top 12"

Mixing 10-15 Subsamples at each point

Soil characteristics

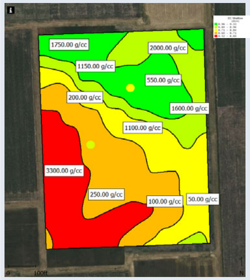
Management zones	EC dS/m
Red	8.52-8.60
Orange	8.60-8.71
Yellow	8.71-8.84
Light green	8.84-8.96
Dark green	8.96-9.33

Management zones vs shallow EC range

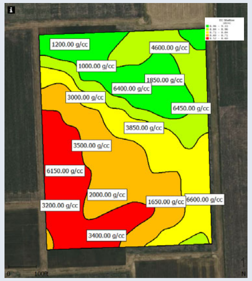
Zones	pH Pre-PL	pH Post H	OM (%) Pre-PL	OM (%) Post H	CEC (meq/g) Pre-PL	CEC (meq/g) Post H	Salts (mmho/cm) Pre-PL	Salts (mmho/cm) Post H	Clay (%) Pre-PL	Clay (%) Post H	K (ppm) Pre-PL	K (ppm) Post H	Mg (ppm) Pre-PL	Mg (ppm) Post H	Ca (ppm) Pre-PL	Ca (ppm) Post H
Dark Green	7.7	8.0	4.6	5.0	32.2	32.6	1.0	0.7	25.0	27.3	313	431	1101	1156	4446	4325
Red	6.1	6.2	4.3	4.3	23.6	22.0	0.4	0.1	27.7	29.3	253	350	610	581	2600	2496
Orange	6.8	6.8	4.6	5.0	25.2	23.9	0.4	0.2	29.0	29.3	309	381	656	662	3369	3204
Yellow	7.3	7.4	5.1	5.3	31.8	28.8	0.8	0.2	27.3	31.7	276	319	1000	911	4138	3983
Light Green	7.0	7.3	5.3	5.5	29.0	29.9	0.5	0.2	34.3	36.7	355	474	1159	1166	3449	3670

Soil properties for different zones (Pre-PL: Prior to planting, Post H: After Harvest)

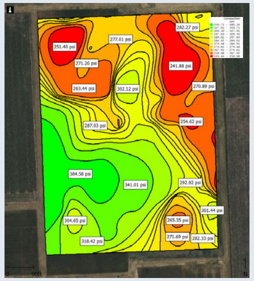
Nematode Distribution



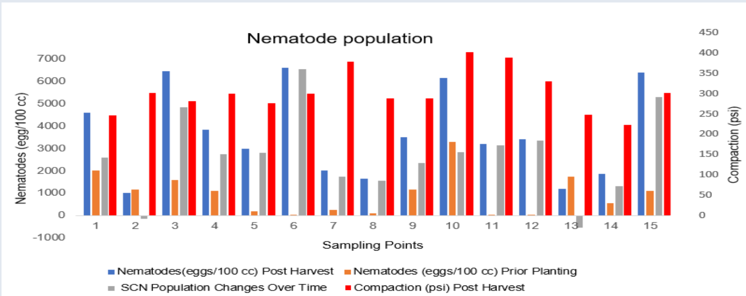
Nematode counts prior-planting (background map is EC shallow)



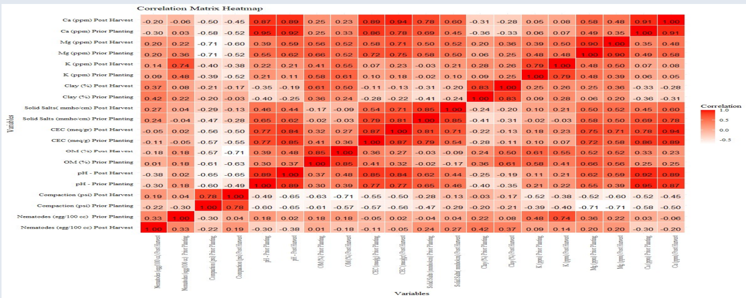
Nematode counts post-harvest (background map is EC shallow)



Compaction map



Correlation matrix



Discussion

- Post-harvest, a significant increase in SCN populations was observed in almost all tested points, supporting the hypothesis that nematode counts are spatially related to soil conditions.
- Correlation matrix table shows among different soil variations K+ and Clay content have the strongest correlation with SCN counts.
- High soil strength and clay content were found to limit SCN breeding, whereas higher organic matter correlated with more nematodes, suggesting a complex interplay with soil biology.

Future works

- ❖ Different ongoing projects in the field make its challenging to create best model for predicting SCN change over the time.
- ❖ More sampling size required for more accurate results.
- ❖ Using satellite imagery for a better SCN detection and data accusation.
- ❖ Designing special device for monitoring compaction in the field.

References

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Minnesota Soybean Research and Promotion Council

Annual Research Progress Report

Site-specific Soybean Cyst Nematodes Detection Using EC Mapping

Ali Nafchi, Assistant Professor, Precision Ag. AHPS, and ABE. ali.nafchi@sdstate.edu
Co-PIs: Christopher Graham, Cheryl Reese, and Xu, Sutie.

Soil sampling is an efficient way to determine if Soybean Cyst Nematodes (SCN) are present in a field to mitigate millions of dollars in yield losses. From a practical standpoint, nematode detection and characterization based on the physical collection of soil samples is labor-intensive and time-consuming. The population of cyst nematodes in the infected area depends on soil and climate conditions and the existence of the host plant. Therefore, accurate detection and quantifying spatially aggregated nematodes, especially in a large production field, is challenging. In addition, early detection is important to manage SCN and minimize yield loss. Plant-parasitic nematodes pose a significant agricultural threat, leading to substantial yield losses in economically important crops like cotton and soybeans (Figures 1-2) worldwide (Blair et al., 1999; Koenning et al., 1996).

They exhibit diverse host interactions, with some entering and feeding within host cells, while others migrate through the soil to feed on roots (Chen et al., 2021). Different nematode types are greatly affected by soil abiotic characteristics (Blair et al., 1999; Overstreet et al., 2014), which include soil pH, organic matter, texture, chemicals, and microbial activity. The southern root-knot, spiral, and lesion nematodes tend to thrive in

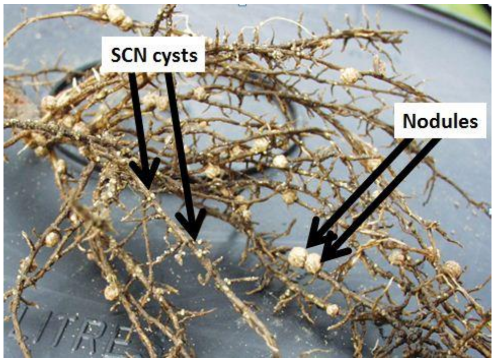


Fig 1. Soybean cyst nematodes feeding on roots
(https://fieldcropnews.com/2020/09/omafra-field-crop-report-september-17-2020/)

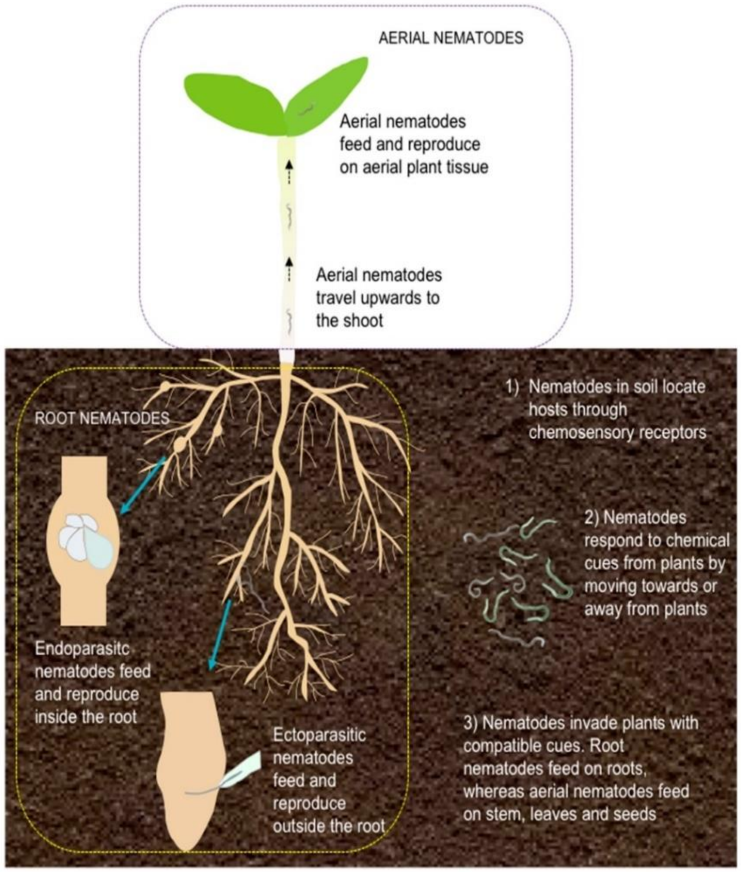


Fig 2. Different type of plant parasitic nematodes

sandy or coarse-textured soils (Monfort et al., 2007; Herring et al., 2010). On the other hand, reniform nematodes are more prevalent in silt-rich soils (Jones et al., 2013). The existence of some nematodes and their population is typically associated with soils containing higher percent sand content (Benjlil et al., 2020). A significant correlation exists between soil nematode distribution and various soil characteristics, including pH, compaction, clay content, and organic matter (Robinson et al.), in line with patterns seen in previous studies (Monfort et al., 2008). It's important to note that this assessment, due to field variations and diverse project objectives, isn't definitive and may yield different results in other locations (Avendaño et al., 2018). High soil strength limits nematode breeding, while less compacted soil promotes nematode growth, similar to the effect of clay content. Organic matter can either help or harm nematodes (Avendaño et al., 2004). The relationship with soil organic matter is less clear in areas where high organic matter is present, nematode counts increase. This increase pattern may be due to the absence of other nematode-feeding soil microorganisms, potentially suppressing nematode populations. Further data collection will provide more clarity (Blair et al., 1999). Despite weak correlations, likely influenced by a small sample size and various errors (Patzold et al., 2008), pH and soil texture play significant roles in determining SCN egg distribution. Determining nematode distribution is challenging due to soil texture variations. For example, clay soil, classified as per USDA, can contain up to 45% sand, creating different-sized pores for nematodes (Williams & Hoey, 1987). Researchers struggle to characterize nematode distribution due to varying soil factors (Acharya et al., 2017), and conventional methods treat the entire field as a unit, ignoring variability can be ineffective and costly (Khalilian et al., 2003). Zone mapping offers an alternative, dividing fields based on soil EC due to close relationship with soil texture (Evans et al., 2002). EC reading could be considered a site-specific nematode management method (Fig 3-5).

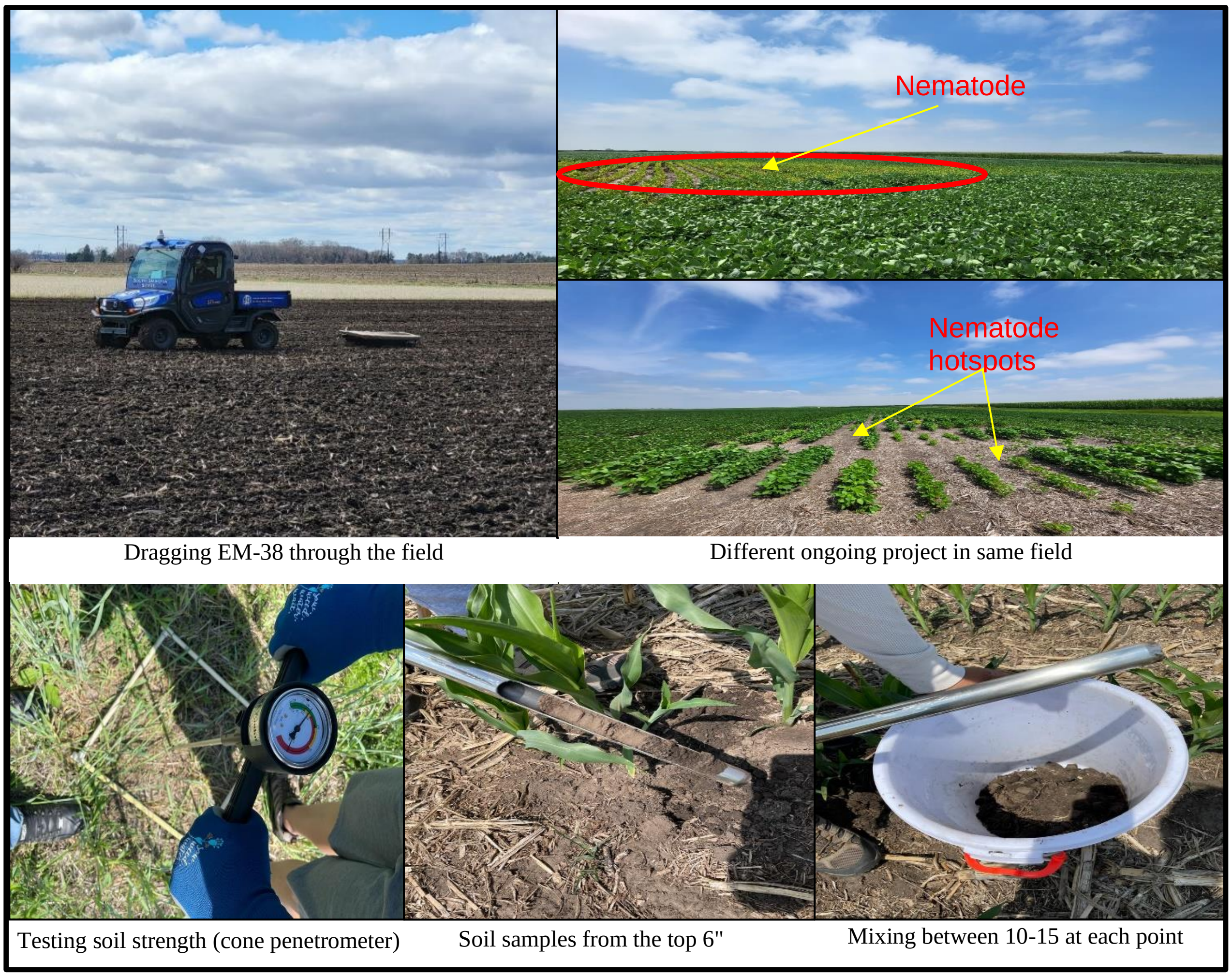


Fig 3. Nematodes population is strongly correlated with soil texture.

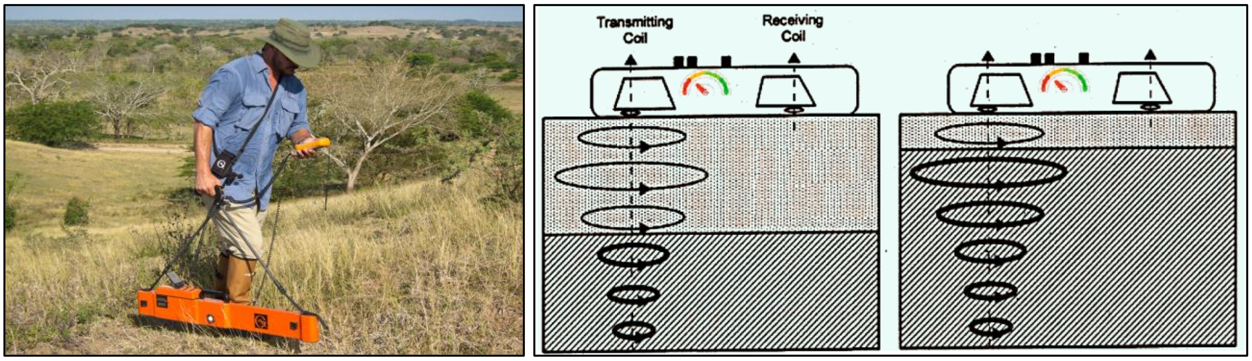


Fig 4. Using EM38 to collect EC information from the field.

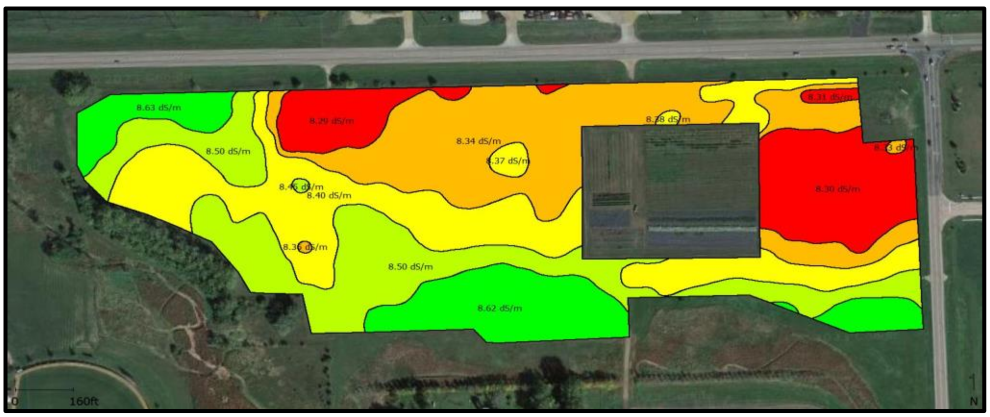


Fig 5. Making management zone based on the soil texture.

Effect of PCCS on population reduction of SCN

Host resistance and crop rotation are commonly used to manage nematodes due to their eco-friendly and cost-effective nature (Doolittle et al., 1994). Previous research has proposed integrating cover crops into these strategies to reduce nematode (Schmitt & Riggs, 1991), densities in infested fields (Fig 6). Cover crops, like oilseed radish, act as trap crops, reducing cyst nematode populations (Chen et al., 2021). The dense roots of red clover and alfalfa hinder SCN juveniles from penetrating and reproducing (Riga et al., 2001). Annual ryegrass and white clover exudates increase SCN egg hatching and

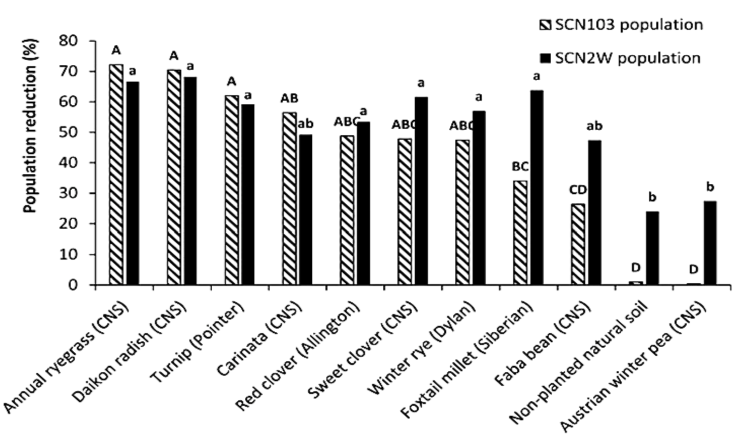


Fig 6. Effect of different type of cover crops on population reduction of SCN (https://doi.org/10.1094/PDIS-08-20-1778-RE)

deplete juveniles' reserves in the absence of host plants (Chen et al., 2021). Although SCN eggs can hatch and penetrate sun hemp roots, they fail to develop into mature SCN females, thus disrupting their life cycle (Chen et al., 2021).

Testing soil strength

Soil compaction, which affects crop performance and yield, varies among fields due to factors such as soil texture and organic matter. Understanding and mitigating its effects is crucial. In this study, we used a cone penetrometer on May 25th to assess soil strength alongside plant sampling. The average compaction reading from subsamples served as the indicator for soil strength in specific sampling areas.

Soil physical characteristic

For each zone, three points were selected based on the absolute value of the EC reading. After collecting samples, all of them were analyzed for pH, K+, Mg, Ca, OM, Solid Salts, CEC, and Texture. Subsequently, these results were imported into the SMS program to create contour maps based on different variations. Our findings revealed a strong relationship between EC readings and pH, solid salts, and texture. Generally, low EC readings indicated larger particle sizes, low nutrient content, acidity, and good moisture drainage, whereas high EC readings indicated smaller particle sizes, nutrient richness, alkalinity, and poor moisture drainage. It is essential to note that while EC readings provide valuable insights into soil characteristics, they do not provide exact estimations. Nonetheless, since it is impractical to take samples from every point in the field, the zones created based on EC readings serve as reliable indicators of areas with similar soil conditions. While taking soil samples is necessary for a more comprehensive understanding, creating zones based on EC readings is preferable to blind and random sampling. Having an overview of the entire field allows for more precise soil sampling, enabling targeted identification of susceptible areas for SCN infestations.

SCN mitigation

A positive SCN detection requires adopting an integrated management approach, including planting resistant cultivars, non-SCN hosts or poor SCN host crop rotation, or the use of nematicide seed treatments (Niblack, 2005). A periodic SCN soil test is also needed to monitor the SCN population changes in the field. An increase in SCN populations would call for tactics or management methods (Strunk and Byamukama,https://extension.sdstate.edu/cover-crop-considerations-when-dealing-soybean-cyst-nematode). The cysts can remain viable for more than ten years and continue to reproduce and accumulate in the soil if an SCN host is included in the crop rotation. The cover crop significantly reduced population densities of nematodes without nematicides application (Marshall et al., 2016). According to a study (2016-2017) at South Dakota State University (SDSU), several weed species are hosts for SCN in South Dakota (Basnet et al., 2020). Similarly, some cover crops can be hosts for SCN (Acharya et al. 2020); therefore, selecting cover crops is very important for soybean producers dealing with SCN in their fields. The effects of non-host cover crops on reducing the soybean cyst nematode population compared to the initial population density reported being from 44 to 67%. At the same time, the natural reductions in fallow were from 4 to 24% (Acharya et al. 2021). This study suggested that cover crops can reduce the SCN populations. Consequently, it is recommended to select non-SCN hosts or poor SCN hosts in cover cropping systems in crop rotation, especially for the suspected area or a positive SCN detected area. The collected soil samples from each point were divided into two equal portions, each labeled differently for soil testing and SCN egg count analysis. These samples were shipped to AGVISE Laboratories in Benson, Minnesota. For a more comprehensive understanding of the field, contour maps of soil variations and SCN egg count distribution were created using the kriging method within the SMS software.

Results and discussion

Site specific management zones: After mapping field with EM-38 prior the planting EC reading was ranged from 8.53-9.33 from the lowest to highest. Field was divided to five different zones based on the EC Shallow reading (Table 1).

Management zones	EC dS/m
Red	8.52-8.60
Orange	8.60-8.71
Yellow	8.71-8.84
Light green	8.84-8.96
Dark green	8.96-9.33

Table 1. Shallow EC range for different management zones.

Soil characteristics

For each zone, three points were selected based on the absolute value of the EC reading. After collecting samples, all of them were analyzed for pH, K+, Mg, Ca, OM, Solid Salts, CEC, and Texture. Subsequently, these results were imported into the SMS program to create contour maps based on different variations. Our findings revealed a strong relationship between EC readings and pH, solid salts, and texture. Generally, low EC readings indicated larger particle sizes, low nutrient content, acidity, and good moisture drainage, whereas high EC readings indicated smaller particle sizes, nutrient richness, alkalinity, and poor moisture drainage (Table 2).

It is essential to note that while EC readings provide valuable insights into soil characteristics, they do not provide exact estimations. Nonetheless, since it is impractical to take samples from every point in the field, the zones created based on EC readings serve as reliable indicators of areas with similar soil conditions. While taking soil samples is necessary for a more comprehensive understanding, creating zones based on EC readings is preferable to blind and random sampling. Having an overview of the entire field allows for more precise soil sampling, enabling targeted identification of susceptible areas for SCN infestations.

	pH Prior to planting season	pH After harvesting	OM % Prior to planting season	OM % After harvesting	CEC (meq/g) Prior to planting season	CEC After harvesting	Salts mmho/cm Prior to planting season	Salts mmho/cm After harvesting	Clay % content Prior to planting season	Clay % content After harvesting	k ppm Prior to planting season	k ppm After harvesting
Dark green	7.70	7.97	4.63	5.03	32.23	32.57	1.00	0.75	25.00	27.33	313.33	430.67
Red	6.13	6.17	4.27	4.30	23.60	21.97	0.44	0.11	27.67	29.33	253.00	350.00
Orange	6.83	6.83	4.60	4.97	25.20	23.93	0.43	0.15	29.00	29.33	308.67	380.67
Yellow	7.30	7.37	5.07	5.27	31.77	28.77	0.84	0.20	27.33	31.67	276.00	319.00
Light green	7.03	7.30	5.33	5.50	28.97	29.93	0.53	0.19	34.33	36.67	355.00	474.00

Table 2. Soil properties in different management zones

SCN Egg counts

Our results indicate a notable increase in SCN populations in almost all tested points post-harvest compared to pre-planting levels. Remarkably, only two samples from the northern corner of the field showed a significant decrease in egg counts. This reduction might be attributed to the use of high-resistance soybean varieties or specific agronomic practices applied to that area (Fig 7).

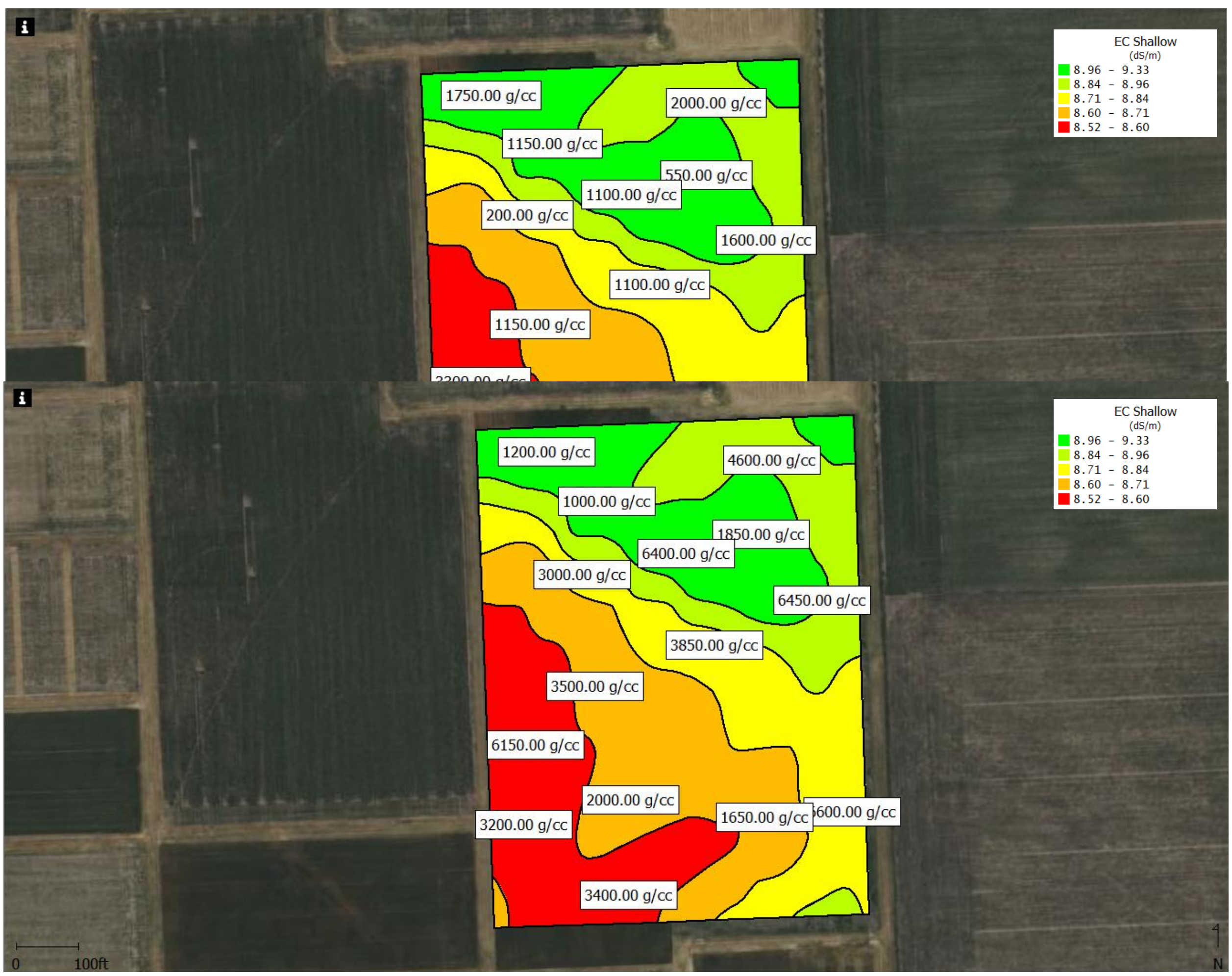
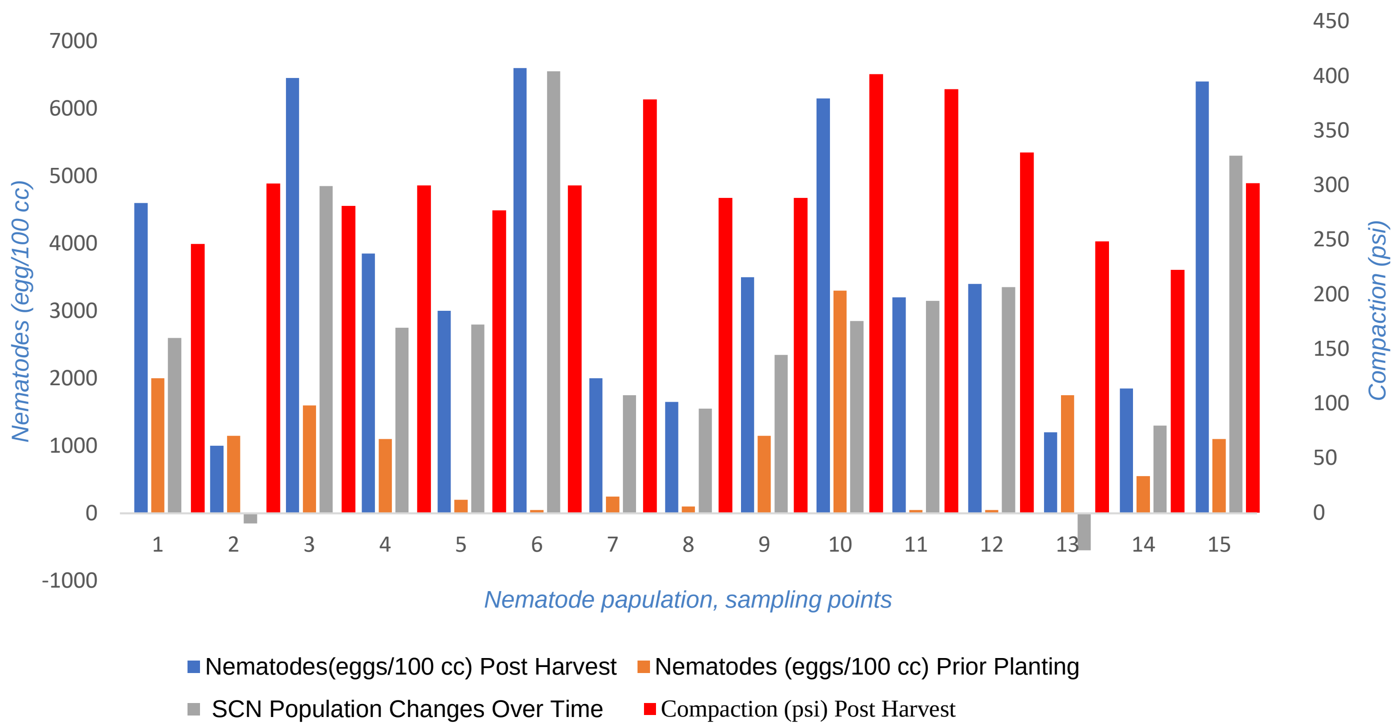


Fig 7. Nematode counts post- harvest (Base map is EC Shallow)



Nematode count vs Soil properties

A notable correlation between soil nematode distribution and various soil characteristics, including pH, compaction, clay content, and organic matter, has been revealed by the research findings, which align with consistent patterns observed in previous studies. However, it is essential to acknowledge that due to many variations in the field and ongoing projects with diverse objectives, the current assessment is not definitive and may result in different outcomes in other locations.Based on observations, it has been noticed that areas with high soil strength restrict nematode breeding, while nematodes thrive more in less compacted soil. A similar trend is also observed for clay content. However, the relationship with soil organic matter is not as straightforward. In areas where organic matter is high, an increase in nematode counts has been observed, which contrasts with findings from some previous studies. This pattern might be attributed to the potential absence of other soil microorganisms that could feed on nematodes or compete with them, possibly suppressing nematode populations below a threshold that limits their life cycles. Further observations and data collection are expected to clarify this correlation. Despite the presence of weak correlations between the results, which could be influenced by the small number of observations and various errors, such as differences in treatments and conditions, it is evident that pH and soil texture play significant roles in determining the distribution of SCN eggs (Fig. 9). Generally, areas with low pH and a high percentage of silt tend to exhibit higher nematode counts compared to other areas.

Fig 8. Soil compaction map

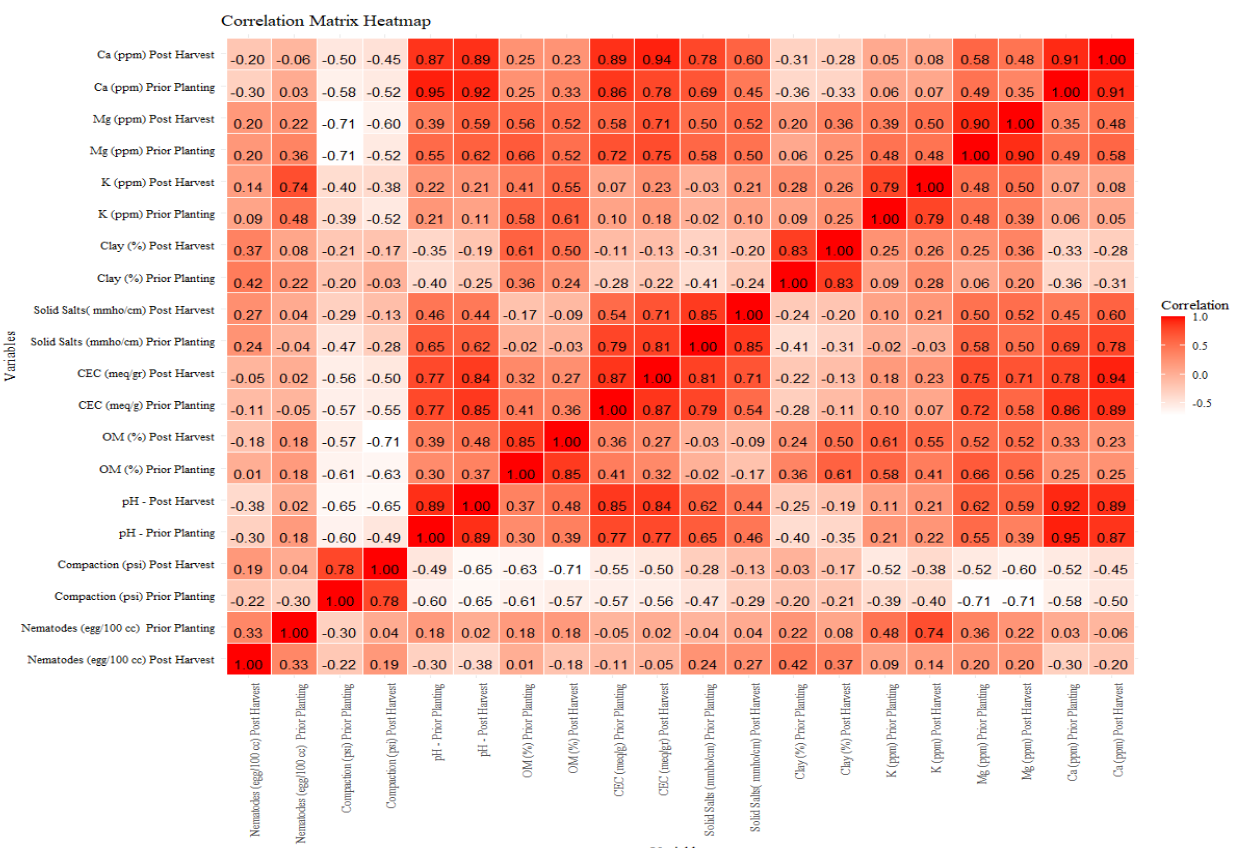


Fig 9. Nematode correlation matrix heat-map

Progress

The soybean harvest has been successfully completed, and while the sampling and initial data collection phase is finished, we are currently awaiting the receipt of detailed harvest data. For a thorough analysis, it's crucial to obtain more specific information about the agricultural practices employed in the field, particularly regarding fertilizer and herbicide applications. This additional data will be instrumental in enriching our understanding and facilitating a comprehensive evaluation of the field conditions and their impact on the crop yield and health.

Outcome

In conclusion, our research provides valuable insights into the relationship between nematode counts and soil properties, but it is crucial to consider the complexity of field conditions and the need for further investigations to establish more robust correlations. Understanding these interactions will enhance our ability to implement targeted management strategies for nematode control, contributing to improved soybean crop health and productivity.

Challenges & future works

One of the biggest challenges faced during the study was the lack of cultivation uniformity in the field, resulting from the presence of three different ongoing projects. Mapping only a single field limited the ability to fully understand and accurately identify the most crucial soil factors influencing SCN breeding under various biotic and abiotic conditions. To obtain more precise insights, it becomes imperative to gather additional data from different fields. The goal is to publish these test results to encourage more farmers to participate in monitoring SCN in their infested fields, paving the way for a clearer path towards comprehensive understanding and effective management strategies. We are currently seeking collaborative partners for the future phase of this project. We need to work and collaborate with growers in their fields to get more precise insights and gather additional data from different fields and disseminate and share the results of this study with them.

Soybean Cyst Nematodes Spatial Detection Using EC Mapping

Cyst Nematode (*Heterodera glycines Ichinolie)* is the most damaging soybean pest. Therefore, it needs to be managed to minimize yield loss. Sampling is an efficient way to determine if Soybean Cyst Nematodes (SCN) are present in a field. A positive SCN detected field requires adopting an integrated management approach, including planting resistant cultivars, non-SCN hosts, poor SCN host crop rotation, or using nematicide seed treatments (Niblack, 2005). The cysts can remain viable for more than ten years and continue to reproduce and accumulate in the soil if an SCN host is included in the crop rotation. A periodic SCN soil test is also needed to monitor the SCN population changes in the field. An increase in SCN populations would call for tactics or management methods (Strunk and Byamukama, https://extension.sdstate.edu-cyst-nematode). From a practical standpoint, nematode detection and characterization based on the physical collection of soil samples is labor-intensive and time-consuming.

The population of cyst nematodes in the infected area depends on soil and climate conditions and the host plant's existence. Based on previous research, the nematode population density is consistently higher in sandy soil than in clay or loam (Wyse-Pester et al., 2002; Avendaño et al., 2004; Monfort et al., 2007; Cheng et al., 2018). Similarly, sand, clay, and silt in the soil are spatially structured and strongly correlated with SCN population density (Avendano et al., 2004).

According to research studies, the percentage of clay or sand in the soil is strongly correlated with EC data and has a significant correlation with SCN populations (Overstreet et al., 2014). On the other hand, cover crops significantly reduced the population densities of nematodes without nematicides application (Marshall et al., 2016). This study also suggest that cover crops can reduce SCN populations. However, selecting non-SCN hosts or poor SCN hosts in cover cropping systems in crop rotation is recommended, especially for the suspected area or a positive SCN detected area.
We propose to evaluate and demonstrate soil property map value as an indicator of where SCN can be expected in an infested field. This study provides the basics for how site-specific soil texture data can improve the spatial prediction of SCN. We will collect soil samples in a geostatistical sampling design based on soil properties variation.

The EM-38 equipment is now available at SDSU and measures equivalent soil electrical conductivity across a field to rapidly determine various soil physical properties. The implement can be operated at 5-20 mph speeds and can measure a 40-60 ft swath in most fields. This equipment would allow a 100-acre field to be mapped for the soil type in a few hours rather than the several days required for manual grid sampling and standard laboratory texture analyses. Soil texture maps allow producers to selectively focus nematode sampling efforts only in the parts of the field with a high probability of having a nematode problem.

This is a **three-year** project with **the overarching goal** of assisting soybean producers in adopting advanced technologies, including site-specific detection strategies in improving SCN management in infested fields. We are seeking to collaborate with soybean growers to work with us on this project.

For more information or/and if you are interested in working with us, don't hesitate to contact Dr. Nafchi at Ali.Nafchi@sdstate.edu.

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