Research Yields Results

2018 Research Report

North Dakota Soybean Council

Our World Is Growing.

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2018 Research Committee Report

Any coach knows that the season is a relentless pursuit of improvement for their team. The goal is to get better, more efficient, and to peak at the right time. Farmers have a similar mindset because we are always on the hunt for ways to be more productive and to show continuous improvement. As is the case with sports, it takes a team effort to make all participants better.

The North Dakota Soybean Council (NDSC) is a vital part of North Dakota's team working to enhance the productivity of the state's soybean farmers and to expand markets for those beans. In fiscal year 2018, NDSC supported 37 research projects designed to improve the agronomics of growing soybeans in North Dakota or to create new, value-added uses for soybeans. The NDSC invested $1,709,822 in research, which is 27.6 percent of our budget.

That investment is crucial because soybeans are becoming increasingly important to North Dakota. The state's production has skyrocketed from 1.85 million acres in 2000 to 7.05 million acres in 2017. Soybean production in the state increased by 1,575 percent between 1980 and 2017. North Dakota is now the nation's fourth-largest in planted soybean acres. We've also seen yields climb from 17.5 bushels per acre in 1980 to a record 41.5 bushels per acre in 2016. Many of those advancements were bolstered by check-off funded research.

Supporting relevant soybean research is a priority for the NDSC. As farmers, members of the NDSC research committee take the responsibility of investing checkoff funds very seriously. We know that research is needed to keep soybean production growing. The NDSC will do its part to provide the state's farmers with the resources they need to perform at their peak. It's what good teammates do.

Troy Uglem
NDSC Research Committee Chair
tuglem@ndsoybean.org

Kendall Nichols
NDSC Director of Research
knichols@ndsoybean.org

NDSC Research Committee Chair Troy Uglem and NDSC Director of Research Kendall Nichols discuss research priorities for North Dakota soybean farmers.

North Dakota Soybean Council Research Committee

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Staff – Kendall Nichols, Director of Research

On The Cover

Front cover: Dr. R. Jay Goos of NDSU screens soybean varieties for iron deficiency chlorosis through his research for North Dakota soybean farmers.

Back cover: Thanks to North Dakota Soybean Council's financial support, valuable soybean research is conducted at NDSU's Agriculture Experiment Station Research Greenhouse Complex in Fargo. Dr. Guiping Yan and team conduct soybean research in the NDSU greenhouse.

—Photos courtesy of Wanbaugh studios

Use of Exogenous Enzymes to Improve the Nutritive Value of Soybean Hulls

Principal Investigator: *Uchenna Anele, former animal scientist, Carrington Research Extension Center*
Co-Investigators: *Chanda Engel, former research specialist, Carrington Research Extension Center; and Bryan Neville, animal scientist, Carrington Research Extension Center*

Funded Project
$12,740

Creep feeding can be a profitable practice if the increased cattle-weaning weight and feed efficiency outweigh the feed's cost. Soybean hulls are an important byproduct of the oil-extraction process and have been utilized effectively in creep feed. Using additives, including exogenous enzymes, has shown the potential to improve feed digestibility in laboratory studies. However, limited beef-cattle research is available in the published literature, so continued research to evaluate the effects of enzyme additives on beef-cattle performance and feed efficiency is warranted.

Domestic animal agriculture remains important to all soybean farmers.

The research's premise was to evaluate the influence of a combination of enzymes on animal performance when given a soybean hull-based creep feed compared to a control treatment with no enzyme additives. To accomplish this task, 87 Red Angus-sired calves were fed similar creep-feed rations that either included or did not include enzyme additives. Creep-feed rations were formulated to contain 13.6 percent crude protein, 0.72 mcal/lb NEm and 0.46 mcal/lb NEg, and the rations consisted of soybean hulls, rolled corn, field peas, modified distillers' grains with solubles, straw, and trace minerals and other supplements.

Including enzyme additives in the creep feed resulted in no difference for the animals' body weight at the study's conclusion or on the calves' average daily gain during the study. However, the experimental power of the current project was limited, so larger projects may yield different results.

While enzyme additives have improved the feeds' digestibility in laboratory studies, benefits for the feed efficiency and digestibility of soybean hull-based creep-feed rations require further research. Understanding the mechanisms by which enzyme additives affect digestibility is an important part of the information that may lead to a greater use of enzyme additives across the beef industry. Producers should depend on economics and production goals to drive decisions about the opportunities creep feeding offers for their operation.

NDSC Director Austin Langley of Warwick raises cattle on his farm.

> "The research's premise was to evaluate the influence of a combination of enzymes on animal performance when given a soybean-based creep feed compared to a control treatment with no enzyme additives."

Road Performance Testing and Promotion of Soy-Based Dust Control

Principal Investigator: *James A. Bahr, NDSU Research and Creative Activity Department*

Funded Project
$32,000

Road dust is a common problem in the United States' rural areas and can lead to health issues for the people living and working in these dusty environments. Calcium chloride and magnesium chloride are the most commonly used dust-suppressant materials because they are inexpensive and easy to apply. However, these salts are corrosive to vehicles and tend to wash away in the rain, resulting in environmental buildup.

In Fiscal Year 2016, we developed a soy-based road-dust control agent at North Dakota State University by combining soy biodiesel with glycerol, a waste product from biodiesel manufacturing, in a chemical reaction to synthesize a non-toxic, biodegradable and non-corrosive dust suppressant. The following year, we scaled up the synthesis to make 1,200 gallons of the product and applied it to a gravel road for testing.

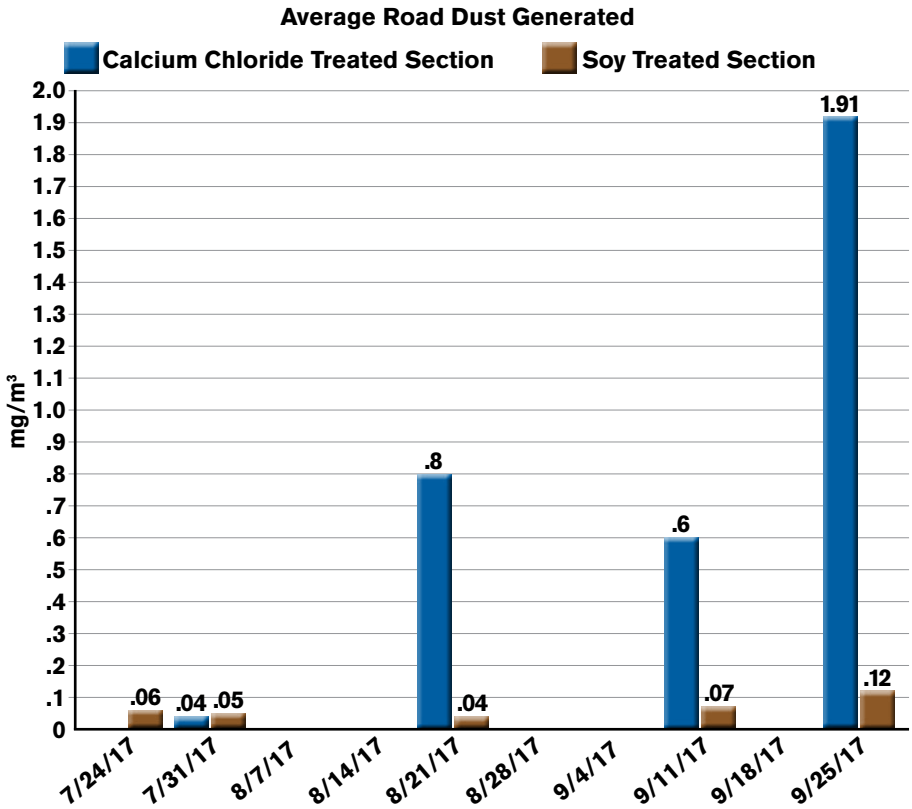
In Fiscal Year 2018, we continued to monitor the performance of both our soy-based dust-control agent and calcium chloride for one full year at a gravel-road test site in Cass County, North Dakota. The data collected with our vehicle-mounted dust meter showed that the soy product was as good as the calcium chloride initially, but as time passed, the calcium-chloride performance began to decline. By the end of the summer, the dust levels on the calcium-chloride section were comparable to the untreated section of roadbed. The soy product's performance remained exceptional over the summer, and its effectiveness carried into the following spring.

In addition to monitoring the performance of the soy-based dust-control agent, we promoted the technology by attending conferences, writing proposals and distributing a marketing survey to people in the industry. These efforts paid off with two new proposals funded and increased awareness of the product. The new funding will allow us to perform a second road test and to study the use of this material as an asphalt rejuvenant.

General road test site remains dust free two months after soy-based treatment.

The market for dust control in the U.S. is quite large with over 1.3 million miles of unpaved roads and over $300 million spent annually to mitigate dust. A dust-control product which is derived from soybean oil and biodiesel waste should increase the demand for these materials and expand the market for soybean oil. In addition, soybean growers who live on gravel roads will benefit from an environment-friendly dust-control product that they can apply to their roads.

Samples of gravel and reclaimed asphalt are prepared in the lab by James Bahr.



Optimization of a Novel Soy-Based Resin for Commercial Acceptance

Principal Investigators: *Dilpreet S. Bajwa, Mechanical Engineering, NDSU; and*
Dean C. Webster, Coatings and Polymeric Materials, NDSU

Funded Project
$25,540

The desire to make environment-friendly, non-toxic and lower-cost wood-based products has created interest for developing adhesives that can replace phenol and formaldehyde adhesives. Soybean oil is the most readily available alternative, and it is one of the lowest-cost vegetable oils in the world. For many years, soybean oil has been a major ingredient in alkyd resins which are dissolved in carrier solvents to make oil-based paints. Alkyd resins are considered to be a building block for the adhesives used with wood composites.

Commonly used adhesives include phenol formaldehyde (PF), urea formaldehyde (UF), melamine urea formaldehyde (MUF) and methyl diphenyl diisocyanate (MDI). Formaldehyde resins are under a great deal of scrutiny because of formaldehyde emissions and chemicals which are known to cause allergies or skin and eye irritations. The Environmental Protection Agency has described formaldehyde as a cancer-causing carcinogenic compound. Our research team has illustrated that soybean-oil-based epoxidized sucrose soyate (ESS) can be successfully used to replace formaldehyde resin without any major technological investment. One barrier for commercial acceptance is a longer curing time for the ESS resin than for traditional resins. This project focuses on understanding and identifying techniques that will reduce the ESS resin's curing time so that the product is acceptable for the industry.

> “Soybean oil is the most readily available alternative, and it is one of the lowest-cost vegetable oils in the world.”

Soy oil

To meet the project's objective, the team had two tasks: 1) to evaluate the ESS resin's curing kinetics using the most-effective cross linker and catalyst blends as well as to optimize/reduce the curing time so that it matches the industry standards and 2) to manufacture particleboards with ESS resin blends which have the lowest curing time as well as to test their physical and mechanical properties. The team showed that two novel cross-linkers (MHHPA and MTHPA) and three catalysts (AC-8, BV-CAT7 and BV-CAT7FC) could help with the curing-time reduction. The materials were supplied by the Broadview Company in New Jersey. After initial testing, three formulations were identified for use when manufacturing lab-scale particleboards. The particleboards were created using a hot press and were tested per the ASTM D1037 standard.

The results showed that crosslinker MHHPA and catalyst BV-CAT7FC can reduce the particleboards' curing time from 30 minutes to 5 or 10 minutes when pressed under 175°C or 190°C. Further, the ESS resin can easily be blended, up to 50 percent, with commercial adhesives without a significant loss in its strength and durability properties. This resin's low curing temperature will help manufacturers conserve energy as well as providing a safe and green alternative to replace formaldehyde adhesives.

This research's outcomes/results are expected to benefit North Dakota soybean farmers because the findings will diversify soy-based products with increased demand for soybean oil, the ESS adhesive's principal component. The market will have a formaldehyde-free adhesive for particleboards. It will also help the North Dakota economy by attracting investors and other soy-processing industries. This work supports and advances the mission and vision set by the North Dakota Soybean Council.

Nitrogen Relationships in Soybeans for Southwest North Dakota

Principal Investigators: *Ryan Buetow, NDSU Extension cropping systems specialist, NDSU Dickinson Research Extension Center; John Rickertsen, NDSU research agronomist, NDSU Hettinger Research Extension Center; and Glenn Martin, NDSU agronomy research specialist, NDSU Dickinson Research Extension Center*

Funded Project $14,944

The Dickinson Research Extension Center worked with the Hettinger Research Extension Center to observe the effects of different management strategies on soybean growth and yield. The objectives were to evaluate the variations among four nitrogen (N) management strategies applied to two soybean cultivars with different maturities, and at two populations. The research was conducted at two locations; however, only data from the Hettinger location were recorded in 2017 due to herbicide damage. Soybean production has increased in southwest North Dakota recently, and there are many questions about the proper management due to the regional differences compared to eastern North Dakota. The 2017 growing season was a difficult year with drought conditions; however, rains during August contributed to soybean yields (Figure 1).

August rainfall aligned with soybean flowering, allowing the plants to attain decent average yields when considering the poor conditions earlier in the growing season. Although there were no significant differences among N treatments alone (Figure 1), there were yield differences for the interaction between populations of 80,000 and 160,000 plants per acre with the N treatments (Figure 2); this interaction needs to further investigation before drawing any conclusions. No significant yield differences were found between populations: 80,000 plants/acre averaged 23.3 Bu/ac while 160,000 plants/acre averaged 24.2 Bu/ac. This lack of a yield difference may be due to the drought; however, more work needs to be conducted in order to observe the effects of plant population on yield in western North Dakota.

Drought conditions in 2017 reduced the soybeans' yield capacity. With drought conditions, a plant population that was half the recommended seeding rate yielded as well as the full rate. While there is the potential that, with higher rainfall, a larger yield is possible, more work should be conducted before changing recommendations. Under drought conditions with a reduced-yield potential, it may possible to reduce seed-input costs without losing bushels.

Photos taken in Hettinger 2017 on August 11th (above) and September 11th (below) observing treatments on a group 0.3 maturity and a 0.6 maturity.

> "With drought conditions, a plant population that was half the recommended seeding rate yielded as well as the full rate."

Using Silver Nanoparticles as an Alternative to Conventional Fungicides in Order to Manage White Mold in Soybeans

Principal Investigators: *Dr. Venkat Chapara and Amanda Arens, NDSU Langdon Research Extension Center; and Dr. Achintya Bezbaruah, Civil and Environmental Engineering, NDSU*

Funded Project
$24,030

This project's goal is to determine the fungicidal properties of silver nanoparticles which are prepared in the laboratory to manage white mold caused by Scelrotinia sclerotiorum on soybeans in field conditions, and to use as an alternative to conventional fungicides in managing white mold.

The effective concentration of silver nanoparticles on Scelrotinia sclerotiorum isolates was determined in the laboratory, and the appropriate concentration and application timing of silver nanoparticles were tested in field conditions. Tests took place at the Langdon Research Extension Center (LREC). Isolates were tested alone and in combination with biological fungicide (Ballard Plus®). Silver nanoparticles were prepared at the NDSU Department of Civil Engineering's laboratory in Fargo. S. sclerotiorum isolates were recovered from sclerotia collected from infected soybean stems during the previous year. Of the 23 S. sclerotiorum isolates, five isolates were randomly picked and tested for efficacy by determining the EC_{50} values (the effective concentration at which 50 percent fungal-growth reduction occurs) at the LREC Plant Pathology Lab. The concentrations of silver nanoparticles used for the sensitivity test were 0; 1; 10; 100; 500 and 1,000 µg/ml.

The efficacy of laboratory-prepared and commercial silver nanoparticles was tested in field conditions using concentrations of 500 and 1,000 µg/ml. Foliar applications of silver nanoparticles alone and in combination with Ballard Plus were compared with standard doses of the conventional fungicide "Endura" and a biological fungicide "Ballard Plus" at the R1 and R4 soybean stages. Supplemental irrigation was provided to enhance disease incidence during the flowering season.

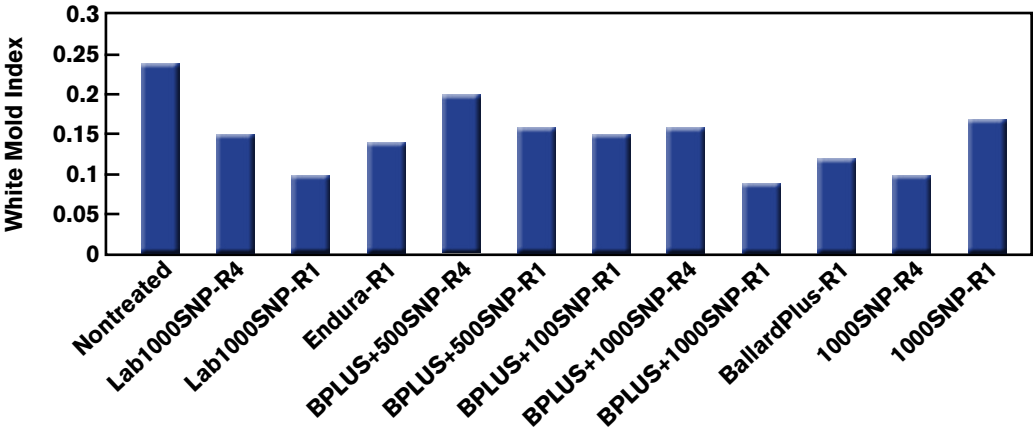
In laboratory results, silver nanoparticles at very high concentrations showed the response of growth reduction on the S. sclerotiorum isolates when grown on silver-nanoparticle-amended potato dextrose agar (PDA) culture media Petri plates. The EC_{50} values ranged from 211 to 703 µg/ml, indicating that silver nanoparticles alone do not have fungicidal properties (Figure 1).

Field-research results indicated that the mean white-mold incidence was high (9.5 percent) for the non-treated control, with a mean severity of 2.5 percent, and had a higher index (percentage of white mold incidence x severity/100) when compared with the other treatments in the current research trial. The lowest white-mold incidence was observed in the combination treatment of commercial-grade silver nanoparticles at 1,000 µg/ml with a standard dose of Ballard Plus when applied at the soybean's R1 stage (Figure 2).

It is difficult to draw conclusions from one year of research with a low disease incidence.

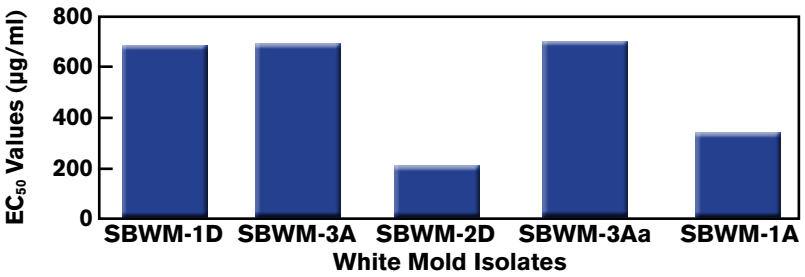
The objective of silver nanoparticle residue determination in soybean seed remains in progress.

Figure 2: Efficacy of silver nanoparticles tested (SNP'S) alone and in combination of biological fungicide BallardPlus (BPLUS) on white mold (mean Index) at R1 and R4 growth stages of soybeans under field condition



Treatments applied at R1 and R4 stage

Figure 1. EC_{50} values of white mold isolates tested on Potato Dextrose Agar culture media amended with silver nanoparticles.



EC_{50} Values (µg/ml) of silver nano particles tested in the laboratory on five *Sclerotinia sclerotiorum* isolates of soybean

Dr. Venkat Chapara shares his research with farmers.

Soil and Water Management for Soybean Production Under Fargo Clay

Principal Investigators: *Dr. Amitava Chatterjee and Dr. Aaron Daigh, Soil Science, NDSU*
Co-Investigator: *Umesh Acharya, Graduate Student, NDSU*

Funded Project
$15,050

Conservation tillage and soil-water management are key components for soybean production in smectitic Fargo clay soil. Installing subsurface drainage is a common practice in waterlogged areas that have the potential to suffer yield losses. Integrating subsurface drainage and reduced tillage (no-till or strip till) can improve soil health and remove excess water, leading to increased soybean production. The extent of the subsurface drainage's benefit depends on its design, depth of tile and spacing between the drains. We are conducting a long-term, on-farm experiment to determine the effects of (i) subsurface drainage and tillage interactions and (ii) subsurface drain depth and spacing combinations on soybean production. This experiment is located at the Ron Holiday farm near Casselton, North Dakota.

Figure 1. Effect of drainage [surface drained(Check), controlled drainage (CD) and conventional drainage (OT)] and tillage practices; chisel (CH), no-till (NT), and strip-till (ST) on soybean yield (Bu/ac) during 2017 growing season.

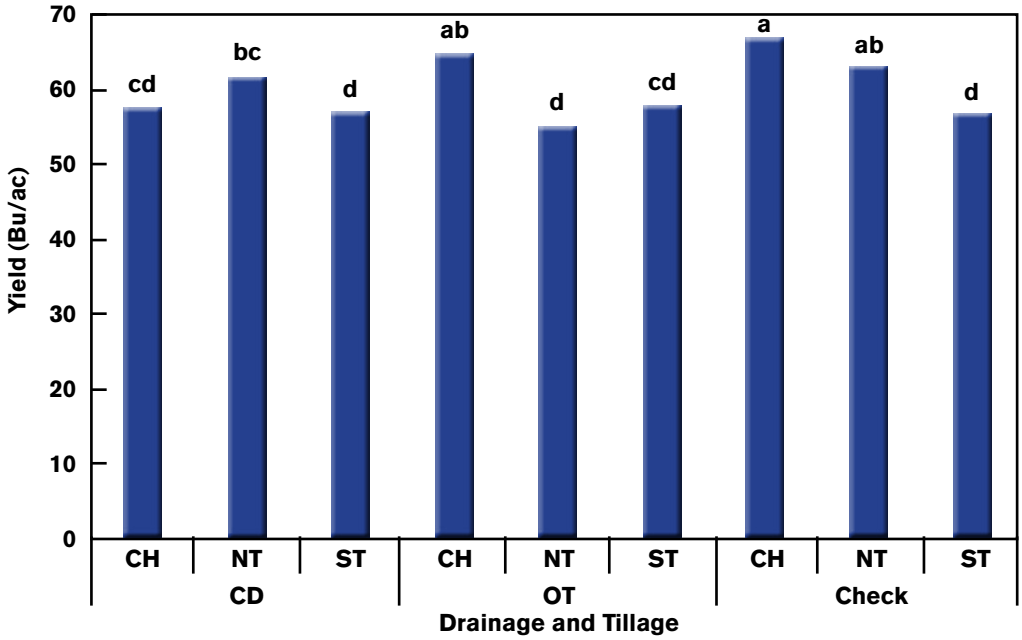
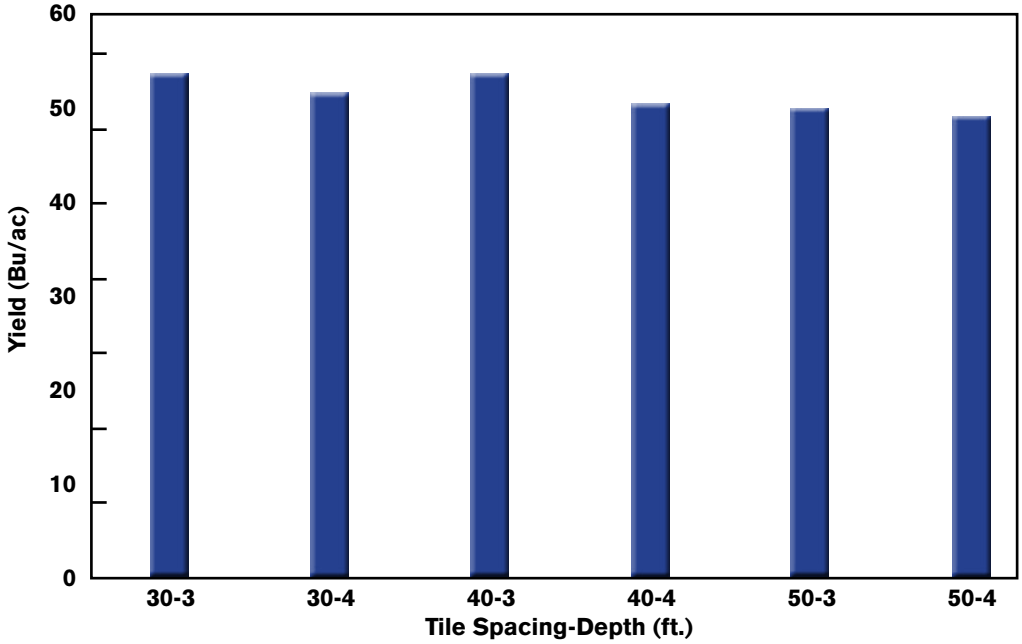


Figure 2. Effect of different subsurface drain spacing (30, 40 and 50 ft.) and placement depth (3 and 4 ft.) combination on soybean yield during 2017 growing season.



For the first objective, three tillage practices, (i) chisel (CH), (ii) strip-tillage (ST) and (iii) no-tillage, are compared for soybean production with surface-drained conditions, which functioned as our check; controlled drainage; and conventional-drained conditions.

The soybean yield for the 2017 growing season is presented in Figure 1. The highest soybean yield was observed with the chisel plough for the check condition (surface drainage), whereas the lowest yield was observed for the conventional drainage and strip tillage. The outcome indicated that performance depends on the growing-weather conditions. In 2017, it was dry with only 217 mm (8.5 inches) of rainfall, which is very low compared to the 30-year average of 397 mm (15.6 inches) during the growing season.

For the second objective, combinations of three subsurface drain spacings, 30, 40 and 50 feet, and two depths, 3 and 4 feet, were evaluated for soybean production (Figure 2). During 2017, the highest soybean yield of 30.5 Bu/ac and the lowest yield of 23.2 Bu/ac were found with the 30-feet tile spacing at the 4-foot depth (30_4) and surface drained, respectively. In 2015, the highest yield of 56.85 Bu/ac was observed with 40-foot drain spacing at a 3-foot depth, and the lowest yield was recorded for the 50-foot tile spacing at 4-foot depth (50.16 Bu/ac).

> "We are conducting a long-term, on farm experiment to determine the effects of subsurface drainage and tillage interactions."

Investigating the Feasibility of Artificial Pollination as a Herbicide-Resistant Weed Management Tool

Principal Investigator: *Michael J. Christoffers, Plant Sciences, NDSU*

Funded Project
$1,399

The problem of herbicide-resistant weeds in soybean production is well documented, and it is important for soybean growers to have diverse tools to fight herbicide resistance. Artificial pollination is when pollen is purposefully applied to plants in order to supplement the pollination that occurs naturally. When using artificial pollination, introducing pollen from normal, herbicide-susceptible plants into resistant weed populations might help reduce the frequency of herbicide resistance. To speed reversion back to herbicide susceptibility, the introduced pollen might even carry genes for new biological pest-management strategies, such as gene drives. However, artificial pollination is poorly studied in weeds.

We performed artificial pollination experiments by using a small birdsrape mustard plant that is often utilized for laboratory experiments in plant sciences. Pollen from birdsrape mustard with purple stems was suspended in a solution that is known to keep pollen alive, and then, the solution was sprayed onto the flowers of birdsrape mustard with green stems. We grew the resulting seed and checked for purple-stemmed plants, which would indicate successful artificial pollination. We did not observe any purple-stemmed plants when the pollen was sprayed, and we only observed successful, but inconsistent, artificial pollination when the flowers were dipped into the pollen-containing solution or dusted with dry pollen. This indicated that achieving artificial pollination using a pollen spray is difficult and that dry pollen applications might have more potential.

If artificial pollination methods were improved and used in the field, herbicide-resistant waterhemp would be a likely target weed. We studied the ability of waterhemp pollen to be kept alive during storage at room temperature, in the refrigerator and in the freezer. We found that waterhemp pollen remained alive for up to two weeks in all conditions but died when stored at room temperature for at least four weeks. Pollen which was kept in the refrigerator or freezer for four weeks remained alive. These results suggested that waterhemp pollen to be used for artificial pollination could be stored for at least a month in a refrigerator or freezer. However, this result needs to be confirmed on a larger scale.

Our results show both the difficulty and potential of artificial pollination. Further development of this potential tool for herbicide-resistant weed management is needed before this or other new technologies are useful in the field. Currently recommended herbicide-resistant weed management practices remain the most important strategies for soybean producers.

Soybean Yield Response with Selected Establishment Factors and Special Inputs

Principal Investigators: *Greg Endres, Extension area agronomist and Dr. Mike Ostlie, NDSU Carrington Research Extension Center*

Funded Project
$8,700

Field study 1 was initiated in 2015 and concluded in 2017 at the CREC to examine the soybeans' response to paired rows and plant canopy types. Data from this study will assist farmers and crop advisors with answering questions regarding any advantages that are achieved by using paired-row spacing and if the plant canopy type is a contributing factor for increasing soybean yield.

Study row spacings were as follows: a) 7-inch pairs (centered on 28-inch spacing), b) 14 inches and c) 28 inches. Averaged over the 3 years, seed yield was similar between the paired (41.9 Bu/ac) and 14-inch (42.4 Bu/ac) rows, and was greater than the 28-inch (37.8 Bu/ac) rows.

The study's two plant canopy types were intermediate and bush. The two varieties with differing canopy types, when compared each year of the study, had similar maturity group ratings, yield potential, plant height and several other agronomic traits. Averaged across row spacings, canopy types had a similar canopy closure each year of the study. Canopy type likely did not influence the seed yield.

Field study 2 was conducted in 2015 and concluded in 2017 at the CREC tri-county research site in the Wishek area in order to examine the soybeans' response to seed-inoculation methods with rhizobia bacteria and special foliar inputs.

With a previous history of soybean production—one year between soybean crops—in a field, is there a yield advantage with double-seed inoculation, including the use of a liquid and granular formulation, versus the use of a single formulation of inoculant? During each study year, there were no statistical yield differences among the inoculation methods, including the untreated check. Averaged over the 3 years, the following soybean yields were obtained with the various seed-inoculation methods: 1) untreated check, 40.2 Bu/ac; 2) liquid, 41.6 Bu/ac; 3) granular, 42.4 Bu/ac; and 4) double inoculation, 42.9 Bu/ac.

If soybeans are grown by using the best management practices according to NDSU recommendations, is there a consistent yield advantage with special foliar inputs? During each study year, there were no statistical yield differences among the special inputs compared to the untreated check. Averaged over the 3 years, the following soybean yields were obtained with the various foliar treatments: 1) untreated check, 40.2 Bu/ac; 2) plant-growth promoter (Ascend, Winfield), 43.7 Bu/ac; 3) multi-nutrient fertilizer (Max-In Ultra ZMB, Winfield), 42.8 Bu/ac; and 4) fungicide (Priaxor, BASF), 42.9 Bu/ac.

Greg Endres speaks to farmers in Carrington.

Harvesting Soil Salts from Soybean-Production Fields: Evaluating a New Method

Principal Investigators: *Dr. Aaron Daigh, and Dr. Thomas DeSutter, Soil Science, NDSU*

Funded Project
$19,482

This project's goal was to test a new method for removing salts from saline soils in order to improve soil health and soybean yields. We surface applied ferric hexacyanoferrate to saline soils, disrupting the formation of a hard salt crust and allowing salt crystals to grow above the soil surface for an easy harvest. Previous studies demonstrated the proof of concept in extremely high saline soils which were contaminated with sodium-chloride brine solutions. This project tested the method on other salt species commonly observed with the naturally occurring saline soils in North Dakota and evaluated any subsequent effects on soybean and wheat health, and soil health.

In this study, sulfate-based salts (calcium, sodium and magnesium sulfates) formed a hard crust at the soil surface and did not allow salt to effloresce (i.e., grow) as anticipated. In previous tests, we observed that up to 60 percent of the sodium-chloride salts effloresced above the soil surface for harvesting. We hypothesized that the lack of sulfate-based salt growth was due to the salts' low solubility as compared to sodium chloride. We then evaluated chemical additives to overcome the sulfate salts' crusting issue. A variety of additives known to increase the sulfate salts' solubility were evaluated. However, such additives were not successful. Investigating in more detail, we concluded that ferric hexacyanoferrate is limited to sodium chloride due to its physical size and geometry that initiates efflorescence and not from early crusting of other salts.

When evaluating the effects of ferric hexacyanoferrate on plant and soil health, we observed that all plant tissues, both above and below ground, and soil metrics were significantly affected by the ferric hexacyanoferrate's loading rate. The only exceptions were for plant-root calcium concentrations and the soil's total fungi, eukaryotes, fungi-to-bacteria ratio, predator-to-prey ratio, monounsaturated-to-polyunsaturated fatty-acid ratio, cation exchange capacity, and soil tests for calcium and magnesium. The soil's bacterial communities within the rhizosphere significantly decreased with loading rates. Moreover, their stress significantly increased with the loading rate. In general, the soil's microbial communities appeared to be more sensitive and affected at lower loading rates for ferric hexacyanoferrate than the plants.

Dr. Aaron Daigh and his research is highlighted on Agweek TV.

The primary goal was to modify the existing method used for brine spills in order to work on natural saline seeps and road-ditch salinity. Unfortunately, modifying our method was not successful, and no clear path is apparent at this time. Thus, the salt-harvesting method remains limited to sodium-chloride brine spills, for example, fracking water spills in northern and western North Dakota. This research still benefits North Dakota soybean farmers by providing insight about the effects that the method will have on soybeans and wheat grown on farmland which has been contaminated via a brine spill and then remediated with existing methods. In general, typical application rates of 200 grams per square meter do not appear to significantly affect soybean and wheat performance. However, the soil's microbial community does appear to be affected at all application rates. Because the ferric hexacyanoferrate increased the stress levels for rhizosphere bacteria, soybeans may endure greater stress during drought periods. Because hexacyanoferrate has a substantially slow degradation rate of hundreds to thousands of years, these microbial stress levels may also persist for a similar time period.

> "The primary goal was to modify the existing method used for brine spills in order to work on natural saline seeps and road-ditch salinity."

Maximizing Soil Warming and Health Under Different Tillage Practices in a Corn-Soybean Rotation

Principal Investigators: *Dr. Aaron Daigh and Dr. Abbey Wick, Soil Science, NDSU; and Jodi DeJong-Hughes, University of Minnesota Extension*

Funded Project
$57,430

There are many advantages when reducing soil tillage. However, reducing tillage creates concern for yield reductions due to cool, wet soils in the poorly drained landscape that dominates much of North Dakota and the Red River Valley. This study's objectives are as follows:

1. Monitor soil warming and water contents under chisel plow, vertical tillage, strip till with shank and strip till with coulter on various soil series
2. Evaluate soil health and crop yields
3. Transfer information to producers

This multi-state effort, involving North Dakota and Minnesota, is in year four of the field study. Four on-farm locations have a corn-soybean rotation and rotate each year. At each location, the four tillage practices are demonstrated by using full-sized equipment in plots that are 40-feet wide by the full length of the field in a replicated design. Soils include silty clay, clay loam, loams and sandy loam. These soil types represent over 67 million acres in the region.

In 2017, the chisel-plow and strip-till berms had the driest and warmest soil conditions, followed by the strip-till berms and then the vertical till as the wettest and coolest soil conditions. The soil's microbial communities appeared to be relatively stable over time during the year.

No differences were observed in soybean-stand counts or yields. However, tile drainage appeared to have a substantially larger influence on soybean yields than tillage or the soil-salinity level. For instance, plot-to-plot variability was 3.9 Bu/ac, on average, among tillage practices, regardless of the soil-salinity levels or drainage management. The same variability was observed among soil-salinity levels. Crop yields were 7.5 Bu/ac higher in tile-drained fields compared to undrained fields.

> "This multi-state effort, involving North Dakota and Minnesota, is in year four of the field study."

Dr. Aaron Daigh

Dr. Aaron Daigh explains his soil warming research to Agweek TV viewers.

This project has produced three videos that have been viewed over 9,700 times around the world and has disseminated information at more than 50 field days, presentations and other university events in order to deliver the study's findings to North Dakota producers. We also developed the Upper Midwest Tillage Guide that was published in 2017 and is available online for free. Information obtained during the 2018 growing season will be presented at joint North Dakota State University-University of Minnesota events in 2018.

Improving Soil Health and the Productivity of Sodic Soils

Principal Investigators: *Dr. Thomas DeSutter and Dr. Amitava Chatterjee, Soil Science, NDSU*
Co-Investigator: *Dr. Abbey Wick , Soil Science, NDSU*

Funded Project
$29,211

Sodium is a natural dispersant. Soil dispersion reduces pore sizes which leads to the blocking or clogging of soil pores and, ultimately, reduces the soil's function. In addition, after drying, sodium-affected soils (sodic soils) become "hard-set" which inhibits proper root and plant growth. Millions of acres of North Dakota soils suffer from too much sodium, ultimately reducing their productivity potential. Identifying and understanding these problem soils is key for proper management and for understanding these soils' economic potential.

We conducted a four-year field study starting in the spring of 2014, examining if sodic-soil amendments and alfalfa could improve the soil health for long-term, improved soybean production on soils which are affected by sodium and salinity. Amendments included three rates each of flue-gas desulfurization gypsum, 5, 15, and 30 tons/acre; sugarbeet spent lime, 5, 15, and 30 tons/acre; and potassium-magnesium sulfate, 1, 2.5, and 5 tons/acre. The two soils used for this study were in the same Natural Resource Conservation Services (NRCS) soil-mapping unit but varied in their properties. One soil was tiled, and the other soil was not tiled. This study's fundamental objective was to enhance the soil properties for improved soybean production.

Dr. Tom DeSutter works on field study research.

Overall, the amendments and their rates of application neither decreased or increased alfalfa yields or quality compared to the control plots. However, the two highest application rates of gypsum and the highest rate of potassium magnesium sulfate on the tiled site increased the iron deficiency chlorosis (IDC) rating to "very high" compared to the control plot. No change in the IDC rating was observed at the non-tiled site. The two highest rates of gypsum, the highest rate of spent lime and the highest rate of potassium magnesium sulfate reduced the potential for swelling and/or dispersion to "medium" compared to the control which was "high." The potential for swelling and/or dispersion was "low" for all plots at the non-tiled site.

Dr. Tom DeSutter identifying soil issues.

> "Identifying and understanding these problem soils is key for proper management and for understanding these soils' economic potential."

Screening Cover Crops to Reduce Soybean Cyst Nematode in Infested Fields

Principal Investigator: *Dr. Guiping Yan, Plant Pathology, NDSU*
Co-Investigators: *Dr. Marisol Berti, Plant Sciences, NDSU; and Dr. Samuel Markell, Plant Pathology, NDSU*

Funded Project
$30,900

Soybean cyst nematode (SCN) is a devastating soybean pest in North Dakota. Host resistance and crop rotation are common practices to manage SCN, but limited resistance sources for this nematode put pressure on a virulence change in populations to overcome the resistance. Therefore, an integrated strategy is necessary for sustainable management of this devastating soybean pest. Cover crops have the ability to reduce plant-parasitic nematodes and may provide an alternative method to manage SCN.

Our objectives were to evaluate common and potential cover-crop species in North Dakota for their hosting abilities to SCN and for reducing SCN numbers in infested fields. Greenhouse and microplot experiments were performed by using SCN-infested soils from two fields in North Dakota's Cass and Richland Counties.

For 35 days, 21 cover crops and two susceptible soybean checks were evaluated for host status in a growth chamber by inoculating each plant with 2,000 eggs (Figure 1). Of the cover crops tested, 13 (annual ryegrass, camelina, carinata, cow pea, ethiopian cabbage, faba bean, foxtail millet, radish, rape dwarf essex, red clover, sweet clover, triticale and winter rye) did not support SCN reproduction, suggesting that they were non-hosts. Six crops (crimson clover, turnip cv. Purple top, hairy vetch, forage pea, Austrian winter pea and field pea cv. Cooper) showed low reproduction for at least one SCN population as poor hosts. Field pea (Aragorn) and turnip (Pointer) showed some reproduction, suggesting that they were hosts for at least one population. SCN reproduced less in all the tested crops compared to the two susceptible checks.

Figure 2. Cover crops grown in large plastic pots with SCN-infested soil in the microplot were under natural conditions to evaluate the SCN-population reduction.

Figure 1. Cover crops grown in cone-tainers with autoclaved sandy soil were inoculated with each SCN population and kept in a growth chamber for 35 days for SCN host-range evaluation.

Ten cover crops were selected for microplot experiments. Crops were planted in pots that contained 5 kg of infested soil (Figure 2). After 75 days of growth before winterkill, soil samples were collected from each pot. Samples were collected again in the spring after winterkill. In both soils, a majority of the crops reduced the SCN populations compared to the susceptible soybeans and non-planted control, where annual ryegrass and radishes were more effective than the others. The spring sampling did not show much reduction in nematode populations compared to the populations before winterkill. Annual ryegrass and radishes greatly reduced SCN by 61 percent and 64 percent, respectively, for the two SCN populations.

Cover crops, which are non-hosts with greater population-reduction abilities, can be integrated into an SCN-management strategy. The research findings will be useful to navigate the selection and use of cover crops for North Dakota farmers who want to reduce SCN damage in order to increase soybean yield.

Soybean Soil Fertility in North Central and Northwest North Dakota

Principal Investigators: *Dr. David Franzen, NDSU Extension soils specialist; and Chris Augustin, NDSU Ph.D. candidate*

Funded Project $15,532

A fertilizer amendment study was conducted near Riverdale, and Columbus, North Dakota, in order to determine whether the current soybean fertility recommendations are appropriate for north-central and northwest North Dakota farmers. In-furrow fertilizer treatments, broadcast fertilizer treatments and foliar treatments were included, along with a side-bar treatment of cobalt as a first look at that element which is not required for soybean growth but is required for N-fixing bacteria.

There were no differences from the check yield between the treatments at either site this year. There were also no differences between treatments with the oil percentage or protein percentage in the seed.

Dr. Dave Franzen conducting field experiments.

North Central Soybean Research Program (NCSRP)

The North Central Soybean Research Program (NCSRP) was founded in 1992 as a Midwest collaboration to facilitate cooperative research and communication among the member states. The NCSRP farmer board members and state staff work together to pool and invest checkoff dollars into research programs for projects that have a regional impact.

NCSRP encourages intra- and inter-university collaborative research programs, thereby reducing duplicative research efforts. NCSRP also fosters increased communication among researchers, with farmers, with companies and with other interested parties and stakeholders through meetings, field days and the Soybean Research & Information Initiative (SRII) website

The NCSRP dedicates $3M - $4M dollars each year to basic and applied soybean research and communication. While research funding must be reviewed and renewed annually, in many cases funded research represents sustained, multi-year projects that deliver state-of-the-art-extending knowledge that directly benefits academics, industry and soybean farmers. Furthermore, many NCSRP funded projects create leveraged projects and funding from private and public sources.

NCSRP research priorities are focused primarily at increasing soybean yield and quality, and managing those insects, diseases, abiotic stressors, weed problems and agronomic challenges that have the potential to significantly limit soybean germination, growth, development and productivity. More recently, the board has considered funding projects related to soil health, soil conservation, soil fertility, nutrient management, water and drainage management, and water quality.

In FY18, all semi-annual reports and final reports were completed in-full and submitted on-time to the National Soybean Checkoff Research Database. Meaningful scientific advancements, new and novel information, and improved agronomic, disease and insect management guidelines were communicated and published. NCSRP-funded researchers developed, submitted and had published numerous scientific and extension articles, brochures, guides and book chapters. NCSRP farmers and staff provided state, regional and national leadership for coordination of research and were successful in obtaining additional USB funding for communications and operations. Finally, NCSRP staff and funded researchers successfully partnered with USB staff and funded researchers to attract multiple private partnerships for the SCN Coalition and a USDA-FFAR grant for soybean yield and quality improvements.

NCSRP program visited North Dakota in August, 2018.

Managing Salinity with Cover Crops: A Whole-System Response

Principal Investigators: *Dr. Caley Gasch, Dr. Abbey Wick and Dr. Tom DeSutter, Soil Science, NDSU; and Dr. Jason Harmon, Entomology, NDSU*

Funded Project
$45,121

In 2017, we initiated a study to see if cereal rye can be used as a cover crop to improve soybean and corn production in saline soils. Soil salinity is a common cause for poor crop yield throughout North Dakota, and effective strategies are needed to enhance the soil health and productivity of salty soils. Cover crops have many soil health benefits, and we think that they can help improve productivity in saline soils, however, they might also compete with the cash crop or encourage pests (Figure 1).

The goals for this research were as follows:

(1) To understand the differences with soils, plant growth and insects in moderately saline soils (soils with an electrical conductivity from 2-4 dS/m).

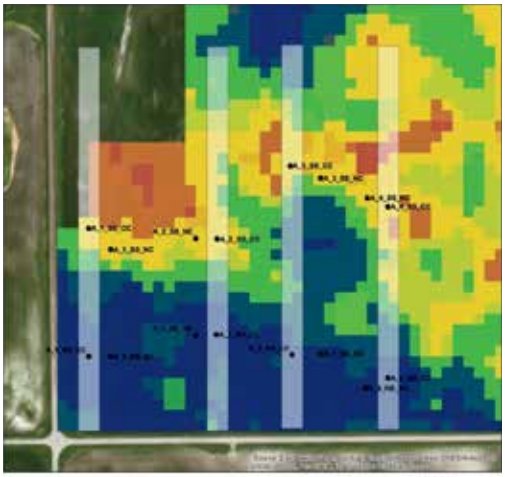
(2) To test if a cereal rye cover crop in a soybean-corn rotation can improve the soil health and crop productivity without introducing too many risks.

We established cover crop trials at four farms that all have patches of salty soil. The trials took place in Aneta, Jamestown and Northwood. We surveyed the soil for salts and interseeded cereal rye at a rate of 40 lbs/ac in strips across the field in order to establish sampling points with and without a cover crop as well as with and without salts (Figure 2). In the first year of the study, we collected baseline soil data, measured yield and surveyed insects. We will continue to measure these for three more years because it takes time for the soil to change.

Figure 1.

Potential Benefits	Whole System Response	Potential Risks
• beneficials, pest predators, weed seed predators	**Insects**	• Different/new pests
• Weed suppression	**Plants**	• ↓ yield • ↑pathogens • Excess water use
• ↓ erosion • ↑organic matter & soil fertility • ↑soil structure & trafficability • Salt & water management	**Soils**	• Excess residue • Fertility tie-up

Figure 2. Aneta Field, Aneta, ND



Plot Info:
SS: saline soil
NS: non-saline soil
CC: cover crop
NC: no cover crop

EC (dS/m)
0-1
1-2
2-4
4-6

In 2017, crops in the saline soils had lower yields, and the cereal rye did not further reduce yields. Saline soils often occur in landscape depressions, so they are consistently wetter throughout the growing season, and the cover crops did not necessarily dry out the soil in the fall. Because there is less plant growth and more water in saline soils, there is a chance that the saline patches contain unused nutrients such as nitrogen and phosphorus. In the next few years of this project, we will continue measuring these properties, and we will also measure the different organisms that live in the soil and in the plant canopy to see if they are good or bad as well as if they change in the areas that have cereal rye.

We still have a lot to learn about cereal rye as a tool for managing soil salinity. In addition to understanding salt management, this research will also help us recognize the uses and limitations of cereal rye for improving soil health and crop yield.

Dr. Carley Gasch conducts field research.

Dr. Carley Gasch chats with farmers about her research.

Iron Fertilizer Evaluation and Improvement

Principal Investigator: *Dr. R. Jay Goos, Soil Science, NDSU*

Funded Project
$10,680

Many iron fertilizers do not work in North Dakota soils because they are quickly converted to insoluble iron oxide (rust) and are, thus, ineffective for alleviating iron deficiency chlorosis (IDC) in soybeans. However, a handful of chelates, FeEDDHA, FeEDDHSA and FeHBED, can "hang on" to the iron tightly enough to keep it soluble. However, these products are difficult to manufacture, and commercial sources are a mixture of isomers and condensates, meaning that their quality varies from product to product.

With so many commercial iron products available, this study's first objective was to evaluate 11 iron fertilizers which are for sale in the region with a greenhouse study. Soybeans were grown for two 4-week "crops," with a control, and the 11 iron fertilizers were applied at a rate of 1 milligram of iron per pot.

One product, "Marathon + Greenboost," was not effective. The label said that it contained 9 percent iron (Fe), and our analysis yielded less than 0.5 percent Fe. All other materials were highly effective with alleviating chlorosis for the first 4-week crop (Figure 1). All materials, except for Marathon + Greenboost, produced plants without chlorosis. (Chlorophyll readings greater than 30 are dark green.)

It was when a second 4-week crop was grown that we observed the fertilizers' "staying power" (Figure 2). Products such as Iron Up, Soygreen, Soygreen Liquid and Ferrale Evo produced plants with the most chlorophyll for the second crop. The chelate FeEDDHSA had some handling advantages over FeEDDHA because it dissolves more easily, but it was estimated that at least 20-25 percent more iron would be needed to equal the iron uptake given by a high-quality FeEDDHA product.

Dr. R. Jay Goos visits with farmers about IDC in Richland County.

One problem with products such as FeEDDHA is that they are mobile in the soil and can leach away from seeds or seedlings with rainfall. The study's second objective was to evaluate ways for slowing this leaching. We are evaluating the effects of granulation and additives to FeEDDHA solutions in order to slow movement. So far, the most promising material is a polymer additive to FeEDDHA solutions that has a gelling action and seems to slow the iron movement.

This work is important to North Dakota farmers because IDC is a widespread and destructive disorder for poorly drained soils. After variety selection, using an effective iron fertilizer is an important control measure.

Figure 1. Average of 1st, 2nd and 3rd trifoliolate leaflets–First crop

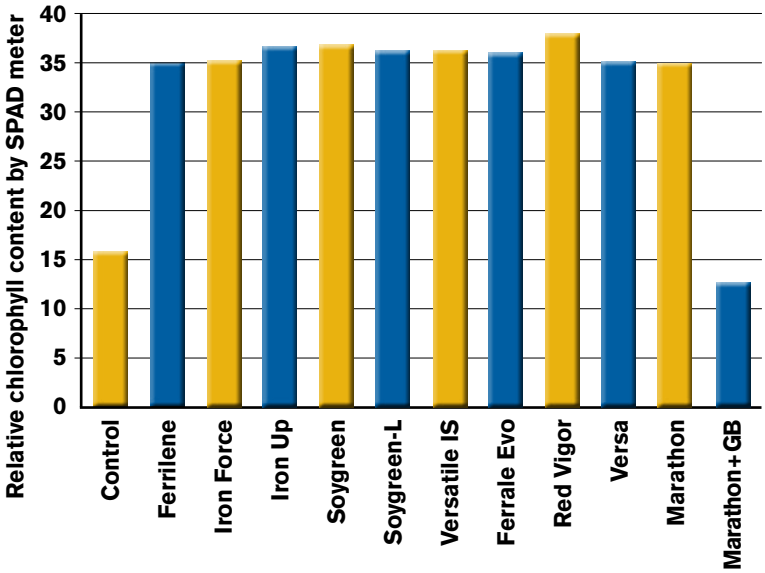
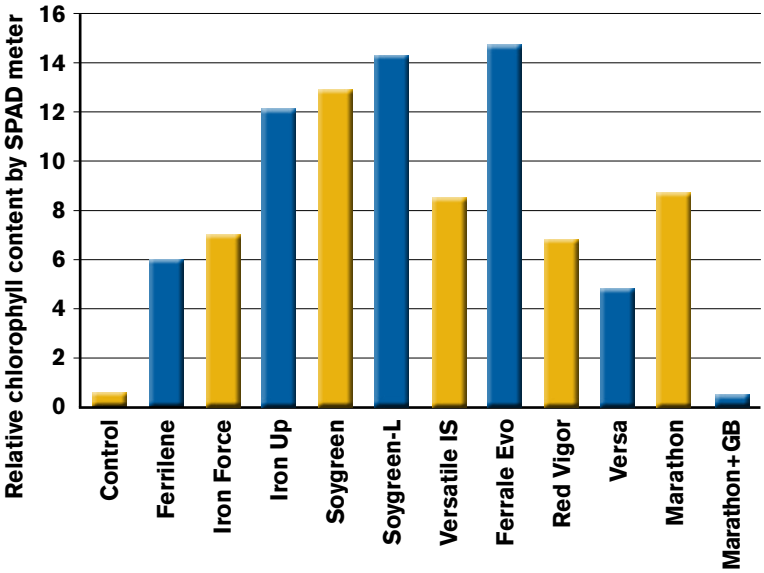


Figure 2. Average of 1st, 2nd and 3rd trifoliolate leaflets–Second crop



Water Stress Development and Mitigation in West Central North Dakota

Principal Investigators: *Dr. R. Jay Goos and Jeremy Wirtz, Soil Science, NDSU; and Eric Eriksmoen, NDSU North Central Research Extension Center*

Funded Project
$30,450

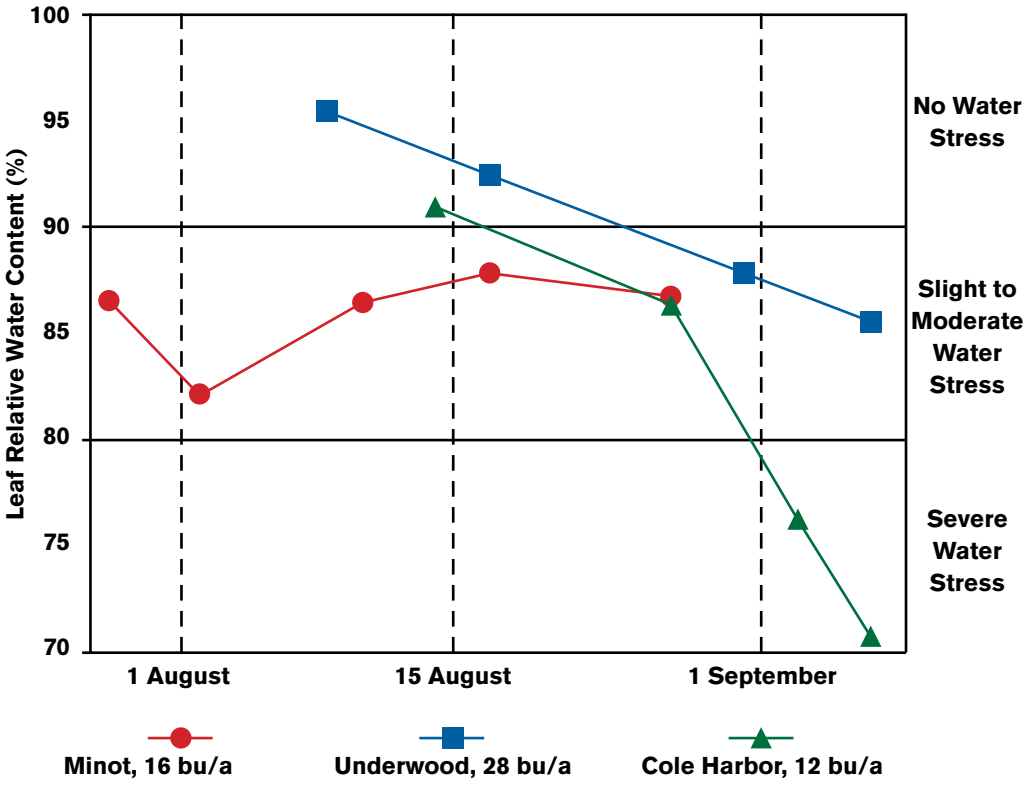
Soybeans are being grown farther west in North Dakota. Water stress is a common yield limiting factor. The purpose of this research was to monitor the development of water stress in soybeans grown at Underwood, Cole Harbor and Minot. Another objective was to determine if "anti-transpirants" could be used to slow the water use earlier in the season in order to make more water available later in the season.

Anti-transpirants slow plants' water use. Modes of action include hormonal or growth-regulator effects; film or barrier anti-transpirants which physically slow water escape from the leaves); and reflective anti-transpirants which reflect light, making the leaf cooler.

Our experiments had 12 treatments that were applied before flowering, after flowering or both. Leaf-water status was monitored using a reliable technique called the Relative Water Content which measures the leaves' water content, allowing the leaves to take up water and rehydrate, and weighing again.

> "Our experiments had 12 treatments that were applied before flowering, after flowering or both."

In general, the experimental treatments did not work. The 2017 growing season was extremely dry in western North Dakota, with water deficits—potential water use minus rainfall—greater than 10 inches. At Cole Harbor and Minot, the growth-regulator ethephon did give some indication of increasing plant-water status, but yields did not increase with anti-transpirant use at any of the three sites.



The water stress patterns were different at the three sites (Figure 1). At the Underwood site, the plants were only under slight-to-moderate water stress at the end of the growing season, and yields were acceptable, given the harshness of the growing season, at 28 Bu/ac. The Minot site had slight-to-moderate water stress for the entire last month of the growing season, and the yield was 16 Bu/ac. The Cole Harbor site was more vigorous than the Minot site for most of the growing season, but essentially "burned up" at the end of the season; the yield was only 10 Bu/ac. Relative Water Content measurements of less than 80 percent were observed, indicating severe stress.

This research is important to North Dakota soybean farmers because a greater understanding of water stress and how water stress affects yields will be important as soybean production moves west.

Breeding of Glyphosate-Resistant Soybean Cultivars

Principal Investigator: *Dr. Ted Helms, Plant Sciences, NDSU*
Co-Investigator: *Dr. Berlin Nelson, Plant Pathology, NDSU*

Funded Project
$164,720

Growers would like to purchase glyphosate-resistant soybean varieties and be able to save their seed to plant the next year. These varieties need to be high-yielding, lodging-resistant, tolerant to iron-deficiency chlorosis (IDC), and have good disease and pest resistance. Soybean varieties are protected by a patent on the glyphosate-resistant gene and are often protected by a second patent on the variety. Monsanto has provided a website to explain these issues (http://www.soybeans.com/patent.aspx).

This purpose is to provide superior glyphosate-resistant varieties that have been developed by North Dakota State University (NDSU). At this time, one glyphosate-resistant soybean variety developed by NDSU is available to growers; it is ND17009GT and is a 00.9 maturity cultivar.

> “This purpose is to provide superior glyphosate-resistant soybean varieties...”

Glyphosate-resistant experimental lines are being developed by the NDSU Soybean Breeding Project. Crosses were initiated in the summer of 2010, and new crosses have been started every subsequent year. As part of the continuing process to develop new lines, 9,150 plant-rows were planted in the spring of 2017. During the 2017 growing season, the first year of replicated yield testing was conducted for 1,152 new glyphosate-resistant, experimental lines. In the 2017 growing season, 174 experimental lines were tested for the second year. A total of 5,440 plots were devoted to this project in 2017. Thirty of those 174 experimental lines were advanced to the third year of yield testing during the 2018 growing season. These advanced experimental lines varied from a 00.7 to a 0.9 maturity.

Seed of four advanced lines that were very competitive with private-company RR2 varieties for yield and agronomic traits were increased in Chile during the 2017-2018 winter season. In the spring of 2018, we planted about 2 acres of seed increase for each of these four experimental lines.

The benefit to the North Dakota soybean industry would be to reduce the cost of soybean seed for varieties that are glyphosate resistant, reducing input costs because growers could save their own seed for glyphosate-resistant soybean varieties that were developed at NDSU. Farmers could then plant this seed without paying a technology fee. Currently, farmers must purchase expensive new seed each year.

Dr. Ted Helms

Dr. Ted Helms and crew harvest his soybean varieties in October, 2018.

Visual Ratings for Iron Deficiency Chlorosis

Principal Investigator: *Dr. Ted Helms, Plant Sciences, NDSU*

Funded Project
$81,762

Iron is less available to the soybean plant with high-pH soils. The symptoms of iron deficiency chlorosis (IDC) include leaves that are yellow in June and sometimes through July. Soybean growers with fields that have a past history of IDC need information to help evaluate varieties from many different companies in side by side comparisons. There are genetic differences for tolerance to IDC among cultivars. Even a small amount of yellowing in the soybean leaves can reduce the final yield by 20 percent. We measure the IDC tolerance by the amount of yellowing in the leaves. For fields with IDC, visual yellowing has been shown to be closely correlated with yield. These data provide unbiased information that enables growers to choose the best variety for their IDC prone fields. Variety choice has been shown to be the most important factor to increase yield for fields where IDC is present.

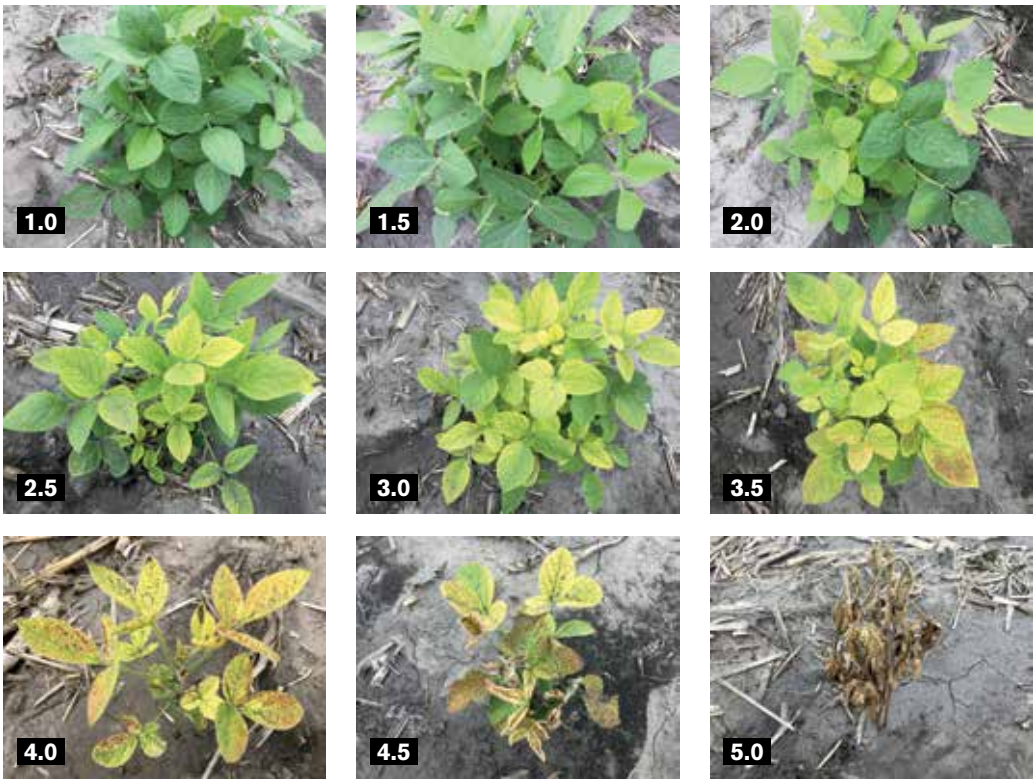
The objective was to screen all private company varieties that have been entered at the Langdon Research and Extension Center (REC), Carrington REC, Minot REC, Williston REC and Fargo Main Station yield trials for visual ratings of IDC at multiple field locations with a past history of IDC symptoms. A second objective was to provide visual IDC screening for the advanced NDSU breeding lines. Assessing soybean varieties from different companies requires that all varieties be evaluated in side by side comparisons in the same field; otherwise, a fair comparison is not possible.

> “The objective was to screen all private-company varieties that have been entered...for visual ratings of IDC at multiple field locations with a past history of IDC symptoms.”

In 2017, four locations on farmer-cooperator fields with a past history of IDC symptoms were identified and were planted with hill plots. There were 270 Roundup Ready company varieties tested as well as 72 Liberty Link and non-GMO company varieties tested. Also, the North Dakota State University (NDSU) soybean breeder evaluated 106 advanced NDSU breeding lines for visual IDC symptoms. Those locations included Leonard, Prosper, Hunter, and Colfax, North Dakota. A total of 7,168 hill plots were planted. Data were analyzed and reported in the NDSU bulletin titled North Dakota Soybean Performance and were posted online.

This is the largest data set with the most comparisons of different company varieties, Roundup Ready, Liberty Link and non-GMO, for North Dakota and western Minnesota. Because the 2017 data were averaged across four locations with four replications per location, the data were quite reliable in helping growers to select the best varieties for their IDC prone fields. These data enabled growers to increase the yield on their IDC prone fields because varieties with the least amount of yellow IDC symptoms will yield the best in fields with that problem.

Dr. Ted Helms shares his research with farmers in Casselton.



IDC Rating Scale

Breeding Improved Non-GMO Cultivars and Germplasm

Principal Investigator: *Dr. Ted Helms, Plant Sciences, NDSU*
Co-Investigator: *Dr. Berlin Nelson, Plant Pathology, NDSU*

Funded Project
$244,207

This research had four broad objectives: i) to increase the yield on iron-deficiency chlorosis (IDC)-prone soils and to increase profits on those problem soils, ii) to enable private companies and growers to compare the yield for soybean cyst nematode (SCN)-resistant cultivars on sites that are infested with SCN, iii) to provide soybean growers in North Dakota with cultivars which are genetically superior to cultivars that are currently grown and iv) to collect grain samples from the Variety Fee Tests and to report the protein and oil data in the NDSU Soybean Performance bulletin.

Growers benefit when different companies' varieties are compared at the same field sites because this enables growers to increase yield on fields that have soil or pest problems. In 2017, yield data were collected on 40 private company Xtend and Roundup Ready 2 (RR2) varieties at three sites that had IDC symptoms. Averaged across the Hunter, Leonard, and Colfax, North Dakota, locations for 2017, the yield range varied from a low of 14.3 Bu/ac for an IDC susceptible company variety to a high of 32.0 Bu/ac for an IDC-tolerant company variety.

> **"Growers benefit when different companies' varieties are compared at the same field sites because this enables growers to increase yield on fields that have soil or pest problems."**

In 2017, four sites that were infested with SCN were planted with 40 Xtend and RR2 company varieties in order to test for SCN resistance. Yields varied from a low of 32.8 Bu/ac to a high of 54.4 Bu/ac. An additional experiment was conducted to evaluate 14 Liberty Link and non-GMO cultivars at four sites that were infested with SCN. The four SCN infested soil test sites were Absaraka, Colfax, Galesburg, and Prosper, North Dakota. These data were published in the North Dakota Soybean Performance Bulletin (A-843) and online.

In 2017, grain samples were collected for protein and oil analyses for all company varieties entered at the LaMoure, Northwood, Grandin, Arthur, Fairmount, and Walcott, North Dakota, testing sites. These samples were analyzed, and the data were reported in the North Dakota Soybean Performance Bulletin (A-843).

A new variety, 'ND Stutsman', was released in January 2017. ND Stutsman is a non-GMO variety with high-yield, good IDC tolerance, resistance to lodging and resistance to race 3 of phytophthora root rot. A second new variety, 'ND Benson', was released in January 2017. ND Benson is a non-GMO variety with good yield, good IDC tolerance, resistance to lodging, resistance to races 3 and 4 of phytophthora root rot, and excellent SCN resistance.

The NDSU breeding program provides growers with the option to plant non-GMO varieties. Growers have the option to purchase non-GMO varieties that have been developed by North Dakota State University (NDSU) without paying a technology fee and can then save their own seed. NDSU's past success to develop non-GMO varieties for the oilseed market includes 'ND Henson', 'ND Stutsman' and 'ND Benson'. The non-GMO varieties developed by NDSU provide growers with an alternative for using glyphosate and permit various herbicides to be rotated in soybean fields across different years.

Dr. Ted Helms harvests his soybean varieties.

NDSU's plot combine harvester.

The Influence of Best Water Management on Soil/Water Quality and Soybean Production

Principal Investigators: *Dr. Xinhua Jia and Dr. Thomas Scherer, Agricultural and Biosystems Engineering, NDSU*

Funded Project
$17,705

Soybeans are very sensitive to soil moisture and salinity conditions in the field. For the last 20 years, it has been difficult to plant or harvest many fields in the Red River Valley due to wet conditions. To solve this problem, tile drainage was quickly established in the region in order to remove excess water, to reduce the soil salinity and to create critical windows of time for planting and harvesting. However, tile drainage water contains high soluble chemicals, including nitrate and dissolved minerals (salts), that can pollute streams and lakes.

In this study, we used six farm fields, four in Clay County, Minnesota, and two in Richland County, North Dakota, to monitor the nutrients and salts coming from tile drainage outlets. We also checked the nutrients and salts in the six fields, comparing their changes due to tile drainage. Crop yields were assessed in the six fields in order to evaluate the tile drainage's effect.

Our results indicated that the nitrate-nitrogen concentration in the tile-drainage water, 6.23 parts per million (ppm), was five times higher than that in the surface drainage ditches, 1.16 ppm. With controlled drainage, the nitrate was retained in the field. Phosphorus monitoring showed that both surface and subsurface flows contained phosphorus concentrations that exceeded the water quality standard. A higher amount of salts was found in the tile drainage flow when compared to the surface ditch water. With good water management practices in the field, we can help retain the nitrate and salts in the field during the late spring and summer, and can improve the water quality for our surface water environment.

Barnes county soybean harvest 2018.

> "In this study, we used six farm fields... to monitor the nutrients and salts coming from tile-drainage outlets."

Soil salinity is a big concern for many soybean growers because it can cause soybean iron chlorosis and can reduce soybean yield. We monitored the soil salinity changes in the field using soil sampling and salinity maps. Our results clearly indicated that soil salinity was reduced with tile drainage. Soil sampling around the tile drains, however, indicated that the soil salinity had increased in one location, likely due to over irrigation. Proper water management is definitely needed for the saline-affected fields. The biggest benefit to the soybean growers and the soybean industry is to understand that, with drainage water management, we can achieve a better yield in the field and can maintain clean water for all citizens in the Red River Valley.

NDSC Director Matt Gast and family of Valley City harvests soybeans in October, 2018.

Management of Soybean Aphids and Interaction with Soybean Cyst Nematode

Principal Investigators: *Dr. Janet Knodel and Dr. Samuel Markell, Plant Pathology, NDSU; and Patrick Beauzay, State IPM Coordinator and Research Specialist, NDSU*

Co-Investigator: *Dr. Ted Helms, Plant Sciences, NDSU*

Funded Project
$40,667

The overall goal of this research is to provide soybean producers with viable pest-management strategies to control two economic pests: soybean aphids and soybean cyst nematode (SCN).

In our first study, the effectiveness of different pest-management strategies for soybean aphids was compared, including insecticide seed treatments and foliar-applied insecticides. Two application timings were tested for the foliar applied insecticides: an early R1 (beginning bloom) and the economic threshold (ET), which is an average of 250 aphids per plant. In conclusion, the best management practices for control of soybean aphids were scouting regularly and using the E.T. for decision-making. These strategies always resulted in the maximum yield. In addition, insecticide seed treatments did not provide an increased yield benefit under low- or high-aphid pressure compared to the non-insecticide treated seed with a foliar applied insecticide at the ET.

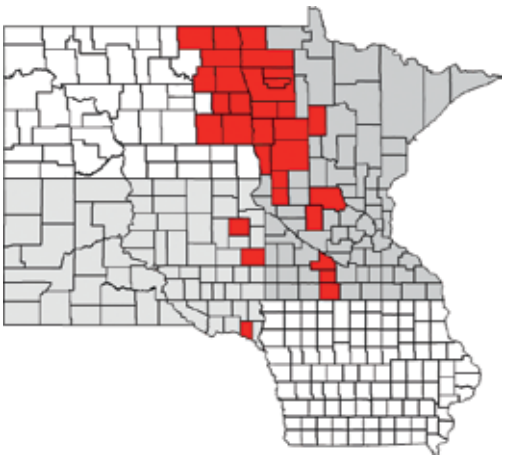
The second study examined SCN populations in SCN-resistant and susceptible varieties as well as how they are affected by different soybean aphid densities. The best pest-management strategy for SCN was using an SCN resistant variety. The SCN resistant variety significantly decreased the SCN population growth and resulted in a significantly higher yield gain, an average of 24 bushels per acre, over the SCN susceptible variety. When soybeans are infested with soybean aphids, SCN reproduction increases on both susceptible and resistant varieties. So, producers are advised to manage soybean aphid populations by scouting and using the E.T. to reduce impacts of SCN.

> “Soybean producers should scout regularly and use the E.T. to control soybean aphids and optimize returns.”

The third study focused on documenting the status of insecticide resistance in North Dakota's soybean-aphid populations. Pyrethroid—an insecticide group—failure to control soybean aphids was reported in nine counties in 2017 (Figure 1). Aphids collected from these problem fields were used to determine if these populations were resistant to pyrethroid insecticides. Laboratory bioassays confirmed that about 70 percent of the soybean-aphid populations tested were resistant to pyrethroid insecticides. Insecticide resistant soybean aphids complicate insecticide management decisions for producers, creating a new challenge for soybean production.

Soybean aphids colonizing underside of soybean leaf (Patrick Beauzay, NDSU).

Dr. Janet Knodel conducts field studies for her research.



Upper Midwest counties with reported failures of pyrethroids for control of soybean aphids in 2017. (Source: Univ. of Minnesota, Dr. Koch)

Soybean Cyst Nematode Sampling Program: 2017

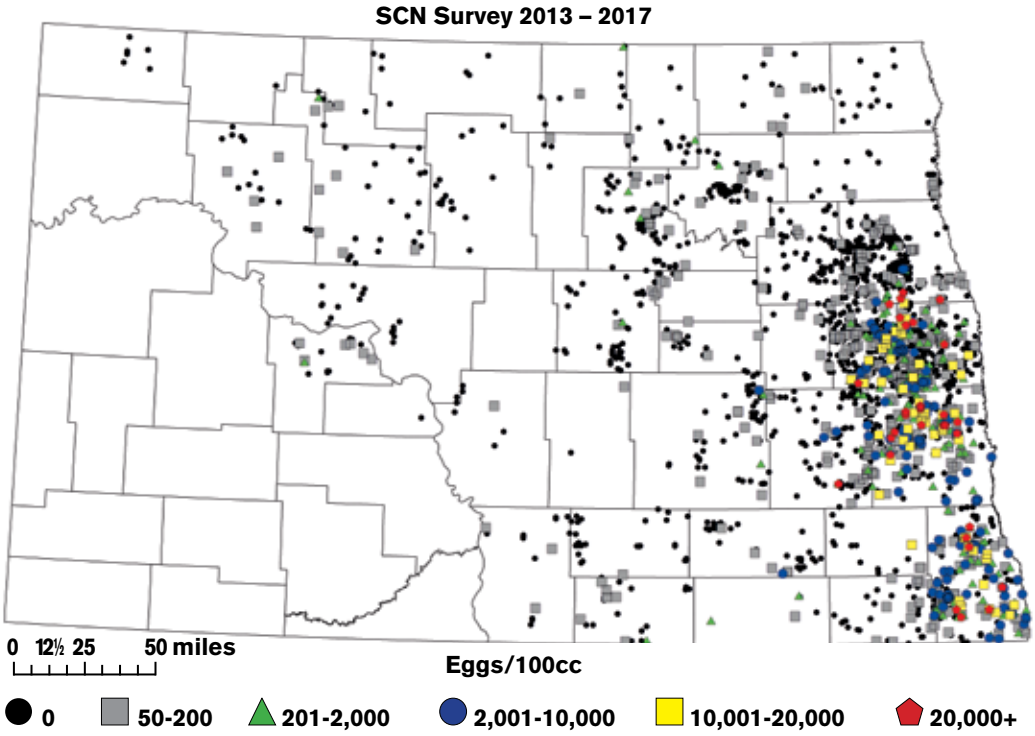
Principal Investigator: *Dr. Samuel Markell, Plant Pathology, NDSU*
Co-Investigators: *Dr. Guiping Yan and Dr. Berlin Nelson Jr., Plant Pathology, NDSU*

Funded Project
$60,580

Soybean Cyst Nematode (SCN) is the most yield limiting soybean disease in the U.S. and was first reported in Richland County in 2003. By 2012, SCN was confirmed in a dozen North Dakota counties. In 2013, NDSU Extension and the North Dakota Soybean Council developed an SCN sampling program that encouraged growers to sample their fields.

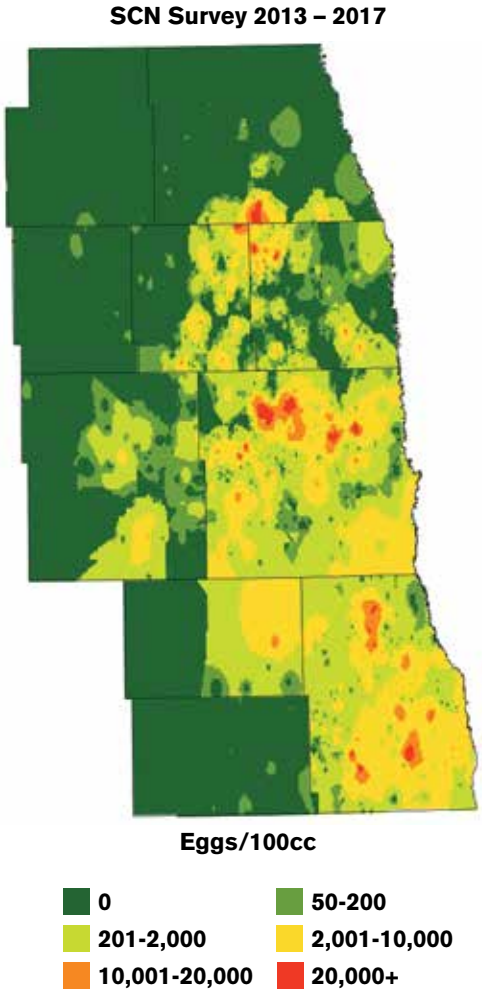
SCN can cause 15-30 percent yield loss before any above-ground symptoms are apparent, making proactive detection with soil sampling extremely important. In this program, SCN sample bags and instructions are distributed to every NDSU county extension office, at field days and by request. Growers send samples to the lab, free of charge, and receive their data in the mail. Maps of SCN distribution in the state are created, but all other grower information is kept confidential.

In the fall of 2017, the lab received 710 samples. Of those 710 samples, 237, approximately 33 percent, were positive, and egg counts ranged from 50 eggs/100 cc of soil to 55,400 eggs/100 cc. Notably, very low egg counts of 50 or 100 eggs/100cc could be false positives. To better visualize the SCN distribution in North Dakota, all data from 2013 to 2017 were combined (Figure 1). In 2017, there was a notable increase in samples from Grand Forks County. While some egg counts in the county were very high, most counts were negative. There were enough data points collected from 2013 to 2017 to create "heat maps" for the southeast and south-central counties in North Dakota (Figure 2).



Since 2013, over 3,000 sample bags have been submitted by growers, of which approximately one-third were positive for egg counts. This likely represents samples for hundreds of thousands of the state's soybean acres. While the yield-loss amount is dependent on many factors, susceptible soybeans planted on SCN ground commonly experience a 40 percent yield loss when conditions are favorable for the disease. Early detection with this program, along with the use of management tools, has likely saved North Dakota soybean growers millions of dollars since 2013.

Dr. Sam Markell educates soybean farmers about SCN in North Dakota.



Control of Soybean Diseases

Principal Investigator: *Dr. Berlin Nelson Jr., Plant Pathology, NDSU*
Co-Investigators: *Dr. Ted Helms, Plant Sciences, NDSU; and Dr. Shalu Jain, Plant Pathology, NDSU*

Funded Project
$57,300

Diseases are a potential problem for soybean production in North Dakota. The most important diseases that cause yield loss are the ones which infect the soybean roots, such as Phytophthora root rot and soybean cyst nematode (SCN). A primary focus of this project is to work with the soybean breeder, Dr. Helms, in order to incorporate resistance to major diseases in NDSU soybean varieties. We also tested commercial cultivars for resistance to certain diseases in order to provide growers with additional information about the resistance level. Another part of this research was to investigate changes in the current pathogens or the presence of new pathogens that would affect soybean production.

In cooperation with Dr. Helms, we continued to incorporate resistance to races 3 and 4 of Phytophthora root rot in the NDSU soybean varieties. These Phytophthora races are found in many fields. In 2018, we tested 68 breeding lines using our greenhouse-inoculation technique, and over 40 percent of those lines were resistant. In 2018, two conventional soybean varieties, Stutsman and ND Benson, and two glyphosate-resistant varieties, ND17009GT and ND18008GT, with resistance to Phytophthora root rot were released. These resistant varieties were the result of years of cooperation between Dr. Helms and Dr. Nelson.

> “We continued to incorporate resistence to 3 and 4 races of Photophthora root rot in the NDSU soybean varieties.”

In addition to Phytophthora root rot, we also screened NDSU breeding lines for resistance to soybean cyst nematode. In 2017-2018, we screened 14 advanced breeding lines for SCN resistance, and nine had high levels of resistance. One resistant line was released by Dr. Helms in 2018 as the conventional soybean variety ND Benson. We also screened 36 commercial RoundUp Ready varieties and 10 conventional varieties for resistance to SCN HG 0. These tests were conducted under controlled conditions in the greenhouse for a more accurate resistance measurement. The results for those tests are reported at https://www.ag.ndsu.edu/varietytrials/fargo-main-station/2017-trial-results/2017-soybean-cyst-nematode-resistance-female-index-for-roundup-ready-and-conventional-varieties/view.

In cooperation with NDSU Extension pathologist Sam Markell, we are investigating the possible occurrence of sudden death syndrome (SDS) in North Dakota soybean fields. SDS is a serious soil-borne disease caused by Fusarium virguliforme; SDS has not been reported in North Dakota. Dr. Markell's project surveyed soybean fields for stem diseases and observed fields with symptoms which are similar to SDS. Stem/root samples were collected, and we used DNA technology to identify the pathogen in the tissue. Although the symptoms in the field looked similar to SDS, we did not detect F. virguliforme in any samples. We will continue our SDS survey in 2019.

Testing the NDSU soybean variety ND Benson for resistance to Phytophthora root rot. On the left side is the resistant check, and on the right side is the susceptible check. No plants of Benson dies after inoculation.

Effects of Soil Salinity on Fusarium and Rhizoctonia Root Rots in Soybeans

Principal Investigator: *Dr. Berlin Nelson Jr., Plant Pathology, NDSU*
Co-Investigator: *Dr. Prabin Tamang, Plant Pathology, NDSU*

Funded Project
$34,000

Fusarium and Rhizoctonia root rots are two major root diseases that affect soybean production in North Dakota. Fusarium solani and F. tricinctum are two of the most important root rot fungi. Rhizoctonia root rot is primarily caused by the R. solani AG4 and AG2-2 groups. A major factor for developing root rots is plant stress. Soil salinity is another stress factor that influences soybean growth. Plant roots are compromised under salt stress, which may increase their susceptibility to root rot pathogens and may result in greater disease.

This project's objective was to determine if soil salinity can increase root rot, especially at low-to-moderate salinity levels where plants will still grow. The primary purpose of this research was to provide growers with information about the potential effects of soil salinity on soybean root rot.

> "The project's goal was to determine is soil salinity can increase root rot, especially at low-to-moderate salinity levels where plants will still grow."

We conducted greenhouse experiments using soil which was infested with two Fusarium pathogens and had soil electrical conductivity (EC) levels from EC 0 to 2. After 3 weeks of growth for the ND Barnes soybean cultivar in the soil, we measured plant height, lesion size on the tap root, dry root weight, root length and dry entire plant weight for each plant. With both pathogens, the EC level had a profound effect on the plants' growth with significant reductions in plant height, dry root weight, root length and total dry plant weight. The reductions were greater at EC2 than EC1. However, the results for plants growing in the presence of the two pathogens were similar to the results for plants growing without the pathogens, indicating that the major effects on plant growth were from salinity and not from the pathogens. These results illustrated how important soil salinity is for plant growth. For example, in one experiment, the reduction in dry root weight and dry plant weight for EC 1 and EC 2 in the absence of the pathogen was 31 percent and 49 percent, and 28 percent and 47 percent, respectively.

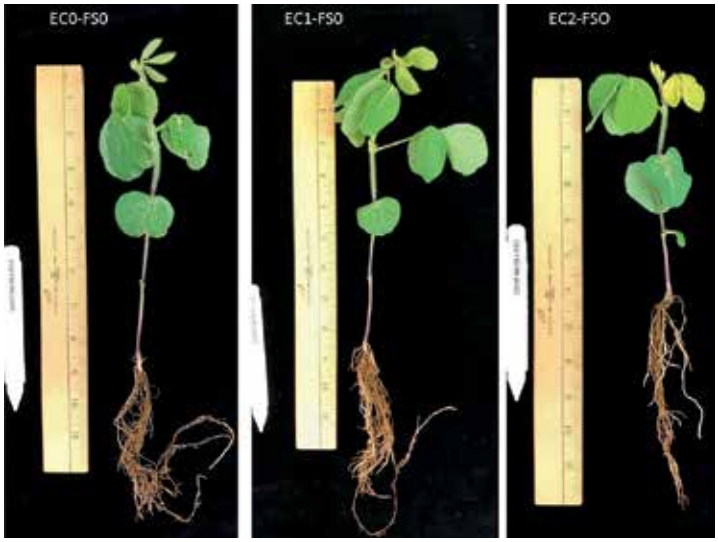


Figure 1. Plants growing in the absence of Fusarium (FS0) and with salinity levels (EC) of 0, 1 and 2. Notice the less-robust root system and shorter plant for EC2 compared to EC0. This difference is due to the salinity.

Increasing the salinity had a large negative effect on soybean growth, especially root growth. The effect of salt on the roots most likely had a negative influence on pathogen development in the root system such that the salinity's effect on root rot could not be well defined. Additional experiments are in progress to determine if salinity increases the root rot caused by various pathogens.

Dr. Berlin Nelson, left, addresses North Central Soybean Research program attendees in August, 2018 at NDSU's greenhouse.

Effect of Soybean Cyst Nematode on Fusarium Root Rot in Soybeans

Principal Investigator: *Dr. Berlin Nelson Jr., Plant Pathology, NDSU*
Co-Investigator: *Dr. Hui Yan, Plant Pathology, NDSU*

Funded Project
$19,250

Fusarium root rot caused by F. solani and F. tricinctum are two serious root-rot pathogens for soybeans in North Dakota. Although Fusarium is common in soybean roots, it does not always cause yield losses. Healthy, well-growing plants can produce new roots and compensate for the loss of decayed roots. Plants are more likely to suffer from Fusarium root rot when there is a high level of pathogens in the soil and when plants are stressed by environmental factors, such as a lack of water; high temperatures; or biological factors, such as the presence of other pathogens. Soybean cyst nematode (SCN) is common in many North Dakota soybean fields. SCN causes wounds because it penetrates the roots and changes the root's physiology while feeding. Therefore, the nematode could increase the damage caused by Fusarium root rot.

This project's goal was to determine if the presence of SCN in the soil with these Fusarium pathogens resulted in greater damage to the plant than caused by the Fusarium pathogens alone.

Greenhouse and field studies were conducted over two years in order to investigate this potential problem. The results indicated that, when levels of Fusarium are high and environmental conditions are conducive for root rot, the addition of SCN to the soil will generally have no effect on plant damage because the Fusarium root rot will have destroyed much of the roots or even killed the plant. Live roots are necessary for SCN to actually affect plant growth. When the Fusarium levels are low to moderate and the root rot is less severe, adding SCN to the soil can result in greater plant damage when compared to plants growing with SCN or Fusarium alone. These results are more likely to occur with higher, rather than lower, SCN egg levels in soil. Growth characteristics, such as plant height and weight, can be reduced by adding SCN in the presence of some root rot. Also, the Fusarium damage's severity on the roots can be increased by SCN.

> "The project's goal was to determine if the presence of soybean cyst nematode in the soil with these Fusarium pathogens resulted in greater damage to the plant than caused by the Fusarium pathogens alone."

At low levels of Fusarium inoculum and moderate-to-high SCN egg levels, the interaction of these two pathogens can reduce plant growth and increase root rot severity. Managing SCN should also focus on keeping the egg levels low in infested fields in order to avoid interactions with soil-borne fungal pathogens.

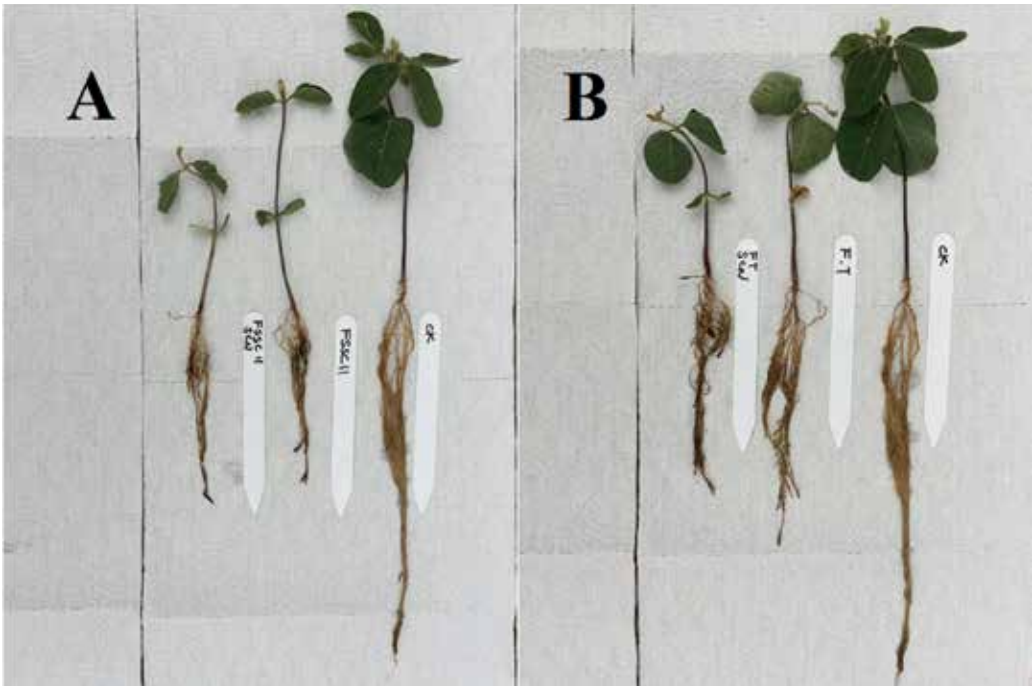


Figure 1. The effect of soybean cyst nematode (SCN) plus Fusarium root rot on soybeans' growth. A is Fusarium solani (FSSC11), and B is Fusarium tricinctum (FT). The plant on the left side of each photo is infected with both SCN and Fusarium. The plant in the middle is only infected with Fusarium, and the plant on the right side is the uninfected one (ck). The plant infected with both SCN and Fusarium is shorter and has less of a root system than the plant which is only infected with Fusarium.

Pre Herbicide Activation for Soybeans

Principal Investigators: *Dr. Mike Ostlie and Greg Endres, NDSU Carrington Research Extension Center*

Funded Project
$9,600

A pre-emerge herbicide program is very important to manage glyphosate-resistant weeds in soybeans. A study was conducted during the 2016 and 2017 growing seasons in order to determine the consequences of delayed herbicide activation for soybean herbicides (no rain). The study was conducted with a center pivot irrigation system to supply 0.5" of water to some treatments. The weeds were redroot pigweed, common lambsquarters and kochia (2017 only). The herbicide treatments were metribuzin, Fierce and Spartan, representing some of the most commonly used active ingredients with soybeans. Activation strategies included watering within 24 hours of herbicide treatment, watering 7 days after herbicide treatment, not watering at all or using a rotary hoe to mechanically activate the products 7 days after application. In both years, there was sufficient delay in natural rainfall to evaluate the treatment differences. In 2016, there was a 16-day absence of activating rain, and in 2017, there was a 22-day delay. During both seasons, there were small, intermittent rainfall events prior to the activation rainfall.

> "Activation strategies included watering within 24 hours of herbicide treatment, watering 7 days after herbicide treatment, no watering at all or using a rotary hoe to mechanically activate the products 7 days after application."

Table 1. The effect of herbicide activation on weed control

Activation	Redroot Pigweed	Lambsquarters	Kochia
	% Control	% Control	% Control
Irrigation 1 DAT	91.5	92.6	54.6
Irrigation 7 DAT	85.0	89.3	60.0
Rotary Hoe 7 DAT	64.3	72.5	32.1
No Water	73.1	75.0	26.3
LSD (0.05)	6.8	8.3	7.3

Table 2. The herbicide and incorporation strategy's effect on weed control

Activation	Herbicide	Redroot Pigweed	Lambsquarters	Kochia
		% Control	% Control	% Control
Irrigation 1 DAT	metribuzin	85.4	92.3	38.8
Irrigation 7 DAT	metribuzin	77.0	86.3	38.8
Rotary Hoe 7 DAT	metribuzin	25.8	36.3	71.3
No Water	metribuzin	49.6	55.6	40.0
Irrigation 1 DAT	Fierce	96.1	87.5	62.5
Irrigation 7 DAT	Fierce	85.8	86.9	71.3
Rotary Hoe 7 DAT	Fierce	89.9	88.1	22.5
No Water	Fierce	88.8	84.4	15.0
Irrigation 1 DAT	Spartan	92.9	98.0	62.5
Irrigation 7 DAT	Spartan	92.1	94.9	70.0
Rotary Hoe 7 DAT	Spartan	77.0	93.0	2.5
No Water	Spartan	80.8	85.0	23.8
LSD (0.05)		6.8	8.3	7.3

A common understanding about pre activation is that smaller rainfall events, totaling about 0.25" or less, are not sufficient to activate a herbicide. Our study provides further evidence for this case. In 2017, there were rain events 6 and 7 days after the herbicide application, totaling 0.19", to go along with an additional 0.09" seven days later. This did not activate the herbicide treatments even though the total was 0.28". The products were not activated until the 0.79" rainfall 22 days after herbicide application.

There was no decreased herbicide activity with a seven-day delay in activation for any product (Table 1). When averaged across herbicides, there was no difference between mechanical incorporation and no activation strategy, except that the mechanical incorporation decreased the redroot-pigweed control.

There are a few important contrasts to note. With redroot pigweed and common lambsquarters, Fierce and Spartan were consistent performers except that the Spartan control dropped after seven days with no activation. Kochia control also dropped off with both products after seven days without activation. Rotary hoeing typically did not improve weed control, except that the hoeing appeared to improve metribuzin's effect on kochia.

Overall, metribuzin's performance decreased the quickest with delayed activation. These data suggested a need to revisit any recommendation relating to mechanical incorporation of herbicides, with special attention to specific weed species and soil moisture status/precipitation.

Effective Winter Rye Management for Maximum Soybean Potential

Principal Investigators: *Dr. Mike Ostlie, Greg Endres and Steve Zwinger, NDSU Carrington Research Extension Center*

Funded Project
$2,700

The 2017 growing season marked the end of a research phase for the rye and soybean relay-cropping system. This system's goals include erosion prevention, managing glyphosate-resistant weeds, grazing/haying and creating a firmer spring seed bed. This research was initiated in 2013 with the goal of identifying effective rye-termination methods so that soybean yields were maximized. Over the last three years, rye and soybean planting dates were added as components.

Rye planting dates ranged from August to November each year. Spring survival remained high through early October planting. The early November planting had 60 percent spring survival, even though it did not emerge after planting in the fall. For some rye uses, this opens the possibility of planting rye after corn harvest, although winter cover and biomass production would be considerably lower than with earlier planting. Mid-season planting into corn or planting after an earlier harvested crop would increase the rye's benefit.

The timing for rye termination is the biggest key to success for the rye and soybean relay. In our previous work with rye termination, we found glyphosate to be the most consistent method for termination. Since 2013 when rye was terminated two weeks prior to planting, there was no effect on soybean yields. Terminating the rye at soybean planting often had a similar yield to the check, but waiting until two weeks after planting often led to lower yields. There was one complete crop failure when terminating at soybean planting and three crop failures when waiting until after planting.

> "Mid-season planting into corn or planting after an earlier-harvested crop would increase the rye's benefit."

Available soil moisture is what determines the success of the soybeans' establishment. One assumption of our research was that planting soybeans into rye earlier would be safer because the rye would be smaller and using fewer resources. In 2016 and 2017, we had two very dry springs where some of the lowest soil-moisture levels for the year occurred in May. For both years, when we planted soybeans into the rye in early May, there were lower yields compared to the check. In both years, we had early June rains, and there was no influence from rye on the soybeans, indicating that it was more risky to plant soybeans early during those years. It should be noted that, even though the early planted soybeans were affected by rye, the yields were still equal to the best treatments at later soybean-planting dates.

Dr. Mike Ostlie addresses farmers about his current research in Carrington.

Effect of Plant Population and Row Spacing on Physiology, Water Use Efficiency and Yield for No-Till Dryland Soybeans

Principal Investigator: *Dr. Gautam Prasad Pradhan, NDSU Williston Research Extension Center*
Co-Investigators: *Dr. Jerald Bergman and Dr. James Staricka, NDSU Williston Research Extension Center*

Funded Project
$18,435

Drought is one of the main abiotic stresses that affect U.S. soybean yield. In North Dakota, 99 percent of soybeans are produced under dryland conditions, and the crop is highly vulnerable to drought stress. Soybean acreage has steadily increased in North Dakota, including the western side of the state which has an exceptionally drier climate than the eastern region. This experiment was conducted to determine a suitable soybean row spacing and plant population for the no-till, dryland conditions in western North Dakota in order to ensure sustainable higher yield and farm income.

A Roundup Ready 2 Yield (RR2Y) soybean variety with a maturity group of 0.3 was planted at the Williston Research Extension Center on June 2, 2017. Row spacings of 7½, 15, 22½ and 30 inches were maintained as the main plots, and plant populations (seeding rates) of 90, 120, 150 and 180 thousand seeds per acre were considered the sub-plots.

There was no effect for plant population and row spacing on the normalized difference vegetation index (NDVI), grain protein and oil content. The average NDVI at 102 days after seeding was 0.76, and the average grain protein and oil content were 38 and 19 percent, respectively. There was a significant row-spacing effect on biomass, plant height and grain yield, but not on pod number. Averaged across the plant population, the 30-inch row spacing had about 1-1½ inches taller plants than the narrow spacings (Fig. 1A); the 7½-inch row spacing produced about 485 to 540 lbs more biomass (Fig. 1B) and 3 to 5 more bushels of grain (Fig. 2B) than the wider row spacings, and the average pod number was 27 per plant (Fig. 2A). There was a significant effect for the plant population on the pod number per plant, but not on grain yield. Averaged across row spacings, the plant population of 90 thousand per acre produced 5 to 10 more pods per plant than the higher plant populations (Fig. 2C), and the average grain yield was 24 bushels per acre (Fig. 2D).

In summary, a row spacing of 7½ inches and a 90-thousand plant population per acre were a suitable planting geometry for the no-till, dryland soybean production in western North Dakota. This result was confirmed by our findings in 2016, illustrating that the no-till, dryland soybean farmers of this region may benefit from planting a lower seeding rate with narrow rows, reducing the expensive seed cost without any yield penalty.

Figure 1. Plant height and biomass.

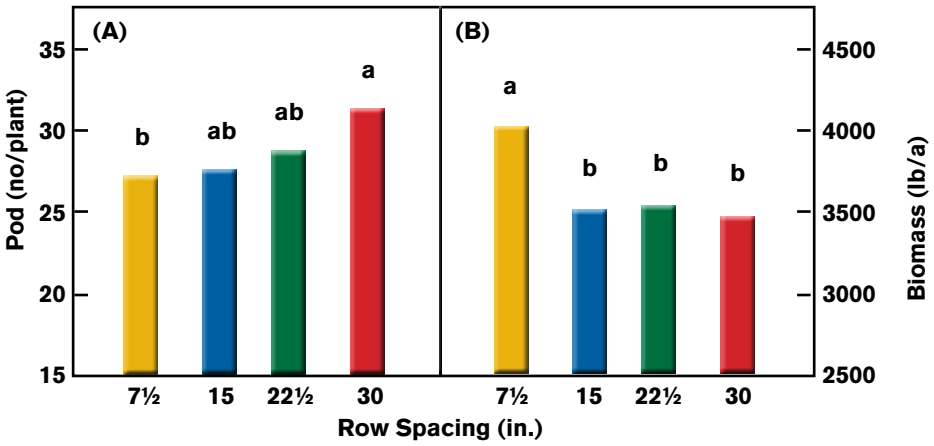
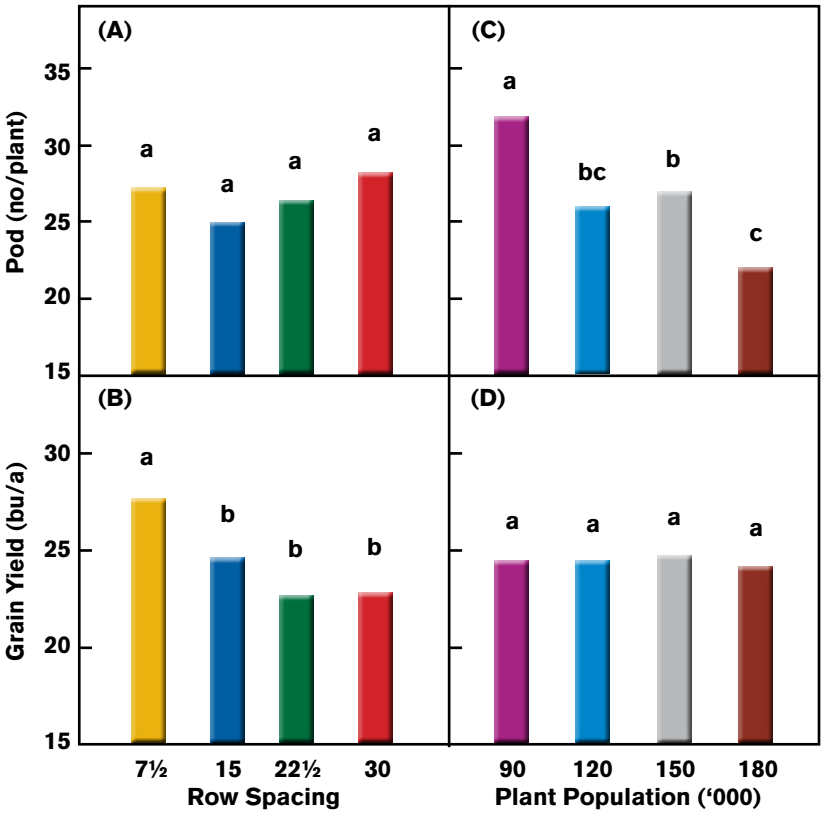


Figure 2. Grain yield and pod number.



> "Soybean acreage has steadily increased in North Dakota, including the western side of the state which has an exceptionally drier climate than the eastern region."

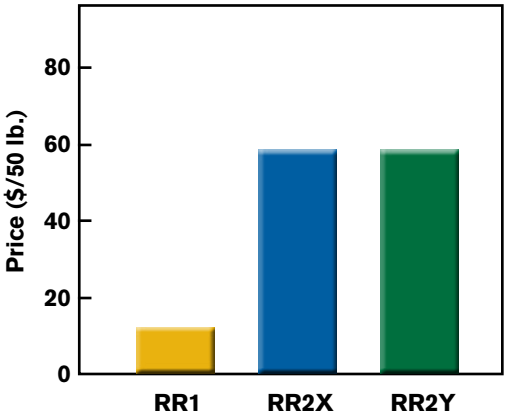
Yield and Economic Evaluation of Soybean Biotechnology Varieties and Their Responses to Selenium

Principal Investigator: *Dr. Gautam Prasad Pradhan, NDSU Williston Research Extension Center*
Co-Investigators: *Dr. Jerald Bergman and Dr. James Staricka, NDSU Williston Research Extension Center*

Funded Project
$16,189

Soybean acreage has been steadily increasing in western North Dakota which has an exceptionally drier climate than the eastern part of the state. Western North Dakota receives about 15 inches of precipitation annually compared to 21 inches in the east. The average annual evapotranspiration in the west is 5 inches higher than it is for the east. Thus, drought is the main soybean yield limiting factor in western North Dakota.

Figure 1. Seed price of different soybean biotechnology varieties.



Source: Local elevator, Williston, North Dakota

In 2016, 95 percent of the 5.9 million soybean acres in North Dakota were planted with herbicide-resistant biotechnology varieties, such as Roundup Ready 1 (RR1), Roundup Ready 2 Yield (RR2Y) and Roundup Ready 2 Extend (RR2X). The RR1 patents expired in 2015, so farmers may now save harvested RR1 seed, dramatically reducing their seed-input cost by more than $45 per acre (Fig. 1). According to the Plant Variety Protection Act, growers should acquire a license from a breeder before saving and replanting any RR1 variety.

> “Selenium (Se), an essential antioxidant for humans, has recently been recognized for delaying soybean plants’ senescence and for alleviating drought strett in wheat, corn and barley under glasshouse conditions.”

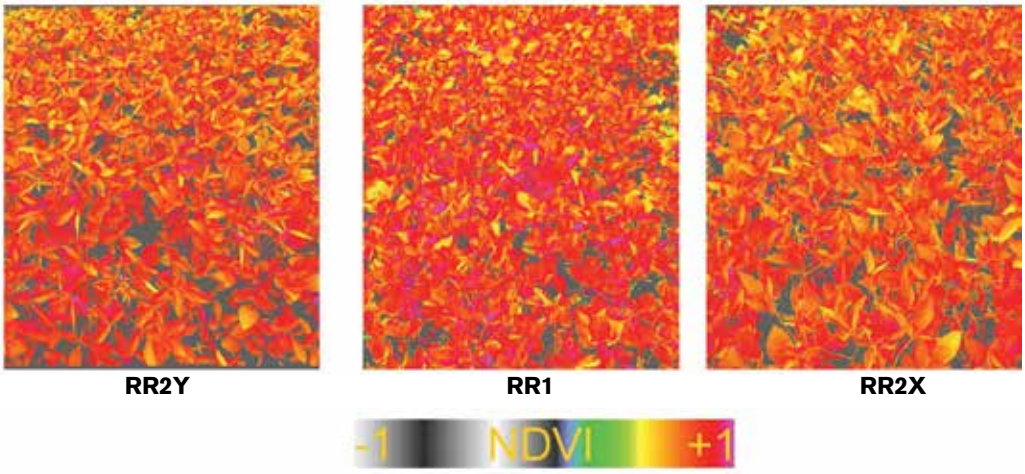
Selenium (Se), an essential antioxidant for humans, has recently been recognized for delaying soybean plants’ senescence and for alleviating drought stress in wheat, corn and barley under greenhouse conditions. Selenium has not been tested in the field. The experiment’s objectives were to determine the most profitable soybean biotechnology varieties for dryland western North Dakota as well as to ascertain the effect of selenium’s foliar application on the yield and performance for the soybean biotechnology varieties.

RR1, RR2Y and RR2X soybean varieties with a maturity group of 0.09 were planted at the Williston Research Education Center on May 18, 2017. Selenium, as sodium selenate at 100 parts per million (ppm), and deionized water, as a control, were sprayed on the afternoon of August 10, 2017. The trial was harvested on October 6, 2017.

There was no effect for the selenium and biotechnology varieties on the normalized difference vegetation index (NDVI), growth and yield for the soybeans. The average NDVI was 0.74 (Picture 1); the biomass yield was 2945 lbs/ac; the pod number was 16 per plant; the grain number was 39 per plant; and the grain yield was 24 Bu/ac. Averaged across selenium treatments, RR1 grain had 38.5 percent protein, which was 1.2 to 1.8 percent higher than RR2Y and RR2X; RR2Y had 21 percent oil, which was 1.2 to 1.7 percent higher than RR1 and RR2X, respectively.

This study showed that the RR1 variety performed similarly to other biotechnology varieties, so planting RR1 varieties may be economically beneficial for the no-till, dryland soybean farmers of western North Dakota.

Picture 1. Color index image depicting NDVI of soybean biotechnology varieties at 82 d after seeding. (Created by using Monitoring Tool in ImageJ)



The NDVI values range from 0.2 to 0.9, and is represented with a classic heat map from green to yellow or red.

Inversion App Development

Principal Investigator: *Daryl Ritchison, North Dakota Agricultural Weather Network*

Funded Project
$XX,XXX

An inversion is a common meteorological phenomenon where the temperature increases with height off the ground, rather than decreasing with height. When inversions occur, the cooler air near the ground, being more dense than the warmer air just above the ground, can increase the risk of spray drift, the off-target movement of spray particles.

Knowing when an inversion is occurring is important when spraying, especially with the herbicide dicamba. The North Dakota Agricultural Weather Network (NDAWN) has equipped 36 stations with sensors that are capable of detecting inversions. The North Dakota Soybean Council funded the development of a smartphone application for both iPhone and Android devices that would alert applicators when an inversion is in place at (a) selected NDAWN station(s). This notification would give sprayers a proactive approach to inversion detection with the application pushing alert notices about an inversion.

Before this application was developed, farmers had to use the reactive approach of constantly checking to see if an inversion had developed or was in progress while spraying.

> “The application development was approved and finished before the peak of the 2018 dicamba spraying season.”

The application development was approved and finished before the peak of the 2018 dicamba spraying season. The application is called the NDAWN Inversion App. Although the exact number of downloads from both the App Store (iOS) and Google Play (Android) are unknown at this time, the iOS version did make it into the top 100 most-downloaded, free weather apps at one time, meaning that it was likely downloaded by numerous local applicators for use in determining when inversions were in place. The application also provides current weather conditions which are updated every five minutes from an NDAWN station, providing crucial wind and temperature data.

NDAWN received numerous positive comments about the NDAWN Inversion App and ways to improve future versions. Because inversions are widespread meteorological events, this application helped applicators who were spraying dicamba on soybeans know when they could legally spray, especially with the application's inclusion of current temperature and wind data. Hopefully, this app helped soybean growers make judgements about when to spray in order to meet both state regulations and label instructions.

In the future, NDAWN hopes to incorporate Delta T, a relationship between temperature and relative humidity that is used by some applicators for nozzle selection and for drift and volatility prevention, to further enhance the soybean growers' ability to spray during optimal time frames.

Invesrion sensors on the Zeeland, ND NDAWN Station.

NDAWN Inversion 4+
North Dakota State University
Free

Assessment of Soybean Plant Population and Planting Date Effect on Performance in Western and Central North Dakota

Principal Investigator: *Dr. Jasper M. Teboh, NDSU Carrington Research Extension Center*
Co-Investigators: *John Rickertsen, NDSU Hettinger Research Extension Center; Eric Eriksmoen, NDSU North Central Research Extension Center; Szilvia Yuja, Dr. Mike Ostlie, and Dr. Paulo Flores, NDSU Carrington Research Extension Center; and Ryan Buetow, Dickinson Research Extension Center*

Funded Project
$28,865

A shortage of rainfall is probably the most limiting factor for soybean acreage in western and central North Dakota. Farmers also deal with the risks of early or late frost. The frost is affected by planting date as well as the duration of crop growth and development, which are affected by a variety's relative maturity group (RMG). The effect of each one, and a combination of these factors, on soybean yields was investigated at Hettinger, Minot and Carrington under dryland and irrigation scenarios. The Dickinson trial was destroyed. The yield effects of planting date (early, normal or late), relative maturity group (RMG0.2 or RMG0.8) and population (150,000; 175,000 and 200,000) were assessed. RMG0.2 is an early maturing variety, and RMG0.8 is a late variety.

At Hettinger, yields from early planting (May 11, 27 Bu/ac) were significantly greater than for late planting (June 11) by 5 Bu. The crop with the normal planting date was destroyed. Yields from RMG0.8 (25.3 Bu/ac) were significantly greater than RMG0.2 by 2.3 Bu/ac. The seeding population did not affect yields.

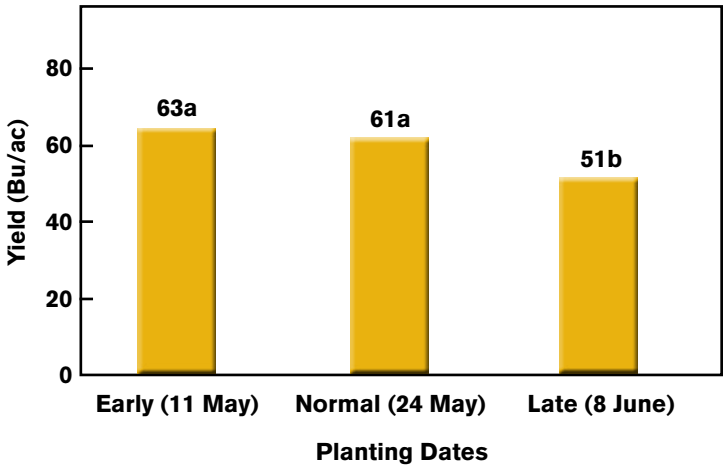
At Carrington, a significant interaction effect for RMG and planting date was observed with yields. This finding indicated that late RMG0.8 produced the highest yields, which occurred with early planting. Meanwhile, yields from RMG0.2 were the lowest when planted early. Yields from the 175,000 (≈50 Bu) and 200,000 (≈49 Bu) populations were not significantly different except between 175,000 and 150,000 (≈47 Bu). With irrigation, yields were similar between the early and normal planting dates, but were significantly greater (by over ≈8 bushels) than for early planting (50 Bu). Yield variations at 200,000 (58 Bu) were not significantly different than 175,000 (56 Bu) but were significant at 150,000 (53 Bu).

At Minot, the average yield was quite low, 25 Bu, due to the drought's effects. Nevertheless, a significant yield advantage of 2.3 Bu was recorded for RMG0.2 compared to RMG0.8.

The benefit for North Dakota soybean producers is to prevent yield losses by not planting late maturing varieties (e.g., RMG0.8) after May 25th in western and central North Dakota. The previous years' data also support that planting seeds which are similar to maturity group RMG0.8 as early as May 10 produced better yields in the Carrington area. Populations between 160,000 and 180,000 would be recommended for similar varieties.

> "The frost is affected by planting date as well as the duration of crop growth and development, which are affected by a variety's relative maturity group (RMG)."

Figure 1. Effect of planting sate on soybean yields under dryland condition (CREC, 2017)



Phosphorus Fertilizer Management Decisions for Soybeans Based on the Planting Time

Principal Investigator: *Dr. Jasper M. Teboh, NDSU Carrington Research Extension Center*
Co-Investigators: *Eric Eriksmoen, NDSU North Central Research Extension Center; Szilvia Yuja, Kelly Cooper, Heidi Eslinger and Blaine G. Schatz, NDSU Carrington Research Extension Center; and Dr. Dave Franzen, Soil Science, NDSU*

Funded Project $21,990

How do soybean yields differ in response to phosphorus (P) that is applied when the crop is planted early or later? This study assessed soybean yields that are influenced by P fertilizer application when the planting time is early, normal or later. The research also provided an assessment of the resulting yields on net return.

The planting dates are shown in Table 1. The rates were 0, 20 and 40 pounds P/ac as triple super phosphate was surface applied and incorporated. At Minot, soybeans were no-till and P banded with 11-52-0 at 5, 10 and 20 lbs of P/ac. Both Carrington sites tested medium for P while the other sites were high.

Table 1

	Carrington		Minot	Oakes	Wishek
Planting Time	Dryland	Irrigated	Dryland	Dryland	Dryland
Early	11-May	11-May	10-May	10-May	9-May
Normal	24-May	24-May	19-May	24-May	
Late	8-Jun	8-Jun	30-May		

Table 2. Planting date and P fertilization effects on soybean yield and seed protein in different North Dakota environments (2017)

	CREC Dryland		CREC Irrigated		Oakes (Irrigated)		Wishek		Minot		
Planting Time	Yield bu/ac	Protein %	Yield bu/ac	Protein %	Yield bu/ac	Protein %	Yield bu/ac	Protein %	**Planting Time**	Yield bu/ac	Protein %
Early	63.2a	34.5b	58.6a	36.3	71.1	36.5a			Early	25.4	16.89ab
Normal	60.9a	35.1b	57.3a	36.8					Normal	25.4	17.00a
Late	50.8b	36.1a	46.2b	36.4	66.7	37.7a			Late	25.4	16.73b
P Rates (lbs/ac)									**P Rates (lbs/ac)**		
0	57.9	35.1	55.9a	36.5	64.6b	37.5	32	36.88	0	56.0	16.90
20	59.2	35.3	52.0b	36.5	70.9a	36.9	33	37.23	5	55.7	16.93
40	58.7	35.2	54.1ab	36.5	71.2a	37.0	31	36.45	10	55.8	16.87
									20	56.24	16.80
Date x P rate											
Early-0	65..4	34.6	60.9	36.2	67.5	36.9cd			Early-0	26.0	32.7d
Early-20	63.4	34.5	57.6	36.5	72.3	36.5de			Early-5	26.8	33.1cd
Early-40	60.8	34.5	57.4	36.1	74.7	36.2e			Early-10	24.4	33.3cd
Normal-0	60.2	35.8	59.1	36.8					Early-20	24.5	33.4bcd
Normal-20	60.8	36.2	55.0	36.8					Normal-0	27.1	33.1cd
Normal-40	61.6	36.2	57.8	36.9					Normal-5	25.7	33.7bc
Late-0	48.2	35.1	47.8	36.5	62.3	38.1a			Normal-10	23.3	33.3cd
Late-20	53.4	35.1	43.4	36.2	70.3	37.3bc			Late-0	26.4	33.8bc
Late-40	53.7	35.0	47.3	36.6	68.7	37.7ab			Late-5	22.0	33.8bc
									Late-10	27.3	34.1ab
									Late-20	25.8	34.7a
Effects					Analysis of Variance (p > F)						
Date	<.0001	.0003	<.0001	<.0001	<.0708	<.0001				.999	.0002
P Rates	.5383	.4859	.0026	.6954	.0015	<.0001	.726	.1376		.752	.0015
Date *P Rate	.1642	.511	.5921	.4312	.4634	.0427				.562	.009

Soil test at all sites were high except ar CREC, where it was medium.
Means with the same letters within a column are statistically not different from each other at 95% confidence level.
Date x P analyzes the combined effects of date and P rates. If date x P is significant (<.05) it would mean important yield differences caused by P rates depend on date.

Across all sites, the effect of P on soybean yield did not depend on the planting date (Table 1). At Carrington, under dryland conditions, the early and normal planting dates produced significantly greater yields than late planting.

- At Carrington's irrigated site, the P rate and planting date significantly affected yields. Planting on or before May 24 improved yields by almost 12 bushels, on average. Yields for the early and normal planting dates were not different. The P treatments produced results which could not be explained, including greater yields for the 0 and 40 pound treatments than at 20 pounds, but these findings will be verified in ongoing studies.
- At Oakes, the yields were significantly increased with phosphorous. Yields were not different between 20 and 40 pounds, but improved by 6.5 bushels compared to the check of 0 pounds added P. Planting on May 10 (early/normal) had a marginally significant yield increase of about 4.5 bushels compared to planting two weeks later.
- At Minot, prolonged droughts led to low yields which were half the normal amount. Yields were not different among the treatments.
- At Wishek, yields were not different between P rates.
- Economically, only the farmer at Oakes would have made some profit. At $8.5/bu for soybeans, $0.707/lb for P fertilizer and $6.39/ac for the application cost, the Oakes farmer who applied 20 pounds compared to 0 pounds would have gained $13/ac and, at 40 pounds, $5/ac when averaged across the two planting dates. A net loss of $25 was estimated for 40 pounds of P at the late planting.
- From these results, farmers would be better planting near the second week of May in order to boost the yield potentials and net return.

Research and Extension Efforts at the Soil Health and Agriculture Research Extension (SHARE) Farm

Principal Investigator: *Dr. Abbey Wick , Soil Science, NDSU*
Co-Investigators: *Dr. Frank Casey, Natural Resource Sciences, NDSU ; Dr. David Ripplinger, Agribusiness and Applied Economics, NDSU; and Dr. Caley Gasch, Soil Science, NDSU*

Funded Project
$57,785

The SHARE Farm is a key project within the NDSU Soil Health program. On site, there are several research projects underway to examine soil health, tile drainage, conservation tillage practices and cover crops in rotation. The site also has the most equipped North Dakota Agricultural Weather Network (NDAWN) station to compeiment research at the SHARE Farm.

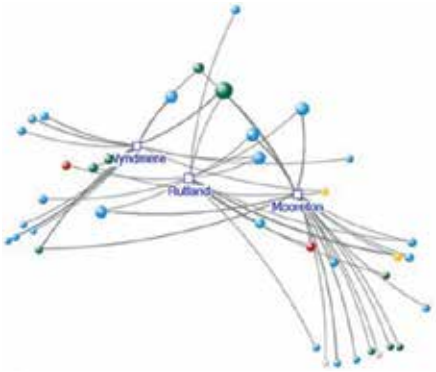
Off site, Extension programs share information with farmers, primarily using the Soil Health Café Talks. The goals are to both listen to farmers and to communicate what we are learning in a discussion based environment. All aspects of the SHARE Farm research and Extension are driven by farmer input; this is truly the "farmer's project."

One of the SHARE Farm's most notable results has been the success of the Café Talks. When they started during the winter of 2014, a total of 41 individuals were reached at three locations in the southeast corner of North Dakota. Since then, we have expanded the Café Talks to 17 locations throughout the eastern part of the state and have reached 500 individuals. The best part is that those 500 people don't meet just once; there have been 397 repeated connections, meaning that people with a similar interest in soil health are crossing paths multiple times. This leads to friendships and multiple resources for information. To see the effect of the Café Talks, we developed a knowledge-network graphic for 2014 and 2014-2018.

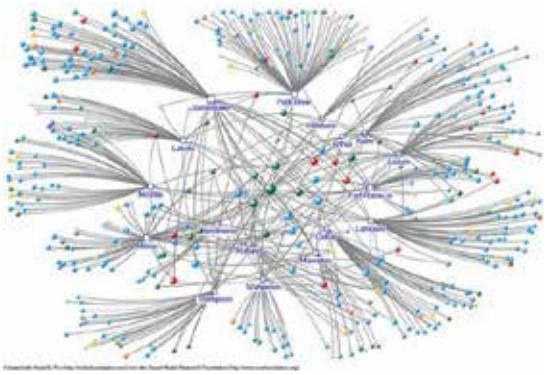
The royal blue dots are the Café Talks' locations. Green circles are NDSU Extension and Research personnel; blue are farmers; red are consultants; yellow indicate industry; and grey are unknown professions. The circle's size and location within the network are important; the larger the circle and the closer the circle is towards the center of the diagram, the more important the individual's role within the network is.

No single individual leads the sharing of soil health information in North Dakota. Instead, a group of people, including farmers, scientists, Extension personnel, consultants and industry representatives, are collectively moving soil health forward in our state. We should all be really proud!

Web: ndsu.edu/soilhealth, Twitter: @ndsusoilhealth



2014 Soil Health Knowledge Network:
- 3 locations
- 41 individuals



2014-2018 Soil Health Knowledge Network:
- 17 locations
- 500 individuals

Dr. Caley Gasch and Extension agent Chandra Langseth collect samples for soil health analyses at the SHARE farm.

Dr. Abbey Wick's soil health cafe talks are well attended during winter months.

Optimizing Fungicide Applications to Manage Sclerotinia in Soybeans

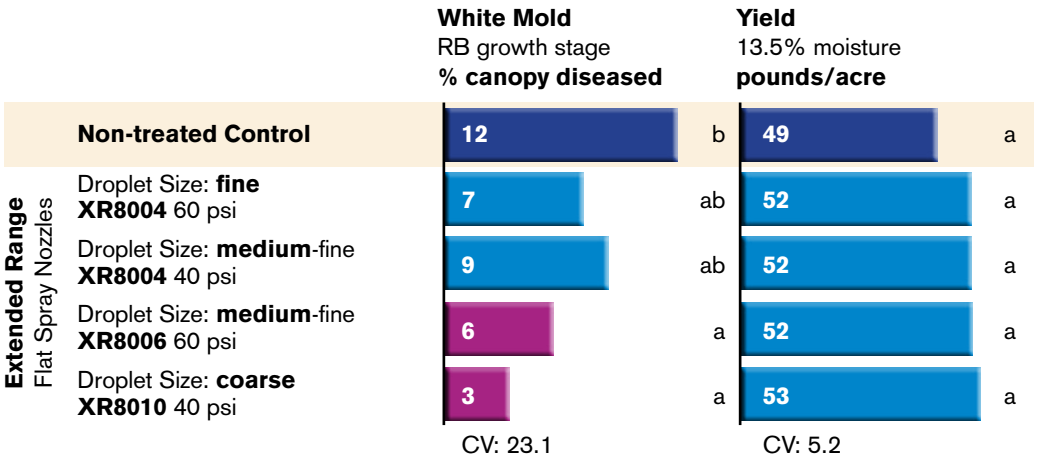
Principal Investigator: *Dr. Michael Wunsch, NDSU Carrington Research Extension Center*

Funded Project
$39,528

Managing Sclerotinia (white mold) in soybeans is constrained by difficulties achieving satisfactory fungicide deposition on the lower canopy where most infections begin. The most effective, registered fungicide applied at optimal timing reduces white mold by an average of approximately 50 percent. While this level of control significantly reduces losses to white mold, it can result in unacceptably high levels of white mold with high disease pressure. This project seeks to improve the effectiveness of fungicides against white mold in soybeans by identifying fungicide application methods that improve fungicide deposition on the stems in the lower soybean canopy where most white mold infections begin.

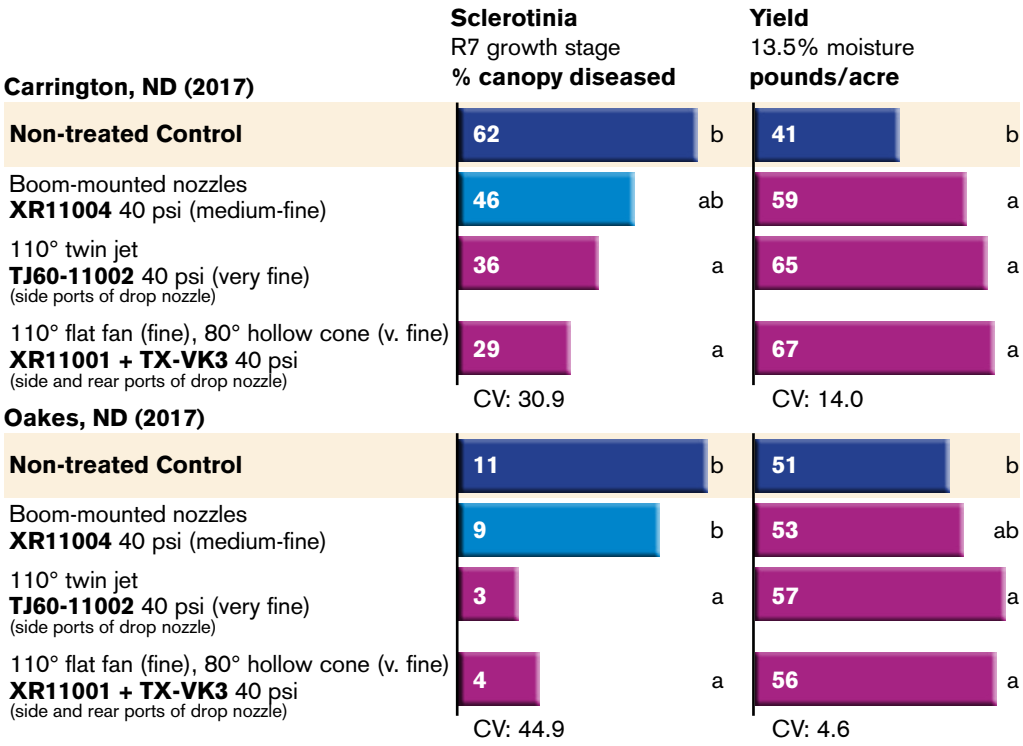
Fungicide coverage is optimized with spray nozzles that deliver small droplets, but small droplets lack the velocity to efficiently penetrate dense canopies. Fungicide deposition on the lower canopy is typically optimized with larger droplets that have the velocity to penetrate the canopy but still confer acceptable coverage. To evaluate the effect of spray droplet size on white mold control, the fungicide Endura (boscalid; BASF) was applied at 5.5 oz/ac with Spraying Systems TeeJet extended range (XR) flat-fan nozzles at 40 or 60 psi in order to emit a range of sprays from fine, approximately 200 microns, to coarse droplets of approximately 350 microns. The spray volume was 15 gallons/acre, and applications were made with a tractor-mounted boom equipped with a pulse-width modulation system to permit a constant driving speed across all treatments. When testing was conducted with soybeans grown under overhead irrigation in Carrington, the coarse, 350-micron spray droplets optimized white mold control (Figure 1).

Figure 1. Response to spray-droplet size with the fungicide Endura applied at 5.5 oz/ac during the R2 growth stage: Carrington, North Dakota (2017). Within-column means followed by different letters are significantly different (P < 0.05).



Soybean producers who use irrigation and regularly experience significant losses due to white mold have inquired about the effectiveness of drop nozzles. In field trials conducted with overhead irrigation in Carrington and Oakes, the 360 Undercover drop nozzle (360 Yield Center; Morton, IL) was tested with a tractor-mounted boom in soybeans which were seeded in 21-inch rows. When equipped with spray nozzles emitting multi-directional sprays within the soybean canopy, the 360 Undercover drop nozzle facilitated sharp increases in white-mold control and soybean yield relative to the applications with boom-mounted nozzles (Figure 2). A single application of the fungicide Endura (5.5 oz/ac) was made at the R2 growth stage.

Figure 2. Response to an application of Endura (5.5 oz/ac) at the R2 growth stage with boom-mounted nozzles versus the Undercover 360 drop nozzle equipped with two different nozzle configurations. Spray-droplet sizes are indicated in parentheses. Within-column means followed by different letters are significantly different (P < 0.05).



Additional studies conducted in 2017 suggest that the practice of lowering the boom height, which is utilized by some producers in an attempt to force fungicide into the lower canopy, may reduce white mold control and that using an aggressive, silicon-based, non-ionic surfactant has the potential to improve disease control.

Optimizing Row Spacing and Plant Populations to Manage Sclerotinia in Soybeans

Principal Investigator: *Dr. Michael Wunsch, NDSU Carrington Research Extension Center*

Funded Project
$41,730

Seeding soybeans in narrow and intermediate rows facilitates faster canopy closure, increasing the conversion of sunlight into biomass and increasing the soybeans' yield potential. However, it also increases the risk of Sclerotinia (white mold) by trapping additional humidity within the canopy. Producers concerned about white mold often seed soybeans in wide rows–generally 30 inches–sacrificing the soybeans' yield potential in the absence of white mold in order to reduce disease-related losses if white mold develops.

Previous research conducted in Michigan, Wisconsin and Ontario confirms that wide rows reduce white mold, but the research also indicates that seeding soybeans in wide rows often results in lower soybean yields, even under white-mold pressure. In two of three multi-year field studies, soybean yields were maximized in narrow-to-intermediate rows despite the increased white mold.

This multi-year, multi-location study sought to determine when using narrow and intermediate row spacing maximizes soybean yield with white mold as well as to quantify the implications for soybean quality. Field studies were established with overhead irrigation at sites near Carrington, Langdon, Oakes and Williston in 2015, 2016 and 2017. Each year, two-to-six, locally adapted soybean varieties, representing a mix of upright and bushy types, were evaluated at every location in each of four row spacings, 7, 14, 21 and 28 inches; or 7.5, 15, 22.5 and 30 inches, as well as three seeding rates: 132,000; 165,000; and 198,000 pure, live seeds per acre.

Narrow and intermediate row spacing increased white mold but almost always maximized the soybeans' yield when the end-of-season incidence of white mold was less than 50 percent (Figure 1). The increased white mold associated with narrow or intermediate row spacing increased the contamination of the harvested grain with sclerotia (resting structures of the Sclerotinia fungus), but the increased contamination with sclerotia was small, less than 0.1 percent by weight, when the end-of-season white mold incidence was less than 40 percent and never resulted in a reduced soybean market grade until the white mold incidence exceeded 45 percent (Figure 2).

The results indicated that seeding soybeans in wide 28- or 30-inch rows is unlikely to be profit-maximizing under white-mold pressure unless the disease incidence is expected to exceed 50 percent at the season's end. When the end-of-season Sclerotinia incidence is less than 50 percent for soybeans seeded in narrow and intermediate rows, the yield gain conferred by faster canopy closure generally exceeded the yield loss resulting from increased white mold in the narrower rows.

Figure 2. Influence of row spacing on the contamination of soybeans with sclerotia (resting structures of the Sclerotinia fungus) in soybeans grown with Sclerotinia disease pressure. Each dot represents a soybean variety which was tested at one location in one year. Pink dots denote a reduction in U.S. market grade due to the grain's increased contamination with sclerotia. Similar results were obtained for soybeans seeded in rows that were 7, 7.5, 14 and 15 inches apart.

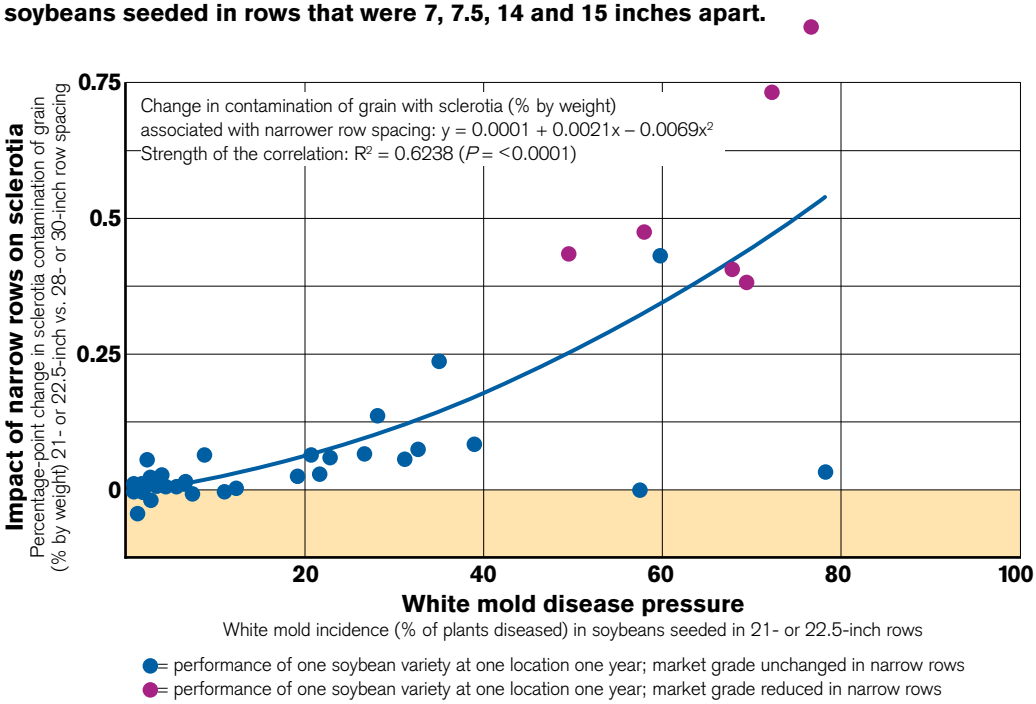
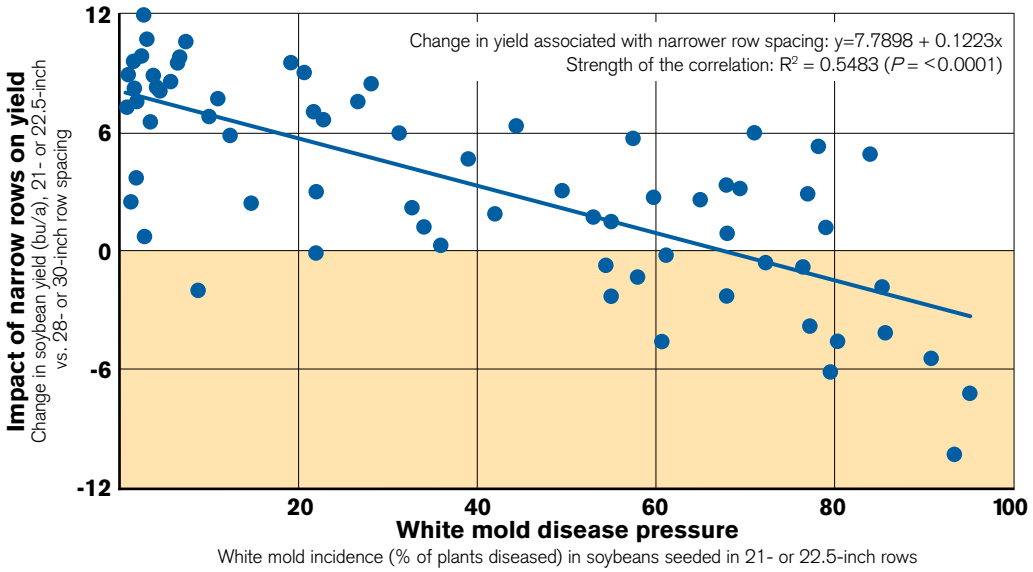


Figure 1. Influence of row spacing on yield for soybeans grown with Sclerotinia disease pressure. Each dot represents a soybean variety which was tested at one location in one year. Similar results were obtained for soybeans seeded in rows that were 7, 7.5, 14 and 15 inches apart.



Molecular Quantification of Soybean Cyst Nematodes in North Dakota's Soil

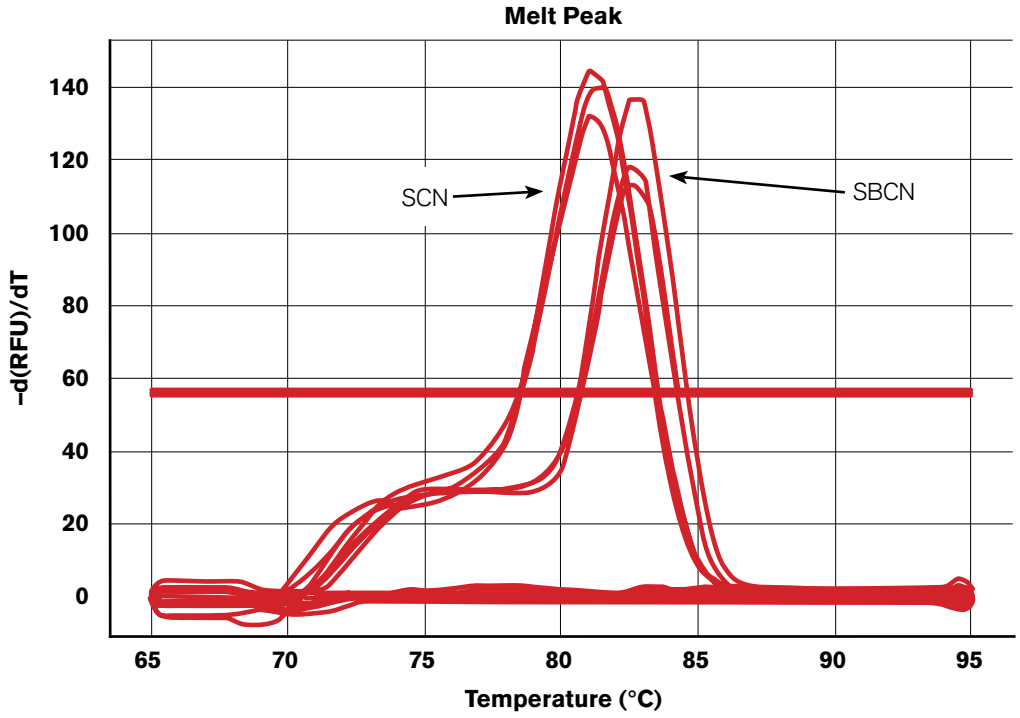
Principal Investigator: *Dr. Guiping Yan, Plant Pathology, NDSU*

Funded Project
$9,587

The soybean cyst nematode (SCN) continues to be a major threat to soybean production in North Dakota. Other nematodes, including sugarbeet cyst nematode (SBCN), clover cyst nematode and cereal cyst nematode, may occur in North Dakota fields. These nematodes are traditionally differentiated based on morphology. However, the distinction between SCN and the other nematodes using the traditional method is not only difficult and time-consuming, but also requires expertise in nematode taxonomy. This project's primary goal was to develop a molecular identification and quantification tool for SCN which was an alternative to the traditional method. The specific objectives were to design quantitative real-time Polymeric Chain Reaction (PCR) (qPCR) primers to detect SCN in the soil and to discriminate it from SBCN and other species as well as to develop a qPCR assay to quantify SCN from DNA extracts of field soils.

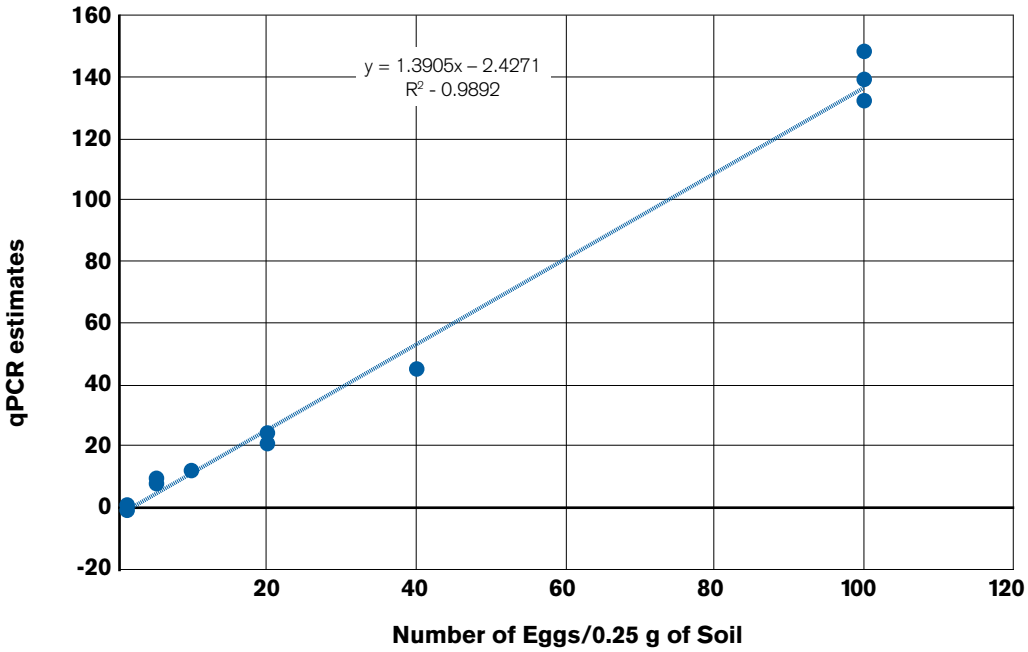
In this project, we designed qPCR primers (SCNF/SCNR) which showed high specificity to SCN. The primers' specificity was evaluated using seven SCN isolates and 31 isolates from other nematode species. Varying numbers of SCN eggs or juveniles, 0, 1, 4, 16, 64 and 256, were inoculated into 0.25 grams of sterilized soil from which soil DNA was extracted. A standard curve relating the threshold cycle and log values for the nematode number was generated. The assay was validated by quantifying different SCN numbers which were artificially added to a sterilized soil (Figure 1).

Figure 2. Distinguishing SCN (soybean cyst nematode) and SBCN (sugarbeet cyst nematode) simultaneously using the CLE2F/CLE2R primers. SCN DNA melts at 81.5°C, whereas SBCN DNA melts at 83.5°C.



The validated assay was used to estimate SCN numbers in 34 field soil samples from North Dakota which were naturally infested with the nematode at varying levels. For each soil sample, 400 grams of soil were collected and divided in half for molecular quantification, and traditional SCN extraction and microscopic enumeration. We also designed another primer pair (CLE2F/CLE2R) specific to both SCN and SBCN, and were able to separate them simultaneously (Figure 2). Finally, we found that different soil-texture classes may have effects on the quantification efficiency because soils with more clay content may inhibit qPCR amplification.

Figure 1. A linear relationship between nematodes actually added to the soil and qPCR (quantitative real-time PCR) estimates.



The developed molecular assay provides a platform to detect and to quantify SCN specifically and directly from DNA extracts of field soils, eliminating the time-consuming steps of nematode extraction, microscopic identification and counting. The qPCR assay is highly specific to SCN and will improve the SCN-detection efficiency in North Dakota's soybean fields, helping to prevent false-positive or negative-detection results for soil samples which are submitted by growers. Further, this assay provides a distinction method for SCN and other closely related cyst nematodes to effectively manage SCN using crop rotation.

Monitoring the Virulence-Changing of Soybean Cyst Nematode and Evaluating Soybean Varieties for Resistance to New Virulence Types

Principal Investigator: *Dr. Guiping Yan, Plant Pathology, NDSU*
Co-Investigators: *Dr. Ted Helms, Plant Sciences, NDSU; and Dr. Samuel Markell and Dr. Berlin Nelson Jr., Plant Pathology, NDSU*

Funded Project
$48,450

Soybean cyst nematode (SCN) is one of the greatest threats to soybean production worldwide. In North Dakota, it was first found in Richland County in 2003 and has since spread to many soybean producing counties. Due to its genetic diversity, this nematode easily adapts to new environments, overcomes resistance and spreads quickly. Therefore, it is very important to monitor its virulence changes across the state and to identify new sources of resistance.

Prior to 2017, only SCN populations from Richland and Cass Counties were tested for virulence (HG type). The research's objectives were to characterize the virulence diversity of SCN populations in other North Dakota counties as well as to evaluate soybean varieties and breeding lines for resistance to the new SCN virulence type which was detected in Cass County, North Dakota.

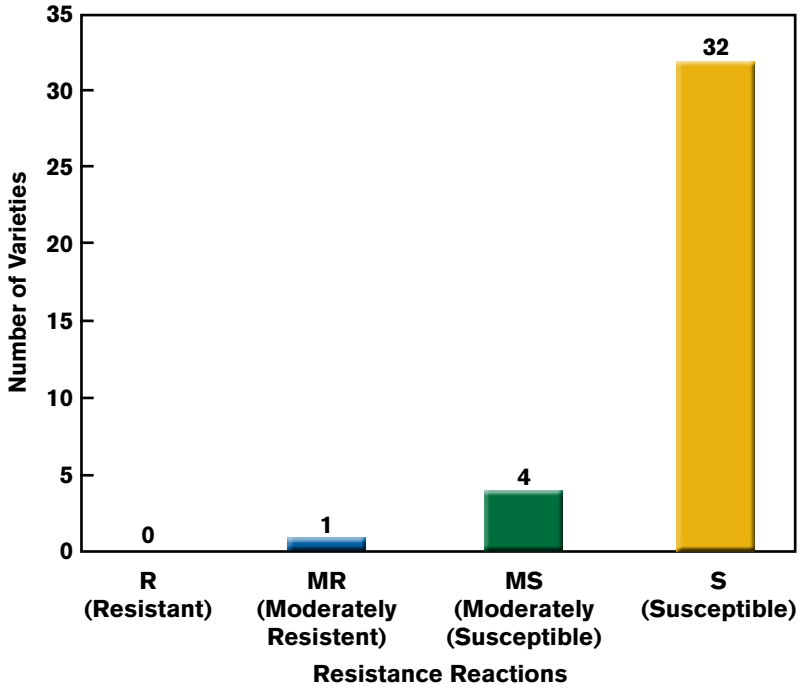
A total of 131 soil samples were collected from 10 major soybean producing counties, and 34 were positive for SCN. Among the successful experiments (Figure 1), the most common HG types were 7 (frequency rate: 33 percent) and 0 (25 percent). Other HG types included 2.5.7 (21 percent), 5.7 (13 percent) and 1.2.5.7 (8 percent). Among the counties surveyed, Traill County had the greatest SCN diversity with four HG types (0, 7, 2.5.7 and 1.2.5.7), followed by Barnes with three (0, 7 and 2.5.7), Grand Forks with two (7 and 5.7) and Steele with two (0 and 5.7). HG type 2.5.7 was the third-most prevalent type, and HG 1.2.5.7 was detected for the first time in North Dakota. This demonstrates the diversity of SCN field populations and breaking of the resistance from the two major sources, PI88788 and Peking.

Thirty-seven soybean varieties and breeding lines as well as a susceptible check were screened for the new virulence type (HG type 2.5.7) in Cass County, North Dakota. A significant difference ($P < 0.001$) was observed in the soybeans' female index (FI). Of the 37 varieties and lines tested, 32 showed susceptible reactions (FI: 77 to 437); four were moderately susceptible (FI: 44 to 59); and only one was moderately resistant (FI: 26). Most soybeans were susceptible (Figure 2). Therefore, additional soybean lines will be screened to identify better resistance against the new virulence type.

These research findings are important to navigate the use of alternative resistance sources for growers and to identify new resistance sources that should be introduced to North Dakota in order to develop new, resistant varieties that combat the new virulence types and increase soybean production.

Figure 1. SCN-virulence (HG type) testing experiments in the growth chamber were maintained at a consistent temperature of 27 °C. Figure 1 shows the HG type experiment but not resistance classification.

Figure 2. Classification of the soybean varieties' resistance responses to the new SCN virulence type (HG type 2.5.7) which was isolated from Cass County, North Dakota. Figure 2 shows the resistance classification but not HG type.



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4852 Rocking Horse Circle South, Fargo, ND 58104 | ndsoybean.org

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