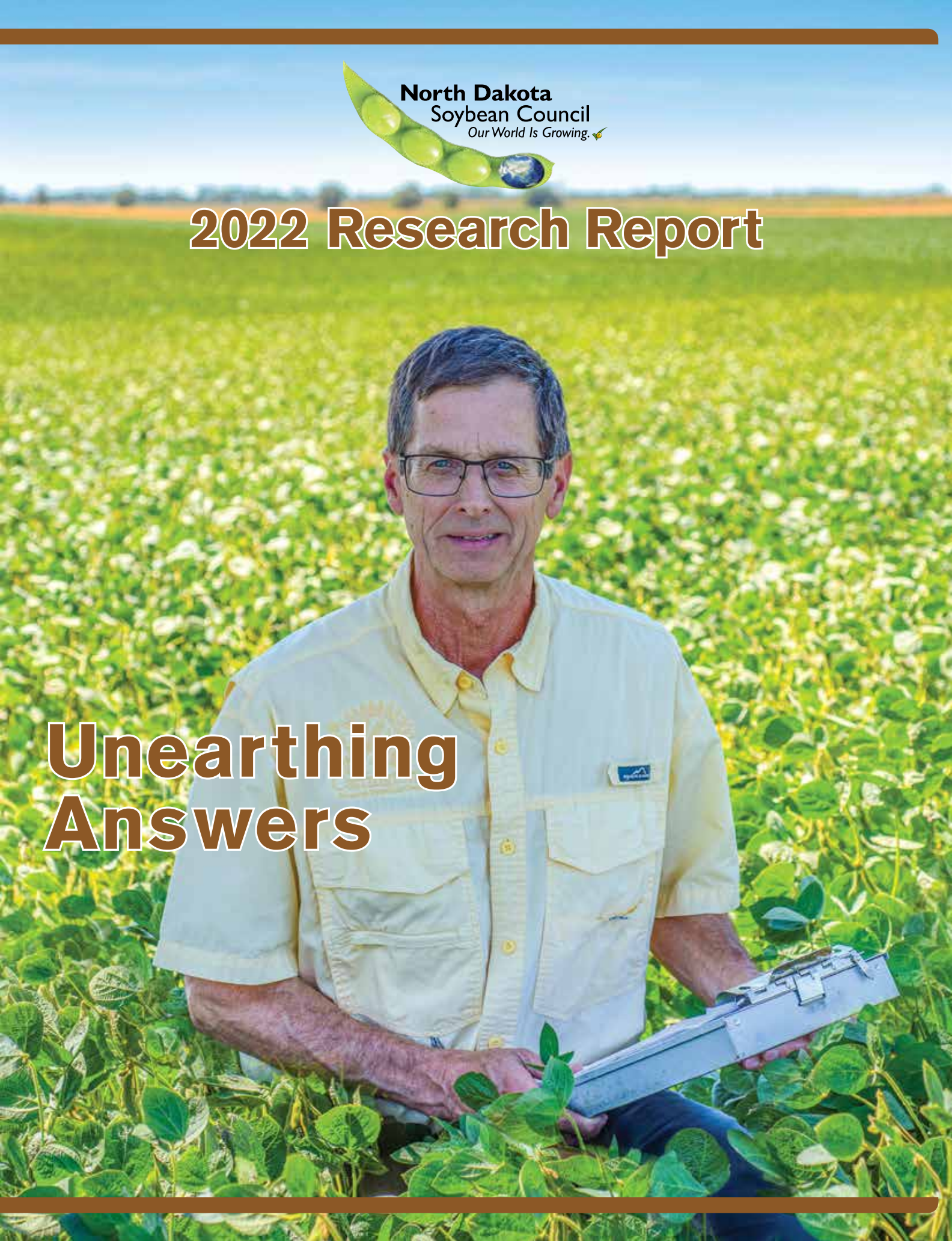
North Dakota Soybean Council
Our World Is Growing.

2022 Research Report



Unearthing Answers

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2022 Research Committee Report

Soybean Research and Innovation Play a Pivotal Role in the Success of North Dakota Soybean Farmers.

Research has been one of the main priorities of the North Dakota Soybean Council (NDSC) since its establishment. The NDSC board is committed to investing a large portion of the checkoff funds that it receives in order to fund research designed to increase soybean yield and profitability while protecting natural resources. The NDSC also provides funding to communicate the research results because getting those findings and recommendations into the hands of farmers, agronomists and crop consultants is a key component of the NDSC's efforts. The NDSC's research mission is to strategically invest research dollars to secure a more profitable future for North Dakota's soybean producers.

In fiscal year 2022, the NDSC board invested 36% of its total budget in the amount of $1,665,719 in new and continuing research projects and programs. The goal is to address soybean-production issues and to provide farmers with timely, relevant and innovative solutions to produce and to market high-yielding and high-quality soybeans.

North Dakota is a unique soybean-production region with numerous production challenges. Soybean farmers face a short growing season, challenging weather conditions and pest pressure that limit the soybean's yield potential. Despite these obstacles, soybean acres and productivity increase annually across the state. Since the 1980s, soybean production in North Dakota has increased over 50 times; the annual average soybean yield on a farm has also increased by 0.2 bushels per acre. Traditionally, soybean production was centered around eastern North Dakota in the Red River Valley, but in recent years, soybean production has exploded in western North Dakota. With soybeans planted on 7.25 million acres in 2021, North Dakota ranked the fourth largest for planted and harvested soybean acres and tenth for soybean-production bushels in the nation.

Soybean-production research is one of the main drivers that played a pivotal role in soybean expansion, sustainability and yield improvements in our state. Breeding for early season, high-yielding varieties that are resistant to iron deficiency chlorosis, diseases and soybean cyst nematode is an example of checkoff-funded research providing solutions for many complex soybean-production issues. Developing region-specific, sound management practices and efficient farming systems is also accomplished through research investments. Supporting the statewide Soybean Cyst Nematode (SCN) sampling program, which is operated by North Dakota State University (NDSU) Extension, is another example of research-checkoff investments helping with the proactive management for one of the top yield-robbing soybean pests in the U.S.

Every year, the NDSC Research Committee works closely with farmers, researchers, Extension personnel, agronomists and crop consultants to identify issues and to set priories for two strategic research initiatives: soybean production and plant breeding, and new-uses research. We thank the farmers, agronomists and researchers who provided valuable input to identify North Dakota's production challenges and research priorities that are used as a guide to fund the NDSC's research projects/programs.

The success of the NDSC research program relies on farmers' and relevant stakeholders' involvement. We welcome your input to gain valuable insight about soybean-production issues or potential opportunities that are most important and relevant to North Dakota's soybean farmers.

In this report, we are proud to share details about the NDSC-funded research projects for Fiscal Year 2022. We hope that you find value in this report and, when appropriate, incorporate the research recommendations on your farm.

Mike Schlosser
NDSC Research Committee Chair
mschlosser@ndsoybean.org

Miki Miheguli
NDSC Research Programs Coordinator
mmiheguli@ndsoybean.org

North Dakota Soybean Council Research Committee

Mike Schlosser, Edgeley, Chair

JP Lueck, Spiritwood

Jennifer Meyer, Wilton

Dallas Loff, Wahpeton

Joe Ericson, Wimbledon

David Teigen, Rugby

Bill Connor, Industry Representative, FMC Agricultural Solutions

Dr. Emmett Lampert, Wimbledon, Research Consultant

Staff: Miki Miheguli, Research Programs Coordinator

On The Cover

Greg Endres is a cropping systems specialist at the Carrington Research Extension Center. Throughout his career, Greg has played an instrumental role in identifying soybean production issues. He has designed and conducted field experiments to answer pressing questions. Greg also provides practical and science-based information for farmers. Greg's research and extension work is focused on spring wheat and row-crop production, including soybeans, dry beans, corn and sunflowers.

Regional Patterns of Herbicide-Resistance Traits in Pigweed Escapees

Principal Investigator: *Dr. Zack Bateson, National Agricultural Genotyping Center*
Cooperators: *Dr. Joseph Ikley, NDSU Department of Plant Sciences; Dr. Michael Christoffers; NDSU Department of Plant Sciences; and Megan O'Neil, National Agricultural Genotyping Center*

Funded Project
$35,000

Why this Research is Important to North Dakota Soybean Farmers

After the recent invasion of Palmer amaranth and the increasing suspicion of extensive HR in other pigweeds, finding HR hotspots is a top priority in North Dakota. Each year, farmers report pigweeds that escape herbicide applications, yet no formal surveys or experiments have explored these issues. Our project is the first in the state to begin a survey to test multiple pigweed species for HR using both herbicide trials and genetic testing.

Research Conducted

The National Agricultural Genotyping Center (NAGC) partnered with weed scientists at North Dakota State University (NDSU) to identify herbicide resistance (HR) in North Dakota pigweed populations. Surveyors collected pigweeds from 16 counties during September through November 2021. NDSU researchers propagated seeds in the greenhouse and divided seedlings into treatment groups to be sprayed with glyphosate, imazamox or fomesafen. Along with herbicide testing, leaf samples were submitted to the NAGC to search for genetic markers associated with resistance to the three herbicides.

Findings of the Research

Seedling survival in the greenhouse and independent genetic testing support widespread HR in pigweeds (Figure 1). In total, 1,796 seedlings, mostly waterhemp, were included in the herbicide treatments (Figure 2). Waterhemp populations in 6 counties could overcome all three herbicides. Genetic analysis found markers linked to glyphosate and fomesafen resistance in both field (parent) and greenhouse (offspring) plants. In fact, waterhemp populations had plants with genetic markers linked to resistance for both herbicides, suggesting stacked resistance within individuals. The survey also found three new infestations of Palmer amaranth in Ward County as well as evidence for imazimox resistance in tumble pigweeds for the first time.

> "Each year, farmers report pigweeds that escape herbicide applications, yet no formal surveys or experiments have explored these issues."

Figure 2. Cone-tainers with pigweed seedlings that are ready for herbicide trials in the greenhouse. Prior to treatment, a single leaf was collected for genetic analysis.

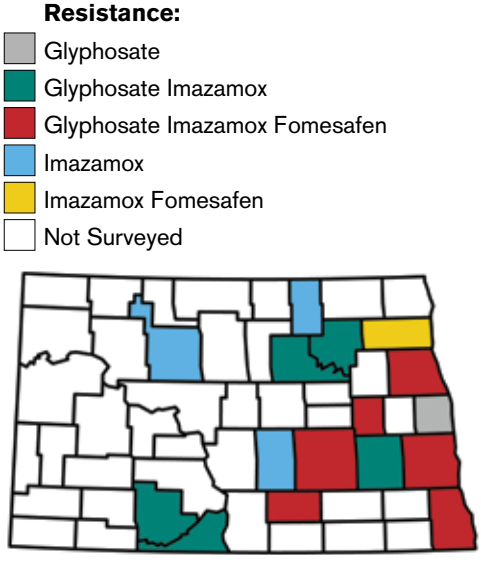


Figure 1. Statewide map describing the particular HR diversity of pigweed samples from the 16 counties in N.D. There were pigweeds resistant to at least one herbicide in all the surveyed counties.

Benefits to North Dakota Soybean Farmers

Identifying HR populations through greenhouse and genetic testing is beneficial at multiple levels. At the county level, reporting HR populations helps agencies monitor the spread of these troublesome traits and provides data about where resources are needed for eradication. Creating a statewide distribution map increases the awareness of encroaching HR pigweeds and intensifies scouting efforts. At the farm level, knowing the exact HR traits in the field helps with decisions about herbicides to include or to avoid. Herbicide mixes are used to combat pigweeds, but the returns of using particular mixes diminish when local pigweeds have resistance to herbicides in the mix. Lastly, growers rely on NDSU Extension for recommendations about effective herbicides; the advice is based on data from greenhouse or test-plot research. The NAGC's ability to provide genetic testing for HR alleviates some of the demands for greenhouse work and further helps researchers select seed sources for herbicide trials when space and time are limited.

Liming Effects on Soybeans and Different Western North Dakota No-Till Soils

Principal Investigator: *Dr. Chris Augustin, NDSU Dickinson Research Extension Center*

Funded Project
$26,780

Why this Research is Important to North Dakota Farmers

Nitrogen (N) fertilizers acidify the soil due to nitrification. No-till soils are particularly susceptible to acidification from the lack of mixing of subsurface alkaline products and the tendency to apply N fertilizers at or near the soil's surface. As a result, the zone of acidification is typically in the area of the fertilizer's placement. Calcium carbonate is a common soil amendment that neutralizes soil acidity. Sugarbeet waste lime is a byproduct of the sugar refinement process and contains approximately 75% calcium carbonate and phosphorus. Sugarbeet waste lime is readily available to North Dakota producers.

Research Conducted

Sugarbeet waste lime was applied to 10 experimental fields at 0, 2, 4, 8 and 16 tons of calcium carbonate/acre to achieve the following objectives:

1. Evaluate impact of lime rates on North Dakota soils and use data to build liming recommendations for North Dakota.
2. Evaluate soybean yield and quality differences among lime treatments.
3. Increase the knowledge base of acidic soil management in western North Dakota.

Table 1. Beet lime impacts on soil pH at various depths.

Beet Lime	0-3 in	3-6 in	0-6 in
Tons CCE/ac	- - - - pH - - - -		
0	5.4e*	6.0d	5.7e
2	6.0d	6.0d	5.9d
4	6.4c	6.2c	6.3c
8	6.7b	6.4b	6.7b
16	7.0a	6.7a	6.9a
P-value	<0.001	<0.001	<0.001
C.V.	4.28	6.50	5.30

*Different letter indicate statistical differences at the 0.05 level

Findings of the Research

All treatments improved soil pH (p-value <0.001) at the 0- to 3-inch depth and reduced soil-extractable aluminum (p-value <0.001). Regression analysis grouped by the soil-buffer pH at the 0- to 3-inch depth produced several statistically significant equations (p-value <0.05). The equations can be used by producers to improve the acid-soil pH to a desirable level. Sugarbeet waste-lime treatments increased the fall Olsen phosphorus test and decreased both soil extractable aluminum and manganese (p-value < 0.001).

> "Sugarbeet waste lime is a byproduct of the sugar refinement process and contains approximately 75% calcium carbonate and phosphorus."

Table 2. Beet lime impacts on soil pH based off of buffer pH

Buffer pH	Desired pH (0-3 in depth)			Equation	r^2
	5.5	6.0	6.5		
6.2	5.6	9.5	14.0	$y^{**} = 1.271x^2 - 6.8828x + 5.0276$	0.99*
6.3	10.0†	11.0	8.5	$y = -7.0431x^2 + 82.954x - 233.15$	0.60
6.4	0.7	3.4	8.6	$y = 5.1047x^2 - 53.374x + 139.86$	0.81*
6.5	2.7	5.2	8.6	$y = 1.5829x^2 - 13.1x + 26.826$	0.60*
6.6	2.0	4.5	8.1	$y = 2.0756x^2 + 18.833x + 26.826$	0.67*
6.7	1.5	5.5	9.2	$y = -0.6377x^2 + 15.394x - 63.884$	0.57*
6.8	0.9	2.4	5.1	$y = 2.3551x^2 - 24.025x + 61.806$	0.54*
6.9	0.1	1.2	3.8	$y = 2.987x^2 - 32.222x + 86.998$	0.61*
7.0	-0.1	0.5	2.5	$y = 2.9062x^2 - 32.259x + 89.428$	0.59*
7.1	1.1	4.2	7.3	$y = -0.1207x^2 + 7.6291x - 37.184$	0.56

*Significant at the 0.05 level
**Y is tons of lime needed, X is desired pH

Table 3. Beet lime impacts of soil nutrients at the 0-6 in depth.

Beet Lime (applied as calcium carbonate equivalent)	Salts	OM	Phosphorus (Olsen)	Calcium	Manganese	Aluminum	Calcium Carbonate Equivalent
tons/ac	mmhos/cm	%	- - - - - - ppm - - - - - -				%
0	0.3b	3.2	18d	1781c	18a	5a	0.6c
2	0.3b	3.1	19d	1999c	14ab	2b	0.6c
4	0.4ab	3.0	20b	2286b	11ab	2b	0.8b
8	0.5	3.0	23b	3096b	9b	2b	1.0b
16	0.5	3.0	26a	4143a	9b	1b	1.5a
P-value	<0.001	0.995	<0.001	<0.001	<0.001	<0.001	<0.001
C.V.	39.4	35.9	33.0	32.8	54.5	157.3	44.5

*Different letter indicate statistical differences at the 0.05 level

Soybean and Other Broadleaf Row-Crop Tolerance to the Preplant, Low-Dose Application of Dicamba

Principal Investigator: *Greg Endres, NDSU Carrington Research Extension Center*

Funded Project
$6,770

Research Conducted

The objective of this research is to evaluate the soybean's plant growth and yield response based on the timing of planting after the application of a preplant, low-dose soil rate of dicamba with or without water activation.

The initial year of this study was conducted at three NDSU research sites in 2021: Carrington (irrigated), and Minot and Prosper (dryland). The four targeted treatments were as follows:

1) untreated
2) treated (Clarity or generic dicamba preplant applied 4 fluid ounces of product per acre in mid May; soybean planted
3) <14 days after dicamba application and before rain or irrigation
4) >14 days after dicamba application and rain or irrigation >1".

Field data included soybean plant-development (emergence, flower and maturity) dates; plant density and canopy; injury ratings 1-2, 3-4, and 6-8 weeks after plant emergence; and crop height 3-4 and 6-8 weeks after emergence. At Carrington, the soybean yield and quality data were generated.

Figure 1. Field experiment showing broadleaf crop tolerance to preplant dicamba.

Findings of the Research

Soybean plant injury (reduction in biomass) with the first planting date, which occurred 2 days following application of dicamba at Prosper and 7 days after application at Minot, was 53-73% at Prosper and 85-87% at Minot. Plant injury for the second planting date, which occurred 16 days and 0.74 inches of rain following application of dicamba at Prosper, and 20 days and 0.96 inches of rain at Minot, was 18-45% at Prosper and 22-39% at Minot. At Carrington, the first evaluation indicated 43% injury with the early planting date, which was 6 days and 0.08 inches of rain after applying dicamba, while minimal injury of less than 6% was observed after the second planting date, which was 19 days after applying dicamba and less than 2 inches of water. Plant density was reduced 17% for the first planting date following the application of dicamba at Carrington; 68% at Minot and 55% at Prosper. At Carrington, the soybean yield with dicamba-treated soil was similar to the untreated checks.

The study continued in 2022.

Figure 2. Soybean injury with preplant dicamba.

Table 1. Crop yield with preplant low-rate dicamba, Carrington, 2021

Planting Date	Herbicide	Crop		
		Soybean (bu/ac)	Pinto bean (cwt/ac)	Sunflower (cwt/ac)
19-May	Untreated Check	77.2	31.3	25.8
	Dicamba	72.9	29.9	30.0
1-Jun	Untreated Check	76.2	30.7	25.2
	Dicamba	71.5	30.4	24.1
LSD (0.05)		NS	NS	NS

Pyrethroid-Resistant Soybean Aphids and Soybean Gall Midge Survey

Principal Investigators: *Dr. Janet J. Knodel, NDSU Professor and Extension Entomologist; Dr. Veronica Calles-Torrez, Post-Doctoral Scientist; and Patrick Beauzay, State IPM Coordinator and Research Specialist*

Cooperator: *Brian Otteson, Director, NDSU Agronomy Seed Farm, Casselton, North Dakota*

Grower Cooperators: *Jared Hagert and Dale Flesberg*

Funded Project
$35,500

Why this Research is Important to North Dakota Soybean Farmers

The soybean aphid is a major insect pest for soybeans in North Dakota. The goal of this research was to develop the best pest-management (BPM) practices for insecticide-resistant soybean aphids. Grower complaints about pyrethroid insecticides not controlling soybean aphids were common and widespread in eastern North Dakota during 2017. Laboratory bioassays confirmed that about 70% of the tested soybean aphid populations were resistant to pyrethroid insecticides.

In 2021, soybean aphid populations were low and present at non-economic levels, so no insecticide testing with new, different modes of action could be done. Because soybean aphids were not present at economic population levels in 2021, we used our soybean-insecticide plots to conduct a grasshopper-insecticide efficacy study, and we evaluated some newer products, such as Vantacor. Recently, the grasshopper populations were at an economic level throughout the state due to the drought increasing the population levels.

This research is important for soybean growers, so they can wisely select which insecticide and mode of action to use against existing insect pests such as grasshoppers and pyrethroid-resistant soybean aphids.

Research Conducted

Our second objective was to survey for the invasive soybean gall midge, a new insect pest in soybeans. The soybean gall midge is now established in five states–Iowa, Minnesota, Missouri, Nebraska and South Dakota–and has increased its distribution from a total of 67 counties in 2018 to 114 counties in 2021. As the soybean gall midge continues to expand its distribution, it is important for North Dakota soybeans growers to know if the pest is present in North Dakota.

A total of 588 soybean fields were inspected for soybean gall midge in 48 of North Dakota's 53 counties, which is 90% of the counties. The results for our 2021 soybean gall midge survey were negative for all the soybean fields surveyed in North Dakota. Future survey work to detect soybean gall midge will be crucial for soybean production in North Dakota.

Our last objective was to produce Extension outreach materials, including a large banner and a Soybean Insect Diagnostic Series (to be completed in the winter of 2022-23), about the economic insect pests for soybeans.

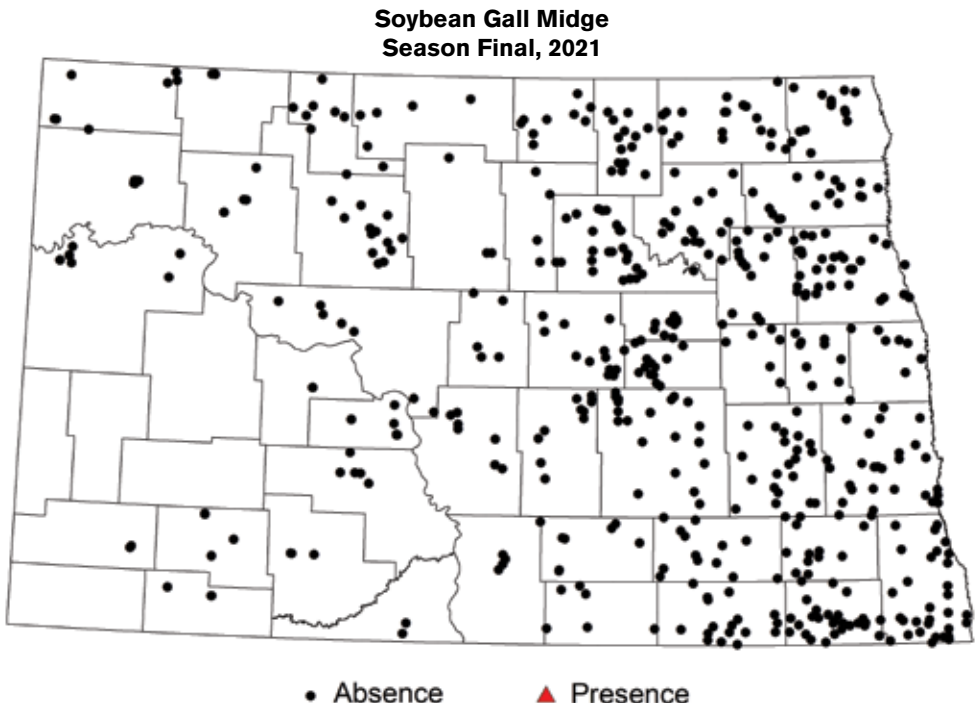


Figure 1. The 2021 survey results for soybean gall midge in North Dakota's soybean fields (Honggang Bu, NDSU).

Professor and Extension Entomologist Dr. Janet Knodel (top photo) and State IPM Coordinator and Research Specialist Patrick Beauzay (bottom photo) provide research updates during the NDSU Agronomy Seed Farm field day.

Winter Rye Cover-Crop Management Techniques for Soybeans

Principal Investigator: *Greg Endres, NDSU Carrington Research Extension Center*

Funded Project
$4,900

Research Conducted

This project's goal is to continue building North Dakota State University (NDSU) databases on soybean yield with two trials examining winter rye as a cover crop prior to soybean production. Research questions:

Rye as a cover crop: Will winter (cereal) rye as a cover crop affect soybean yield while providing benefits compared to conventional soybean production?

Fall seeding dates and rates for rye: What is the best seeding rate and established stand for the rye based on fall seeding dates and the following seasonal factors that affect soybean production: ground cover, soil moisture and weed suppression with rye?

- **Study 1:** The fourth and final year of the study was conducted in 2021; the assessment was done at the Carrington Research Extension Center's (CREC) tri-county off-station research site. Winter rye was seeded on October 21, 2020, and resulted in a mid-May 2021 stand of 262,000 plants per acre, based on 6 plants per square foot. The treatments were as follows: 1) soybeans grown without rye, 2) rye terminated with glyphosate 9 days before soybean planting and 3) rye terminated with glyphosate 6 days after soybean planting. Soybeans were planted on May 13 and harvested on October 8.
- **Study 2:** The third year of the study was conducted at the CREC during 2020-21. The treatments were as follows: Winter rye was seeded on September 17 and October 8, 2020, at 25, 50 and 75 pounds per acre (six treatments). Soybeans were planted on May 18, 2021, followed by rye termination with glyphosate on May 20, and harvested on September 17.

Findings of the Research

- **Study 1:** In 2021, the soybean yield with the conventional production check was greater than the two treatments with rye. Limited topsoil water due to the drought and rye growth resulted in reduced soybean-plant production during the first half of the season.

Figure 1. Trial location in Carrington, North Dakota.

Also, the rye provided minimal suppression of weeds compared to the weed control with a soil-applied herbicide that was used for the check. About 30 people viewed the crop and heard a discussion about the study during the July 1 field tour.

- **Study 2:** The rye's plant density and ground cover, which were measured during the last half of May 2021, ranged from 29,880-448,210 plants per acre and 3-23%, respectively, among the combinations for the rye seeding dates and rates. The greatest rye density and the largest amount of ground cover resulted from planting late at the 75 pounds per acre seeding rate. Green foxtail

Table 1. Winter rye plant cover crop density, ground cover and weed suppression with winter rye cover crop seeding dates and rates, Carrington, 2021.

Rye seeding treatment		Rye		Weed control
Date	Rate	Plant density 18-May	Ground cover Visual (24-May)	Green foxtail 16-Jun
	lb/ac	plt/ac	%	%
17-Sep	25	29,880	4	61
	50	75,410	3	54
	75	152,250	6	64
8-Oct	25	99,600	10	59
	50	264,660	19	67
	75	448,210	23	64
CV (%)		36.6	24.3	22.0
LSD (0.10)		82,180	3	NS

suppression of 54-67% was similar among the 6 rye treatments. The soybean's plant density and maturity, and yield, which averaged 40.6 bushels per acre, and quality were similar among the rye treatments. The study continues in 2022.

Benefits/Recommendations for North Dakota Soybean Farmers

- **Study 1:** The timing of rye termination with glyphosate needs to be carefully considered in order to balance the benefits of the cover crop while preserving soil moisture for the soybean crop.
- **Study 2:** Fall planting dates and rates need to be considered based on the farmer's goals for the cover crop, including soil cover and moisture, weed control and soybean performance.

> "This project's goal is to continue building NDSU databases on soybean yield with two trials."

Greg Endres evaluates soybean growth at one of the research locations at Carrington Research Extension Center.

Table 2. Soybean response with winter rye cover crop seeding dates and rates, Carrington, 2021.

Rye seeding treatment		Plant				Seed				
Date	Rate	Stand	Emergence	Canopy closure (17-Aug) Canopeo	Physiological maturity (R8)	Yield	TW	Count	Protein	Oil
	lb/ac	plt/ac	Day of Year	%	Day of year	bu/ac	lb/bu	no./lb	%	
17-Sep	25	128,160	154	82	254	38.6	57.2	3,276	33.8	20.1
	50	142,100	155	85	254	39.9	57.3	3,346	33.8	20.3
	75	136,790	155	88	255	40.7	57.0	3,237	34.0	20.2
8-Oct	25	139,450	155	89	255	41.3	57.1	3,117	33.9	20.1
	50	153,390	154	86	255	41.8	57.2	3,197	33.9	19.9
	75	130,150	155	87	255	41.0	57.4	3,102	34.1	19.9
CV (%)		9.2	0.3	3.5	0.4	9.1	0.4	3.7	1.1	1.3
LSD (0.10)		NS	1	4	NS	NS	NS	NS	NS	NS

Resistance to Important Soybean Diseases

Principal Investigators: *Dr. Jack Rasmussen, NDSU Plant Pathology*
Cooperating Scientists: *Dr. Carrie Miranda, Soybean Breeder, NDSU Plant Sciences.*

Funded Project
$61,850

Why the Research is Important to North Dakota Soybean Producers

A major focus of this research was to identify resistance to major soybean diseases in North Dakota and to work with the North Dakota State University (NDSU) soybean breeder, Dr. Carrie Miranda, to incorporate resistance into NDSU soybean varieties. The emphasis this past year was on identifying and verifying resistance to sudden death syndrome (SDS) caused by Fusarium virguliforme, a new disease for our northern soybean-production area (Figure 1). In addition, we continued our program of incorporating resistance to Phytophthora root rot into the NDSU soybean breeding lines.

Research Conducted

In cooperation with Dr. Miranda, 180 advanced breeding lines were screened for resistance to Phytophthora sojae during 2022. Most of the screening was for Race 4 resistance because the source of resistance in the breeding lines is probably from the Rps 6 gene. Of the 130 lines tested for race 4 resistance, 80 were resistant. Of the 50 lines tested for race 3 resistance, 14 were resistant. Maintaining resistance in the breeding lines allows new cultivars to be developed with high levels of resistance to certain races of Phytophthora. We maintain a variety of races of P. sojae in storage, and each year, the races used for screening are grown in the laboratory and tested to be sure that they are virulent.

Figure 1. Soybean sudden death syndrome symptoms in the field.

A major effort is underway to identify and to verify sources of resistance to sudden death syndrome (SDS) in germplasm adapted to our northern soybean-production area. From 2021 to 2022, various experiments were conducted both in the field and in the greenhouse to evaluate resistance to SDS in different early maturing varieties (maturity group 0 to 00). Most of these tests were conducted by growing plants in naturally infested soil until the F6 to F7 growth stage. Resistance was evaluated based on the extent of foliar symptoms for SDS.

> “A major effort is underway to identify and to verify sources of resistance to SDS in germplasm adapted to our northern soybean-production area.”

Findings of the Research

The testing has identified two NDSU soybean varieties, Benson and Bison, with good levels of resistance to SDS. Other early maturing varieties from Minnesota have also been found to have resistance to SDS. Multiple years of testing are needed to verity that the source of resistance is expressed under various growing conditions. In addition, research is underway to develop screening methods that will consistently result in SDS foliar symptoms under greenhouse conditions. A reliable greenhouse screening method would be a useful tool to identify breeding lines with high levels of resistance and will facilitate development of SDS-resistant, NDSU soybean varieties.

Visual Ratings for Iron-Deficiency Chlorosis

Principal Investigator: *Dr. Carrie Miranda, NDSU Department of Plant Sciences*

Funded Project
$87,316

Why the Research is Important to North Dakota Soybean Farmers

Iron-deficiency chlorosis (IDC) is common in North Dakota and reduces yield. The best way to reduce the yield losses associated with IDC is to select a tolerant cultivar. Growers need data that compare varieties from all the different companies at the same locations.

Research Conducted

This proposal permitted 253 different genetically modified organism (GMO) company varieties and non-GMO varieties to be evaluated for IDC tolerance. An additional 113 NDSU breeding lines were also evaluated. All private-company varieties that were entered into the Langdon Research and Extension Center (REC), Carrington REC, Minot REC and Fargo Main Station yield trials were evaluated for visual IDC ratings at multiple field locations. These data provided independent confirmation for the IDC tolerance of company products and enabled growers to compare varieties from different companies. This project provided an unbiased comparison of yield data in the same environment for growers to select tolerant cultivars to increase the yield for fields that have a past history of IDC.

In 2021, there were 215 GMO company varieties tested, and 38 Liberty Link and non-GMO company varieties were planted at 3 locations: Leonard, Colfax, and Erie, North Dakota. One location successfully showed IDC symptoms, and three scoring dates were recorded. The data were analyzed and reported in the NDSU bulletin titled "North Dakota Soybean Performance" and were posted online.

This work's goal was to give growers additional data so that farmers can make the best decisions when choosing varieties, especially with IDC-affected soils. Support for this project was high among private companies as well; 253 varieties were entered in 2021. IDC-infected fields were selected for the 2022 season during 2021. Due to the usefulness of the data collected, this project will continue in 2022.

> "IDC is common in North Dakota and reduces yield. The best way to reduce the yield losses associated with IDC is to select a tolerant cultivar."

The trial location near Fargo shows a different level of Iron Deficiency Chlorosis in soybean.

Managing Salinity with Cover Crops: A Whole-System Response (Year Four)

Principal Investigators: *Dr. Caley Gasch, NDSU School of Natural Resource Sciences*
Co-Investigators: *Dr. Jason Harmon, NDSU School of Natural Resource Sciences; Dr. Sam Banerjee, NDSU Department of Microbiological Sciences; Dr. Tom DeSutter, NDSU School of Natural Resource Sciences; and Dr. Abbey Wick, NDSU School of Natural Resource Sciences*

Funded Project
$29,375

Why the Research is Important to North Dakota Soybean Producers

Soil-salinity management is only possible through managing water. Soil-water removal by plants (transpiration) is an effective way to dry the soil while encouraging the salts to remain deep in the soil's profile. We wanted to quantify the cereal rye's water use so that we could better understand the potential of this cover-crop species to assist with salt and water management and to make appropriate seeding-rate recommendations.

Research Conducted

During the 2019 growing season, we interseeded cereal rye (80 pounds per acre) into strips in the soybean fields and monitored the soil's water content (0-6") in the rye strips and the adjacent control strips that traversed saline and non-saline portions of the fields. We also grew cereal rye at different seeding rates (40, 80, 120 and 240 pounds per acre) in replicated pots in the greenhouse; there was an unlimited water supply for 5 weeks.

Benefits/Recommendations for North Dakota Soybean Farmers and the Industry

The water content in the field's soil was consistent throughout the 2019 season and did not differ between the cereal rye and the control strips. The soil water was a little higher in the saline soils, which produced less cereal rye biomass than non-saline soils (Figure 1). Cereal rye grows well in soils up to salinity levels of 6 dS/m (saturated paste extract). In the greenhouse, the cereal rye's biomass production and cumulative transpiration increased as the seeding rate increased to 120 pounds per acre (Figure 2). We did not measure spring water use, but fall cereal rye transpiration is similar to that of winter small grains, which is 25 inches of water per year.

If water use is the goal of growing cereal rye, we recommend using the highest seeding rate within your comfort level. We found that a seeding rate (drilled) between 120 and 240 pounds per acre provided the most water use.

Figure 1. The soil's water content (0-6") for two fields (near Jamestown) in soy with cereal rye (80 pounds per acre, dots) or without cereal rye (squares) in 2019. The left charts are for non-saline points, and the right charts are for saline points. The vertical line indicates cereal rye interseeding, and the numbers are the cereal rye's average biomass production until fall freeze.

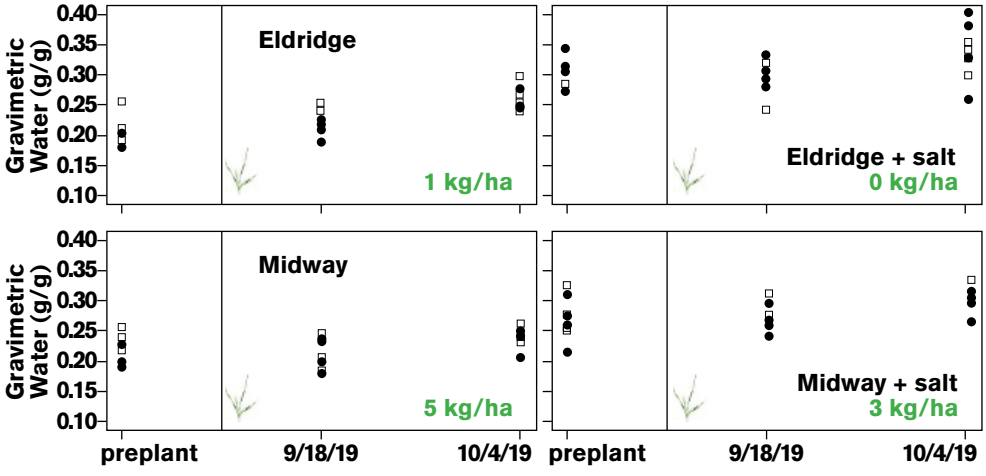
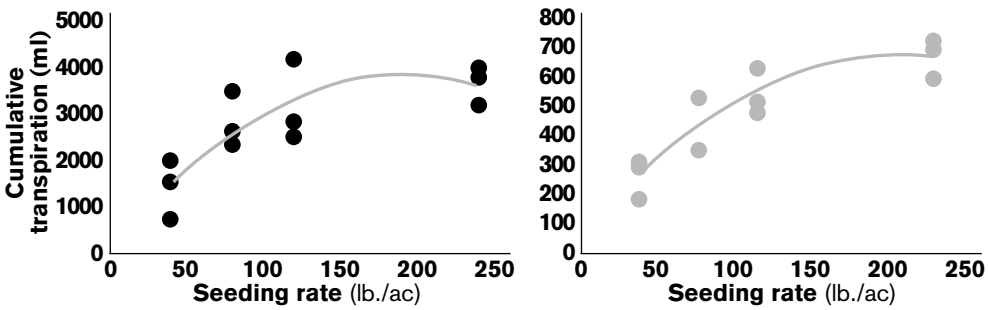


Figure 2. Cumulative water use (left) and rye biomass (right) across four seeding rates; the plants were grown in a greenhouse with an unlimited water supply for 5 weeks. The data were collected by graduate student Alec Deschene.



Dr. Caley Gasch examines a soybean plant in the field.

A Tool for Cheap and Rapid Tracking of Soybean Inoculate Populations in Field Soil

Principal Investigator: *Dr. Barney Geddes, NDSU Department of Microbiological Sciences*

Funded Project
$5,978

Why the Research is Important to North Dakota Soybean Producers

Unnecessary inoculation wastes farmers' money and cuts into their bottom line. However, choosing not to inoculate carries significant risk. If optimal nodulation does not occur, soybean crops may not get enough nitrogen, resulting in yield losses. Unfortunately, no practical approach currently exists for farmers to predict the requirement for inoculation prior to planting.

Research Conducted

With this project, we wanted to develop a cheap and rapid tool that can be used to track inoculant populations in field soil. We successfully established an assay that we named NDSoy1.0. When we applied the assay to fields in western North Dakota with varying years since the previous soybean crop, we found a wide disparity for the rhizobia concentrations present in the fields, ranging from less than 1,000 cells per gram (undetectable by NDSoy1.0) to over 1,000,000 cells per gram. Based on preliminary work in the greenhouse to identify the threshold of rhizobia above which optimal nodulation is achieved, we anticipated a mix of recommendations: do inoculate, do not inoculate or consider inoculating next year based on this spread of results. The wide range of rhizobia concentrations further validated the usefulness of this tool to guide the farmers' inoculant decisions, particularly in western North Dakota where rhizobia populations may decline more rapidly than in eastern North Dakota. Although the sample numbers were limited, sampling at the irrigated sites indicated that drought conditions might be an important factor for the rhizobia population's decline in western North Dakota's field soils.

Work in the coming year will focus on further refining the assay to improve sensitivity and to evaluate robustness for the sample-collection procedures and various sample types. Beyond that, field trials should be conducted to establish critical rhizobia levels that must be maintained for optimal nodulation, nitrogen fixation and yield in order to guide recommendations to farmers. This study created the groundwork for the near-term deployment of a tool that can provide actionable information about the soil's biology to the farmers.

Dr. Barney Geddes, Assistant Professor at NDSU

Figure 1. Dr. Barney Geddes and his team collecting samples from one of the trial sites.

> "If optimal nodulation does not occur, soybean crops may not get enough nitrogen, resulting in yield losses."

Identification of Suppressive Soil to Manage Soybean Cyst Nematode in North Dakota

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

Funded Project
$7,740

Why the Research is Important to North Dakota Soybean Farmers

Soybean cyst nematode is the most damaging pathogen of soybean. Management of this disease is crucial to reduce the economic losses to the farmers. Enhancement of soil-based natural suppression could be an alternative means to manage SCN or as a part of an integrated pest management program. This project targets the integrated pest management approach to managing SCN through identification of suppressive soil. This is the first study in ND to investigate suppressive soil for SCN management.

Research Conducted

A total of 23 soybean fields from 8 counties in North Dakota were sampled for soybean cyst nematode (SCN) population densities; these plots were previously reported to have decreasing populations over past years. Ten fields with lower SCN populations were selected for greenhouse experiments. Three experiments were conducted; each test had four replications. Susceptible soybean cultivar Barnes was used as the SCN host. After 60 days of growth and inoculation, the cysts were extracted from the plant roots and the soil, and white females were identified and counted under a microscope. The cysts were then crushed, and the SCN eggs and juveniles were extracted and counted. The reproductive factor was calculated by dividing the final nematode population density by the initial population density.

Findings of the Research

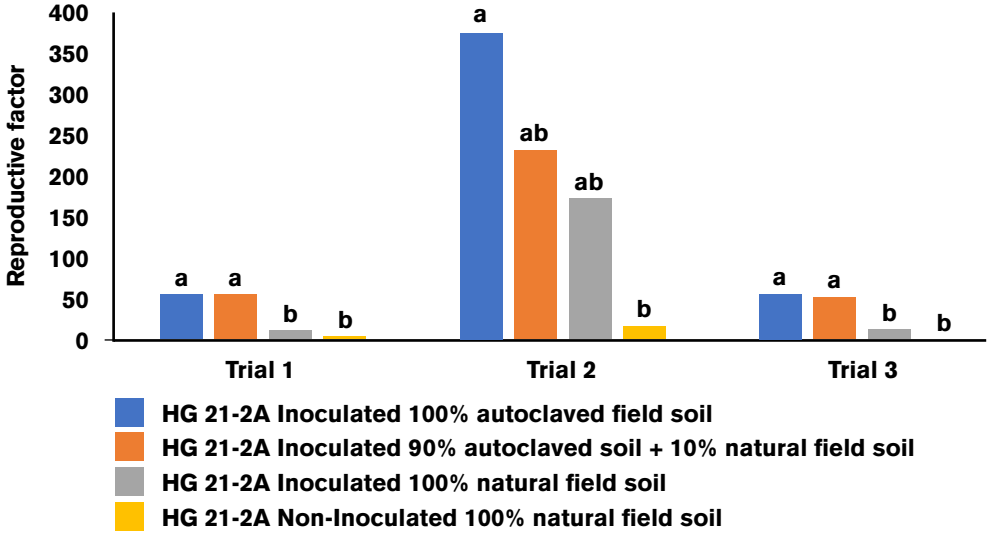
Two greenhouse experiments (Trial 1 and Trial 3) consistently showed that one field in Richland County has the potential to be suppressive against SCN because they significantly reduced the SCN white females (per 100 cubic centimeters of soil) and SCN eggs (per gram of soil) in 100% inoculated field soil (suppressive treatment) when compared to inoculated, 100% autoclaved field soil (conducive treatment). The reproductive factor values were significantly reduced in the HG 21-2A soil for those two trials (Figure 1) with the suppressive treatment. Four of the 10 selected fields showed lower SCN populations for the non-inoculated, 100% natural field soil with all the trials.

Dr. Guiping Yan, Assistant Professor – Nematologist at NDSU

Benefits/Recommendations for North Dakota Soybean Farmers and the Industry

These research findings can be beneficial because suppressive soil (HG 21-2A) can reduce nematode numbers in infested fields for SCN management. Further research on its transferability should be performed. Soil microbiome analysis will help identify specific microbes that play a key role in the suppressiveness against SCN for developing biocontrol agents. Biocontrol agents and bionematicides have become increasingly attractive because they are highly specific to the target nematodes and are friendly to the environment.

Figure 1. Reproductive factor values of SCN populations among 4 treatments after 60 days of planting and inoculation for the field soil sample HG 21-2A. The same letters within each trial correspond to no significant difference between the treatments at $\alpha = 0.05$.



Breeding of Glyphosate-Resistant Soybean Cultivars

Principal Investigator: *Dr. Carrie Miranda, NDSU Department of Plant Sciences*
Cooperating Scientists: *Dr. Berlin Nelson, NDSU Department of Plant Pathology, and Dr. Guiping Yan, NDSU Department of Plant Pathology*

Funded Project
$248,282

Research Conducted

This project was successful with the first glyphosate-tolerant (GT) variety (ND17009GT) released in 2017, and two new varieties were successfully released in 2020. 21ND08GT73 is a maturity group (MG) 0.8 and is the first later-maturing GT line released by the NDSU program. This line gives more North Dakota growers access to the cost-effective NDSU GT lines. 21ND008GT20 is a MG 00.8 variety and is considered to be an improvement on ND17009GT due to its increased iron deficiency chlorosis tolerance.

A successful breeding pipeline has promising materials continually moving through it. In addition to the two variety releases, prereleases are continually entered. There is an MG 00.6 experimental line that is suggested for prerelease which requires additional data.

In addition, there is also an MG 0.2 experimental line that is suggested for prerelease which also has moderate soybean cyst nematode resistance; this resistance was validated by Dr. Guiping Yan. Phytophthora resistance for all these lines and other in advanced yield trials was validated by Dr. Berlin Nelson.

Why this Research is Important to North Dakota Soybean Farmers

This project has enabled North Dakota State University (NDSU) to continue the process of developing glyphosateresistant soybean cultivars. There are glyphosate-resistant experimental lines in the NDSU breeding program that are being tested in a maturity range that varies from a 1.0 to a 00.4 maturity, and properly adapted throughout the entirety of North Dakota. New experimental lines are developed each year, including in 2021. This project has significantly reduced seed costs for soybean growers. The cultivars with glyphosate resistance that are developed at NDSU are not patented. The cost savings for growers who purchase NDSU's glyphosate-resistant cultivars will occur in the second and subsequent years after the seed's initial purchase. The seed of new experimental lines has been increased in Chile each winter to speed the development and release.

Figure 1. Soybean Experimental lines in the NDSU Soybean Breeding Program are crossed with other experimental lines to create superior new varieties to test.

Figure 2. After taking pollen from another NDSU experimental line, it is used to fertilize the female flower. Once pollination is completed, a tag is attached. The seed that is produced from this cross is the beginning of a new soybean line.

NDSU Soybean Breeder Dr. Carrie Miranda creates new soybean germplasm from superior parents in her crossing block at Agronomy Seed Farm.

Breeding of Improved Non-GMO Cultivars and Germplasm

Principal Investigator: *Dr. Carrie Miranda, NDSU Department of Plant Sciences*
Cooperating Scientist: *Dr. Berlin Nelson, NDSU Department of Plant Pathology*

Funded Project
$137,044

Research Conducted

In 2021/2022, the non-GMO breeding project continued to flourish by identifying superior lines in the project that can be utilized both for food grade soybean varieties or for parents in the glyphosate tolerant project. These lines are superior due a combination of yield and other favorable traits such as hilum color, seed size, protein or sugar content, and disease resistance. They will also serve as parents in new crosses that are created to ensure their superior genetics continue to influence the NDSU soybean program.

In addition, NDSU has continued to test commercial varieties in SCN infected fields to ensure nonbiased and equal comparison of private company varieties to aid farmers in their decision making for varieties to purchase especially if they have infected soils. Data was analyzed and reported in the NDSU bulletin entitled 'North Dakota Soybean Performance' and was posted online.

Finally, development of IDC and phytophthora tolerant lines continues to be a priority for the NDSU breeding program. This upcoming year, in addition to IDC field testing and phytophthora screening of NDSU experimental lines, molecular markers will be used to test for IDC and phytophthora resistance in nursery lines, to ensure that resistance isn't lost during generation advancement.

A seed increase of the NDSU variety at the Agronomy Seed Farm in Casselton.

Why the Research is Important to North Dakota Soybean Producers

This project provides soybean farmers with improved non-GMO cultivars that have been developed by NDSU. Also, growers need information that enables them to select the best private company variety for their farm and to identify which varieties are best on Soybean Cyst Nematode (SCN) infested soil and iron-deficiency chlorosis (IDC) prone soils. This project provides yield results of variety testing on SCN-infested soils and soils that exhibit IDC symptoms. The NDSU soybean breeding program has a long history of providing very competitive varieties. There are many improved non-GMO experimental lines that are close to being released as named cultivars. The non-GMO breeding effort is very important as a source of high-yielding parents for use in the development of glyphosate-resistant cultivars.

In addition, food grade/yellow hila soybean varieties are produced in the non-GMO project. By partnering with soy food companies, specialty soy lines such as tofu and natto are created and identified and then tested by companies for their market specifications.

NDSU Soybean Breeding team plants soybean in Grandin, spring 2022.

Resistance of Soybean Cultivars and Germplasm to Soybean Cyst Nematode

Principal Investigator: *Dr. Guiping Yan, NDSU Department of Plant Pathology*
Co-Investigators: *Dr. Carrie Miranda, NDSU Department of Plant Sciences, and Dr. Sam Markell, NDSU Department of Plant Pathology*

Funded Project
$46,850

Why the Research is Important to North Dakota Soybean Farmers

Both SCN and SDS are important diseases in soybean. SDS is most likely to occur in areas where SCN is a problem and SDS combined with SCN cause the most yield losses. Soybean cultivars with resistance to both SDS and SCN are desirable for managing this disease complex. This research is important to navigate the new resistance sources that should be introduced to breeding programs for developing new resistant cultivars and help growers select resistant cultivars.

Research Conducted

For this study, 101 soybean cultivars, breeding lines and germplasm were screened for their resistance reactions to soybean cyst nematode (SCN) HG type 2.5.7, and 110 were screened for HG type 0. The plants were inoculated with SCN eggs and were kept in a growth chamber at 27 °C for 30 days (Figure 1). SCN white females were extracted, and the female index was calculated to categorize resistance phenotypes. Then, 21 lines were further selected and tested for their reactions to Fusarium virguliforme, the fungal pathogen of sudden death syndrome (SDS). Root-rot severity was evaluated for levels of resistance or susceptibility..

Figure 1. Soybean plants grown in a controlled growth chamber that was maintained at 27 °C for SCN-resistance evaluation.

Findings of the Research

Among the 101 soybeans tested for HG type 2.5.7, 15% were resistant; 5% were moderately resistant; 24% were moderately susceptible; and 56% were susceptible. Among the 110 soybeans tested for HG type 0, 16% were resistant; 29% were moderately resistant; 32% were moderately susceptible; and 23% were susceptible. Multiple lines were resistant to both HG types 0 and 2.5.7.

A significant difference with the root-rot severity was observed among the 21 lines screened for SDS (Figure 2). PI 548642 had the lowest root-rot severity (2.5%), followed by PI 603426B, PI 594314 and PI 603438A in Experiment 1. PI 548642 also showed resistance to HG type 2.5.7 and moderate resistance to HG type 0. In Experiment 2, PI 603169 and PI 603426B had the lowest root-rot severity (7.5%), followed by PI 603153. These lines had root-rot severity less than 10%, indicating a good level of resistance. PI 603426B had root-rot severity less than 10% for both trials.

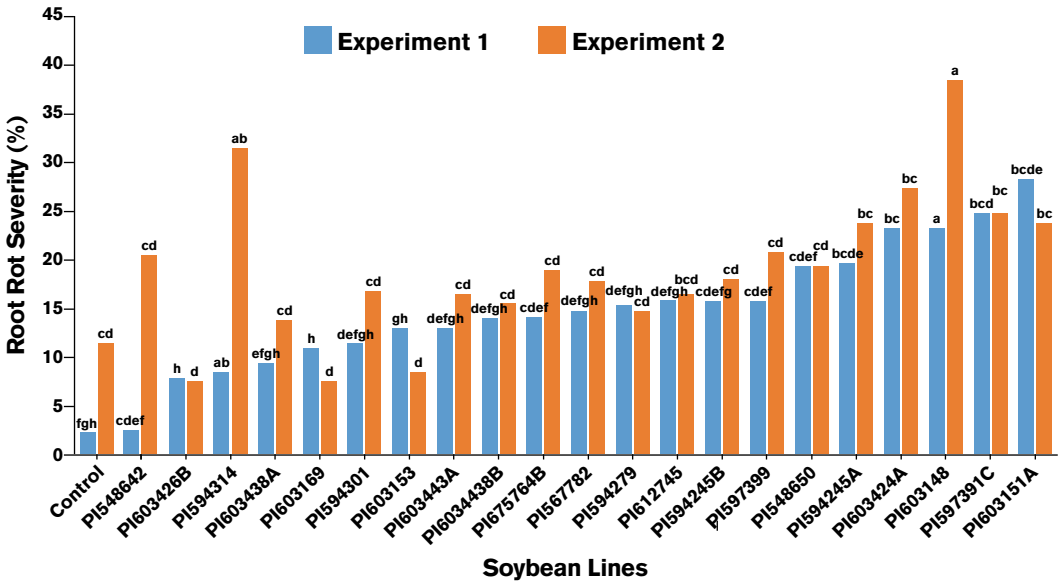


Figure 2. Root-rot severity for 21 soybean lines and 1 control 40 days (experiment 1) and 48 days (experiment 2) after inoculation of the fungal pathogen Fusarium virguliforme in the greenhouse. Means followed by the same letters are not significantly different at $\alpha = 0.05$.

Benefits/Recommendations for North Dakota Soybean Farmers and the Industry

The data were communicated to the crop consultants, farmers and the breeder who provided the seed. This research's findings will be useful for farmers when selecting resistant soybean cultivars for the infested fields and for the breeder to develop new cultivars with improved resistance to manage SCN and SDS.

The Potential to Combat Iron Deficiency Chlorosis with the Soybean Microbiome

Principal Investigator: *Dr. Barney Geddes, NDSU Department of Microbiological Sciences*

Funded Project
$3,724

Why the Research is Important to North Dakota Soybean Producers

Iron deficiency chlorosis (IDC) is a widespread problem that strongly affects soybean production in North Dakota. The characteristic yellowing of plant leaves that are suffering from IDC is caused by a lack of chlorophyll formation due to the poor function of the iron-requiring enzymes involved with chlorophyl biosynthesis. Normally, North Dakota soils contain more than enough iron for plant function; however, much of the iron is not in the soluble form which the plant needs. Despite a decades-long recognition of the problem, few effective solutions are available for farmers. One option involves applying iron fertilizer in-furrow at planting. Only red chelate fertilizers, such as Soygreen, are effective, and these fertilizers are impractically expensive for most farmers. Some soybean genes that confer resistance have been identified, and varieties that incorporate these genes can help, although traits to improve IDC tolerance are often not sufficiently incorporated into commercial varieties with other desirable traits, such as weed control.

Research Conducted

The microbes' ability to solubilize iron, making insoluble iron available to the plant, represents a new opportunity to combat IDC. Such microbes could be cultured and deployed with rhizobia as inoculants. By isolating these microbes from North Dakota soils, the likelihood that they will be persistent and effective when growers apply them in our environmental conditions would be enhanced (a "tailored-inoculant" approach).

In this study, we aimed to evaluate the soybean microbiome's composition under IDC conditions. We found evidence for selection in the soybean rhizosphere's microbiome, indicating that it is actively tailoring its microbial community, and observed significant differences for the compositions of the soybean microbiome that correlated with IDC levels at four fields in North Dakota (Figure 1). To set the stage for future investigation of North Dakota microbes from these microbiomes, we optimized a colorimetric Chrome Azurol S assay that can be used to identify siderophore-producing microbes. Finally, we adapted a greenhouse assay from Dr. Jay Goos; this analysis can be utilized to test for IDC recovery in the same field soil that we used for the microbiome analysis (Figure 2).

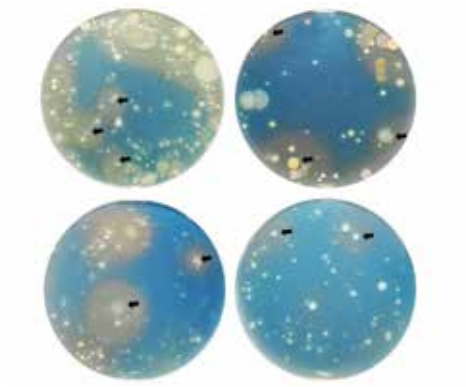


Figure 1. Iron chelating microbes identified on indicator plates by orange halo production.

Overall, this project has established important, pioneering groundwork that sets the stage for future research efforts to more comprehensively evaluate the potential for the soybean microbiome to be another tool that could be utilized by North Dakota farmers in order to combat IDC.

> "North Dakota soils normally contain more than enough iron for plant function; however, much of the iron is not in soluble form needed by the plant."

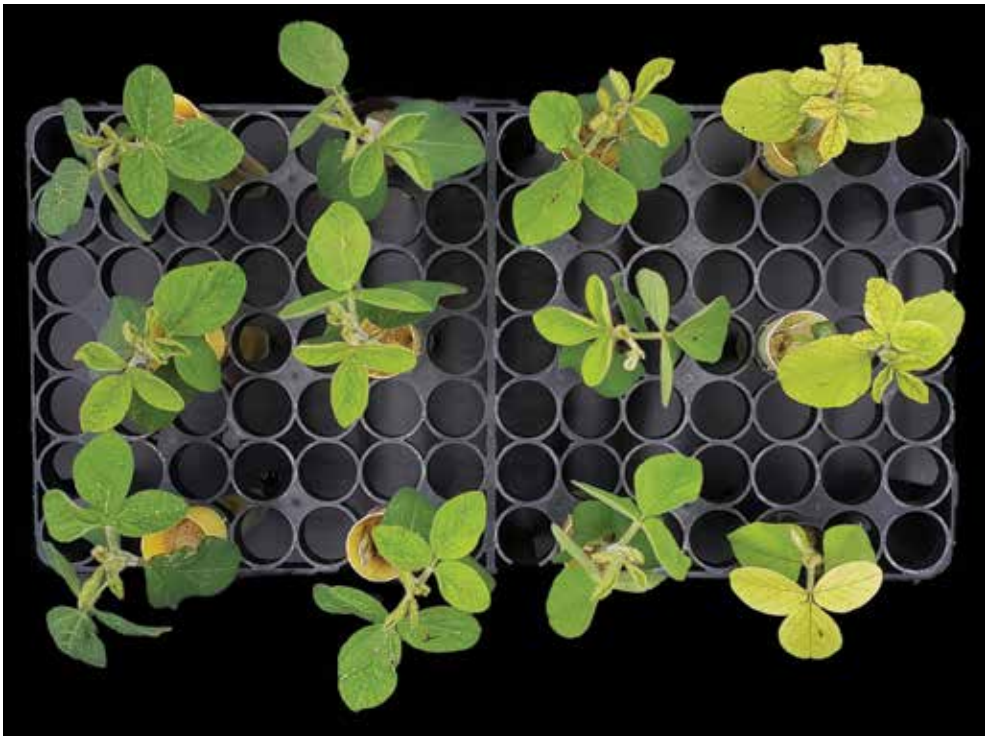


Figure 2. Soybean plants show IDC symptoms in the greenhouse study.

Evaluating the Allowable Storage Time for Two Soybean Varieties at Four Moisture Levels and the Typical Storage Temperatures

Principal Investigators: *Dr. Kenneth Hellevang, NDSU Department of Agricultural and Biosystems Engineering; Dr. Ewumbua Monono, NDSU Department of Agricultural and Biosystems Engineering; and Ibukunoluwa Ajayi-Banji, NDSU Department of Agricultural and Biosystems Engineering*

Funded Project $25,300

Why the Research is Important to North Dakota Soybean Producers

Soybean production and the need for long-term storage has been increasing. The existing, allowable storage-time information lacked the appropriate research foundation and was not based on the current varieties. Farmers need this storage-management information to maintain the quality of their stored soybeans.

Research Conducted

The allowable storage time for two common soybean varieties in North Dakota was evaluated at moisture levels of 11%, 13%, 15% and 17%; the soybeans were stored at temperatures of -15 °C, 4 °C and 23 °C. Soybeans at 13% moisture were also stored at a sequence of temperatures, 4 °C, -15 °C, 4 °C and 23 °C, to represent the recommended storage temperatures and the typical seasonal temperatures in the region during a year. The quality of the stored soybeans was monitored for germination, mold growth and oil quality over a period of 12 months.

Findings of the Research

At 17% and 15% moisture content and 23 °C, Variety A germination decreased after 8 weeks of storage. The stored seeds showed secondary infection and mold spores on the germinated seedlings as early as the fourth week of storage. Variety B soybeans showed faster deterioration when compared to Variety A, indicating a varietal difference. It was not until the 48th week of storage that some drop in the germination potential was recorded for both varieties at 11% moisture content. Soybean seeds stored at 13% moisture content, rotated in the sequence of storage temperatures, showed germination exceeding 93% at the end of the 44th week of storage.

Soybeans stored at 17% moisture and 23 °C showed an almost doubling for the mold counts by the end of the first storage week. At 15% moisture, the doubling occurred between the fourth and eighth weeks. A minimal increase for the mold counts occurred at storage temperatures of 4 °C and -15 °C. At 11% moisture content, a minimal increase for the mold count was observed after 32 weeks of storage, irrespective of the storage temperature. The 13%-moisture soybeans rotated within the seasonal temperatures exhibited a minimal increase for the mold count until the 24th week of storage.

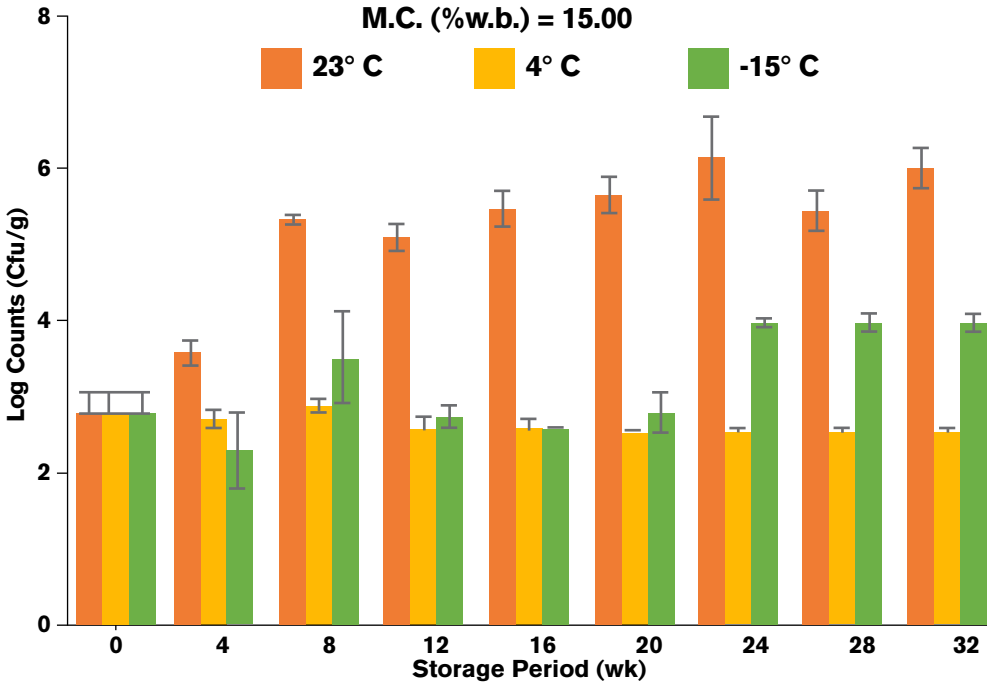


Figure 3. R Fig. 3. Mold counts (Log counts CFU/g) detected for stored soybeans at moisture contents of 15% and 17% for variety (B) EL80-23.

The free fatty acid (FFA) value did not show any marked increase after 24 weeks for the three storage environments. The FFA value of the 17% moisture-content soybeans was not measured due to the excessive mold growth.

Benefits/Recommendations for North Dakota Soybean Farmers and the Industry

The research found a difference between some current, allowable storage-time guidelines and the ones observed in the study. There was also a difference between the two varieties. Data analysis is continuing, and estimated safe-storage times, based on the quality parameters, will be developed. Research being done on dry-matter loss and respiration rates at other locations needs to be evaluated along with the data from this research to estimate the allowable storage times and to determine if additional research is needed. The information will enable better allowable storage-time estimates that soybean farmers, university Extension specialists and industry personnel can use to manage stored soybeans in order to minimize losses.

> “Farmers need this storage management information to maintain the quality of their stored soybeans.”

Utility of an Oat Cover Crop for Iron Deficiency Chlorosis and Waterhemp Management

Principal Investigator: *Dr. Joseph T. Ikley, NDSU Extension Weed Scientist*

Funded Project
$20,000

Why the Research is Important to North Dakota Soybean Farmers

IDC and glyphosate-resistant waterhemp are both problematic for North Dakota soybean farmers. Planting a small-grain companion crop has proven beneficial in some environments, including wet years, to manage IDC. Small grains can also be a competitive crop for late-emerging, summer annual weeds, such as waterhemp. As herbicide-resistant waterhemp continues to spread in North Dakota, we need to evaluate programs with integrated weed-management tactics.

Research Conducted

This research evaluated the ability of an oat companion crop to alleviate the symptoms of iron deficiency chlorosis (IDC) and to suppress/control Powell amaranth and glyphosate-resistant waterhemp. This research was conducted using a Roundup Ready Xtend (AG06X8) soybean variety, and the companion crop was terminated using glyphosate + dicamba applied at the 6-, 12-, 18- and 24-inch height for the companion crop. IDC severity, pigweed control and yield were evaluated throughout the year. A companion-crop-free and weed-free plot was included for comparison.

Final Findings of the Research

The oat companion crop did not provide suppression for waterhemp until the oats were over 6 inches tall in 2021 and over 12 inches tall in 2020. This also coincided with yield loss due to companion-crop and weed competition. Even though a companion crop may provide some relief from IDC symptoms, we did not see a benefit for pigweed management with this system. Delaying postemergence

Table 1. Presence of oat and oat termination timing on pigweed aboveground biomass at Fargo and Prosper in 2020 and 2021.[ab]

Presence of oats*	Fargo 2020	Fargo 2021	Prosper 2020	Prosper 2021
Termination timing	kg ha^{-1}			
No oats * 15 cm	36.8 d	14.5 e	13.8 d	1.4
No oats * 30 cm	118.8 cd	217.3 c	89.5 cd	30.8
No oats * 45 cm	333.0 b	607.8 b	233.2 b	191.4
No oats * 60 cm	759.5 a	946.0 a	359.4 a	253.6
Oats * 15 cm	37.8 d	9.7 e	15.3 d	2.0
Oats * 30 cm	123.6 cd	62.0 de	80.6 cd	56.5
Oats * 45 cm	156.5 c	164.9 c	91.1 cd	161.8
Oats * 60 cm	219.8 bc	158.3 cd	139.0 bc	205.5

[a] Means within a column and under the same factor that do not share the same letters are significantly different using Tukey's HSD at the 5% level of significance.
[b] The pigweed species at Prosper was Powell amaranth and the pigweed species at Fargo was waterhemp.

Table 2. Waterhemp control 14 days after treatment at different termination timing at Fargo in 2020 and 2021.[a]

Main effects	Fargo 2020	Fargo 2021
	14 DAT[b]	14 DAT
Termination timing	- - - % - - -	
15 cm	94 a	96 a
30 cm	74 b	83 b
45 cm	73 b	67 c
60 cm	58 c	51 d

[a] Means within a column and under the same factor that do not share the same letters are significantly different using Tukey's HSD at the 5% level of significance.
[b] Abbreviation: DAT = days after initial treatment.

Table 3. Presence of oats and termination timing on soybean yield at Prosper and Fargo in 2020 and 2021.[a]

Main effects	Fargo 2020	Fargo 2021	Prosper 2020	Prosper 2021
Presence of oats	kg ha^{-1}			
No oats	1039 a	14.5 e	13.8 d	1.4
Oats	630 b	217.3 c	89.5 cd	30.8
Termination timing				
No termination	132 d	946.0 a	359.4 a	253.6
15 cm	1406 a	9.7 e	15.3 d	2.0
30 cm	1555 a	62.0 de	80.6 cd	56.5
45 cm	761 b	164.9 c	91.1 cd	161.8
60 cm	320 c	158.3 cd	139.0 bc	205.5
Presence of oats* Termination timing				
No oats * no termination	185 e	694	791	469 d
No oats * 15 cm	1654 ab	1188	3945	3416 b
No oats * 30 cm	1718 a	1072	3875	3242 b
No oats * 45 cm	1160 c	1255	3452	2770 b
No oats * 60 cm	480 d	1111	2864	2019 c
Oats * no termination	78 e	305	616	404 d
Oats * 15 cm	1157 c	891	4109	4188 a
Oats * 30 cm	1393 bc	982	3792	3187 b
Oats * 45 cm	362 d	585	3446	2770 b
Oats * 60 cm	160 e	585	3446	2770 b
ANOVA	P-value			
Presence of oats	<.001	.005	.742	.099
Termination timing	<.0001	.046	<.0001	<.0001
Presence of oats*	.007	.643	.563	.001
Termination timing				

[a] Means within a column and under the same factor that do not share the same letters are significantly different using Tukey's HSD at the 5% level of significance.

applications until the companion crop was 6 inches tall also resulted in the need for a second postemergence application in order to achieve greater than 90% control of glyphosate-resistant waterhemp with dicamba. If uncontrolled all season long, waterhemp reduced the soybean yield by 45-90%, depending on the year, compared to a weed-free check.

Benefits/Recommendations for North Dakota Soybean Farmers and the Industry

Oats will eventually suppress pigweed biomass in the absence of herbicides but not before becoming too competitive with the soybeans. Based on results from 2020 and 2021, a small-grain companion crop will not suppress pigweed species in soybeans until yield loss occurs. These companion crops can still help with IDC in some environmental situations, but we did not see the benefit for pigweed management. The companion crop should be terminated before it competes with soybeans and causes yield loss. If waterhemp control is a top priority in a soybean field, comprehensive preemergence and postemergence herbicide programs should be utilized.

Dr. Joe Ikley provides research updates during a summer field day.

Reversing Herbicide Resistance in Waterhemp: Gene Editing of ALS

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

Funded Project
$6,275

Why the Research is Important to North Dakota Soybean Growers

Herbicide-resistant waterhemp represents an important problem for North Dakota soybean production, and new tools are needed to study emerging methods for controlling this weed. However, when growing herbicide-resistant weeds for research, it is important to minimize the risk of seeds or pollen escaping and spreading into fields. This factor is especially important when researching new genetic biocontrol methods. The current research advanced the application of CRISPR technology to waterhemp herbicide-resistance research using laboratory-grown waterhemp cells that were incapable of escaping into the environment.

Research Conducted

CRISPR is a new genetic technique that can produce specified changes in plant DNA. Emerging genetic biocontrol methods may be able to use CRISPR with self-propagating systems that could reverse herbicide resistance in waterhemp populations. This research project evaluated conditions under which the CRISPR components could be put into laboratory-grown waterhemp cells, and it assessed the ability of CRISPR to target the waterhemp ALS gene, a target of group 2 herbicides, in both purified DNA and live cells.

Findings of the Research

By using purified DNA, the CRISPR system was able to target specified locations in the waterhemp's ALS gene, paving the way for the development of genetic biocontrol methods that could reverse herbicide resistance. CRISPR components were successfully put into live waterhemp cells, but targeting and subsequent repair of the ALS gene were not observed in these cells. This finding may be due to inactive repair systems for the waterhemp cells in our treatment conditions. This area is the subject of future research.

Benefits/Recommendations to North Dakota Soybean Farmers and the Industry

This research has introduced new genetic techniques to study herbicide resistance in waterhemp. These techniques will allow the study and potential application of emerging genetic biocontrol methods for a weed-control problem that is important to North Dakota's soybean production.

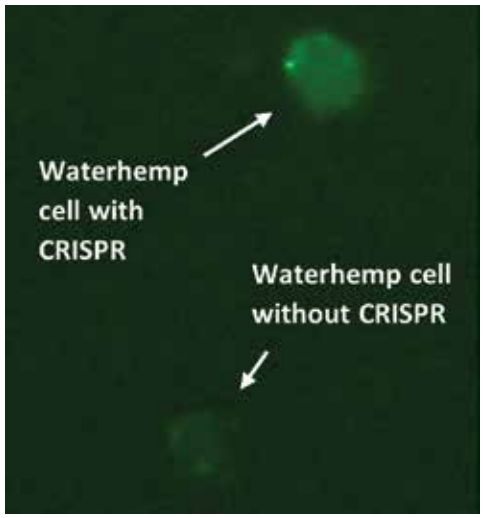


Figure 1. Waterhemp cells in laboratory culture. Top: The CRISPR enzyme for gene editing was taken up by the cell, generating green fluorescence. Bottom: The CRISPR enzyme was not taken up by the cell.

Optimizing the Fungicide's Application Frequency and Application Interval Relative to Soybean Maturity for Improved White-Mold Management in Soybeans

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

Funded Project
$30,830

Why the Research is Important to North Dakota Soybean Farmers

In soybeans of mid-zero maturity and longer, two fungicide applications are often needed for satisfactory white mold management in soybeans. North Dakota producers have struggled to consistently achieve satisfactory white mold management in soybeans with fungicides. Empirical data are lacking on the optimal interval between sequential fungicide applications, and this study sought to identify the number of days between applications that optimizes soybean yield..

Research Conducted

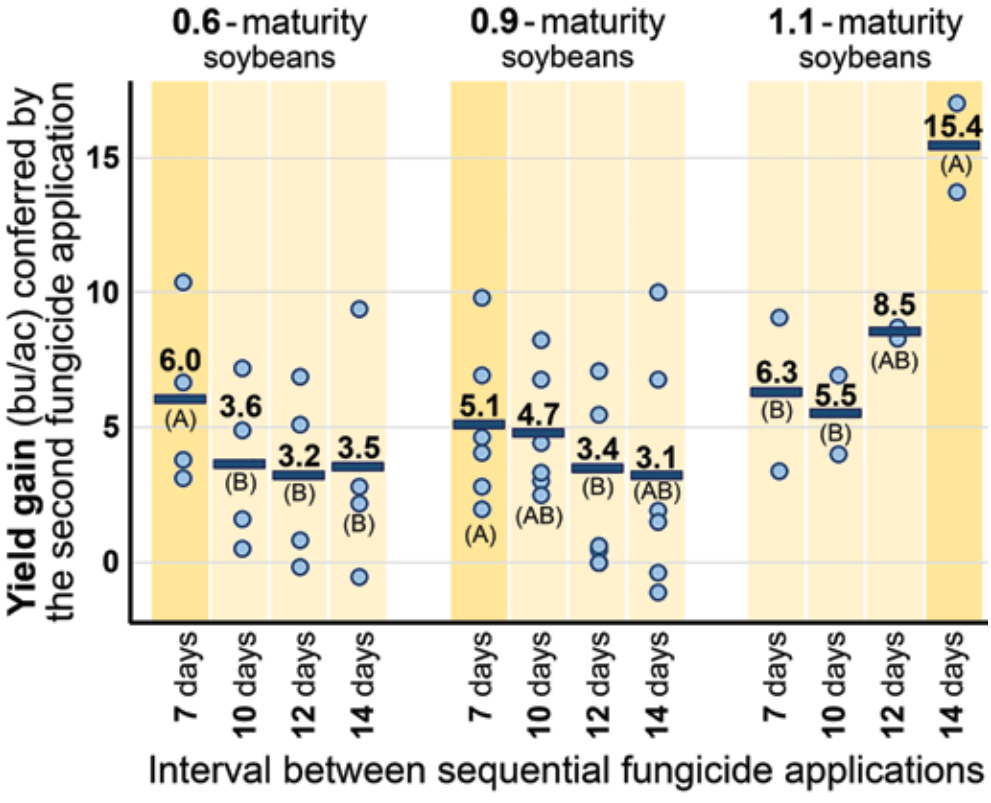
Field trials were conducted in Carrington and Oakes under overhead irrigation. Testing was conducted on soybeans of 00.9, 0.6, 0.9 and 1.1 maturity with Endura (5.5 oz/ac) applied once versus twice sequentially and with Topsin (40 fl oz/ac) applied once versus 40 fl oz Topsin followed by 5.5 oz Endura. Sequential applications 7, 10, 12 and 14 days apart were tested for each of these fungicide sequences. Applications were made in 15 gal/ac with a hand-held boom and fungicide droplet size calibrated relative to canopy closure. The first application was made at the R2 growth stage..

Findings of the Research

The optimal number of days between sequential fungicide applications was contingent on soybean maturity (Figure 1). A second fungicide application was profitable in all varieties except the 00.9-maturity variety. Yield gains from two sequential fungicide applications were maximized when applications were made 7 days apart for the

Dr. Michael Wunsch, Research Plant Pathologist at Carrington Research Extension Center.

Figure 1. Yield gain conferred by a second fungicide application made 7, 10, 12, or 14 days after the first application in soybeans of 0.6, 0.9 and 1.1 maturity; Carrington and Oakes, ND (2020-21). Dots represent results from individual studies; bars represent average values.



> "In soybeans of mid-zero maturity and longer, two fungicide applications are often needed for satisfactory white mold management in soybeans. Empirical data are lacking on the optimal interval between sequential fungicide applications."

0.6-maturity soybeans, 7 to 10 days apart in 0.9-maturity soybeans and 14 days apart in 1.1-maturity soybeans. The length of the bloom period increases with soybean maturity, and delaying the second application until 14 days after the first application leaves the soybeans with relatively low levels of residual fungicide as they approach the second application but extends the period in which fungicides provide protection. This extension of the protection only outweighed the relatively low residual levels in the longest-maturity soybeans which have the greatest period of susceptibility to white mold.

Statistical separation between Endura (5.5 ounces per acre) and Topsin (40 fluid ounces per acre) was not observed in any individual study, but Topsin was consistently less effective than Endura in all varieties in which white mold pressure was economically relevant. The reductions in disease control and yield were observed irrespective of whether Topsin was applied once (Figure 2) or applied as the first application in a two-application sequence (Figure 3).

Benefits for North Dakota Soybean Farmers and the Industry

When making two sequential applications to target white mold, this study suggests that the optimal interval between applications increases with soybean maturity. Follow-up research to confirm these findings is being conducted.

Figure 2. Comparative efficacy of a single application of Topsin (40 fl oz/ac) versus Endura (5.5 oz/ac) made at the R2 growth stage. The soybean canopy was at or near closure in all studies, and fungicides were applied with coarse droplets using TeeJet AIXR110015 nozzles at 50 psi.

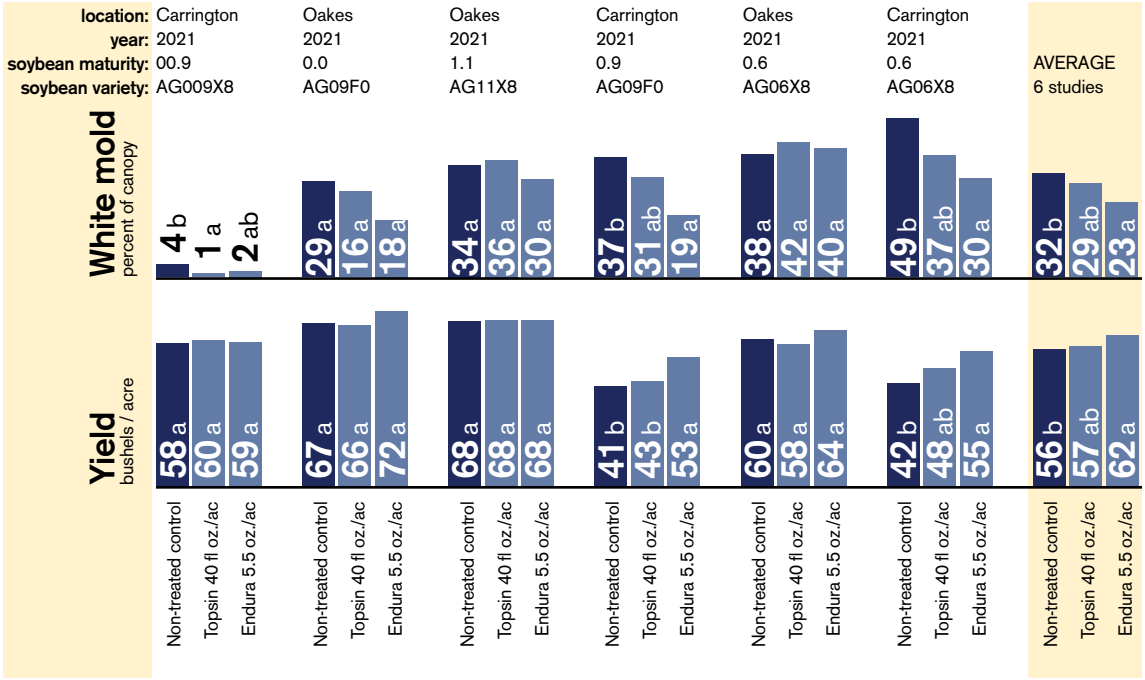
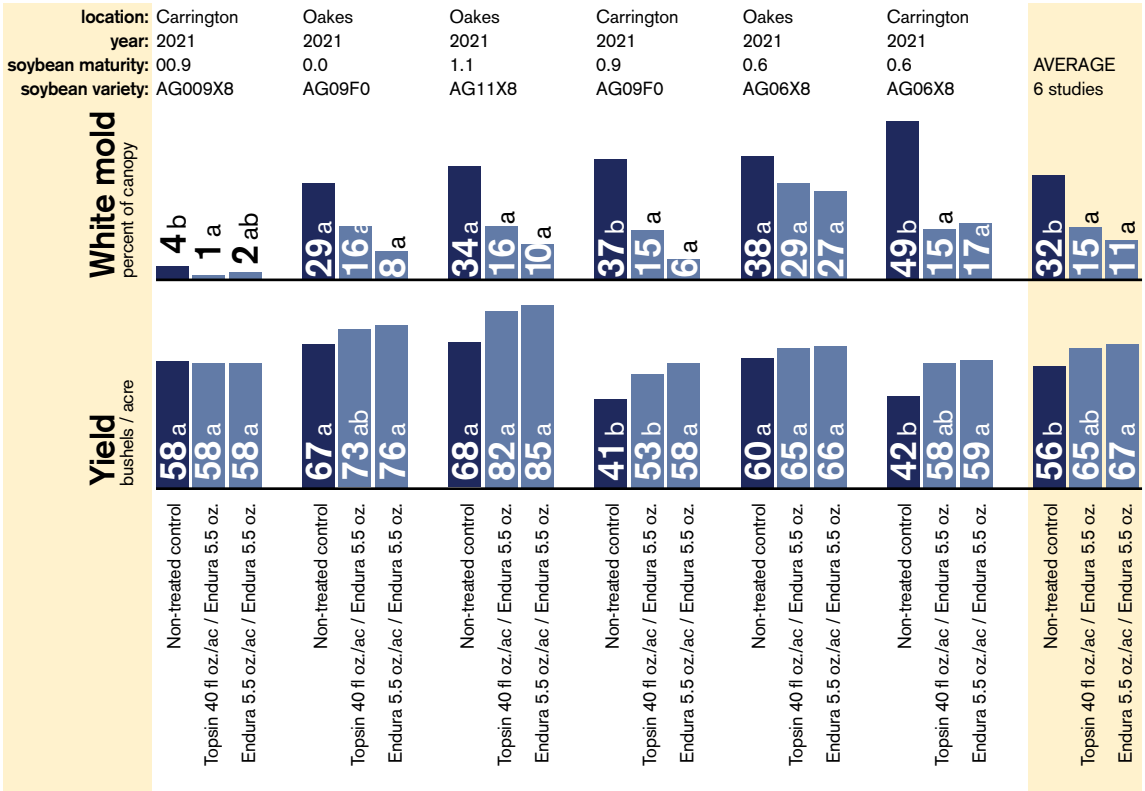


Figure 3. Comparative efficacy of sequential applications of Endura (5.5 oz/ac) vs. Topsin (40 fl oz/ac) followed by Endura (5.5 oz). Applications were made at the R2 growth and 7 days later (0.6-maturity and 0.9-maturity varieties) or 14 days later (1.1-maturity varieties). The soybean canopy was at or near closure in all applications, and fungicides were applied with coarse droplets using TeeJet AIXR110015 nozzles at 50 psi.



Determining Rye Safety to Soybeans with Soil-Moisture Status

Principal Investigator: *Dr. Mike Ostlie, NDSU Carrington Research Extension Center (REC)*
Cooperating Scientists: *Szilvia Yuja, NDSU Carrington REC; Jasper Teboh, NDSU Carrington REC; Greg Endres, NDSU Carrington REC; Steve Zwinger, NDSU Carrington REC; Dr. Paulo Flores, NDSU Department of Agricultural and Biosystems Engineering; and Ezra Aberle, NDSU Carrington REC*

Funded Project
$13,556

Why the Research is Important to North Dakota Soybean Producers

Soybean cropping systems can benefit greatly by including a rye cover crop the fall prior to seeding. Some key benefits include reduced wind and water erosion, improved weed control, better soil stability when planting and more opportunities for grazing/haying. One key for successful implementation is choosing the best time to terminate rye. If termination occurs too early, the benefits of rye are greatly diminished, but if the crop is terminated too late, rye may use excessive water and affect soybean yields.

Research Conducted

From 2018 to 2021, trials were conducted at the North Dakota State University (NDSU) Carrington Research Extension Center (REC) to monitor soil-water changes based on rye-termination timings and how they relate to soybean yields. Each year of the study was distinctly different, ranging from excessive moisture to record drought.

Figure 1. Dr. Mike Ostlie speaks to farmers at the tri-county research site near Wishek on winter rye cover crop preceding soybean.

Findings of the Research

From 2018-2020, the timing of the spring rainfall events resulted in no loss of soybean production even when planting green (terminating rye with 24 hours of planting soybean). There was always a yield penalty if terminations were delayed any further. In 2021, there was a near-total rye crop failure due to no soil moisture for rye emergence during the previous fall.

To simplify the data, we summarized the information into three distinct lines in Figure 1. We can compare rye alone, soybean alone and fallow ground (no water use) to demonstrate peak water-use times. These data, coupled with the rainfall totals, provide a nice visual display of yearly variability. In some years, the rye used a majority of available water, and in other years, the soybeans drew the soil moisture to very low levels.

In 2018 and 2019, the rye's water use reached concerning levels, starting at anthesis through physiological maturity. In 2018 and 2020, the soybeans drew soil moisture to near-maximum lows during pod fill (late July through August). These data reinforce that peak water use between rye and soybeans occurs at completely different times, which is one reason why this system works.

The termination timing data are more difficult to visually display, and we are continuing to identify specific water-use levels that can endanger soybean production. Each year, we had termination treatments that affected soybean yields and many treatments that did not, providing a great dataset for continued evaluation. We will create a tool from these data; this instrument can be implemented via the North Dakota Agricultural Weather Network (NDAWN) to help predict soybean risk from rye. The assessment is based on soil-moisture sensors and growing-degree units.

> "There was always a yield penalty if terminations were delayed any further. In 2021, there was a near-total rye crop failure due to no soil moisture for rye emergence during the previous fall."

Determining a Suitable Planting Date and Soil Temperature for Enhanced Growth and Yield of Soybeans with No-Till Semi-Arid Conditions

Principal Investigators: *Dr. Gautam Pradhan, NDSU Williston Research Extension Center (WREC)*
Co-Investigators: *Dr. Jerald W. Bergman and Dr. James W. Staricka, NDSU WREC*

Funded Project $11,637

Why the Research is Important to North Dakota Soybean Farmers

Two glyphosate-tolerant varieties ('ND17009GT' and 'ND18008GT'), either treated with the fungicide Obvious at 4.6 ounces per 100 pounds of seed or untreated, were planted on seven different dates (3rd, 10th, 17th, 25th and 31st of May along with the 7th and 14th of June 2021) under no-till, dryland conditions.

Research Conducted

Soybean acreage has been steadily increasing in North Dakota, including the western part of the state which has an exceptionally drier climate, with precipitation of less than 15 inches per year, compared to the eastern part of that state which averages over 20 inches per year. There is a lack of soybean-production management guidelines that are suitable for western North Dakota's no-till, dryland producers. Determining suitable planting dates and soil temperatures is crucial to avoid abiotic and biotic stress as well as to have a sustainable, higher soybean yield and farm income with no-till, dryland conditions.

Findings of the Research

It was an extreme drought year in 2021. From October 1, 2020, to September 30, 2021, we received 9.5 inches of annual precipitation, which was 4.5 inches lower than the 65-year average. In 2022, the month of June accounted for approximately 40% of the 9.5 inches of annual precipitation.

The effect of the seed's treatment was not evident on the soybeans. The crop planted on June 14 had at least 1.3 times higher plant stand and 1.1 times higher aboveground biomass than the other planting dates (Figures 1A and 1B). Soybeans planted on June 14 had 0.9 pounds per bushel more test weight than the May 17 planting and were 1.3-1.9 pounds per bushel higher than all other planting dates (Figure 1C). Soybeans planted on June 14 yielded 16 bushels per acre of grain, 3 bushels more than the May 17 planting and 6-7 bushels higher than all other planting dates (Figure 1D). Per acre, variety ND17009GT had 5,300 more plants, 1.9 pounds per bushel more test weight and 1.8 more bushels of grain yield than ND18008GT (Figures 2A, 2C and 2D).

Figure 2. Soybean varietal performance for growth and yield (A) Plant stand, (B) Above ground biomass, (C) Test weight, and (D) Grain yield.

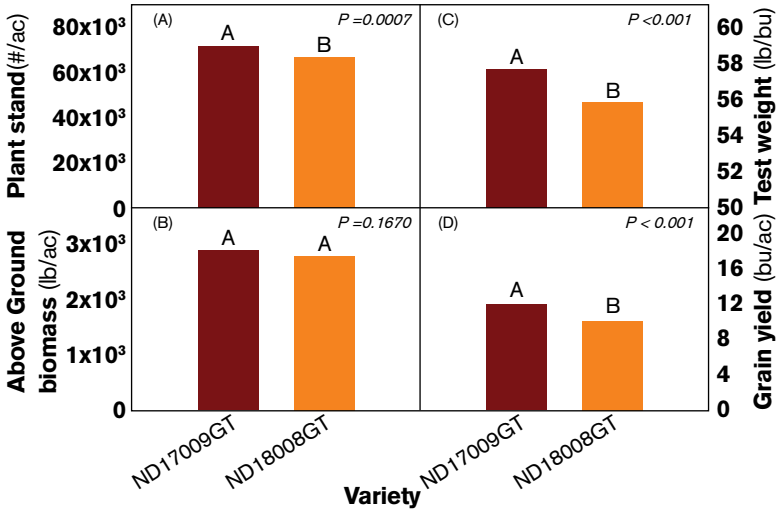
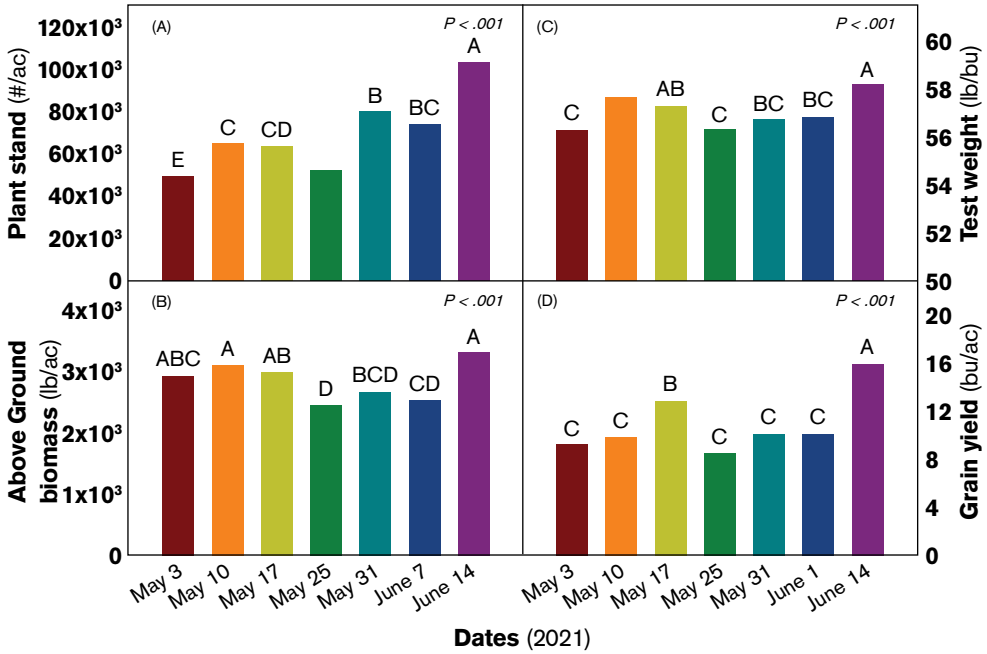


Figure 1. Soybean growth and yield under different planting dates. (A) Plant stand, (B) Above ground biomass, (C) Test weight, and (D) Grain yield.



Benefits/Recommendations for North Dakota Soybean Farmers and the Industry

The results from this year showed that a season-long drought might result in a massive decline for the soybeans' yield (average trial yield: 10.9 bushels per acre in 2021 versus 30 bushels per acre 2019). The relatively higher per-acre plant stand and yield from the June 14 planting (16 bushels per acre versus 9-13 bushels per acre) indicated that a good rainfall at an appropriate time may make a big difference in the soybeans' performance. The results also showed that ND17009GT performs better under severely dry conditions than ND18008GT when measuring the plant stand, grain yield and test weight.

Soil Health and Agriculture Research Extension (SHARE) Farm Research Projects in Mooreton, North Dakota, and Logan Center, North Dakota

Principal Investigator: *Dr. Abbey Wick, NDSU School of Natural Resource Sciences; Dr. Caley Gasch, NDSU School of Natural Resource Sciences; Dr. Aaron Daigh, NDSU School of Natural Resource Sciences; Dr. Marisol Berti, NDSU Department of Plant Sciences; Greg Endres, NDSU Carrington Research Extension Center; and Naeem Kalwar, NDSU Langdon Research Extension Center*

Funded Project
$43,883

Why the Research is Important to North Dakota Soybean Producers

The SHARE Farm project provides regional, science-based information on soil health and cropping systems to farmers so they can reduce risk and set reasonable expectations when adopting new soil health building practices. Unlike most small-plot research, farmers and other interested parties are welcomed and encouraged to check out the SHARE Farm firsthand.

Research Conducted

The Soil Health and Agriculture Research Extension (SHARE) Farms located in Mooreton and Logan Center, North Dakota are long-term, field-scale projects aimed at evaluating changes in soil health and crop productivity under various soil health management approaches. Data for several parameters was collected from 2013 to 2021 at the Mooreton site and from 2019 until present at Logan Center:

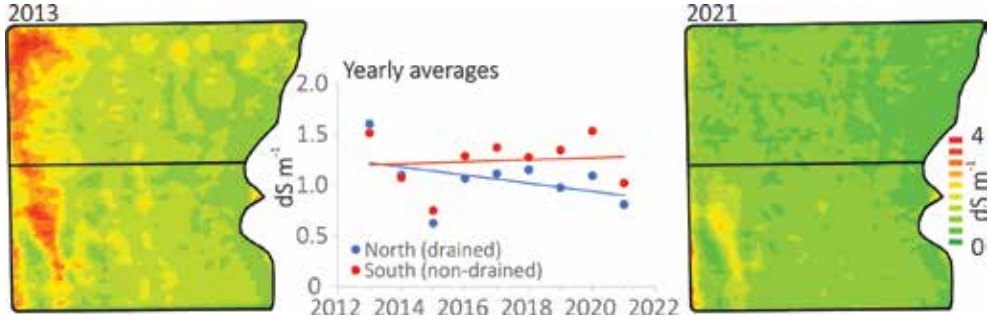
- Soil moisture and temperature under no-till and conventional tillage practices
- Crop yield and grain quality under no-till and conventional tillage practices
- Cover crop establishment and productivity
- Soil properties, crop productivity, and groundwater quality in tile drained and undrained fields

Findings of the Research

At the Mooreton site, eight years of data showed tile drainage, used in conjunction with no-till and cover crops, helps to reduce topsoil electrical conductivity (EC) compared to undrained portions of the field. Additionally, under no-till management, EC and ion concentrations decreased over time in shallow groundwater in both the drainage treatments.

Historically, the Mooreton site had reduced grain yields in certain areas due to high salt concentration and wet soil conditions; however, as the project continued, average yield increased across the field and variability decreased under the given management practices. In the three years of crop production at the Logan Center site, yield comparisons were made between no-till and conventional tillage practices. The 2020 corn yields were 13 bu/ac higher in the tilled system. Pinto bean and soybean yield in 2019 and 2021, respectively, showed no yield difference between tillage practices. The no-till treatments at each site exhibited less daily temperature fluctuation and lower average temperatures compared to the tilled treatments helping to prevent heat induced plant stress mid-summer. Additionally, the notill systems generally have a higher volumetric water content compared to the tilled systems.

Figure 2. Changes in electrical conductivity (EC) from 2013 to 2021 at the Mooreton SHARE Farm. The chart shows yearly EC averages and trendlines for the North (drained) and South (non-drained) sides of the field.



Recommendations to North Dakota Soybean Farmers and Industry

For updates on the ongoing SHARE Farm research, publications, field days, and other soil health news visit the NDSU Soil Health webpage (NDSU.edu/soilhealth).

Dr. Abbey Wick, Associate Professor, Extension Soil health Specialist at NDSU.

Determining Frogeye Leaf Spot Incidence and Fungicide Sensitivity in North Dakota

Principal Investigator: *Dr. Sam Markell, NDSU Plant Pathologist*
Collaborators: *Dr. Danilo Neves and Dr. Carl Bradley, University of Kentucky Plant Pathology*

Funded Project
$15,000

Why the Research is Important to North Dakota Soybean Farmers

Frogeye Leaf Spot is an economically important foliar disease that is common throughout warmer and wetter soybean growing regions in the United States. Two critical pieces of information were missing and were needed to determine a management strategy for future growing seasons: 1) how widespread the disease was and 2) if the pathogen had already adapted to QoI fungicides (FRAC 11, commonly called strobilurins) in North Dakota (had already occurred in other areas of the U.S.).

Research Conducted

In late August to early September 2020, Frogeye Leaf Spot (FLS) was identified in North Dakota for the first time. Over a two-day period in early September 2021, 50 fields across 10 North Dakota counties were surveyed for FLS. Symptomatic leaves were sent to the laboratory of Dr. Carl Bradley, University of Kentucky, to determine if QoI (strobilurin) fungicides would effectively manage the disease.

Findings of the Research

FLS was found in all surveyed counties in North Dakota (Figure 1). The severity levels within the fields ranged from approximately "trace" to approximately 10%. Of the 334 total Cercospora sojina (Frogeye Leaf Spot pathogen) isolates tested, 23% were resistant to strobilurin fungicides (Figure 2).

Dr. Sam Markell provides research update during the North Central Research Extension Center Field Day.

Benefits/Recommendations for North Dakota Soybean Farmers and the Industry

Growers should be aware that FLS could appear in their field during warm and wet growing seasons. If FLS becomes an economic problem in North Dakota (which is unknown and perhaps unlikely), the disease is best managed with fungicides that have multiple modes of action because the pathogen populations in North Dakota are already adapting to strobilurin fungicides.

Acknowledgements

We acknowledge Jessica Halvorson, Brandt Berghuis and Bryan Hanson for the identification, survey and sample collection of FLS in North Dakota. We acknowledge Dr. Carl Bradley's team and his financial supporters for their cooperation with this project.

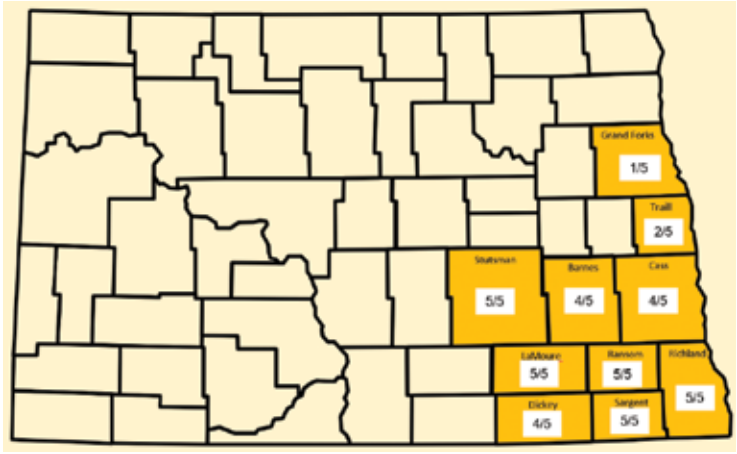


Figure 1. Number of fields surveyed where Frogeye Leaf Spot was identified (For example, 4/5 indicates that Frogeye Leaf Spot was identified in 4 of the 5 surveyed fields.).

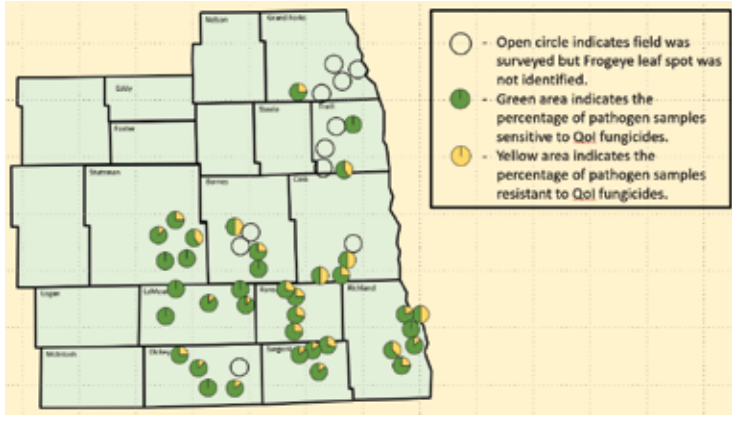


Figure 2. Proportion of the Frogeye Leaf Spot pathogen (Cercospora sojina) determined to be "sensitive" or "resistant" to QoI fungicides (FRAC 11, strobilurins) in North Dakota counties in 2020.

Soybean Cyst Nematode Sampling Program: 2021

Principal Investigator: *Dr. Sam Markell, NDSU Plant Pathology*
Co-Investigator: *Dr. Guiping Yan, NDSU Plant Pathology*
Collaborators: *NDSU County Extension Agents*

Funded Project
$62,580

Research Conducted

This project is designed to encourage growers to soil sample for soybean cyst nematode (SCN), the most-damaging soybean pest in the United States. Growers submit soil samples to the partner laboratory in pre-labeled bags; the North Dakota Soybean Council covers the laboratory fees; and growers receive data directly through the mail. North Dakota State University (NDSU) Extension receives egg-level and geographic data to construct distribution maps. (No additional information about the submitters is obtained.)

Why the Research is Important to North Dakota Soybean Farmers

SCN causes damage before aboveground symptoms appear, making detection with soil sampling the most effective way to identify an SCN infestation. Additionally, monitoring egg levels is the best way to determine if management tools, such as resistance, rotation or seed treatments, are working. This program directly supports North Dakota soybean growers' efforts to monitor, to identify and to manage SCN.

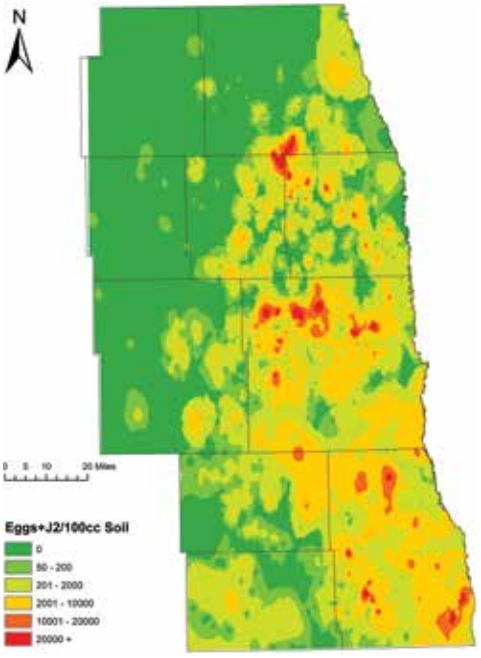


Figure 2. The 2013-2021 distribution and egg level of soybean cyst nematode (eggs/100 cc soil) in southeast and east-central North Dakota that was received though the NDSC/NDSU Extension sampling program. Note of caution: SCN is very spotty in regions and fields, and heat maps do not have the resolution to reflect the SCN presence or level in any specific fields.

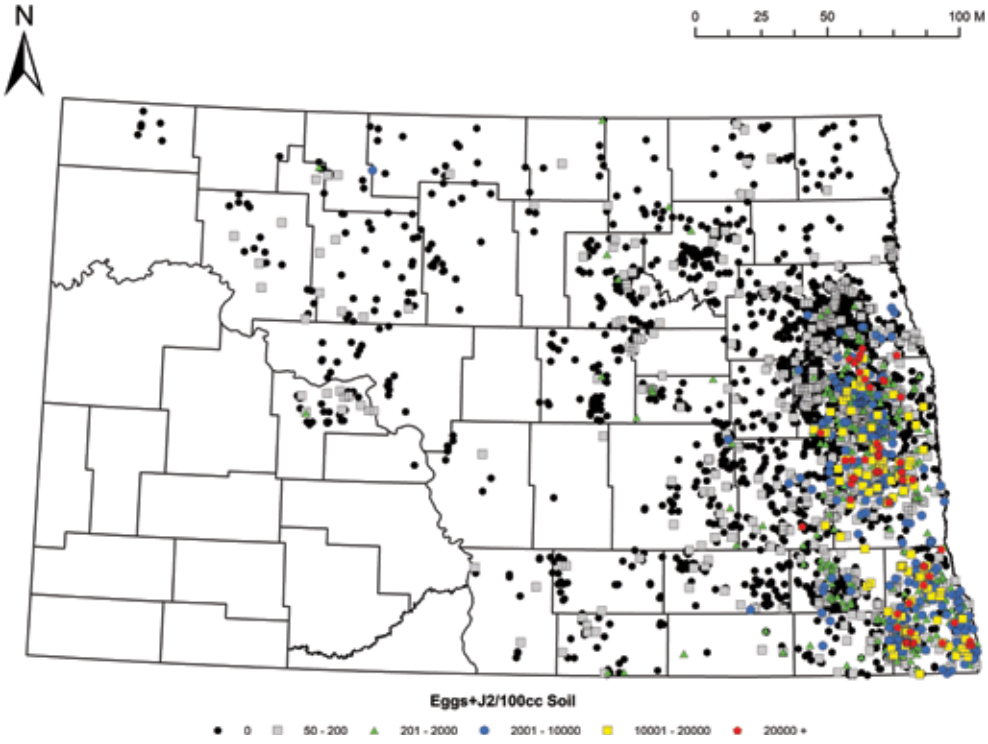


Figure 1. Distribution of soybean cyst nematode (eggs/100 cc soil) in North Dakota that was received though the NDSC/NDSU Extension sampling program from 2013-2021.

Findings of the Research

In 2021, there were 490 SCN samples. Nematode eggs were detected in approximately one-third of the samples. Distribution maps for 2013 to 2021 (Figure 1) demonstrate that SCN is most common and in the highest levels in the southeastern North Dakota (Figure 2).

Benefits/Recommendations for North Dakota Soybean Farmers and the Industry

For growers who have not detected SCN, we recommend that they concentrate on areas in the field where SCN is most likely to be introduced, such as field entrances. For growers who know that they have SCN, we recommend that they soil sample to determine if the current management strategies are working.

Acknowledgements

We express our thanks to the many growers, Extension agents, crop consultants, and others who participated in this program; to Michaela Halvorson for map construction; to Agvise for sample processing; and, finally, to the North Dakota Soybean Council (NDSC) for its support.

> "Nematode eggs were detected in approximately one-third of the samples SCN is most common and in the highest levels in the southeastern North Dakota."

Extending the Life of Aged Roofing Shingles: An Expanded Market for Soy-Based Dust Control

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

Funded Project
$68,608

Why the Research is Important to North Dakota Soybean Farmers

The soy-based dust suppressant previously developed at North Dakota State University (NDSU) was able to rejuvenate aged asphalt. Early trials indicated that the dust-control product could also soften aged asphalt shingles, thereby increasing their repairability and extending their lifespan. The goal of this research was to modify the existing dust-control formula with a soy-based additive, to make 36+ different versions of the formula and to test them on 18-year-old shingles.

Research Conducted

After 8 months of outdoor exposure, the treated shingles were brought into the lab for testing. These tests included a water jet to measure surface aggregate retention, a mandrel bend test to determine crack resistance and a 3-point bend test to measure flexibility. The optimal formula was then down selected for transfer to our commercial partner for production and sales.

The 36 formulations were based on the dust-control formula plus a soy-based additive, resulting in 3 components to the rejuvenation formula (A, B and C). The testing matrix varied A, B and C amounts from rack to rack as well as within each rack. This approach allowed for both the individual and collective effects of A, B and C on the rejuvenator's performance to be studied.

Figure 1. Ten test racks covered with 18-year-old shingles. Each rack was divided into four sections that were 2 x 4 ft. for treatment. Right-treated shingles before drying.

Findings of the Research

The testing indicated trends among the ratios of components A, B and C on the treated-shingle properties of aggregate retention, flexibility and crack resistance. Based on these trends, an optimal formula, which gave the best overall results, was determined.

The water-jet data showed that the treatments substantially improved the aggregate retention (Figure 2) even more than new, untreated shingles. The mandrel bend test mimicked shingle repair. After the bend, specimens were examined for cracking. The best-performing samples had no cracks, suggesting that the treatments absorbed deep enough into the shingles to prevent cracking on the underside. Finally, the 3-point bend test measured the flexibility, which is important for shingle maintenance. Almost all formulations improved the flexibility of the aged shingles with some restoring flexibility to the level of new shingles.

> "Treatments substantially improved the aggregate retention even more than new, untreated shingles."

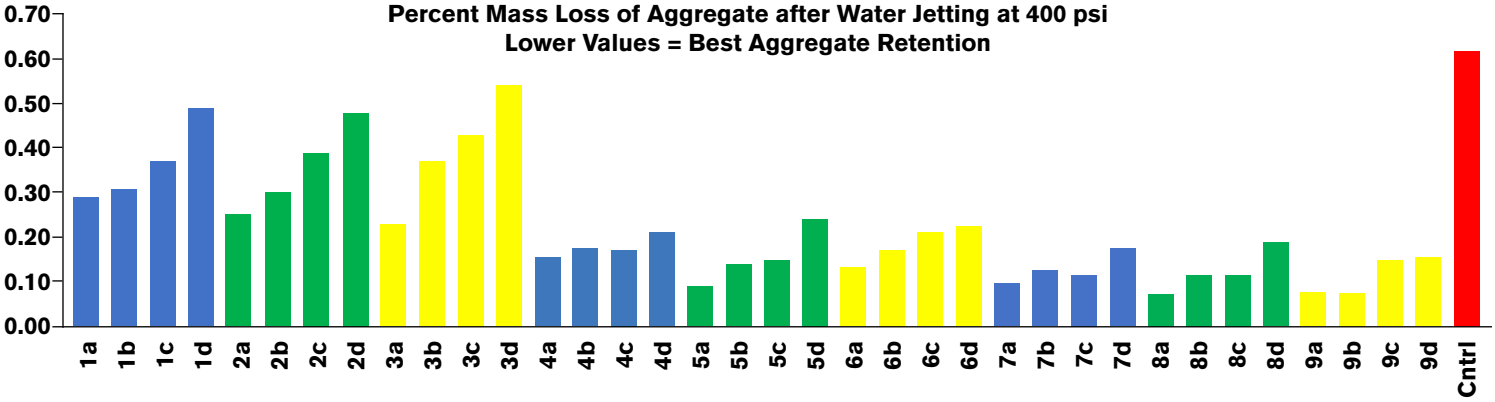


Figure 2. Water-jetting data with the untreated control. All treated shingles showed an improved aggregate adhesion. New shingles lost 0.34 wt. %.

Soy Protein-Based Soft Gels for Sensors and Soft Robotics

Principal Investigator: *Dr. Long Jiang, NDSU Department of Mechanical Engineering*

Funded Project
$37,336

Why the Research is Important to North Dakota Soybean Growers

Soft and stretchable, conductive hydrogels have attracted a lot of attention for their promising applications in the fields of artificial intelligence, soft robotics and wearable devices. However, most existing conductive hydrogels suffer from the limitations of low mechanical robustness, low stretchability, and a vulnerability to drying and freezing, which hinder their durability and application areas/environments in real life. Moreover, most of the existing hydrogels are made from non-renewable materials.

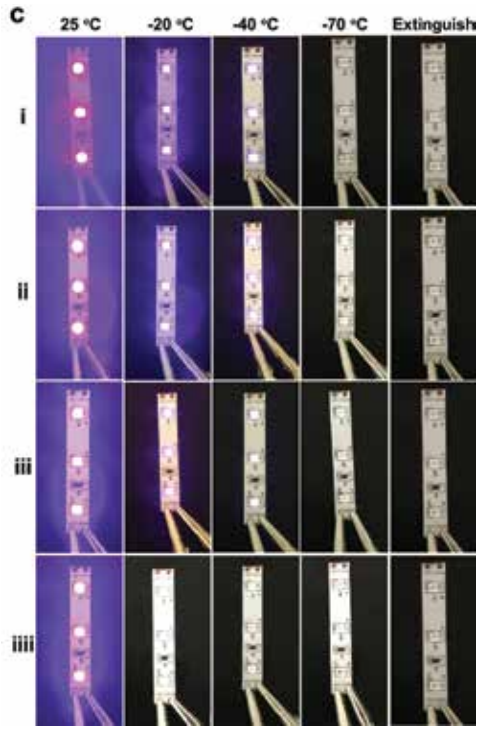


Figure 1. Visually demonstrated the conductivity of the hydrogels by using them to connect a circuit containing a light-emitting diode (LED).

Research Conducted

For this project, we developed a soy protein-based hydrogel that is strong, highly stretchable, conductive, and freezing and drying resistant. The strength and flexibility of the new hydrogel is attributed to the double-network structure inside the material formed by the soy-protein molecules and another polymer. Additives, including a salt, low-temperature plasticizer and a natural fibrous material, were incorporated into the hydrogel formulation to offer the other desirable properties. The formulation was meticulously investigated, and the key ingredients and their contents were identified. Hydrogels with properties suitable for a scope of different applications can, therefore, be produced by adjusting the formulation.

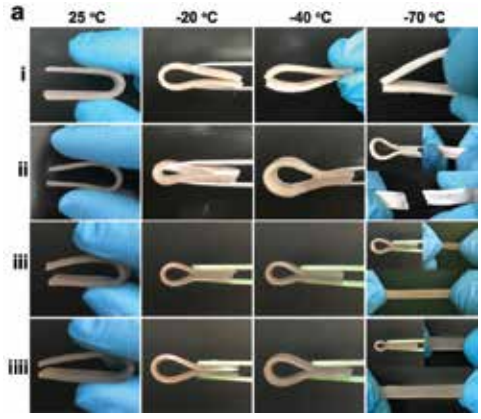


Figure 2. The flexibility and stretchability of the hydrogels demonstrated under different temperatures.

The hydrogel's flexibility and stretchability, even under very low temperatures (down to −70 °C), are demonstrated in Figure 2, where the hydrogel is bent and stretched without fracture. At the same time, the hydrogel's conductivity under these low temperatures is still high enough to lighten up LEDs (Figure 1). The properties exhibited by this new gel makes it an ideal material to make wearable sensors and soft robotics. Further development can be pursued to enable industrial applications.

Cost-Effective Soy-Based Garden Pots

Principal Investigator: *Dr. Nita Yodo, NDSU Department of Industrial and Manufacturing Engineering*

Funded Project
$34,400.44

Research Conducted

This research developed two soy-based, bioplastic formulations for garden pots. These soy-based pots are biodegradable, self-fertilizing and prevent root circling. The objectives accomplished were as follows:

Objective 1: Two soy-based pot formulations with different compositions of soy-hulls, soy protein isolate (SPI) and polylactic acid (PLA) were molded into 3" garden pots. These new formulations were compared with existing garden pots. The four types of studied pots were as follows:

1) Plastic (polyethylene)
2) Existing bio-based DDGS formulation
3) F1: New formulation 1 (70% PLA + 30% soy hulls)
4) F2: New formulation 2 (65% PLA + 30 soy hulls + 5% SPI)

Objective 2: Five plant species (Black-seeded simpson lettuce, Tacitus R2 lettuce, Zinnia, French marigold and Sheyenne tomatoes) were studied for their plant growth and root-circling conditions. Degradation analysis was done by measuring the pot's dry weight before plantation and after harvesting.

Objective 3: A techno-economic analysis was performed to ensure cost competitiveness.

Why the Research is Important to North Dakota Soybean Farmers

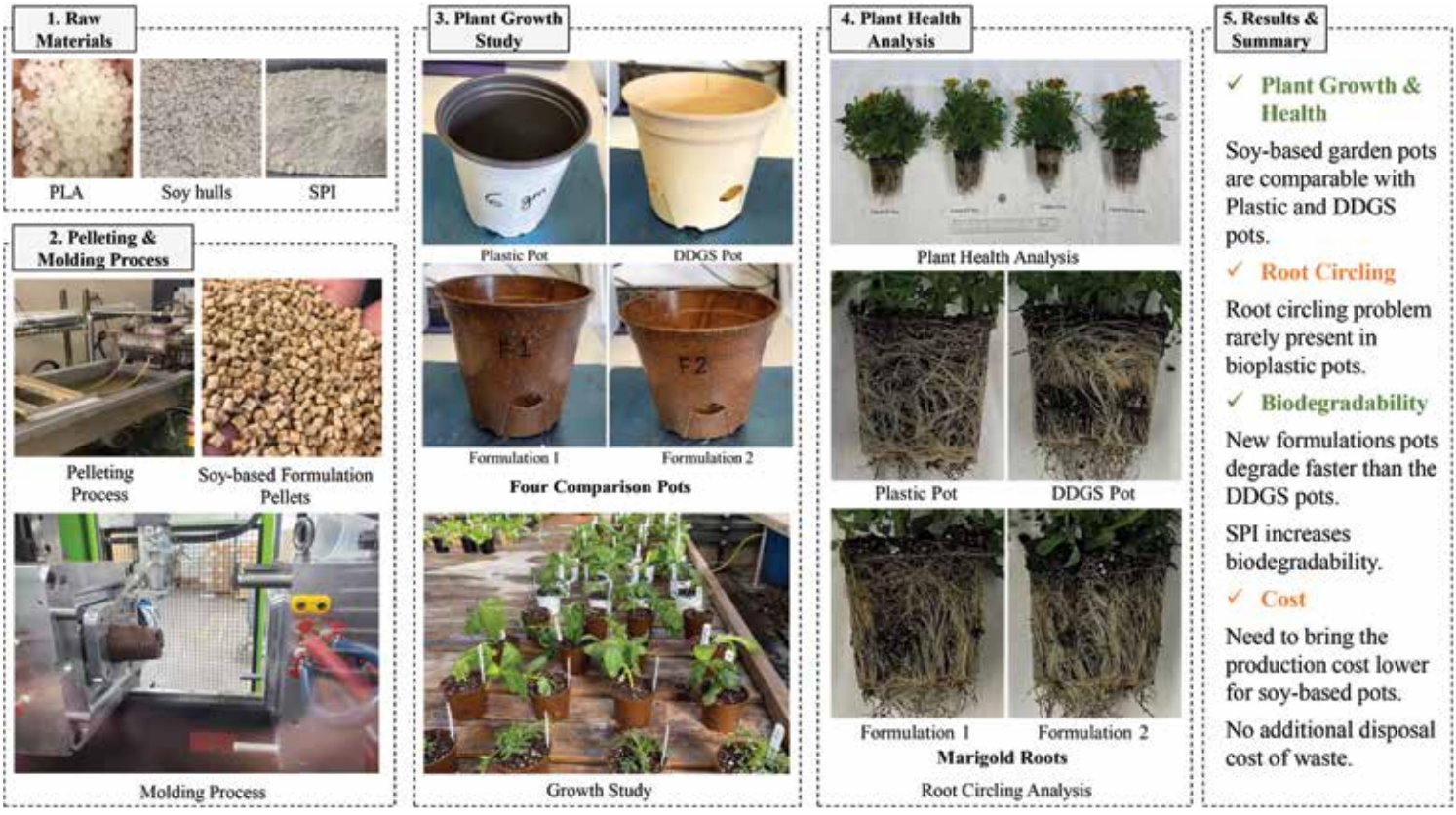
It is anticipated that, with the market acceptance of soy-based garden pots, container manufacturers will be able to replace as much as 50% of the product weight with protein or hauls derived from soybeans within 3-5 years. With North Dakota's annual soybean production of 239 million bushels, the new product will directly affect 5% (12.5 million bushels) of the crop. Additional economic benefits are the profit realized from utilizing domestic raw materials and the development of new domestic jobs.

Findings of the Research

Overall, the performance of soy-based potsF1 and F2, in terms of plant health and biodegradability, was better than the plastic and DDGS pots for several cases. The plant height was significantly better for Zinnia plants grown in an F1 pot instead of a DDGS pot. From the visual inspections, the root-circling problem was rarely observed in the bioplastic pots. Both of the newly formulated pots were deemed to have the ability to degrade faster than the DDGS pot. Over a period of 6weeks, the average degradation rate for the F1, F2 and DDGS pots was found to be 3.121%,5.647% and 2.815%, respectively. When comparing the two new formulations, the significantly increased biodegradability.

Benefits and Recommendations

The biodegradability of soy-based pots can be deemed unique compared to plastic pots. Another advantage of these soy-based formulations is that the root-circling problem was significantly reduced.



Plastic Films from Soybean Derivatives for Food Packaging

Principal Investigator: *Dr. Andriy Voronov, NDSU Department of Coatings and Polymeric Materials*

Funded Project
$32,642

Research Conducted

The industry for food-packaging materials has been expanding significantly over the past few decades in order to provide progress with maintaining the food's quality, improving the shelf life of the food products, and providing a safe environment for food storage and transportation. The problems associated with using synthetic food-packing materials have moved the research to utilize natural resources to produce food-packaging materials.

Some plant-based materials can be an attractive option for bioplastic formation because they demonstrate inherent properties, such as flexibility and water-barrier performance, which are desirable for plastic-film formation.

In this work, we demonstrate the feasibility of using soy derivatives, including soy protein and soybean oil, to synthesize bioplastic films which can be utilized for food packaging.

Why the Research is Important to North Dakota Soybean Farmers

Using soybean protein and soybean oil to make new bioplastics has the ability to add more value to the crop, thereby making it more profitable for farmers. Newly developed materials can diversify soy-based products with the increased demand for soybean oil and soy protein when manufacturing of bioplastics.

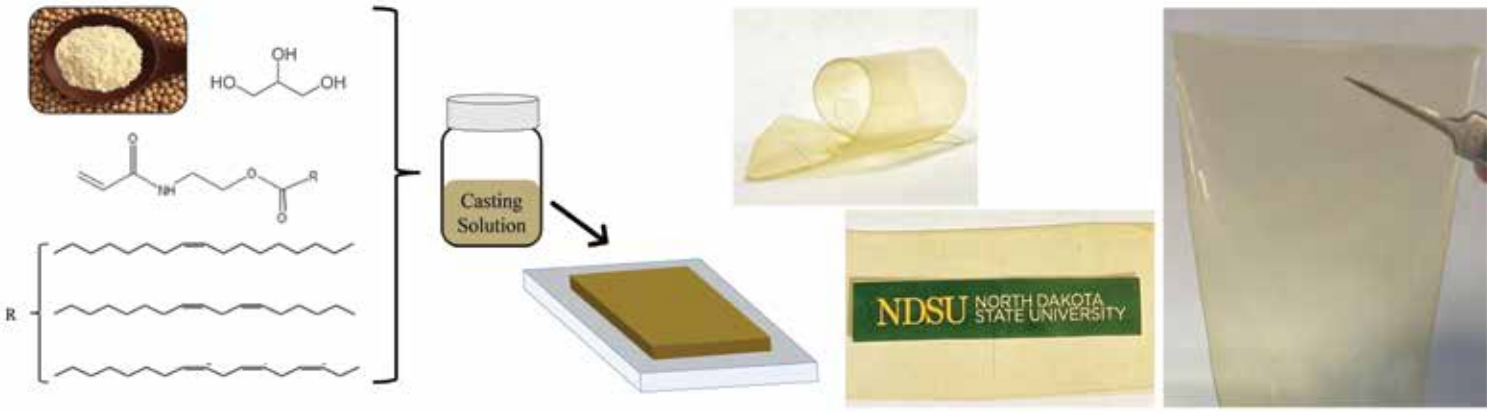
The market will receive soy-based food-packaging materials. This will also help North Dakota to involve investors and other soy-processing industries.

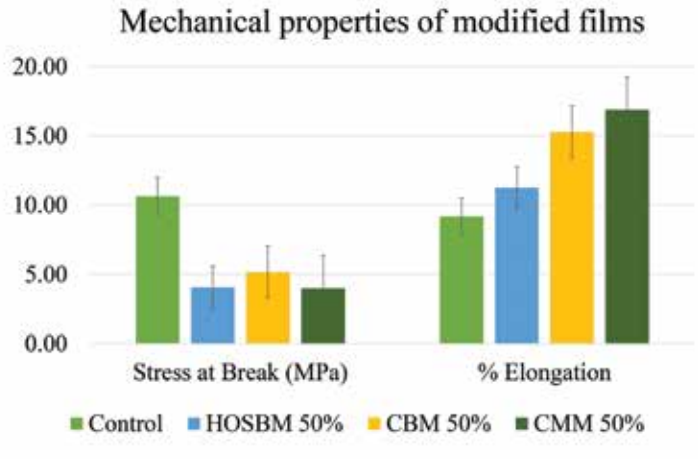
Findings of the Research

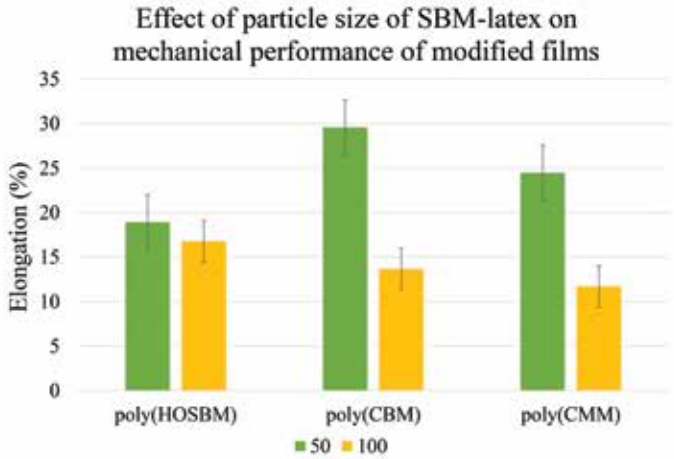
We show that bioplastic films from soy derivatives (soy protein and soybean oil) are not only feasible, but also have advanced the mechanical and barrier properties, as well as providing an enhanced performance. These materials can be attractive alternatives for traditional plastics. The compatibility of multiple soybean-derived materials alongside natural film-forming additives is also demonstrated.

Benefits/Recommendations for North Dakota Soybean Farmers and the Industry

This work benefits North Dakota soybean farmers and the soy industry by establishing additional uses for multiple soybean derivatives. The current study focuses on use for food-packaging applications; however, there is evidence that these advances may be utilized with agricultural applications as well, thus benefitting the farmers and the industry even further by providing a biobased and literally "home-grown" option for agricultural products such as mulch and plant clips.







All-Soy-One-Component Bioplastics for Food Packaging

Principal Investigator: *Dr. Andriy Voronov, NDSU Department of Coatings and Polymeric Materials*

Funded Project
$19,791

Research Conducted

The food industry's demand for packaging materials that maintain food quality, improve the food's shelf life, and provide a safe environment for food storage and transportation has expanded over the past few decades. Both consumers and regulatory agencies indicate the demands for less-polluting, more environment-friendly, renewable plastic materials, particularly for food packaging. For specific applications, compostable or biodegradable plastics (either naturally derived or made from sustainable resources) could replace traditional petroleum-based, polymeric food-packaging materials. By degrading with microorganisms, such plastics help to reduce the solid-waste environmental concerns.

One targeted, renewable raw material for use with bioplastic manufacturing is plant proteins, including soy protein, which are natural polymers that are formed from amino acids linked by peptide bonds in long chains. Plant protein-based films are considered to be a great alternative for food-packaging industries. In this work, we demonstrate the feasibility of using soy protein in combination with soybean oil to synthesize bioplastic films which can be utilized for food packaging.

Why the Research is Important to North Dakota Soybean Farmers

The research aims to provide the feasibility of using soybean protein and soybean oil produced in the state of North Dakota for high-value and high-profit food-packaging materials. this technology has the ability to add more value to the crop and to make it more profitable for farmers. Newly developed materials can diversify soy-based products with the increased demand for soy protein and soybean oil when manufacturing bioplastics.

The market will be given soy-based food-packaging materials. This will also help North Dakota to attract new investors and other soy-processing industries.

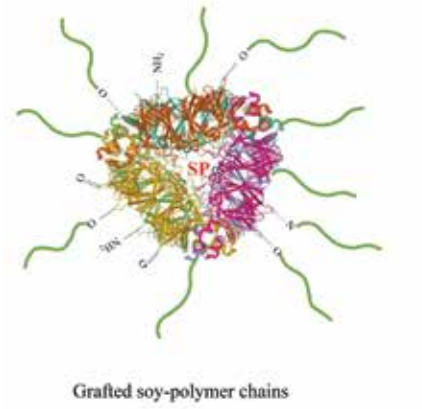
Findings of the Research

We show that bioplastic films from all-soy-one component bioplastics (soy protein/soy oil grafted copolymers) are not only feasible and provide decent film-forming ability, but also possess mechanical properties which can be attractive to achieve enhanced material performance for a variety of applications. Overall, new materials, in combination with our recently developed "two-component systems" (where soy protein is modified with soybean oil-based latexes), can be considered as a versatile biobased platform, providing an alternative to the traditional, petroleum-based plastics.

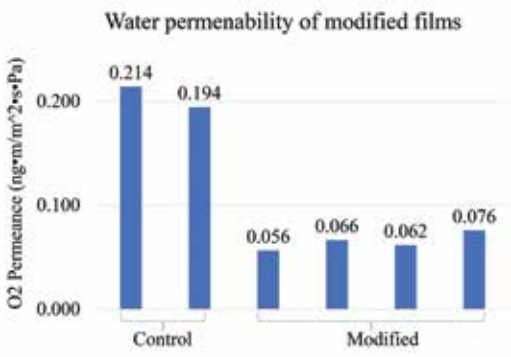
Benefits/Recommendations for North Dakota Soybean Farmers and the Industry

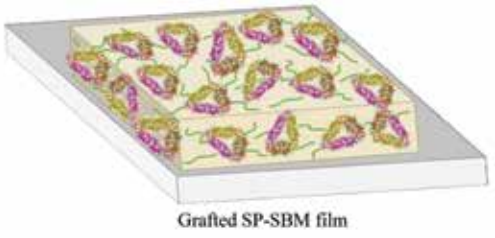
This work benefits North Dakota soybean farmers and the industry by establishing additional uses for multiple soybean derivatives, including soy protein and soybean oil.

This technology focuses on use for food-packaging applications; however, the advances may also be turned to other agricultural applications—particularly for agricultural mulch or other bioplastic films—thus benefitting the farmers and the industry even further by providing a sustainable, biodegradable, environment-friendly option for various agricultural technologies and products.

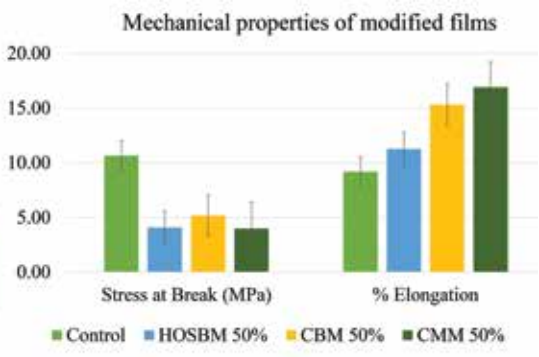


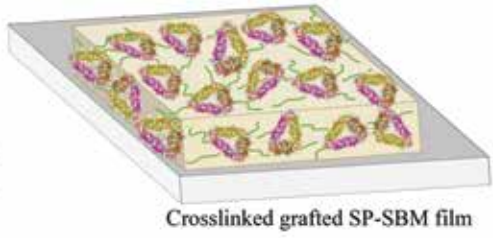
Grafted soy-polymer chains





Grafted SP-SBM film





Crosslinked grafted SP-SBM film

Development of Soy-Based Polyurethane Foam with Flame-Retardant Properties

Principal Investigator: *Dr. Gurjot Dhaliwal, United Tribes Technical College, Intertribal Research and Resource Center*

Funded Project
$25,715.73

Why the Research is Important to North Dakota Soybean Growers

Soy-based polyurethane (PU) foam will be used for insulation applications in housing, commercial buildings and refrigeration. Traditionally, PU foams were fabricated using petroleum-based raw materials. Because of fluctuations with the supply and the price of petroleum, the scientific community has been experimenting with vegetable oils to fabricate PU foams. Due to a high renewable content and a high insulation value, the soy-based PU foam will receive Leadership in Energy and Environmental Design (LEED) certification from the U.S. Green Building Council and a 5-Star energy rating from the Environmental Protection Agency (EPA). This will open a massive market for soy-based foam structures and will provide economic benefits for soybean farmers. The soy-based PU is poised to move from the laboratory to high-volume applications, creating new agricultural product markets.

Research Conducted

The objectives of this study were as follows:

1. Investigate the effectiveness of adding nano-silicate-based fire retardants in the formulation of soy-based PU foams.

2. Develop soy-based PU foam with thermal and mechanical properties that are comparable with commercially available insulation foams and enhanced flame-retardant properties.

Four different kinds of flame-retardant nanoclays were investigated by using various product quantities. The soy-based PU foam samples were prepared with nanoclays. The samples were tested for thermal insulation, strength, moisture absorption and flame-retardant properties.

Findings of the Research

In this research, we tested the soy-based PU foam samples for various properties, such as strength, thermal insulation, moisture absorbance and flame retardancy. The testing results were compared with the samples that did not contain nanoclay additives. The foam samples' mechanical strength improved with the addition of nanoclay. The foam samples' compressive strength improved by 50.32%, and the tensile strength improved by 63.61% with the addition of nanoclays. The R-Value of the PU foam also increased from 24.81 (samples with no nanoclay additives) to 29.35. The burning rate was reduced by about 44%, from 17.49 cubic meters/minute to 9.82 cubic meter/minute, with the addition of Cloisite 116A. The mechanical strength of the foam samples was also improved due to the addition of the nanoclay. The compressive strength of the foam samples improved by 50.32%, and tensile strength improved by 63.61% with

Table 1. Testing results of thermal and physical properties of foam samples

Sample	R-Value		Rate of Burning		Cell Size		Density	
	((K•m)/W)	SD	cm/min	SD	mm^2	SD	Kg/m^3	SD
Control	24.81	0.02	17.49	0.19	0.160	0.006	77.25	0.03
Na-I	25.06	0.06	16.06	0.24	0.055	0.007	49.25	4.04
Na-II	25.19	0.02	14.78	0.18	0.047	0.002	48.00	2.58
Na-III	25.32	0.06	12.51	0.17	0.043	0.006	63.50	1.29
Na-IV	25.42	0.04	11.42	0.26	0.039	0.005	56.50	4.51
Na-V	25.64	0.03	10.75	0.27	0.035	0.002	57.50	8.81
Ca-I	26.63	0.03	16.45	0.15	0.210	0.030	64.50	4.12
Ca-II	26.32	0.14	16.14	0.14	0.110	0.010	68.00	5.72
Ca-III	26.01	0.1	15.18	0.21	0.080	0.020	49.75	2.63
Ca-IV	25.48	0.18	14.57	0.17	0.410	0.040	47.5	3.32
Ca-V	25.40	0.02	14.32	0.45	0.210	0.010	55.00	5.48
20A-I	26.96	0.06	15.77	0.04	0.130	0.030	67.25	2.50
20A-II	26.63	0.07	15.01	0.17	0.090	0.010	68.50	1.00
20A-III	26.32	0.08	13.87	0.41	0.080	0.050	68.50	4.36
20A-IV	26.21	0.03	12.53	0.11	0.110	0.020	76.25	4.99
20A-V	26.2	0.02	11.45	0.16	0.160	0.010	71.00	2.94
116A-I	29.35	0.05	14.87	0.24	0.110	0.010	72.75	1.71
116A-II	29.21	0.01	13.57	0.17	0.210	0.030	68.50	1.73
116A-III	28.96	0.05	11.78	0.11	0.350	0.050	49.00	1.41
116A-IV	28.35	0.03	10.55	0.20	0.340	0.070	48.25	2.22
116A-V	28.79	0.04	9.82	0.19	0.690	0.050	47.75	1.26

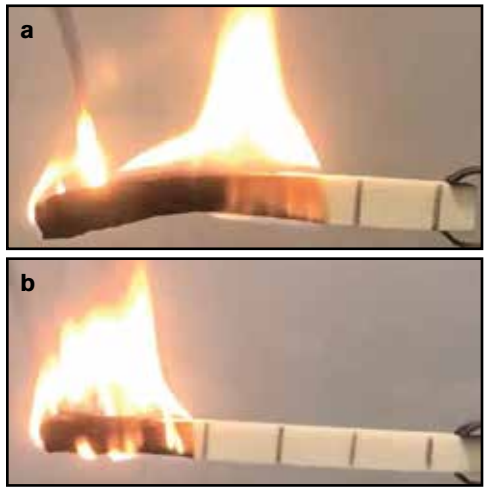


Figure 1: Horizontal burning test showing the rate of burning of soy-based PU foam samples. The above images show (a) sample with no flame retardant and (b) sample with 10 g of Cloisite 116A flame retardant. These pictures were taken after 50 seconds of burning. As seen, Cloisite 116A slows the spread of fire.

the addition of nancolay. Also, a significant reduction for moisture absorbance was noted in the samples with the addition of the nanoclay flame retardants.

Benefits/Recommendations to North Dakota Soybean Farmers and the Industry

In this work, we achieved a reduction in the spread of flames. With further research and by investigating other categories of flame retardants, soy-based PU foam can achieve full flame retardancy. Once full flame retardancy is achieved, soy-based PU foam can be introduced to the market as a commercial product. It is worth noting that the investigator achieved better strength and better insulation properties with soy-based PU foam compared to the commercially available insulation foams.

North Central Soybean Research Program (NCSRP)

Funded Project $200,000

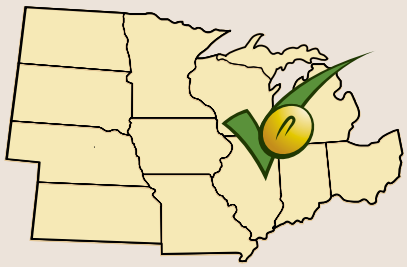
The North Central Soybean Research Program (NCSRP) is a multi-state research program that is recognized as a leader in collaborative research and outreach efforts to support soybean farmers and to drive the soybean industry forward. The NCSRP combines soybean check-off funds from its 13 state checkoff boards–North Dakota, South Dakota, Nebraska, Kansas, Minnesota, Iowa, Missouri, Wisconsin, Illinois, Indiana, Michigan, Ohio and Pennsylvania–to sponsor basic and applied research, extension, outreach and communications. To successfully deliver this program, farmer leaders, state staff and funded researchers work together to prioritize, monitor and communicate the basic and applied research efforts on behalf of 400,00 soybean farmers in the region, representing more than 85% of the nation's soybean production. The NCSRP's focus is to increase soybean profitability and to enhance and protect yield, while maintaining and improving soybean quality and composition, through genetic improvement, agronomics, and biotic and abiotic stress mitigation for soybean maturity groups 00-IV.

Since 1992, the NCSRP has established broader collaboration and built partnerships to deliver research results to farmers as well as to provide farmers with a solid return for the check-off investments. The NCSRP Board funds research projects that address the goals to increase the soybean growers' productivity and profitability while improving environmental stewardship. The NCSRP also funds both applied and basic research, along with the communication of research results to support Midwestern soybean producers.

The NCSRP funded the following projects in 2022:

- An integrated approach to enhance durability of SCN resistance for long-term, strategic SCN management
- Using data-driven knowledge for profitable soybean management systems
- Comparison of Non-Chemical Control Methods as Part of an Integrated Weed Management Strategy in Soybean
- SOYGEN2: Increasing soybean genetic gain for yield and seed composition by developing tools, know-how and community among public breeders in the north central US
- Mapping soybean protein and oil quality in farmer fields
- Multi-dimensional approaches for improved productivity, sustainability, and management of major soybean diseases in the North Central US
- Research and extension on emerging soybean pests in the North Central Region
- Weed seed bank depletion: investigating an overlooked benefit of cover crops
- The SCN Coalition: Building on Economic Impact

NCSRP NORTH CENTRAL SOYBEAN RESEARCH PROGRAM



Details and summaries for the listed projects can be found online at bit.ly/FY22NCSRPprojects

For more information about the NCSRP, visit NCSRP.com and soybeanresearchinfo.com

Kansas State University researchers provide research update to NCSRP farmer-leaders and staff in August 2022.

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