MINNESOTA WHEAT

RESEARCH & PROMOTION COUNCIL

MINNESOTA WHEAT RESEARCH REVIEW

On-Farm Cropping Trials

Wheat Research Reports

2024

2024 On-Farm Trials | UMN Extension On-Farm Cropping Trials

The mission of University of Minnesota Extension and Northwest Research and Outreach Center (NWROC) is to contribute within the framework of the Minnesota Agricultural Experiment Station (MAES) and the College of Food, Agricultural, and Natural Resource Sciences to the acquisition, interpretation and dissemination of research results to the people of Minnesota. Additionally, its intent is to add to the knowledge base of the United States and globally. Within this framework, major emphasis is placed on research and education that is relevant to the needs of northwest Minnesota, and includes projects initiated by Center scientists, other MAES scientists and state or federal agencies.

Contributors to the On-Farm Trials include: Dr. Angie Peltier, Extension Regional Office, University of Minnesota-Crookston; Dr. Daniel Kaiser, Soil, Water, and Climate, UMN; Anthony Hanson, Robert Koch and Bruce Potter, Extension Integrated Pest Management, UMN; Andrew Lueck, Owner/Research Lead, Next Gen Ag, Renville; Jenna Whitmore, Research Manager, Next Gen Ag; Maykon Jr. da Silva and Seth Naeve, Dept. of Agronomy and Plant Genetics, UMN; Megan McCaghey, Ph.D., Assistant Professor UMN Department of Plant Pathology.

These projects were made possible thanks to the hard work of many people. This includes farmers, county and regional extension eucators, and specialists who participated in these trials.

Previous On-Farm Cropping Trials booklets can be found online at: https://mnwheat.org/council/wheat-research-reports/

2024 Wheat Research Review

In 2024, the Minnesota Wheat Research & Promotion Council allocated about $519,882 of the total $1,519,050 in estimated checkoff income to wheat-related university research and education projects. The 2024 reports from these projects are printed in this book.

Wheat Research Project Funding Process:
Every September, the Minnesota Wheat Research & Promotion Council requests wheat research pre-proposals from researchers in Minnesota, North Dakota and South Dakota. Researchers are given an opportunity to meet with a small group of wheat growers to get feedback on project ideas. Pre-proposals are reviewed by the Research Committee of the Minnesota Wheat Council. This committee listens to presentations from each researcher and then the Committee determines which ones should be asked to submit full proposals.

The proposals are evaluated on the following criteria: 1) Is it a priority for growers? 2) Impact on Profitability? 3) Probability of Success? 4) Cost vs. Benefit?

At the end of January, the committee meets again to review the full proposals and make funding recommendations to the Minnesota Wheat Research & Promotion Council.

In addition to the project reports printed and distributed through this booklet, some of the project researchers deliver oral presentations at the Prairie Grains Conference, Best of the Best Workshops and Small Grains Updates - Wheat, Soybean and Corn. Also, some of the projects are reported in Prairie Grains Magazine. The Minnesota Wheat Research Committee comprises wheat growers, agronomists, unbiased researchers and industry representatives.

Information about the committee and previously funded research can be found online at www.mnwheat.org/council. Click on the Research Committee tab.

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2024 Hard Red Spring Wheat Regional Quality Survey

Principal Investigator(s): Dr. Shahidul Islam

Project Period: January 1, 2024-December 31, 2024

Research Question/Objectives:
Annual Survey of Hard Red Spring wheat grown in Minnesota as Part of the Northern Great Plains States. This report details the survey of hard red spring wheat cultivated in Minnesota in 2024, as a key component of the Northern Great Plains states' wheat production. The survey includes the collection, analysis and reporting of significant wheat quality attributes that are critical for marketing the crop. Due to a diversity of environmental conditions, cultivars, and agronomic practices across the region, a variety of quality attributes emerge. This survey assesses these important marketing attributes as the wheat enters commercial market channels.

Results:
This year a total of 118 samples of hard red spring wheat were collected from Minnesota, distributed across two regional crop reporting areas, designated as A and B. The sample size from each county was determined by its wheat production volume; counties with higher production yielded more samples. Specifically, in counties with lower production, a minimum of two samples were collected, whereas in high-producing counties, up to 15 samples were gathered. Efforts were concentrated on obtaining samples that accurately represent the condition of the grain available to the commercial market within each area. The collection of these samples was facilitated under a contract with the USDA-National Agricultural Statistics Service, based in Fargo, N.D.

Table 1: list of the collected samples

County	Samples collected
Region A	
Kittson	15
Roseau	13
Marshall	15
Polk	15
Pennington	11
Red Lake	7
Norman	12
Mahnomen	4
Lake of the Woods	2
Region B	
Clay	8
Becker	3
Wilkin	7
Ottertail	2
Traverse	2
Grant	2

Approximately 60% of the HRS wheat samples collected were graded by a federally licensed grain inspector. These samples were also analyzed for protein content, falling number, test weight and thousand-kernel weight, providing a basis for estimating assay distributions within the crop. To represent each of the two HRS wheat crop reporting areas (CRAs) in Minnesota, composite samples were prepared by combining equal portions of individual samples.

Comprehensive analyses on these composite samples were conducted to assess quality. Assays included measurements of test weight, falling number, size distribution, protein, ash, 1000-kernel weight, grade, wet gluten, solvent retention capacity (SRC), among others. Milling yields and flour quality traits such as ash and protein content were determined. Dough testing utilized instruments like the Farinograph, Alveograph and Extensograph. The end-product performance model was based on bread (100 g pup loaves), evaluating baking absorption, bread loaf volume, crumb and crust color, symmetry, grain, and texture properties.

The results were detailed in multiple tables within a published bulletin, and further elaborations are presented in the following pages. Bulletins summarizing findings across HRS-growing states were published and distributed mainly by the sponsoring agencies, with approximately 4,100 copies printed. Additionally, the data are available electronically on the North Dakota Wheat Commission website.

Furthermore, wheat samples representing protein ranges of less than 13.5%, 13.5% to 14.5%, and greater than 14.5% protein (12% moisture basis) were selected from the sample population for detailed analysis. Complete assessments of wheat, flour, and bread baking properties were performed on these categorized samples. Reports on these findings were submitted to U.S. Wheat Associates to aid in their international wheat marketing efforts.

Table 2: Wheat grading data

Crop Growing Area	Test Weight (Ib/bu)	Test Weight (KG/HL)	Damaged Kernel (%)	Foreign Materials (%)	Shrunken/ Broken kernel (%)	Total Defects (%)	Wheat of Contrast Classes (%)	Grade	Vitreous Kernel (%)
MN A	61.7	81.1	1.0	0.0	0.4	1.4	0.0	1 NS	49
MN B	59.6	78.4	1.4	0.0	0.4	1.8	0.0	1 RS	21
2023 Avg	61.4	80.7	1.1	0.0	0.4	1.5	0.0	1 NS	45
2022 Avg	62.1	81.7	0.3	0.0	0.2	0.5	0.0	1 NS	48

Table 3: Kernel quality data

Crop Growing Area	Dockage (%)	Moisture (%)	1000 Kernel Weight (g)	Kernel Size Distribution medium (%)	Kernel Size Distribution large (%)	Protein Content (%) [Dry basis]	Protein Content (%) [12% moisture basis]	DON (ppm)	Wheat Ash (%)	Wheat Falling Number (sec)	Zeleny Sedimentation (cc)
MN A	0.3	13.0	35.7	31	68	15.1	13.3	0.7	1.50	336	64
MN B	0.5	13.1	32.4	42	56	15.6	13.7	1.9	1.60	339	61
2023 Avg	0.4	13.0	35.2	33	66	15.2	13.4	0.9	1.52	336	64
2022 Avg	0.4	12.9	38.2	25	74	16.3	14.3	0.0	1.47	373	62

Table 4: Flour quality data

Crop Growing Area	Extraction (%)	Flour Ash (%)	Flour Protein (%)	Starch Damage (%)	Wet gluten (%)	Gluten Index	Falling Number (sec)	Peak 65G FL	SRC: GPI	SRC: Water	SRC: 50% Sucrose	SRC: 5% Lactic Acid	SRC: 5% Sodium Carbonate
MN A	69.4	0.45	12.1	6.5	31.7	93	359	373	0.76	66	105	146	87
MN B	69.2	0.51	12.4	6.3	32.5	82	346	271	0.71	66	107	137	84
2023 Avg	69.4	0.46	12.1	6.5	31.8	91	357	358	0.75	66	105	145	87
2022 Avg	68.7	0.49	13.0	6.2	33.7	95	372	532	0.70	70	114	147	97

Table 5: Dough physical properties data (Farinograph)

Crop Growing Area	Absorption (%)	Peak Time min	Stability min	MTI BU	Quality Number mm
MN A	60.0	6.0	11.5	27	134
MN B	60.0	5.7	10.3	27	126
2023 Avg	60.0	6.0	11.3	27	133
2022 Avg	62.9	7.4	15.3	19	169

Table 6: Dough physical properties data (Extensograph and Alveograph)

Crop Growing Area	Extensograph						Alveograph			
	Extensibility 45 min	Resistance 45 min	Area cm	Extensibility 135 min	Resistance 135 min	Area cm	P mm	L mm	P/L ratio	W JOULES X 104
MN A	18.5	549	122	15.3	897	163	82	129	0.64	385
MN B	17.0	452	94	15.2	847	152	72	126	0.57	318
2023 Avg	18.3	534	118	15.3	890	161	81	129	0.63	375
2022 Avg	16.1	668	133	12.8	1251	178	104	119	0.87	456

Table 7: Baking data

Crop Growing Area	Absorption (%)	Dough Handling*	Loaf Volume cc	Grain & Texture*	Crumb Color*	Crust Color*	Symmetry*
MN A	62.7	9.0	940	7.0	7.0	10.0	8.0
MN B	63.2	8.0	955	7.5	7.5	9.0	8.0
2022 Avg	62.8	8.9	942	7.1	7.1	9.9	8.0
2021 Avg	64.9	8.8	959	7.4	8.1	10.0	8.6

**Dough handling, grain and texture, crumb color, crust color, symmetry all have a scale of 1-10. The highest rating is 10.*

Application/Use:

This project stands as one of the most effective strategies for marketing Minnesota-grown HRS wheat, contributing significantly to the enhancement and sustenance of HRS wheat sales both domestically and internationally. Quality analysis results are promptly published in the HRS Regional Quality Report and the US Wheat Associates Crop Quality Report, which serve as key marketing tools for US wheat.

Furthermore, the project's principal investigator, Dr. Shahidul Islam, has presented these quality analysis results to numerous international trade teams and milling companies worldwide, major importers of U.S. hard red spring wheat. Additionally, representatives from U.S. Wheat Associates have also presented these findings to national and international buyers, further bolstering the visibility and marketability of this crop.

Materials and Methods:

SAMPLE COLLECTION – Each sample contained approximately 2 to 3 pounds of wheat, stored in sealed, moisture-proof plastic bags.

MOISTURE – Official USDA procedure using Dickey-John Moisture Meter.

GRADE – Official United States Standards for Grain, as determined by a licensed grain inspector. North Dakota Grain Inspection Service, Fargo, N.D., provided grades for composite wheat samples representing each crop reporting area.

VITREOUS KERNELS – Approximate percentage of kernels having vitreous endosperm.

DOCKAGE – Official USDA procedure. All matter other than wheat which can be removed readily from a test portion of the original sample by use of an approved device (Carter Dockage Tester). Dockage may also include underdeveloped, shriveled and small pieces 0f wheat kernels removed in properly separating the material other than wheat and which cannot be recovered by properly rescreening or recleaning.

TEST WEIGHT – American Association of Cereal Chemists International (AACCI) Method 55-10. Measured as pounds per bushel (lb/bu), kilograms per hectoliter (kg/hl) = (lbs/bu X 1.292) + 1.419. *Approved Methods of the AACCI Approved Methods (11th Edition), St. Paul, MN.

THOUSAND KERNEL WEIGHT – Based on 10-gram sample of cleaned wheat (free of foreign material and broken kernels) counted by electronic seed counter.

KERNEL SIZE DISTRIBUTION – Percentages of the size of kernels (large, medium, small) were determined using a wheat sizer equipped with the following sieve openings:
•top sieve—Tyler #7 with 2.92 mm opening;
•middle sieve—Tyler #9 with 2.24 mm opening; and
•bottom sieve—Tyler #12 with 1.65 mm opening.

PROTEIN – AACCI (NIR) Method: 39.10.01 expressed on dry basis and 12 percent moisture basis.

ASH – AACCI Method 08.01, expressed on a 14 percent moisture basis.

DON – Analysis was done on ground wheat using a gas chromatograph with an electron capture detector as described in J. Assoc. Official Anal. Chem 79,472 (1996)

FALLING NUMBER – AACCI Method 56.81.04; units of seconds (14 percent moisture basis).

SEDIMENTATION – AACCI Method 56.61.01, expressed in centimeters.

FLOUR EXTRACTION – Samples are cleaned and tempered according to AACCI 26-01.02. The milling laboratory is controlled at 68 percent relative humidity and 72°F to 74°F. Milling is performed on a Buhler laboratory mill (Type MLU-202). Straight grade flour (of all six flour streams) is blended and reported as "flour extraction."The blended flour is rebolted through an 84 SS sieve. All mill settings are optimized to achieve maximum laboratory mill flour extraction with standardized ash content.

ASH – AACCI Method 08.01, expressed on a 14 percent moisture basis.

PROTEIN – AACCI Method 39.10.01 (NIR Method), expressed on a 14 percent moisture basis.

WET GLUTEN – AACCI Method 38.12.02, expressed on a 14 percent moisture basis determined with the glutomatic instrument.

GLUTEN INDEX – AACCI Method 38.12.02, determined with the glutomatic instrument as an indication of gluten strength.

FLOUR FALLING NUMBER – AACCI Method 56.81.03, units of seconds. Determination is performed on 7.0 g of Buhler milled flour (14 percent moisture basis).

AMYLOGRAM – (65 g) AACCI Method 22.10.01, modified as follows: 65 g of flour (14 percent moisture basis) are slurried in 450 ml distilled water, paddle stirrers are used with the Brabender Amylograph. Peak viscosity reported in Brabender units (B.U.), on a 14 percent moisture basis.

STARCH DAMAGE – AACCI Method 76.31.01. Spectrophotometric method (Megazyme).

SOLVENT RETENTION CAPACITY (SRC) – AACCI 56-11.02, expressed on a 14 percent moisture basis. SRC is used to predict commercial baking performance. Flour is shaken with excess of four types of solvent, to determine the amount of solvent held by the flour. The four solvents used relate to the functionality to flour components as follows: Water – Water absorption; Sucrose – Non-starch polysaccharides; Lactic Acid – Glutenins; Sodium Carbonate – Damaged Starch; Gluten Performance Index (GPI) – is a ratio of the solvents and used as an overall performance of flour glutenins especially in relation to bread wheat flour.

PHYSICAL DOUGH PROPERTIES FARINOGRAM – AACCI Method 54-21.02; constant flour weight method, small (50 g) mixing bowl. (Flour weight 14 percent moisture basis). Farionograph-E.

ABSORPTION – Amount of water required to center curve peak on the 500 Brabender unit line, expressed on 14 percent moisture basis.

PEAK TIME – The interval, to the nearest 0.5 min, from the first addition of water to the maximum consistency immediately prior to the first indication of weakening. Also known as dough development time.

STABILITY – The time interval, to the nearest 0.5 min, between the point where the top of the curve that first intersects the 500-BU line and the point where the top of the curve departs the 500-BU line.

MIXING TOLERANCE INDEX – The difference, in Brabender units, from the top of the curve at the peak to the top of the curve measured five minutes after the peak.

QUALITY NUMBER – AACCI Method 115. The length, expressed in mm, along the time axis, between the point of water addition and the point where the height in the center of the curve decreased by 30 BU compared to the height of the center of the curve at development time. Stronger flours have a higher quality number.

EXTENSOGRAM – AACCI Method 54-10.01; modified as follows: (a) 100 grams of flour (14 percent moisture basis), 2.0 percent sodium chloride (U.S.P.) and water (equal to farinograph absorption minus 2 percent) are mixed to optimum development in a National pin dough mixer; (b) doughs are scaled to 150 grams, rounded, moulded, placed in extensigram holders, and rested for 45 minutes and 135 minutes, respectively, at 30°C and 78 percent relative humidity. The dough is then stretched as described in the procedure referenced above. For conversion purposes, 500 grams equals 400 B.U.

EXTENSIBILITY – Total length of the curve at the base line in centimeters.

RESISTANCE – Maximum curve height, reported in Brabender units (B.U.).

AREA – The area under the curve is measured and reported in square centimeters.

ALVEOGRAPH – AACCI Method 54.30.02. Alveolab is used to measure dough extensibility and resistance to extension.
"P" – Maximal overpressure; related to dough's resistance to deformation.
"L" – Dough extensibility.
"W" – The "work" associated with dough deformation.

BAKING PROCEDURE – AACCI Method 10-09.01, modified as follows: (a) fungal amylase (SKB 15) replacing malt dry powder, (b) Instant dry yeast (1 percent) in lieu of compressed yeast, (c) 5 to 10 ppm ammonium phosphate, where added oxidants are required, (d) 2 percent shortening added. Doughs are mechanically punched using 6-inch rolls, and mechanically moulded using a National Laboratory Test moulder. Baking is accomplished in "Shogren-type" pans.

BAKING ABSORPTION – Water required for optimum dough baking performance, expressed as a percent of flour weight on a 14 percent moisturebasis.

DOUGH CHARACTER – Handling conversion assessed at panning on a scale of 1 to 10 with higher scores preferred.

LOAF VOLUME – Rapeseed displacement measurement made 30 minutes after bread is removed from the oven.

CRUMB GRAIN AND TEXTURE –Visual comparison to standard using a constant illumination source. Scale of 1 to 10, the higher scores preferred.

CRUMB COLOR – Visual comparison with a standard using a constant illumination source on a scale of 1 to 10, the higher scores preferred.

CRUST COLOR – Visual comparison with a standard using a constant illumination source on a scale of 1 to 10, the higher scores preferred.

SYMMETRY – Visual comparison with a standard using a constant illumination source on a scale of 1 to 10, the higher scores preferred.

Economic Benefit to a Typical 500 Acre Wheat Enterprise:
This project has markedly enhanced the market presence of Hard Red Spring (HRS) wheat grown in Minnesota. Wheat quality is understood as the amalgamation of characteristics that determine the excellence of the final product, which is crucial for maintaining the viability of the HRS wheat market to meet the demands of food manufacturers producing sought-after products. Each milling and baking group possesses distinct expectations, which can differ significantly across global export markets due to local consumer preferences. For example, U.S. millers and bakers often have specifications that diverge from those of their international counterparts. Conversely, farmers assess quality based on traits that provide the greatest economic return, indicating that the concept of quality is inherently variable, dependent on the market context. Ultimately, it is the end user who establishes the value of a specific quality standard. This initiative employs advanced quality assessment techniques to measure wheat quality for a variety of uses in both local and international markets.

Related Research:
Since the early 1960s, the Department of Plant Sciences at North Dakota State University has conducted annual quality assessments of HRS wheat grown in North Dakota. These surveys collect, analyze, and report crucial wheat quality characteristics to support marketing efforts. Recognizing that other states in the Northern Great Plains contribute approximately 40% of the region's HRS yield, the surveys from 1980 onward have included data from the four main plains states, collectively representing 90% of U.S. HRS production. Recently, the scope of the survey has been extended to encompass HRS wheat from the Pacific Northwest (PNW), now accounting for about 95% of total U.S. production.

The variation in environmental conditions, crop varieties, and farming practices results in a wide range of quality attributes. By expanding the survey to include the entire Northern Great Plains and the PNW, a comprehensive evaluation of the primary marketing traits of HRS wheat as it enters commercial distribution channels is achieved, enhancing its marketability and industry relevance.

Recommended Future Research:
Wheat quality analysis of every year's production is strongly recommended to be continued as one of the most effective ways of marketing Minnesota grown HRS wheat.

Publications (if any):

- 2024 Regional Quality Report, U.S. HARD RED SPRING WHEAT (https://www.uswheat.org/wp-content/uploads/2024-Hard-Red-Spring-Regional-Report.pdf)

- US Wheat Associates 2024 Crop Quality Report, HARD RED SPRING (https://www.uswheat.org/wp-content/uploads/2024-USW-Crop-Quality-Report.pdf)

Pictures with captions:

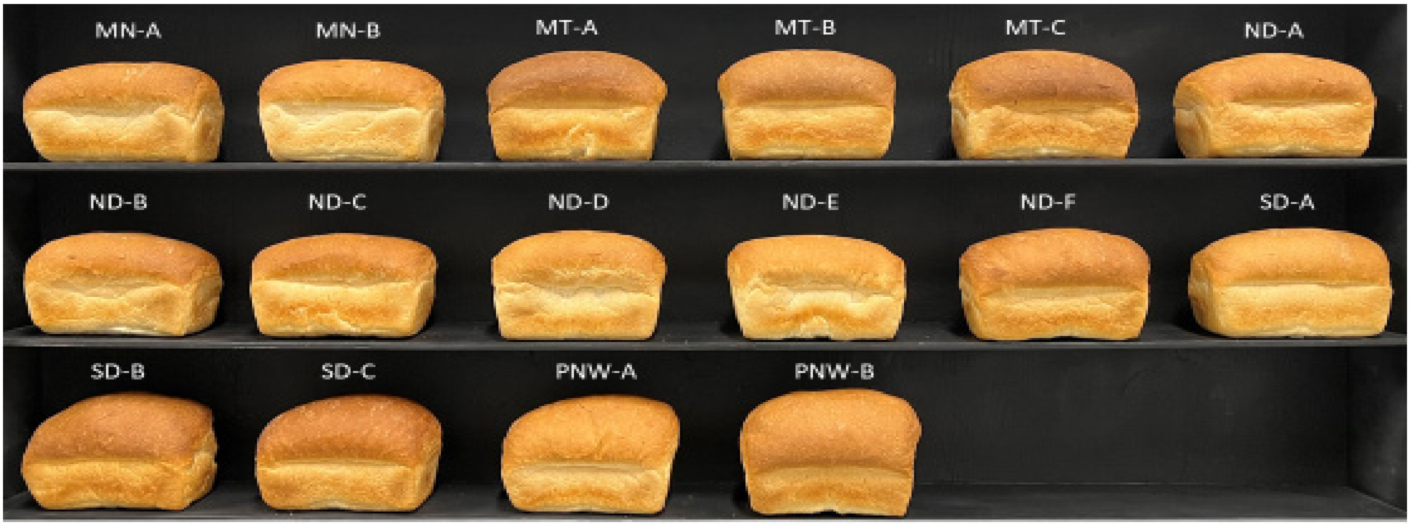

Figure 1: Bread volume analysis of the different crop reporting areas (CRAs) in 2024.

Accelerated Breeding for Resistance to Fusarium Head Blight

Principal Investigator(s): Karl D. Glover
Project Period: January 1, 2024-December 31, 2024

Research Question/Objectives:
Complete resistance to Fusarium Head Blight (FHB) is unavailable, yet genetic variability for resistance is well documented. Steady progress toward increasing resistance levels has been demonstrated by breeding programs through implementation of largely repeatable FHB screening procedures. Breeding programs must sustain efforts to simultaneously select resistant materials with desirable agronomic characteristics. The objective of this project is to use traditional plant breeding and selection techniques to develop hard red spring wheat germplasm and cultivars that possess agronomic characteristics worthy of release in addition to acceptable levels of FHB resistance.

Results:
Entries retained in the advanced yield trial (AYT) are generally at least moderately resistant to FHB. Those that do not perform adequately are discarded after the first year of AYT observation. Results of the 2024 AYT are presented in Table 1. Thirty-seven experimental breeding lines were tested along with eleven check cultivars during the 2024 growing season. Of the thirty-seven experimental lines, 19 had FHB disease index (DIS) values that were lower than the test average. Among these entries, thirteen produced more grain than average. Among the thirteen, test weight of all but SD4930 were higher than average. Of these twelve entries, protein content of eight were greater than average and included SD4905 and SD5090. Both SD4930 and SD4905 will be considered for release in November 2024. An initial round of SD5090 seed increase will take place this winter near Yuma, Arizona. Sufficient seed quantities may be produced this winter and next summer so that release consideration could be as soon as fall 2025. Each of these lines are more resistant to FHB than average and among the most productive AYT entries.

Application/Use:
With the progression of time, increases in FHB resistance levels should help to prevent devastating loses to growers caused by severe FHB outbreaks.

Materials and Methods:
Focused efforts to increase resistance began within this program after the 1993 FHB epidemic in the spring wheat production region. Both mist-irrigated greenhouse and field screening nurseries were established, and disease evaluation methods were developed. Breeding materials are evaluated for FHB resistance using three generations per year: two in the greenhouse and one in the field. We have the capacity to screen as many as 4,500 individual hills in the greenhouse (over two winter seasons). We can also have as many as 4 acres in the field under mist-irrigation. Both the field and greenhouse nurseries are inoculated with grain spawn (corn that is infested with the causal fungus) and spore suspensions. Mist-irrigation is used to provide a favorable environment for infection. Approximately 50 percent of the experimental populations possess Fhb1 as a source of resistance. Most of what remains are crosses with various “field resistant” advanced breeding lines. Experimental materials are advanced through the program in the following fashion;

Year 1	Field Space-planted F2 populations
Year 1	Fall greenhouse F2:3 hills
Year 1	Spring greenhouse F3:4 hills
Year 2	Field F4:5 progeny rows
Year 2	Off-season Nursery F5:6 progeny rows
Year 3	Field F5:7 Yield Trials (1 replication, 2 locations)
Year 4	Field F5:8 Yield Trials (2 replications, 5 locations)
Year 5	Field Advanced Yield Trials (3 reps, 10 locations)

F2 populations are planted in the field and individual plants are selected. These are advanced to the fall greenhouse where seed from each plant is sown as individual F2:3 hills and evaluated for FHB resistance. Four plants from each of the top 25% of the hills are advanced to the spring greenhouse. They are sown as individual F3:4 hills and evaluated for FHB resistance. Those with FHB resistance nearly equal to or better than 'Brick' are then advanced to the mist-irrigated field nursery as F4:5 progeny rows. They are evaluated again for resistance and general agronomic performance. Plants are selected within the superior rows and sent to New Zealand as F5:6 progeny rows for seed increase. A portion of seed from each selected plant is also grown in the fall greenhouse to confirm its resistance. If the FHB resistance of an F5:6 line is confirmed, then the respective progeny row is harvested in New Zealand. In the following South Dakota field season, selected lines are tested in a two replication, multi-location yield trial. Those that have agronomic performance and yield similar to current cultivars are included in more advanced, multi-location, replicated yield trials the following year. In year 5, lines advanced through this portion of the program are included in the AYT along with entries from the traditional portion of the program. Performance data with respect to Disease Index, along with agronomic potential from the 2024 AYT are presented in Table 1.

Economic Benefit to a Typical 500 Acre Wheat Enterprise:
The presence of FHB inoculum within fields and favorable weather conditions are just two factors that heavily influence whether this disease becomes problematic. Immediate economic benefits are therefore difficult to assess. When conditions become favorable for disease development, however, cultivars with elevated FHB resistance levels can help to reduce potentially serious grower losses.

Table 1. South Dakota State University advanced yield trial spring wheat entries ranked according to FHB disease index values (lowest to highest – collected at Brookings) presented along with agronomic data obtained from three replication trials conducted at eight environments in 2024.

ENTRY	DIS INDEX	YIELD (BU/AC)	TW (LB/BU)	PROTEIN (%)	HEADING (D > 6/1)	HEIGHT (INCHES)
BRICK	15.0	39.2	60.6	15.8	4.6	33.8
SD5196	16.5	47.1	60.3	15.5	8.3	31.2
SD5180	16.8	48.5	60.3	15.2	12.8	33.0
SD5131	18.0	40.4	60.0	15.7	10.9	33.4
ASCEND-SD	18.4	46.5	59.7	15.7	11.2	35.5
SD5168	18.6	35.8	59.7	16.5	10.6	33.9
SD5158	18.7	44.4	62.0	15.0	4.8	32.3
SD5181	19.0	49.2	60.0	15.2	12.8	33.1
SD5090	20.0	43.3	60.8	15.8	9.2	32.5
FOREFRONT	20.3	41.6	60.0	15.7	5.3	36.3
SD5095	20.9	41.7	61.1	15.4	11.1	33.2
SURPASS	21.0	43.0	59.0	15.3	6.8	32.0
SD5231	21.6	47.9	60.8	15.2	10.3	34.4
SD4905	22.0	44.2	59.4	15.8	7.4	33.0
SD5213	22.2	41.0	59.5	15.7	11.4	31.2
SD5197	22.4	46.1	60.6	15.4	8.3	30.4
BRAWN-SD	22.6	44.1	60.4	14.7	9.4	33.2
SD4930	23.1	46.4	58.4	15.3	10.8	33.0
SD5138	23.1	43.3	61.4	15.4	6.0	31.6
SD5155	23.2	43.0	60.8	15.8	8.5	31.9
PREVAIL	23.3	43.7	59.9	15.0	7.4	32.7
SD5134	23.5	43.4	59.7	16.0	9.4	33.5
SD5228	23.6	44.2	59.8	15.5	9.7	34.0
BOOST	23.9	39.0	58.9	15.5	12.4	33.9
DRIVER	24.0	41.7	59.2	15.4	10.9	33.1
SD5082	24.2	40.9	60.9	15.6	9.6	31.6
SD5175	24.3	44.7	61.1	16.0	6.8	31.3
SD5224	25.0	41.8	59.5	15.2	12.1	33.5
SD5103	25.1	42.9	60.2	15.4	10.8	32.8
SD5214	25.4	40.1	59.1	15.1	11.8	32.4
SD5102	25.5	42.7	60.8	15.5	8.9	32.7
SD5215	25.7	41.7	60.0	15.8	12.1	32.2
SD5072	26.6	40.7	59.3	15.9	10.8	32.7
SD5184	26.6	42.2	59.1	15.8	9.1	32.0
SD5119	26.9	43.2	60.0	15.2	10.9	26.7
SD5104	27.2	42.2	60.2	14.7	8.4	31.6
SD5091	27.9	42.5	60.9	15.8	8.3	33.2
SD5187	28.2	45.4	59.6	15.9	12.3	35.4
SD4944	28.5	36.7	57.9	15.8	14.1	30.8
TRAVERSE	28.6	43.9	57.2	14.7	7.5	34.5
SD5096	29.3	44.1	59.5	15.4	9.2	30.2
SD5050	29.4	45.6	60.2	15.1	7.2	30.7
SD5037	30.2	42.6	59.5	15.5	10.9	31.9
SD5080	30.5	39.8	61.0	15.6	9.6	32.5
SY-VALDA	30.7	45.0	59.3	15.0	9.6	31.4
SD5189	31.1	44.9	59.6	15.3	11.5	33.9
LCS-TRIG-GER	33.4	44.4	59.0	13.4	14.0	34.0
SD5105	39.8	40.2	55.7	15.3	10.4	27.4
MEAN	24.4	43.1	59.8	15.4	9.7	32.5
LSD (0.05)	5.4	1.7	1.7	0.3	0.7	0.7
CV	13.9	6.8	1.1	2.7	10.2	3.2

Breeding Winter Wheat Varieties with FHB Resistance and Straw Strength

Principal Investigator(s): Sunish K. Sehgal, Gazala Ameen, Peter Sexton
Project Period: January 1, 2024- December 31, 2024 (Year 3)

Research Question/Objectives:
Winter wheat (soft wheat and hard wheat) offers several advantages over spring wheat including a 20% yield increase and fits well with cover crop rotation, conserves soil moisture, improves water quality, reduces soil erosion, and builds soil structure and soil health. Winter wheat can provide an opportunity for MN farmers to adopt a fall crop in their rotation considering the above-discussed advantages. Therefore, there is a need to develop varieties with good Fusarium head blight resistance and straw strength that are well adapted to this region. The primary objectives of the project are to enhance the FHB resistance and straw strength in soft and hard winter wheat and to release improved winter wheat varieties for the region.

Results:
Population development and Speed breeding: We planted 65 F2:4 populations developed through speed breeding were planted in the field in October 2023 and single plant selections were performed in July 2024 (Figure 1). New crosses (104) initiated in March of 2023 were advanced using speed breed F2:4 and have been planted in the field in October 2024 for selection in summer 2025. In March-April 2024 270 hard winter wheat and 27 soft white wheat crosses were performed in the third year of the new project. The F1's from these crosses were vernalized and are currently growing to develop F2 populations. The F2 plants carrying Fhb1 from each cross will then be advanced using the speed breeding technique to F2:4 for field selection (Figure 1).

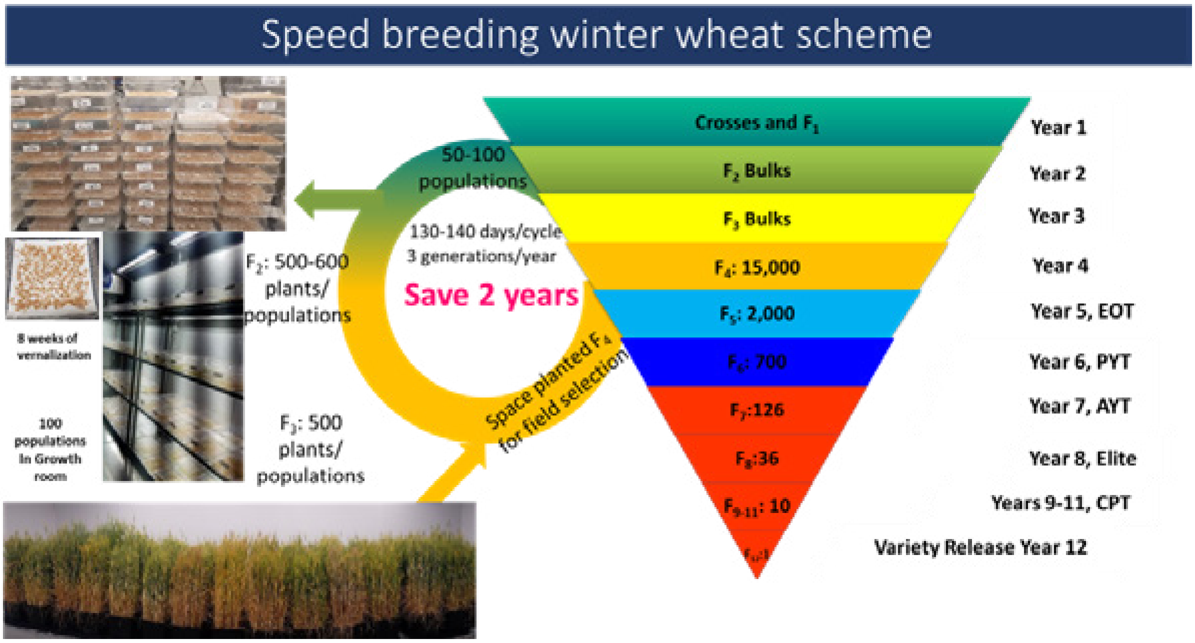

Figure 1: Speed breeding scheme implemented in winter wheat breeding to shorten the variety development time.

Selections in Segregating populations: Selections in space-planted 65 F2:4 populations were made for dwarf height, tillering capacity, earliness, and rust resistance. Of these 65 populations, about 35 populations carried Fhb1/Fhb6. On average we selected 20 desirable plants from each of the 50 populations and advanced them to 4-row early observation trials (EOT is individual plant short rows) for the 2025 season to get an observation of yield potential and agronomic traits (Fig.1). The selected lines from EOT will be advanced to preliminary yield trials (PYT) in 2026. The 45 F2:4 populations evaluated in 2023 resulted in 955 entries in the 2024 EOT of which more than 300 of them were advanced to preliminary yield trials for 2025.

Advanced and Elite yield trials:
Hard winter wheat advanced yield trial (AYT 2024) with 126 entries and Elite yield trial (Elite 2024) with 36 entries were performed at 7 and 8 locations, respectively, across SD. In AYT, the yield ranged from 48 bu/acre at Wall to 106 bushels/acre at Selby, SD. Superior performing entries from AYT 2024 were advanced to Elite 2025 trials including seven hard white wheat experimental lines SD21D107-1W SD21D025-3W, SD22B039-3W, SD22D138-6W, SD22W240-10-1tW, SD22W240-10-2tW, and SD22W240-1-2tW. SD21D025-3W exhibited medium height, good winter hardiness, good lodging resistance, and good FHB resistance. Two HRW wheat lines (SD22B052-2 and SD22C234-3) in the AYT2024 carry Fhb1 and showed good FHB resistance and agronomic traits and were advanced to Elite Trials for 2025.

In the elite yield trials (Elite 2024) 30 new entries were evaluated along with six check cultivars. Of the 30 entries, 21 had a lower disease index than the trial average and 15 entries had above-average grain yield (Table 1). Two entries SD21B046-4, and SD21B102-4 with good FHB resistance or below-average height were advanced to state-wide crop performance trials (CPT) for the 2025 growing season. A few stable and high-yielding elite lines from CPT are also entered in MN winter wheat trials. In 2024 MN winter wheat trials conducted by UMN two of the top four yielding varieties namely Winner (rank 2nd) and SD Andes (rank 4th) were from the SDSU winter wheat program (https://varietytrials.umn.edu/winter-wheat).

In the Soft White Wheat (SWW) advanced yield trial (2024) we evaluated 15 entries including 4 check cultivars. The SWW trials were conducted at three locations along the I-29 corridor North Brookings, Aurora farm, and Beresford, SD. The average grain yield, test weight, and protein content were 70.5 bu/ac, 54.7 lb/bu, and 11.4 %, respectively. Cultivar 'Piranha' and experimental lines MI22W213 (MI) and SD21D123-7W (SD) topped the trials.

Application/Use:
Breeding efforts with time will result in the enhancement of FHB resistance and good straw strength in winter wheat germplasm. The improved lines will be recommended for release as varieties for production in the region. In the fall of 2023, SD18B025-8 was released as 'SD Pheasant' with support from MNWR&PC.
New varieties:
SD PHEASANT- 'SD Pheasant' hard red winter wheat was developed by the South Dakota Agricultural Experiment Station (SD AES) and released to seed producers. The line was tested as SD18B025-8 and was developed from the cross OK07719W/SD07W083-4//SD07W053/3/SD09161. It is a medium-tall variety (Rht-B1b) with excellent winter hardiness and medium maturity (2 days later than Winner). SD Pheasant is a high-yielding line with good test weight and good grain protein content. It has a good disease-resistance package and is resistant to leaf rust and moderately resistant to stem rust. Along with excellent grain yield potential, SD Pheasant has good milling characteristics and excellent baking characteristics. SD Pheasant was awarded the Best-Of-Show award at the 2023 Wheat Quality Council Meetings for overall excellent milling and baking quality. PVP V has been filed for 'SD Pheasant'.
Further, the improved germplasm will form the foundation of the next breeding cycle and will also be shared with breeding programs in the region.

Materials and Methods:
Each year we make several hundred crosses in hard winter wheat (HWW) and about 25-40 crosses/backcrosses in soft white winter wheat (SWW) market class. The crosses are developed for agronomic traits (grain yield, test weight, protein content, straw strength, etc.), end-use quality traits, and resistance to diseases and insect pests. However, the main goal of this project is to enhance straw strength and FHB resistance in winter wheat along with winter hardiness to develop varieties adapted to this region. The major sources of FHB resistance are native (Lyman, Everest Overland, and Emerson), Fhb1 and Fhb6 for increasing straw strength, the focus is on semidwarf genotypes carrying Rht1b.

The F1's are backcrossed or seed increased in the greenhouse and then ~500 F2 plants are screened for with molecular markers (Fhb1/Fhb6) in target crosses and the selected F2 plants are advanced to the next generation as mini-bulks through speed breeding (Fig. 1) or in the field to F4 generations. The F4 population is space planted to select plants with shorter height, tillering capacity and early maturity. The selected plants are planted in a short 5 ft 4-row early observation trial (EOT). The EOT entries are screened for FHB markers (for confirmation) and selected based on winter hardiness, resistance to other diseases (rust and Bacterial Leaf Streak), and agronomic traits like plant height, maturity, yield, test weight, and grain protein. The best-performing breeding lines from EOT are advanced to preliminary (three locations) then to advanced yield trials (AYT) at 3 (SWW-AYT) and 7 (HWW-AYT) locations and finally, the hard winter wheat lines are advanced to elite yield trials (Elite) at 8 locations. Currently, we are evaluating 15-20 SWW lines in our SWW-AYT, 126 in our HWW-AYT, and 36 lines in our HWW-Elite trials. The AYT and Elite lines are evaluated for FHB resistance in our mist-irrigated FHB field nursery. Further, all quality parameters of the advanced and Elite lines are evaluated. GS approaches are also being evaluated in the breeding program for various traits. The 2-3 lines showing superior performance in AYT, and Elite trials are submitted to the Minnesota State Variety trials conducted by (Dr. Jared J. Goplen and Dr. Jochum J. Wiersma) at 5 locations in Minnesota.

Economic Benefit to a Typical 500 Acre Wheat Enterprise:
The development of winter wheat varieties adapted to Minnesota and the region can bring significant benefit to the regional producers in terms of revenue as winter wheat varieties would typically yield ~10 % more than spring wheat due to the longer growing season. This would account for an additional 5 bu per acre. In addition, winter wheat on a farm would spread the producer's workload as it is planted in the fall and helps compete with weeds in a corn-soybean rotation. The fall-planted winter wheat keeps the ground covered, preventing soil erosion and captures fall moisture and provides an opportunity to include cover crops in rotation. Lastly, studies have shown having wheat in crop rotation enhances yield in the following corn crop by nearly 10%.

Table 1. South Dakota State University hard winter wheat Elite yield trial (Elite) entries ranked according to FHB disease index values (lowest to highest – collected at Volga farm) presented along with agronomic data obtained from three replication trials conducted at five test environments in 2024. The heading data is days to on Julian calendar and Lodging was rated at harvest on a scale of 0-9; 0- no lodging and 9- complete lodging.

Genotype	Rank	Yield (bu/ac)	Protein (%)	TW (lb/bu)	Heading	Height (inches)	Lodging	FHB Index
WINNER	2	89.4	11.7	61.3	152.6	34.4	4.4	14.7
SD21D123-7W	15	81.7	11.9	59.6	152.9	33.7	3.8	15.8
SD21B110-1	20	80.2	11.8	60.8	153.4	34.4	3.1	16.4
SD21B052-1	24	78.1	11.8	61.1	154.7	34.7	2.9	18.4
SD21D057-1	22	79.3	11.8	60.3	153.9	32.4	3.4	22.9
SD21B061-7	13	82.0	11.7	60.8	152.4	34.5	3.8	25.1
SD ANDES	4	86.8	11.8	62.2	155.7	32.9	2.1	25.5
SD21B073-3	14	81.9	11.6	58.8	151.9	34.5	3.6	26.0
SD21B046-4	16	81.6	11.7	60.8	153.8	33.4	3.2	26.4
SD21B102-4	6	86.2	11.9	59.9	154.3	33.3	3.3	26.9
SD21C048-2	17	81.3	11.8	59.3	154.0	32.0	3.7	26.9
SD21C033-1	3	87.6	11.6	60.0	153.4	34.7	4.9	27.1
SD21B042-2	12	82.6	11.8	61.0	154.3	32.9	3.0	29.0
SD21C070-3	25	77.6	11.8	60.1	153.9	33.1	2.9	31.5
SD20B006-2	9	83.2	11.9	61.0	153.5	34.6	4.1	31.5
EXPEDITION	33	72.2	11.9	59.7	151.0	36.2	4.8	31.6
SD21D107-1W	5	86.4	11.7	60.0	154.3	34.1	3.7	32.0
SD20D009-3	30	75.3	11.9	59.1	154.7	33.0	4.3	34.9
KELDIN	1	90.0	11.4	61.4	155.7	34.3	4.0	35.9
SD21C078-3	8	83.8	11.7	59.8	155.0	35.7	3.5	39.7
SD20B057-1	11	82.7	11.9	60.6	151.9	34.0	4.5	41.1
SD21B046-6	7	84.0	11.8	60.4	155.0	35.1	2.7	43.8
SD21D022-4	29	75.7	11.8	59.5	153.6	33.7	3.6	45.1
SD21B021-2	10	82.8	11.6	60.0	154.7	33.3	3.7	47.4
SY MONUMENT	27	76.7	11.7	59.4	154.3	33.9	3.9	52.6
SD21B113-3	21	79.6	11.9	59.8	154.1	32.3	3.1	54.3
SD21D099-3	19	80.4	11.7	60.0	152.6	35.2	3.7	58.2
SD20D036-7	34	71.3	11.9	59.2	154.2	33.7	3.3	59.0
SD21D113-7	26	77.1	11.7	60.9	154.5	33.8	3.7	59.6
SD21C052-2	23	78.6	11.8	59.3	154.8	33.8	3.4	61.3
SD21D110-6	28	76.5	11.9	60.2	151.4	32.8	4.4	67.8
AP CLAIR	18	81.1	11.7	60.7	154.1	32.6	3.8	69.6
SD21D121-1	31	73.4	11.8	57.5	153.9	31.6	3.8	74.1
SD21D121-2	35	70.9	12.0	57.4	154.9	30.7	4.5	78.2
SD21C010-3	32	72.9	11.4	58.9	153.2	34.3	3.8	79.2
SD20B027-9	36	67.2	10.4	55.2	155.1	34.2	5.4	96.4
Trial Average		79.9	11.7	59.9	153.8	33.7	3.7	42.5
LSD		8.2	0.6	1.1	0.7	0.9	1.1	17.9
CV		5.4	5.4	1.6	0.4	3.5	23.0	30.0

Related Research:
These funds provide general support for our breeding program to develop winter wheat varieties adapted to the region and provide value addition to the producer and meet the needs of the local milling industry. Additional funding for

breeding activities comes from the South Dakota Wheat Commission and the U.S. Wheat and Barley Scab Initiative via USDA-ARS.

Publications (if any):

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Organismal Responses During Drought and Recovery in Globally and Regionally Selected Wheat Varieties

Principal Investigator(s): Zhikai Liang

Project Period: January, 1, 2024-December 31, 2025

Research Question/Objectives:
1. Understanding image-based photosynthetic variations across organs in the single wheat plant resolution under drought stress and recovery conditions;
2. Developing new image-based metrics and statistical models to evaluate drought tolerance and recovery ability in wheats;
3. Quantifying drought tolerance and recovery ability in globally and regionally selected wheat germplasms

Results:
In the Year 1 of this project, we have propagated seeds of 19 wheat germplasms from John Innes Centre (JIC) at the United Kingdom, including 15 globally representative wheat varieties (originated from 9 regions over the world including Australia, Canada, Germany, Japan, Switzerland, France, United Kingdom, United States and Mexico) with fully assembled genomes, 3 Hard Red Spring Wheats (Sumai3, Rollag and Glenn) and 1 spring wheat used for assembling the first reference genome of wheat (Chinese Spring). These bulked seeds enable us to extend this experiment to more developmental stages of each genotype and subject them to drought stress and recovery conditions. Our taken images of harvested seeds show strong phenotypic diversity in this panel (Figure 1).


Figure 1. Our harvested spikes of selected wheat varieties in NDSU greenhouse.

In June 2024, our lab at NDSU received the PlantExplorer Pro+ phenotyping machine (PhenoViation, Netherlands). Our team participated in an onsite training session conducted by Vincent Jalink, where we learned to operate the PlantExplorer Pro+ and its software, CropReporter. This training enabled us to refine our experimental designs and capture a range of photosynthetic parameters, including Fv/Fm (Maximum Quantum Efficiency of Photosystem II), NPQ (Non-Photochemical Quenching), chlorophyll content, and MTR (Maximum Transmittance Ratio). The chlorophyll fluorescence camera on this system captures detailed plant images that conventional RGB cameras cannot, enabling us to detect nuanced response differences among the varieties (Figure 2). Additionally, we established a collaboration with Prof. Marcin Grzybowski at the University of Warsaw (Poland) to conduct NPQ kinetics analyses, allowing us to derive specific NPQ traits from PAM quenching assessments. By tracking NPQ kinetics, we can assess the speed and effectiveness of a plant's protective mechanisms in response to stress. Under challenging conditions, shifts in NPQ activity reveal insights into a plant's stress tolerance, with faster or stronger NPQ responses indicating more robust stress management. This makes NPQ a valuable marker for evaluating plant resilience.

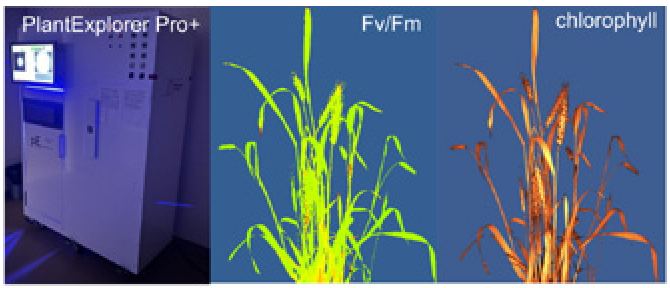

Figure 2. Images captured by the PlantExplorer Pro+ system. Two photosynthetic parameters (Fv/Fm and chlorophyll content) were visualized, each represented by color-enhanced images to indicate parameter ranges

We initiated our first batch of experiments with 10 spring wheat varieties—Glenn, Rollag, Landmark, Faller, Sumai3, Chinese Spring, Norin 61, Mace, Lancer, and Stanley – using the PlantExplorer Pro+ system. The objective was to compare photosynthetic responses from a whole-plant perspective between control and drought-treated conditions. Preliminary results revealed significant variability in photosynthetic responses among these wheat varieties. Typically, healthy plants maintain Fv/Fm values between 0.7 and 0.8, with lower values indicating increased stress. For instance, drought stress in this study showed a stronger negative effect on Fv/Fm values in the variety Faller than Sumai3, highlighting distinct differences in drought tolerance (Figure 3).

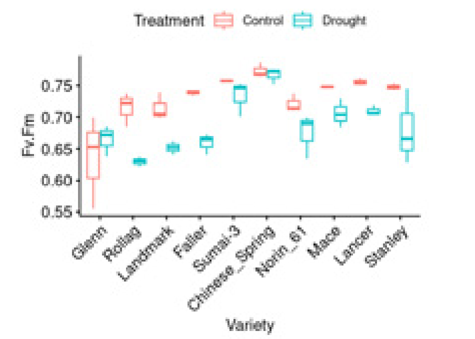

Figure 3. Drought response differences among spring wheat genotypes revealed by Fv/Fm calculated from PlantExplorer Pro+ imaging system.

Application/Use:
Evaluations of crop stress responses are often qualitative, as plants exhibit a wide range of physiological and morphological responses to stress, which are difficult to measure precisely. Using the chlorophyll fluorescence imaging system – PlantExplorer Pro+ – in this study, we will be able to create quantitative metrics (including NPQ, Fv/Fm, MTR) to precisely score crop stress responsiveness.

Materials and Methods:
In the initial experiment, all 10 spring wheat varieties were subjected to a two-week drought treatment at the heading stage, with a control group maintained under regular watering conditions. We used the soil moisture meter to monitor Soil Water Content (SWC) per day to ensure the water content in the drought condition was maintained ~10% and well-watered condition >30%. We included 3 replicates per variety per treatment. At the end of two-week drought stress treatment, we moved all plants from greenhouse room to the dark room for at least 15 mins dark adaptation before starting the imaging to ensure photosynthetic machinery in the plants to reset to a baseline state. We chose the default protocol of PlantExplorer Pro+ to take side-view images per plant and collect photosynthesis parameters per plant. All images were analyzed using CropReporter and produced the output file to a separate text file. T-test was performed to compare differences per parameter between treatments for each variety.

Economic Benefit to a Typical 500 Acre Wheat Enterprise:
The application of the PlantExplorer Pro+ system in evaluating and selecting drought-tolerant wheat varieties could offer significant economic advantages to a 500-acre wheat operation. By identifying wheat varieties from hundreds of candidate germplasms with superior photosynthetic efficiency and resilience under drought conditions, this technology enables growers to make data-driven decisions that reduce yield losses in water-limited environments. For example, with wheat varieties showing higher Fv/Fm and NPQ values, indicating better stress management, a wheat enterprise could potentially reduce inputs, increase yield stability, and minimize the economic impact of drought conditions. Over time, using drought-tolerant varieties optimized through such advanced phenotyping could lead to improved yield consistency, reduce water use requirements, and enhance overall farm profitability on a per-acre basis.

Related Research:
Photosynthetic parameters like Fv/Fm and NPQ are indicators of a plant's health and resilience to stress. Fv/Fm values decrease under stress, signaling reduced photosynthetic efficiency, while NPQ increases as the plant activates protective mechanisms to prevent photodamage. Together, these metrics help assess how well a plant responds to and tolerates stress conditions.

One of the related researches in our group is to employ this system to investigate spatial variations of heat stress response in a world-core collection of spring barleys.
Our group is developing a high-throughput approach to image ~300 individual leaves from corresponding varieties (e.g. breeding lines) per day to evaluate abiotic stress-resilience (including drought, heat, salinity, heavy metal) and biotic resilience (like Bacteria Leaf Streak) in crops. This approach can deliver stress resilience measurements in precise numeric values for leaf tissues collected from any developmental stages in crops. We are interested in offering this assessment as a fee-based service in the future.

Recommended Future Research:
We will extend this method and treatment to additional developmental stages of selected wheat varieties under parallel drought and control conditions. This approach will enable us to assess drought sensitivity across multiple growth stages, providing a comprehensive understanding of each variety's response to water stress over time;
This imaging system provide us a tool to precisely quantify stress response in crops. Using a core collection of approximately 400 spring wheat individuals, we will perform a genome-wide association study (GWAS) to identify genetic loci associated with drought response. The identified loci will inform a genomic selection program aimed at enhancing drought resilience in wheat.

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Publications:
Published papers are not available for this project at this time.

University of Minnesota Wheat Breeding Program

Principal Investigator(s): James A. Anderson & Jochum Wiersma

Project Period: Jan. 1, 2024-Dec. 31, 2024
Research Question/Objectives: This is a continuation of the University of Minnesota's spring wheat breeding program with the objectives: 1) Develop improved varieties and germplasm combining high grain yield, disease resistance, and end-use quality; and 2) Provide performance data on wheat varieties adapted to the state of Minnesota.

Results:
The 2024 State Variety Trial, which contained 51 released varieties, 18 University of Minnesota experimental lines, 2 experimental lines from other programs, and 3 long term checks was evaluated at 13 locations. The Fergus Falls location was lost due to hail and the data from Waseca is not reported due to excess early season rainfall. Another 178 advanced experimental lines were evaluated in advanced yield trials at 7-8 locations and 396 lines were evaluated in preliminary yield trials at 3 locations and 125 lines at one location. A total of 7,128 yield plots were harvested in 2024. Fusarium-inoculated, misted nurseries were established at Crookston and St. Paul. An inoculated leaf and stem rust nursery was conducted at St. Paul. DNA sequence information was obtained from 2,081 pre-yield trial lines and their FHB resistance, dough mixing properties, and pre-harvest sprouting response were predicted based on a training set of 210 lines and their 49 parents. These predictions were used to help select the 521 preliminary yield trial lines from the 2,081 candidate lines, therefore avoiding more expensive and time-consuming field-based evaluations on more than 1,400 lines with lower genetic potential. Data from the yield and disease nurseries are summarized and published in Prairie Grains magazine and the MAES's 2024 Minnesota Field Crop Variety Trials (https://varietytrials.umn.edu). Table 1 has comparative data of the 8 most popular varieties in Minnesota, based on the 2024 variety survey results provided by the Minnesota Association of Wheat Growers.

			Grain Yield					Straw	TWT	Prot.	Bake			
	Rel.	% MN	North, bu/A			HD	HT	Str.	lbs/bu	(%)	Qual.	PHS	BLS	FHB
Variety	Yr.	Acres	2024	2 Yr	3 Yr	d	in.	1-9	2 yr	2 yr	1-9	1-9	1-9	1-9
MN-Rothsay	2022	21.7	99.7	98.5	95.7	61.1	31.0	3	59.8	14.0	5	2	4	4
SY Valda	2015	10.2	100.1	99.3	95.5	58.4	33.3	5	59.8	13.7	6	2	4	4
MN-Torgy	2020	11.9	97.6	96.2	92.8	57.2	33.4	4	60.4	14.3	4	1	3	3
TCG-Wildcat	2020	2.9	96.2	95.4	92.3	59.4	34.1	3	59.8	14.3	4	1	5	7
WB9590	2017	23.4	95.3	95.6	92.3	56.2	30.2	3	59.3	14.5	4	2	6	7
AP Murdock	2020	4.4	96.5	92.4	91.3	57.1	32.6	5	58.9	13.9	5	1	4	7
WB9479	2017	6.6	94.7	92.2	88.6	56.8	30.5	3	59.6	15.1	1	1	5	7
Linkert	2013	2.6	85.1	85.4	82.6	58.1	31.7	2	60.1	15.0	1	1	4	5

Table 1. Comparison of MN-Rothsay (2022 UMN release), MN-Torgy (2020), Linkert (2013) and the other five most popular spring wheat varieties grown in Minnesota in 2024. Entries are sorted based on grain yield (bu/A) over 22 location-years since 2022. For traits scored on a 1-9 scale, 1 is best and 9 is worst.

Application/Use:
Experimental lines that show improvement over currently available varieties are recommended for release. Improved germplasm is shared with other breeding programs in the region. Scientific information related to efficiency of breeding for particular criteria is presented at local, regional, national and international meetings and published.

Materials and Methods:
Approximately 300 crosses are made per year. A winter nursery is used to advance early generation material when appropriate, saving 1-2 years during the process from crossing to variety release. Early generation selection for plant

height and leaf and stem rust resistance is practiced in nurseries in St. Paul and Crookston. Approximately 400 new lines are evaluated in preliminary yield trials at 3 locations. Advanced yield trials – containing 170-180 experimental lines – are evaluated at 8-9 locations. All yield nurseries are grown as 42-70 sq. ft. plots. Misted, inoculated Fusarium head blight and bacterial leaf streak nurseries are grown at Crookston and St. Paul and an inoculated leaf and stem rust nursery is grown at St. Paul. The disease nurseries involve collaboration with agronomists and pathologists at Crookston and with personnel from the Plant Pathology Department and the USDA-ARS. Pre-harvest sprouting resistance is assessed on named varieties and advanced lines. Genomic prediction is used at the pre-yield trial stage to predict the performance of experimental lines based on DNA sequence information of related lines. This allows us to screen a larger number of lines than we could accommodate in our field trials and can help us find the rare lines that combine all the desired traits in a high yielding line.

Economic Benefit to a Typical 500 Acre Wheat Enterprise: Choice of variety is one of the most important decisions growers make each year. The development of high-yielding varieties that are resistant to the prevalent diseases and have good end-use quality are necessary to increase grower profitability. As an example, a new variety that yields 5% higher will produce 4 extra bushels/acre in a field that averages 80 bu/A. At $6.00/bushel that equates to more than $12,000 in additional gross revenue for a 500-acre wheat enterprise.

Related Research: These funds provide general support for our breeding & genetics program. Additional monetary support for breeding activities in 2024 came from the MN Small Grains Initiative via the Minnesota Agricultural Experiment Station, and the U.S. Wheat and Barley Scab Initiative via USDA-ARS.

Recommended Future Research: We increased our use of genomic prediction in the past year, adding pre-harvest sprouting resistance in addition to Fusarium head blight resistance and gluten strength. Drone images were captured from three locations in 2024 and we intend to expand our capacity for this form of data collection in 2025.

References:

Publications:

Anderson, J. A., J. J. Wiersma, S. K. Reynolds, E. J. Conley, N. Stuart, R. Caspers, J. Kolmer, M. N. Rouse, Y. Jin, R. Dill-Macky, M. J. Smith, and L. Dykes. 2024. Registration of 'MN-Rothsay' Spring Wheat with High Grain Yield and Lodging Resistance. Journal of Plant Registrations. doi: 10.1002/plr2.20400.

Edae, E.A., Z. Kosgey, P. Bajgain, K. Ndung'u, A. Gemechu, S. Bhavani, J.A. Anderson, and M.N. Rouse. 2024. The genetics of Ug99 stem rust resistance in spring wheat variety 'Linkert'. Front. Plant Sci. 15:1343148. doi: 10.3389/fpls.2024.1343148

ElDoliefy, A.E., J.A. Anderson, K.D. Glover, E.M. Elias, H.A. Ashry, I.M. ElZahaby, and M. Mergoum. 2024. Mapping of main and hidden epistatic QTL effects in spring wheat population using medium parental FHB resistance. Discover Plants https://doi.org/10.1007/s44372-024-00001-6

Identification of Bacterial Leaf Streak (BLS) Resistance in Minnesota Germplasm

Principal Investigator(s): Rebecca Curland, James Anderson, and Ruth Dill-Macky
Research Staff: Emily Conley

Project Period: Jan. 1, 2024-Dec. 31, 2024

Research Question/Objectives:

Since its re-emergence in the late 2000s, bacterial leaf streak (BLS) has posed a persistent challenge to wheat production in Minnesota. Caused by the pathogen Xanthomonas translucens pv. undulosa, BLS symptoms first appear as greasy, water-soaked lesions on leaves, which then progress to chlorotic and necrotic patches (Fig. 1A). In some instances, a condition known as "black chaff" can develop, leading to darkening of the glumes (Fig. 1B). This damage to leaf tissue compromises grain fill, often resulting in significant yield losses. With no available cultural practices or effective chemical controls for BLS, the most promising approach for managing this disease lies in identifying and deploying BLS-resistant wheat varieties.

Genome-wide association studies (GWAS), allow researchers to find associations between specific DNA markers and genes controlling important traits, such as disease resistance. In GWAS, a panel of lines is sent for DNA sequencing to identify DNA markers throughout the whole genome. Then, the panel is field-tested for traits of interest, and each DNA marker is tested to determine if it is significantly associated with the trait. Once we know which markers are associated with a trait, we can use them in marker-assisted selection (MAS). The MAS markers help breeding programs choose parent plants or decide which plants in a new breeding population to advance for further testing. This allows us to focus on the most promising lines early in the breeding process, giving us a better chance of developing high-yielding, disease-resistant varieties.

In this project, we screened 74 hard red spring (HRS) wheat lines from the Minnesota wheat breeding program for BLS nurseries at two Minnesota locations, St. Paul and Crookston, to complete phenotyping for a genome-wide association study (GWAS). We combined this data with historical phenotypic and genotypic data, then performed GWAS on 188 HRS wheat lines to identify genomic regions associated with resistance to BLS. Additionally, we screened a biparental mapping population of 95 lines, derived from a cross between a resistant and a susceptible parent, along with both parents, in St. Paul and Crookston to map BLS resistance in this population.

Results:

Wheat BLS GWAS Panel Genotyping Results: Genotyping-by-Sequencing (GBS) of the 74 new UMN wheat lines in the Wheat BLS GWAS Panel produced over 4,000 high-quality SNP markers across the genome. After merging this new data with our previous dataset of 114 lines and retaining the common markers, the final dataset includes 188 wheat lines and 3,333 SNP markers. These markers provide coverage across all chromosomes. A marker count of 3,000 is generally targeted for achieving good genome coverage in GWAS, so this panel meets coverage expectations.

The GWAS analysis identified 11 significant marker-trait associations (MTAs), representing eight unique genomic regions associated with BLS resistance. Of these regions, three had been identified in our preliminary screening last year, while five were newly detected in this expanded panel. Two regions identified in the previous analysis were not significant in the expanded dataset. A summary of these eight unique regions, including their chromosomal locations and allele frequencies, is presented in Table 1.

The GWAS analysis also showed a significant linear relationship between the number of favorable alleles and reduced BLS disease severity, as illustrated in Figure 2. The model's adjusted R^2 value of 0.36 indicates a moderate association, suggesting that the accumulation of favorable alleles contributes meaningfully to BLS resistance, with each additional allele providing incremental protection against the disease. This highlights the potential of these markers to inform breeding for BLS resistance.

Application/Use:

The identified marker-trait associations provide practical tools to breed for BLS resistance in wheat. The genomic regions identified can be used to screen breeding parents for favorable alleles, allowing breeders to select parents with more favorable alleles to maximize BLS resistance in future generations. Additionally, early-generation breeding populations can be enriched for BLS resistance by selecting individuals with higher counts of favorable alleles before phenotypic disease screening and yield trials. This approach enables breeders to focus resources on populations with enhanced genetic potential for BLS resistance, which can help accelerate progress toward developing more resistant wheat varieties. By integrating these markers into the breeding pipeline, programs can achieve more efficient and targeted improvements in BLS resistance. We have already screened our Fall 2024 Crossing Parents with MAS markers designed from the MTAs identified last year. We are in the process of designing and validating MAS markers designed from the newly discovered genomic regions.

Materials and Methods:
Phenotyping: Nurseries were planted in St. Paul on April 24, 2024, and in Crookston on May 22, 2024. Within each nursery site, wheat lines were planted in two replicates. Plots in St. Paul were inoculated on June 18 and in Crookston on July 2, and disease severity ratings were collected 3 weeks post inoculation. We compiled phenotypic data from our cooperative BLS screening nursery (dating back to 2013), naturally infected breeding plots across the state and performed two years additional phenotyping for lines with low number of data points from past testing.

To enable a genome-wide association study (GWAS) for BLS resistance, phenotypic data from all testing environments between 2013 and 2024 were analyzed together. A best linear unbiased prediction (BLUP) was calculated for each wheat line, which allowed for the integration of historical data across years, even though different lines were tested in different years and environments. BLUPs provide an estimate of each line's genetic value, adjusting for inconsistencies in testing conditions.

Genotyping:
Genotyping by sequencing (GBS) uses next-generation DNA sequence technology to obtain single nucleotide polymorphism (SNP) markers across the entire genome. It is a fast and cost-effective method to genotype mapping panels with thousands of DNA markers that can be used in GWAS. GBS was performed at the University of Minnesota's Genomics Center using the AVITI platform by Element Biosciences.

Association mapping was conducted using GAPIT software (Wang and Zhang, 2021), which evaluated each DNA marker for its association with BLS disease severity. Five statistical models were applied to ensure robustness in the detection of significant associations.

Economic Benefit to a Typical 500 Acre Wheat Enterprise:
The genetic markers identified in this study provide wheat breeders with tools to improve BLS resistance more efficiently and effectively. For a typical 500-acre wheat enterprise, the use of resistant varieties can lead to direct economic benefits by reducing yield loss from BLS disease. We have already begun screening our Fall 2024 crossing parents using Marker-Assisted Selection (MAS) markers developed from MTAs identified last year, and we are in the process of designing and validating additional markers from the newly discovered genomic regions. By incorporating these MAS markers into breeding programs, wheat enterprises can benefit from a faster path to more resistant varieties, thereby reducing BLS disease-related losses. The use of genetic markers in parent selection can provide growers with access to new wheat lines that are more resilient to BLS, ultimately improving profitability and reducing economic risks associated with BLS disease outbreaks.

Related Research:
Since 2013, the University of Minnesota's Small Grains Pathology lab has coordinated a cooperative bacterial leaf streak screening nursery with North Dakota State University and South Dakota State University. Trials are conducted each growing season at four locations: St. Paul and Crookston, MN; Fargo, ND; and Brookings, SD. These trials generate valuable data on BLS susceptibility and resistance across a range of wheat varieties under different environmental conditions. The historical phenotypic data collected from these nurseries played an essential role in the GWAS conducted in this project, enabling robust identification of regions associated with BLS resistance.

Recommended Future Research:
The genotypic data collected for this study can be used to train genomic prediction models for BLS resistance, providing breeders with a predictive tool to estimate BLS resistance in early-generation breeding populations. Preliminary testing of these models has shown promising results. Additionally, further validation of the MTAs identified in this study is needed to confirm their effectiveness across various genetic backgrounds. Identifying candidate genes within these associated regions could provide insights into the biological mechanisms underlying BLS resistance, supporting more targeted breeding efforts.

We have also completed genotyping the bi-parental mapping population, consisting of 97 lines (95 RILs plus two parents) and over 5,000 markers. Mapping within this population is underway and may provide further validation of the MTAs discovered in the GWAS panel. Any regions found to be consistent across both populations will strengthen the validity of these MTAs and be included in our GWAS publication, anticipated for journal submission in Spring 2025. Future research will aim to incorporate these findings into breeding pipelines to develop BLS-resistant wheat varieties tailored to regional growing conditions.

References:

Wang, Jiabo, and Zhiwu Zhang. 2021. "GAPIT version 3: boosting power and accuracy for genomic association and prediction." Genomics, Proteomics and Bioinformatics 19: 629-640.

Publications:

We anticipate submitting a manuscript detailing this work to the peer-reviewed journal Plant Disease in 2025.

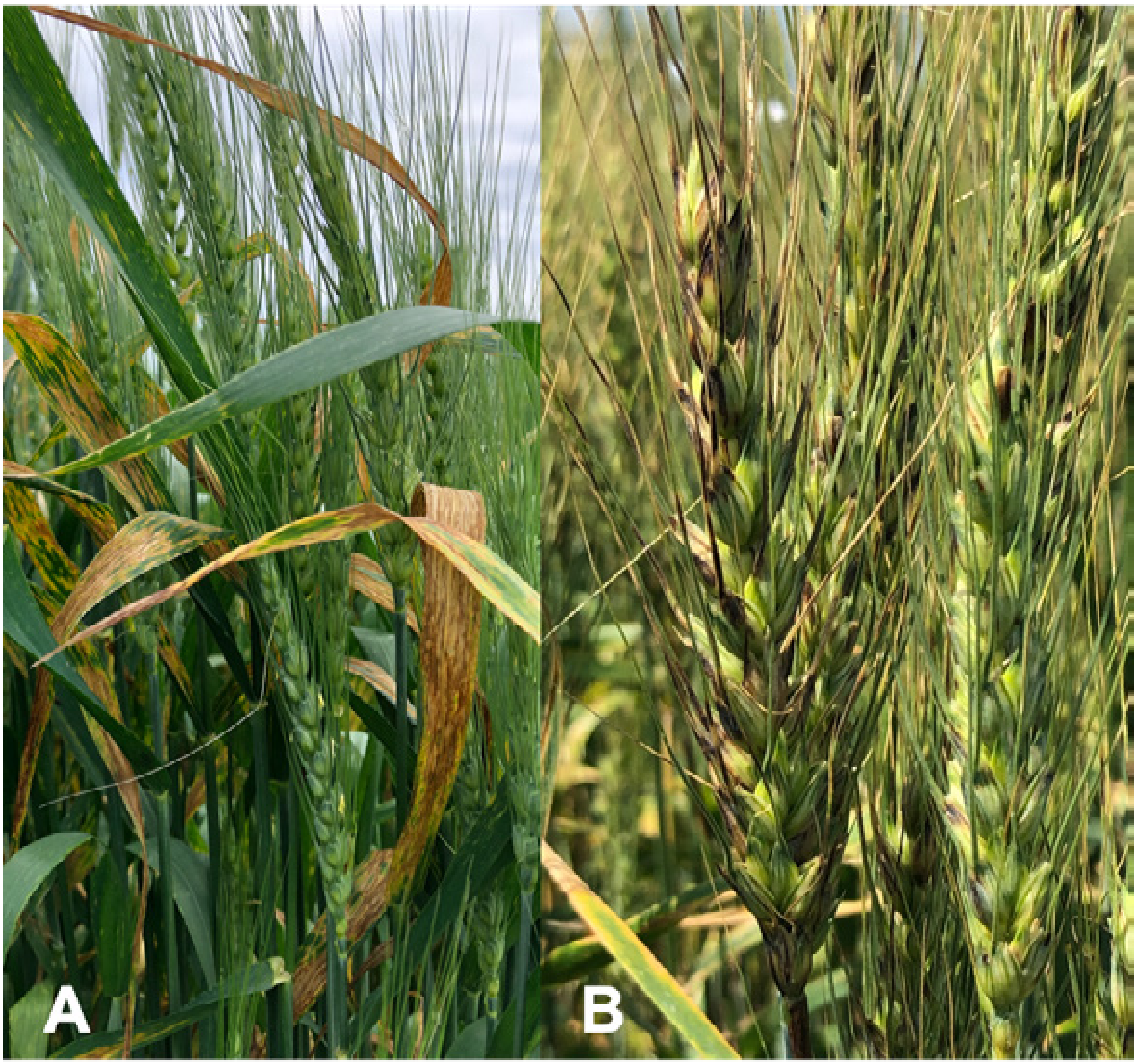


Figure 1. Bacterial leaf streak (BLS) foliar symptoms: lesions coalesce and become chlorotic and necrotic (A). In some advanced BLS infections black chaff symptoms occur, observed as a darkening of the glumes and banding on the awns (B).

Table 1. Wheat genomic regions associated with BLS resistance. Regions of the wheat genome associated with resistance to Bacterial Leaf Streak (BLS) disease. Each BLS-associated region represents a grouping of DNA markers identified through genome analysis. The chromosome location and approximate position on the chromosome of each region is provided, along with the average frequency of the favorable allele and the estimated reduction in BLS severity associated with that region. Higher frequencies indicate that the favorable allele is more common in the population. This information helps identify genetic regions that may be targeted in breeding programs to enhance BLS resistance in wheat varieties.

BLS-Associated region	Chromosome	Approximate position	Frequency of favorable marker genotype	Estimated BLS Reduction (%)
BLS_1D.1	1D	12 Mb	0.81	4.1
BLS_5B.1	5B	550-556 Mb	0.59	4.5
BLS_5B.2	5B	699 Mb	0.33	5.1
BLS_6A.1	6A	10.3 Mb	0.18	8.8
BLS_6A.2	6A	26.3 Mb	0.14	7.1
BLS_6A.3	6A	585 Mb	0.05	6.9
BLS_6B.1	6B	304 Mb	0.34	4.7
BLS_7A.1	7A	52 Mb	0.14	5.3

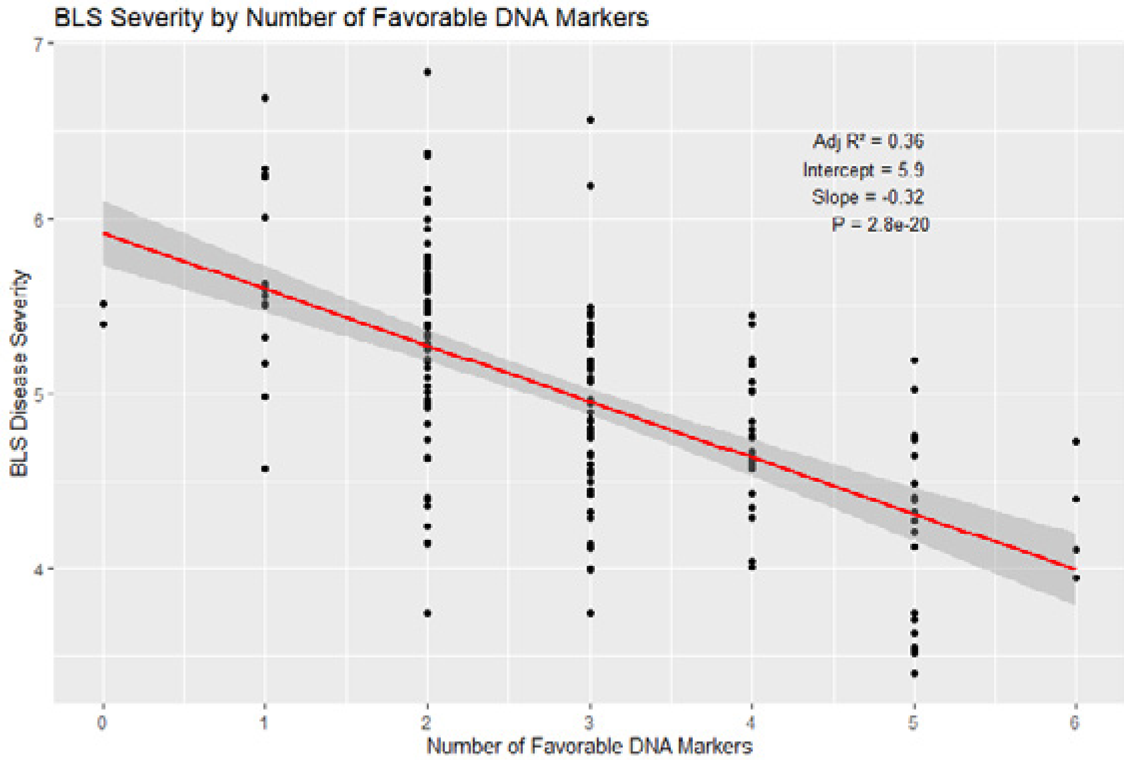


Figure 2. BLS Severity by Number of Favorable DNA Markers: This figure illustrates the relationship between the number of favorable DNA markers and the severity of Bacterial Leaf Streak (BLS) disease in wheat. The x-axis represents the count of favorable DNA markers identified in the GWAS, while the y-axis shows BLS disease severity. The red regression line indicates a moderate linear relationship, suggesting that an increase in the number of favorable alleles is associated with significant reductions in BLS disease severities. The model's adjusted R^2, intercept, slope, and p-value (shown on the graph) indicate the usefulness of these markers to select breeding lines with greater BLS resistance.

Wheat Stem Sawfly Resistance Screening

Principal Investigator(s): Jochum J. Wiersma and James. A. Anderson
Project Period: January 1, 2024-December 31, 2024

Research Question/Objectives: Evaluate current, adapted HRSW varieties for stem solidness.

Results:
Historically breeders have scored stem solidness at or near harvest ripe. The discovery of the WB Gunnison derived stem solidness trait (Cook et al. 2019), which is transitional in nature and present only during stem elongation, made this timing to score stem solidness mute. Therefore, we implemented a new protocol this past growing season to score for stem solidness/presence of a pith. Using a hedge trimmer, all stems in one foot of row were cut halfway the length of the second internode on June 27 and again on July 8. Stem solidness was scored as either no pith present (0), a partial pith (1), or a full pith (2) in the majority of stems. Expression of stem solidness is both positional and environmental dependent, meaning that tillers tend not to express stem solidness as well as main stems and that cooler conditions tend to reduce expression of the stem solidness trait. Based on pedigree alone, we did not expect any HRSW varieties entered in this year's yield trials to have solid stems at either Feekes 6 or Feekes 8. Twenty-four HRSW varieties had a median score of 2 across the three replications at Feekes 6, meaning that the majority of stems had a solid pith present at the midpoint of the second node at Feekes 6. All varieties scored as having either a hollow or a partial pith at Feekes 8. This year's data suggest that there may be additional alleles or QTLs for stem solidness (Table 1).

Application/Use:
None (too early to draw any solid conclusions)

Economic Benefit to a Typical 500 Acre Wheat Enterprise: The expansion of the area where WSS can readily be found is a concern. Economic losses because of a slowdown when combining are, at this point, largely limited to the first 120 feet of field edges as long as wheat following wheat is avoided.

Related Research: None

Recommended Future Research: The protocol that was adopted this past summer makes screening of the current HRSW varieties for stem solidness much easier and faster as it relies not on the presence of the insect yet allows for the determination of stem solidness when it matters in the life cycle of the insect. The first timing at Feekes 6 is just around the time egg laying occurs, while the second timing coincides when stem elongation is nearly complete. We therefore plan to continue to screen all varieties that are entered in the variety trials in the same manner in future years w/o a supplemental request for funding. The additional benefit of this approach is that all entries can be screened compared to screening with the molecular marker for the Qss.msub-3BL.c QTL associated with the WSS resistance expressed in WB Gunnison which is limited to these entries for which permission to screen with the marker was granted.

References:
Cook, J.P., Weaver, D.K., Varella, A.C., Sherman, J.D., Hofland, M.L., Heo, H.-Y., Caron, C., Lamb, P.F., Blake, N.K. and Talbert, L.E. 2019). Comparison of Three Alleles at a Major Solid Stem QTL for Wheat Stem Sawfly Resistance and Agronomic Performance in Hexaploid Wheat. Crop Science, 59: 1639-1647. https://doi.org/10.2135/cropsci2019.01.0009

Publications: None

Table 1 – Predicted stem pith type based on stem cutting of first internode at midpoint when entries in the 2024 HRSW variety trials reached the Feekes 6 and Feekes 8 growth stages.

Entry	Median for Score1	Median for Score2	Predicted Stem Pith Type
AP Elevate	2.0	1.0	Transitional
AP Gunsmoke CL2	1.0	0.0	Hollow
AP Murdock	2.0	0.0	Transitional
AP Smith	1.0	1.0	Hollow
Ascend-SD	2.0	0.0	Transitional
Brawn-SD	1.0	1.0	Hollow
CAG Ceres	1.0	0.0	Hollow
CAG Justify	1.0	1.0	Hollow
CAG Reckless	2.0	1.0	Transitional
CAG Recoil	1.0	0.0	Hollow
CP3055	1.0	1.0	Hollow
CP3099A	0.0	1.0	Hollow
CP3188	1.0	1.0	Hollow
CP3322	0.0	0.0	Hollow
CP3360AX	2.0	1.0	Transitional
CP3915	1.0	1.0	Hollow
Driver	0.5	0.0	Hollow
Dyna-Gro 8582	2.0	0.0	Transitional
Dyna-Gro Ambush	2.0	1.0	Transitional
Dyna-Gro Ballistic	2.0	1.0	Transitional
Dyna-Gro Commander	1.0	0.0	Hollow
Dyna-Gro Rocker	1.0	1.0	Hollow
LCS Ascent	1.0	0.0	Hollow
LCS Boom	2.0	1.0	Transitional
LCS Buster	2.0	1.0	Transitional
LCS Cannon	1.0	0.0	Hollow
LCS Dual	2.0	0.0	Transitional
LCS Hammer AX	2.0	1.0	Transitional
LCS Trigger	1.0	0.0	Hollow
Linkert	1.0	0.0	Hollow
Marshall	2.0	1.0	Transitional
MN-Rothsay	1.0	1.0	Hollow
MN-Torgy	1.0	0.0	Hollow
MS Charger	2.0	0.0	Transitional
MS Cobra	2.0	0.0	Transitional
ND Heron	2.0	0.0	Transitional
ND Stampede	2.0	1.0	Transitional
ND Thresher	1.0	0.0	Hollow
PFS Buns	1.0	1.0	Hollow
PFS Rolls	2.0	1.0	Transitional
SD4905	2.0	0.0	Transitional
Shelly	1.0	1.0	Hollow
SY 611 CL2	2.0	1.0	Transitional
SY Valda	1.0	0.0	Hollow
TCG-Badlands	2.0	0.0	Transitional
TCG-Teddy	2.0	1.0	Transitional
TCG-Wildcat	2.0	0.0	Transitional
TCG-Zelda	2.0	0.0	Transitional
TW Olympic	1.0	0.0	Hollow
TW Starlite	0.0	1.0	Hollow
TW Trailfire	1.0	0.0	Hollow
WB9479	0.0	1.0	Hollow
WB9590	1.0	1.0	Hollow

Southern Minnesota Small Grains Research and Outreach Project

Principal Investigator(s): Dr. Jochum J. Wiersma

Project Period: January 1, 2024-December 31, 2024

Research Question/Objectives:
The objectives of this grant were to:

Evaluate variety performance for Hard Red Spring Wheat (HRSW) and Hard Red Winter Wheat (HRWW) varieties across southern Minnesota with locations at Becker, Benson, Le Center and Rochester.
Organize extension programming for small grain production and management in southern Minnesota using summer field days and winter meetings.

Results:
The winter extension programming for small grains production and management in central and southern Minnesota were held in Morris, Le Center, Rochester, Slayton and Benson in 2024. Each workshop had a regional focus. Attendance totaled about 150 people across these five locations. The very dry fall had more growers interested in switching corn acres to small grains. Field days to showcase the variety trials were held at the trials near Rochester, Le Center and Benson. Attendance totaled 75.

A summary of the attained grain yield of the HRSW and HRWW variety trial results can be found in tables 1 and 2. The average yield across the southern Minnesota locations reported at the time of writing was 76 bu/acre for HRWW (4 locations) and 66 bu/acre for HRSW (5 locations). Plots were also used as sentinel plots to monitor disease and insect pests during the growing season (In conjunction with the Minnesota Small Grains Pest Survey).

Application/Use:
Central and southern Minnesota have not had large small grain acreages in recent decades. Small grains have often been grown in this region for reasons other than maximized production, such as manure applications, straw production, forage/cover-crop establishment or tiling projects. The combination of weed and insect resistance issues, and interest in diversifying crop rotations to improve soil health has inspired more farmers in these regions to consider growing small grains. Our research and demonstration plots have documented the ability to grow small grains in central and southern Minnesota with high yield and quality that can maximize profitability. Our results have been echoed by reports from farmers in these regions who utilize advanced management tools and genetics despite the added production risks of heat and disease stressors that are more prevalent in southern Minnesota.

Materials and Methods:
The winter wheat and rye variety trials had 29 and 14 released varieties as entries, respectively. The spring wheat, oats and barley variety trials had 51, 20, and 14 released varieties amongst the entries, respectively. Trials were all a randomized complete block design with either three or four replications. Field preparations and fertility management were completed by plot cooperators and represented typical production practices. Planting, weed control, data collection and harvest were completed by the research group.

Economic Benefit to a Typical 500 Acre Wheat Enterprise:
Variety selection is one of the most critical decisions made on a wheat enterprise. A well-adapted versus a poorly-adapted variety can be the difference in farm profitability. In 2024, there was a 22 bu/acre difference between the highest-yielding 10% of varieties and the lowest-yielding 10% of varieties in the HRSW variety trials across the five southern Minnesota locations. This larger-than-normal difference was not just a function of differences in yield potential but more so by the differences in susceptibility to stripe rust, stem rus and Fusarium head blight. This 22 bu/acre difference in yield could increase returns by over $130 per acre, or $66,000 in gross returns for a 500-acre wheat enterprise. All while only changing variety selection. Variety trials are especially valuable in southern Minnesota, where variety trial information is otherwise limited. The ability to recommend varieties adapted to southern Minnesota as well as for farmers to see varieties firsthand before planting them has an invaluable impact on current and future wheat farmers in southern Minnesota. These trials also influence the spring wheat, barley and oat breeding programs at the University of Minnesota, by allowing on-farm assessments of yield, disease, lodging and other agronomic characteristics that are used to influence future varietal releases and agronomic ratings. These factors further add to the long-term impact that this project has on a typical wheat farm in Minnesota.

Related Research:
This research is integrally linked with the small grain breeding programs at the University of Minnesota. The spring wheat, barley and oat breeding programs utilize the data generated in these trials as part of their southern small grain variety performance evaluations, which expands the geographical coverage of small grain variety trials as well as provides on-farm credibility to the variety evaluations. Likewise, the winter rye variety trials are co-located at a number of southern locations too.

Recommended Future Research:
Variety trial data is much more valuable when it is aggregated with ongoing variety trials. Just because a variety performed well one year does not mean it will repeat the same in the future. Variety selections should be based on multiple years of data from multiple locations. This is why these variety trials should be continued into the future so that farmers can continue to refine their variety selections as new genetics become available.

References:

Publications:
Results of yield trials for spring and winter wheat, barley, oats and winter rye are part of the variety trial results that will be published in the online publication Minnesota Field Crop Variety Trials (https://varietytrials.umn.edu/). The 2023 trial results were published in:

Anderson J.A. et al. 2023. Hard Red Spring Wheat. In: 2023 Minnesota Field Crop Variety Trials (varietytrials.umn.edu). Minnesota Agricultural Experiment Station. University of Minnesota, St. Paul, MN.
Smith, K. et al. 2023. Barley. In: 2023 Minnesota Field Crop Variety Trials (varietytrials.umn.edu). Minnesota Agricultural Experiment Station. University of Minnesota, St. Paul, MN.
Smith K. et al. 2023. Oat. In: 2023 Minnesota Field Crop Variety Trials (varietytrials.umn.edu). Minnesota Agricultural Experiment Station. University of Minnesota, St. Paul, MN.
Wiersma, J.J. 2023 Winter Rye. In: 2023 Minnesota Field Crop Variety Trials (varietytrials.umn.edu). Minnesota Agricultural Experiment Station. University of Minnesota, St. Paul, MN.
Wiersma, J.J. et al. 2023 Winter Wheat. In: 2023 Minnesota Field Crop Variety Trials (varietytrials.umn.edu). Minnesota Agricultural Experiment Station. University of Minnesota, St. Paul, MN.

Table 1 - Summary of grain yield of spring wheat varieties tested in performance evaluations in six locations across southern Minnesota in 2024.

Entry	Becker (irrigated)	Benson	Lamberton	Le Center	St. Paul	Average
	(bu/acre)	(bu/acre)	(bu/acre)	(bu/acre)	(bu/acre)	(bu/acre)
AP Gunsmoke CL2	58.9	80.0	52.8	62.5	52.3	68.4
AP Murdock	60.0	92.0	63.9	73.1	70.4	61.3
AP Smith	59.0	88.6	46.7	72.0	69.1	71.9
Ascend-SD	58.6	96.8	66.5	69.9	77.8	67.1
Brawn-SD	62.7	95.3	56.2	73.4	61.1	73.9
CAG Justify	60.8	95.3	57.5	60.6	71.6	69.8
CAG Reckless	54.6	92.3	60.9	72.2	65.9	70.0
CAG Recoil	58.6	83.2	53.2	65.3	66.9	69.2
CP3099A	56.4	83.9	37.5	44.7	28.1	69.2
CP3188	55.0	92.4	48.4	65.8	66.5	65.5
CP3322	39.3	76.3	36.4	41.1	52.1	67.0
CP3915	60.7	95.5	48.4	60.6	66.2	50.1
Driver	57.1	79.2	46.8	58.3	69.4	65.6
Dyna-Gro Ambush	56.6	85.9	63.0	70.4	66.8	49.0
Dyna-Gro Ballistic	68.1	97.5	56.7	75.5	67.7	76.8
Dyna-Gro Commander	61.8	92.0	63.6	80.3	71.7	66.3
LCS Ascent	60.7	98.2	68.2	71.5	62.9	62.2
LCS Boom	62.4	87.9	65.8	65.3	74.5	74.0
LCS Buster	54.2	101.0	59.0	56.0	62.5	68.5
LCS Cannon	63.0	87.3	63.8	67.0	72.3	73.1
LCS Dual	52.6	85.1	53.2	63.8	51.0	73.9
LCS Trigger	60.2	104.5	72.1	70.4	79.4	48.0
Linkert	49.5	76.8	50.3	60.1	61.5	72.3
MN-Rothsay	51.1	90.2	50.0	58.9	70.5	71.2
MN-Torgy	59.5	92.2	57.5	68.2	68.4	66.5
MS Charger	57.2	98.9	70.9	73.6	68.6	70.7
MS Cobra	57.0	84.4	51.5	63.1	67.0	61.1
ND Heron	58.7	83.9	60.3	62.5	62.1	57.0
ND Stampede	56.4	95.6	61.9	75.3	81.5	77.3
PFS Buns	47.9	102.0	50.8	64.1	63.7	59.6
Shelly	51.7	88.1	49.9	64.4	66.8	64.1
SY 611 CL2	61.7	87.3	56.5	70.0	60.5	69.1
SY Valda	55.6	97.3	62.2	76.4	77.4	73.8
TCG-Teddy	55.9	75.4	46.1	60.7	62.5	64.6
TCG-Wildcat	53.8	82.5	39.5	55.9	74.1	65.5
WB9479	55.4	77.8	55.6	65.3	57.1	74.1
WB9590	59.3	88.6	58.9	74.0	60.3	67.1
AP Elevate	56.4	92.9	55.0	74.1	63.6	65.7
CAG Ceres	62.9	83.8	62.1	72.7	68.7	65.8
CP3055	57.1	93.1	54.9	66.1	63.9	64.2
CP3360AX	66.6	94.2	66.1	74.5	82.5	67.2
Dyna-Gro 8582	57.7	89.7	70.6	71.4	80.7	73.8
Dyna-Gro Rocker	59.8	68.0	26.6	40.2	45.3	65.4
LCS Hammer AX	56.6	69.2	44.5	58.5	56.0	60.1
ND Thresher	54.0	96.2	53.6	64.1	67.3	61.1
PFS Rolls	59.0	87.1	50.0	63.0	70.2	68.3
TCG-Badlands	60.6	87.4	46.5	64.6	67.9	69.9
TCG-Zelda	69.3	85.7	47.1	69.8	69.7	65.8
TW Olympic	58.8	91.0	59.0	68.8	71.7	70.4
TW Starlite	52.5	91.0	58.5	56.2	70.6	62.3
TW Trailfire	58.0	81.1	68.8	74.0	70.2	68.2
Mean (bu/acre)	**55.8**	**87.7**	**53.7**	**63.8**	**66.9**	**65.6**
LSD (0.1)	**4.1**	**6.1**	**3.2**	**4.0**	**4.7**	**3.3**

Table 2 - Summary of grain yield of winter wheat varieties tested in performance evaluations in four locations across southern Minnesota in 2024.

Entry	Becker (irrigated)	Lamberton	LeCenter	St. Paul	Average
	(bu/acre)	(bu/acre)	(bu/acre)	(bu/acre)	(bu/acre)
AAC Vortex	79.9	75.3	103.2	102.0	80.1
AC Emerson	62.8	62.6	92.3	97.3	67.4
AP Bigfoot	70.4	37.6	108.9	130.9	77.8
FourOSix	69.6	67.1	93.1	93.4	73.1
Jupiter[1]	76.1	47.9	101.6	115.3	80.9
Keldin	85.7	79.2	110.0	123.0	96.3
LCS Radar	72.2	22.6	116.4	117.8	72.8
LCS SteelAX[2]	77.7	56.5	102.8	122.9	83.3
LCS WarbirdAX[2]	68.1	35.3	109.9	129.9	71.5
MS Sundown	73.1	34.1	117.4	121.4	71.9
ND Noreen	72.9	66.6	98.0	102.2	73.6
SD Andes	74.6	69.0	110.8	124.4	75.6
SD Midland	74.5	67.9	115.4	119.6	75.5
SD Pheasant	77.5	55.7	92.8	120.7	75.6
SY Wolverine	58.6	37.2	100.0	116.2	68.6
Viking 211	68.4	59.3	95.6	114.9	75.4
WarCat	76.6	56.8	89.2	93.5	76.7
WB4309	69.6	50.1	107.6	125.7	80.7
WB4422	65.7	56.1	97.9	129.2	65.7
Winner	76.3	69.0	111.5	111.3	83.5
Mean (bu/acre)	**72.5**	**55.3**	**103.7**	**115.6**	**76.3**
LSD(0.1)	**8.1**	**11.0**	**10.0**		**9.9**

[1] Soft white winter wheat
[2] CoAXium wheat varieties tolerant to Aggressor AX herbicide

Resubmission: Utilization of Wheat Fertility Trials to Enhance Educational Opportunities for Future Ag Professionals

Principal Investigator(s): Adam Alford Ph.D., Elliot Vaughan Ph.D.

Project Period: January 1, 2024-December 31, 2024

Research Question/Objectives:
Objective 1: Demonstrate how varying rates of N fertilizer (soil and foliar) impact wheat growth rates, canopy development (quantified via drone photography), final yield, and the overall protein content of the grain for educational purposes.

Objective 2: Familiarize Southwest Minnesota State University (SMSU) agriculture students (along with the intern hired to conduct this work) with wheat production practices and provide hands-on learning opportunities and data for the SMSU agriculture curriculum using the wheat plots this project funds.

Trt #	Variety	Total Season N	Lab Quant Protein %	Lab Quant Fat %	Lab Quant Carb %
1	Linkert	90	16.39a	0.95a	64.95a
2	Linkert	120	16.45a	0.99a	64.60a
3	Linkert	150	16.28a	0.87a	63.36b
4	Torg	120	16.11a	1.14a	65.36a

Results:
Objective 1:
By altering the amount of N fertilizer (ranging from 90-150 lbs/acre) we applied to our wheat plots, we were able to impact the wheat grain quality. (Carbs: F3,20: 6.751, p-value=0.003 /Fat: F3,20: 1.233, p-value=0.324 /Protein: F3,20: 0.092, p-value=0.45). While there was no effect of fertility on protein, there was an impact on the amount of carbs produced indicating a slight possible yield drain associated with the higher 150 rate of N. Regardless, this yield drag did not manifest at the treatment level and all plots yielded similarly regardless of treatment (F3,17: 1.085, p-value=0.382) or block (F3,17: 2.056, p-value=0.144). The average yield across the plot was 61.11 bu/acre with a standard deviation of 13 bu/acre. Our wheat farmer collaborator also had a similar wheat yield average of 55 bu/acre.

When we analyzed our data for canopy coverage, all treatments had similar canopies by 51 days post plant. Within the first 44 days post plant, the Torgy variety consistently had higher canopy coverages despite being planted as the same density as Linkert treatments indicating a varietal impact on canopy. Minor differences were observed in the Linkert treatments, but no consistency was found across N levels.

			Percent of canopy closed by XX days post planting:					
Trt	**Variety**	**Total N**	**30 days**	**37 days**	**44 days**	**51 days**	**58 days**	**64 days**
1	Linkert	90	24.28ab	41.07b	48.63b	81.22a	85.55a	96.03a
2	Linkert	120	24.85ab	45.41ab	52.19b	81.22a	84.87a	95.03a
3	Linkert	150	22.41b	42.55ab	52.32b	78.84a	85.32a	94.44a
4	Torgy	120	30.61a	49.59a	60.87a	79.92a	86.16a	96.26a

At the time of this updates writing, soil samples are currently being analyzed and we are awaiting the data.

There was no significant difference in soil respiration between the different fertilizer application rates or wheat varieties (Fig. 1, $p = 0.99$). There was a significant change in soil respiration through the course of the growing season ($p < 0.00001$), with the highest CO_2 fluxes observed in June and July.The lack of a fertilizer effect can be linked to the lack of a yield difference in the wheat in the same plots, suggesting no significant difference in plant root respiration or microbial response. The seasonal pattern indicates increased plant root and microbial activity during the growing season, and rates were higher than last growing season likely due to an increase in rainfall and soil moisture this year.

Soil nutrients (N, P, and K) generally increased between the spring and fall, and N in particular was higher post-harvest in the plots receiving increased levels of N fertilizer. However, due to variability between plots, this difference was not statistically significant in soil N ($p = 0.37$), P ($p = 0.82$), or K ($p = 0.99$). Compared to last growing season, much less N remained in the soil post-harvest indicating that much of the fertilizer added to fields was either taken up by plants or otherwise lost. This is in contrast to last growing season when very dry conditions prevented the uptake of a significant amount of applied fertilizer.

Treatment	Nitrogen (lbs/ac)	Phosphorus (ppm)	Potassium (ppm)	Soil Organic Matter (%)
Pre-Fertilization	*18*	*66*	*280*	*4.8*
90 lbs N - Linkert	22	71	284	4.75
120 lbs N - Linkert	52	66	285	4.73
120 lbs. N - Torgy	69	55	271	4.88
150 lbs N - Linkert	40	57	276	4.75

Objective 2:
While the experimental portion of this project provided some interesting results, we believe the main strength of this project is to familiarize individuals to wheat production. This project has reached hundreds of individuals, and increased their familiarity of wheat as a crop. The following is a list of direct visitors to the wheat plots, and future uses of data associated with this grant which will be used in classes.

Direct use and visitation of the wheat plots
90 people for the SMSU field day held in mid-July where attendees were introduced to the aims of the project and to wheat growing in general

25 Middle schoolers for SMSU's first annual ag camp. The purpose of the ag camp was to introduce middle schoolers to various aspects of Minnesotan ag, and while at the SMSU research farm they got to see some of the aspects of wheat production

6 additional middle schoolers who were doing community service. While weeding various plots they learned about wheat as a crop.

8 agronomy majors in AGRO 341 Principles of Pest Management scouted the wheat plots for insect and weed pests as an assignment, and saw how alteration of planting density (in our bulk wheat plot) allowed weed species to pop up.

14 students for AGRO 132 Principles of Crop Production in which we introduced ag majors to a wheat field, common weeds, pests, etc.

19 students in AGRO 212 Grain and Forage Crops were exposed to wheat growing through a class field trip and drone photos were displayed of how a lower planting density of wheat can lead to more weed pressure. Once soil analysis data is received, that will be presented in class as well.
18 agriculture students in AGRO 390 Introduction to Precision Agriculture used drone photos of wheat plots to demonstrate how canopy growth can be monitored and quantified via drone, and that lower stands of wheat can lead to increased incidence of weeds

19 non ag-major students in AGRO 250, Sustainable gardening who learned about wheat production, took a few samples, and learned about the cover crop value of wheat in a gardening setting.

7 interns who worked the plots in some way/shape/form

~15 People from the general public not affiliated with the school but just interested in Ag and asked for a plot tour

Future uses of data provided from the funding of this grant
In AGRO 332 Crop Quality and Traits (Spring 2026) we will have a demo where the students will grind the harvested wheat, and make pasta with it to help them understand how gliadin and glutenin combine into gluten during processing. Protein content will be demonstrated as well and related to workability of the dough.

In AGRO 454 Experimental Design (Spring 2025) grain quality and canopy coverage data will be used in a lab for teaching/reinforcing ANOVAs and coding in the R statistical programming language.

In ENVS 107 Introduction to ArcGIS (Spring 2025) soil quality parameters collected from the wheat field with different fertility regimens, will be paired with GPS data to demonstrate how field soil data can be mapped into a digital model.

Application/Use: The use of this project's data is primarily limited to educational purposes. SMSU is one of the few 4-year ag schools in MN so providing hands-on learning opportunities to the students is incredibly important in order to provide a well-educated and multi-experienced workforce. The many ways in which this project enhanced the educational experience at SMSU is described in the results section above.

Materials and Methods: In order to investigate and provide data on the role N-rates on canopy development, yield, and grain quality in hard red spring wheat, 6 treatments were created as follows

Trt #	Variety	Lbs of Preplant N	Lbs of Foliar N	Lbs of Preplant P	Lbs of Preplant K	# of Plots of this Trt
1	Linkert	90	0	23	30	4
2	Linkert	120	0	23	30	4
3	Linkert	150	0	23	30	4
4	Linkert	90	30	23	30	4
5	Linkert	120	30	23	30	4
6	Torgy	120	0	23	30	4

While we intended to apply 30 lbs of foliar N during flowering, we received large amounts of rain occurred during this time period and were unable to drive a tractor onto the field to make applications. This reduced the number of our treatments down to 4 as follows, as we incorporated treatments 4 and 5 into treatments 1 and 2 respectively:

Trt #	Variety	Lbs of Preplant N	Lbs of Preplant P	Lbs of Preplant K	# of Plots of this Trt
1	Linkert	90	23	30	8
2	Linkert	120	23	30	8
3	Linkert	150	23	30	4
4	Torg	120	23	30	4

Fertilizers were drop spread and shallowly incorporated 4/15/24, followed by a burndown application of MSO, Sharpen, and Cornerstone on 4/17/24. Wheat seed was planted on 4/16/24 at 2.75 million plants per acre on 7.5 inch rows with the aid of a local wheat farmer. All treatments were planted 4 times. Each experimental plot was 20' wide 60' long. Drone photos started on 5/15/24 and continued weekly until 7/9/24. On 5/11/24 plots were sprayed with Stinger at label rates to control a few Canada thistle outbreaks primarily on the South side of the plot. Harvest of wheat plots took place on 8/13/24 and yield was recorded with a weigh wagon.

To collect data on canopy coverage, drone photos were analyzed with the ImageJ software. The following photos (Figures 2-5 at the end of this update) demonstrate how that process occurs and is the same process we use to analyze photos in the AGRO 390 Introduction to Precision Agriculture class.

Economic Benefit to a Typical 500 Acre Wheat Enterprise:
While this grant does have an experimental component, the main strength, and main purpose of this project, is in its potential to provide educational experiences. Through the use of the award funds, SMSU has been able to increase wheat familiarity to hundreds of individuals, most of which are college students, in Southwest Minnesota. While wheat was historically a much more important crop to SWMN, not much wheat has been grown in SWMN since 2008 (Figure 1) and as such, many of the local residents and students lack any familiarity with wheat. This grant was put together to help bridge this gap, and increase students familiarity with wheat production systems. SMSU is one of the few MN universities with an Agronomy Major and our graduates go on to be the future crop scouts, consultants, product sales service, and researchers that our MN wheat farmers rely on. A broad and robust agricultural education during their college years will not only ensure they can identify and get the jobs best suited to their individual abilities, but once hired, will allow them to excel and help MN wheat growers to be agricultural leaders they always have been. When you have a better trained workforce, on-farm decisions come more quickly, and with more confidence.

Related Research:
Additional competitive grant funds were awarded from thee Minnesota Soybean Research & Promotion Council (MSR&PC), but that projects dealt with the influence of phosphate application on the impact of NDVI values to familiarize students with see-and-spray technologies. Another MSR&PC competitive grant was awarded to help prepare students for the CCA exam and to offset its cost. The final grant received by SMSU Agronomy was from Minnesota Corn Research & Promotion Council and the goal was to familiarize students to the impacts, and importance, of fertility. No other received grants overlapped with this one.

Recommended Future Research:
SMSU is largely an education school. We have a 50-acre research farm, but research is primarily conducted to help provide experiential learning opportunities to our students, and expose them to the research environment. While this project doesn't immediately have a follow up research question and project, we will continue to apply for funding from the Minnesota Wheat Research and Promotion council to continue providing educational opportunities to our students.

References:
Schneider, C.A., W.S. Rasband, and K.W. Eliceiri. 2012. NIH Image to ImageJ: 25 years of image analysis. Nature Methods 9: 671-675

Publications: None.

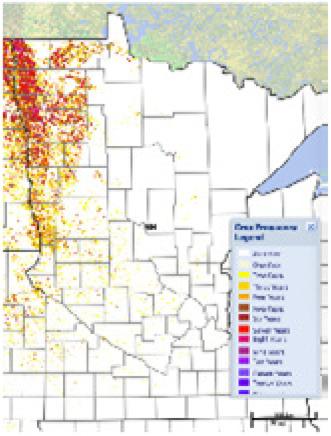


Figure 1 USDA CropScape data layer showing how many years wheat has been grown at a particular point from 2008-2022

Figure 2 An unmanipulated photo is visually analyzed to look for oddities that may impact the results of measuring the canopy. In the above photo, some Canada Thistle is present in the center top and center bottom of the photograph and it looks like there is some less dense canopy in the center of the plot. Our summer intern, Victoria Imafidor is standing on the southwest corner of this plot and is the one who took and processed these photos.

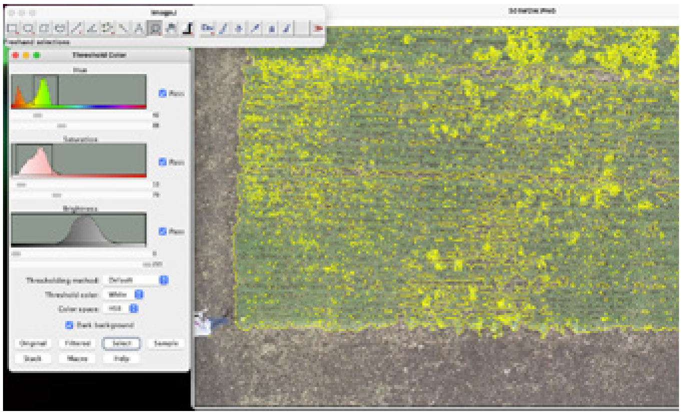


Figure 3 The photo is then loaded into the ImageJ program which allows the user to select all pixels of a certain shade of green. This allows the program to be able to discern the target plant (wheat green) from weeds (Canada Thistle green) and the surrounding soil. In this photo, the program is outlining all instances of wheat green in yellow.

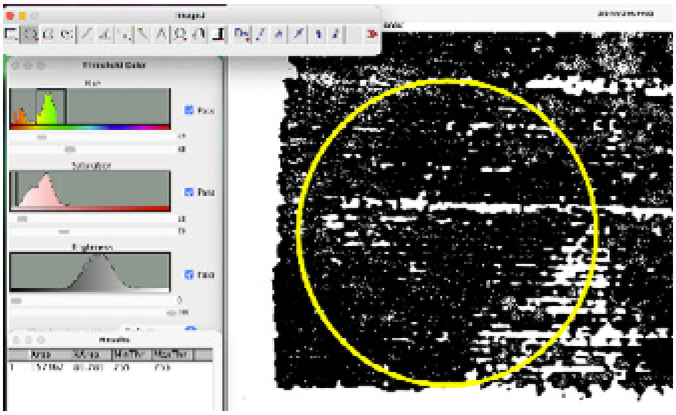


Figure 4 Finally, the image is ready to be analyzed! After all the wheat green is selected, the photo is converted to black and white. Wheat green is represented by black, and everything else including soil and Canada Thistles is represented by white. We then drew a circle at a random spot within the plot and with the program, calculated the % area covered by wheat. In this instance, wheat comprises 86.77% of the canopy space in the given yellow circle. We can also confirm a reduced wheat stand/canopy in the center bottom of the photograph, and if you look close enough, you'll see individual Canada thistle plants represented as white splotches in the photo.

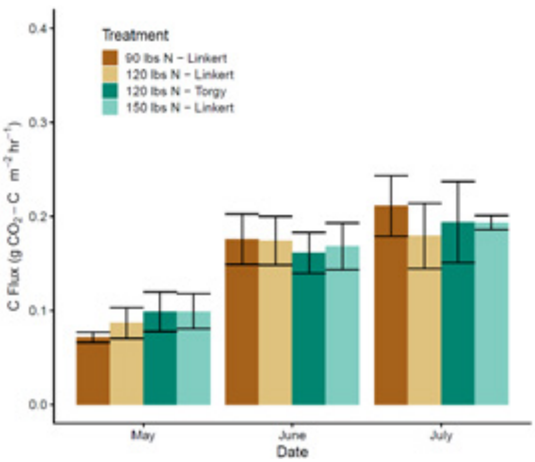


Figure 5. Soil respiration measured throughout growing season. There is no statistically significant difference by treatment ($p=0.99$), but there was significant increase by measurement date across all treatments ($p < 0.00001$).

Innovative Uses for Wheat Biomass: A New Income Path for Farmers

Principal Investigator(s): Srinivas Janaswamy

Overview:
Plastics are used for convenience in every household, but many are not appropriately recycled and are dumped everywhere around the globe. They take over 700 years to degrade, and the consequent perils are alarming. Plastic waste is a transboundary, complex, social, economic, and environmental problem that needs to be addressed effectively. Before worsening, meaningful methods of developing consumer-friendly packaging materials far from plastic are needed. Many countries around the globe have imposed restrictions on the use of plastics. Despite these concerted efforts, a pressing scientific need still exists to find alternatives to plastics. Toward this end, lignocellulose residue from renewable agricultural biomass, such as wheat, stands out as a viable option. It is biodegradable, has a low density with a strong and stiff structure, and meets the desirable qualities of plastics. However, the intrinsic structural functionality of plastics outweighs the lignocellulosic-based materials to create versatile products, mainly due to the higher structural flexibility. Instead, plant-based products tend to be more rigid, presumably having been mainly processed from the lignocellulosic segments, but their safely biocompatible nature and readily biodegradable properties make them potential alternatives. The primary source of lignocellulosic material is trees, and if harvested for any invention, their depletion will lead to deforestation, another severe environmental issue to be concerned about. In this regard, finding an alternative and sustainable lignocellulose source is a priority. To this end, agricultural biomass, e.g., wheat biomass - instead of trees - presents as a suitable source, which could be reformulated satisfactorily to replace plastics. This proposal is to develop value-added functional products such as biodegradable films by extracting lignocellulose from wheat biomass and solubilizing using the economical and versatile inorganic salt methodology developed by the PI. The flexibility of the films will be enhanced by complexing lignocellulose with proteins such as wheat gluten.

Research objectives:
(1) To extract and solubilize lignocellulose of wheat biomass, complex with wheat gluten, soy protein isolates, and whey protein isolate, and to understand the role of salts on the solution properties, and (2) To determine the tensile strength, elongation at break and water vapor permeability of films, and demonstrate the biodegradability in soil.

Accomplishments:
One graduate student, Mr. Sharad Bhattarai from Nepal, was recruited. He joined the program on August 5th, 2024. Since then, Sharad has extracted lignocellulose from wheat biomass. During initial experiments, we used 0.4 g of wheat lignocellulose, solubilized in 68% $ZnCl_2$ and crosslinked with 200 mM $CaCl_2$ and 1% Glycerol. Later, 5%, 10%, and 15% gluten were added. The results obtained are interesting. The addition of gluten affected both tensile strength and elongation at break. The 5% gluten addition yielded the film with a tensile strength of 40.1 MPa but with 3.8% elongation at break. Surprisingly, the rise of gluten to 10% reduced the tensile strength to 10.1 MPa, but with an increased 21.2% elongation at break. However, a further rise of gluten to 15% yielded the tensile strength of 46.5 MPa and 2.6% elongation at break. The gluten addition increased the water vapor permeability from 8.2×10^{-11} g.m-1.s-1.Pa-1 to 6.5×10^{-11} g.m-1.s-1.Pa-1 to 1.0×10^{-10} g.m-1.s-1.Pa-1, in the same gluten amount order. In a separate experiment, the crosslinking calcium ions amount of 500 mM and 5% gluten, the impact of 1% and 2% glycerol amount was studied. This resulted in 5.9 and 2.4 MPa tensile strength, 13.6% and 16.0% elongation at break, and 1.1×10^{-10} g.m-1.s-1.Pa-1 and 6.6×10^{-11} g.m-1.s-1.Pa-1. These results suggest the impact of gluten amount and the crosslinking of calcium ions and glycerol on the film properties. We obtained another

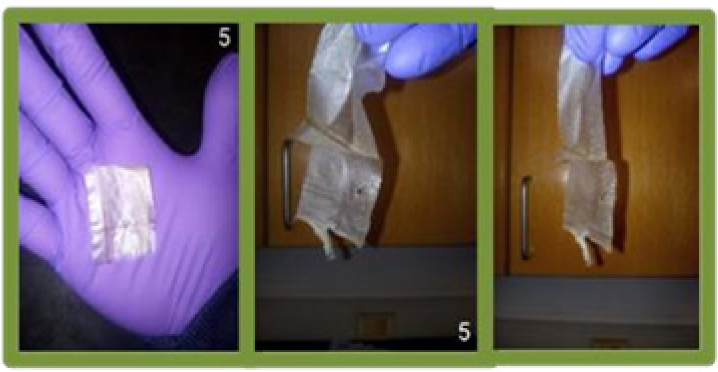


Fig. 1. The wheat biomass lignocellulose film with gluten (leftmost film) is heat sealable (middle and rightmost two film).

interesting result: the films prepared could be sealed with heat for the first time. So far, we have prepared biodegradable films using the lignocellulose extract of corn stalks, wheat biomass, oat biomass, corncobs, soyhulls, switchgrass, and Prairie cord grass. Despite the high tensile strength of the film, they were not sealable. However, gluten addition to wheat biomass lignocellulose films appears to yield films that could heat sealed. However, more research is needed to establish the heat sealability concept in biomass lignocellulose films.

Research that needs to be completed: Though the preliminary studies are interesting, to understand the effect of gluten on the film properties, first, we plan to optimize the lignocellulose, CaCl2, and glycerol amounts using Box Behnken Design (BBD). We have experience with BBD analysis. Later, we will use the optimized film combination and add a series of gluten amounts, e.g., 5 to 50%, and determine the tensile strength, elongation at break, and water vapor permeability. The films will be further characterized for color, moisture amount, moisture uptake kinetics, water contact angle, UV absorption, antioxidant properties, and soil biodegradability.

Minnesota Small Grains Pest Survey 2024

Principal Investigator(s): Dr. Anthony Hanson, Dr. Angie Peltier, & Dr. Jochum Wiersma

Project Period: January 1, 2024-December 31, 2024

Research Question/Objectives: The goals of this pest survey were to produce timely alerts for small grains producers throughout the growing season so that sound economic control options can be implemented. We integrated this survey with the ongoing efforts in North Dakota that are coordinated by NDSU's IPM Survey to improve efficiency and impact of this program across Minnesota and North Dakota. Specific project objectives included:

Survey small grain fields each week from mid-May through July in western and northwestern Minnesota small grain production areas monitoring for agronomic, insect and disease issues.

Generate survey maps along with NDSU Extension cooperators regarding scout findings.

Provide timely alerts about pest and disease issues in small grains so that producers can implement sound economic control options.

Estimate the area in which wheat stem sawfly has established successfully as an economic pest in spring wheat in Minnesota

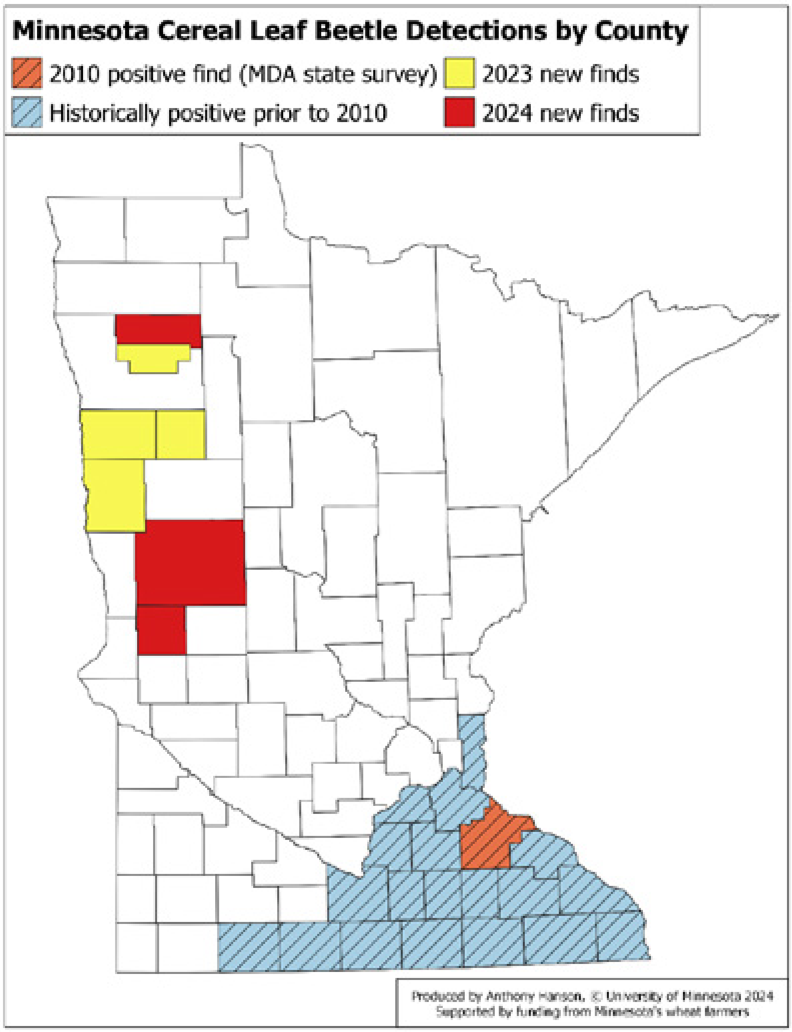
Results:
The 2024 small grain scouting program had 194 unique field visits of 70 fields during the small grain scouting season. These fields were volunteered by producers in early spring and scouted throughout spring and early summer by three survey scouts. One scout was based around the Crookston area. Normally two additional scouts would be hired to cover the Moorhead and Morris areas as well, but because a scout was not found for the Moorhead area, two scouts were hired at the Morris location that covered the Moorhead and Morris areas. Areas scouted primarily focused on northwestern Minnesota and then south and east to approximately Fergus Falls and Elbow Lake with additional southern sites near Marshall. Scouting started June 4 and continued through the first week of July. A final check for crop status and head disease incidence at all fields was performed during the last week of July and first week of August.

Data was collected on severity and incidence of the major cereal diseases in Minnesota and some of the important insect pests. Data was submitted each week to the NDSU IPM team that then generated distribution maps for the region (See Appendix). Archived distribution data can be found at: https://www.ag.ndsu.edu/ndipm for various crops. Postings were also made to the Minnesota Crop News Blog at https://blog-crop-news.extension.umn.edu/ for commentary on disease development. There were a total of 12 pest updates posted to the Minnesota Crop News Blog with a total of more than 5,041 views, averaging 458 views per post. One webinar was also held through the in-season Strategic Farming: Field Notes program that focused in part on wheat issues.

Likely in part due to the wet spring and early summer, higher disease incidence was found during the 2024 survey than in 2023. Wheat scab and loose smut was found with some regularity across Northwestern Minnesota, though at least in the fields surveyed, severity was relatively low. Tan spot was found in counties south of Polk. Norman and Becker Counties had fields with incidence ranging between 16-50% percent occurrence, though disease severity was relatively low. Tan spot was found at low incidence and severity across west-central Minnesota, but fields in Lyon County had the highest incidence, ranging from 56-78% of plants exhibiting tan spot symptoms.

Cereal leaf beetle (CLB) was the most concerning find among insects this year. CLB is native to Europe and was first detected in the U.S. in Michigan in the early 1960's. Since then, the insect has spread through the eastern states, west to Montana, south to Missouri and east to Virginia. It has been reported in southern Minnesota, primarily east of the Minnesota River Valley. Economically damaging infestations haven't been widely reported in Minnesota prior to 2023. More than 3 larvae per flag leaf can cause significant impact on plant growth and vigor, resulting in decreased yield and grain quality (Fig. 1). After the boot stage, the threshold lowers to one larva per flag leaf.

Figure 1. Cereal leaf beetle larvae feeding on a wheat leaf. Larvae carry their frass (i.e., feces) on their back to protect against predators. This gives larvae a slimy, black and sometimes striped appearance. Photo credit: Anthony Hanson – University of Minnesota Extension IPM.



Prior to 2023, this insect pest had not been found in northwestern Minnesota, but was found in Clay, Norman, Mahnomen, Red Lake counties during our 2023 surveys, sometimes at economically damaging levels (Fig. 2). CLB was found again in each of these counties except Clay County in 2024. However, fields with CLB infestations were found in two new counties in 2024: Pennington and Otter Tail. The Otter Tail field was directly adjacent to the northern border of Grant County, so CLB should be considered present at least in northern Grant County. Of the 11 fields in 2024 where CLB was found, most had relatively mild infestations with 2-6% of stems infested. Two fields in Red Lake County had 20 and 10% infestation rates, respectively, and a Mahnomen County field had 14% of stems infested. During the 2023 survey, the largest infestation was a Mahnomen field with 30% of stems infested. Overall, population densities in 2024 were slightly lower than in 2023, though individual fields with larger populations found in each year would warrant additional scouting for possible insecticide application. Especially since this insect had not been observed in this part of the state prior to 2023, growers in these areas should be actively scouting during the 2025 growing season for cereal leaf beetle.

Figure 2. Counties in which cereal leaf beetle has been found; new finds during June 2024 are in red. The Otter Tail County find was on a field directly adjoining the county line with Grant County, so it is apt to assume that Grant County is also infested with cereal leaf beetle.

Wheat stem maggot was found in larger numbers in Otter Tail, Grant and Lyon Counties this year (12-30% infestation), though other fields where it was present (Becker, Norman, and Swift Counties) generally had low incidence. Cereal aphid reports were more widespread in 2024 than 2023, but population densities within individual fields were still relatively low. Barley yellow dwarf virus, a virus vectored by cereal aphids, was not found in the wheat survey this year. Wheat stem sawfly was not found in the Minnesota survey this year, though it was found in western North Dakota. Wheat stem sawfly has been occasionally found in the Crookston area in previous surveys.

Grasshoppers were prevalent in the sweep net samples from early-June onward, though both adults and nymphs were at low population densities throughout the year. Grasshopper densities were high during 2023 going into last fall, so risk was originally high this spring. Cool, wet weather helped entomopathogenic fungi control grasshopper populations before they became a major risk by increasing egg and nymph mortality. Timely rains during most of the 2024 growing season may have helped suppress grasshopper populations. However, with drought conditions returning in late 2024, continued dry conditions, especially in spring 2025, may increase the risk of widespread grasshopper feeding injury.

The Season Summary maps by disease or insect are provided in an appendix at the end of the report (Appendix 1).

Application/Use: Results from this scouting project are used widely by farmers, crop consultants, and Extension educators throughout Minnesota. The in-season commentary published online in Minnesota Crop News blog and distributed to subscribers via email provides Minnesota farmers with real-time pest reports and recommendations to make informed pest management decisions. These results were also used to give updates during summer webinars, such as Strategic Farming: Field Notes. The findings were also included at in-person events such as Farm Fest by Hanson and will be included in 2024 winter research updates as well as 2025 pesticide recertification workshops. Wiersma provided information in-person through the Small Grains Summer Plot Tours at cooperator field locations in Rochester (June 17), Le Center (June 19), Benson (June 19), Humboldt (July 15), Oklee (July 16), and Strathcona (July 19). This year, a major new reporting component of the project was to provide any growers who volunteered fields for sampling a link to weekly field status reports. Growers were also directly notified if scouts noticed problems requiring further attention (e.g., cereal leaf beetle).

Materials and Methods:
Three scouts operating throughout western Minnesota scouted approximately 20-30 small grains fields per week during the small grains growing season. Scouts underwent training at the beginning of the season to learn how to identify and score pest incidence and severity and how to record the data collected. The MN survey was conducted according to the same protocol followed by the NDSU IPM survey so that the output could be merged and reflect regional trends. The only difference from the North Dakota survey is fields in Minnesota are volunteered each spring to ensure we have permission to scout various fields in addition to variety trial locations. Scouts collected GPS data to aid the construction of distribution maps for each week of data collected for each disease or insect pest. Fields were scouted by walking out past the headland in each field and walking in a "w" pattern, collecting observations on 10 plants at each point of the "w". Sweep nets were used to monitor the number of grasshoppers per four sweeps in field margins and ditches. Incidence and severity data were collected for leaf rust, tan spot, Septoria spot blotch, and Fusarium head blight (FHB). Incidence only data was collected for bacterial leaf streak, Barley yellow dwarf virus, Wheat streak mosaic virus, stem rust, stripe rust, powdery mildew and loose smut. For FHB, scab index was calculated by combining the severity and incidence data. The weekly scouting data was combined and sent to the NDSU IPM team who then used this data to construct both weekly distribution maps, as well as end of season maps. Data was interpreted and distributed weekly as commentaries posted to the Minnesota Crop News blog.

Economic Benefit to a Typical 500 Acre Wheat Enterprise:
A follow-up survey to the users of the Minnesota Crop News blog is necessary to fully assess whether the timely disease and pest updates and commentary altered producer decisions for their disease and pest management in 2024. Each update posted to the Minnesota Crop News Blog had an average of 458 page visits (approximately double the readership of similar articles from 2023), indicating a large potential impact with this scouting program as most Minnesota Crop News blog subscribers are farmers or crop consultants. Even small impacts on a typical wheat enterprise have the potential for large economic benefits, as informed pest management decisions can easily provide impacts of more than $10 per acre, with drastically greater impacts in some situations. Even at these conservative levels a 500-acre wheat enterprise could increase gross returns by $5,000 in a given year with timely alerts. This year, the overall lack of some major pest issues in the surveys would reassure growers that risk of economic loss was low, and that extra costs for pest management largely were not needed. This survey also informed growers of new pests, such as cereal leaf beetle, that may lead to additional expense through yield loss or insecticide costs that they may have to prepare for. If cereal leaf beetle becomes a more widespread issue, this survey will help to avoid growers being caught unaware.

Related Research:
This project directly ties in with the North Dakota State University Integrated Pest Management scouting program in North Dakota as reflected by the regional scouting maps produced between the two programs. This project also ties in with the Wheat Stem Sawfly screening program in an effort to identify the geographic area affected by wheat stem sawfly. This project also collaborates with the Minnesota Soybean Scouting project funded by the Minnesota Soybean Research and Promotion Council, as these programs complement each other by providing a full summer scouting experience for scouts, who are able to scout small grains in the spring and early summer, shifting to soybeans mid-summer. We would also like to thank our 2024 IPM scouts who gathered survey data: Katie Olson, Logan Blanke, and Brett Barbeln.

Recommended Future Research: The PIs would like to continue the small grains pest survey across the state to continue monitoring pest levels in the state and to continue providing well-informed commentaries for Minnesota small grain producers into the future. The hope is to continue the scouting program to include three locations in the state again to obtain better coverage of fields in the western half of the state. In terms of the number of volunteered fields, the northwestern portion of the state is well-represented, though additional effort may be needed to recruit cooperating farmers in west-central Minnesota.

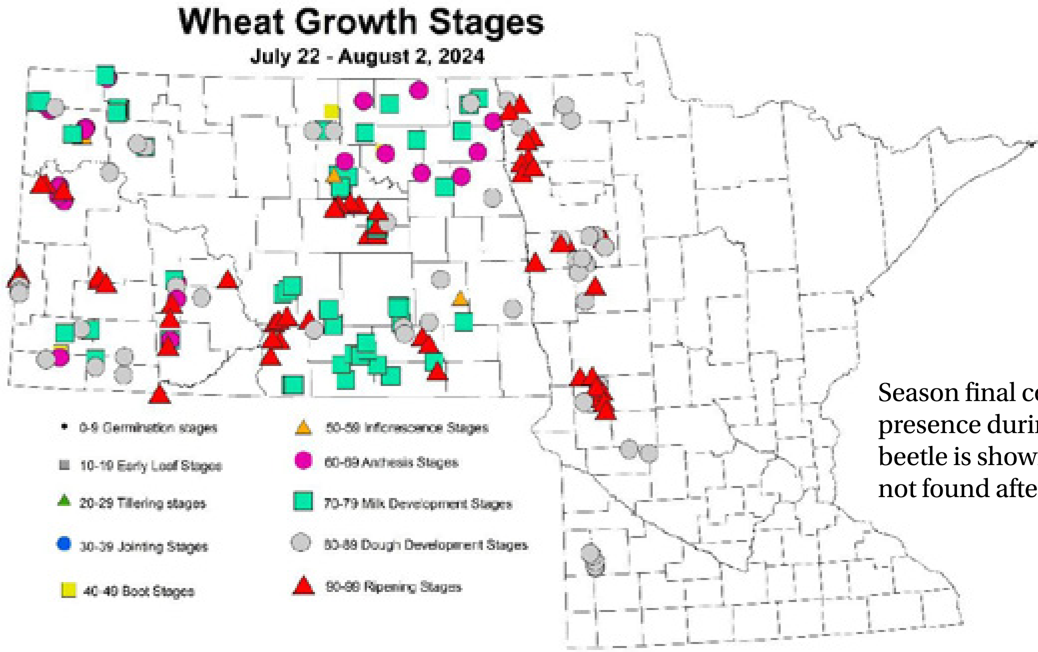
Continuing the survey in future years will also benefit small grains growers by helping to better target education efforts to fit the geographic region occupied by emerging pests, such as cereal leaf beetle.

Publications:
Minnesota Crop News (https://blog-crop-news.extension.umn.edu/)
Field Notes talked seedling disease and small grains in a wet spring. P. Bongard, J. Wiersma, & D. Malvick. May 23, 2024. 247 views.
A Not So Pretty Picture. J. Wiersma. May 30, 2024. 435 views.
Everything and the Sink. J. Wiersma. May 30, 2024. 241 views.
Fungicide Efficacy for Control of Wheat Diseases. J. Wiersma. June 3, 2024. 129 views.
Stripe Rust of Wheat. J. Wiersma. June 4, 2024. 138 views.
Small Grains Disease and Pest Update 06/10/24. J. Wiersma. 249 views.
Small Grains Disease and Pest Update 06/14/24. J. Wiersma. 252 views.
Fusarium Head Blight (Scab) Risk, Fungicide Selection and Fungicide Timing. J. Wiersma. June 20, 2024. 472 views
Small Grains Disease and Pest Update 06/24/24. J. Wiersma. 795 views.
Small Grains Disease and Pest Update 07/01/24. J. Wiersma. 276 views.
Small Grains Disease and Pest Update 07/09/24. J. Wiersma. 937 views.
Small Grains Disease and Pest Update 07/18/24. J. Wiersma. 1008 views.

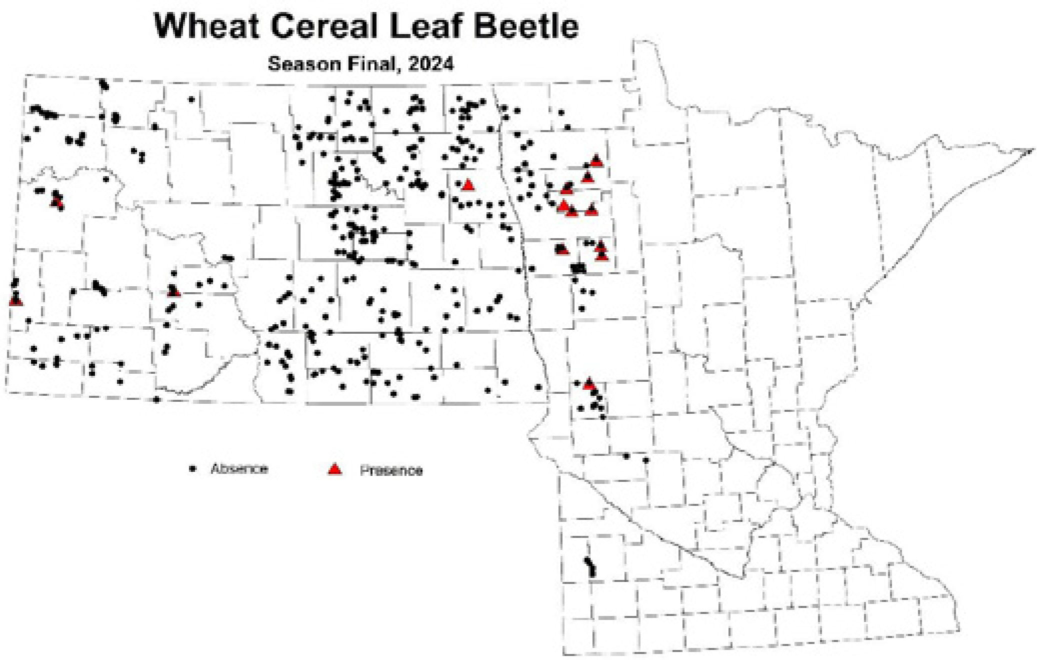
Strategic Farming: Field Notes webinar and podcast (https://strategicfarming.transistor.fm)
May 22, 2024. Seedling diseases and small grains in a wet spring. ~50 attendees, 51 downloads.

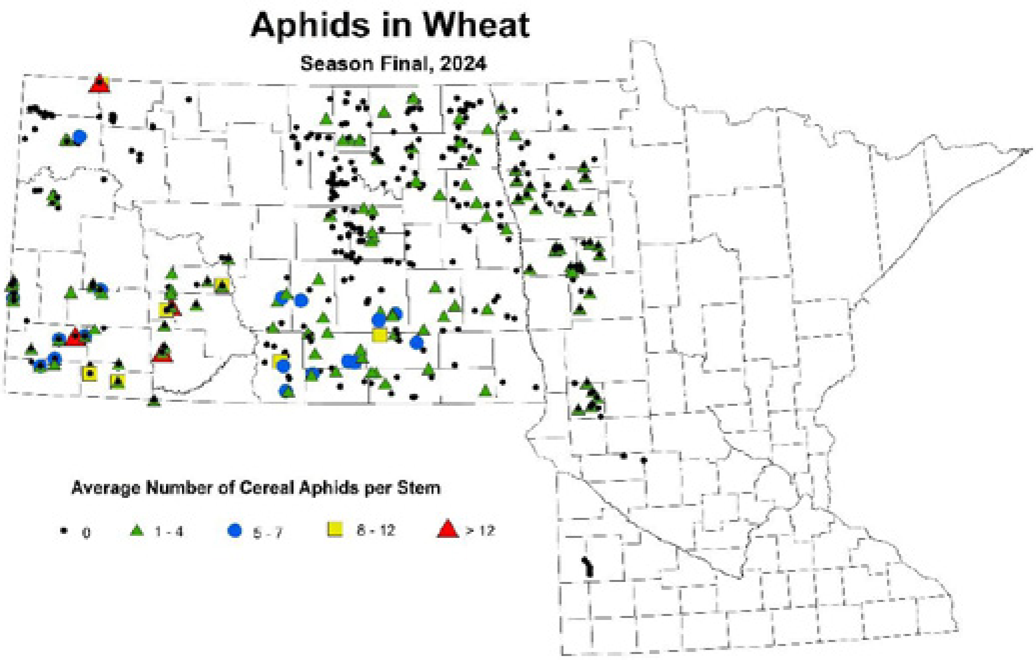
Appendix I: Weekly maps of crop development, disease and pest incidence and severity can be viewed at NDSU's IPM website: https://z.umn.edu/mn-ndsu-wheatipm. Seasonal summary maps for each category are included below.

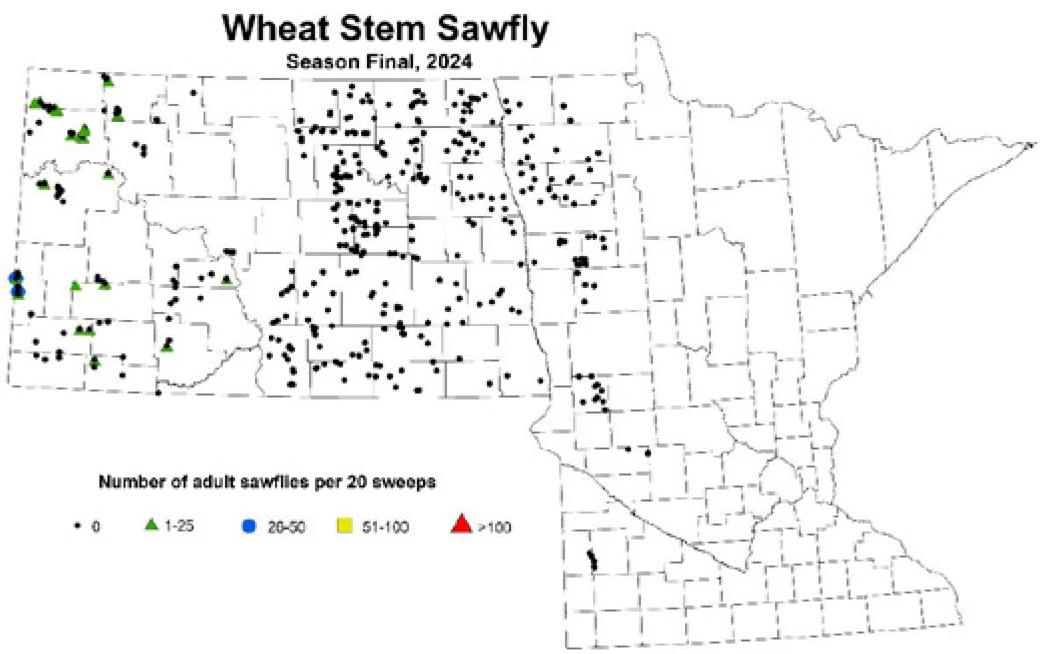
Wheat growth stages during late-July to early-August as a snapshot map representing all wheat fields sampled in MN during 2024.

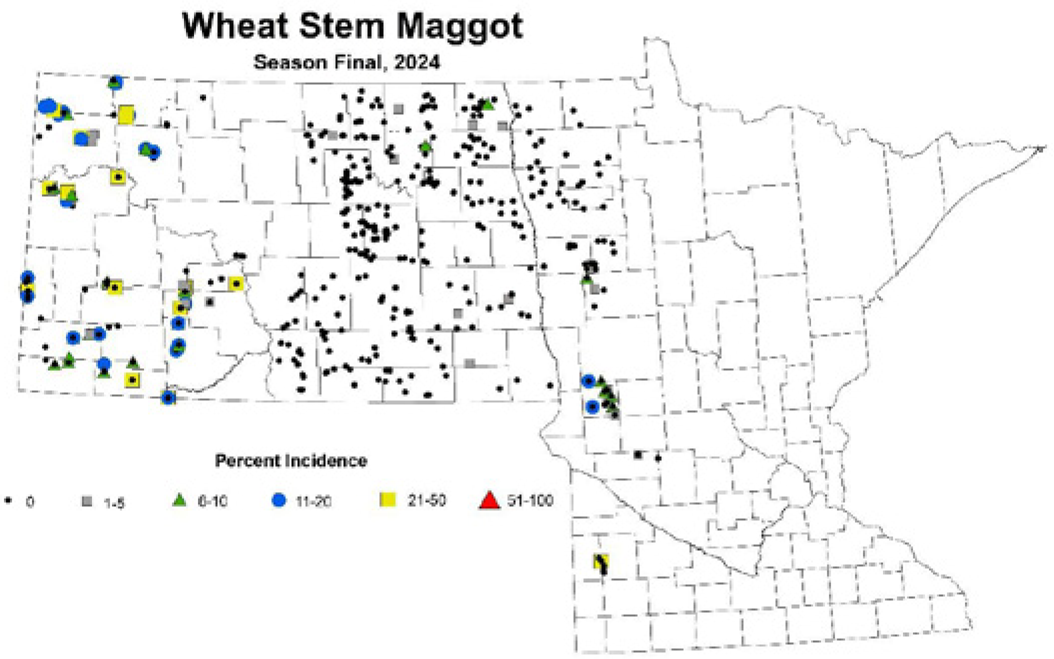


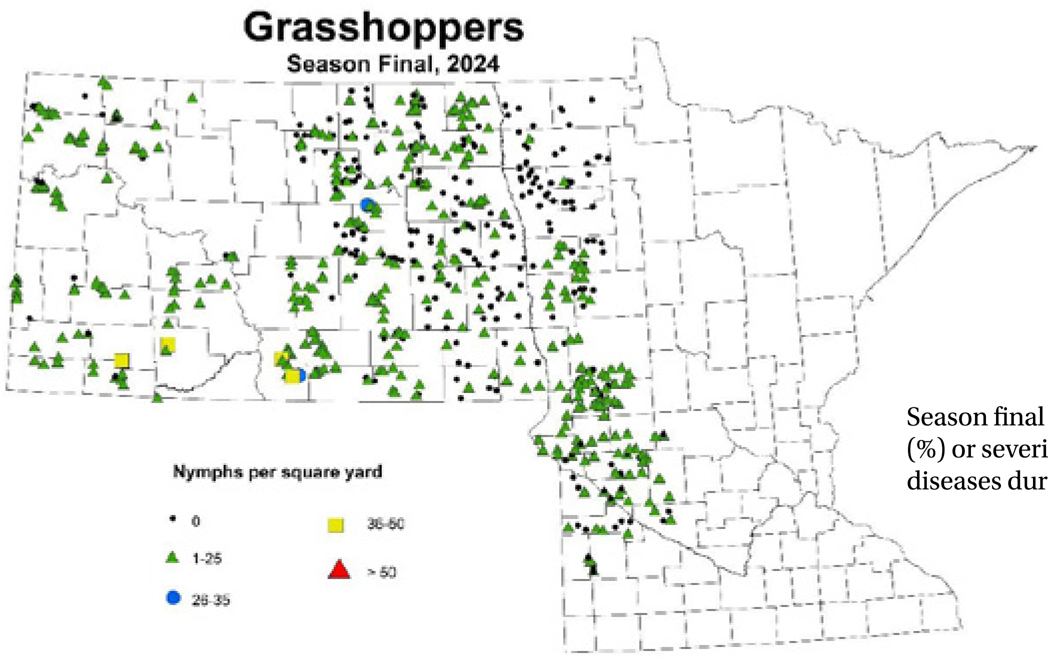
Season final counts for insect presence during 2024. Cereal leaf beetle is shown for June since it was not found after June 26th.



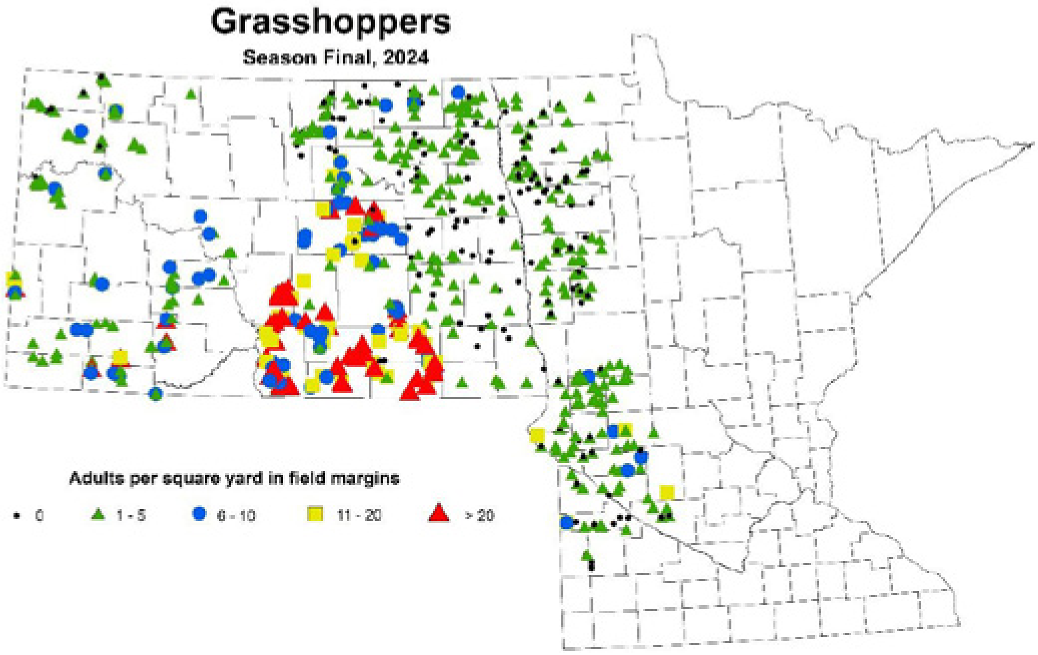

Aphids in Wheat
Season Final, 2024
Average Number of Cereal Aphids per Stem
0
1 - 4
5 - 7
8 - 12
> 12

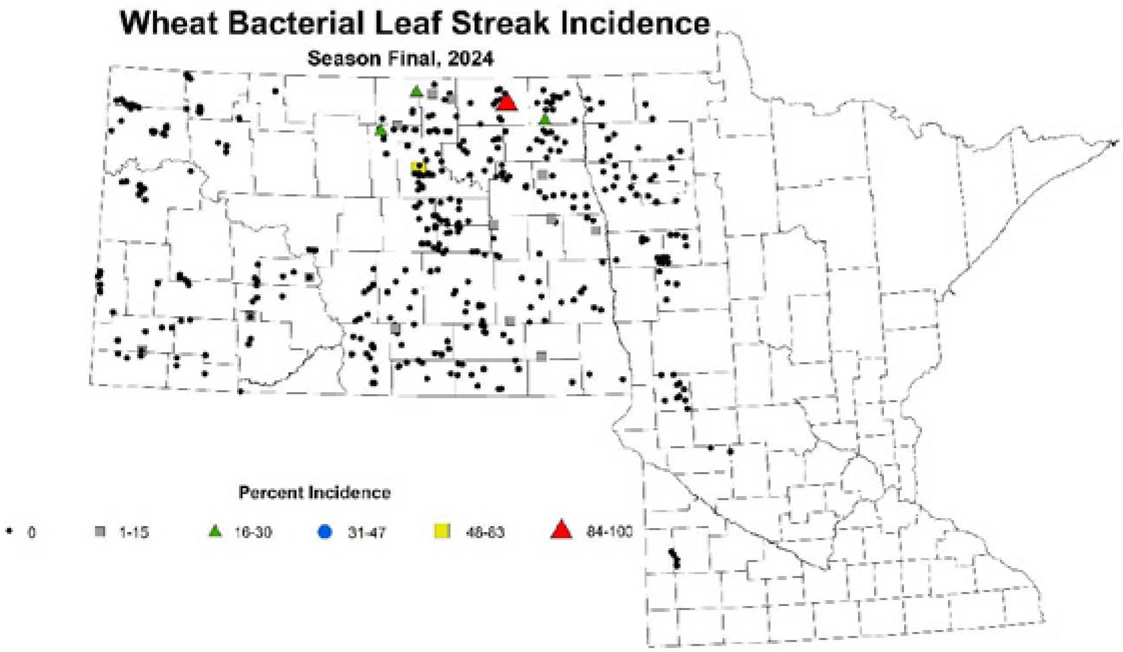

Wheat Stem Sawfly
Season Final, 2024
Number of adult sawflies per 20 sweeps
0
1-25
26-50
51-100
>100

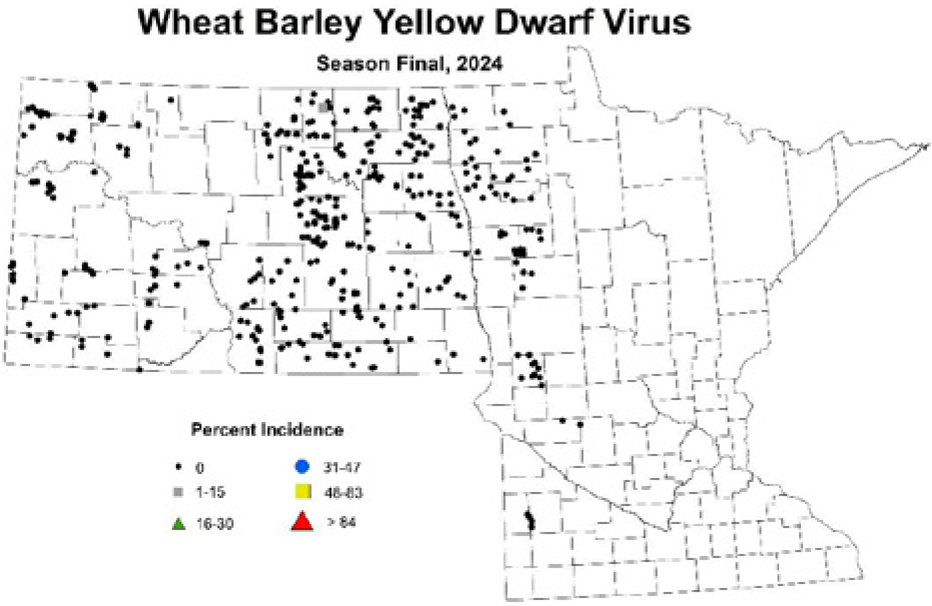


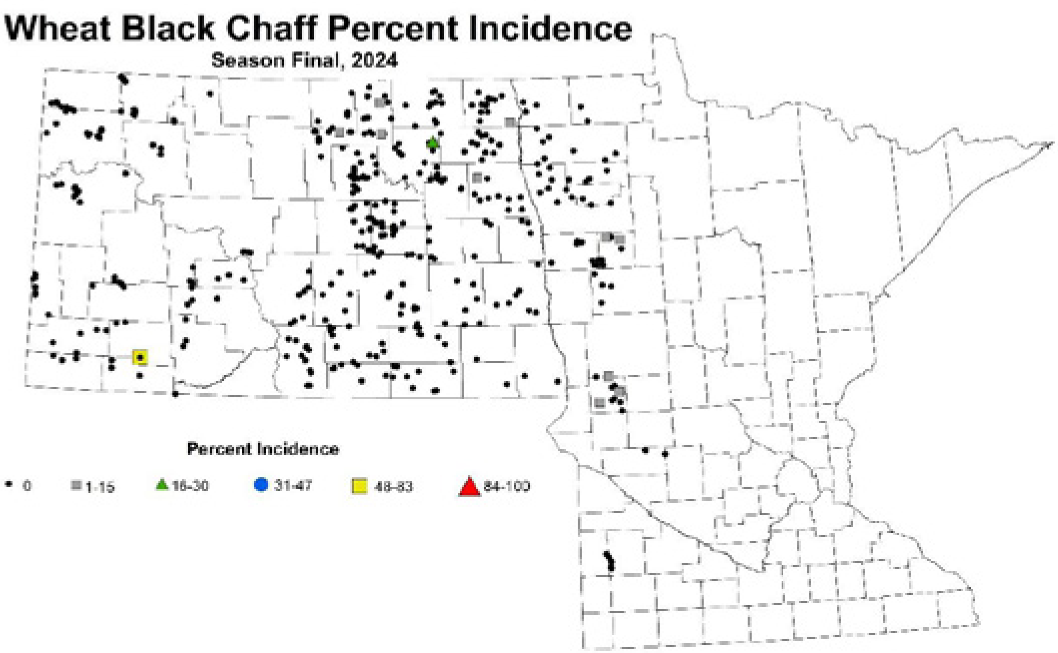


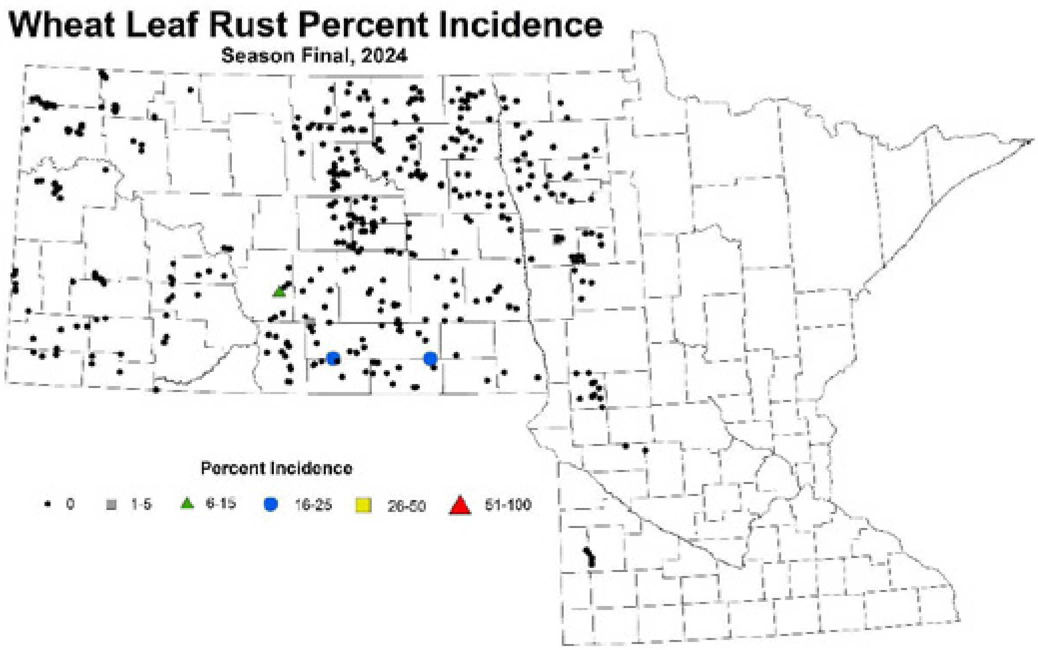
Season final incidence (%) or severity for wheat diseases during 2024.

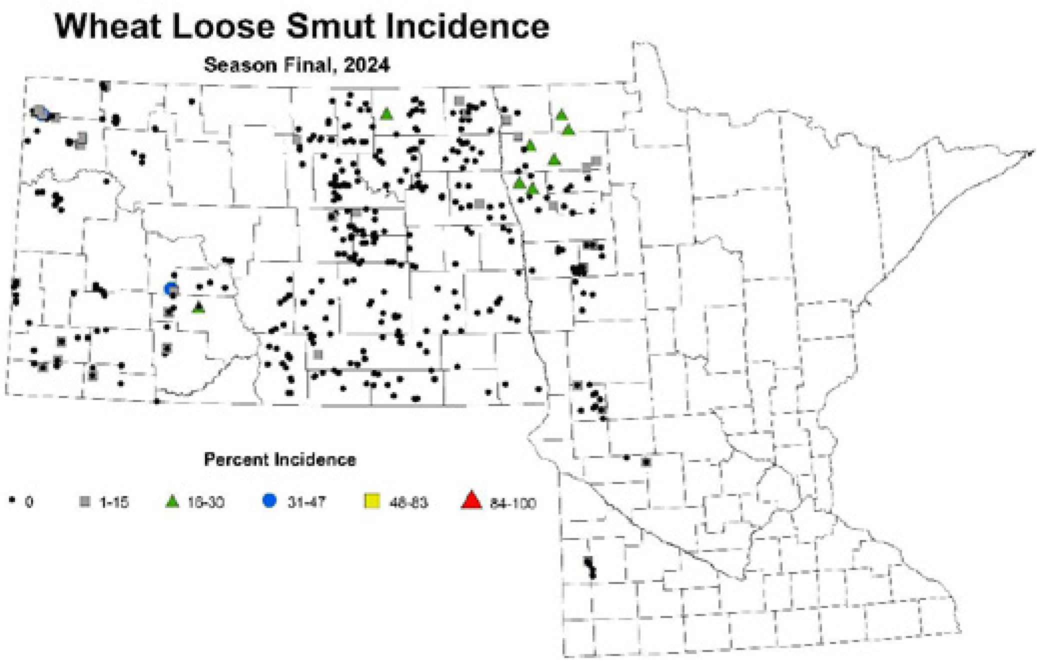

Grasshoppers
Season Final, 2024
Adults per square yard in field margins
0
1 - 5
6 - 10
11 - 20
> 20

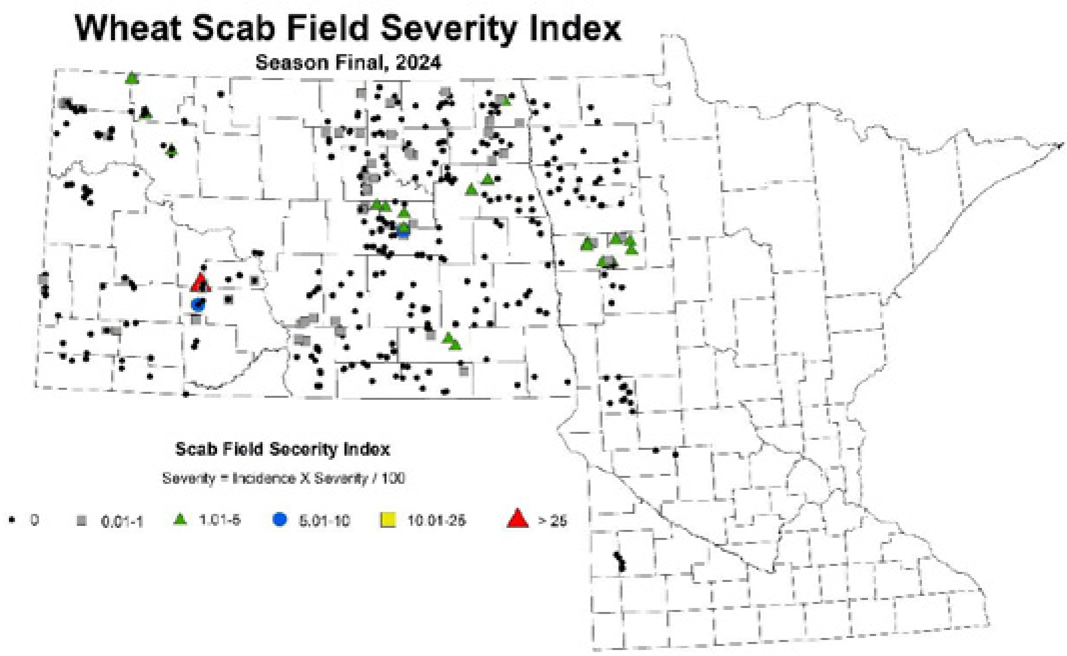

Wheat Bacterial Leaf Streak Incidence
Season Final, 2024
Percent Incidence
0
1-15
16-30
31-47
48-63
84-100

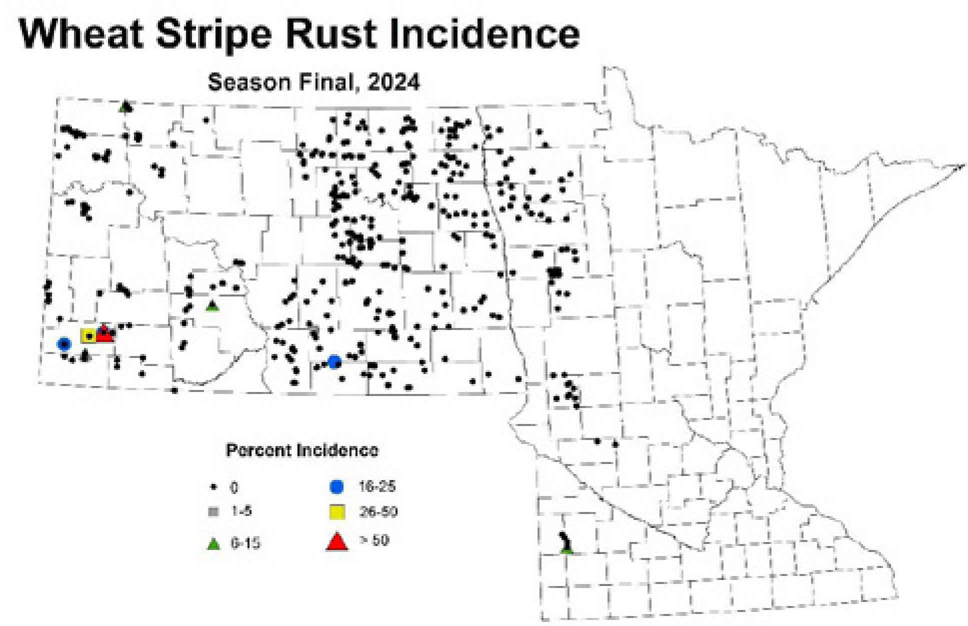

Wheat Barley Yellow Dwarf Virus
Season Final, 2024
Percent Incidence
0
1-15
16-30
31-47
48-83
> 84

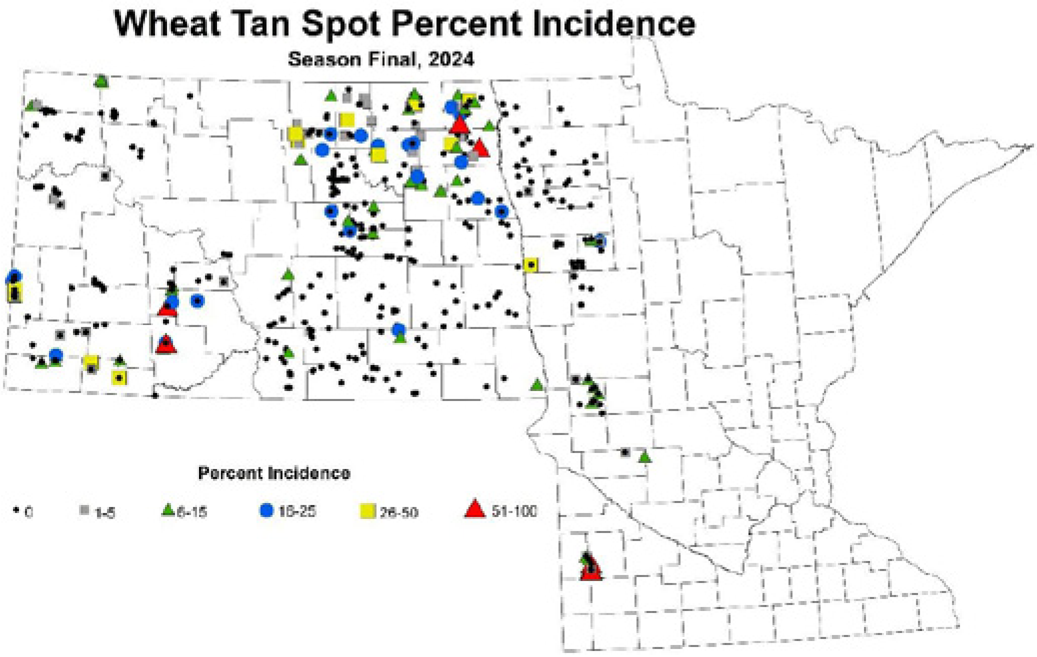

Wheat Black Chaff Percent Incidence
Season Final, 2024
Percent Incidence
0
1-15
16-30
31-47
48-83
84-100

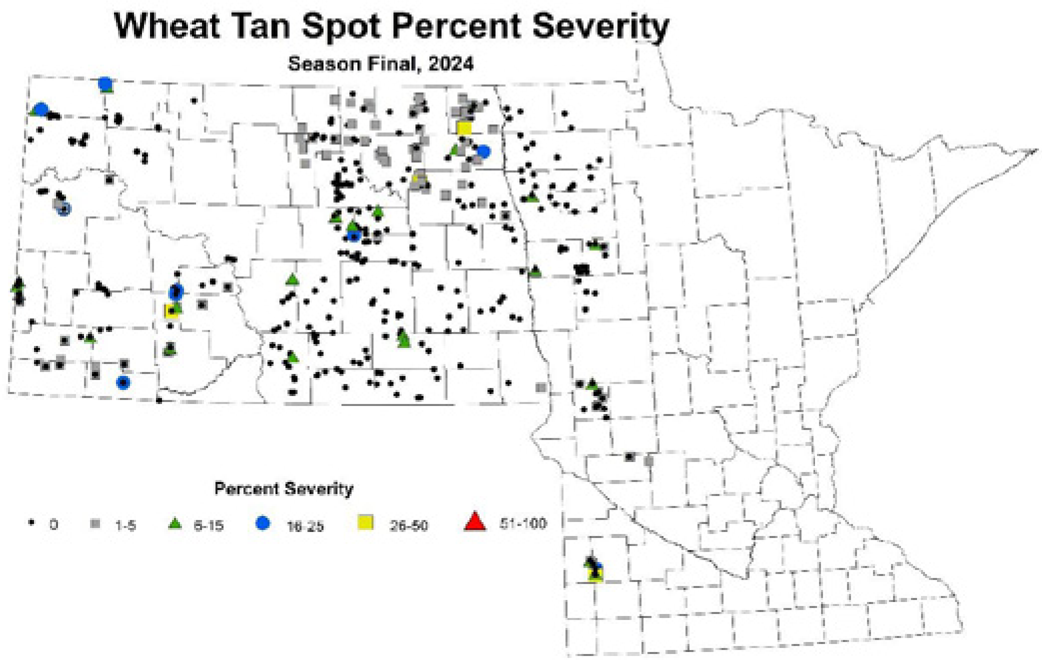

Wheat Leaf Rust Percent Incidence
Season Final, 2024
Percent Incidence
0
1-5
6-15
16-25
26-50
51-100


Wheat Loose Smut Incidence
Season Final, 2024
Percent Incidence
0
1-15
16-30
31-47
48-83
84-100


Wheat Scab Field Severity Index
Season Final, 2024
Scab Field Secerity Index
Severity = Incidence X Severity / 100
0
0.01-1
1.01-5
5.01-10
10.01-25
> 25


Wheat Stripe Rust Incidence
Season Final, 2024
Percent Incidence
0
1-5
6-15
16-25
26-50
> 50


Wheat Tan Spot Percent Incidence
Season Final, 2024
Percent Incidence
0
1-5
6-15
16-25
26-50
51-100


Wheat Tan Spot Percent Severity
Season Final, 2024
Percent Severity
0
1-5
6-15
16-25
26-50
51-100

Enhancing Spring Wheat Yields through Split In-Season Nitrogen and Sulfur Applications in Conventional and No-Till Systems

Principal Investigator(s): Sergio Cabello-Leiva, Soil Scientist, Carrington REC, North Dakota State University

Project Period: 2024 season

Research Question/Objectives:
Hypothesis: the use of a split application of nitrogen and sulfur significantly increases wheat yield under conventional and no-till cropping systems
Objectives:

- Determine the combined effect of nitrogen and sulfur split rates, finding the correct ratio to achieve the highest wheat yield and quality in conventional and no-till systems
- Determine the effect, in wheat yield and quality, of nitrogen and sulfur split application in conventional and no-till systems
- Determine the best method to predict nitrogen and sulfur plant status and fertilizer rates, considering regular soil testing, plant analysis, and multispectral data from active and passive sensors. If the multispectral data is significant, we will proceed to use the most accurate vegetation index to predict and correct in-season N and S fertilizer rates in wheat

Results:
Rainfall Impact on Nutrient Use and Yield
In 2024, rainfall played a significant role in our wheat-growing regions. From April to August, Carrington received 15.01 inches of rainfall, 32% above the average, while Staples saw 23.3 inches, a substantial 57% above average. These high rainfall levels raised the risk of nitrogen (N) and sulfur (S) leaching, which reduces nutrient use efficiency. Across both locations, the differences in treatment effects were apparent, as seen in the aerial green index and NDVI images in Figure 1, especially at the wheat Feekes 5 growth stage.

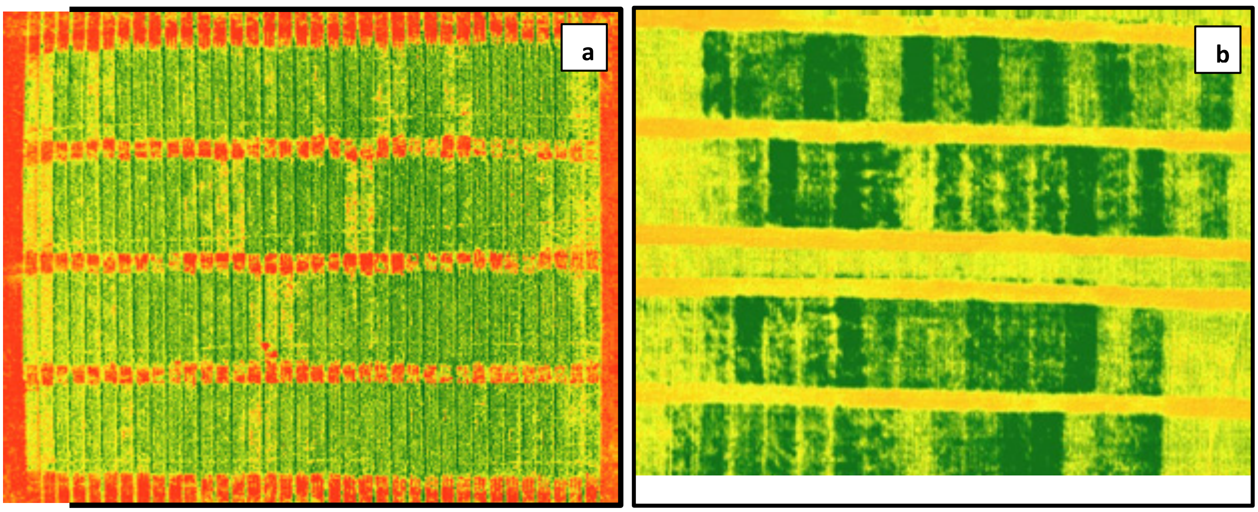


Figure 1. Carrington, ND, wheat green index at Feekes 5 (a), Staples, MN, wheat NDVI index at Feekes 5.

Using GreenSeeker, NDVI readings showed a strong correlation with ground cover photos (Figure 2), allowing us to create multiple regression models to predict N and S application rates at Feekes 5 for target yields with high accuracy (R^2 of 0.78 for Carrington and 0.81 for Staples). These models offer robust seasonal predictions for N and S applications, and further details will be provided in a future publication.

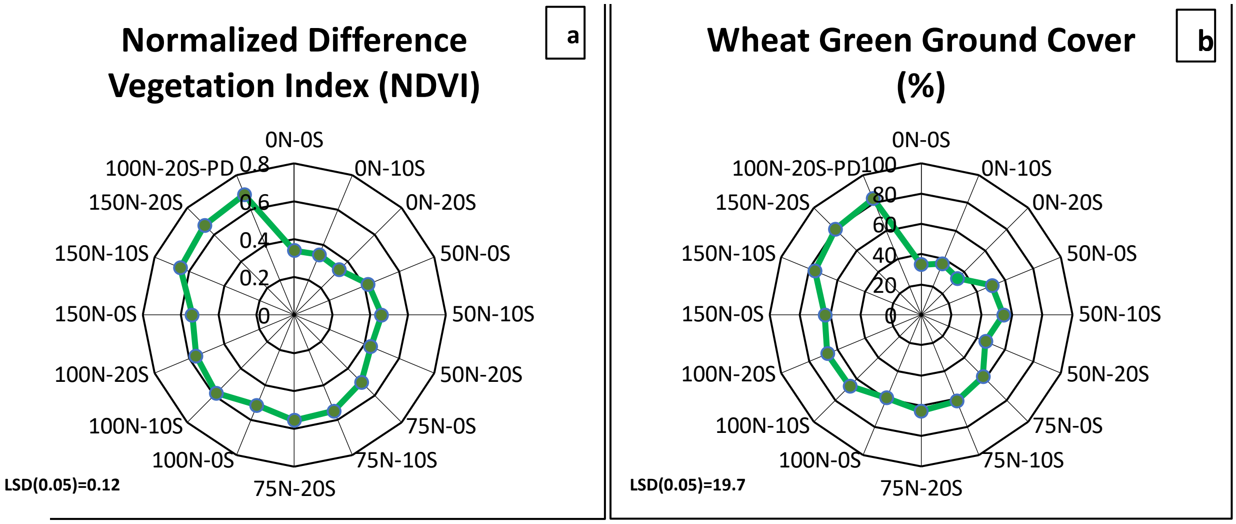


Figure 2. Wheat normalized difference vegetation index (NDVI measured with greenseeker) at Feekes 5(a). Wheat green ground cover (RGB smartphone photo) at Feekes 5 (b). Both graph values averaged across Carrington, ND, and Staples, MN, 2024

Yield Results and Nutrient Efficiency

Yields show significant differences across treatments (Figure 3). Sulfur application increased wheat yield by 30.5% at the same nitrogen levels. Specifically, 150N-20S (55.7 bu acre^{-1}) and 150N-10S (56.1 bu acre^{-1}) treatments significantly outperformed the 150N-0S treatment (40.bu acre^{-1}). This could be

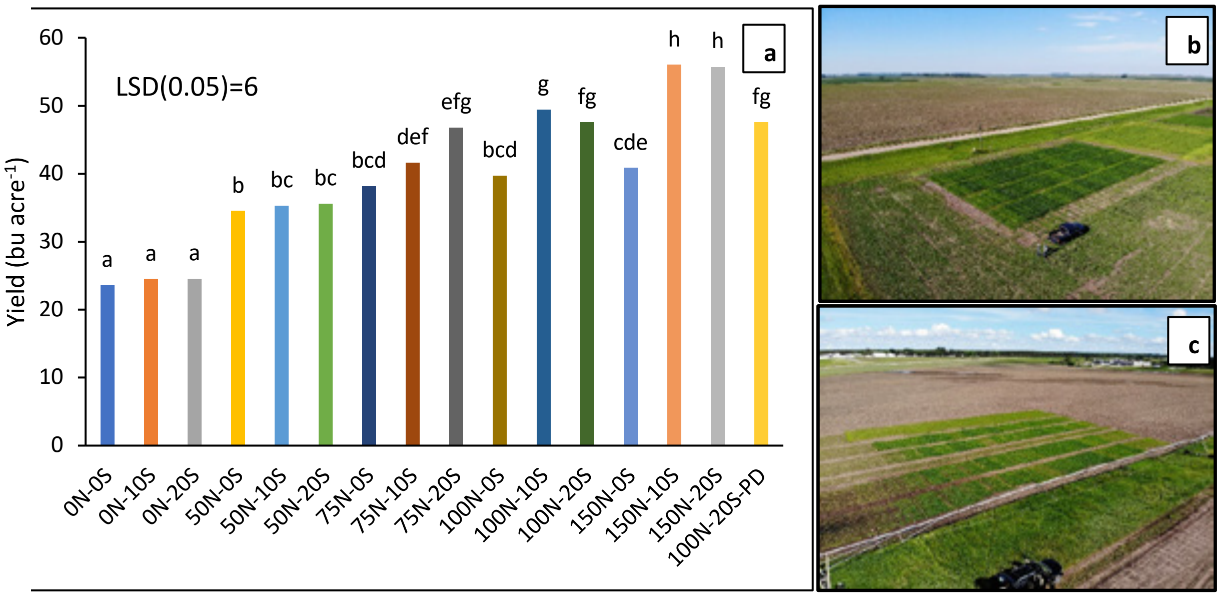


Figure 3. Wheat grain yield combined across Carrington, Mn, and Staples, MN 2023 (a). Carrington aerial picture of spring wheat field trial at Feekees 5, June 2024 (b). Staples aerial picture of spring wheat field trial at Feekees 5, June 2024 (c). Different lowercase letters above each graph bar indicate significant differences with 95% confidence

explained by findings from Franzen et al. (2016); this study claims that high Nitrogen rates (in this case, 150 lc acre^{-1}) can increase Sulfur deficiency severity, which opens a new approach in the cropping system, presenting even a more significant challenge under no-till. There was no significant difference between the

100N-20S-PD (47.6 bu acre^{-1}) and 75N-20S (46.8 bu acre^{-1}) treatments, showing that a split application with 25% less nitrogen can match the effectiveness of a full-rate, single application at planting.

Protein levels varied by location. Carrington maintained protein levels above 13% across treatments, thanks to fertile, loamy soil under no-till conditions. However, Staples showed protein content below 12% in most treatments, likely due to sandy soil conditions. Lower yields with higher N rates did show some increase in protein content. Total grain nitrogen was highest in treatments that included S, reinforcing the benefit of split applications, particularly in scenarios where N was reduced by 25%.

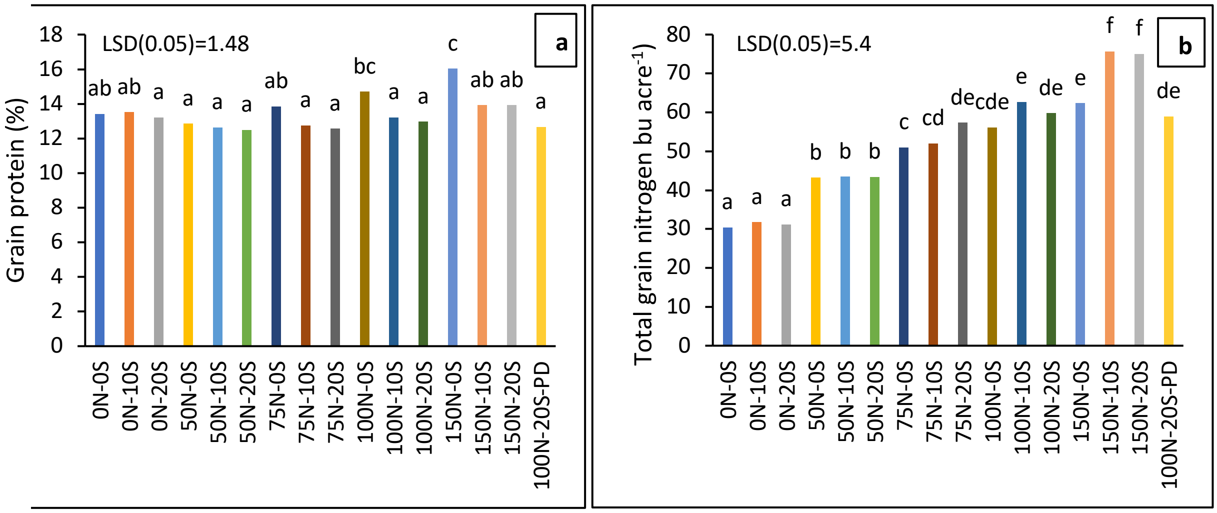


Figure 4. Wheat grain protein averaged across Carrington, ND, and Staples, MN 2024 (a). Wheat total grain nitrogen averaged across Carrington, ND, and Staples, MN 2024 (a). Different lowercase letters above each graph bar indicate significant differences with 95% confidence

Nitrogen Use Efficiency (NUE) Gains with Sulfur

Adding sulfur led to significant NUE improvements. In Carrington, NUE increased by 7% with sulfur applications and Staples by 10%. A split application with 75N-20S (25% less N) further boosted NUE by 13% in Carrington and 21% in Staples, proving that split applications improve yield and make nitrogen use more efficient.

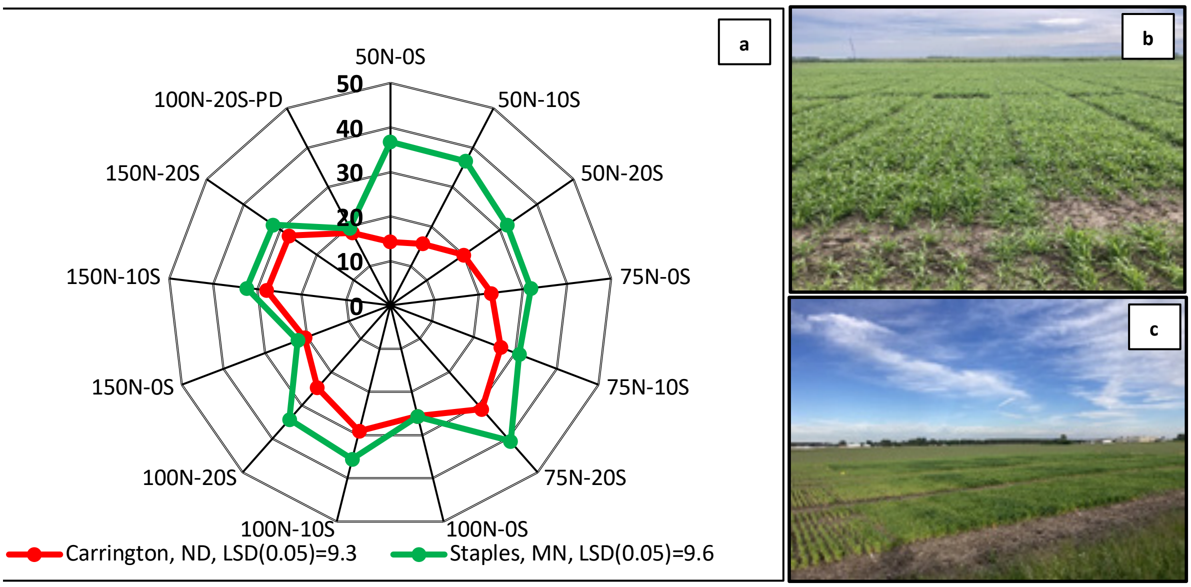


Figure 5. Wheat nitrogen use efficiency (NUE) at Carrington, ND (red line), and Staples, MN (green line) (a). Wheat field trail Carrington, ND, June 2024 9b). Wheat field trail Staples, MN, June 2024 (b).

Conclusions

Adopting sulfur and split N applications offers multiple benefits for wheat production. Sulfur rates of 10 and 20 lbs acre^{-1} increased wheat yield by 30.5% at equal nitrogen levels. Additionally, split applications with 25% less nitrogen proved as effective as full-rate applications at planting. Nitrogen use efficiency was also improved with sulfur, with gains of 7-12% at the same N rate, boosting wheat yield potential in Minnesota and North Dakota.

Split N and S applications have shown the potential for higher yields with less fertilizer, offering a promising strategy for sustainable wheat production. Although these results are promising, further testing during the season will help fine-tune N and S recommendations across varying conditions in North Dakota and Minnesota. This report serves as an encouraging first step toward more efficient, profitable, and environmentally friendly wheat farming.

Application/Use:

This research is relevant to any farming operation in Minnesota and North Dakota. Farmers can apply split applications using the same equipment as they would for a single fertilizer application. The fertilizer sources needed for split applications are readily available and widely used across various cropping systems in the Northern Great Plains.

With precision agriculture technologies becoming more accessible, farmers and crop advisors have excellent opportunities to increase profitability while reducing environmental impact. Although these technologies are widely available, calibration and development of simple, user-friendly methods that make them easy to use in the field remain necessary.

The potential for positive change is substantial, yet further research is essential to ensure these practices achieve maximum regional impact.

Materials and Methods:

Field establishment: The first location was Carrington, ND, where plots were located on dryland, no-till loamy soils. The second location was Central Minnesota Demonstration and Research Irrigation Farm in Staples, MN, where plots were located on conventional tillage irrigated sandy soils. The experimental unit was 25 ft x 10 ft in size.

Spring Wheat MN Rothsay (seeding rate of 2.3 bu acre^{-1}) was randomized in a complete block design (RCBD) with four replicates in late April. Seventeen treatments were applied with urea and ammonium sulfate, adding the following N and S nutrient rates (lb acre^{-1}) of 0N-0S, 0N-10S, 0N-20S, 50N-0S, 50N-10S, 50N-20S, 75N-OS, 75N-10S, 75N-20S, 100N-0S, 100N-10S, 100N-20S, 150N-0S, 150N-10S, and 150N-20S. In addition, one treatment with 100N-20S was applied at the planting date as a control. N and S rates were split 60% as a starter and 40% as the wheat Feekes 5 stage.

Plant Sampling: Mid-season biomass samples were taken from a four sq ft section of the wheat plot at Feekes 5 stage. These samples were weighed and tested for nitrogen (N) and sulfur (S) content. The sulfur-to-nitrogen ratio will indicate sulfur sufficiency in the plant tissue. Wheat biomass was retaken close to harvest from a four sq ft section, and these samples were weighed but not analyzed (this data will be published in a future report). Each plot was harvested to determine grain yield, test weight, and protein content.

Soil sampling: Composite samples were taken at 0-6- and 6-24-inches depth in early spring for NO3-N soil pH, P, K, Sulfate-S, Zinc, pH, and organic matter, and samples taken at 6-24 inches were tested for NO3-N and Sulfate-S. These samples were used to determine the N and S recommendations. In-season soil sampling was done in wheat at Feekes 5 stage, testing for NO3-N and Sulfate-S. After harvest, samples were collected at 0-24 inches depth, testing for NO3-N and Sulfate-S. This data will be published in future reports.

Multispectral wheat canopy data:

The GreenSeeker hand-held sensor collected NDVI in each plot at Feekes stages 3, 5, and 10.5 of the wheat stages. A drone DJI Phantom 4 MicaSense Red-Edge multispectral camera will collect canopy reflectance images at 550, 670, 715, and 840 (green, red, red-edge, and near-infrared). Data collection will be at Feekes stages 3, 5, and 10.5 of the wheat stages. This data is partially published in this report.

Weather and soil data: Daily temperature (min and max), relative humidity, and rainfall were obtained from the NDAWN weather station in North Dakota. Soil moisture and temperature were obtained from check plots with a Decagon 5TM soil moisture sensor (5,15, and 30 cm depth), and reads were recorded daily with a Decagon EM50 datalogger. This data will be used in a prediction model for N and S rates.

Statistical analysis was conducted using standard procedures for a randomized complete block design (RCBD). The variance analysis was performed using the MIXED procedure of SAS 9.4 for all variables above. A mean separation test was performed using the least significant difference (LSD) ($P \leq 0.05$).

Economic Benefit to a Typical 500 Acre Wheat Enterprise:
In this study, we conducted a combined economic analysis on a 500-acre wheat production scenario across Carrington, ND, and Staples, MN (This is just a research exercise). Table 1 shows a negative partial income for wheat without nitrogen applications. (Note: This is a partial income as it does not account for all miscellaneous production costs; it is used here as a research example.)
At a rate of 100 lb of nitrogen (N) per acre, adding 10 lbs of sulfur (S) per acre increased partial net income by $30,920. Compared with 100N-0S, A similar outcome was seen at 150 lb N per acre, where adding 10 lb of S per acre boosted income by $49,727 across the 500-acre operation.
This season's findings highlight the clear economic benefits of sulfur application, which improves profitability and supports sustainable wheat production. This opens a promising opportunity for enhancing the financial and environmental impact of spring wheat farming in the Northern Great Plains.

Table1. Spring wheat initial economic analysis for a 500-acre operation averaged values from Carrington, ND, and Staples, MN, 2024

Treatment split application	Yield	Wheat gross value†	Urea‡	Ammonium sulfate§	Farming cost₣	Split application cost††	Partial Wheat net value
		--USD$--					
lb acre^{-1}	Bu						
0N-0S‡‡	11,796	83,753	4,933	0	96,337	4,610	-22,127
0N-10S‡‡	12,263	87,067	2,465	4,725	96,460	4,610	-21,194
0N-20S	12,265	87,080	0	9,450	96,461	4,610	-23,440
50N-0S	17,262	122,563	12,326	0	97,775	4,610	7,851
50N-10S	17,648	125,300	9,861	4,725	97,876	4,610	8,228
50N-20S	17,787	126,290	7,396	9,450	97,913	4,610	6,922
75N-0S	19,100	135,608	18,489	0	98,258	4,610	14,251
75N-10S	20,832	147,907	16,024	4,725	98,714	4,610	23,834
75N-20S	23,398	166,127	13,559	9,450	99,389	4,610	39,120
100N-0S	19,863	141,024	24,652	0	98,459	4,610	13,303
100N-10S	24,716	175,480	22,187	4,725	99,735	4,610	44,223
100N-20S	23,789	168,901	19,722	9,450	99,491	4,610	35,628
150N-0S	20,438	145,109	36,978	0	98,610	4,610	4,911
150N-10S	28,042	199,096	34,513	4,725	100,610	4,610	54,638
150N-20S	27,862	197,818	32,048	9,450	100,563	4,610	51,148
100N-20S-PD§§	23,807	169,027	19,722	9,450	99,496	0	40,359

† Wheat gross value was USD$7.1 per bushel

‡ Urea cost was USD$506 per metric ton

§ Ammonium sulfate cost was USD$500 per metric ton

₣ Farming cost of USD$219.31 per acre, including land rent, tillage, planting, seed, fungicide, and harvesting. Drying and hauling costs were calculated based on bushels. 2024 North Dakota custom rates

†† Split application cost considered broadcast application at USD$9.22 per acre

‡‡ These treatments considered urea application to equalized N application from ammonium sulfate treatments

§§ 100N-20S-PD treatment considered a full rate of nitrogen and sulfur fertilizer applied at planting date

Related Research:
Dr. Franzen in North Dakota and Dr. Kaiser in Minnesota have conducted similar research. Our study supports several of their findings while introducing the split application component. It was tested across two environments with varying soil types, tillage systems, and irrigation methods, and a modeling component with precision ag tools was added.
While further research is needed to fine-tune the split application of nitrogen (N) and sulfur (S) under different weather conditions, these initial results are promising. They highlight the advantages of incorporating sulfur into spring wheat production to improve yields and nutrient efficiency.

Recommended Future Research:
We recommend testing the same treatments in the 2025 season to validate these promising results further. In 2026, the model developed from previous seasons should be tested to optimize the agronomic and economic benefits of split applications for spring wheat in Minnesota and North Dakota. This approach will help establish the best practices for sustainable and profitable regional wheat production.

References:

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Ullah, I., D. Muhammad, and M. Mussarat. 2023. Effect of Various Nitrogen Sources at Various Sulfur Levels on Maize–Wheat Yield and N/S Uptake under Different Climatic Conditions. J Plant Growth Regul 42(3): 2073–2087. doi: 10.1007/s00344-022-10682-6.

Publications:
This research project acknowledged Minnesota Wheat Research and Promotion Council support, and results were published at:

- NDSU All Ag Conference, poster: Enhancing Spring Wheat Yields through Split In-Season Nitrogen and Sulfur Applications in Conventional and No-Till Systems. Fargo, ND, 11/06/2024
- All Innovations for Changing Climate, ASA, CSSA, SSA International Annual Meeting. An oral presentation titled Enhancing Spring Wheat Yields through Split In-Season Nitrogen and Sulfur Applications in Combination with RGB Smartphone Images and NDVI-Based Yield Prediction Models. San Antonio, TX, 11/13/2024.
- Annual Reports Carrington Research Extension Center, NDSU. Extension publication titled: Split In-Season Nitrogen and Sulfur Applications Increase Spring Yield and Quality in Conventional and No-Till Systems. It will be published in December 2024.

Breeding to Boost Seed-Filling and Increase Minnesota Wheat Yields

Principal Investigator(s): Walid Sadok, James A. Anderson

Project Period: January 1, 2024 – December 31, 2024

Research Question/Objectives:

Seed-fill is the 'money-making' window for wheat growers. During this critical phase of the crop's growth, the wheat plant invests aggressively all the carbohydrates and nitrogen that are available to fill the developing grain with protein, starch and other nutritional factors. We have recently identified a novel trait that has the potential to increase the rate of seed-fill in wheat and therefore increase yield, and possibly, grain protein levels. Our hypothesis is that increasing the ability of flag leaves to perform photosynthesis during that window could lead to yield increases. This is because a higher rate of photosynthesis means a higher rate of trans-location of proteins and other nutritional factors to the developing seed. Our goal is to support the U of MN wheat breeding program by developing a selection pipeline to identify breeding lines with superior photosynthesis during seed-fill.

In the first year, a first objective was to screen a wide range of breeding and commercial lines to identify those that express superior photosynthesis during seed-fill and thus, could be used as donors in breeding crosses. A second objective was to test the hypothesis that higher yields in this panel are associated with increases in seed-fill photosynthesis. In the second year, we will target the third objective, which is the development of a high-throughput technique for detecting this difference on a much larger number of genotypes in the field.

Results:

Yield results are reported on Figure 1. These show that the tested wheat cultivars indeed expressed large variation in yield, and that the U of MN wheat breeding program has succeeded in increasing the yield potential of MN-adapted spring wheat varieties consistently from 1915 to 2022, at a rate of 17 kg/ha/yr (or 0.26 bu/ac/yr). Importantly, we found that higher levels of flag leaf photosynthesis during seed-fill positively correlated with the year of release of the tested varieties ($P < 0.0001$, $R2 = 0.11$). This result indicates that higher yields achieved by the wheat breeding program through cycles of breeding in the 1915-2022 window are at least in part due to rising photosynthesis during seed-fill. Consistently with this idea, wheat yields correlated positively with flag leaf photosynthesis ($P < 0.0001$, $R2 = 0.10$) as shown on Figure 2. Furthermore, we found that leaf greenness during seed fill exhibited the same tendency, that is, went up as a function of the year of release ($P < 0.0001$). While image analyses from the drone flights are still underway, this result indicates that it is possible to use leaf greenness as a fast and reasonably accurate way to screen for increased flag leaf photosynthesis during seed-fill.

Application/Use:

This research is enabling the development of a new breeding pipeline to rapidly screen hundreds/thousands of breeding lines for higher flag leaf photosynthesis during the seed-fill window as a new strategy to increase MN wheat yields. This pipeline will rely on direct and indirect measurements of photosynthesis and will support the U of MN breeding program by making it possible to screen a larger number of breeding lines and identify promising ones at lower costs, that is, without necessarily needing multi-location yield trials at each round of selection. Additionally, once fully matured, this approach could potentially be deployed on mapping population and thus enable detecting genes underpinning this trait and pyramid the favorable alleles in elite genetic material.

Materials and Methods:

For this study, we have grown a diverse set of 30 lines consisting of i) check cultivars (Shelly, Linkert, MN-Torgy, MN-Rothsay), ii) varieties with different years of releases and iii) a selection of highly diverse advanced breeding lines. These genotypes were field-planted in yield plots (approx. 4 ft. X 9 ft.) at the U of MN St. Paul campus using a randomized complete block design with three replications. Plots were managed per the typical management practices. Flag leaf photosynthesis was measured at solar noon on sunny days using a portable photosynthesis system (LiCOR 6800). Photosynthesis was also measured indirectly by tracking leaf greenness both proximally and remotely. The proximal measurement consists of using a small hand-held chlorophyll meter (MC-100 Chlorophyll Concentration Meter) that clamps on the leaf to measure its greenness. The remote-sensing approach relies on scanning the entire canopy using an RGB (Red-Green-Blue) camera mounted on an unmanned aerial system (UAS; Inspire 2, DJI), following protocols developed by the wheat physiology lab (Lopez et al., 2022). These greenness measurements represent indirect measurements of photosynthesis, and therefore they are less precise, but are much faster to perform. By using them, our goal was to evaluate their potential for higher-throughput screening of seed-fill photosynthesis.

Economic Benefit to a Typical 500 Acre Wheat Enterprise:
Our goal is to support the development and release of higher-yielding wheat varieties to MN growers and thus maximize farmers' economic returns. Our research has discovered that rising flag leaf photosynthesis during seed-fill has likely contributed to historic yield increases in MN-grown wheat. This means that MN wheat breeders can now intentionally breed to boost yields by specifically targeting the improvement of seed-fill photosynthesis. In addition to this important discovery, we are developing remote-sensing techniques that aim to make this screening effort cheaper and higher-throughput to accelerate the breeding effort. Both outcomes will boost the ability of the U of MN wheat breeding program to deliver more productive wheat at a faster rate to the farmer.

Related Research:
This project directly supports research benefiting the U of MN wheat breeding and wheat physiology programs. Investigators Sadok and Anderson have received federal funding (USDA) to support a graduate student who is already participating in the UAV remote-sensing effort. The historical yield trials are also being leveraged to understand the role of "Green Revolution" genes on flag leaf photosynthesis and boost their combined benefits on grain yield. The approach being developed for this project is based on state-of-the art research conducted in the area of photosynthesis by the wheat physiology team and led by another graduate student who is involved in this project as well (Ding et al. 2025).

Recommended Future Research:
Future research will focus on confirming the yield results and their association with flag leaf photosynthesis, by replicating the yield trials in two independent locations. Another goal will be to develop a higher-throughput technique for detecting variation in flag leaf photosynthesis on a much larger number of genotypes in the field. Once the pipeline is matured, an ultimate goal would be to deploy it on mapping populations so that we will be able to directly associate variation in flag leaf photosynthesis with particular genes or their variations (or alleles).

Publications:
Lopez, J.R., Tamang, B.G., Monnens, D.M., Smith, K.P. & Sadok, W. (2022). Canopy cooling traits associated with yield performance in heat-stressed oat. European Journal of Agronomy 139, 126555.

Ding, Q., Zhen, X. & Sadok, W. (2025). Association between rising photosynthesis, and breeding for wheat yield gains in trials across the globe. Crop Science (under review).

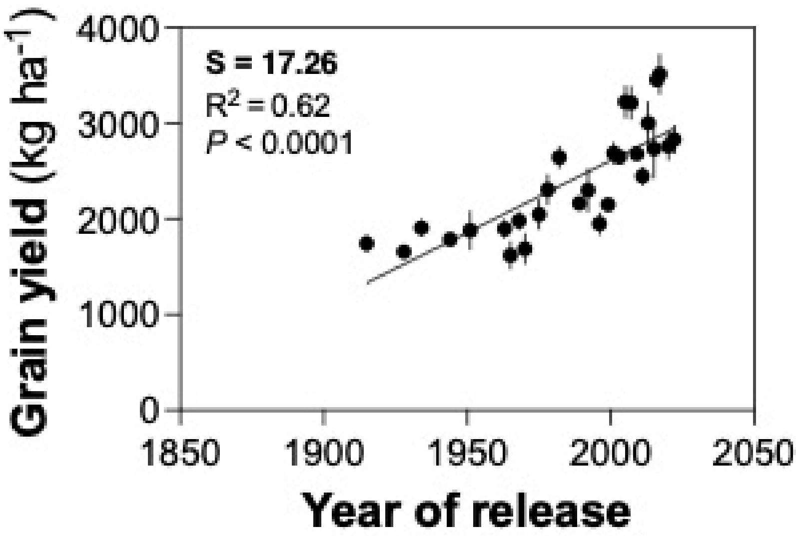

Figure 1. Yield gains as a function of the year of release across 28 varieties released by the U of MN wheat breeding program from 1915 to 2022 (two varieties are missing due to severe rust infestation).

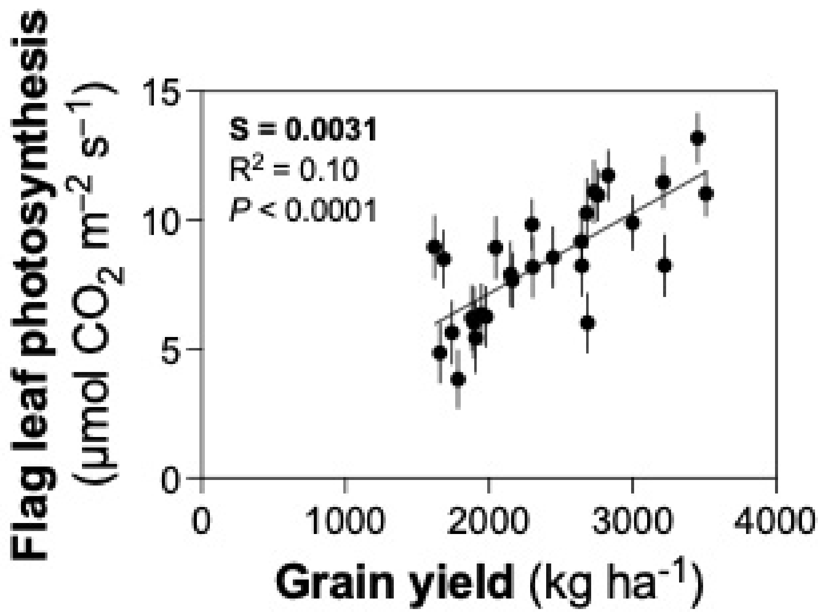

Figure 2. Relationship between wheat yield and flag leaf photosynthesis during seed fill across the tested population of spring wheat varieties released by the U of MN wheat breeding program from 1915 to 2022.

Wheat Multi-Trait Predictions: A Quantitative, Genotype x Environment (GxE) Approach to Supporting Minnesota Wheat Breeding and Farmer Varietal Selections

Principal Investigator(s): Kevin Silverstein (PI), Yuan Chai (co-PI) James Anderson (co-PI)

Project Period: February 1, 2024-December 31, 2024

Research Question/Objectives:
A perennial challenge faced by wheat breeders and producers is to identify and select the best performing varieties for each location. A high-yielding variety at one location during one season may not perform well at another location and/or another season, exemplifying the strong effects of Variety (Genotype) by Environment (GxE) interactions on crop performance. In this project, researchers at the UMN CFANS GEMS Informatics Center (led by Dr. Yuan Chai and Dr. Kevin Silverstein), in collaboration with breeder Dr. Jim Anderson from the Department of Agronomy and Plant Genetics, sought to develop a wheat trait prediction tool to intelligently combine crop performance data, genomic information, environmental conditions, and their GxE interactions to accurately predict the performance of different varieties under different environments. This tool aimed for simultaneous optimization in the selection of relevant traits under different environments, including grain yield, protein content, straw strength, heading date, height, and disease resistance.

Results:
Phenotype data from field trials: A database of wheat grain yields for 183 varieties and experimental lines grown in one or more years and up to 15 locations per year (Figure 1) was assembled from annual performance data files maintained by the UMN wheat breeding program. We obtained permission from the developers to include 135 varieties/lines in this study. End-use quality data from these same lines, grown at 2 locations per year and produced by the USDA-ARS Hard Spring and Durum Wheat Quality Laboratory (HSDWQL) in Fargo, has also been assembled.
MN wheat varieties genotyping results: For the panel of selected wheat varieties, GBS (Genotyping-by-Sequencing) resulted in over 11,000 SNP markers across the genome in each of the 128 panel lines that met stringent data quality thresholds. There was coverage across all the chromosomes. The distribution of SNP markers on each chromosome is shown in Figure 2. The underrepresentation of the D-genome is typical for wheat and was expected. The number of SNP markers obtained was about four times higher than we typically use in our prediction work, so marker coverage for genomic prediction should be excellent.

Environmental data and crop growth modeling: The wheat grain yield data from 15 trial locations and multiple years was used to select weather and soil features that were most important for yield prediction. A gridded map was produced for Minnesota showing environmental similarity of different zones with the trial sites using only the selected environmental features for comparison as shown in Figure 3. The spatially-explicit weather data was averaged over the preceding three years for more reliability as shown by Neyhart et al. (2022) to generate the environmental similarity grid. The idea is to be able to predict which of the already-tested lines would perform best in new untested locations that are similar in agroecological (i.e., soil and climate) terms to the trial sites.

Application/Use:
Faster varieties to market: In a typical wheat breeding cycle (as illustrated in Figure 4), it takes 9 years starting from the first cross to create a commercial variety. By the time the variety is released, it is already slightly out of date due to rapid climate changes, novel pest pressures, and changing market forces. It is anticipated that our novel prediction pipeline could shrink some time off the breeding cycle, which would allow growers to gain a season or two when the germplasm's design objectives will be most relevant.
Seeds better suited to growers' field conditions: The goal of the model we developed aimed at predicting which wheat varieties would perform most reliably well at any selected location within Minnesota in terms of yield, and selected quality traits (e.g., grain yield, protein content, straw strength, heading date, height, and disease resistance). If the error bars on predicted performance are too high for locations, then ranks of varieties could be returned.

Materials and Methods:
Phenotyping: Yield trial nurseries were grown as 50-80 sq. ft. plots with 3 replications per entry. Trial nurseries (up to 15 locations per year) are located across the wheat growing areas in the state of Minnesota. Spatial correction was performed within each location prior to calculating entry means.

Genotyping:
Genotyping by sequencing (GBS) uses next-generation DNA sequence technology (Illumina) to obtain single nucleotide polymorphism (SNP) markers across the entire genome. It is a fast and cost-effective method to genotype breeding populations with thousands of DNA markers that can be used in genomic selection. A panel of 128 cultivars and advanced experimental breeding lines phenotyped in yield trials in a minimum of 13 environments, and up to 138 environments, were genotyped at the University of Minnesota's Genomics Center (UMGC) using GBS. The short DNA sequence reads from each individual line were mapped to the Chinese Spring V2.1 reference genome (Zhu et al. 2021) to find the SNP markers and determine their physical positions in the genome.

Model development:
A coding pipeline has been designed to source weather data for each trial site and year combination from the GEMS Weather API. The soil data for each trial site was obtained by querying the GEMS Soil API. We recoded in Python our multi regression model, which was originally coded in R as published by Neyhart et al. (2022) for barley, and obtained similar performance when using a leave-one-location-out approach for testing prediction accuracy. However, we had concerns for overtraining. The weather in large swaths of the Midwest are largely similar in a given year, but highly variable from year to year. So training a model on a site in North Dakota and "leaving out" a Minnesota location, and then trying to "predict" the left-out site in that same year is not a challenging task. However, if you train your model over two years, and then predict over the next year, that is a much more difficult test – because you might observe weather patterns (e.g., drought during early vegetative stage) in that test year that were never observed in the trained years. Indeed, even the barley case, training a model on 2 years and testing that model on the third year yields much poorer correlation between predicted and observed yield and quality traits (< 0.5) compared with leave-one-out cross validation (> 0.95).

We tried many things with our 10 year wheat data set to create an acceptable predictive model without risking overtraining (e.g. train on 2012-2017 and test on 2018; train 2012-2018 and test 2019; migrate to a fully Bayesian model with great effort to enable us to make predictions for any arbitrarily related germplasm in any arbitrary location). Thus far, our best predictions out of the training sample never exceeded an R^2 value of 0.47. Figure 5 graphically shows the model performance comparison for yield. It's important to note that a model that completely disregards the input features (weather, soils and genetic variables) and always predicts the average yield value would score a 0 on this scale, and a model achieving perfect agreement would score a 1. So this model was able to explain nearly half of the variance driven by the input features.

Economic Benefit to a Typical 500 Acre Wheat Enterprise:
With further improvements in model performance, the spring wheat multi-trait prediction tool developed by this project should be able to improve the cost-effectiveness of regional spring wheat breeding programs by enabling breeders to select for varieties with a higher likelihood of success for a number of commercially valuable traits. As a result, a typical 500 acre wheat enterprise in Minnesota could have benefited from having earlier access to a wider selection of improved wheat varieties that are better matched to their local environmental conditions and changing market demands.

Future Work:
Our model performance has been unfairly penalized. Given how sporadic weather is, it is unrealistic to believe that we can train a dataset on 6 years of data and then predict the full yield outcomes for any given year in the future with reasonable accuracy. Yield is an incredibly complex trait and highly influenced by erratic weather patterns that may not have appeared at the same growth stage in the past. We plan to perform a more realistic, and still very valuable comparison in the future: Take the model trained on yields for the 6 year period 2012-2016 and then compute the performance ranks of each variety at every trial location from the model. Then compare that predicted performance rank at each site for each variety to the variety's average actual performance over the next five years 2017-2022. The reliable winning varieties at each location should percolate to the top when averaged over 5 years. The erratic ones should be somewhere in the middle, having had some good years and some bad years. And the reliably poor varieties should always be near the bottom. We suspect our performance on this measure will be good, and this would be very useful information for farmers. Also, we plan to do the same analysis over several additional traits (e.g., protein content, straw strength, heading date, height, and disease resistance) as some of these may be less complex and easier to predict than yield.

Related Research:
The model we have developed requires accurate weather data, soil characteristics, and crop calendar (planting date, harvest date) information for each location (training sites and farm query sites). The University of Minnesota's GEMS Informatics Center has invested substantial effort over the past few years into developing Application Programmer Interfaces (APIs) to make accessing this data easy, for any site on the globe. Both the multi-trait prediction tool and the API data retrieval tools are subject to on-going improvement. GEMS also has in-house hardware engineers who have developed sophisticated weather and soil sensor stations within our GEMS Sensing program. 2,200 sensing stations have already been deployed at various locations throughout the world, including across all of the ROCs (Research and Outreach Centers) located throughout Minnesota. Further, we have been working on predictive algorithms that use historic Crop Data Layer records to make estimates of which crops will be planted next season at 30 meters resolution. This will enable us to create improved crop-pest risk maps that are properly spatially resolved.
References:
Zhu, T., Wang, L., Rimbert, H., Rodriguez, J.C., Deal, K.R., De Oliveira, R., Choulet, F., Keeble-Gagnère, G., Tibbits, J., Rogers, J., Eversole, K., Appels, R., Gu, Y.Q., Mascher, M., Dvorak, J. and Luo, M.-C. (2021), Optical maps refine the bread wheat Triticum aestivum cv Chinese Spring genome assembly. The Plant Journal. Accepted Author Manuscript. https://doi.org/10.1111/tpj.15289 Neyhart J.L., Silverstein K.A.T., Smith K.P. (2022), Accurate predictions of barley phenotypes using genomewide markers and environmental covariates. Crop Science. DOI: 10.1002/csc2.20782

Publications (if any): NA.

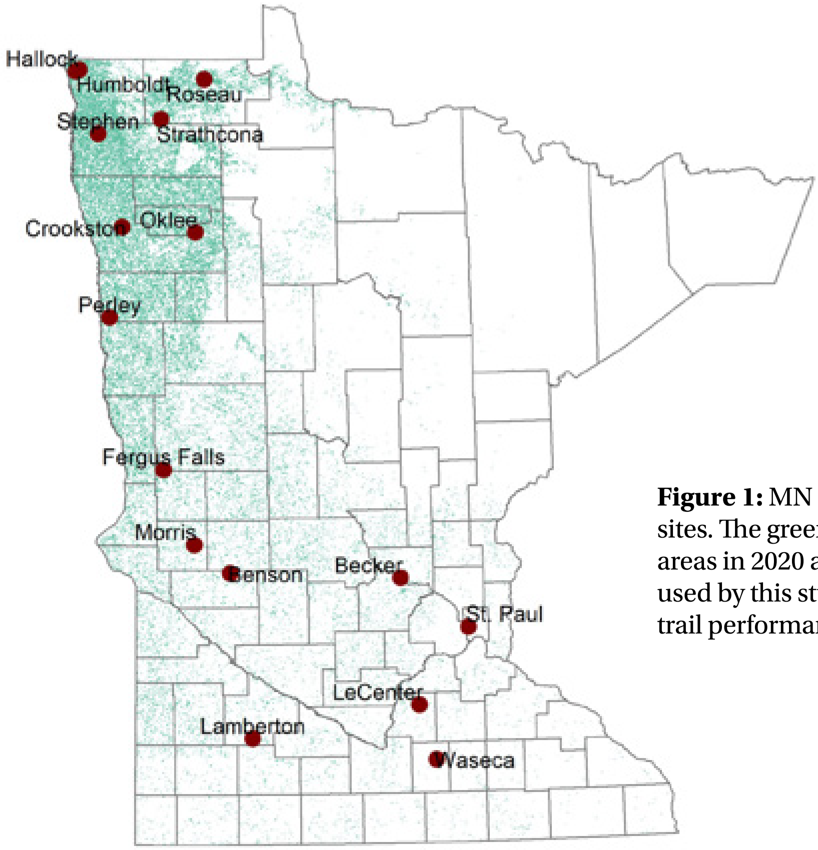

Figure 1: MN spring wheat phenotypic data trial sites. The green pixels represent wheat growing areas in 2020 and the red dots are the trial sites used by this study to source our phenotypic (i.e., trail performance) data.

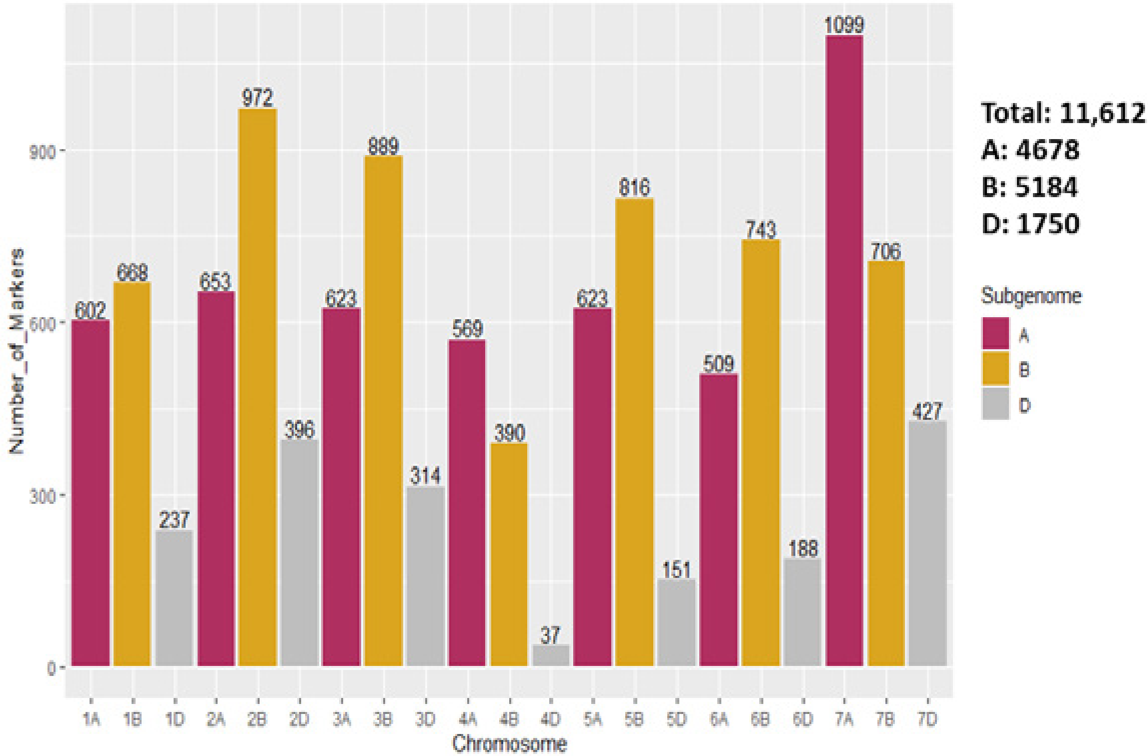

Figure 2: Number of markers by chromosome. Chromosomes are shown on the x-axis and the number of markers on the y-axis. The A-subgenome is depicted in maroon, the B-subgenome in gold, and the D-subgenome in gray. The total number of markers for the whole genome, and for each of the three subgenomes are listed to the right of the graph.

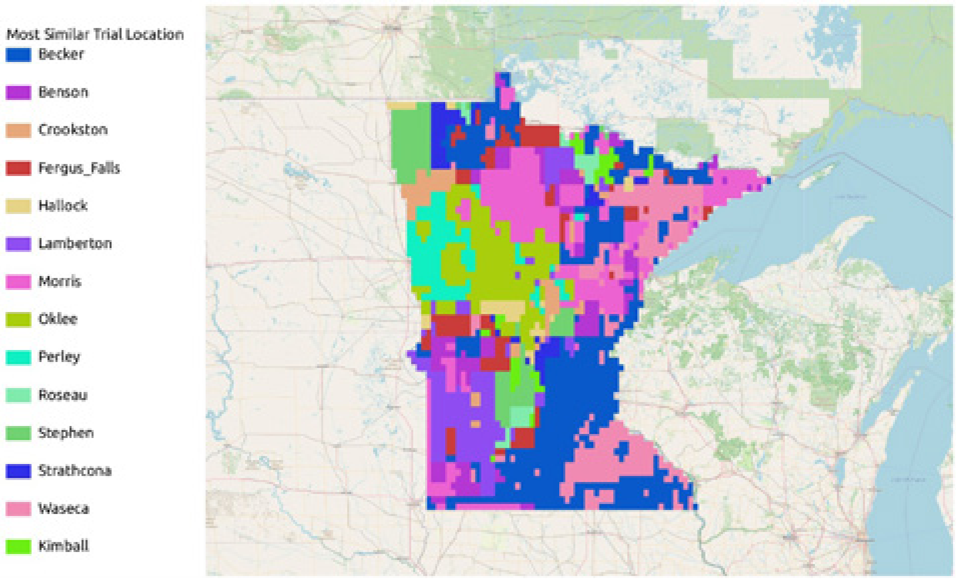

Figure 3: Environmental similarity map of Minnesota. A gridded map of Minnesota showing the environmental similarity of locations throughout the state with the trial sites used for this study. Each grid cell is 9 km2 in size and the color key for location similarity is given on the left of the map. Environmental features important for wheat yield were selected using the lasso grid search algorithm. Similarity of zones was based on Spearman's rank correlation calculation.The zones shown in this map are preliminary as we are still surveying different correlation metrics and feature selection protocol. Final procedures will be settled after conferring with our breeding team and growers.

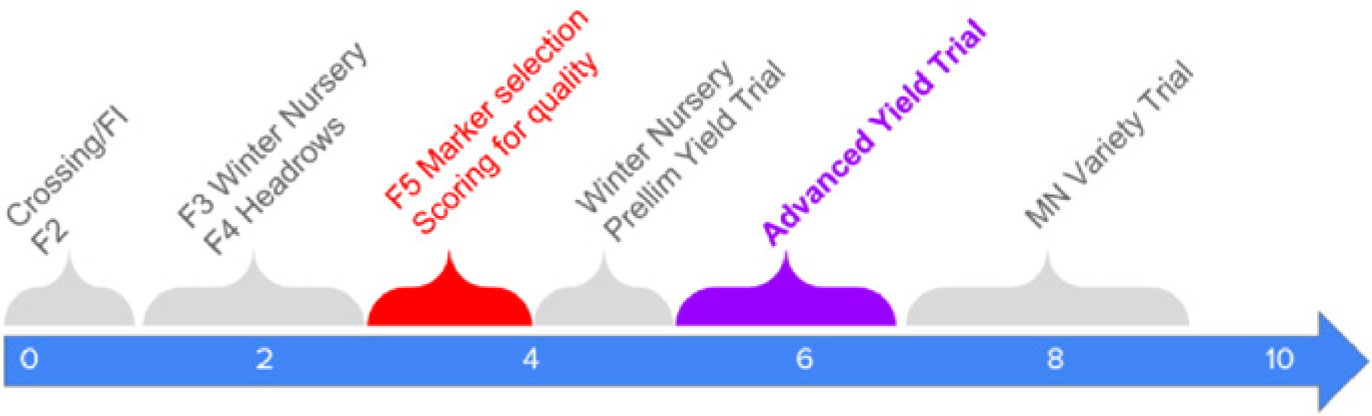

Figure 4. Typical MN wheat variety breeding cycle. The advancements in this research project are expected to shave a year off each of the activities highlighted in red and purple. In the red activity, there are far too many lines to do a complete phenotypic scoring. However, genotyping them all is easy. And based on those genotypes, our tool can produce very accurate phenotypic predictions. In the purple activity, our phenotypic predictions will greatly speed up the selection of the final parents to pass on to the next cycle.

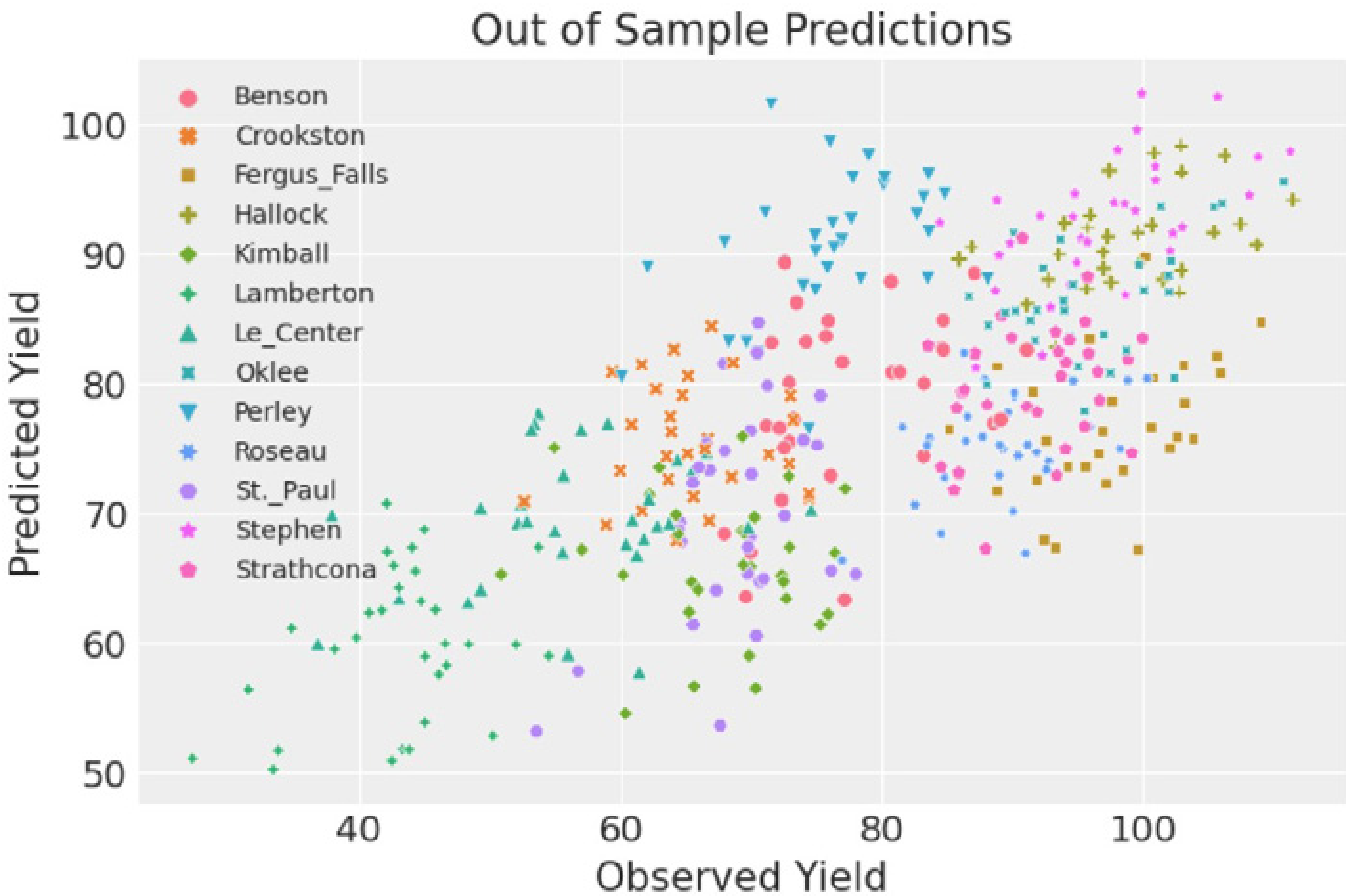

Figure 5. Predicted and observed wheat yield comparison. Bayesian model trained on 6 years of wheat yield data from 2012-2017 was used to predict yields for 2018 at the trial locations and demonstrated an accuracy score (R^2) of 0.47.

Continued Provision of Rapid End-use Quality Characterization Services to the University of Minnesota Wheat Breeding Program

Principal Investigator(s):

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Project Period: January – December 2024
Research Question/Objectives:
How does breeding activities by the University of Minnesota Breeding Program affect end-use Quality of Wheat?

Results:
We currently finishing up running the F5 samples since they were received at the end of October. About 370 of the samples from NZ have been run. Below is a graph of the predicted water absorption of about 400 of the samples that have been run.

Variety/ exp line	Predicted Water Absorption (%)	Variety/ exp line	Predicted Water Absorption (%)	Variety/ exp line	Predicted Water Absorption (%)	Variety/ exp line	Predicted Water Absorption (%)	Variety/ exp line	Predicted Water Absorption (%)	Variety/ exp line	Predicted Water Absorption (%)	Variety/ exp line	Predicted Water Absorption (%)	Variety/ exp line	Predicted Water Absorption (%)
MN24001	60	MN24066	57	MN24127	58	MN24189	63	MN24254	56	MN24325	49	MN24390	52	MN24479	55
MN24003	63	MN24067	67	MN24128	66	MN24190	58	MN24255	51	MN24326	57	MN24393	46	MN24480	55
MN24005	52	MN24068	66	MN24129	62	MN24192	55	MN24256	45	MN24327	57	MN24395	61	MN24481	58
MN24007	66	MN24069	54	MN24130	57	MN24193	51	MN24257	48	MN24328	49	MN24396	43	MN24482	58
MN24009	48	MN24070	56	MN24131	45	MN24194	68	MN24258	63	MN24329	37	MN24397	46	MN24483	51
MN24010	48	MN24071	60	MN24133	40	MN24196	42	MN24259	56	MN24330	45	MN24398	53	MN24485	55
MN24011	53	MN24073	69	MN24134	61	MN24197	50	MN24260	58	MN24331	62	MN24399	56	MN24486	57
MN24013	61	MN24075	57	MN24136	69	MN24199	54	MN24261	60	MN24332	61	MN24400	52	MN24487	40
MN24016	56	MN24076	66	MN24138	58	MN24200	64	MN24262	60	MN24333	66	MN24402	68	MN24488	69
MN24017	62	MN24077	68	MN24139	49	MN24201	59	MN24263	61	MN24335	63	MN24404	51	MN24490	66
MN24019	50	MN24079	58	MN24141	55	MN24202	61	MN24268	69	MN24336	68	MN24407	64	MN24491	58
MN24020	44	MN24080	64	MN24143	58	MN24203	52	MN24269	66	MN24337	61	MN24408	62	MN24492	44
MN24021	59	MN24081	58	MN24144	64	MN24205	65	MN24271	56	MN24338	59	MN24410	52	MN24493	57
MN24022	52	MN24082	56	MN24145	66	MN24206	67	MN24272	54	MN24339	47	MN24411	64	MN24494	44
MN24024	61	MN24083	52	MN24146	45	MN24207	52	MN24274	59	MN24340	43	MN24414	61	MN24495	59
MN24025	64	MN24084	67	MN24147	48	MN24208	64	MN24277	66	MN24341	55	MN24416	56	MN24496	56
MN24026	56	MN24085	55	MN24148	67	MN24209	64	MN24278	58	MN24342	66	MN24418	60	MN24497	59
MN24027	66	MN24088	52	MN24149	69	MN24210	46	MN24279	55	MN24348	60	MN24420	59	MN24498	52
MN24028	56	MN24089	55	MN24150	51	MN24211	66	MN24282	68	MN24351	56	MN24421	51	MN24499	64
MN24029	64	MN24090	68	MN24151	63	MN24212	57	MN24283	59	MN24352	59	MN24422	56	MN24500	65
MN24032	63	MN24092	54	MN24152	61	MN24213	57	MN24284	67	MN24353	36	MN24423	58	MN24501	39
MN24033	50	MN24093	66	MN24155	46	MN24214	52	MN24285	43	MN24354	49	MN24430	66	MN24502	64
MN24034	56	MN24094	61	MN24156	62	MN24215	53	MN24286	64	MN24355	60	MN24433	47	MN24503	48
MN24035	68	MN24095	59	MN24157	64	MN24216	69	MN24287	57	MN24356	53	MN24434	45	MN24504	49
MN24036	59	MN24097	49	MN24158	54	MN24220	67	MN24288	61	MN24357	67	MN24435	63	MN24505	53
MN24037	55	MN24098	65	MN24159	61	MN24221	54	MN24292	56	MN24358	55	MN24436	36	MN24507	67
MN24038	58	MN24099	41	MN24160	51	MN24222	67	MN24293	50	MN24359	57	MN24437	60	MN24508	61
MN24040	61	MN24100	55	MN24161	69	MN24223	54	MN24295	52	MN24361	64	MN24438	68	MN24510	43
MN24041	66	MN24101	63	MN24162	60	MN24224	65	MN24296	63	MN24362	45	MN24439	60	MN24511	35
MN24042	67	MN24103	67	MN24163	67	MN24225	67	MN24299	69	MN24363	46	MN24440	62	MN24512	59
MN24043	69	MN24104	60	MN24164	57	MN24226	55	MN24301	67	MN24364	47	MN24441	67	MN24513	55
MN24044	54	MN24105	59	MN24165	63	MN24227	60	MN24302	63	MN24365	39	MN24442	52	MN24514	59
MN24045	52	MN24106	54	MN24166	58	MN24228	66	MN24303	61	MN24366	44	MN24445	60	MN24515	64
MN24047	60	MN24107	66	MN24167	65	MN24229	48	MN24305	60	MN24367	51	MN24447	58	MN24516	59
MN24048	53	MN24108	57	MN24168	69	MN24230	49	MN24306	65	MN24368	45	MN24448	59	MN24517	58
MN24049	43	MN24109	53	MN24169	66	MN24231	62	MN24307	65	MN24369	52	MN24449	59	MN24518	67
MN24050	61	MN24110	56	MN24170	65	MN24232	67	MN24309	49	MN24371	54	MN24451	50	MN24519	52
MN24051	61	MN24111	63	MN24171	68	MN24234	55	MN24310	44	MN24373	53	MN24452	69	MN24520	54
MN24053	67	MN24112	54	MN24172	56	MN24235	61	MN24311	64	MN24374	41	MN24453	56	MN24521	55
MN24054	59	MN24113	58	MN24174	59	MN24236	53	MN24313	59	MN24375	53	MN24457	55	Linkert	66
MN24055	64	MN24115	61	MN24175	61	MN24237	59	MN24314	51	MN24376	55	MN24458	53	MN-Rothsay	61
MN24056	50	MN24116	44	MN24176	67	MN24239	57	MN24315	67	MN24377	60	MN24459	59	Linkert	69
MN24057	47	MN24117	64	MN24177	58	MN24240	63	MN24316	52	MN24378	57	MN24461	56	MN-Rothsay	47
MN24058	54	MN24119	57	MN24180	69	MN24241	62	MN24317	55	MN24379	62	MN24463	67	MN-Rothsay	48
MN24059	66	MN24120	63	MN24181	36	MN24243	62	MN24318	50	MN24381	54	MN24465	54	Linkert	49
MN24060	48	MN24121	59	MN24183	58	MN24244	67	MN24319	54	MN24383	61	MN24466	65	MN-Rothsay	66
MN24061	65	MN24122	68	MN24184	59	MN24246	53	MN24320	61	MN24384	66	MN24468	58	Linkert	65
MN24062	69	MN24123	66	MN24186	53	MN24247	53	MN24321	57	MN24385	60	MN24473	48	MN-Rothsay	58
MN24063	52	MN24124	62	MN24187	64	MN24248	58	MN24323	49	MN24387	65	MN24474	61	Lang-MN	59
MN24065	53	MN24125	64	MN24188	61	MN24252	64	MN24324	48	MN24388	58	MN24478	68	MN11394-6	39
														MN-Torgy	64

Application/Use:
The calculated water absorptions, along with grain protein and test weight data are the only end-use quality data the breeding program needs to help decide which of these entries will be advanced for yield trials in 2024.

Materials and Methods:
For this period, we received a total of about 815 samples for analysis. The samples were made up of about 550 wheat samples from the 2024 PY remnant from NZ and 265 samples from the 2024 F5s from Minnesota. These samples were milled into flour and their protein aggregation kinetics being determined using the Brabender Gluten Peak tester. The samples also included some checks as well.

Economic Benefit to a Typical 500 Acre Wheat Enterprise:

Results from this study enables the University of Minnesota Wheat breeding program to incorporate selection for good end-use quality earlier in the breeding efforts, thus avoiding the continued testing poor quality lines. The results of this research will be used to develop models that can be used to select for varieties with end-use quality parameters that are valued by our hard-red spring wheat customers. Such varieties will help to maintain the price premium of hard red spring wheat.

Related Research:
N/A

Recommended Future Research:
N/A

References:

N/A

Publications:
N/A

North Dakota Hard Red Spring Wheat Variety Trial Results for 2024 and Selection Guide

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Hard red spring (HRS) wheat was planted on 5.4 million acres in 2024, down slightly from 5.6 million acres in 2023. The average yield of HRS wheat was 59 bushels/acre (bu/a) across the state, up substantially from 49 bu/a in 2023. If downward revisions are not made, 2024 will be a new record for highest average state-wide spring wheat yield in North Dakota. The 2024 growing season was generally favorable for high spring wheat yields with a long, cool spring and abundant moisture compared to recent drought years, especially in the western and central parts of the state. While most of the spring was ideal for spring wheat vegetative growth, a few weeks of extremely high temperatures during early grain fill coupled with a dry July took the top off what could have been even bigger yields.

WB9590 was the most popular HRS wheat variety in 2024, reportedly occupying 13.8% of the planted acreage, followed by SY Valda (10.0%), AP Murdock (9.8%), MN Torgy (4.7%), and SY Ingmar (4.4%) rounding out the top 5 varieties. WB9590 was released by WestBred/Monsanto. SY Valda, AP Murdock, and SY Ingmar are Syngenta/ AgriPro varieties. MN Torgy is a University of Minnesota release. NDSU varieties Faller and Glenn were reported on 3.0% and 1.7% of acres, respectively. Glenn is considered a very high-quality spring wheat and is still contracted on some acres by the ND Mill to ensure the high-quality flour demanded by discerning buyers.

In regards to quality characteristics important to end users, the marketed 2024 HRS wheat crop was characterized by high grades, average protein levels, and good functional characteristics across the northern HRS wheat growing region. Slightly more than 90% of samples tested by the NDSU Hard Red Spring Wheat Quality Laboratory graded at US class No.1, an exceptionally high proportion. Average test weight was 61.3 lbs/ bu, similar to the 5-year average. Protein was somewhat below normal in samples from eastern ND, largely assumed to be a result of high yields, and slightly above average for western portions of the state. Crop damage ranging from mild to severe was experienced in central and eastern regions of ND when 2-6” of rain fell in less than a one-week period in mid-August on many fields of mature HRS wheat prior to harvest. This unfortunate situation contributed to low falling numbers, pre-harvest sprout damage, and discounts and/ or rejection of HRS wheat loads for some producers in the central portion of the state.

Successful wheat production depends on numerous factors, including selecting the right variety for a particular area. The information included in this publication is meant to aid in selecting that variety or group of varieties. Characteristics to consider in selecting a variety may include yield potential, protein content when grown with proper fertility, straw strength, plant height, response to problematic pests (diseases, insects, etc.) and maturity. Every growing season differs; therefore, when selecting a variety, we recommend using data that summarize several years and locations. Choose the variety that, on average, performs the best at multiple locations near your farm during several years.

Selecting varieties with good milling and baking quality also is important to maintain market recognition and avoid discounts. Hard red spring wheat from the northern Great Plains is known around the world for its excellent end-use quality. It is recommended that readers balance their variety selection taking into consideration not only yield, but also the quality rankings presented in this publication on Table 6.

Millers and bakers consider many factors in determining the quality and value of wheat they purchase. Several key parameters are: high test weight (for optimum milling yield and flour color), high falling number (greater than 300 seconds indicates minimal sprout damage), high protein content (the majority of HRS wheat export markets want at least 14% protein) and excellent protein quality (for superior bread-making quality as indicated by traditional strong gluten proteins, high baking absorption and large bread loaf volume). These data are presented in Tables 6 and 7.

Gluten strength and milling and baking quality ratings are provided for individual varieties based on the results from the NDSU field plot variety trials in multiple locations in 2023 (Table 7). The wheat protein data often are higher than obtained in actual production fields but can be used to compare relative differences among varieties.

The agronomic data presented in this publication are from replicated research plots using experimental designs that enable the use of statistical analysis. These analyses enable the reader to determine, at a predetermined level of confidence, if the differences observed among varieties are reliable or if they might be due to error inherent in the experimental process.

The LSD (least significant difference) values beneath the columns in the tables are derived from these statistical analyses and apply only to the numbers in the column in which they appear. If the difference between two varieties exceeds the LSD value shown at the bottom of the table, it means that with 90% confidence (LSD probability 0.10), the higher-yielding variety has a significant and real yield advantage. When the difference between two varieties is less than the LSD value, no significant difference was found between those two varieties under those growing conditions. Ideally, aim to select varieties that are high-yielding, preferably across locations and years, for your region of the state, along with those varieties that appear in the top half of the Wheat Quality Index ratings.

NS is used to indicate no significant difference for that trait among any of the varieties tested at the 90% level of confidence. CV stands for coefficient of variation and is expressed as a percentage. The CV is a measure of variability in the trial. Large CVs (CV > 10%) indicate that a large amount of variation could not be attributed to differences among the varieties. Yield is reported on a 13.5% moisture basis, while protein content is reported at 12% moisture content, as per industry standards.

Presentation of data for the entries tested does not imply approval or endorsement by the authors or agencies conducting the test. North Dakota State University approves the reproduction of any table in the publication only if no portion is deleted or altered, appropriate footnotes are given, and the order of the data is not rearranged. Additional data from county sites are available from each NDSU Research Extension Center and at https://www.ag.ndsu.edu/varietytrials/variety-trial-results.

Due to the high rainfall and cool early-season growing conditions, fungal pathogens of HRS wheat were much more prevalent in 2024 than the previous 5 years. Below is a list of disease issues of concern at the trial locations in which they were observed. The reader is cautioned to keep the disease susceptibility ratings presented in Table 1 in mind when evaluating characteristics of susceptible varieties in Tables 2-5.

Location	**2024 Disease observations**
Carrington	Fusarium Head Blight (FHB), or head scab, pressure high and assumed to have reduced yields and test weight in susceptible varieties.
Casselton	Stripe rust pressure was high and disease was present on the flag leaf at head emergence. Moderate tan spot and bacterial leaf streak pressure, with heavy stem rust and significant damage from FHB. Leaf rust was also present on susceptible varieties which still had leaves in later stages of grain fill.
Forman	Very high levels of FHB damage from high disease pressure throughout the season.
Prosper	Low to moderate levels of leaf and stem rust present and moderate FHB pressure.
Hettinger	Severe stripe rust pressure early in the season but as the weather turned hot and dry, the infestation
subsided.	Stripe rust-susceptible varieties are assumed to have lost yield.
Dickinson	Similar to Hettinger, early strip rust pressure was high; however, the season turned hot and dry and the disease subsided. Susceptible varieties may have lost some yield.

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Table 1. North Dakota hard red spring wheat variety descriptions, agronomic traits, 2024.

Variety	Agent or Origin[1]	Year Released	Height (inches)[2]	Straw Strength[3]	Days to Head[4]	Reaction to Disease[5]: Stem Rust[6]	Leaf Rust	Tan Spot	Bact. Leaf Streak	Head Scab	Stripe Rust
Ambush	Dyna-Gro	2016	33	5	57	2	6	NA	6	5	NA
AP Elevate	**Syngenta/AgriPro**	**2024**	**32**	**4**	**60**	**2**	**4**	**NA**	**7**	**5**	**3**
AP Gunsmoke CL2	Syngenta/AgriPro	2021	33	6	58	2	4	5	8	5	**4**
AP Murdock	Syngenta/AgriPro	2019	33	4	58	2	5	3	6	5	3
AP Smith	Syngenta/AgriPro	2021	32	3	60	1	3	5	5	6	**4**
Ascend-SD	SD	2022	38	4	60	2	4	6	4	4	**3**
Ballistic	Dyna-Gro	2018	35	5	59	1	9	NA	7	4	NA
Bolles	MN	2015	34	4	61	2	1	4	6	5	4
Brawn-SD	SD	2022	36	4	59	2	2	4	5	7	6
CAG-Ceres	**Champions Alliance Grp**	**2024**	**33**	**3**	**64**	**2**	**9**	**NA**	**7**	**7**	**6**
CAG-Justify	Champions Alliance Grp	2021	33	6	58	2	2	4	6	6	4
CAG-Reckless	Champions Alliance Grp	2021	36	4	60	2	2	7	6	4	4
CAG Recoil	Champions Alliance Grp	2022	36	2	59	2	2	NA	5	7	3
Commander	Dyna-Gro	2019	34	4	57	2	2	NA	8	5	NA
CP3055[7]	**Croplan**	**2023**	**35**	**3**	**67**	**6**	**8**	**NA**	**6**	**7**	**3**
CP3099A	Croplan	2020	38	4	64	7	5	6	5	7	1
CP3119A[7]	Croplan	2021	37	2	67	2	8	NA	5	7	1
CP3188	Croplan	2020	35	8	59	7	2	6	6	7	9
CP3322[7]	**Croplan**	**2023**	**34**	**3**	**65**	**3**	**8**	**NA**	**6**	**8**	**3**
CP3360AX	**Croplan**	**2024**	**33**	**4**	**57**	**2**	**6**	**NA**	**6**	**5**	**8**
CP3915	Croplan	2019	33	4	59	2	1	NA	6	5	6
Driver	SD	2019	35	4	61	2	1	6	8	4	2
Faller	ND	2007	36	7	60	2	8	NA	6	5	8
Glenn	ND	2005	38	4	57	2	7	6	6	4	3
Lanning	MT	2016	34	4	59	2	6	4	6	7	4
LCS Ascent	Limagrain	2022	33	6	56	2	6	8	7	4	2
LCS Boom	**Limagrain**	**2023**	**33**	**4**	**56**	**1**	**5**	**8**	**6**	**6**	**2**
LCS Buster	Limagrain	2020	36	4	64	1	3	4	4	4	4
LCS Cannon	Limagrain	2018	32	3	56	1	5	6	7	5	4
LCS Dual	Limagrain	2020	34	3	58	2	4	6	7	6	6
LCS Hammer AX	Limagrain	2022	33	2	58	2	7	8	7	8	2
LCS Trigger	Limagrain	2016	36	5	65	2	1	3	4	3	6
MN- Rothsay	MN	2022	31	3	61	2	6	3	6	6	6
MN-Torgy	MN	2020	34	4	59	2	3	4	6	4	3
MS Charger	Meridian Seeds	2022	33	8	58	2	3	6	7	5	8
MS Cobra	Meridian Seeds	2022	33	5	59	1	2	8	7	6	3
MS Nova	**Meridian Seeds**	**2024**	**33**	**4**	**57**	**NA**	**4**	**NA**	**8**	**5**	**3**
MS Ranchero	Meridian Seeds	2020	38	7	62	2	6	6	6	5	4
MT Carlson	**MT**	**2023**	**33**	**5**	**58**	**1**	**8**	**NA**	**7**	**8**	**4**
MT Dutton	**MT**	**2023**	**34**	**4**	**59**	**2**	**4**	**NA**	**8**	**6**	**6**
MT Ubet	**MT**	**2024**	**34**	**5**	**59**	**2**	**8**	**NA**	**6**	**8**	**8**
ND Frohberg	ND	2020	37	3	60	2	4	8	5	5	3
ND Heron	ND	2021	34	6	56	1	6	4	7	4	6
ND Stampede	**ND**	**2024**	**34**	**4**	**58**	**1**	**6**	**NA**	**7**	**5**	**9**
ND Thresher	**ND**	**2023**	**33**	**5**	**60**	**2**	**5**	**4**	**4**	**4**	**6**
ND VitPro	ND	2016	34	4	58	2	4	6	6	4	4
PFS Buns	Peterson Farm Seeds	2021	33	7	68	1	3	4	4	6	9
PFS Rolls	**Peterson Farm Seeds**	**2023**	**35**	**4**	**61**	**3**	**4**	**NA**	**5**	**8**	**6**
Rocker	**Dyna-Gro**	**2019**	**34**	**4**	**61**	**2**	**6**	**NA**	**7**	**8**	**NA**
Shelly	MN	2016	33	5	61	2	6	4	7	5	4
SY 611CL2	Syngenta/AgriPro	2019	31	4	58	2	6	5	6	4	4
SY Ingmar	Syngenta/AgriPro	2014	33	4	60	2	3	5	6	5	4
SY Longmire[7]	Syngenta/AgriPro	2019	32	4	59	2	5	5	6	7	3
SY Valda	Syngenta/AgriPro	2015	33	5	59	2	3	5	7	5	8
TCG-Badlands	**21st Century Genetics**	**2024**	**33**	**3**	**59**	**1**	**6**	**NA**	**6**	**7**	**3**
TCG-Teddy	**21st Century Genetics**	**2023**	**30**	**2**	**60**	**2**	**4**	**6**	**6**	**7**	**2**
TCG-Wildcat	21st Century Genetics	2020	34	3	60	2	4	7	7	7	6
WB9590	WestBred	2017	30	3	58	2	3	7	8	8	8
WB9719	WestBred	2018	32	4	61	2	5	3	5	7	4

[1]Refers to agent or developer: MN = Univ of Minnesota; MT = Montana State Univ; ND = North Dakota State Univ; SD = South Dakota State Univ

Varieties in bold text = either recent release or first year in NDSU trials with limited data available and rating values may change.

[2]Height data averaged from 9 locations in 2024.

[3]Straw Strength = 1 to 9 scale, with 1 the strongest and 9 the weakest. These values are based on recent data and may change as more data become available.

[4]Days to Head = the number of days from planting to head emergence from the boot, averaged based on data from 7 locations in 2024.

[5]Disease reaction scores from 1 to 9, with 1 = resistant and 9 = very susceptible, NA = not available.

[6]Stem rust scores determined from field severity ratings and *Puccinia graminis* f. sp. *tritici* race QFCQ

[7]Solid stem or semi-solid stem for increased resistance to wheat stem sawfly.

Table 2. Yield of hard red spring wheat varieties at 5 locations in eastern North Dakota 2022-2024.

	Carrington		Casselton		Forman		Langdon		Prosper		Average	
Variety	**2024**	**3 Yr.**	**2024**	**3 Yr.**	**2024**	**2 Yr.**	**2024**	**3 Yr.**	**2024**	**2 Yr.**	**2024**	**3 Yr.**
					(bu/a)							
Ambush	71.7	--	85.8	--	61.5	--	82.8	80.5	86.9	--	77.7	--
AP Elevate	**76.0**	**--**	**90.3**	--	**65.4**	--	**89.0**	**--**	**90.7**	**--**	**82.3**	**--**
AP Gunsmoke CL2	56.8	62.2	80.6	79.3	62.2	67.0	77.3	78.2	84.2	85.9	72.2	73.2
AP Murdock	78.2	66.1	88.9	84.7	69.4	68.9	85.5	83.7	91.2	89.8	82.6	78.1
AP Smith	77.1	65.0	88.8	80.3	64.9	66.2	86.2	80.4	85.5	85.1	80.5	75.2
Ascend-SD	75.9	73.2	90.7	83.0	59.0	64.0	80.2	83.8	91.5	96.4	79.4	80.0
Ballistic	75.1	--	97.9	--	67.8	--	90.2	86.9	96.8	--	85.5	86.9
Bolles	68.2	60.9	84.7	78.4	56.0	60.5	76.7	73.7	84.9	86.5	74.1	71.0
Brawn-SD	70.5	66.0	89.5	84.2	57.7	66.1	84.6	82.8	94.1	101.5	79.3	77.7
CAG-Ceres	**72.5**	**--**	**84.3**	--	**59.4**	--	**79.8**	**--**	**83.5**	**--**	**75.9**	--
CAG-Justify	68.6	66.4	90.9	85.8	58.0	64.5	83.5	85.6	88.1	92.4	77.8	79.3
CAG-Reckless	64.5	63.1	90.6	84.9	61.1	65.6	84.5	83.8	87.8	93.6	77.7	77.2
CAG Recoil	66.2	--	86.4	--	62.0	--	90.4	--	83.4	--	77.7	--
Commander	76.0	--	91.1	--	66.8	--	81.7	77.6	87.2	--	80.5	77.6
CP3055[7]	**58.3**	**--**	**77.1**	--	**42.3**	--	**91.5**	**--**	**77.7**	**--**	**69.4**	--
CP3099A	66.4	63.0	58.7	72.9	39.3	55.8	78.9	79.3	95.5	99.0	67.8	71.7
CP3119A[7]	53.9	--	74.8	--	39.6	--	85.8	--	74.7	--	65.7	--
CP3188	66.5	62.0	86.8	81.5	59.7	64.1	78.5	76.6	78.4	84.6	74.0	73.4
CP3322[7]	**51.3**	**--**	**71.8**	--	**40.8**	**52.2**	**79.0**	**--**	**79.2**	**85.0**	**64.4**	--
CP3360AX	**--**	**--**	**87.4**	--	**60.4**	--	**83.3**	**--**	**85.1**	**--**	**79.1**	**--**
CP3915	70.6	--	92.6	--	57.5	63.1	81.9	80.5	84.5	89.1	77.4	80.5
Driver	72.6	68.2	94.0	82.9	61.6	64.5	82.2	82.7	90.4	90.9	80.1	77.9
Faller	76.1	--	87.7	--	59.8	--	89.2	85.2	96.7	--	81.9	85.2
Glenn	67.2	59.6	79.8	71.2	52.7	60.7	69.0	68.4	81.2	82.4	70.0	66.4
Lanning	55.7	58.3	76.7	75.4	50.8	59.2	78.5	71.4	83.6	87.4	69.0	68.4
LCS Ascent	78.8	63.1	94.1	87.7	65.4	65.9	83.7	84.2	89.3	89.6	82.3	78.4
LCS Boom	**81.8**	**--**	**90.4**	--	**71.5**	**64.6**	**86.2**	**--**	**84.5**	**86.8**	**82.9**	--
LCS Buster	66.1	65.0	92.0	85.6	61.9	66.7	93.5	86.7	98.0	101.6	82.3	79.1
LCS Cannon	81.2	64.8	87.0	81.3	65.8	66.3	80.1	81.1	82.8	82.5	79.4	75.7
LCS Dual	66.2	64.1	84.9	82.7	38.9	54.3	80.8	77.9	76.8	85.7	69.5	74.9
LCS Hammer AX	77.2	68.1	70.4	76.9	48.7	55.1	83.3	80.7	81.7	87.6	72.2	75.3
LCS Trigger	72.3	67.8	99.4	89.8	67.7	69.2	88.3	87.2	92.2	98.1	84.0	81.6
MN- Rothsay	70.2	64.7	85.7	79.8	61.0	64.5	87.6	81.6	90.2	89.5	78.9	75.3
MN-Torgy	72.5	64.4	96.9	80.9	65.2	68.0	81.5	79.6	88.2	93.4	80.9	75.0
MS Charger	86.9	70.6	90.1	90.2	72.6	69.3	87.2	87.3	89.7	93.0	85.3	82.7
MS Cobra	74.0	65.7	91.3	82.9	64.6	65.2	82.9	76.3	88.9	89.0	80.3	74.9
MS Nova	**69.6**	**--**	**86.5**	-	**60.6**	-	**73.3**	**--**	**79.9**	**--**	**74.0**	--
MS Ranchero	38.9	58.6	87.7	66.0	60.5	56.3	88.3	80.9	82.3	81.8	71.5	68.5
MT Carlson	**69.3**	**--**	**74.0**	-	**51.5**	-	**83.5**	**--**	**82.1**	**--**	**72.1**	--
MT Dutton	**60.9**	**--**	**79.4**	-	**53.7**	-	**81.3**	**--**	**78.7**	**--**	**70.8**	--
MT Ubet	**65.7**	**--**	**82.1**	-	**49.6**	-	**80.9**	**--**	**85.0**	**--**	**72.7**	--
ND Frohberg	68.1	65.6	85.9	81.5	51.4	58.8	75.4	76.1	84.8	87.1	73.1	74.4
ND Heron	67.4	59.9	80.6	76.3	62.2	62.0	74.1	74.3	87.9	86.0	74.4	70.2
ND Stampede	**84.5**	**70.2**	**80.8**	**84.4**	**73.4**	**71.1**	**89.8**	**85.6**	**98.6**	**94.6**	**85.4**	80.1
ND Thresher	**68.1**	**62.2**	**82.2**	**74.1**	**62.5**	**60.5**	**75.4**	**75.0**	**84.8**	**92.2**	**74.6**	70.5
ND VitPro	65.9	57.3	82.6	73.3	52.9	58.7	74.1	71.7	82.9	85.0	71.7	67.4
PFS Buns	63.9	62.5	80.1	78.8	55.1	58.6	94.2	--	88.7	96.3	76.4	70.7
PFS Rolls	**63.3**	**--**	**81.7**	-	**57.2**	-	**90.2**	**--**	**95.3**	**--**	**77.5**	--
Rocker	**59.4**	**--**	**72.7**	-	**40.5**	-	**77.9**	**--**	**83.8**	**--**	**66.9**	--
Shelly	69.2	66.6	88.1	82.4	64.5	68.6	91.0	84.2	93.5	92.8	81.3	77.7
SY 611CL2	73.3	67.8	93.9	80.2	69.5	66.4	82.2	83.4	87.7	92.7	81.3	77.1
SY Ingmar	75.4	62.2	84.4	78.5	60.3	62.5	74.0	73.5	84.6	86.7	75.8	71.4
SY Longmire[7]	67.6	62.5	73.4	71.3	45.1	57.3	76.4	72.7	81.9	89.7	68.9	68.8
SY Valda	77.3	68.3	96.5	84.2	74.9	72.0	86.6	84.0	93.9	96.3	85.8	78.8
TCG-Badlands	**72.9**	**--**	**84.4**	-	**57.5**	-	**77.9**	**--**	**86.1**	**--**	**75.8**	--
TCG-Teddy	**70.6**	**--**	**80.1**	-	**57.9**	**62.7**	**81.2**	**--**	**83.4**	**86.1**	**74.6**	--
TCG-Wildcat	82.3	69.6	89.6	85.4	56.8	59.3	82.6	80.6	96.1	95.5	81.5	78.5
WB9590	67.6	64.4	75.9	82.5	57.6	61.1	83.6	79.0	88.9	92.2	74.7	75.3
WB9719	65.7	--	76.5	-	47.2	57.1	81.0	--	88.9	99.0	71.9	--
Mean	69.8	64.6	85.3	80.6	59.1	63.0	82.8	80.1	87.3	90.5	76.5	75.7
CV%	7.2	--	4.9	--	4.2	--	4.3	--	4.6	--	7.3	--
LSD 0.10	5.9	--	6.3	--	3.6	--	4.1	--	3.6	--	5.8	--

Table 3. Yield of hard red spring wheat varieties grown at 5 locations in western North Dakota 2022-2024.												
	Dickinson		Hettinger		Mandan		Minot		Williston		Average	
Variety	2024	2 Yr.	2024	3 Yr.	2024	3 Yr.	2024	3 Yr.	2024	2 Yr.	2024	3 Yr.
		---------- (bu/a) ----------										
Ambush	68.5	--	56.9	--	58.6	--	62.7	--	69.4	--	63.2	--
AP Elevate	**67.4**	**--**	**60.4**	**--**	**70.0**	**--**	**65.3**	**--**	**77.1**	**--**	**68.0**	**--**
AP Gunsmoke CL2	67.0	60.0	61.3	75.0	62.2	59.3	50.6	58.9	74.5	56.0	63.1	64.4
AP Murdock	69.3	55.5	56.7	68.5	68.7	62.2	67.3	63.1	76.3	54.8	67.7	64.6
AP Smith	57.7	55.4	54.6	70.6	61.3	56.2	51.9	59.4	70.4	45.0	59.2	62.1
Ascend-SD	66.4	57.5	60.2	72.6	74.4	65.5	55.7	--	75.9	48.6	66.5	69.1
Ballistic	62.5	--	59.2	--	71.5	--	64.6	--	77.8	-	67.1	--
Bolles	58.5	52.1	60.8	69.0	60.6	56.1	66.9	66.3	63.2	40.5	62.0	63.8
Brawn-SD	66.8	58.5	64.0	79.0	67.5	62.9	66.6	--	74.6	47.3	67.9	71.0
CAG-Ceres	**61.7**	**--**	**55.4**	**--**	**62.3**	**--**	**62.6**	**--**	**65.5**	**--**	**61.5**	--
CAG-Justify	64.4	62.8	65.0	80.3	69.5	62.3	75.1	68.3	76.9	--	70.2	70.3
CAG-Reckless	69.8	57.6	60.6	73.2	67.3	59.2	69.2	65.4	79.2	-	69.2	65.9
CAG Recoil	69.1	--	57.5	--	71.5	--	51.2	--	72.5	-	64.4	--
Commander	70.0	--	61.1	--	66.8	--	61.3	--	76.4	-	67.1	--
CP3055	**65.0**	**--**	**57.8**	**--**	**65.5**	**--**	**52.8**	**--**	**69.2**	**48.4**	**62.1**	**--**
CP3099A	65.9	60.3	60.0	76.2	60.3	59.2	63.0	64.9	75.2	54.8	64.9	66.8
CP3119A	62.0	--	60.2	73.7	67.3	--	69.5	69.3	75.4	54.8	66.9	71.5
CP3188	51.8	53.1	51.7	69.9	47.3	54.2	56.7	59.4	71.0	53.1	55.7	61.2
CP3322	**64.5**	**63.5**	**54.9**	**--**	**56.5**	**--**	**35.8**	**--**	**57.1**	**50.3**	**53.8**	--
CP3360AX	**62.8**	**--**	**57.1**	**--**	**60.9**	**--**	**38.2**	**--**	**69.8**	**-**	**57.8**	**--**
CP3915	62.3	--	54.4	--	61.5	--	39.4	--	62.5	-	56.0	--
Driver	67.8	57.2	61.8	75.2	67.5	60.5	49.9	56.8	70.4	54.7	63.5	64.2
Faller	51.7	--	54.5	--	63.8	--	52.2	--	58.4	44.8	56.1	--
Glenn	67.6	56.6	51.5	65.3	59.7	53.4	47.4	55.3	55.8	42.5	56.4	58.0
Lanning	70.7	59.0	59.3	71.7	60.9	56.4	48.0	57.9	81.1	57.6	64.0	62.0
LCS Ascent	72.9	63.6	58.0	73.0	69.1	56.5	65.4	66.2	85.7	58.6	70.2	65.2
LCS Boom	**76.8**	**61.6**	**59.3**	**--**	**62.8**	**--**	**54.3**	**--**	**74.1**	**52.5**	**65.5**	--
LCS Buster	58.2	58.9	58.8	76.9	70.2	66.2	58.4	65.7	68.9	47.3	62.9	69.6
LCS Cannon	70.5	62.4	56.9	70.9	66.4	56.0	48.9	57.9	68.1	49.0	62.2	61.6
LCS Dual	59.7	54.3	55.4	73.6	61.7	54.0	66.7	66.6	68.2	46.3	62.3	64.7
LCS Hammer AX	72.7	61.2	61.4	70.8	61.5	58.7	54.1	--	76.8	-	65.3	64.8
LCS Trigger	59.2	56.6	57.1	75.8	73.0	67.9	58.0	65.1	70.7	48.3	63.6	69.6
MN- Rothsay	63.2	57.3	55.5	71.6	64.5	61.6	64.8	66.4	69.2	-	63.4	66.5
MN-Torgy	66.3	59.9	60.1	74.2	71.6	66.0	67.8	65.5	72.8	-	67.7	68.6
MS Charger	59.1	55.9	59.3	78.2	64.0	57.5	52.5	57.2	73.7	55.3	61.7	64.3
MS Cobra	71.2	58.5	60.1	71.5	69.2	60.6	66.5	61.1	76.1	49.0	68.6	64.4
MS Nova	**70.4**	**--**	**60.8**	**--**	**64.1**	**--**	**53.6**	**--**	**71.8**	**-**	**64.1**	--
MS Ranchero	64.9	62.1	55.5	75.0	68.8	66.6	63.9	56.5	67.4	49.2	64.1	66.0
MT Carlson	**73.2**	**--**	**58.7**	**--**	**64.3**	**--**	**44.5**	**--**	**78.8**	**-**	**63.9**	--
MT Dutton	**69.5**	**--**	**57.5**	**--**	**65.5**	**--**	**59.8**	**--**	**77.1**	**-**	**65.9**	--
MT Ubet	**66.4**	**--**	**60.8**	**--**	**64.7**	**--**	**57.7**	**--**	**80.4**	**-**	**66.0**	**--**
ND Frohberg	71.1	57.7	56.4	69.5	60.3	55.3	48.3	57.4	70.9	47.0	61.4	60.7
ND Heron	65.1	55.2	54.4	68.1	62.8	53.7	52.7	--	69.9	51.5	61.0	60.9
ND Stampede	**60.9**	**55.3**	**53.6**	**75.9**	**67.5**	**57.2**	**65.2**	**63.9**	**76.0**	**59.1**	**64.6**	65.7
ND Thresher	**57.9**	**52.1**	**58.1**	**71.2**	**58.8**	**55.4**	**46.4**	**--**	**63.3**	**40.3**	**56.9**	63.3
ND VitPro	63.5	53.2	53.7	66.5	58.7	52.4	34.8	49.0	64.0	42.3	54.9	56.0
PFS Buns	42.5	49.9	52.5	--	63.8	--	50.9	60.8	64.8	-	54.9	60.8
PFS Rolls	**63.0**	**--**	**55.7**	**--**	**67.3**	**--**	**66.4**	**--**	**73.6**	**-**	**65.2**	--
Rocker	**67.3**	**--**	**60.3**	**--**	**62.3**	**--**	**48.2**	**--**	**73.4**	**-**	**62.3**	**--**
Shelly	66.5	59.1	58.4	74.6	68.1	60.1	64.7	64.2	67.1	46.7	65.0	66.3
SY 611CL2	69.6	59.5	56.6	73.6	69.6	62.6	48.6	57.4	66.7	53.8	62.2	64.5
SY Ingmar	65.1	57.4	53.9	63.3	63.6	55.9	51.5	54.7	68.4	44.8	60.5	58.0
SY Longmire	66.1	55.6	59.5	68.9	58.8	55.5	42.7	54.2	71.8	53.1	59.8	59.5
SY Valda	63.1	59.3	56.1	72.5	66.1	62.4	52.9	57.2	72.3	48.5	62.1	64.0
TCG-Badlands	**73.2**	**--**	**62.2**	**--**	**65.8**	**--**	**64.5**	**--**	**76.7**	**-**	**68.5**	--
TCG-Teddy	**75.2**	**62.9**	**62.0**	**--**	**65.8**	**--**	**52.5**	**55.7**	**74.5**	**-**	**66.0**	55.7
TCG-Wildcat	69.1	59.8	57.4	70.5	65.3	61.6	61.2	65.7	75.4	-	65.7	65.9
WB9590	70.5	57.3	56.8	71.2	64.4	55.8	59.2	61.7	73.0	51.8	64.8	62.9
WB9719	71.0	61.9	57.2	--	56.0	--	49.2	--	73.1	53.0	61.3	--
Mean	65.6	58.0	57.7	72.4	64.9	59.1	56.1	60.9	71.8	49.6	63.2	64.2
CV%	6.3	--	5.3	--	7.1	--	6.5	--	6.7	--	8.1	--
LSD 0.10	3.8	--	2.5	--	4.2	--	5.0	--	6.5	--	5.3	--

Table 4. Protein at 12% moisture of hard red spring wheat varieties across 9 locations in North Dakota, 2024.										
Variety	Carrington	Casselton	Forman	Langdon	Prosper	Dickinson	Hettinger	Mandan	Minot	State Avg.
	-----	-----	-----	-----	(%)	-----	-----	-----	-----	-----
Ambush	15.9	14.5	14.7	14.4	15.0	15.2	11.4	13.9	14.2	14.3
AP Elevate	**15.4**	**14.0**	**14.4**	**13.8**	**14.4**	**15.0**	**12.1**	**13.8**	**14.1**	**14.1**
AP Gunsmoke CL2	18.0	15.4	15.8	13.3	15.1	15.1	11.4	13.9	13.5	14.6
AP Murdock	15.4	13.4	13.8	12.9	14.3	14.7	11.5	13.6	13.6	13.7
AP Smith	15.0	13.9	14.4	14.1	14.3	14.2	12.0	13.9	14.3	14.0
Ascend-SD	16.7	14.7	15.3	13.9	15.9	15.0	11.6	13.4	14.0	14.5
Ballistic	15.3	13.1	14.1	13.0	14.3	14.1	11.8	13.2	13.5	13.6
Bolles	17.4	15.8	16.6	14.4	16.0	16.6	12.6	14.2	16.4	15.6
Brawn-SD	15.8	13.8	13.7	12.6	14.3	14.2	11.8	12.3	13.1	13.5
CAG-Ceres	**14.6**	**13.5**	**13.9**	**13.7**	**14.6**	**13.8**	**12.5**	**14.2**	**14.8**	**14.0**
CAG-Justify	15.3	13.1	13.5	12.6	13.5	14.7	12.0	12.0	12.9	13.3
CAG-Reckless	15.5	13.9	14.8	13.8	14.5	14.1	11.9	14.1	13.9	14.0
CAG Recoil	15.3	14.4	14.8	13.2	14.6	15.2	12.2	13.4	13.3	14.0
Commander	15.1	13.9	14.2	13.6	14.0	14.2	11.8	13.9	14.2	13.9
CP3055	**14.4**	**12.6**	**13.4**	**12.1**	**13.8**	**14.5**	**12.3**	**11.9**	**12.7**	**13.1**
CP3099A	13.2	10.2	10.5	10.5	12.6	13.3	11.0	10.0	11.0	11.4
CP3119A	14.2	12.2	12.6	12.2	13.7	14.2	11.8	11.5	12.1	12.7
CP3188	14.7	12.5	13.1	12.1	14.0	13.9	11.5	12.0	12.8	13.0
CP3322	**15.4**	**13.1**	**13.7**	**11.8**	**13.8**	**13.7**	**11.5**	**12.7**	**13.3**	**13.2**
CP3360AX	**--**	**13.0**	**13.5**	**12.7**	**13.9**	**13.6**	**11.2**	**12.2**	**12.9**	**12.9**
CP3915	15.2	14.0	14.8	13.8	14.3	14.7	11.7	13.7	14.5	14.1
Driver	15.4	14.1	14.5	13.6	14.0	14.7	12.0	13.7	13.7	14.0
Faller	15.3	13.2	14.1	12.8	14.1	14.4	12.2	12.9	13.4	13.6
Glenn	16.1	15.0	15.4	14.5	15.6	15.4	12.0	14.6	14.7	14.8
Lanning	17.0	14.9	15.4	14.3	15.1	15.4	12.1	14.2	14.3	14.7
LCS Ascent	14.4	13.1	13.7	12.9	13.2	13.7	11.8	12.9	13.3	13.2
LCS Boom	**15.3**	**14.5**	**14.5**	**13.3**	**14.5**	**14.7**	**12.2**	**13.3**	**13.9**	**14.0**
LCS Buster	14.2	12.5	12.8	11.1	12.1	13.1	11.6	12.3	11.5	12.4
LCS Cannon	15.4	14.2	14.4	13.5	14.3	14.4	12.6	12.8	13.8	13.9
LCS Dual	15.7	13.5	14.4	13.0	14.9	14.0	11.9	13.2	13.9	13.8
LCS Hammer AX	14.7	13.4	14.4	13.4	14.3	14.2	11.8	13.5	13.8	13.7
LCS Trigger	13.3	11.7	12.7	11.1	12.7	13.9	11.4	11.4	12.2	12.3
MN- Rothsay	15.2	14.0	14.5	13.3	14.3	14.4	11.9	13.9	13.6	13.9
MN-Torgy	16.1	14.4	14.9	14.3	15.1	14.9	12.0	14.4	14.5	14.5
MS Charger	14.1	12.3	12.9	12.0	13.5	13.3	11.1	11.9	12.2	12.6
MS Cobra	15.4	13.9	14.3	13.8	15.1	14.9	12.2	13.9	14.0	14.2
MS Nova	**15.7**	**14.1**	**14.9**	**14.1**	**15.1**	**14.3**	**11.9**	**14.0**	**14.3**	**14.3**
MS Ranchero	17.0	13.1	14.0	13.1	14.4	14.4	11.9	12.8	13.7	13.8
MT Carlson	**15.3**	**14.1**	**14.1**	**13.3**	**13.8**	**14.0**	**11.6**	**13.2**	**13.8**	**13.7**
MT Dutton	**16.9**	**14.7**	**15.8**	**13.6**	**15.5**	**14.3**	**11.7**	**13.9**	**14.1**	**14.5**
MT Ubet	**16.3**	**14.2**	**14.6**	**13.7**	**14.3**	**14.4**	**11.1**	**13.7**	**13.9**	**14.0**
ND Frohberg	15.8	14.1	15.1	13.5	15.2	15.0	11.8	14.2	13.9	14.3
ND Heron	15.9	14.9	15.1	14.1	15.3	15.1	12.0	13.9	15.2	14.6
ND Stampede	**15.5**	**13.6**	**14.6**	**13.6**	**15.0**	**14.3**	**11.5**	**13.4**	**14.3**	**14.0**
ND Thresher	**16.0**	**14.6**	**15.3**	**14.0**	**15.1**	**14.9**	**12.3**	**13.7**	**14.2**	**14.4**
ND VitPro	16.1	15.3	15.5	14.7	15.6	15.6	12.3	15.2	14.8	15.0
PFS Buns	14.1	12.8	13.5	11.7	12.9	14.8	11.7	12.0	12.1	12.8
PFS Rolls	**15.5**	**13.9**	**14.3**	**13.1**	**14.9**	**14.5**	**11.4**	**13.5**	**13.7**	**13.8**
Rocker	**16.1**	**14.1**	**15.0**	**14.0**	**14.6**	**14.8**	**11.7**	**13.1**	**15.1**	**14.3**
Shelly	15.3	13.4	14.3	13.0	14.3	14.3	12.2	13.0	13.3	13.7
SY 611CL2	15.7	14.1	14.8	13.9	14.6	15.0	11.4	13.8	14.9	14.2
SY Ingmar	15.4	14.1	15.1	14.2	14.9	14.8	11.6	14.8	15.0	14.4
SY Longmire	15.6	14.2	14.8	13.8	14.6	14.7	10.7	14.2	14.6	14.1
SY Valda	14.9	13.5	14.0	13.2	14.2	14.8	11.5	13.7	14.1	13.8
TCG-Badlands	**15.1**	**13.5**	**14.0**	**13.4**	**14.6**	**14.6**	**12.4**	**14.3**	**13.5**	**13.9**
TCG-Teddy	**15.2**	**14.7**	**15.0**	**13.8**	**14.6**	**14.8**	**12.4**	**13.7**	**14.2**	**14.3**
TCG-Wildcat	15.6	14.0	14.9	14.4	15.1	14.4	12.2	13.6	14.5	14.3
WB9590	15.9	14.0	14.6	13.8	14.8	14.8	11.3	13.6	14.1	14.1
WB9719	14.8	14.1	14.3	13.6	14.7	14.2	11.7	13.2	14.0	13.8
Mean	15.5	13.8	14.4	13.4	14.5	14.5	11.8	13.4	13.8	13.9
CV%	2.8	--	1.4	2.7	2.3	2.7	8.3	4.8	3.3	3.3
LSD 0.10	0.5	--	0.28	0.42	0.3	0.4	0.9	0.6	0.6	0.4

Table 5. Test weight of hard red spring wheat varieties grown at 9 locations in North Dakota, 2024.

Variety	Carrington	Casselton	Forman	Langdon	Prosper	Dickinson	Hettinger	Mandan	Minot	State Avg.
	(lb/bu)									
Ambush	57.9	58.0	59.7	61.7	57.1	59.9	58.4	61.3	63.1	59.7
AP Elevate	**58.4**	**57.8**	**59.4**	**60.3**	**57.7**	**58.4**	**58.3**	**60.8**	**60.4**	**59.1**
AP Gunsmoke CL2	56.4	56.7	58.6	60.5	56.9	57.1	57.5	60.5	61.2	58.4
AP Murdock	59.3	57.4	58.1	60.1	57.8	57.8	55.5	60.2	61.1	58.6
AP Smith	58.3	57.4	58.3	60.4	57.5	56.8	59.0	59.9	60.8	58.7
Ascend-SD	59.2	56.8	59.6	61.7	57.6	58.9	59.6	61.3	60.7	59.5
Ballistic	57.0	55.9	57.6	61.0	56.4	56.1	56.3	60.6	61.1	58.0
Bolles	57.2	56.8	57.5	61.1	56.7	56.4	57.8	59.3	61.5	58.2
Brawn-SD	59.5	57.4	59.2	62.1	60.0	59.8	60.1	61.8	63.7	60.4
CAG-Ceres	**57.7**	**57.0**	**58.8**	**61.0**	**56.4**	**56.8**	**57.6**	**60.6**	**62.1**	**58.7**
CAG-Justify	56.1	55.0	56.9	59.4	55.8	52.8	55.6	59.5	60.6	56.9
CAG-Reckless	57.3	57.3	59.1	61.7	58.3	58.8	59.0	60.6	62.7	59.4
CAG Recoil	58.1	55.4	57.4	60.8	57.7	57.4	57.3	59.4	59.6	58.1
Commander	58.4	58.0	58.4	60.7	56.7	58.5	58.6	60.7	61.8	59.1
CP3055	**53.7**	**52.4**	**54.5**	**59.0**	**53.1**	**56.4**	**56.3**	**57.0**	**58.3**	**55.6**
CP3099A	55.1	47.5	51.3	56.6	56.6	55.5	55.4	55.3	57.3	54.5
CP3119A	51.4	51.8	53.7	57.8	50.3	55.3	53.8	56.8	58.9	54.4
CP3188	55.4	54.6	55.9	59.3	54.7	54.6	55.3	58.9	59.4	56.5
CP3322	**56.3**	**55.0**	**57.3**	**59.4**	**55.7**	**56.8**	**58.2**	**57.8**	**57.7**	**57.1**
CP3360AX	**--**	**57.6**	**59.4**	**62.2**	**58.9**	**59.7**	**58.0**	**62.1**	**62.4**	**60.0**
CP3915	58.8	58.9	59.9	61.7	58.6	58.9	58.4	61.4	62.2	59.8
Driver	59.6	57.1	59.4	61.9	57.7	59.0	59.4	61.7	62.6	59.8
Faller	58.4	56.9	58.7	61.7	58.4	55.6	57.6	61.0	61.1	58.8
Glenn	61.5	60.5	61.1	62.7	59.8	61.7	59.5	62.5	64.2	61.5
Lanning	54.6	55.0	56.8	60.6	56.0	57.2	57.8	59.6	59.2	57.4
LCS Ascent	57.7	57.5	58.6	61.8	55.9	59.7	58.2	61.5	62.9	59.3
LCS Boom	**58.9**	**59.1**	**60.4**	**61.8**	**56.9**	**61.1**	**59.0**	**62.2**	**62.9**	**60.3**
LCS Buster	56.2	54.6	56.6	60.1	54.8	55.2	57.0	58.7	59.7	57.0
LCS Cannon	58.8	58.7	59.8	61.9	57.6	60.4	58.3	61.9	62.7	60.0
LCS Dual	56.7	57.8	57.8	61.6	57.0	56.9	57.7	60.2	62.6	58.7
LCS Hammer AX	56.8	54.5	56.6	61.1	56.2	58.9	57.7	60.9	61.5	58.2
LCS Trigger	58.3	58.3	59.6	61.8	58.4	56.2	57.8	61.0	60.4	59.1
MN- Rothsay	57.9	56.7	58.9	61.1	58.5	57.6	58.0	60.0	62.6	59.0
MN-Torgy	57.9	58.2	59.1	61.7	59.0	59.8	58.7	60.9	63.2	59.8
MS Charger	56.6	56.6	58.3	60.5	55.9	55.8	57.6	60.3	61.8	58.2
MS Cobra	57.7	57.1	58.8	61.2	57.6	59.2	58.9	60.2	62.2	59.2
MS Nova	**57.7**	**57.3**	**58.2**	**60.3**	**56.2**	**58.9**	**58.8**	**60.3**	**62.4**	**58.9**
MS Ranchero	51.3	56.0	58.2	60.8	56.7	58.2	57.0	60.3	60.7	57.7
MT Carlson	**56.5**	**53.3**	**54.8**	**61.0**	**56.4**	**57.5**	**57.2**	**60.7**	**60.7**	**57.6**
MT Dutton	**53.4**	**55.1**	**56.6**	**60.0**	**55.1**	**56.8**	**56.7**	**59.5**	**60.7**	**57.1**
MT Ubet	**56.1**	**54.4**	**56.4**	**60.8**	**55.4**	**56.4**	**57.2**	**60.0**	**60.5**	**57.5**
ND Frohberg	58.9	57.2	58.6	61.6	58.8	60.0	58.0	60.9	60.6	59.4
ND Heron	58.9	58.1	59.5	62.4	58.3	59.5	59.5	62.2	63.1	60.2
ND Stampede	**58.2**	**55.9**	**58.0**	**61.2**	**56.3**	**56.6**	**55.8**	**59.8**	**60.7**	**58.0**
ND Thresher	**57.8**	**56.6**	**58.9**	**60.4**	**58.1**	**54.8**	**56.2**	**58.7**	**59.4**	**57.9**
ND VitPro	60.1	59.1	60.4	62.8	59.8	59.7	58.6	61.9	62.8	60.6
PFS Buns	54.7	53.0	55.2	59.4	53.7	51.9	55.7	58.3	58.6	55.6
PFS Rolls	**56.7**	**54.6**	**58.0**	**61.4**	**58.3**	**58.1**	**58.1**	**59.5**	**62.1**	**58.5**
Rocker	**57.4**	**54.6**	**56.0**	**60.3**	**56.0**	**59.3**	**57.8**	**61.0**	**61.7**	**58.2**
Shelly	57.5	56.6	58.2	61.3	59.1	58.9	58.1	60.7	62.4	59.2
SY 611CL2	58.9	57.9	58.9	61.6	57.1	59.3	59.3	60.7	62.1	59.5
SY Ingmar	59.1	57.9	59.6	61.2	58.8	59.1	58.8	60.6	60.5	59.5
SY Longmire	58.2	55.6	58.1	60.8	58.0	59.6	59.4	61.0	61.7	59.2
SY Valda	58.8	56.9	58.9	60.7	57.3	57.7	58.4	60.5	61.2	58.9
TCG-Badlands	**58.9**	**56.3**	**58.0**	**60.5**	**56.7**	**58.6**	**58.4**	**60.2**	**61.6**	**58.8**
TCG-Teddy	**56.4**	**56.0**	**57.1**	**60.3**	**56.9**	**59.1**	**58.8**	**60.1**	**60.4**	**58.3**
TCG-Wildcat	59.1	56.8	57.9	61.5	58.7	58.9	58.2	60.4	61.8	59.3
WB9590	55.7	55.8	57.4	60.7	56.8	57.7	57.9	60.3	61.3	58.2
WB9719	59.9	57.2	59.6	63.2	58.6	61.4	58.4	62.6	63.1	60.4
Mean	57.5	56.4	58.1	61.0	57.1	57.9	57.8	60.4	61.3	58.6
CV%	1.8	--	0.6	0.7	1.3	1.3	1.3	0.8	1.0	1.6
LSD 0.10	1.2	--	0.5	0.5	0.7	0.7	0.7	0.5	0.8	0.7

Table 6. Quality data from 2021-2023. The Wheat Quality Index (WQI) is a weighted average developed to summarize the relative milling and baking quality of lines in the trial. Data from across years are from 2021-2023 for all varieties which were tested in a minimum of two years (and four locations per year) across North Dakota.

Variety	Test Weight[1]	Vitreous Kernels[2]	Wheat Protein[3]	Farinograph Absorption[4]	Flour Extraction[5]	Farinograph Stability[6]	Loaf Volume[7]	WQI RANK[8]
	lb/bu	%	12% m.b.	%	%	min	cm^3	
MS Cobra	61.4	85.3	15.0	65.9	68.2	12.6	1053.2	1
Glenn	63.4	85.6	15.2	65.0	66.4	17.0	971.1	2
TCG Heartland	62.2	74.6	15.5	64.2	67.8	17.5	956.1	3
CP3915	61.8	79.1	15.1	63.7	69.3	16.4	969.8	4
ND Stampede	61.2	77.9	14.7	66.5	65.6	15.3	977.3	5
Bolles	60.6	79.8	16.3	65.0	65.2	21.7	935.5	6
CP3530	60.7	75.1	14.8	64.6	68.8	13.3	995.9	7
ND Frohberg	61.9	74.1	14.7	66.5	66.4	16.4	937.9	8
SY Longmire	61.3	73.4	14.8	64.4	67.6	15.3	988.1	9
ND VitPro	62.6	86.4	15.4	65.2	67.4	11.7	967.2	10
CAG Recoil	60.1	79.8	14.4	63.4	68.2	24.1	942.7	11
CAG Reckless	61.5	76.7	14.8	65.0	66.0	15.9	966.1	12
TCG Teddy	60.5	71.2	15.0	64.0	66.7	25.9	929.4	13
Boost	60.6	69.4	14.9	65.5	67.4	11.5	966.8	14
LCS Cannon	62.7	59.6	14.6	63.2	69.1	15.6	952.4	15
Lanning	60.2	81.5	15.2	63.4	67.6	13.5	984.3	16
SY Ingmar	61.7	81.0	15.0	63.1	67.8	15.4	961.6	17
TCG Spitfire	60.5	71.7	14.1	64.7	66.5	14.8	980.2	18
SY611CL2	62.0	77.9	14.7	68.6	65.7	10.6	949.5	19
WB 9590	61.5	77.6	15.1	64.0	66.9	15.7	934.5	20
AP Smith	60.8	73.9	14.8	62.9	66.9	16.5	969.4	21
ND Thresher	59.6	77.9	15.2	65.1	67.4	11.7	942.0	22
MS Ranchero	60.0	81.1	14.2	66.3	65.9	13.9	932.1	23
ND Heron	62.7	77.5	15.4	72.4	64.6	9.2	937.0	24
Ascend-SD	61.3	87.9	14.7	64.1	66.5	12.0	969.0	25
LCS Boom	62.3	57.5	14.8	63.4	68.4	12.8	950.4	26
AP Murdock	60.3	65.7	14.5	63.9	67.2	15.1	951.6	27
LCS Ascent	62.1	48.7	14.1	63.5	67.7	16.3	939.5	28
WB 9719	63.7	63.5	14.0	63.3	67.0	15.1	947.9	29
TCG Wildcat	61.9	77.2	14.8	64.1	67.6	10.4	936.2	30
MN Rothsay	61.3	66.0	14.6	61.9	68.2	15.9	948.2	31
LCS Dual	61.9	81.1	14.0	64.2	67.9	12.0	919.0	32
Faller	60.7	70.5	14.2	64.6	68.8	11.8	904.3	33
MN Torgy	61.7	74.3	14.8	62.3	67.1	15.0	919.6	34
MS Charger	61.4	61.0	13.4	64.6	67.1	12.5	928.4	35
Brawn-SD	62.5	67.0	13.9	61.7	67.7	17.9	913.5	36
LCS HammerAX	61.1	65.9	14.4	62.8	67.5	13.5	929.0	37
Shelly	61.6	66.4	14.1	61.4	69.1	16.8	906.6	38
CP3322	60.1	83.9	13.5	62.9	67.7	11.4	950.4	39
AP Gunsmoke CL2	60.6	72.7	15.2	61.5	66.5	14.3	916.7	40
SY Valda	61.4	79.8	14.4	63.4	66.8	9.2	898.8	41
Driver	62.0	69.7	14.3	60.8	68.1	12.3	907.2	42
CP3188	59.5	62.9	13.4	60.4	68.5	17.9	898.9	43
LCS Trigger	60.8	75.6	13.0	64.4	68.1	11.3	837.9	44
CAG Justify	58.8	73.7	13.8	62.8	68.4	10.1	879.4	45
PFS Buns	58.2	67.5	14.0	60.8	65.5	16.4	912.7	46
CP3099A	58.5	80.7	12.6	61.7	66.3	15.6	896.8	47
LCS Buster	59.0	56.5	12.8	57.9	69.0	18.4	849.1	48

[1]Test weight - Expressed in pounds (lbs) per bushel. A high test weight is desirable. A 58 lb test weight is required for a grade of US No. 1.

[2]Vitreous kernels - Percentage of seeds having a vitreous-colored endosperm, a high percentage is desirable. US No. 1 DNS requires > 75% vitreous kernels.

[3]Wheat Protein - Measured by NIR at a 12% moisture basis. A high protein is desirable for baking quality.

[4]Farinograph Absorption - Measured by NIR at a 14% moisture basis. A measure of dough water absorption, expressed as percent. A high absorption is desirable.

[5]Flour Extraction - Percentage of milled flour recovered from cleaned and tempered wheat. A high flour extraction percentage is desirable.

[6]Farinograph Stability - A measure of dough strength expressed in minutes above the 500 Brabender unit line during mixing. A high stability is desirable.

[7]Loaf Volume - The volume of the pup loaf of bread, expressed in cubic centimeters. A high volume is desirable.

[8]Standardized means were used to calculate the Wheat Quality Index (WQI). The WQI is a weighted index calculated as: Test Weight (5%); Vitreous kernel (5%); Wheat Protein (10%); Flour Extraction (10%); Farinograph Absorption (23.3%); Farinograph Stability (23.3%) and Loaf Volume (23.3%). Adjusted means across locations were calculated for each trait using a mixed model. These means were standardized (mean=0 and standard deviation=1) to remove the effect of scale, which varies between traits.

Table 7. Quality Data from 2023 from 4 locations across North Dakota. The Wheat Quality Index (WQI) is a weighted average developed to summarize relative milling and baking quality of the varieties tested. Data below are from all varieties tested in 2023 at Hettinger, Williston, Forman, and Casselton, ND. These data are always presented from the previous year due to the amount of time it takes to process and test samples.

Variety	Test Weight[1]	Vitreous Kernels[2]	Wheat Protein[3]	Farinograph Absorption[4]	Flour Extraction[5]	Farinograph Stability[6]	Loaf Volume[7]	WQI Rank[8]
	lb/bu	%	12% m.b.	%	%	min	cm^3	
ND Frohberg	60.91	61.02	14.22	66.46	67.89	18.85	1004.09	1
Glenn	62.65	77.5	14.51	65.09	67.66	18.97	998.24	2
ND VitPro	61.59	80.18	14.68	64.69	69.5	13.71	1002.48	3
ND Heron	61.26	64.78	14.75	72.51	66.76	11.78	1015.79	4
MS Cobra	60.34	76.24	14.76	65.86	67.87	11.81	1032.86	5
Bolles	59.88	71.41	15.28	65.46	66.53	21.31	949.73	6
Boost	59.98	61.04	14.63	65.73	68.06	11.2	1004.08	7
ND Thresher	59.12	66.57	14.66	64.01	70.35	12.87	997.69	8
TCG Spitfire	60.04	60.66	13.6	64.69	67.1	18.86	986.5	9
ND Stampede	59.94	71.23	14.06	66.25	65.64	14.72	980.69	10
SY611CL2	61.35	62.81	14.19	68.66	66.64	11.14	957.72	11
AP Murdock	59.18	57.44	14.51	64.78	67.58	15.07	972.89	12
TCG Teddy	59.68	57.44	14.48	64.1	67.36	28.19	919.35	13
Ascend-SD	60.84	80.36	14.35	64.87	67.41	11.43	973.71	14
SY Longmire	60.72	57.98	14.52	64.15	67.73	13.97	968.91	15
WB 9590	60.4	67.29	14.53	64.16	67.55	15.83	947.54	16
LCS Cannon	61.89	41.86	14.37	64.24	69.73	12.13	935.34	17
SY Ingmar	61.02	64.6	14.4	63.74	68.48	14.1	943.33	18
CP3530	59.93	64.07	14.08	64.06	68.57	10.98	976.9	19
LCS Boom	61.43	42.04	14.34	63.51	69.24	12.68	946.53	20
LCS Dual	60.85	68.19	13.67	64.96	68.38	13.2	925.75	21
MS Ranchero	59.19	68.54	13.73	66.63	66.81	13.84	909.76	22
CP3915	60.86	65.14	14.61	63.74	69.4	14.03	887.38	23
WB 9719	62.88	48.84	13.57	63.47	67.67	15.35	943.33	24
Lanning	59.73	68.01	14.51	62.84	67.4	12.33	962.52	25
TCG Wildcat	61.19	66.57	14.45	64.19	67.84	11.3	908.16	26
CAG Reckless	60.3	60.66	14.06	64.01	67.18	13.45	927.35	27
Brawn-SD	61.76	54.57	13.6	61.93	67.81	22.08	884.18	28
Shelly	60.63	43.47	13.46	61.3	69.66	19.92	909.76	29
SY Valda	60.45	61.2	13.7	63.33	68.51	12.15	933.88	30
MN Rothsay	60.11	43.47	14.15	61.8	68.78	18.02	908.16	31
LCS Ascent	61.11	28.96	13.72	63.69	68.54	15.22	898.57	32
LCS Trigger	60.27	57.98	12.82	64.96	69.63	11.01	890.58	33
CP3322	59.25	71.77	13.04	63.02	68.48	11.04	946.53	34
MS Charger	60.45	44.9	13.06	64.42	67.92	11.46	914.56	35
LCS HammerAX	59.92	47.59	13.95	62.88	68.13	12.62	906.57	36
AP Smith	59.94	59.77	14.28	62.66	67.65	12.68	900.17	37
CAG Justify	58.11	57.98	13.27	63.11	70.06	10.78	908.16	38
AP Gunsmoke CL2	59.93	60.13	14.62	61.62	66.57	13.04	895.38	39
MN Torgy	60.54	60.48	14.31	61.98	67.26	12.42	877.79	40
PFS Buns	57.64	48.66	13.51	61.21	66.28	19.66	908.16	41
Driver	61.06	53.68	13.89	61.12	68.87	11.39	866.6	42
CP3188	58.2	50.1	13.13	60.94	68.88	13.94	884.18	43
CP3099A	57.62	72.84	11.97	62.34	66.37	16.29	890.58	44
LCS Buster	58.73	41.68	12.59	58.46	69.44	24.23	841.02	45

[1]Test weight - Expressed in pounds (lbs) per bushel. A high test weight is desirable. A 58 lb test weight is required for a grade of US No. 1.

[2]Vitreous kernels - Percentage of seeds having a vitreous-colored endosperm, a high percentage is desirable. US No. 1 DNS requires > 75% vitreous kernels.

[3]Wheat Protein - Measured by NIR at a 12% moisture basis. A high protein is desirable for baking quality.

[4]Farinograph Absorption - Measured by NIR at a 14% moisture basis. A measure of dough water absorption, expressed as percent. A high absorption is desirable.

[5]Flour Extraction - Percentage of milled flour recovered from cleaned and tempered wheat. A high flour extraction percentage is desirable.

[6]Farinograph Stability - A measure of dough strength expressed in minutes above the 500 Brabender unit line during mixing. A high stability is desirable.

[7]Loaf Volume - The volume of the pup loaf of bread, expressed in cubic centimeters. A high volume is desirable.

[8]Standardized means were used to calculate the Wheat Quality Index (WQI). The WQI is a weighted index calculated as: Test Weight (5%); Vitreous kernel (5%); Wheat Protein (10%); Flour Extraction (10%); Farinograph Absorption (23.3%); Farinograph Stability (23.3%) and Loaf Volume (23.3%). Adjusted means across locations were calculated for each trait using a mixed model. These means were standardized (mean=0 and standard deviation=1) to remove the effect of scale, which varies between traits.

2024 Giant Ragweed Resistance Management in Corn-Soybean

Principal Investigator(s): Next Gen Ag LLC - Andrew Lueck, Research Lead & Jenna Whitmore, Research Manager

Project Period: April 2024 – March 2025

Research Question/Objectives:
Collaborate with industry partners (8 participants) (Done).
Successfully apply chemistry (Done).
Successfully record data and images (Done).
Summarize and publish data (Done & continuing).
Publications; published to Next Gen Ag LLC website (Done).
Speak at SMSU Plot tour (Done).
Present at summer conference (Done).
Present at Prairie Grains conference (December).
Present at Ag Expo conference (January).

Results:
GIANT RAGWEED IN CORN
Giant ragweed pressure was uniform and significant across the study. Pre-emergence (PRE) product control at A+14, evaluation was taken 4-days prior to early post application, averaged 82.6% and ranged between 66.3 and 98.8%, with exception of one treatment that did not receive a PRE. The top 4 treatments were statistically similar. Products included in these treatments were Verdict and FortiTRI+Sinder 3L. Common actives within the premixes of FortiTRI and Verdict include saflufenacil (Sharpen) and dimethenamid-P (Outlook). FortiTRI included a third component, pyroxasulfone (Zidua), as compared to Verdict. The 2024 North Dakota Weed Control Guide (p.114-115; a digital version can be accessed online) summarizes pyroxasulfone alone provides poor-fair ragweed control and dimethenamid-P alone provides no control of ragweed. Saflufenacil in FortiTRI at 21 fl oz/A was applied at 0.084 lbs/ai/a while in Verdict at 15 fl oz/A was applied at 0.067 lbs/ai/a which are equivalent to 3.76 and 3.00 fl oz/a of Sharpen respectively, which are rates that provide good-excellent control of ragweed; thus, a conjecture can be drawn that saflufenacil appeared to be the most effective PRE active ingredient in corn in 2024. Saflufencil requires less water to activate which may have impacted the increased efficacy in this particular environment. Other PRE actives that performed in the second-tier ratings were dicamba (Status), a component of DiFlexx; clopyralid (Sinder 3L, Stinger), a component of Triple Flexx II and Trisidual; mesotrione (Callisto); and, atrazine (AAtrex). Overall, only 2 of the 16 treatments achieved the grant goal of 95% giant ragweed as PRE only applications.

Lay-by or early postemergence applications were made 4-days after the A+14 evaluation and 11-days prior to the A+28 evaluation to 4-6 inch tall giant ragweed. This evaluation emphasized the impact of the early post emergence foliar activity efficacy. Treatments averaged 98.3% and ranged between 88.8 and 100% giant ragweed control. The top 12 treatments were statistically similar. Common post emergence foliar actives included mesotrione (Callisto, Carabiner 4SC, Incinerate), a component of Resicore XL, Maverick, Acuron, and Acuron GT; clopyralid (Stinger), a component of Kyro, Maverick, and Resicore XL; dicamba (Status, Rifle), a component of DiFlexx; atrazine (AAtrex), a component of Acuron; topramezone, a component of Kyro; bicyclopyrone, a component of Acuron and Acuron GT; and, tembotrione (Laudis). Overall, 15 of 16 treatments achieved the grant goal of 95% giant ragweed control.

The A+42 evaluation occurred 26-days after the early post emergence application. This evaluation emphasized the impact of layered residual herbicides as PRE + EPOST treatment combinations began to separate. Treatments averaged 97.2% and ranged between 86.3 and 100% giant ragweed control. The top 11 treatments were all statistically similar. A common theme included a PRE residual followed by layering of one or more post emergence residuals in addition to a foliar activity active ingredient. Common post emergence residuals included dicamba, mesotrione, atrazine, tembotrione, topramezone, cloypyralid, and bicyclopyrone. Post activity products without significant residual impact included glyphosate, an active ingredient with little impact on the highly resistant population of giant ragweed. Overall, 14 of the 16 treatments achieved the grant goal of 95% giant ragweed control.

The A+56 evaluation occurred 39-days after early post emergence application. The A+56 rating emphasized the season-long durability of the residual products utilized in combination with crop canopy. The evaluation averaged 93.1% and ranged between 77.5 and 97.3% giant ragweed control. The top 12 treatments were statistically similar. The A+42 discussion above is relevant to this evaluation timing as well. We potentially observe a waiver in dicamba and mesotrione residuals wearing off late season with more reliance on post emergence applications inclusive of atrazine and clopyralid. Overall, only 5 of the 16 treatments achieve the grant goal of 95% giant ragweed control.

Table 2. Giant Ragweed control in corn in 2024.

		App.	Giant Ragweed Control			
Treatment[a]	Rate	Code[b]	A+14[c]	A+28	A+42	A+56
	oz/A* or fl oz/A		---------------%---------------			
Surtain / Status+RU3+NIS+Dry AMS	14 / 5*+32+0.25%	A / B	75.0	96.3	99.5	93.3
Verdict / Status+Callisto+Atrazine+RU3+COC+AMS	15 / 3*+3+16+30	A / B	89.5	99.5	99.0	93.8
Harness Max+DiFlexx / Laudis+Atrazine+RU3+AMS[d]+MSO	55+10 / 3+16+30+0.5%	A / B	87.5	99.5	97.0	94.0
TripleFlex II+DiFlexx / Laudis+DiFlexx+RU3+MSO+Class Act Ridion	32+10 /	A / B	87.5	98.5	94.5	90.0
Surpass NXT / Kyro+AAtrex+RU3+COC+Amsol	32 / 45+16+30+2.5%	A / B	76.3	99.0	98.8	95.8
Surpass NXT / Resicore XL+AAtrex+RU3+COC+Amsol	32 / 45+16+30+2.5%	A / B	71.3	100	100	96.5
Anthem Maxx+Callisto+AAtrex / Status+RU3+AMS	4.5+5.5+32 / 5*+30	A / B	85.0	99.0	97.8	93.8
Anthem Maxx+Callisto+AAtrex+RU3+AMS+COC	4+3+32+30	B	-	96.5	94.5	91.3
FortiTRI+Sinder 3L / Rifle+Missile	21+2 / 8+0.25%	A / B	98.8	99.5	99.5	95.0
FortiTRI+Sinder 3L+Infuse / Rifle+Carabiner 4SC+Missile	21+2+24 / 8+3+0.25%	A / B	94.5	100	99.5	94.5
Calibra / AAtrex+Acuron GT+AMS	64 / 16+60	A / B	72.5	100	100	96.5
Acuron / Acuron+RU3+AMS	48 / 48+30	A / B	66.3	98.3	99.0	94.5
Harness / AAtrex+Maverick+RU3+AMS+HSMOC	44 / 16+14+30	A / B	73.8	97.8	93.3	92.5
DiFlexx / AAtrex+Maverick+RU3+AMS+HSMOC	8 / 16+24+30	A / B	76.3	99.5	97.5	93.3
Trisidual / Cornerstone 5 Plus+Incinerate	32 / 32+3	A / B	87.5	88.8	86.3	77.5
Verdict / Acuron+RU3+AMS	18 / 48+30	A / B	97.0	100	99.5	97.3
LSD (0.1)			**10.4**	**2.0**	**2.7**	**4.6**

aPRE treatment applications contained no additional adjuvants. bApplication codes refer to the information in Table 1. cA+[#] or B+[#]=Days after "A" or "B" application. dAMS=Class Act NG 2.5%v/v; RU2/3=Roundup 2/3; COC=Crop Oil Concentrate 1%v/v; HSMOC=Destiny HC 0.5%v/v.

GIANT RAGWEED IN SOYBEAN

Giant ragweed pressure was uniform and significant across the study. Pre-emergence (PRE) product control at A+14 was evaluated 2-days prior to early postemergence application and averaged 48.6% and ranged between 12.5 and 75.1%. The top 8 treatments were statistically similar. Products included in these treatments included Zidua Pro, Authority First, and Sonic. Common actives within these premixes include sulfentrazone (Spartan), a component of Authority First and Sonic; cloransulam (FirstRate), a component of Authority First, Tendovo, and Sonic; pyroxasulfone (Zidua), a component of Zidua Pro; saflufenacil (Sharpen), a component of Zidua Pro; and imazethapyr (Pursuit), a component of Zidua Pro. The 2024 North Dakota Weed Control Guide (p.114-115) summarizes pyroxasulfone alone provides poor-fair ragweed control while sulfentrazone and imazethapyr alone provide no control of ragweed. Saflufenacil at the Zidua Pro rate provides about 1 fl oz of Sharpen equivalent and provides fair control of ragweed. The FirstRate (cloransulam only product) label indicates giant ragweed is controlled at appropriate use rates. Thus, a majority of giant ragweed control PRE was likely a result of saflufenacil and cloransulam active ingredients. Overall, none of the pre-emergence alone treatments were able to provide the grant goal of 95% giant ragweed control.

Lay-by or early postemergence applications were made 2-days after the A+14 evaluation and 12-days prior to the A+28 evaluation to 4-6 inch tall giant ragweed. This evaluation emphasized the impact of the early post emergence foliar efficacy. Treatments averaged 91.4% and ranged between 80.0 - 98.0% giant ragweed control. The top 7 treatments were statistically similar. Foliar activity products included Liberty ULTRA (glufosinate) and Enlist One (2,4-D). Overall, only 2 of 15 treatments achieved the grant goal of 95% giant ragweed control.

The A+42 evaluation occurred 26-days after the early post emergence application. This evaluation emphasized the impact of layered residual herbicides as PRE + EPOST treatment combinations began to separate. Treatments averaged 81.7% and ranged between 68.8 and 97.0% giant ragweed control. The top 5 treatments were all statistically similar. A common theme included a strong PRE residual followed by layering of one or more post emergence residuals. All top treatments had a pre-emergence product statistically similar to the best performer at A+14 AND a foliar product of glufosinate or 2,4-D at the early postemergence timing. Residual herbicides added to the treatments at early postemergence included dimethenamid-P (Outlook), acetachlor (Warrant), fluthiacet (AnthemMaxx), and s-metholachlor (EverPreX). Overall, only 1 of 15 treatments achieve the grant goal of 95% giant ragweed control.

The A+56 evaluation occurred 39-days after early post emergence application. The A+56 rating emphasized the season-long durability of the residual products utilized in combination with crop canopy. The evaluation averaged 72.1% and ranged between 55.0 and 91.8% giant ragweed control. The top 4 treatments were statistically similar. As evidence of a 9.6% drop in average giant ragweed control from the A+42 evaluation, one can conclude that residual herbicides continue to degrade over time, losing efficacy. There are not many residual active ingredients that control giant ragweed in soybean effectively, so options are limited. In a grower's field, the addition of a second post emergence application of glufosinate or 2,4-D based products would have been necessary. None of the treatments achieve the grant goal of 95% giant ragweed control.

Table 3. Giant ragweed control in soybean in 2024.						
		App.	Giant Ragweed Control			
Treatment[a]	Rate	Code[b]	A+14[c]	A+28	A+42	A+56
	oz/A* or fl oz/A		---------------%---------------			
Zidua Pro / Liberty ULTRA+RU3+Dry AMS	6 / 24+30+3lb/A	A / B	68.8	93.8	85.0	70.0
Zidua Pro / Liberty ULTRA+Outlook+RU3+Dry AMS	6 / 24+10+30+3lb/A	A / B	67.5	94.5	90.0	77.5
Auth. First / War+RU3+Liberty+AMS[d]	6.45* / 48+30+32	A / B	65.0	92.0	86.3	78.8
Auth. First / War.+RU3+Enlist One+AMS	6.45* / 48+30+32	A / B	65.0	98.0	97.0	91.8
Sonic / Enlist One+Liberty+AMS	5* / 32+32	A / B	67.5	93.3	88.3	82.5
Sonic / Enlist One+Liberty+EverpreX+AMS	5* / 32+32+16	A / B	65.0	94.5	91.3	86.3
Auth. First / Enlist One+RU3+Anthem Maxx-+AMS	6.4* / 32+30+4	A / B	75.1	96.5	93.7	85.0
Tribal / Enlist One+Mad Dog+Missile	72 / 32+36+0.25%	A / B	22.5	80.0	70.0	57.5
Tribal+Infuse / Enlist One+Mad Dog+Missile	72+32 / 32+36+0.25%	A / B	42.5	87.5	71.3	62.5
Prefix / Enlist One+Sequence+AMS	32 / 32+48	A / B	42.5	88.8	77.5	70.0
Tendovo / Enlist One+Sequence+AMS	48 / 32+48	A / B	57.5	92.5	85.0	78.8
Fierce MTZ / Enlist One+Perpetuo+RU3+AMS	16 / 32+6+30	A / B	17.5	87.5	75.0	62.5
Fierce MTZ / Enlist One+Resource+RU3+AMS	16 / 32+4+30	A / B	17.5	86.3	68.8	55.0
Dimetric Charged+Interlock / Enlist One+Liberty+Cornerstone 5+StrikeLock+AMS	12+4 / 32+32+32+12	A / B	42.5	91.3	77.0	62.5
Presidual+Interlock / Enlist One+Liberty+Cornerstone 5 Plus+StrikeLock+AMS	24+4 / 32+32+32+12	A / B	12.5	88.8	70.0	61.3
LSD (0.1)			**21.3**	**3.3**	**7.2**	**11.7**

aPRE treatment applications contained no additional adjuvants. bApplication codes refer to the information in Table 1.
cA+[#] or B+[#]=Days after "A" or "B" application.
dAMS=Class Act NG 2.5%v/v; RU2/3=Roundup 2/3; War=Warrant; COC=Crop Oil Conc. 1%v/v; HSMOC=Destiny HC 0.5%v/v.

Application/Use:
Resistant Giant Ragweed Control; Industry Comparison; Return on Investment.

Materials and Methods:
Experiments were conducted on a severe infestation with various levels of ALS, HPPD, and glyphosate-resistant giant ragweed near Renville, Minnesota, in 2024. Soil was a fine-textured webster-clay loam soil with 4.4% organic matter and a 6.3 soil pH. Spring tillage was a field cultivator at 3" depth. Enestvedts 654 Enlist PWC corn was seeded 2.00 inches deep on 30-inch row spacings at 33,000 seeds per acre on May 6, emerging May 15. Preemergence herbicide treatments applied to corn on May 6, and early-postemergence treatments to V3 corn on May 23 (Table 1). Becks 1830E3 soybean was seeded 1.25 inches deep on 30-inch row spacings at 140,000 seeds per acre on May 13, emerging May 21. Preemergence herbicide treatments applied to soybean on May 13, and early-postemergence treatments to V1 soybean on May 29 (Table 1). All treatments applied with bicycle sprayer in 15 GPA spray solution through AIXR11002 air-induction flat fan nozzles pressurized with CO2 at 26 psi to the center two rows of four row plots 40 feet in length.

Giant ragweed control in corn was evaluated May 20, June 3, June 18, and July 1 (Table 2). Giant ragweed control in soybean was evaluated May 27, June 10, June 24, and July 8 (Table 3). Giant ragweed evaluations were a visual estimate of percent fresh weight reduction between center two rows as compared to adjacent untreated strips. Experimental design was a randomized complete block with 4 replications. Data were analyzed with GLM procedure of SAS (Statistical Analysis Software, SAS Academic Studio October 30,2024, SAS Institute, Inc.) at alpha=0.10 and differences are determined with 90% confidence; meaning, if the study was repeated 100 times that 90 times out of 100, we would expect statistically similar treatments (within one LSD value of each other) to remain similar in performance groupings.

Table 1. Application information for Renville giant ragweed control trials in 2024.

Crop	Corn		Soybean	
Application Code	A	B	A	B
Date	May 6	May 23	May 13	May 29
Time of Day	6:00 PM	8:00 AM	5:00 PM	9:00 AM
Air Temperature (F)	75	66	75	65
Relative Humidity (%)	58	67	29	59
Wind Velocity (mph)	19	5	2	2
Wind Direction	SE	S	N	E
Soil Temp. (F at 6”)	58	56	61	59
Soil Moisture	Good	Good	Good	Good
Cloud Cover (%)	80	20	10	10
Crop Growth Stage (avg)	-	V3	-	V1
Giant Ragweed Height	-	4”	-	4”

Economic Benefit to a Typical 500 Acre Corn/Soybean Enterprise:
Giant ragweed population was excellent for evaluations. Rainfall was sufficient for activation of pre-emergence herbicides. Primarily there was consistency across crops in regards to evaluation timing meaning. The A+14 evaluations observed the PRE only performance; the A+28 evaluations observed the immediate early post application impact; the A+42 evaluations observed the layered residual impact; and, the A+56 evaluations observed the season-long performance of the programs demonstrated. Overall, a strong PRE with two or more active ingredients in addition to a post application of two or more active ingredients, with at least one of the actives having foliar activity, is critical for season long giant ragweed control. However, controlling giant ragweed in soybean is a much greater challenge and likely requires a 3rd later application timing of a foliar activity herbicide. Growers should use the data set as a guide to visit with their crop consultants or local suppliers to determine a giant ragweed program that provides the greatest control at an economical cost based on local supplier pricing and availability of products.

Related Research:
2024 Waterhemp Resistance Management Programs in Corn-Soybean Rotations; All articles available at www.nxtgenag.com under the “Latest News” tab.
Recommended Future Research:
Next Gen Ag LLC, and our industry collaborators, are very appreciative for the funding of our competitive industry trials. Next Gen Ag LLC collaborates with 25+ national and international agriculture crop protection companies annually. Collaborators of Next Gen Ag LLC provide all the treatment and products required at no cost for the work to be conducted. MSRPC dollars fund all the operating and labor costs associated with the project to provide Minnesota Soybean Growers a non-biased data set to compare products on the market in weed control, aphid control, white mold control, and value-added inputs. Next Gen Ag LLC and our industry collaborators are already hard at work developing grant proposals for 2025. We intend to repeat our 2024 competitive industry studies and plan to have new proposals looking at adjuvant impact on postemergence foliar herbicides on giant ragweed and waterhemp in addition to a grant looking at broadcasted/inter-seeded rye impact on soybean yield and SCN. Each year the latest products entering the market have an opportunity to be showcased to Minnesota Soybean Growers. Non-biased, collaborative, and ROI focused research.

Publications:
2024 Giant Ragweed Resistance Management Programs in Corn-Soybean Rotations; All articles available at www.nxtgenag.com under the “Latest News” tab.
Next Gen Ag: Conducting Research with the Next Generation [of soybean growers] in Mind!
This publication and more MSRPC funded research conducted by Next Gen Ag, LLC can be found online at www.nxtgenag.com under the “Latest News” tab and “Public Grant Research Studies” page.

2024 Soybean Aphid Control Product Impact on Yield

Principal Investigator(s): Next Gen Ag LLC - Andrew Lueck, Research Lead & Jenna Whitmore, Research Manager

Project Period: April 2024 - March 2025

Research Question/Objectives:
Collaborate with industry partners (7 participants) (Done).
Successfully apply aphid chemistry, 100 threshold (Done).
Record aphid count and yield data (Done).
Summarize and publish data (Done & continuing).
Publications; published to Next Gen Ag LLC website (Done).
Speak at SMSU Plot tour (Done).
Present at summer conference (Done).
Present at Prairie Grains conference (December).
Present at Ag Expo conference (January).

Results:
Treatments were first separated by aphid counts into two tiers (Table 2). Tier 1 included products or tank mixed products that were not group 3A insecticides (pyrethroids) and generally had significantly better aphid control compared to Tier 2 treatments which were all group 3A active ingredients only. Tier 1 includes treatments with Renestra, Sivanto Prime, Leverage 360, Ridgeback, Endigo ZCX, Sefina, Transform, Dimethoate, and Belay.
Common actives in these products include afidopyropen (Sefina, Inscalis active, Group 9D), also a component of Renestra; flupyradifurone (Sivanto Prime, Group 4D); imidacloprid (Group 4A), a component of Leverage 360; thiamethoxam (Group 4A) a component in Endigo ZCX; sulfoxaflor (Transform, Isoclast active, Group 4C) also a component of Ridgeback; dimethoate (Group 1B); clothianidin (Belay, Group 4A). The untreated is located at the bottom of the table for comparisons.

The untreated at all timings was statistically worse in treatment-to-treatment comparisons with all Tier 1 aphid counts 3, 7, and 14 DAA demonstrating excellent aphid infestation and product response. Aphid counts at 3 DAA were generally lower in Tier 1 compared to Tier 2; although, not all Tier 1 treatment comparisons were statistically better than all Tier 2 treatments. Tier 2 treatment 14 was statistically similar to Tier 1 treatments 1, 4, 6, and 8; and, Tier 2 treatment 17 was statistically similar to Tier 1 treatments 1, 6, and 8 at the 3 DAA evaluation as noted by the same letter designation next to the data within Table 2. However, neither of these Tier 2 treatments would keep pace with any Tier 1 treatment at the 7 and 14 DAA in treatment-to-treatment comparisons indicating the very high level of pyrethroid resistance in the aphid population.

Tier 2 treatments were statistically better than the untreated check at 3 and 7 DAA aphid counts. At the 14 DAA evaluation, treatments 14 and 17 were statistically similar in treatment-to-treatment comparisons with the untreated check and treatments 12 and 16 were statistically worse than the untreated check. This phenomenon is likely due to random error as it is unlikely that any insecticide would actually increase aphid populations 14 DAA; however, it is possible that neighboring plot treatments to 12 and 16 may have been better performing as compared to neighboring plot treatments to the untreated check which may have driven increased quantities of pyrethroid resistant aphids to seek refuge in the nearest pyrethroid only/untreated plot forcing an inadvertent consolidation of population. Adjuvant use or absence of adjuvant in Tier 2 treatment comparisons were not significant; meaning, use of adjuvant does not definitively increase aphid control.

Tier 1 aphid count treatment-to-treatment comparisons will be discussed to determine statistically significant differences in top of the market product performance. At the 3 DAA evaluation, Transform at 5.5 dry ounces per acre had the lowest average aphid per plant count (2/plant); however, it was statistically similar to all Tier 1 treatments with the exception of treatments 1 and 6. The 3 DAA evaluation demonstrates knockdown capabilities of products. At the 7 DAA evaluation, Transform at 5.5 dry ounces per acre continued to have the lowest average aphid per plant count (15/plant); however, it was statistically similar to all Tier 1 treatments with the exception of treatment 9. The 7 DAA evaluation demonstrates the short-term residual capabilities of products. At the 14 DAA evaluation, Sivanto Prime at 5.5 fluid ounces per acre had the lowest average aphid per plant count (11/plant); however, it was statistically similar to all Tier 1 treatments with the exception of treatment 8. The 14 DAA evaluation demonstrates the long-term residual capabilities of products in a timeline relevant to aphid population peak window. Any Tier 1 product is likely a responsible choice for aphid control for 14-days after application; however, there were statistical differences in yield data.

Soybean yield data determined treatment rank within each tier and listed in descending order (Table 2). Renestra at 6.8 fluid ounces per acre had the highest average soybean yield; however, it was statistically similar to Sivanto Prime at 5.5 and Leverage 360 at 2.8 fluid ounces per acre at 70.9, 70.6, and 69.7 bushels per acre respectively. Leverage 360 was statistically similar to Ridgeback and Endigo ZCX at 10.3 and 4.5 fluid ounces per acre, respectively, both averaged 65.6 bushels per acre. Sefina at 3.0 fluid ounces per acre and Transform at
5.5 dry ounces per acre were statistically similar to Ridgeback and Endigo ZCX to round out the top 7 performers.

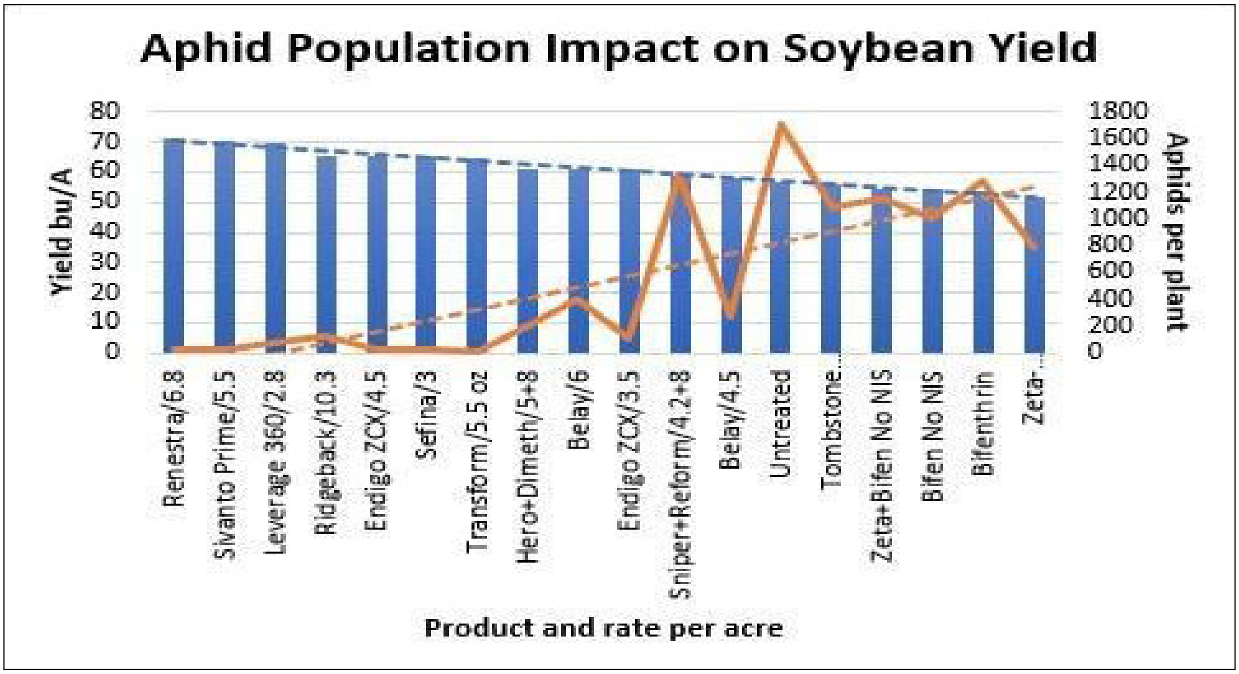
Ranked treatments 8-11 were not significantly better than the untreated check and had a significant yield reduction as compared to ranked treatments 1-5, so although the aphid counts supported sufficient control from these treatments which placed them in Tier 1, the yield data did not support the aphid counts. This may be attributed to residual wear-off after 14-days, potential biological trade-offs as a result of treatments, or potential random error based on the geographical location of the six plots per treatment that were harvested and averaged. Additionally, one must keep in mind that although six replications were harvested, aphid count data were only collected from three of the six replications; meaning, potentially aphid infestation in the back three replications may have differed from the front three replications resulting in an unaccounted-for impact. As stated before, any Tier 1 product is likely a responsible choice and a grower may weigh insecticide cost points against yield impact to determine an ideal return on investment.

In Tier 2, with the exception of treatment 12, all treatments numerically yielded below the untreated check; and, 4 of the 6 Tier 2 treatments were statistically worse yielding than the untreated check. One must be reminded of the severe frequency of pyrethroid resistance in the tested aphid populations and understand that it does not mean these products are not effective on a susceptible aphid population. It is critical for growers to be aware of their population resistance.

Table 2. Aphid control product impact on aphid population and soybean yield in 2024.									
			App.	Aphids Counts[c]				Harvest	
Treatment[a]		Rate	Code[b]	1DBA	3 DAA	7 DAA	14 DAA	Yield	Company
#		oz/A* or fl oz/A		/Plant	/Plant	/Plant	/Plant	Bu/A[d]	
TIER 1									
1	Renestra	6.8	A	441	120 b-d	31 a	18 a	70.9 a	BASF
2	Sivanto Prime	5.5	A	526	14 ab	22 a	11 a	70.6 a	Bayer
3	Leverage 360	2.8	A	469	34 ab	85 a	58 a	69.7 ab	Bayer
4	Ridgeback	10.3	A	375	52 a-c	130 ab	105 a	65.6 bc	Corteva
5	Endigo ZCX	4.5	A	393	12 ab	30 a	38 a	65.6 bc	Syngenta
6	Sefina	3	A	389	152 b-d	26 a	20 a	65.1 cd	BASF
7	Transform	5.5*	A	417	2 a	15 a	14 a	64.5 cd	Corteva
8	Hero+Dimethoate	5+8	A	446	105 a-d	210 ab	278 b	61.1 de	FMC
9	Belay	6	A	336	35 ab	396 b	128 ab	61.1 de	Valent
10	Endigo ZCX	3.5	A	301	32 ab	117 a	18 a	61.0 de	Syngenta
11	Belay	4.5	A	269	10 a	267 ab	78 a	57.8 e-g	Valent
TIER 2									
12	Sniper+Reform+Lib-erate	4.2+8+0.25%v/v	A	353	439 f	1326 d	1372 f	58.7 ef	Loveland
13	Tombstone Helios +Reform+Liberate	2.8+8+0.25%v/v	A	312	342 ef	1086 cd	786 c	55.6 f-h	Loveland
14	Zeta-Cyper+Bifen (No Adj)	5	A	357	240 c-f	1145 cd	1259 ef	54.6 f-h	NGA
15	Bifenthrin (No Adju-vant)	4.2	A	247	288 ef	1001 cd	822 c	54.6 f-h	NGA
16	Bifenthrin	4.2	A	346	392 f	1284 d	1301 f	54.0 gh	NGA
17	Zeta-Cyperme-thrin+Bifenthrin	5	A	292	289 d-f	799 c	895 cd	51.4 h	NGA
UNTREATED									
18	Untreated Check	-	-	341	654 g	2006 e	1155 de	56.8e-g	-

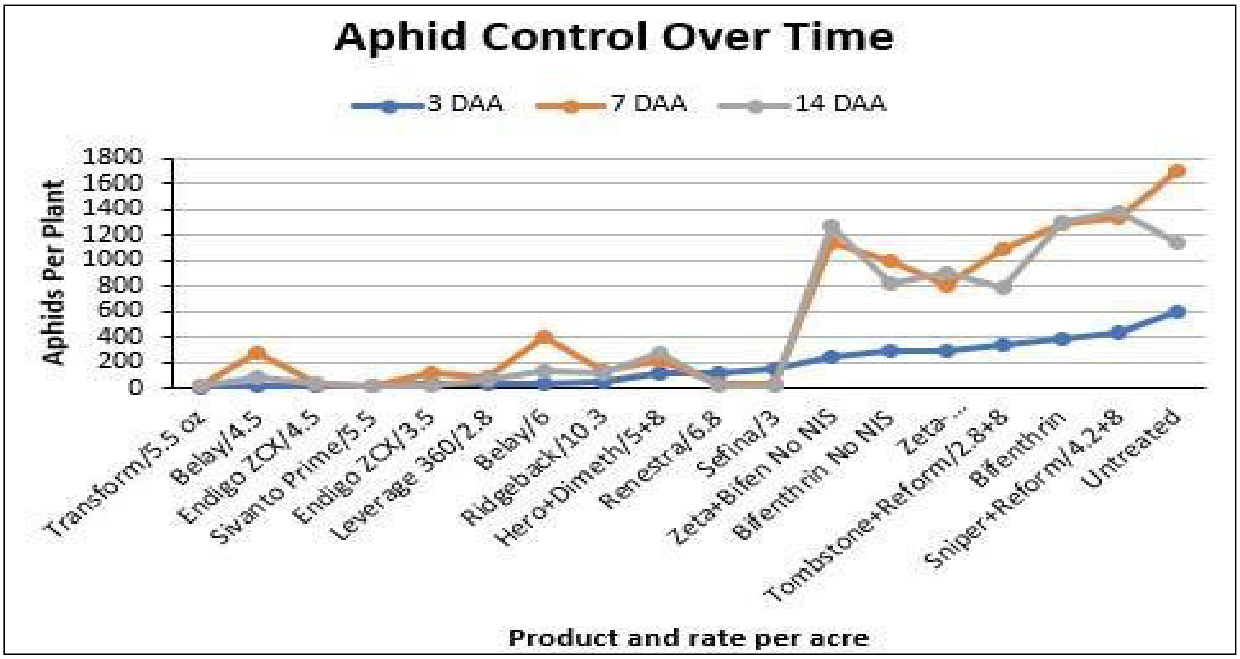
aMasterlock at 6.4 fl oz/A to all treatments unless noted otherwise. bApplication codes refer to the information in Table 1. cLetters next to data indicate statistical significance at 90% repeatability wherein data with the same letters are similar. dBu/A=Soybean yield in bushels per acre corrected to a standard moisture of 13.5%.

Correlation can be applied to many data sets, however, not all data sets should be considered for correlation and the statistical value of correlation can become meaningless if used inappropriately. Correlation values range from -1 to +1; a value of 0 means no correlation, a negative value demonstrates a negative relationship between two data sets (moving in different directions), and a positive value demonstrates a positive relationship between two data sets (moving in the same direction). The further from "0" the correlation value is, the stronger the relationship; so, the closer to -1 the more negative the correlation relationship while the closer to +1 the more positive the correlation relationship. The correlation between the 7 DAA aphid count data and soybean yield is 0.76 indicating there is a strong negative correlation between higher aphid populations in the data set that is consistently resulting in lower yields (Graph 1). The value of this strong correlation reiterates the importance of controlling aphids in soybean and applying products at an economic threshold of 250 aphids per plant. This strong negative correlation also suggests there was little impact on the data set from any other pest or disease and increases the confidence growers can have making decisions on aphid control based on this data set.



Graph 1. Aphid population impact on soybean yield in 2024.

Product residual impact on aphid population from application date to 14 DAA provided note-worthy observations (Graph 2). Transform, Sivanto Prime, Endigo ZCX, Leverage 360, and Ridgeback had great knockdown and consistent residual over time. Renestra and Sefina were less effective with initial knockdown, however had consistent and reliable residual control over time. Belay was an interesting one as both Belay treatments had a great knockdown at 3 DAA, a population increase at 7 DAA, while returning to a lower aphid count 14 DAA; a pattern only consistent with the untreated check. This may mean Belay functions better at a low-mid infestation proportionally than at a high infestation; meaning, if the aphid infestation for the year is anticipated to be severe in both numbers and duration as compared to mild in both numbers and duration that a grower should proceed with caution in selecting this Tier 1 product. Hero+Diomethate had knockdown, but lacked residual 14 DAA as compared to the other Tier 1 products evaluated. All Tier 2 products appeared to follow a similar response within the tier demonstrating the progression of resistant populations.



Graph 2. Aphid population impact over time

Application/Use:
Soybean Aphid Control; Plant Health: Maximizing Yield Potential; Industry Comparison; Return on Investment.
Materials and Methods:
Experiments were conducted on a fine-textured webster-clay loam soil with 5.0% organic matter and a 6.8 soil pH near Renville, Minnesota, in 2024. Spring tillage was a field cultivator at 3" depth. Untreated soybean was seeded 1.25 inches deep on 30-inch row spacings at 140,000 seeds per acre on May 14, emerging May 22. Since soybean seed was untreated, Renestra was applied at 6.8 fluid ounces with 4 fluid ounces of Interlock as a blanket application for soil insect control at VE soybean June 1. Study was kept weed free with a pre-emergent application of Outlook on May 14 followed by a postemergence application of Enlist One, Roundup Powermax II, Zidua SC, and Class Act NG on June 1. A second postemergence application of Enlist One, Class Act NG, Section 3, Liberty 280SL and Interlock was applied on June 27. Treatments were applied July 29 to soybean with a hand boom sprayer in 20 GPA spray solution through AIXR11002 air-induction flat fan nozzles pressurized with CO_2 at 40 psi to the center two rows of four row plots 40 feet in length. All treatments included Masterlock adjuvant at 6.4 fluid ounces per acre unless indicated otherwise in the treatment name as "No Adjuvant".

Early season rainfall led to abundant water resources for germination and growth throughout the entire growing season. Aphid arrival began July 25, with a trial baseline per plant aphid count taken July 28 at 1 DBA on 285 individual plants to determine the economic threshold of 250 aphids per plant had been attained with an average of 367 aphids per plant (Table 1). The study was conducted on an aphid population that was estimated to be approximately 50% resistant to Group 3A pyretheroids in a 2023 aphid grant study. In 2024, the population was estimated to be approximately 89% resistant to Group 3A pyretheroids. This number was the average of non-3A aphid counts at 7 DAA evaluation divided by the average of 3A only aphid counts at 7 DAA and subtract that number from 1 and multiplied by 100.

Aphid data were collected from replications one, two, and three where five random plants per plot were counted the day before application (1 DBA), 3 DAA, 7 DAA and 14 DAA, on July 29, August 1, August 6 and August 12, respectively. Yield data were collected on September 24 utilizing a Hege 160 two-row small plot research combine equipped with a HarvestMaster large plot weight hopper. The middle two rows of the four-row plot were harvested and samples were taken with moisture and test weights recorded using a Perten 5200-A moisture tester. Experimental design for yield data was a randomized complete block with 6 replications; however, aphid count data were collected and analyzed as a randomized complete block with 3 replications. Data were analyzed with GLM procedure of SAS (Statistical Analysis Software, SAS Academic Studio October 30,2024, SAS Institute, Inc.) at alpha=0.10 and differences are determined with 90% confidence; meaning, if the study was repeated 100 times, that 90 times out of 100 we would expect treatments that are statistically similar (within one LSD value of each other) to continue to be similar.

Table 1. Application information for aphid control trials in 2024.	
Description	367 Aphids per Plant
Application Code	A
Date	July 29
Time of Day	12:00 PM
Air Temperature (F)	85
Relative Humidity (%)	78
Wind Velocity (mph)	2
Wind Direction	NW
Soil Temp. (F at 6")	77
Soil Moisture	Good
Cloud Cover (%)	25
Crop Growth Stage (avg)	R4

Economic Benefit to a Typical 500 Acre Soybean Enterprise:
Aphids continue to be an economically impactful pest in soybean. The difference between controlling soybean aphid that has reached economic threshold with a Tier 1 product compared to the untreated check can be a yield difference of 1.0 to 14.1 bushels with an average gain of 8.0 bushels of soybean per acre. At $10.00 per bushel the economic impact can be calculated between $10 to $141 and an average of $80 financial loss per acre based on the results of this singular study. Resistance in aphid populations continues to be a

challenge for growers. New modes of actions or premixed products with multiple modes of action included in a single jug can help in combating resistance. Overuse of any single mode of action without the addition of a second family of insecticides for multiple cropping seasons can create or grow resistance in aphid populations. It is critical for a grower to know if they have a resistant aphid population prior to selecting a product for aphid control. Growers should use the data set as a guide to visit with their crop consultants or local suppliers to determine an aphid control product, if any, that may provide the greatest aphid control and return on investment based on their aphid population resistance, if any, and on local supplier pricing and availability of products.

Related Research:
2024 Soybean White Mold Product Impact on Yield; 2024 Soybean Value-Added Product Impact on Yield; All articles available at www.nxtgenag.com under the "Latest News" tab.

Recommended Future Research:
Next Gen Ag LLC, and our industry collaborators, are very appreciative for the funding of our competitive industry trials. Next Gen Ag LLC collaborates with 25+ national and international agriculture crop protection companies annually. Collaborators of Next Gen Ag LLC provide all the treatment and products required at no cost for the work to be conducted. MSRPC dollars fund all the operating and labor costs associated with the project to provide Minnesota Soybean Growers a non-biased data set to compare products on the market in weed control, aphid control, white mold control, and value-added inputs. Next Gen Ag LLC and our industry collaborators are already hard at work developing grant proposals for 2025. We intend to repeat our 2024 competitive industry studies and plan to have new proposals looking at adjuvant impact on postemergence foliar herbicides on giant ragweed and waterhemp in addition to a grant looking at broadcasted/interseeded rye impact on soybean yield and SCN. Each year the latest products entering the market have an opportunity to be showcased to Minnesota Soybean Growers. Non-biased, collaborative, and ROI focused research.

Publications:
2024 Soybean Aphid Control Product Impact on Yield; All articles available at www.nxtgenag.com under the "Latest News" tab.
Next Gen Ag: Conducting Research with the Next Generation [of soybean growers] in Mind!
This publication and more MSR&PC-funded research conducted by Next Gen Ag, LLC can be found online at www.nxtgenag.com under the "Latest News" tab and "Public Grant Research Studies" page.

2024 Soybean Value-Added Product Impact on Yield

Principal Investigator(s): Next Gen Ag LLC - Andrew Lueck, Research Lead & Jenna Whitmore, Research Manager

Project Period: April 2024 – March 2025

Research Question/Objectives:
Collaborate with industry partners (10 participants) (Done).
Successfully apply plant health chemistry (Done).
Record yield data (Done).
Summarize and publish data (Done & continuing).
Publications; published to Next Gen Ag LLC website (Done).
Speak at SMSU Plot tour (Done).
Present at summer conference (Done).
Present at Prairie Grains conference (December).
Present at Ag Expo conference (January).

Results:
Soybean yield was evaluated across six replications with each treatment randomized and appearing only once within each of the six replications to mitigate impact of field location and environment on the data set. Overall, the study was uniform and high-yielding, with an average yield of 70.2 bushels/ac across the study. Data table has been displayed in descending order of yield (Table 2). There was an 11.1-bushel per acre range in the yield data set. A few observations could be made, that out of 22 entries, the top 13 treatments were all statistically similar, however, only one treatment (top performer by 0.5 bu/A) was statistically better than the untreated check. Treatments including an in-furrow were all statistically similar to the top performer. The addition of more than one value-added product or multiple application timings in a treatment did appear to have an advantage on final yield in some cases, but not consistently.

Table 2. Value-added impact on soybean yield and moisture in 2024.					
		App.	Harvest		
Treatment	Rate	Code[a]	Yield	Moisture	Company
	oz/A* or fl oz/A		Bu/A[b]	%	
Delaro+Masterlock	8+6.4	D	75.2 a	11.7 ab	Bayer
AZterknot+VCP-035+Masterlock	8+4+6.4	D	74.1 ab	11.2 a-d	Vive
Fort. Stim. Yield Enhan. Plus + Energy Power / Stimulate Auxin/Cytokinin+Bio-Forge Advanced+Keylate Manganese / Stimulate Auxin/Cytokinin+ Harvest More Urea Mate / Sugar Mover Premier+X-Cyte	4+8 / 2+16+32 / 2+40* / 32+8	A/B/C/D	73.9 a-c	10.8 b-f	Stoller (Now Corteva)
Delaro Complete+Masterlock	8+6.4	D	73.6 a-d	11.5 ab	Bayer
Bio-ForgeAdvanced+Energy Power / Stimulate Auxin/Cytokinin+Bio-Forge Advanced+ Keylate Manganese / Energy Power+Stimulate Auxin/Cytokinin / Sugar Mover Premier+Harvest More Urea Mate	8+8 / 2+16+32 / 16+2 / 32+40*	A/B/C/D	73.3 a-e	11.0 b-e	Stoller (Now Corteva)
Vigorion	27	D	72.6 a-e	10.8 b-f	Fertinagro
AZteroid FC 3.3 +6-26-6+Masterlock+AZterknot+VCP-035	4.2+3 Gal.+6.4 / 8+4	A/D	71.8 a-f	10.4 c-g	Vive
Revytek+Masterlock	8+6.4	D	71.6 a-f	11.6 ab	BASF
Superbia / Superbia	16*	B/D	71.5 a-f	11.0 b-e	Fertinagro
Accomplish MAX+Riser / Terramar+Radiate+ReaxK / Radiate Next	32+128 / 32+2+16 / 2	A/B/C	71.0 a-g	11.2 a-d	Loveland
AZteroid FC 3.3+Bifender FC+6-24-6+Masterlock	4.2+4+3 Gal.+6.4	A	70.8 a-g	11.2 a-d	Vive
Yield On	24	C	70.7 a-g	11.3 a-c	Winfield
Levitate / Terramar+Radiate+ReaxK / Radiate Next+Nutrisync Complete 3d	128 / 32+2+16 / 2+16	A/B/C	70.2 a-h	10.9 b-e	Loveland
Miravis Neo+Masterlock	13.7+6.4	D	69.8 b-h	12.2 a	Syngenta
Miravis Neo+Masterlock / Miravis Neo+Masterlock	13.7+6.4 / 13.7+6.4	C/D	69.5 b-h	12.1 a	Syngenta
Untreated Check	-	-	69.5 b-h	10.8 b-f	-
6-24-6 Check	3 Gal.	A	69.4 b-h	10.0 e-g	-
Veltyma+Masterlock	7+6.4	D	68.8 c-i	11.4 ab	BASF
AZterknot+VCP-035+Masterlock	14+4+6.4	D	68.5 d-i	10.9 b-e	Vive
Delaro Complete+Masterlock+Yield On	8+6.4+24	C	68.2 e-i	9.60 fg	Winfield
Voyagro 4-0-16+Masterlock	16+6.4	C	67.1 f-i	10.2 d-g	Winfield
Sosdia Stress / Sosdia Stress	6.4+6.4	B/C	65.9 g-i	11.0 b-e	Corteva
Ascend SL	3.4	C	65.3 hi	10.0 e-g	Winfield
LSD (0.1)			**5.2**	**1.4**	

aApplication codes refer to the information in Table 1. bBu/A=Soybean yield is corrected to a moisture of 13.5%. Same letters next to values are statistically similar values at alpha=0.1.

Application/Use:

Soybean Plant Health; Maintaining/Maximizing Yield Potential; Industry Comparison; Return on Investment.

Materials and Methods:

Experiments were conducted on a fine-textured webster-clay loam soil with 5.0% organic matter and a 6.8 soil pH near Renville, Minnesota, in 2024. The study area has been a corn-soybean rotation for decades. Spring tillage was a field cultivator at 3" depth. Becks 1830E3 soybean was seeded 1.25 inches deep on 30-inch row spacings at 140,000 seeds per acre on May 14, emerging May 22. Study was kept weed free with a preemergent application of Outlook on May 14 followed by a postemergence application of Enlist One, RoundUp PowerMax II, Zidua SC and Class Act NG on June 1. A subsequent postemergence application of Enlist One, Class Act NG, Section 3, Liberty 280 SL, MSO, and Interlock was made on June 27. On July 30, Endigo ZCX at 4.5 fl oz was applied as a blanket insecticide. Treatments were applied to soybean in-furrow, at V4, at R1, and at R3 soybean growth stages (Table 1). In-furrow treatments were applied with a planter in a 7 GPA spray solution through #30-flat disk orifice pressurized with CO_2 at 30 psi to all four rows directly overtop the seed, but prior to furrow closure. Foliar treatments applied with bicycle sprayer in 15 GPA spray solution through AIXR11002 air-induction flat fan nozzles pressurized with CO_2 at 26 psi to the center two rows of four row plots 40-foot in length.

Yield data were collected on September 27 utilizing a Hege 160 two-row small plot research combine equipped with a HarvestMaster large plot weigh hopper. The middle two rows of the four-row plot were harvested and samples were taken with moisture and test weights recorded using a Perten 5200-A moisture tester. Experimental design was a randomized complete block with 6 replications. Data were analyzed with GLM procedure of SAS (Statistical Analysis Software, SAS Academic Studio October 30, 2024, SAS Institute, Inc.) at alpha=0.10 and differences are determined with 90% confidence; meaning, if the study was repeated 100 times, that 90 times out of 100 we would expect treatments that are statistically similar (within one LSD value of each other) to continue to be similar.

Table 1. Application information for value-added product trial in 2024.

Description	In-Furrow	V4 Growth Stage	R1 Growth Stage	R3 Growth Stage
Application Code	A	B	C	D
Date	May 14	June 19	July 2	July 16
Time of Day	7:00 PM	1:00 PM	1:30 PM	10:00 AM
Air Temperature (F)	64	69	78	72
Relative Humidity (%)	45	70	70	82
Wind Velocity (mph)	5	3	3	2
Wind Direction	NE	NW	SW	NW
Soil Temp. (F at 6”)	60	66	71	69
Soil Moisture	Good	Very Wet	Good	Good
Cloud Cover (%)	20	80	80	5
Crop Growth Stage (avg)	-	V4	R1	R3

Economic Benefit to a Typical 500 Acre Soybean Enterprise:
The addition of multiple value-added products or multiple application timings in a treatment may have an advantage on final yield. Although only a single treatment yielded above the untreated check, 14 of the 22 entries appeared above the untreated check. This would suggest a grower should consider the addition of at least one value-added product to their program. A grower should consider adding an in-furrow value-added product to their program as this timing appears to have 100% chance of trending above the untreated check for final yield, however, there were plenty of single foliar application timings that trended above the untreated check as well. This study was uniform and high-yielding, allowing treatments a better chance of achieving a “yield ceiling”. Growers should use the data set as a guide to visit with their crop consultants or local suppliers to determine a value-added product, if any, that may provide the greatest return on investment based on local supplier pricing and availability of products.

Related Research:
2024 Soybean Aphid Control Product Impact on Yield, 2024 Soybean White Mold Product Impact on Yield; All articles available at www.nxtgenag.com under the “Latest News” tab.
Recommended Future Research:
Next Gen Ag LLC, and our industry collaborators, are very appreciative for the funding of our competitive industry trials. Next Gen Ag LLC collaborates with 25+ national and international agriculture crop protection companies annually. Collaborators of Next Gen Ag LLC provide all the treatment and products required at no cost for the work to be conducted. MSRPC dollars fund all the operating and labor costs associated with the project to provide Minnesota Soybean Growers a non-biased data set to compare products on the market in weed control, aphid control, white mold control, and value-added inputs. Next Gen Ag LLC and our industry collaborators are already hard at work developing grant proposals for 2025. We intend to repeat our 2024 competitive industry studies and plan to have new proposals looking at adjuvant impact on postemergence foliar herbicides on giant ragweed and waterhemp in addition to a grant looking at broadcasted/inter-seeded rye impact on soybean yield and SCN. Each year the latest products entering the market have an opportunity to be showcased to Minnesota Soybean Growers.
Non-biased, collaborative, and ROI focused research.

Publications:
2024 Soybean Value-Added Product Impact on Yield; All articles available at www.nxtgenag.com under the “Latest News” tab.

Next Gen Ag: Conducting Research with the Next Generation [of soybean growers] in Mind!
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2024 Soybean White Mold Product Impact on Yield

Principal Investigator(s): Next Gen Ag LLC - Andrew Lueck, Research Lead & Jenna Whitmore, Research Manager

Project Period: April 2024 - March 2025

Research Question/Objectives:
Collaborate with industry partners (7 participants) (Done).
Successfully apply aphid chemistry, 100 threshold (Done).
Record aphid count and yield data (Done).
Summarize and publish data (Done & continuing).
Publications; published to Next Gen Ag LLC website (Done).
Speak at SMSU Plot tour (Done).
Present at summer conference (Done).
Present at Prairie Grains conference (December).
Present at Ag Expo conference (January).

Results:
Soybean white mold severity index scores, moisture, and yield were evaluated across four replications with each treatment appearing once within each replication to mitigate impact of field location and environment on the data set, however, with the magnitude of the study, plot geographical location appeared to have an impact on harvest moisture in replications 2 and 3 which were impacted by stunting from very wet soil conditions between June 10 and July 30. Despite environmental effects, severity index score data was still able to determine significant differences between treatments. Data table has been displayed in descending order of yield data (Table 2). There were no significant differences in the 7DAA data, this is likely due to baseline existing infection as fungicides are a proactive solution to white mold suppression rather than reactive. All treatments were significantly better than the untreated checks at 14DAA, however, no treatment outperformed another treatment. At the 21 DAA evaluation timing, Treatment 13 significantly outperformed treatment 1 but this may be attributed to random error as treatment 1 was the top yielder.

Harvest moisture was statistically greater for treatments 3 and 6 which appeared predominantly on the right side of the study, which was less impacted by soybean stunting earlier in the growing season, allowing plots to appear to have better plant health. In regards to soybean yield, Endura at 6.0 dry ounces per acre applied at R1 followed by Priaxor at 4.0 fluid ounces per acre applied at R3 had the greatest yield; however, it was statistically similar to ranked treatments 2 through 10. All treatments yielded statistically similar to the untreated check, this could potentially be due to the lower infection during the late-season drought conditions and soybean canopy not occurring until mid-August which may have created a less than ideal late season environment for the fungus to thrive in. There was stunting from sitting water in portions of reps 2 and 3; thus, overall uniformity of the study was less than expectation.

Table 2. White mold fungicide impact on white mold severity, soybean yield, and moisture in 2024.									
			App.				Harvest		
Treatment		Rate	Code[a]	7DAA	14DAA	21DAA	Moisture	Yield	Company
#		oz/A* or fl oz/A					%	Bu/A[b]	
1	Endura+NIS / Priaxor+NIS	6*+0.25%v/v / 4+0.25%v/v	A / C	0.08	0.31	1.92	13.45	66.48	BASF
2	AZterknot+VCP-035 / Azterknot+VCP-035	8+4 / 8+4	A / C	0.17	0.54	1.79	13.60	65.27	Vive
3	AZterknot+VCP-035	14+4	B	0.04	0.21	0.85	14.78	63.14	Vive
4	Delaro+NIS	8+0.125%v/v	A	0.1	0.35	1.29	13.53	61.86	Bayer
5	AZterknot+VCP-035	8+4	B	0.06	0.75	1.10	11.25	61.30	Vive
6	VCP-035	4	B	0.04	0.44	1.71	17.75	59.86	Vive
7	Delaro Complete+NIS	8+0.125%v/v	A	0.04	0.52	1.17	12.48	58.90	Bayer
8	Untreated Check	-	-	0.49	2.15	4.17	12.23	58.48	-
9	Endura+NIS / Endura+NIS	6*+0.25%v/v	A / D	0.19	0.73	1.36	13.18	58.20	BASF
10	Endura+NIS	6*+0.25%v/v	A	0.17	0.77	1.67	11.60	57.58	BASF
11	Endura Pro	20	A	0.12	0.81	1.52	12.63	55.54	BASF
12	Aproach Prima+Aproach+NIS / Aproach Prima+Aproach+NIS		A / D	0.52	0.44	1.17	12.63	54.71	Corteva
13	Miravis Neo+Masterlock / Miravis Neo+Masterlock	13.7+6.4 / 13.7+6.4	A / C	0.12	0.42	0.67	12.50	54.51	Syngenta
14	Delaro Complete+NIS	8+0.125%v/v	C	0.21	0.71	0.85	13.70	53.07	Bayer
15	Delaro Complete+NIS / Delaro Complete+NIS	8+0.125%v/v / 8+0.125%v/v	A / C	0.25	0.42	1.44	12.95	52.87	Bayer
16	Viatude+NIS / Viatude+NIS	16+0.25%v/v / 16+0.25%v/v	A / D	0.31	0.65	1.08	13.18	52.42	Corteva
17	Aproach+NIS / Aproach+NIS	9+0.25%v/v / 9+0.25%v/v	A / D	0.19	0.44	0.96	12.40	52.34	Corteva
	LSD (0.1)			**NS**	**0.72**	**1.17**	**2.83**	**10.26**	

aApplication codes refer to the information in Table 1. bBu/A=Soybean yield is corrected to a moisture of 13.5%. Same letters next to values are statistically similar values at alpha=0.1.

Application/Use:
Soybean White Mold Control; Plant Health: Maximizing Yield Potential; Industry Comparison; Return on Investment.

Materials and Methods:
Experiments were conducted on a fine-textured webster-clay loam soil with 5.8% organic matter and a 6.6 soil pH near Renville, Minnesota, in 2024. Spring tillage was a field cultivator at 3" depth. BASF 1822E3 soybean was seeded 1.25 inches deep on 30-inch row spacings at 158,000 seeds per acre on May 15, emerging May 23. Study was kept weed free with a preemergent application (PRE) of Outlook on May 14 followed by a postemergence application of Enlist One, Roundup Powermax II, Zidua SC, and Class Act NG on June 1. A second postemergence application of Enlist One, Class Act NG, Section 3, Liberty 280 Sl and MSO was applied on June 27. Endigo ZCX was applied at 4.5 fl oz for aphid control on July 30. Whitemold treatments were applied at growth stages R1, R2, R3, and 14DAA (14 days after the R1 application). Both applications "C"(R3) and "D"(14DAA) occurred on the same day. All treatments were applied with a bicycle sprayer at 20 GPA through AIXR11002 air-induction flat fan nozzles pressurized with CO2 at 40 psi to the center two rows of four row plots 35 feet in length.

In season white mold evaluations were recorded as a numerical severity rating 0-3 and percent incidence on 20 plants per plot. The numerical severity rating scale was 0=no sign of disease, 1=disease present on main stem, 2=disease present on main stem and lateral branches, and 3=plant is wilted or dead. Percent incidence was calculated as the total number of plants (out of 20 rated) that had a numerical rating greater than "0". Percent incidence and numerical severity rating were combined in an equation common to the industry represented as a "Severity Index" score. Severity index is a scale of 0-100 and is calculated as Dx=%incidence(as a whole number)*numerical severity average (of 20 plants)/3 with the higher values being more severe. Yield data were collected on September 25 utilizing a Hege 160 two-row small plot research combine equipped with a HarvestMaster large plot weigh hopper. The middle two rows of the four-row plot were harvested and samples were taken with moisture and test weights recorded using a Perten 5200-A moisture tester. Experimental design was a randomized complete block with 4 replications. Data were analyzed with GLM procedure of SAS (Statistical Analysis Software, SAS Academic Studio October 30, 2024, SAS Institute, Inc.) at alpha=0.10 and differences are determined with 90% confidence; meaning, if the study was repeated 100 times, that 90 times out of 100 we would expect treatments that are statistically similar (within one LSD value of each other) to continue to be similar.

Table 1. Application information for Renville white mold fungicide trials in 2024.

Description	R1 Growth Stage	R2 Growth Stage	R3 Growth Stage	14DAA
Application Code	A	B	C	D
Date	July 3	July 8	July 17	July 17
Time of Day	8:30 AM	3:30 PM	9:00 AM	9:00 AM
Air Temperature (F)	66	77	67	67
Relative Humidity (%)	85	67	78	78
Wind Velocity (mph)	3	4	4	4
Wind Direction	SW	NW	NW	NW
Soil Temp. (F at 6”)	64	75	66	66
Soil Moisture	Good	Good	Good	Good
Cloud Cover (%)	20	80	10	10
Crop Growth Stage (avg)	R1	R2	R3	R3

Economic Benefit to a Typical 500 Acre Soybean Enterprise:
Despite environmental effects, severity index score data was still able to determine significant differences between treatments and the untreated check indicating product response, while moisture differences were most likely due to plot orientation. The addition of more than one product or application timing, did not appear to have a significant advantage to yield. This data set concluded that adding a fungicide application to soybeans reduced secondary white mold infection as compared to the untreated check. Growers should use this data set as a guide to visit with their crop consultants or local suppliers to determine an appropriate fungicide program, if any, that may provide the least amount of yield loss from white mold and the best return on investment based on their white mold disease pressure and on local supplier pricing and availability of products.

Related Research:
2024 Soybean Aphid Control Product Impact on Yield; 2024 Soybean Value-Added Product Impact on Yield; All articles available at www.nxtgenag.com under the “Latest News” tab.
Recommended Future Research:
Next Gen Ag LLC, and our industry collaborators, are very appreciative for the funding of our competitive industry trials. Next Gen Ag LLC collaborates with 25+ national and international agriculture crop protection companies annually. Collaborators of Next Gen Ag LLC provide all the treatment and products required at no cost for the work to be conducted. MSRPC dollars fund all the operating and labor costs associated with the project to provide Minnesota Soybean Growers a non-biased data set to compare products on the market in weed control, aphid control, white mold control, and value-added inputs. Next Gen Ag LLC and our industry collaborators are already hard at work developing grant proposals for 2025. We intend to repeat our 2024 competitive industry studies and plan to have new proposals looking at adjuvant impact on postemergence foliar herbicides on giant ragweed and waterhemp in addition to a grant looking at broadcasted/inter-seeded rye impact on soybean yield and SCN. Each year the latest products entering the market have an opportunity to be showcased to Minnesota Soybean Growers. Non-biased, collaborative, and ROI focused research.

Publications:
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2024 Waterhemp Resistance Management Programs in Corn-Soybean Rotations

Principal Investigator(s): Next Gen Ag LLC - Andrew Lueck, Research Lead & Jenna Whitmore, Research Manager

Project Period: April 2024 – March 2025

Research Question/Objectives:
Collaborate with industry partners (8 participants) (Done).
Successfully apply chemistry (Done).
Successfully record data and images (Done).
Summarize and publish data (Done & continuing).
Publications; published to Next Gen Ag LLC website (Done).
Speak at SMSU Plot tour (Done).
Present at summer conference (Done).
Present at Prairie Grains Conference (December).
Present at Ag Expo conference (January).

Results:
WATERHEMP IN CORN
Waterhemp pressure across the study area was uniformly distributed. Waterhemp germination was later than expected due to lower soil temperature and cooler weather conditions until the first week of June. Pre-emergence (PRE) product control at A+14 was 99.97% across all treatments as a result of late-emerging waterhemp. PRE product treatments had consistent rain activation all spring and through July, which allowed the products to consistently prevent new waterhemp germination well into crop canopy. There were no statistically significant differences, meaning all treatments performed equally to each other with 90% repeatability. All treatments met the grant goal of 95% waterhemp control at A+14, A+28, and A+42. At the last evaluation of A+56 on July 8, one of the 16 treatments fell below 95% however, no statistically significant differences.

Table 2. Waterhemp control in corn in 2024.						
		App.	Waterhemp Control			
Treatment[a]	Rate	Code[b]	A+14[c]	A+28	A+42	A+56
	oz/A* or fl oz/A		--------------%----------------			
Surtain / Status+RU3+NIS+Dry AMS[d]	14 / 5*+30+1.5lb/A	A / B	100	98.5	98.8	98.8
Verdict / Status+Callisto+Atrazine+RU3+COC+Dry AMS	15 / 3*+3+16+30+1.5lb/A	A / B	100	100	100	98.8
Trivolt / Laudis+DiFlexx+RU3+MSO+Class Act Ridion	12 / 3+8+30+0.5%+1%	A / B	100	98.3	97.0	92.5
Harness Max / Capreno+Atrazine+RU3+MSO+AMS	40 / 3+16+30+0.5%	A / B	100	99.5	100	97.5
Surpass NXT / Kyro+AAtrex+RU3+COC+Amsol	32 / 45+16+30+2.5%	A / B	100	100	100	96.3
Surpass NXT / Resicore XL+AAtrex+RU3+COC+Amsol	32 / 45+16+30+2.5%	A / B	100	100	100	98.8
Anthem Maxx / AAtrex+RU3+Callisto+AMS+COC	4.5 / 32+30+3	A / B	100	100	100	99.5
Anthem Maxx+Callisto+AAtrex / AAtrex+Anthem Maxx+RU3+DiFlexx+AMS	4.5+5.5+16 / 16+2.5+30+8	A / B	100	100	100	100
FortiTRI+Sinder 3L / Rifle+Missile	21+2 / 8+0.25%	A / B	100	100	98.8	97.0
FortiTRI+Sinder 3L+Infuse / Rifle+Carabiner 4SC+Missile	21+2+24 / 8+3+0.25%	A / B	100	99.5	100	98.8
Calibra / AAtrex+Acuron GT+AMS	64 / 16+60	A / B	100	100	100	99.0
Acuron / Acuron+RU3+AMS	48 / 48+30	A / B	100	100	99.5	100
Harness / AAtrex+Maverick+RU3+AMS+HSMOC	44 / 16+14+30	A / B	100	100	100	98.8
TriVolt / AAtrex+Maverick+RU3+AMS+HSMOC	10 / 16+14+30	A / B	99.5	100	100	100
Trisidual / Cornerstone 5 Plus+Insinerate	32 / 32+3	A / B	100	98.8	98.8	96.3
Verdict / Acuron+RU3+AMS	18 / 48+30	A / B	100	100	99.5	96.3
LSD (0.1)			**NS**	**NS**	**NS**	**NS**

aPRE treatment applications contained no additional adjuvants. bApplication codes refer to the information in Table 1. cA+[#] or B+[#]=Days after "A" or "B" application. dAMS=Class Act NG 2.5%v/v; RU3=Roundup 3; COC=Crop Oil Concentrate 1%v/v; HSMOC=Destiny HC 0.5%v/v.

WATERHEMP IN SOYBEAN

Waterhemp pressure across the study area was uniformly distributed. Waterhemp germination was later than expected due to lower soil temperature and cooler weather conditions until the first week of June. Pre-emergence (PRE) product control at A+14 averaged 99.7% and ranged between 98.3 and 100%. The top 14 treatments were statistically similar; however, all treatments exceed 98% waterhemp control which would be considered
"excellent" and all 16 treatments achieved the goal of 95% waterhemp control.

Lay-by or early postemergence applications were made 10-days after the A+14 evaluation and 4-days prior to the A+28 evaluation to 4-6 inch tall waterhemp. This evaluation emphasized the impact of the early post emergence foliar efficacy. PRE product treatments had consistent rain activation all season through July, which allowed the products to prevent new waterhemp germination well into the growing season. Treatments averaged 99.2% and ranged between 95.3 and 100%. The top 14 treatments were statistically similar; however, all treatments exceed 95% waterhemp control which would be considered "excellent" and all 16 treatments achieved the goal of 95% waterhemp control.

The A+42 evaluation occurred 18-days after the early post emergence application. This evaluation emphasized the impact of layered residual herbicides. Treatments averaged 98.6% and ranged from 95 to 100%. The top 14 treatments were statistically similar; however, all treatments exceed 95% waterhemp control which would be considered "excellent" and all 16 treatments achieved the goal of 95% waterhemp control.

The A+56 evaluation occurred 32-days after the early post emergence application. This evaluation emphasized the season-long durability of the residual products utilized, without a lot of help from crop canopy, as the soybeans did not canopy until early-mid August as a result of excessive early rainfall and subsequent stunting. Treatments averaged 95.5% and ranged between 87.5 and 100. The top 7 treatments were statistically similar. One take away at this evaluation is the importance of applying two or more active ingredients PRE and to follow with an early post application that includes at least one residual active ingredient in addition to an active ingredient with foliar activity. The lower performing treatments at A+56 did not contain any residual active ingredients as part of the early post emergence tank mix. Overall, 8 of the 16 treatments achieved the goal of 95% waterhemp control.

Table 3. Waterhemp control in soybean in 2024.						
		App.	Waterhemp Control			
Treatment[a]	Rate	Code[b]	A+14[c]	A+28	A+42	A+56
	oz/A* or fl oz/A		--------------%--------------			
Zidua Pro / Liberty ULTRA+Outlook+RU3+Dry AMS[d]	6 / 24+10+30+3lb/A	A / B	100	99.5	97.8	93.8
Zidua Pro / Liberty ULTRA+RU3+Dry AMS	6 / 24+30+3lb/A	A / B	99.5	99.0	95.3	94.5
War.+Mauler / War.+RU3+Liberty+AMS	48+8 / 64+30+32	A / B	100	99.5	97.8	93.8
War. Ultra / War.+RU3+Liberty+AMS	48 / 48+30+32	A / B	100	99.5	99.5	95.8
Sonic / Enlist One+Liberty+AMS	5* / 32+32	A / B	98.3	98.3	95.0	93.8
Sonic / Enlist One+Liberty+EverpreX+AMS	5* / 32+32+16	A / B	99.5	99.5	98.3	95.0
Auth. Edge / Anthem Maxx+RU3+Enlist One+AMS	10 / 2.5+30+32	A / B	100	100	100	100
Auth. Edge / Anthem Maxx+RU3+Enlist One+AMS	8 / 3+30+32	A / B	100	98.3	99.0	97.0
Tribal / Enlist One+Mad Dog+Missile	72 / 32+36+0.25%	A / B	100	95.3	98.8	98.3
Tribal+Infuse / Enlist One+Mad Dog+Missile	72+32 / 32+36+0.25%	A / B	100	99.5	98.5	96.3
Boundary+Blanket / Enlist One+Sequence+AMS	32+5 / 32+48	A / B	100	99.5	99.5	95.0
BroadAxe XC / Enlist One+Prefix+RU3+AMS	28 / 32+32+30	A / B	100	100	100	98.8
Fierce MTZ / Liberty+Perpetuo+RU3+AMS	16 / 36+6+30	A / B	100	100	100	100
Fierce MTZ / Liberty+Resource+RU3+AMS	16 / 36+4+30	A / B	100	99	100	96.3
Dimetric Charged+Interlock / Enlist One+ Liberty+Cornerstone 5+StrikeLock+AMS	12+4 / 32+ 32+32+12	A / B	98.3	100	98.8	92.5
Presidual+Interlock / Enlist One+ Liberty+Cornerstone 5+StrikeLock+AMS	24+4 / 32+ 32+32+12	A / B	100	100	99.0	87.5
LSD (0.1)			**1.0**	**1.6**	**2.3**	**3.9**

aPRE treatment applications contained no additional adjuvants. bApplication codes refer to the information in Table 1. cA+[#] or B+[#]=Days after "A" or "B" application.
dAMS=Class Act NG 2.5%v/v; RU2/3=Roundup 2/3; War=Warrant; COC=Crop Oil Conc. 1%v/v; HSMOC=Destiny HC 0.5%v/v.

Application/Use:
Resistant Waterhemp Control; Industry Comparison; Return on Investment.

Materials and Methods:
Experiments were conducted on a low to moderate infestation of waterhemp near Renville, Minnesota, in 2024. Soil was a fine-textured webster-clay loam soil with 4.7% organic matter and a 6.4 soil pH. Spring tillage was a field cultivator at 3" depth. Enestvedts 654 Enlist PWC corn was seeded 2.00 inches deep on 30-inch row spacings at 33,000 seeds per acre on May 13 and emerging May 21. Preemergence herbicide treatments were applied to corn on May 14 and early-postemergence treatments to V4 corn on June 7 (Table 1). Becks 1830E soybean was seeded 1.25 inches deep on 30-inch row spacings at 140,000 seeds per acre on May 13 and emerging May 22. Preemergence herbicide treatments were applied to soybean on May 14 and earlypostemergence treatments to V2 soybean on June 7 (Table 1). All treatments applied with bicycle sprayer in 15 GPA spray solution through AIXR11002 air-induction flat fan nozzles pressurized with CO2 at 26 psi to the center two rows of four row plots 40 feet in length. Field area had moderate levels of ALS and glyphosate-resistant waterhemp.

Waterhemp control in corn was evaluated May 28, June 11, June 25, and July 8 (Table 2). Waterhemp control in soybean was evaluated May 28, June 11, June 25, and July 8 (Table 3). Waterhemp evaluations were a visual estimate of percent fresh weight reduction in center two treated rows compared to adjacent untreated strips. Experimental design was a randomized complete block with 4 replications. Data were analyzed with GLM procedure of SAS (Statistical Analysis Software, SAS Academic Studio October 30, 2024, SAS Institute, Inc.) at alpha=0.10 and differences are determined with 90% confidence; meaning, if the study were repeated 100 times that 90 times out of 100, we would expect treatments that are statistically similar (within one LSD value of each other in data tables 2 and 3) to continue to be similar.

Table 1. Application information for Renville waterhemp control trials in 2024.

Crop	Corn		Soybean	
Application Code	A	B	A	B
Date	May 14	June 7	May 14	June 7
Time of Day	8:00 AM	9:00 AM	11:00 AM	9:00 AM
Air Temperature (F)	60	61	68	61
Relative Humidity (%)	38	64	38	64
Wind Velocity (mph)	4	5	4	5
Wind Direction	NE	W	NE	W
Soil Temp. (F at 6”)	58	59	58	59
Soil Moisture	Good	Good	Good	Good
Cloud Cover (%)	10	5	10	5
Crop Growth Stage (avg)	-	V4	-	V2
Waterhemp Height	-	3”	-	3”

Economic Benefit to a Typical 500 Acre Soybean/Corn Enterprise:
In general, waterhemp pressure was late-germinating due to cooler soil temperatures and cooler weather conditions through the first week of June. Both studies had regular rainfall from planting through July providing great activation for residual products. Inclusion of residual herbicides applied at the “A” applications, along with rain activation, was important to maintain weed-free environments. The “B” applications were vital in controlling weeds that may have germinated through the first application, along with layered residuals to continue to prevent new germination. In both corn and soybean crops, there is a plethora of programs demonstrated, across various companies. Growers should use the data set as a guide to visit with their crop consultants or local suppliers to determine a giant ragweed program that provides the greatest control at an economical cost based on local supplier pricing and availability of products.

Related Research:
2024 Giant Ragweed Resistance Management Programs in Corn-Soybean Rotations; All articles available at www.nxtgenag.com under the “Latest News” tab.
Recommended Future Research:
Next Gen Ag LLC, and our industry collaborators, are very appreciative for the funding of our competitive industry trials. Next Gen Ag LLC collaborates with 25+ national and international agriculture crop protection companies annually. Collaborators of Next Gen Ag LLC provide all the treatment and products required at no cost for the work to be conducted. MSRPC dollars fund all the operating and labor costs associated with the project to provide Minnesota Soybean Growers a non-biased data set to compare products on the market in weed control, aphid control, white mold control, and value-added inputs.
Next Gen Ag LLC and our industry collaborators are already hard at work developing grant proposals for 2025. We intend to repeat our 2024 competitive industry studies and plan to have new proposals looking at adjuvant impact on postemergence foliar herbicides on giant ragweed and waterhemp in addition to a grant looking at broadcasted/inter-seeded rye impact on soybean yield and SCN. Each year the latest products entering the market have an opportunity to be showcased to Minnesota Soybean Growers. Non-biased, collaborative, and ROI focused research.

Publications:
2024 Waterhemp Resistance Management Programs in Corn-Soybean Rotations; All articles available at www.nxtgenag.com under the “Latest News” tab.
Next Gen Ag: Conducting Research with the Next Generation [of soybean growers] in Mind!
This publication and more MSRPC funded research conducted by Next Gen Ag, LLC can be found online at www.nxtgenag.com under the “Latest News” tab and “Public Grant Research Studies” page.

Tackling Twin Threats to Soybean in NW MN: SCN & IDC

Principal Investigator(s): Angie Peltier & Heather Dufault, Cooperator: Corey Hanson, Hanson Farms
Project Period: May 1 – Nov 15, 2024
Research Question/Objectives:
Collect SCN soil samples in both spring and fall from which to estimate SCN egg counts, collect foliar IDC ratings and soybean yield parameters in the OF "Tackling Twin Threats to Soybean in NW MN: SCN & IDC" pilot study.
Hold an in-season, OF field day focusing on IDC, SCN and the "Tackling Twin Threats to Soybean in NW MN: SCN & IDC" study being conducted on-farm in Norman County near Gary, MN. This field day is essential to remind farmers in NW MN of the tremendous threat that SCN poses to long-term soybean production and how to test for and manage it.

Results:

Stand Count.
The soybeans in the experimental field experienced hail injury during the late vegetative growth stages. The wet conditions experienced by the crop after planting along with hail-associated injury, led to many fewer plants compared to the 160,000 to 165,000 seeds planted per acre (Figure 1). There were no treatment differences observed in this trial for stand count and all treatments had more than 100,000 plants/acre, the density at which a soybean crop is thought to have sufficient population to maximize yield potential.

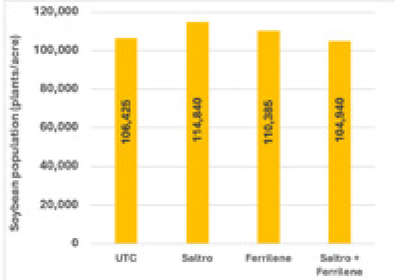


Fig. 1. Per acre soybean plant population (P = 0.255, CV = 10.45%).

IDC.
The 2024 growing season was a 'tale of two planting date ranges' in that early planted soybeans were met with very wet, cool weather resulting in severe symptoms of iron deficiency chlorosis. Later planted soybeans, particularly those in fields with a history of IDC and poor drainage also resulted in both severe and lasting IDC symptoms and slowed crop growth and development. However, although there was a history of IDC and soils were wetter than in a typical growing season in the study field, pattern tiling and the resulting adequate drainage likely decreased overall IDC symptom severity, regardless of treatment (Figure 2). In addition, while there may have been plants exhibiting more or less IDC symptom severity, areas of the field rated for IDC severity were selected randomly. No differences in IDC severity were observed among treatments.

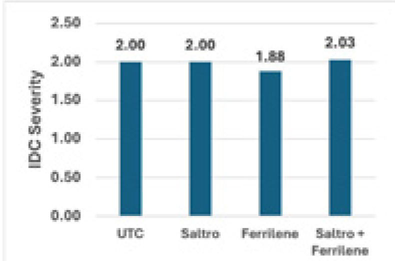


Fig. 2. IDC symptom severity, *P* = 0.49, CV - 11.01%.

Soybean yield.
Despite the late planting date of this experiment, soybean yields averaged between 49.6 and 54.0 bushels/acre (Figure 3) when corrected to 13% moisture. Untreated control (UTC) plots, in which neither treatment was applied, had the lowest yield at 49.6 bu/A, the plots grown to soybean treated with either the in-furrow iron chelate or the Saltro seed treatment and vice-versa yielded 52.6-52.9 bu/A and the plots in which both treatments were applied had the highest numerical yield at 54 bu/A. While the trends appear promising, there is little certainty that the trends would be similar in a different growing season or field without statistically significant differences being observed.

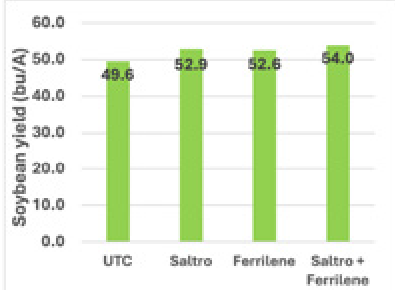


Fig. 3. Soybean yield, P = 0.138, CV = 5.550%.

Soybean moisture.
The 2024 growing season began with wetter than normal conditions that delayed spring field work including planting and both pre- and post-emergence herbicide applications. Contrastingly, the end of the 2024 growing season was unseasonably hot and dry, with many days reaching above 80 degrees and strong winds resulting in overly dry grain at harvest. Untreated control plots had numerically higher soybean moisture than the plots treated with either Saltro or Ferrilene or both (Figure 4). There were no statistical differences among treatments.

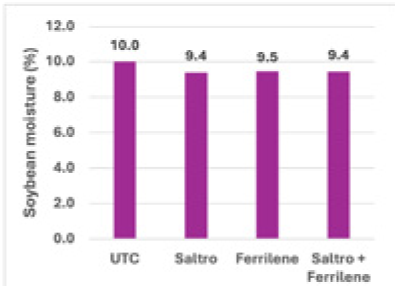


Fig. 4. Soybean moisture, P = 0.404, CV = 7.495%.

Soybean cyst nematode. To determine soybean cyst nematode egg counts (a population density estimate), fifteen 8-inch soil cores were collected at an angle from within the rooting zone of soybean rows of each plot on June 26 and on October 17 & 18, 2024, before and after soybeans were grown, respectively. Egg counts can provide information about population density growth as affected by our experimental treatments during the growing season.

Spring, initial SCN egg counts were moderate, ranging from an average of 350 to 850 eggs/100 cc (Table 1). The in-field variability of SCN egg counts resulted in there being no statistically significant differences in the initial SCN population to which soybeans were exposed. Initial numerical population densities were lowest in the plots assigned the Ferrilene treatment (x) with the Saltro-alone and Saltro + Ferrilene plots with egg counts 1.5x that of the Ferrilene plots and the untreated control plot with an initial population density 2.4x that of the Ferrilene plots.

Table 1. SCN egg count in spring, fall and the difference between spring and fall (egg count growth) along with results of a statistical analysis at the Corey Hanson Farm near Gary, MN

Treatment	Spring egg count	Fall egg count	Egg count growth
	Mean SCN eggs per 100 cubic centimeters of soil		
Untreated control (UTC)	850	3,783	2,933
Saltro alone	563	2,567	1,538
Ferrilene alone	350	3,917	3,567
Saltro + Ferrilene	538	2,483	1,425
P=	0.751	0.526	0.464
CV(%)	98	46	62

The fall egg counts ranged from 2,483 to 3,917 eggs/100 cc (Table 1). The same relationship among plots for relative egg counts was not observed after soybeans were produced in the field. The two treatments with the lowest fall SCN egg counts were those that included the Saltro seed treatment, suggesting that although the in-field variability didn't allow for statistical differences, the plots in which seed was treated with a seed treatment labeled for SCN may have had an impact on SCN population growth. Twelve hundred to 1,400 more eggs/100 cc were observed in the plots that had not been planted to soybeans treated with Saltro than in plots that had.

SCN population density growth throughout the 2024 growing season in the plots planted to seed treated with Saltro was approximately half that of plots planted to seed that didn't have the Saltro seed treatment. While the soybean variety planted was labeled by the seed company as having the PI88788 source of SCN resistance, it appears that the multiple generations of SCN that occurred in 2024 added between 3 and up to 10 times the population density that had been present in the field in the spring. As non-host crops prove less profitable or the PI88788 source of SCN resistance continues to lose its potency as an SCN management tactic, farmers may more frequently begin to consider using a biological or chemical soybean seed treatment labeled for SCN management.

Materials and Methods: Abnormally wet weather during spring 2024 led to a delay in planting this experiment at the Corey Hanson Farm near Gary, MN in Norman County, MN. The experiment was planted to Integra 0544EFortus at a depth of 1 inch into soil characterized as a Grimstad or Rockwell fine sandy loam at 160,000-165,000 seeds/ A on June 9 using seed treated with CruiserMax Apex at 1.95 oz/130,000 either with or without 0.8 fl oz/140,000 seeds Saltro (a.i. pydiflymetofen). Saltro is labeled for plant parasitic nematodes including soybean cyst nematode. Ferrilene, a liquid, EDDHA-chelated form of iron (6%) was also applied at 3 lbs/A to some plots in-furrow at planting.

Treatments included, 1) no Saltro + no Ferrilene, 2) Saltro + Ferrilene, 3) Saltro + no Ferrilene and 4) no Saltro + Ferrilene. Each on-farm, 700 ft long strip plot was planted to a soybean variety with a PI88788 source of SCN resistance (not lab-confirmed by this team) in a randomized complete block design in ten 22-inch spaced rows with two unplanted rows between each plot. Only 610 ft of each strip plot was harvested on October 17 with a 12-row reel on a farm-scale John Deere combine. Plot yields were determined with a weigh wagon, with samples collected to determine soybean moisture content. Iron deficiency chlorosis ratings of foliar symptoms were collected from two locations throughout each plot using the 1-5 ratings scale used by NDSU soybean breeders (Figure 5). Soybean stand count data were also collected from two locations in each plot.

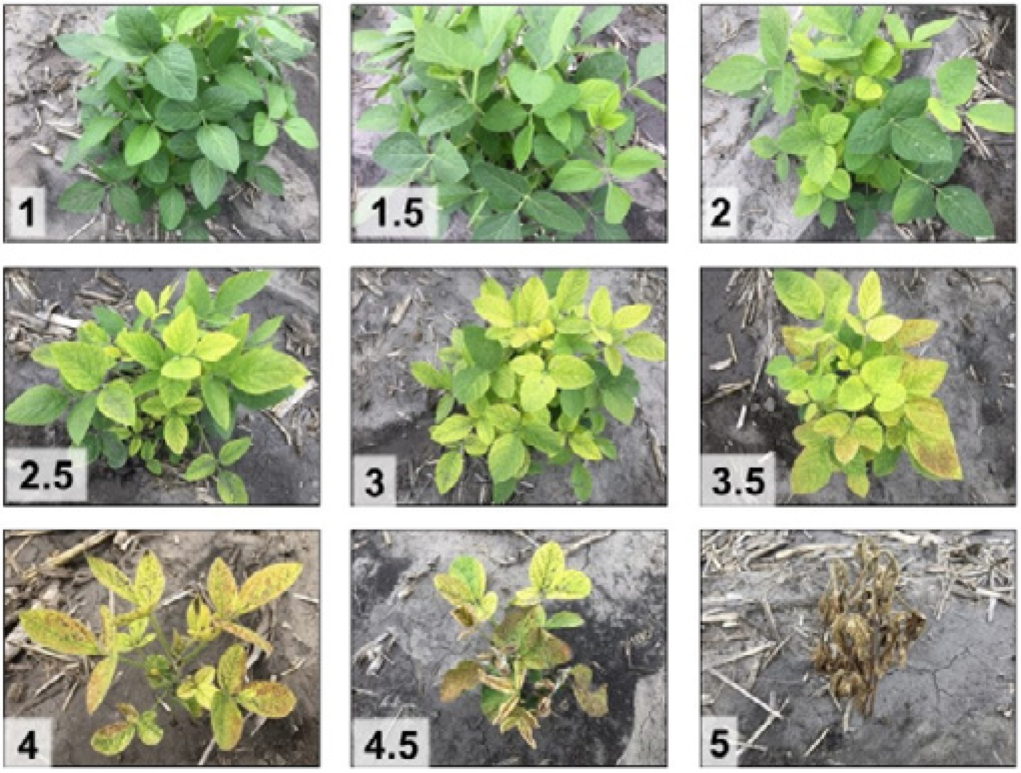


Figure 5. Iron deficiency chlorosis foliar ratings scale, where a score of 1 indicates green, healthy leaf tissue and a score of 5 indicates severe symptoms leading to plant death, used to estimate foliar symptoms of IDC. Source: North Dakota State University.

A field day focused on iron deficiency chlorosis and soybean cyst nematode was held for approximately 35 attendees at the plot location in Norman County on August 28, 2024.
Economic Benefit to a Typical 500 Acre Soybean Enterprise: Soybean cyst nematode is the most yield-limiting pathogen of soybean, responsible for significant yield losses each growing season. What makes SCN particularly pernicious is that it can cause up to 30% yield losses without there being any above-ground symptoms to alert the soybean producer of its presence. Other than an errant frost, drought or flooding, we argue that iron deficiency chlorosis is the abiotic disease most limiting to soybean yield potential in western Minnesota, capable of resulting in an average loss in yield potential of 20% for each increase in the IDC severity score of '1' (Figure 5). The goal of this experiment was to demonstrate the utility of actively managing both diseases. The inherent variability in this farm field and the limited number of replications did not result in statistical differences among treatments, meaning that we have little certainty that the results we saw in this field in 2024 would be similar in different fields or years. However, from a thought-experiment standpoint, with $9.30 soybeans (on Nov 14, 2024), had we been able to say with any certainty that these results were likely to happen in different fields or different years, each treatment on its own would have paid for itself or nearly paid for itself, but together would have cost ~$9/A more than was made back in yield.

Recommended Future Research: The goal of this experiment was to test two means of managing the most economically impactful biological and abiotic soybean diseases in northwest Minnesota. To give the SCN seed treatment Saltro 'a fighting chance' against a pathogen that can have 3 to 4 generations a year in northwest Minnesota. This experiment was planted in a field with known moderate SCN population densities. Perhaps either a more substantial population density or additional replications so that treatments can better overcome inherent in-field variability is indeed required to observe statistical differences among treatments. Despite the experiment being planted in a field with a known history of IDC, perhaps the fact that the field had subsurface drainage and so was less likely to have the saturated soil conditions that often favors IDC development didn't give the Ferrilene enough of a chance to visibly 'work.'

The authors would like to thank the Minnesota soybean farmer, the councilors of the Minnesota Soybean Research & Promotion Council and Agrimax.

2024 Western Minnesota Soybean IPM Survey

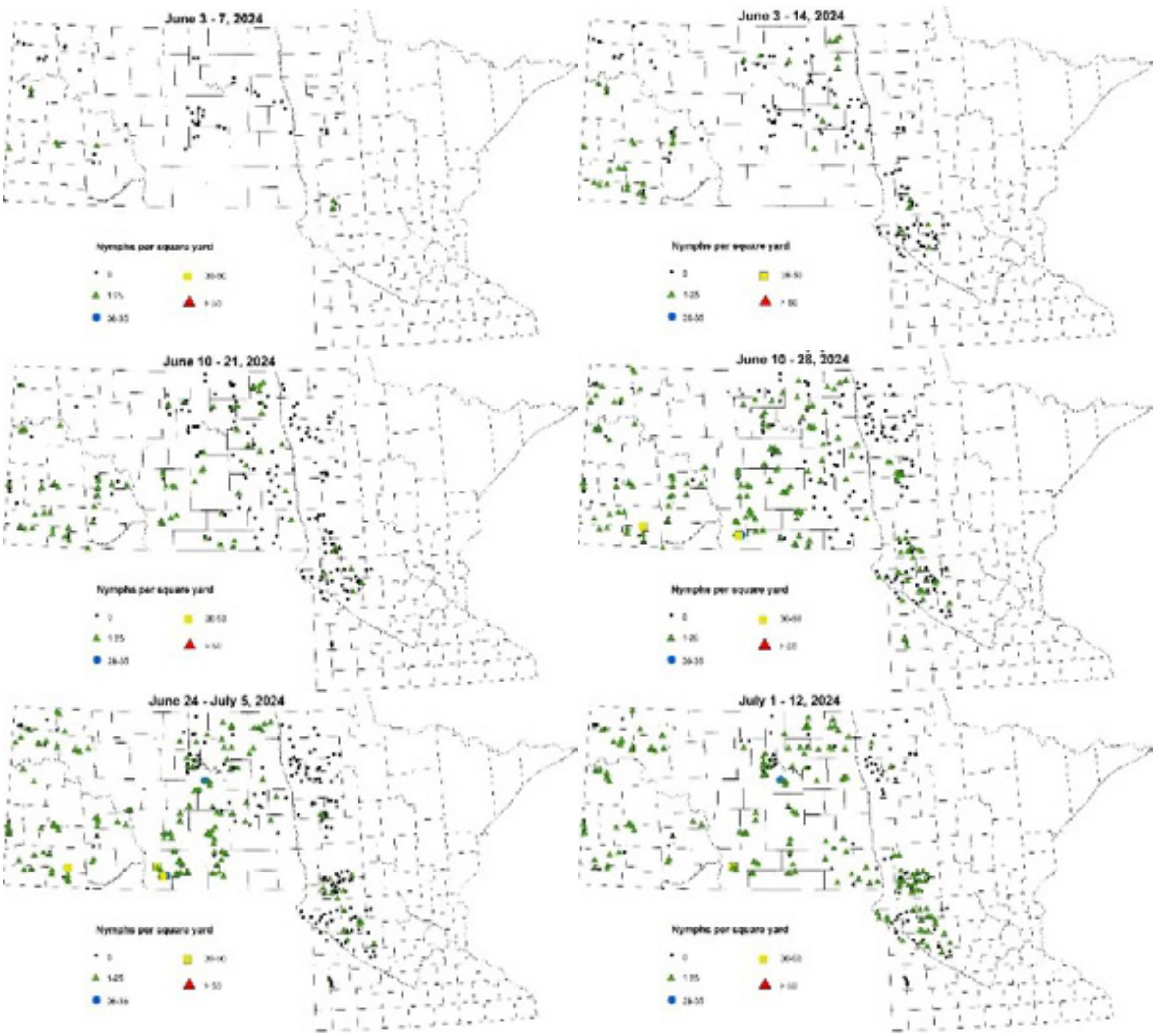
Principal Investigators: Angie Peltier & Anthony Hanson, UMN Extension

Project Period: May 1, 2024 - November 15, 2024

Research Question/Objectives:

1) Conduct field surveys to report soybean crop stage and pest conditions in NW and WC MN.
    a) Partner with the NDSU IPM program in conducting and reporting field and pest conditions across a region that includes NW and WC MN and eastern ND.
b) Deliver timely crop updates based on field observations with an emphasis on soybean aphid, two-spotted spider mite and other crop pest conditions as they develop.

Results: Please find Figures 1 through 20 below. Note that figure captions follow each figure and that figures may spread across multiple pages.



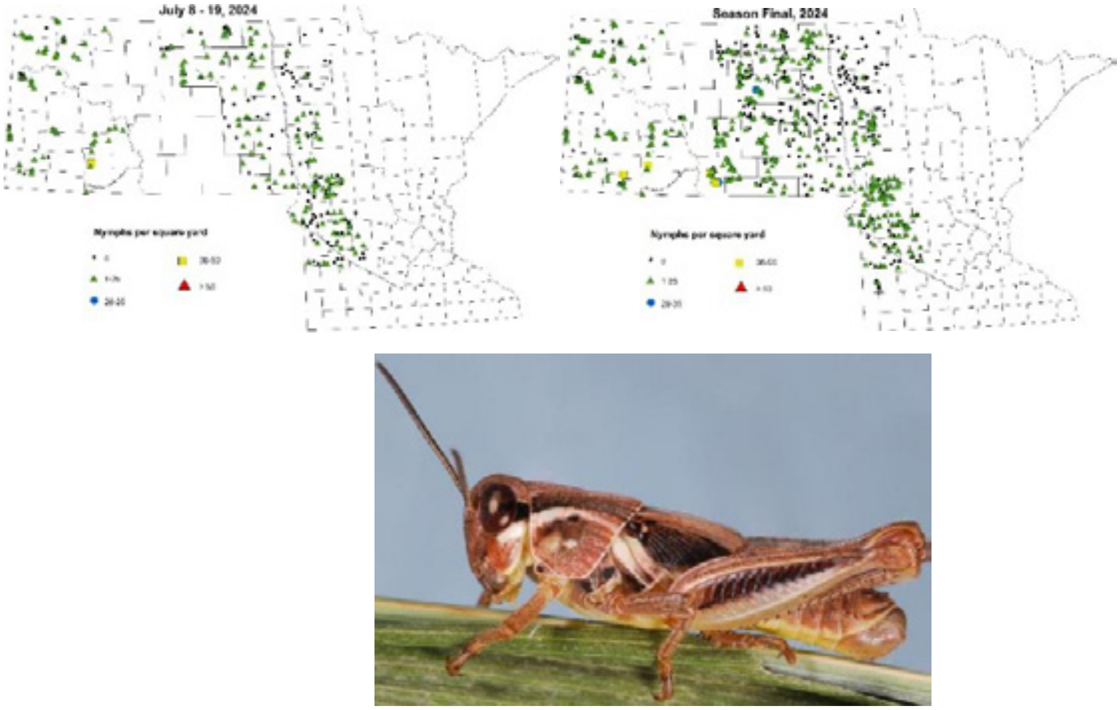
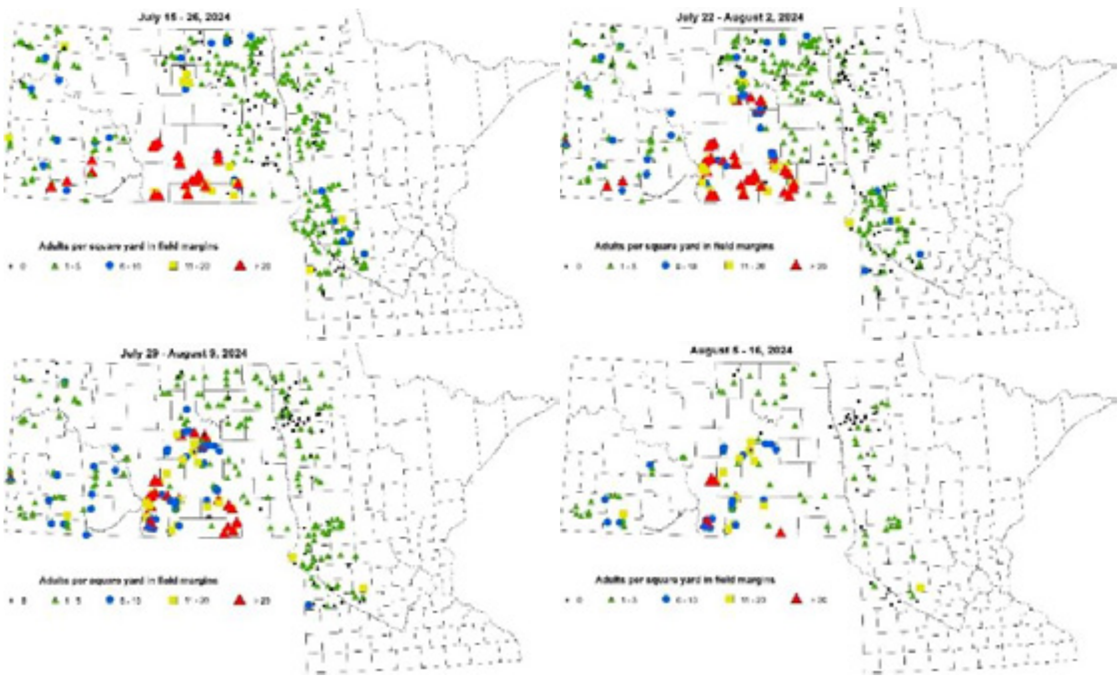


Figure 1. Grasshopper (multiple spp.) nymphs caught on the edge of scouted soybean fields over two-week periods from June 3 through July 19, 2024 and season-long final map. Redlegged grasshopper (*Melanoplus femurrubrum)* nymph, photo: Joseph Berger, Bugwood.org; Maps: NDSU IPM.



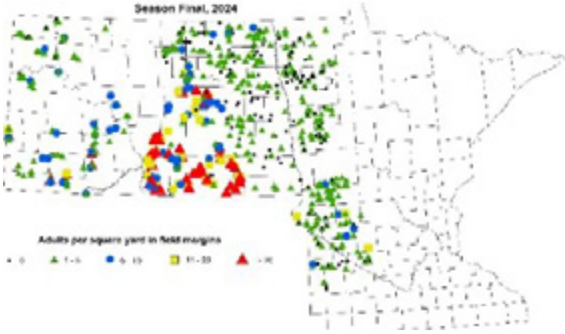
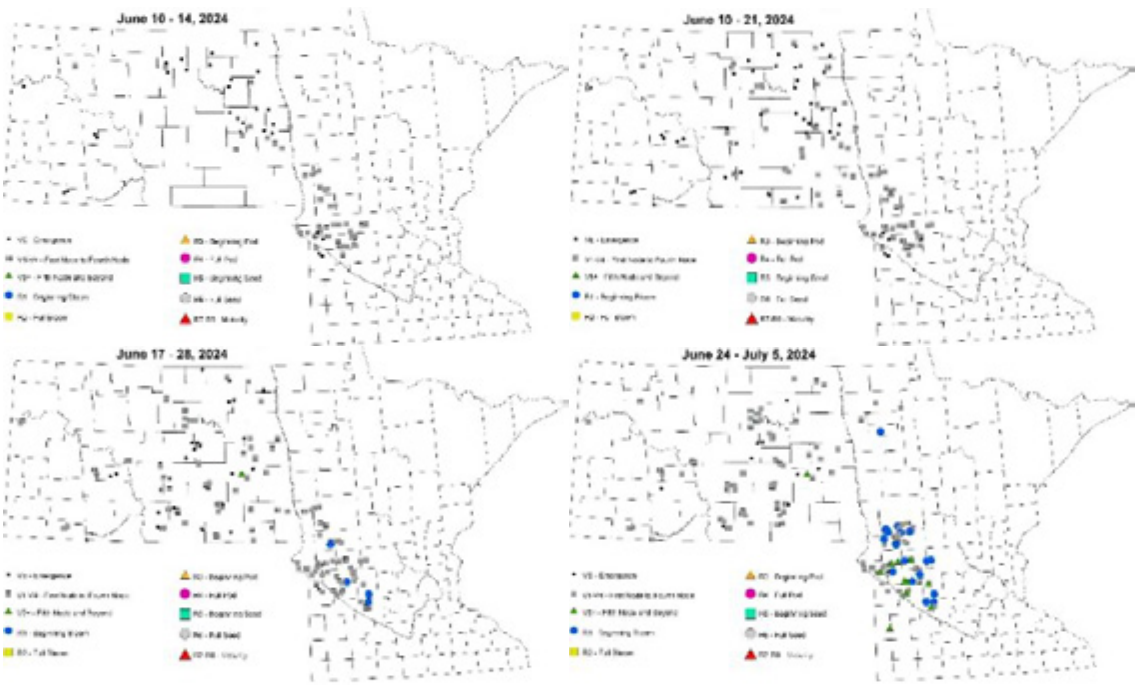


Figure 2. Grasshopper (multiple spp.) adults caught on the edge of scouted soybean fields over two-week periods from July 15 to August 16, 2024 and the season-long final. Redlegged grasshopper (*Melanoplus femurrubrum)* adult, photo: Joseph Berger, Bugwood.org; Maps: NDSU IPM.

Grasshoppers. Grasshoppers observed outside of surveyed fields were more likely to be adults than nymphs by mid-July (**Figures 1 & 2**). As small grains fields began to mature, grasshopper adults were likely to move to adjacent soybean fields. Field edges in WC MN had more adult grasshoppers (colored symbols) than those in NW MN in which there were many more 'no grasshopper' (black dot) locations.

For more information about grasshopper management, visit:
https://extension.umn.edu/corn-pest-management/grasshopper-management-minnesota-crops.



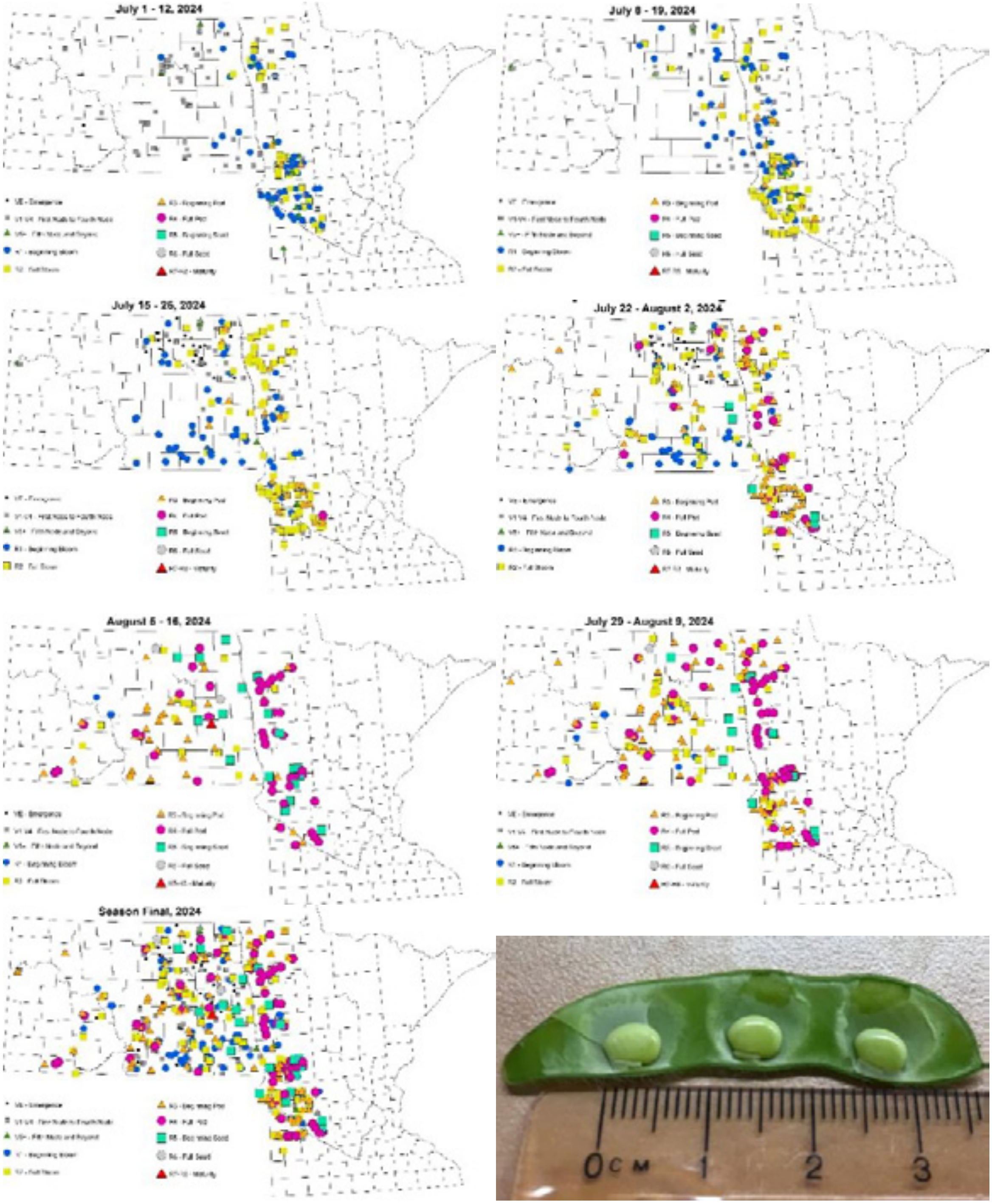
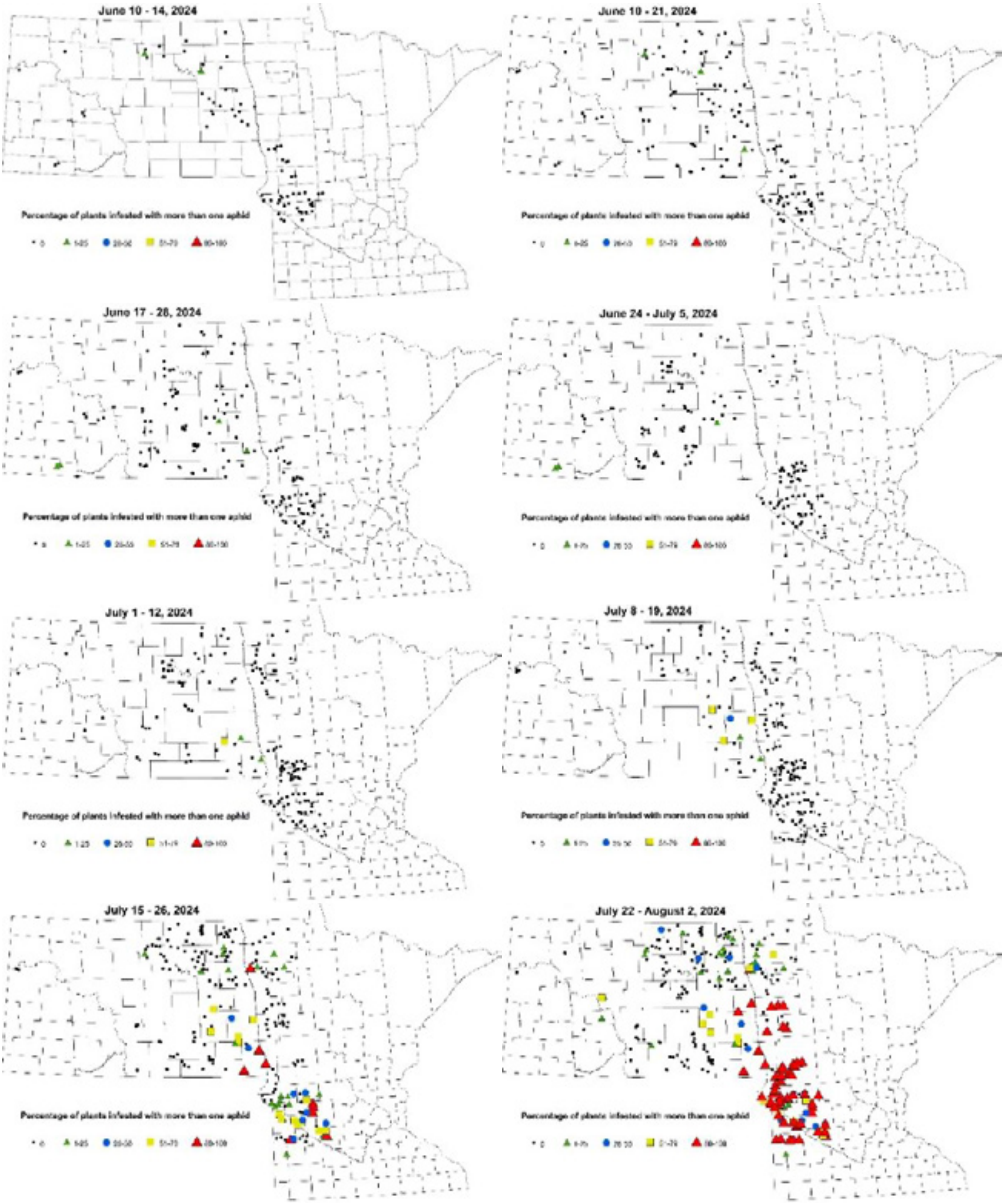


Figure 3. Soybean growth stages over two-week periods from June 10 to August 2, 2024 and season final map; Photo of R5 (beginning seed) soybeans, Angie Peltier, Maps: NDSU IPM.

Soybean growth stages. Early on and throughout the survey period, soybean growth stages in the middle of the Minnesota survey area were delayed in comparison to the NW and SW MN survey area (**Figure 3**). By the last week of the survey, a handful of fields had progressed to the beginning seed

For more information about growth staging soybeans, visit:
https://extension.umn.edu/growing-soybean/soybean-growth-stages.



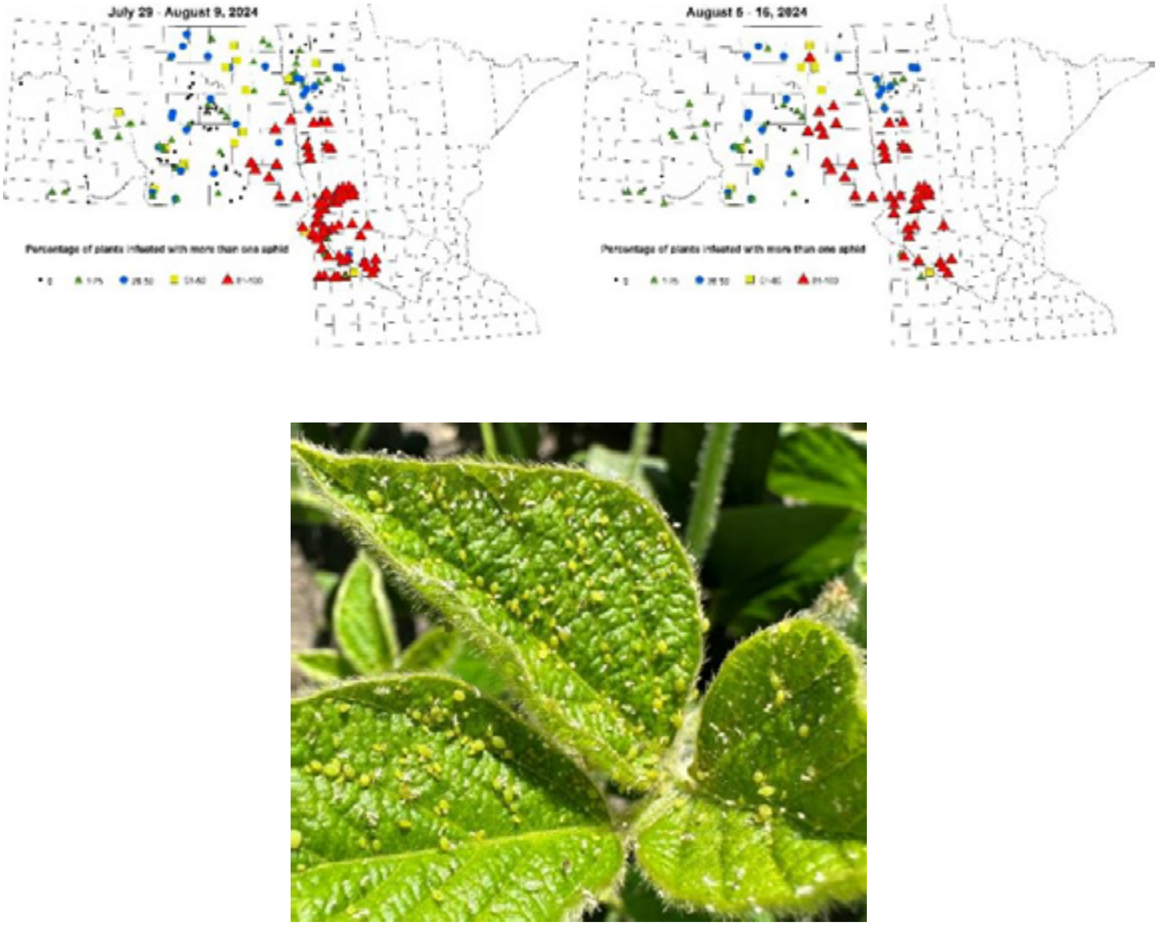
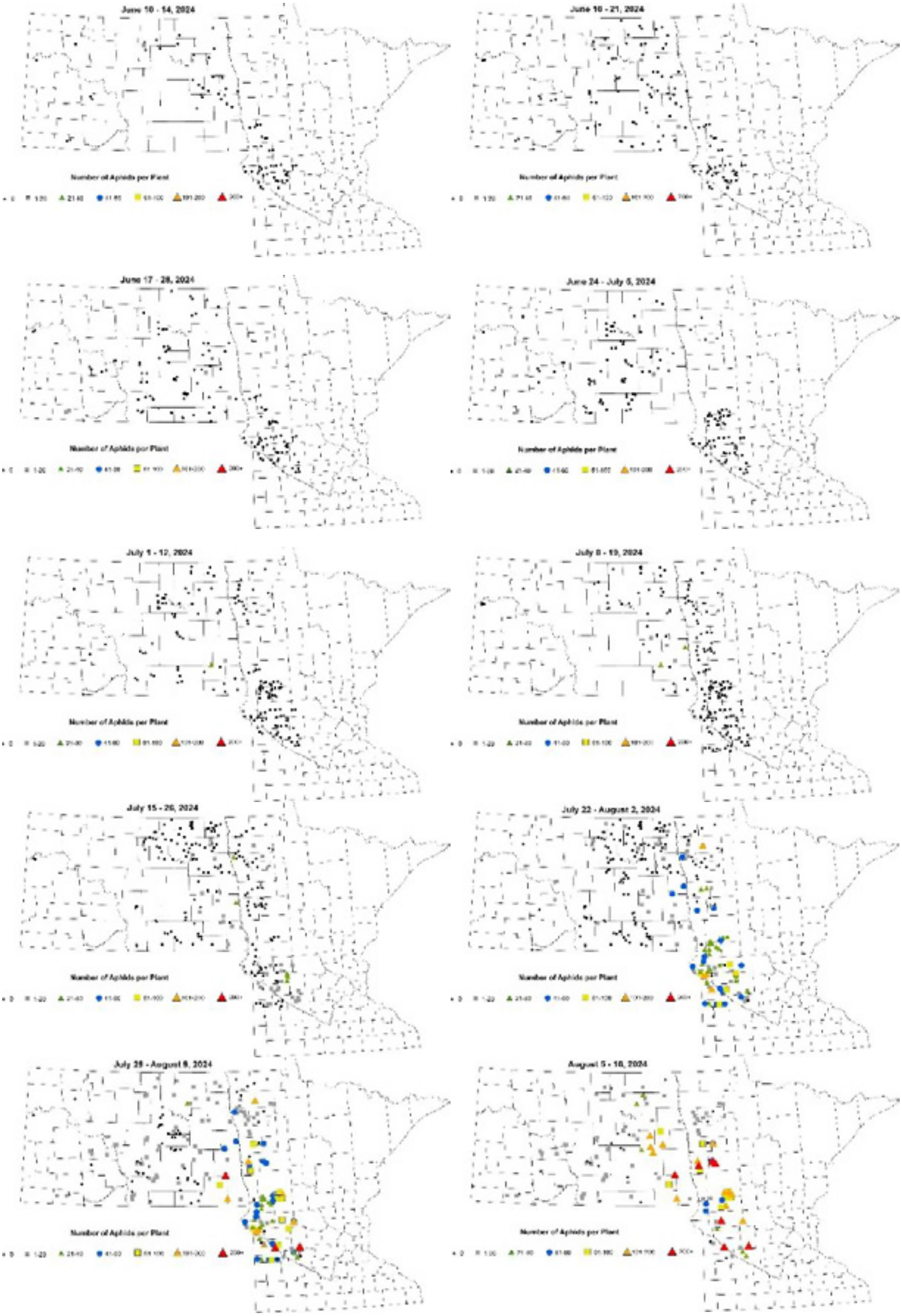


Figure 4. Soybean aphid incidence (percentage of plants infested) over two-week periods from June 10 to August 16, 2024. Soybean aphid infestation in NW MN in 2024, photo: Angie Peltier; Maps: NDSU IPM.

Soybean aphid. Soybean aphid (SBA) incidence, or the percentage of plants infested with SBA grew from zero plants infested during the Jul 8-19 survey period to 1-25% and up to 81-100% of plants infested by July 15-26 survey period (**Figure 4**).


June 10 - 14, 2024
June 10 - 21, 2024
June 17 - 28, 2024
June 24 - July 5, 2024
July 1 - 12, 2024
July 8 - 19, 2024
July 15 - 26, 2024
July 22 - August 2, 2024
July 29 - August 9, 2024
August 5 - 16, 2024
Number of Aphids per Plant

e **5.** Soybean aphid (*Aphis glycines*) severity (number of aphids per plant) over two-week periods une 10 to August 16, 2024; Maps: NDSU IPM.

everity, or the average number of SBAs per plant also began to ramp up by mid-July, with ɔle fields reaching treatment thresholds (more than 250 aphids per plant + aphids on more than f plants + population densities growing) by the end of the survey period (**Figure 5**). Several fields ed treatment thresholds in both 2023 and 2024 after 3-years (2019, 2021 & 2022) in which no ved fields reached the treatment threshold. With 2024 turning out to be a 'good SBA year', ɔly in part due to the warm 2023-24 winter, there were likely plenty of adult SBAs traveling to their intering host (buckthorn) to mate and lay eggs to find 2025 soybean fields.
ore information about soybean aphid scouting, treatment threshold and insecticide options,

//extension.umn.edu/soybean-pest-management/soybean-aphid.

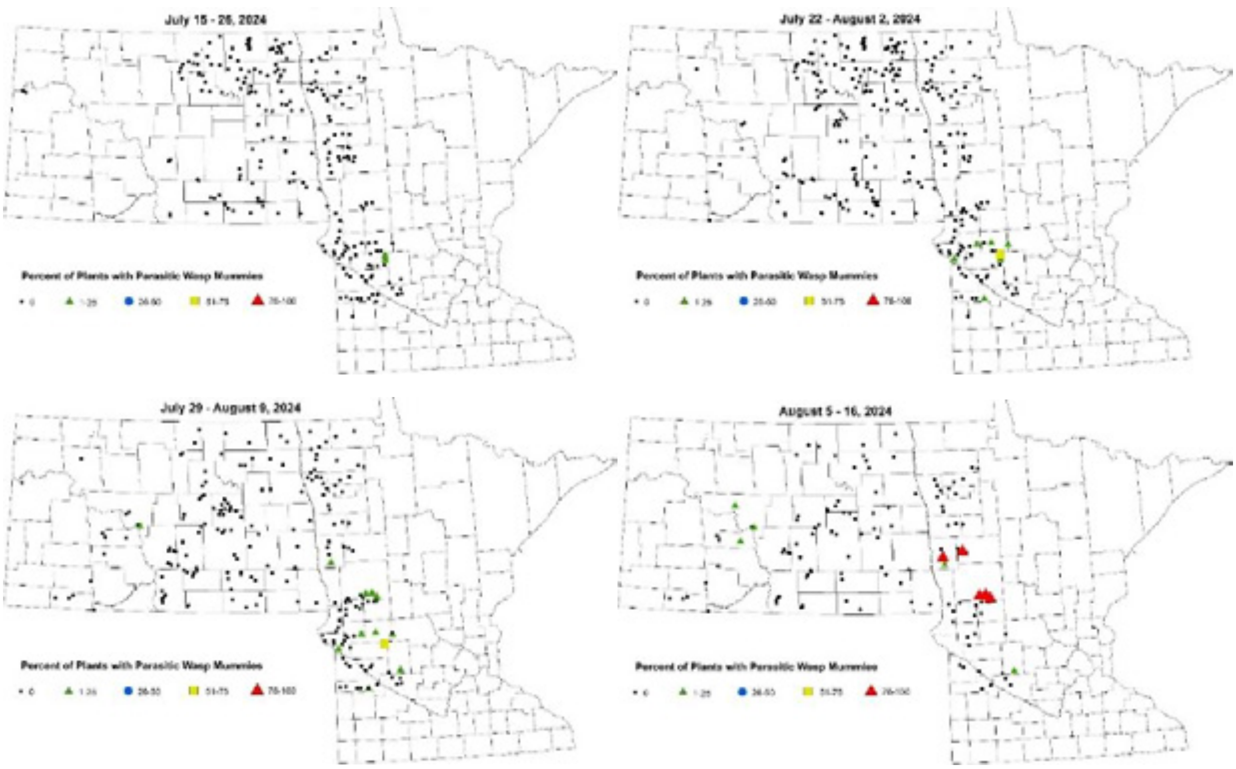


Figure 6. Percentage of plants with soybean aphids (*Aphis glycines*) that were colonized by parasitic wasps over two-week periods from July 15 through August 16, 2024; *Aphelinus* spp. colonizing an aphid, photo: Frank Peairs, Colorado State University, Bugwood.org. Maps: NDSU IPM.

Wasps parasitic to SBA. Several natural enemies of soybean aphids (SBA) are commonly observed in Minnesota, including Asian lady beetles/larvae, lacewings, pirate bugs and parasitic wasps. These insects can feed on SBA adults and nymphs and help to keep their population densities in check. Many of the insecticide active ingredients are effective against both SBA *and* these natural enemies. Careful scouting for both SBA and these natural enemies can ensure that one does not spray for SBA before treatment thresholds have been reached, unintentionally eliminating these natural enemies. Similar to 2023, in 2024, natural enemies such as the *Aphelinus* spp. of wasp were slow to build to detectable levels in soybean fields as evidenced by mummies, or infested SBA only being observed beginning in the middle of July (**Figure 6**).

For more info on natural enemies of SBA, visit: https://extension.umn.edu/soybean-pest-management/scouting-soybean-aphid#predators-and-parasites-of-soybean-aphid-1354514.

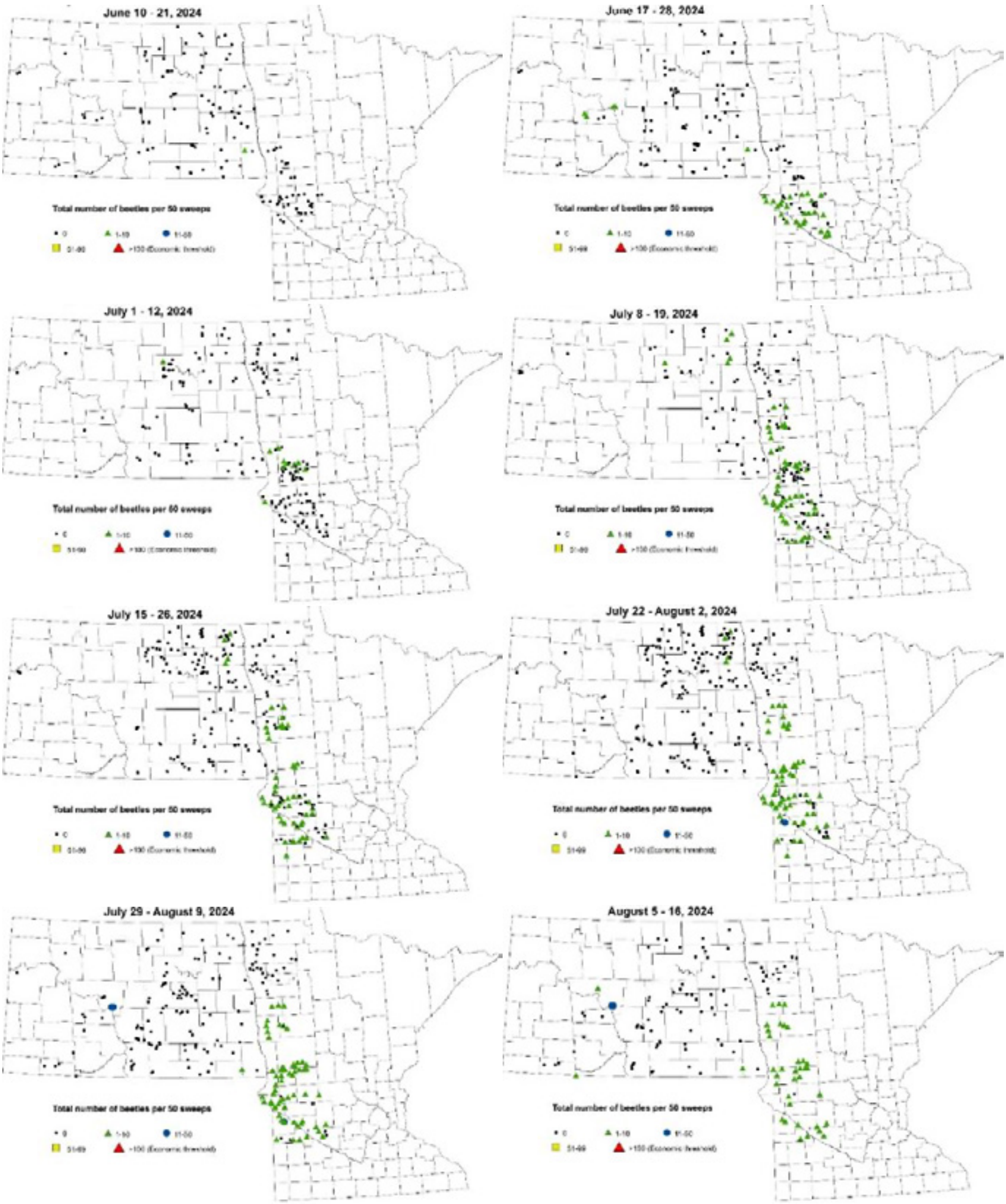
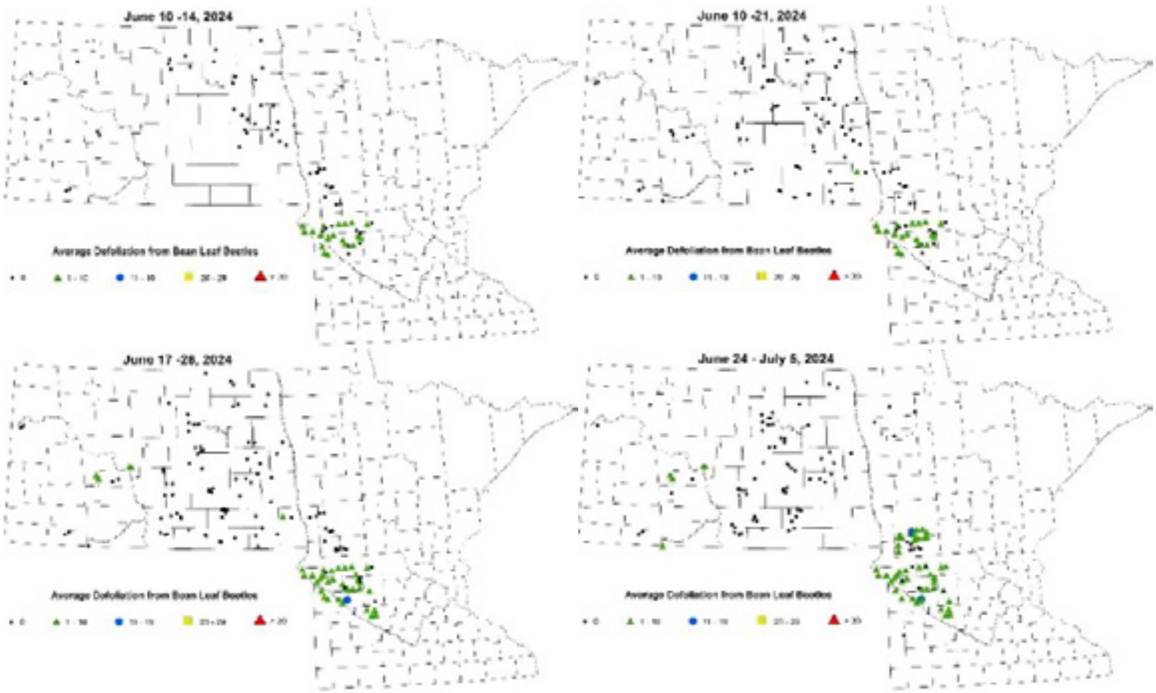

June 10 - 21, 2024
June 17 - 28, 2024
July 1 - 12, 2024
July 8 - 19, 2024
July 15 - 26, 2024
July 22 - August 2, 2024
July 29 - August 9, 2024
August 5 - 16, 2024
Total number of beetles per 50 sweeps

Figure 7. Number of bean leaf beetles (*Cerotoma trifurcate)* per 50 sweeps over two-week periods June 10 to August 16, 2024, Photo: Angie Peltier; Maps: NDSU IPM.



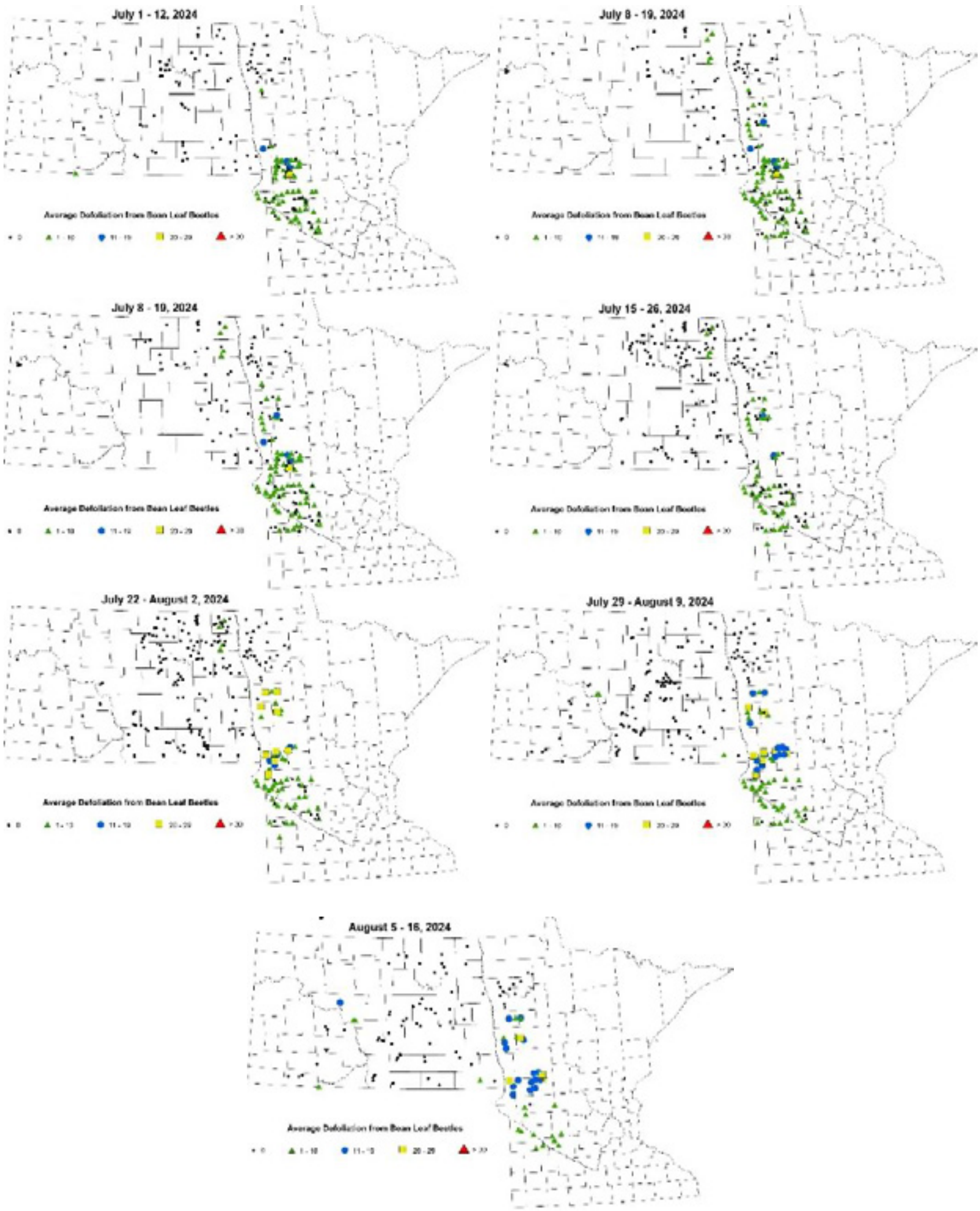


Figure 8. Average bean leaf beetle (*Cerotoma trifurcate)* defoliation injury over two-week periods June 10 to August 16, 2024; Maps: NDSU IPM.

Bean leaf beetle. Scouts used a sweep net to estimate bean leaf beetle (BLB) population densities and examined soybean leaves to estimate feeding injury. Severity of BLB infestations remained relatively low with all field locations in which they were detected having fewer than 11 beetles (**Figure 7**). UMN treatment thresholds are not based on BLB population density but rather feeding injury plus continued presence of the beetles. Feeding injury as high as 20-29% defoliation was observed in multiple fields, primarily in WC MN in early July (**Figure 8**). Treatment thresholds are reached before flowering when beetles are present, and defoliation is 30% or greater and between flowering (R1) and pod fill (R6) when beetles are present, and defoliation is greater than 20% throughout the canopy.

For more information about bean leaf beetle, visit:
https://extension.umn.edu/soybean-pest-management/bean-leaf-beetles.

Figure 9. Presence of two-spotted spider mites (*Tetranychus urticae*) field edges (red triangle) over two-week periods July 15-26, 2024, Photo: two-spotted spider mites (red arrows) and their eggs (blue arrows), Angie Peltier; Maps: NDSU IPM.

Two-spotted spider mites. Scouts evaluated the presence (red triangles) or absence (black dot) of two-spotted spider mites (TSSM) on field edges (**Figure 9**) and inside fields. TSSM can first often be observed feeding on perennial plants outside of fields where they survive the winter. TSSM were present on the outside of scouted fields by mid-July in a handful of fields.

As the quality of the perennial plants outside the field declines, TSSM can begin to move into the field, using webbing to 'balloon' into the soybean field starting from field edges and progressing further into the field over time. The abnormally wet 2024 growing season during the scouting period resulted in few sightings of TSSM and no infestations meeting treatment thresholds in the survey period.

For more information about TSSM, visit:
https://extension.umn.edu/soybean-pest-management/managing-spider-mite-soybean.

For more information about managing the crop when both TSSM and soybean aphid are present, visit:
https://blog-crop-news.extension.umn.edu/2023/07/management-of-soybean-aphids-and.html.

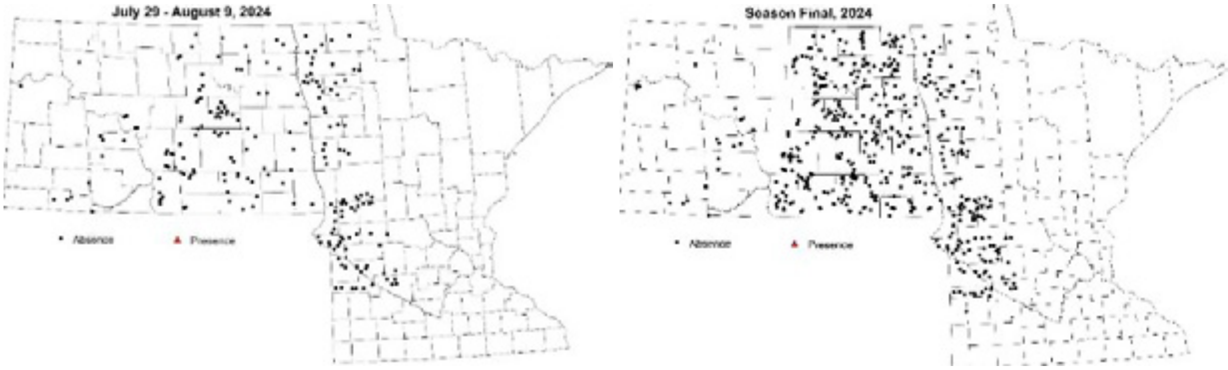


Figure 10. Soybean gall midge (*Resseliella maxima*) presence (red triangle) and absence (black dots) in scouted soybean fields July 29 - August 9, 2024 and season-long, Photo: soybean gall midge larvae, Bruce Potter; Maps: NDSU IPM.

Soybean gall midge. There were no sightings of soybean gall midge in any of the surveyed fields visited during the survey period in 2024 (**Figure 10**).

For more information about soybean gall midge, visit: https://extension.umn.edu/soybean-pest-management/soybean-gall-midge-minnesota-soybean.

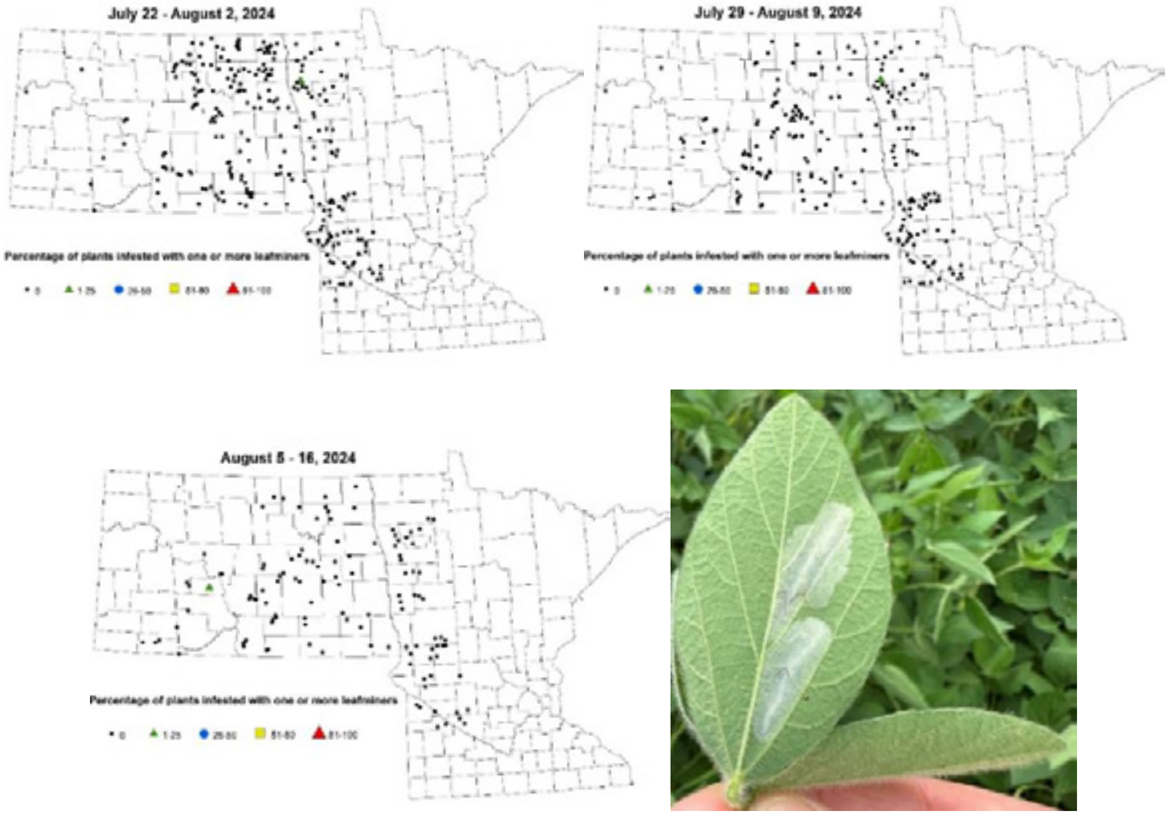


Figure 11. Soybean tentiform leafminer (*Macrosaccus morrisella*) presence (red triangle) and absence (black dots) in scouted soybean fields July 22-August 16, 2024, Photo: soybean tentiform leafminer mines, Angie Peltier; Maps: NDSU IPM.

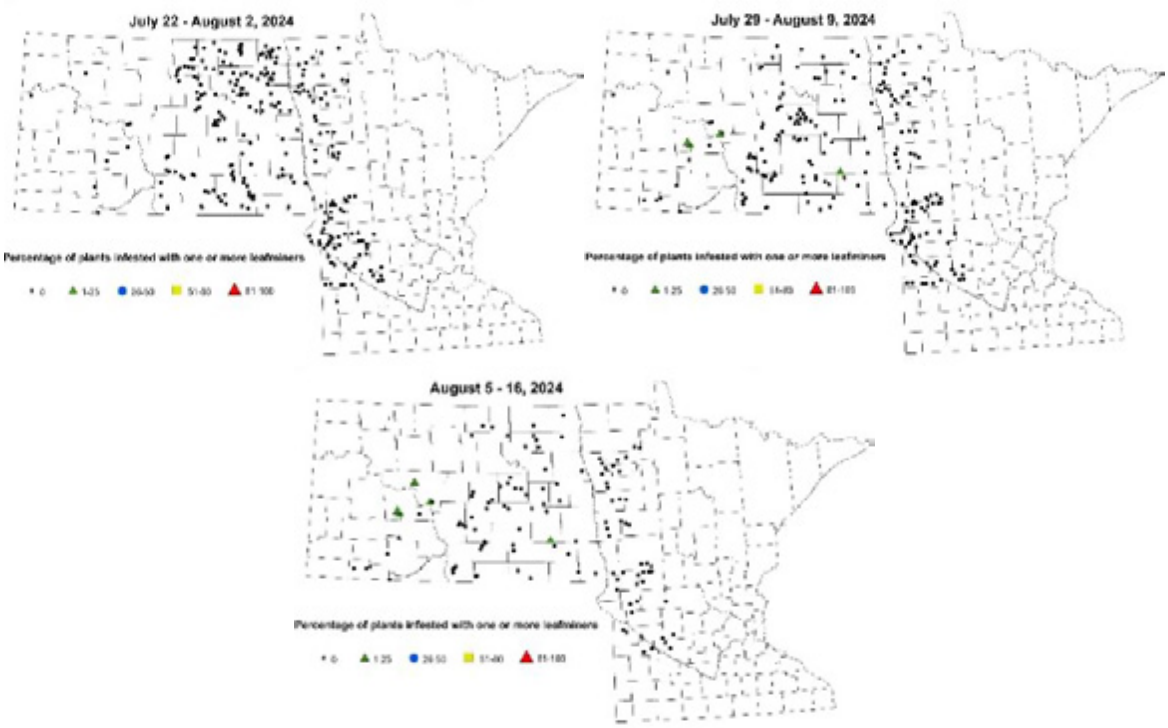


Figure 12. Soybean tentiform leafminer (*Macrosaccus morrisella*) presence (red triangle) and absence (black dots) on the edge of scouted soybean fields July 22 - August 16, 2024; Maps: NDSU IPM.

Soybean tentiform leafminer. While native to North America and a pest of two native legumes, American hogpeanut and slickseed fuzzybean, soybean tentiform leafminer (STL) was initially found feeding on soybean leaves in southeast Minnesota. Mined leaf tissue can reduce a leaf's photosynthetic area and if enough leaf area is affected (similar to injury caused by defoliating insects), yield loss will occur.

Scouts looked for mines on the underside of soybean leaves of plants both inside (**Figure 11**) and on the edge (**Figure 12**) of scouted fields. If the field had a wooded area adjacent to it, the soybeans closest to the wooded area were examined first. Only one surveyed field on the border of western Polk and Marshall Counties in NW MN was infested with STL (**Figure 11**). Other Minnesota surveys targeted specifically for STL have continued to find widespread presence. At least in 2024, populations likely were not large enough for widespread detection in this general pest survey.

For more information about soybean tentiform leafminer, visit: https://extension.umn.edu/soybean-pest-management/soybean-tentiform-leafminer-minnesota-soybean.

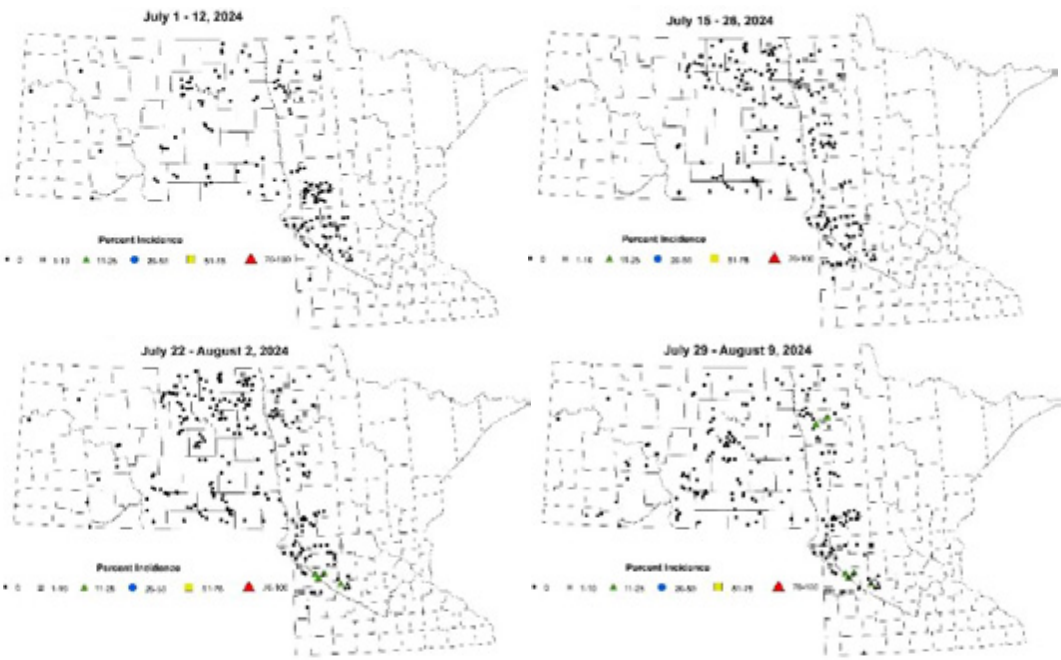


Figure 13. Incidence (%) of foliage feeding caterpillars in scouted soybean fields from July 1 through August 9, 2024. Maps: NDSU IPM.

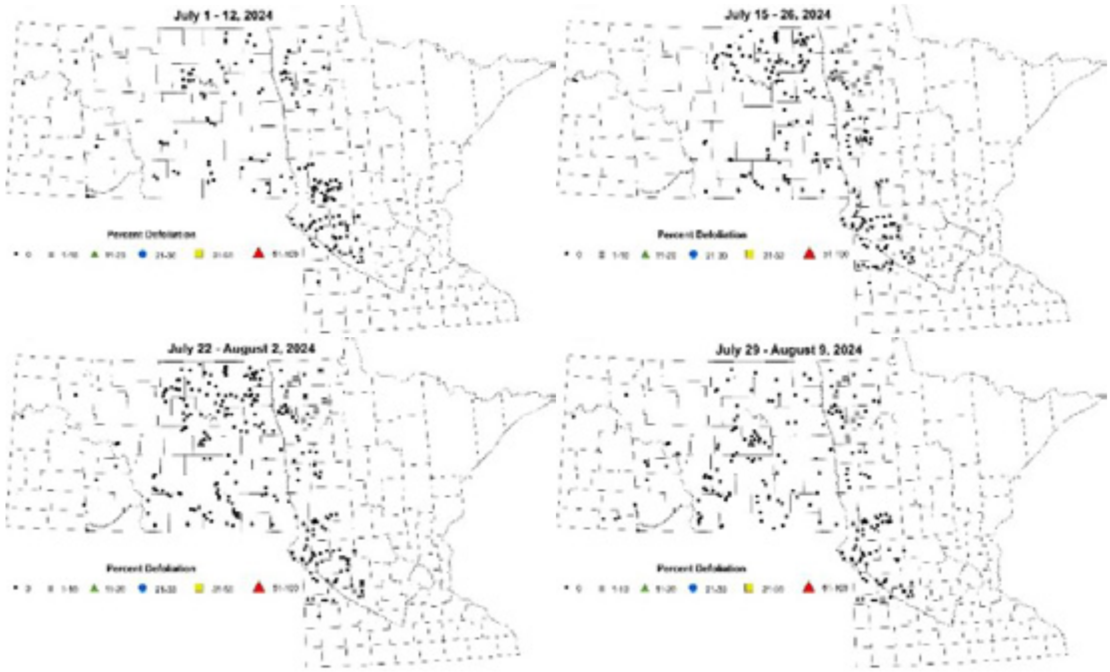


Figure 14. Defoliation injury (%) from foliage feeding caterpillars in scouted soybean fields from July 1 through August 9, 2024. Maps: NDSU IPM.

Foliage feeding caterpillars. Overall, there was low incidence of foliar feeding caterpillars (think green cloverworms & thistle caterpillars) in 2024 (**Figure 13**). This low incidence of caterpillars resulted in feeding injury that fell below treatment thresholds (**Figure 14**, see discussion about treatment thresholds in the bean leaf beetle section).

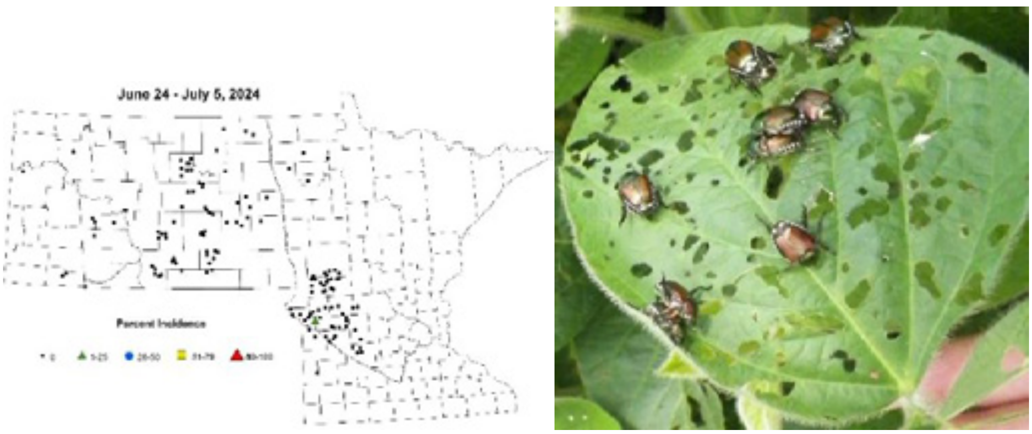


Figure 15. Incidence (%) of Japanese beetles in scouted soybean fields from June 24 through July 5, 2024, Photo: Japanese beetles, Angie Peltier. Maps: NDSU IPM.

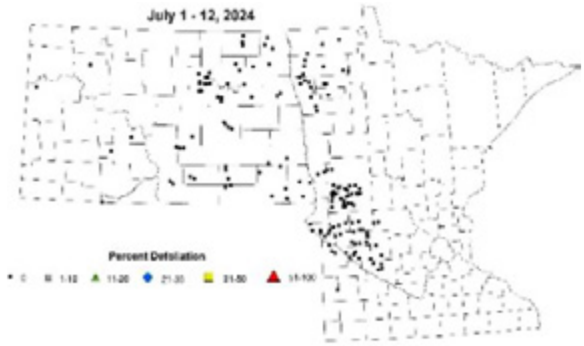
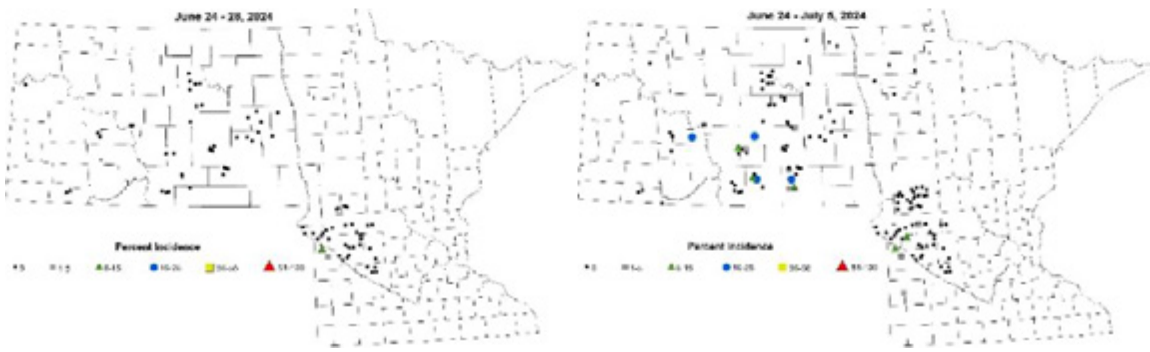


Figure 16. Defoliation injury (%) caused by Japanese beetles in scouted soybean fields July 1-12, 2024. Maps: NDSU IPM.

Japanese beetles. Only a single Japanese beetle infestation on the edge of Big Stone and Swift Counties was found in Minnesota during this survey (**Figure 15**). While Japanese beetles can easily reach defoliation-based treatment thresholds after becoming endemic in a region, the foliage feeding injury (**Figure 16**) observed and attributed to Japanese beetle in NW MN was very likely caused by another defoliating insect as this pest has not yet been found in Polk County.

For more information about Japanese beetle, visit: https://extension.umn.edu/soybean-pest-management/japanese-beetle-soybean.



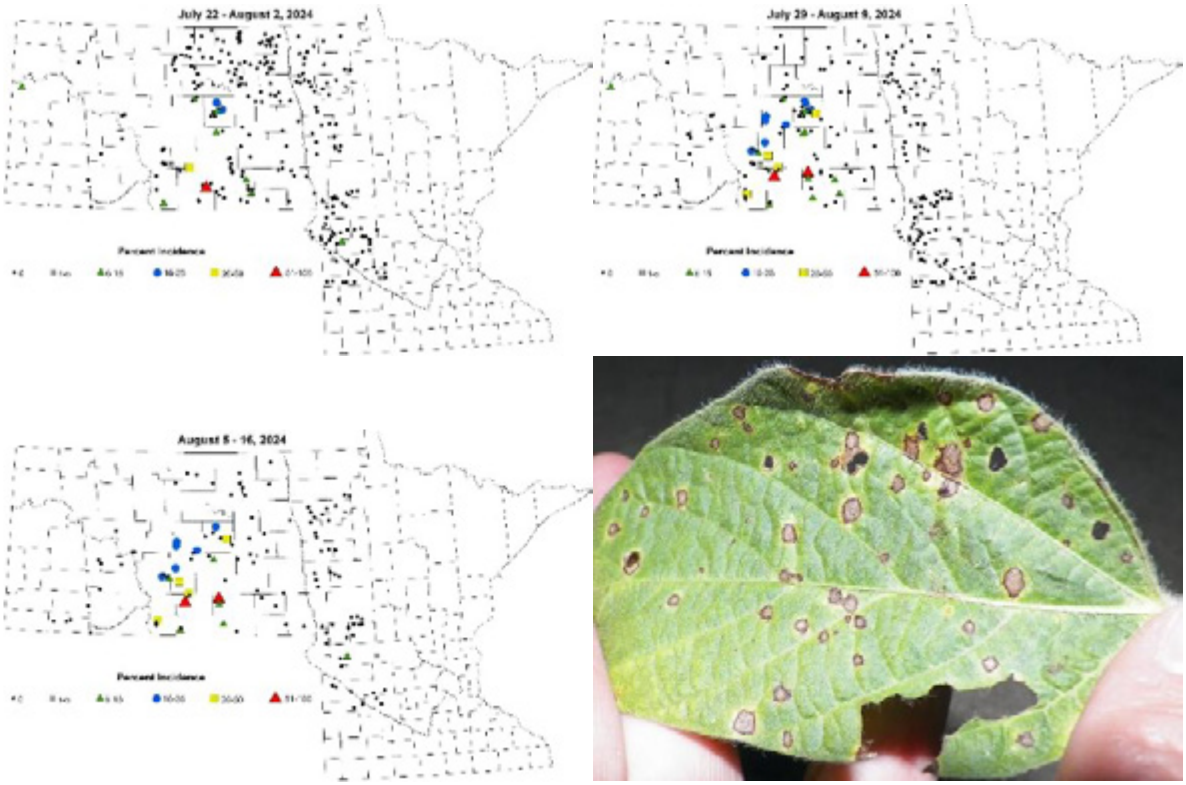
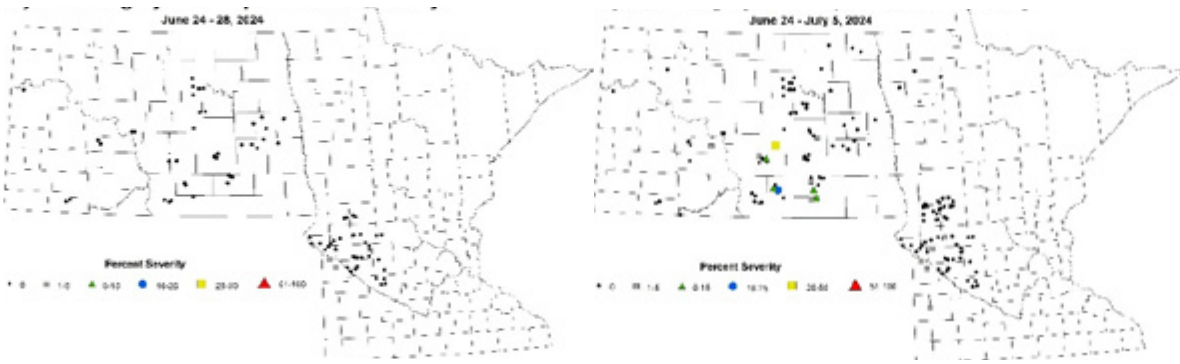


Figure 17. Incidence (%) of Frogeye leaf spot in scouted soybean fields June 24 - August 16, 2024, Photo: FLS lesions, Angie Peltier. Maps: NDSU IPM.



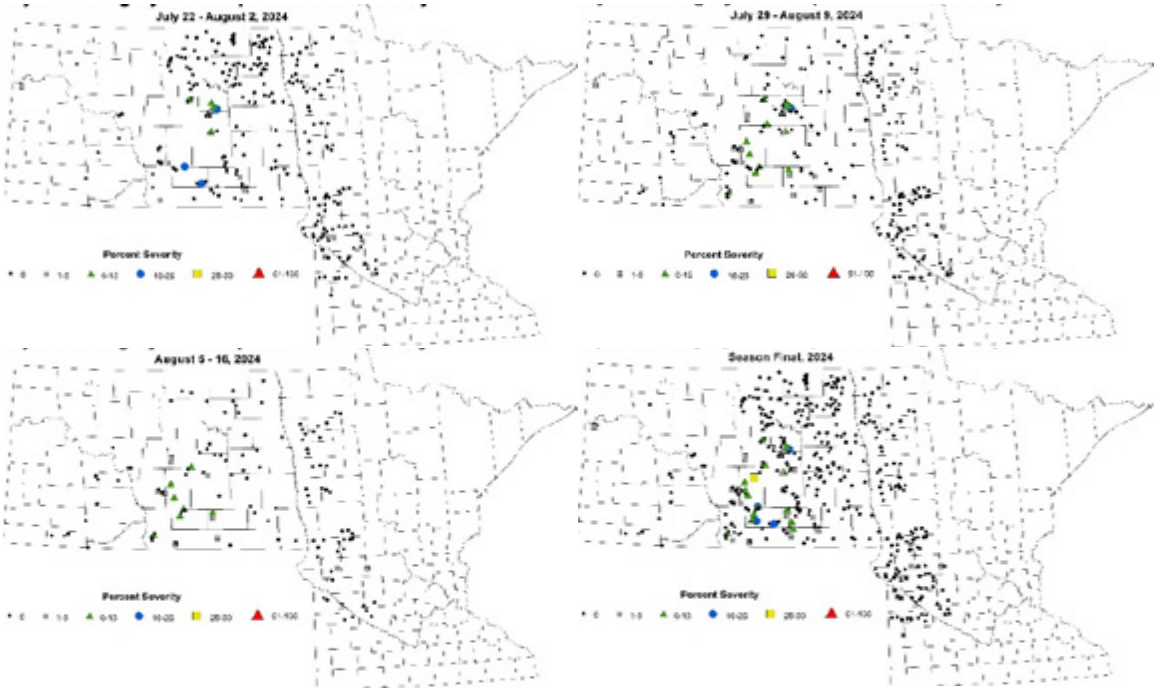
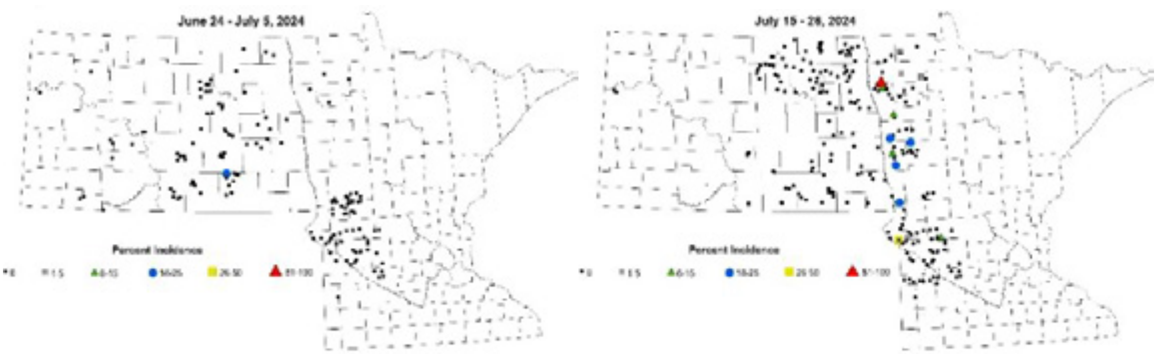


Figure 18. Severity (%) of Frogeye leaf spot in scouted soybean fields June 24 - August 16, 2024. Maps: NDSU IPM.

Frogeye leaf spot. Frogeye leaf spot (FLS) is a fungal disease of soybean favored by periods of warm weather and high relative humidity, conditions that are common in the southern half of Minnesota, but much less so in NW MN. The northernmost positive FLS infestation in Minnesota was found in Wadena County several years ago. There were several locations in the southern part of the survey range in 2024 that had FLS (**Figure 17**), although severity remained low overall (**Figure 18**).

For more information about frogeye leaf spot, visit: https://extension.umn.edu/soybean-pest-management/frogeye-leaf-spot.



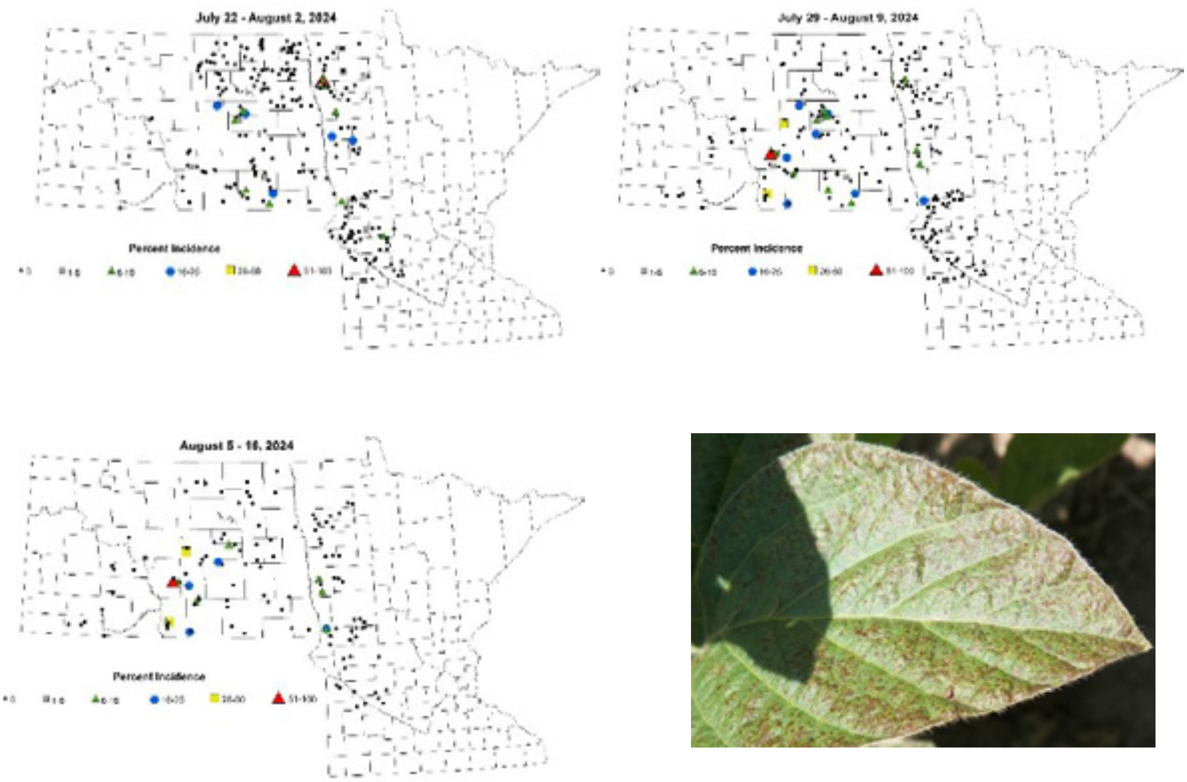
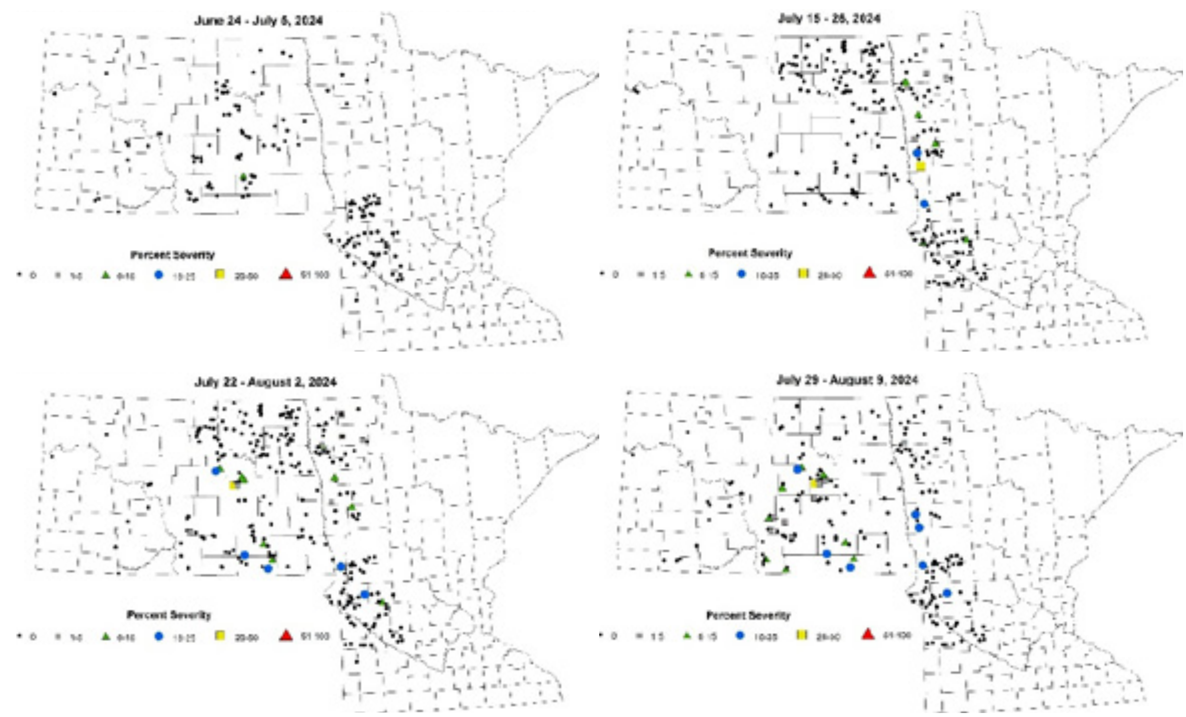


Figure 19. Incidence (%) of Cercospora leaf blight in scouted soybean fields June 24 - August 16, 2024: Photo: CLB, Angie Peltier. Maps: NDSU IPM.



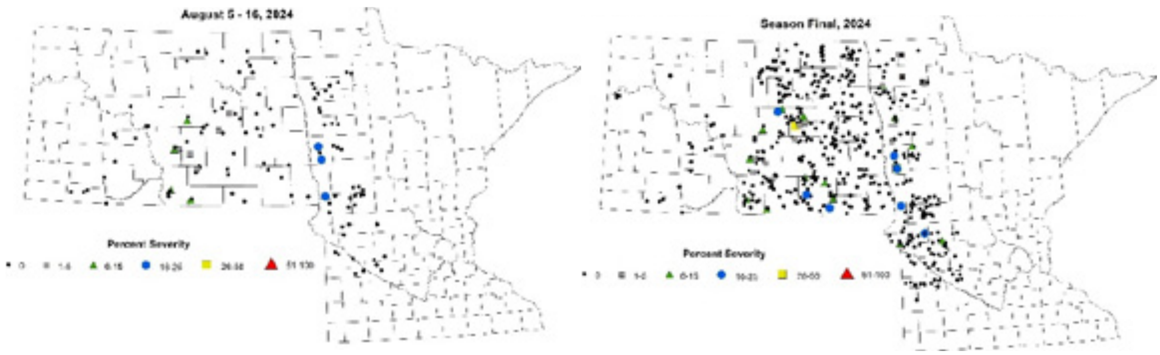


Figure 20. Severity (%) of Cercospora leaf blight in scouted soybean fields June 24 - August 16, 2024. Maps: NDSU IPM.

Cercospora leaf blight. Cercospora leaf blight (CLB) is caused by a fungal pathogen that has been observed throughout Minnesota for many years. Symptoms of CLB appear on the uppermost leaves and petioles of soybean plants as the pathogen produces a light-activated toxin; severe infections can lead to premature defoliation. CLB can also result in seed symptoms called purple seed stain when pods and seeds become infected.

For more information about Cercospora leaf blight, visit: https://extension.umn.edu/soybean-pest-management/cercospora-leaf-blight-and-purple-seed-stain-soybean.

Application/Use: The MSRPC-sponsored western IPM survey is essential to feed valuable pest incidence and severity information to UMN Extension specialists and regional educators (such as these authors) alike. This information is then used to provide timely research-based information regarding pest ID, scouting strategy, treatment thresholds and management. Local and regional radio interviews, digital and email newsletter articles shared on social media and webinars were all used during the 2024 growing season to share information gathered through this survey.

Materials and Methods: The MSRPC-sponsored IPM Survey was funded and conducted for the first time in 2015. UMN Extension continued this project in 2024 in coordination with similar efforts in North Dakota.

IPM scouts began the season scouting small grains fields, switching over to soybean fields mid-season. A total of 469 soybean fields were visited throughout the scouting season, resulting in several timely articles, webinars and radio interviews. Scouts collected data both inside and outside fields. Outside each field, grass areas that bordered fields were swept for grasshopper nymphs (**Figure 1**) and adults (**Figure 2**). Soybeans were inspected for growth stage (**Figure 3**), soybean aphid incidence (**Figure 4**), soybean aphid severity (**Figure 5**), presence of aphids colonized by parasitic wasps (**Figure 6**), number of bean leaf beetles (**Figure 7**) and the severity of chewing injury they caused (**Figure 8**), two spotted spider mite (TSSM) presence on the field edge (**Figure 9**) and inside fields, soybean gall midge presence (**Figure 10**), soybean tentiform leafminer presence within the field (**Figure 11**) and on the field edge (**Figure 12**), incidence of foliage-feeding caterpillars (**Figure 13**), percentage defoliation injury caused by foliage-feeding caterpillars (**Figure 14**), Japanese beetle incidence (**Figure 15**), percent of foliar injury caused by Japanese beetles (**Figure 16**), frogeye leaf spot incidence (**Figure 17**), frogeye leaf spot severity (**Figure 18**), Cercospora leaf blight incidence (**Figure 19**) and Cercospora leaf blight severity (**Figure 20**).

Economic Benefit to a Typical 500 Acre Soybean Enterprise: It has been several years since many farmers last saw threshold-level soybean aphid populations and so armed with the results of this IPM survey, the PIs were able to share with farmers how best to manage this pest given our current labeled pesticides. With pyrethroid-resistant soybean aphid populations still the norm, it is important to understand how using premixes with active ingredients from two different insecticide groups may impact both current management and the insecticide-resistance profile of soybean aphid populations. Premixes have multiple active ingredients combined often at lower than the label rates when each active ingredient (a.i.) is packaged on its own. When one of the a.i.'s is in the pyrethroid class of insecticides, the other tank mix partner is doing the 'heavy lifting' from a position of vulnerability. This is because lower rates of a single effective active ingredient puts tremendous selection pressure on the soybean aphid population to select out those individuals capable of surviving what would now be two different classes of insecticides. Having effective pesticides from multiple insecticide classes to control this damaging insect is essential for long-term, high-yielding soybean production in Minnesota and so is priceless.

Related Research: The 2024 soybean IPM scouts began the summer scouting wheat fields in western MN in a complementary survey. Look elsewhere in this booklet for a summary of the Minnesota Wheat Research & Promotion Council-sponsored Small Grains IPM survey.

Thank you: The authors would like to thank the 2024 IPM scouts, Katie Olson, Brett Barbeln and Logan Blanke for their hard work on behalf of western MN soybean producers. The NDSU IPM Crop Survey is supported by the Crop Protection and Pest Management Program - Extension Implementation Program, award number 2021-70006-35330 from the USDA National Institute of Food and Agriculture and is coordinated by Dr. Janet Knodel and Patrick Beauzay of NDSU Extension Entomology.

Farmer-driven Research Into Planting Green Along the Red

Principal Investigator(s): Angie Peltier & Jodi DeJong Hughes, UMN Extension; Anna Cates, UMN Extension & Minnesota Office for Soil Health; Lindsay Pease, UMN Extension & Northwest Research & Outreach Center; Dorian Gatchell, Minnesota Agricultural Services; Kat LaBine & Heidi Reitmeier, UMN research technicians, Mark Bernards, USDA Agricultural Research Service (ARS) weed scientist and Cecelia Kuklok, USDA ARS technician

Farmer partners in Barrett and Granite Falls

Project sponsors: USDA NC-SARE, UMN Extension, Minnesota Agricultural Services, USDA ARS, Bayer Crop Science, Minnesota Soybean Research & Promotion Council, Minnesota Wheat On-Farm Research Network & Saddlebutte Ag

Purpose of Study:
MN farmers face difficult choices when deciding to prioritize either long-term soil health goals or the immediate benefits of tillage for residue management and seedbed preparation. Despite the reported soil health benefits of cover crops, a short growing season makes delays to spring field work risky. Research on cover cropping suggests that early season cover crops can stabilize yields by mitigating excess and limited soil moisture, improving field trafficability, and reducing wind erosion. Reliable advice on agronomic outcomes of cover cropping is critically needed by MN farmers interested in adopting reduced-tillage and cover cropping systems. To meet this need, we partnered with MN farmers to design replicated, production-scale research and demonstration trials that were sown to cereal rye in Fall 2023 (Figure 1, Table 1). Soybeans were seeded in spring 2023 and cover crops terminated before, at or after soybean planting; 2023 is the second of four seasons for this work.

On-farm Experimental Design:
Treatments were arranged as large strips wide enough to accommodate farmers' equipment in a randomized complete block design with three replications. Nutrient cycling, soil health, rye biomass at termination, weed density and biomass, IDC and other disease ratings, soybean stand count, yield, moisture & test weight data were collected from each plot.

Treatments: 1) Current tillage practice without a fall-seeded rye cover crop (CC),
2) CC terminated 1-2 weeks before soybean planting,
3) CC terminated at soybean planting,
4) CC terminated 1-2 weeks after soybean planting.

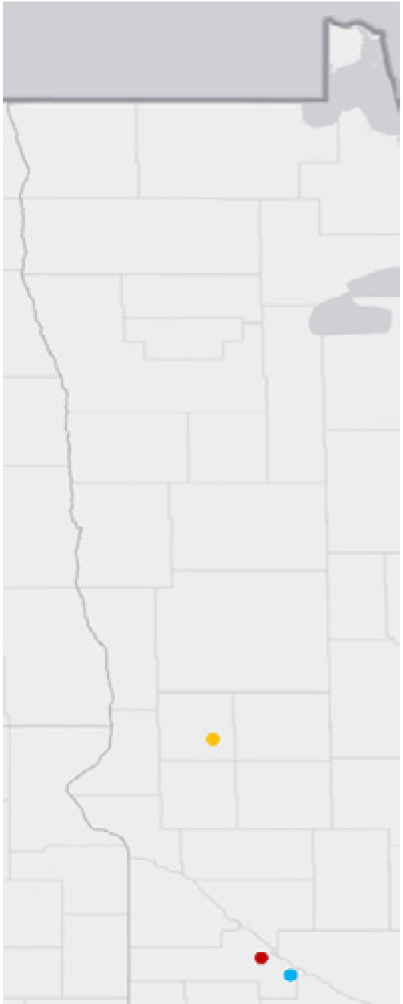


Figure 1. Locations of on-farm and small plot research trials seeded to rye in fall 2023 and to soybean in 2024; orange dot = Barrett location, red dot = Granite Falls-grain location, blue dot = Granite Falls-silage location.

Each trial location grew different soybean varieties and had different soybean seeding dates and rates and therefore different dates of rye termination and so results are presented by location.

Table 1. Locations of on-farm strip trials, 2023 cash crop, any tillage that took place between 2023 crop harvest and rye seeding, rye seeding date and method, 2024 soybean seeding date, soil texture and May-September 2024 precipitation totals

MN Town/ County	2023 cash crop	Tillage	Rye seeded (2023)	Soybean seeded (2024)	Soil texture	May-Sept. rainfall (inches)*
Granite Falls/ Yellow Medicine	corn grain	Fall chisel plow/spring cultivator in no rye plots	Sept. 18 Bdcst.	May 19	clay loam, loam	18-20
Granite Falls/ Yellow Medicine	corn silage	Fall chisel plow/spring cultivator in no rye plots	Sept. 6 Drilled	May 18	loam, clay loam	18-20
Barrett/Grant	corn grain	Vertical tillage in no rye plots, NT for rye plots	Sept. 15 Bdcst.	May June 9	clay loam	18-20

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*Rain estimates were provided by the Midwest Regional Climate Center's cli-MATE application tools environment maps of gridded accumulated precipitation for the period of May 1-September 30, 2024 (see Figure 2).

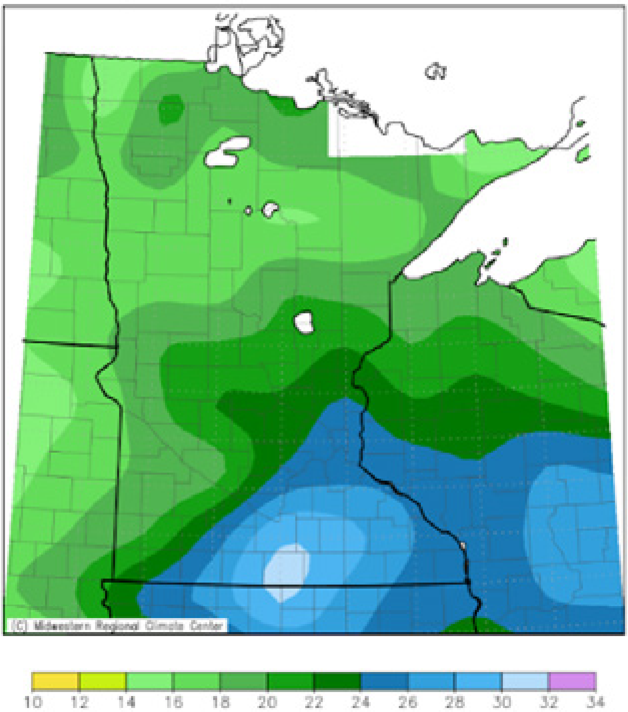


Figure 2. Accumulated precipitation (in inches), May 1-September 30, 2024. Rainfall totals were 2-4 inches above normal in Barrett and up to 2 inches above normal in Granite Falls. than Source: Midwestern Regional Climate Center cli-MATE: MRCC Application Tools Environment. Generated Nov 5., 2024.

Weather-related plot loss

The very wet spring weather led to very wet soil conditions, particularly in the no-rye plots at a Red Lake County on-farm location. The farmer-cooperator ended up not being able to seed soybeans, even significantly later than ideal. Consequently, he opted to take a prevented plant insurance payment for those acres and the experiment was not continued.

Despite the dry conditions experienced in both 2022 and 2023 experienced at an on-farm location in Tintah, the 2-4 extra inches of spring rain led to this location also being lost as an experimental location due to the cooperating farmer opting to take prevented plant insurance payments.

West-central locations

Barrett, MN.

In Barrett, the after-planting rye termination timing plots accumulated more biomass than the rye plots terminated before-planting, which showed essentially no growth (Table 2). The soybean stands in the rye plots terminated before and after planting were statistically similar and less than in the no-rye plots, while the rye plots terminated at-soybean planting had statistically similar soybean stands to those of all other termination timing treatments. Soybean yields were remarkably similar among treatments, with the maximum average yield numerically differing by at most 1 bu/a. Soybean moisture content varied numerically by treatment by a maximum of 2.2%, with moisture tending to be greater in the rye plots likely due to the soybean crop's delayed maturity. While soybean test weights did not differ among treatments, the no-rye and rye plots terminated before planting had numerically higher test weights than the at- and after-planting termination timings.

Table 2. The effect of rye termination timing on rye biomass, soybean stand count, yield, moisture and test weight at a farm near Barrett, MN in 2024

Rye termination timing	Rye biomass (lb/A)	Soybean stand count (plants/A)	Yield (bu/A)	Moisture (%)	Test weight (lb/bu)
Before planting	3 b[x]	104,703 b	44.8	15.1	54.8
At planting	NA[y]	108,689 ab	43.8	15.4	53.2
After planting	50 a	105,151 b	44.8	16.5	53.7
No rye	0 b	114,417 a	44.6	14.3	55.6
LSD (90% CL)	26.6	7,472	NS[z]	NS	NS
CV (%)	142.4	4.9	2.5	16.0	3.8

x Treatment means within a column that are followed by different letters are significantly different at P = 0.10.
y Dry weight of rye biomass samples was not available (NA) at the time of publication.
z Treatment means not significantly (NS) different from one another.

Granite Falls, MN – following corn grown for grain.
Significantly more rye biomass accumulated at the Granite Falls location in the rye plots that were terminated at and after planting than in the plots in which rye was terminated before planting (Table 3). Soybean stand count, yield, moisture and test weight did not differ among rye termination timing treatments. However, with the wet start to the growing season, it appears that having an actively growing rye cover crop before-, at- and after-soybean planting resulted in numerically higher yields overall than were observed with no rye. The fact that yield was numerically lower with each delay in rye termination timing suggests that there is a fine line between 'just enough' actively growing rye to draw down excess soil moisture and 'too much' rye creating a situation in which soybean yield potential was limited due to forced competition with the cover crop for limited resources. There was also a numerical trend in soybean moisture content, with the lowest moisture content in the no-rye plots. In these plots, there were no cover crop roots to create water infiltration/root channels that may have helped to 'bank' soil moisture for when there weren't timely rains later in the growing season. The earliest termination timing resulted in the numerically highest grain moisture, with less soybean moisture content with each subsequent delay in termination timing. This trend makes sense; the earliest terminated rye plots would have had time to establish root channels but not as much time as the rye roots in the plots in which the rye was terminated at or after planting to take up through evapotranspiration much of the rainwater that had infiltrated.

Table 3. The effect of rye termination timing on rye biomass, soybean stand count, yield, moisture and test weight at a farm near Granite Falls, MN in 2024 in which the preceding crop was corn grown for grain

Rye termination timing	Rye biomass (lb/A)	Soybean stand count (plants/A)	Yield (bu/A)	Moisture (%)	Test weight (lb/bu)
Before planting	38 b[y]	121,581	41.6	9.6	55.9
At planting	77 a	113,837	37.4	9.2	55.3
After planting	85 a	109,384	36.7	8.8	55.9
No rye	0 c	115,385	33.8	8.5	56.4
LSD (90% CL)	31	NS[z]	NS	NS	NS
CV (%)	39.4	6.6	13.3	9.0	2.5

y Treatment means within a column that are followed by different letters are significantly different at P = 0.10.
z Treatment means not significantly (NS) different from one another.

Granite Falls, MN – following corn grown for silage.

Significantly more rye biomass accumulated at the Granite Falls - silage location in plots in which the rye was terminated at or after soybean planting than in plots in which the rye was terminated before planting (Table 4). Soybean stand count was greater where rye was allowed to grow until after soybean planting, and similar in all other treatments. Soybean yield differed among plots, with the rye plots terminated at planting yielding significantly less than all others for some unknown reason. Soybean moisture and test weights were statistically similar among treatments.

Table 4. The effect of rye termination timing on rye biomass, soybean stand count, yield, moisture and test weight at a farm near Granite Falls, MN in 2024 in which the preceding crop was corn grown for silage

Rye termination timing	Rye biomass (lb/A)	Soybean stand count (plants/A)	Yield (bu/A)	Moisture (%)	Test weight (lb/bu)
Before planting	76 b[y]	134,640 a	51.7 a	8.7	57.4
At planting	178 a	134,640 a	42.9 b	8.5	56.9
After planting	165 a	126,400 b	51.4 a	8.8	57.3
No rye	0 c	136,752 a	51.5 a	8.6	57.4
LSD (90% CL)	19.8	5,777	6.5	NS[z]	NS
CV (%)	11.9	2.7	8.3	3.3	0.9

y Treatment means within a column that are followed by different letters are significantly different at P = 0.10.
z Treatment means not significantly (NS) different from one another.

Summary

In a wet spring such as 2024, an actively growing cover crop can help to draw down soil moisture content, assisting with water infiltration. In this case, low CC biomass production in all sites likely didn't affect soil moisture levels. However, there is still a risk in delaying cover crop termination too long in relation to when the cash crop is planted as the more robust cover crop root system is better able to compete with the newly emerging soybean crop for both sunlight and soil moisture. Stand count differences between no rye and all rye plots could also be due to insufficient planter down pressure or other settings preventing seed to soil contact. At all three locations, soybean stand counts in the rye plots terminated after planting were either numerically or statistically lower than the no-rye plots. However, as each of the soybean populations was greater than the minimum of 100,000 plants needed to maximize soybean yield potential, no impact of lower plant stands on soybean yield was observed.

At only one of the three on-farm locations were there statistical differences among treatment yields. However, it is not clear precisely why the rye plots terminated at planting in the Granite Falls location following corn grown for silage yielded between 8.5 to 8.8 bu/A less than the no-rye plots or rye plots terminated before and after soybean planting. Similarly to 2023, the Granite Falls location following corn grown for grain did not see lower yields with any of the rye termination timings. At this location, having an actively growing rye cover crop numerically increased yield over the no-rye plots. This may be due to a planting system optimized to plant through rye residue.

Terminating rye before soybean planting only lowered soybean yields at two of the 14 location-years. The risk of yield loss increases with each delay in termination, with delaying termination resulting in significant yield losses in six of the 14 location-years and significant yield losses in seven of the 14 location-years when termination was delayed until after soybean planting. Having an actively growing rye cover crop in spring but terminating the rye before planting soybean provides the most favorable balance between soil health and cash crop yield.

Determining the Current Phytophthora Sojae Population and the Status of Variety Resistance in Minnesota Using Improved Methods

Principal Investigator(s): Kathleen Markham, Suma Sreekanta, Linnea Johnston, Jane Fenske-Newbart, Cathy Johnson, Senyu Chen, Carol Groves, Damon Smith, Dean Malvick, Megan McCaghey

Project Period: May 1, 2024 – April 30, 2025

<u>Research Question/Objectives:</u>

Above-average soil moisture promotes the development of *Phytophthora sojae*, a pathogen causing significant yield losses in soybeans. Planting soybean varieties with resistance genes (Rps) is an effective management strategy, but these genes must align with the specific *P. sojae* pathotypes present in the field. This study aims to identify the current *P. sojae* pathotypes in Minnesota to recommend appropriate resistant soybean varieties to the farmers.

Objective 1: **To understand the *Phytophthora sojae* pathotype diversity in Minnesota that is subject to selection by modern soybean varieties.**

In Objectives 1 we aimed to isolate Phytophthora species from MN soil. In the 2023 growing season, we received 25 soil samples from growers' or research fields, representing 12 MN counties (Fig 1a). Six of these 12 counties are amongst the top soybean producing counties in MN (USDA, Fig. 1b). In our FY2024 MSRPC cycle, we are continuing to collect soil from other top soybean producing counties, particularly the western/central western/southeastern regions (Fig. 1b). Additional counties we have received samples from so far in 2024 include Rice, Norman, Dodge, McLeod, Mower, and Freeborn, and Waseca. These additional samples will allow us to capture the representative pathogen profile of the state.

We are currently isolating Phytophthora species from these soil samples by a technique called soil baiting. To test the method, we artificially infested sterilized soil with known variants of *P. sojae*, then we allowed *P. sojae* in the soil to infect a susceptible soybean cultivar (Fig. 2a). After 10 days, we plated the infected soybean tissue onto *Phytophthora*-selective growth media and allowed *Phytophthora* to grow on the media (Fig. 2b-c). Finally, we confirmed the *Phythophthora* species via a molecular method known as Polymerase Chain Reaction (PCR) that can identify *P. sojae* specifically (Fig. 2d, Bienapfl *et al.* 2011).

We are currently processing the samples collected. The results from the soils so far processed for soil baiting and PCR confirmation for the presence of *P.sojae* is detailed below (Table 1). We have successfully processed and completed soil baiting on 14 samples and extracted DAN from cultures isolated from two of the soil samples. We will continue baiting and *P. sojae* isolation from the remaining samples.

(a)

Soil sample	MN County	Source	Sampled by	Sampling date
1	Norman	Grower's field	Grower	Aug 2023
2	Martin	Grower's field	Extension personnel	Sep 2023
3	Jackson	Grower's field	Extension personnel	Sep 2023
4	Nobles	Grower's field	Extension personnel	Dec 2023
5	Sherburne	Research field	Researcher	Dec 2023
6	Redwood	Research field	Researcher	Dec 2023
7	Redwood	Grower's field	Grower	Dec 2023
8	Redwood	Grower's field	Grower	Dec 2023
9	Redwood	Research field	Researcher	Jun 2023
10	Waseca	Research field	Researcher	May 2023
11	Waseca	Research field	Researcher	Jun 2023
12	Waseca	Research field	Researcher	May 2023
13	Faribault	Grower's field	Seed dealer	Jun 2023
14	Faribault	Grower's field	Seed dealer	Jun 2023
15	Faribault	Grower's field	Seed dealer	Jun 2023
16	Nicollet	Grower's field	Seed dealer	Jun 2023
17	Nicollet	Grower's field	Seed dealer	Jun 2023
18	Nicollet	Grower's field	Seed dealer	Jun 2023
19	Sibley	Grower's field	Seed dealer	Jul 2023
20	Sibley	Grower's field	Seed dealer	Jul 2023
21	Sibley	Grower's field	Seed dealer	Jul 2023
22	Sibley	Grower's field	Seed dealer	Jul 2023
23	Polk	Research field	Researcher	Jun 2023
24	Ramsey	Research field	Researcher	Jun 2023
25	Ramsey	Research field	Researcher	Aug 2023

(b)

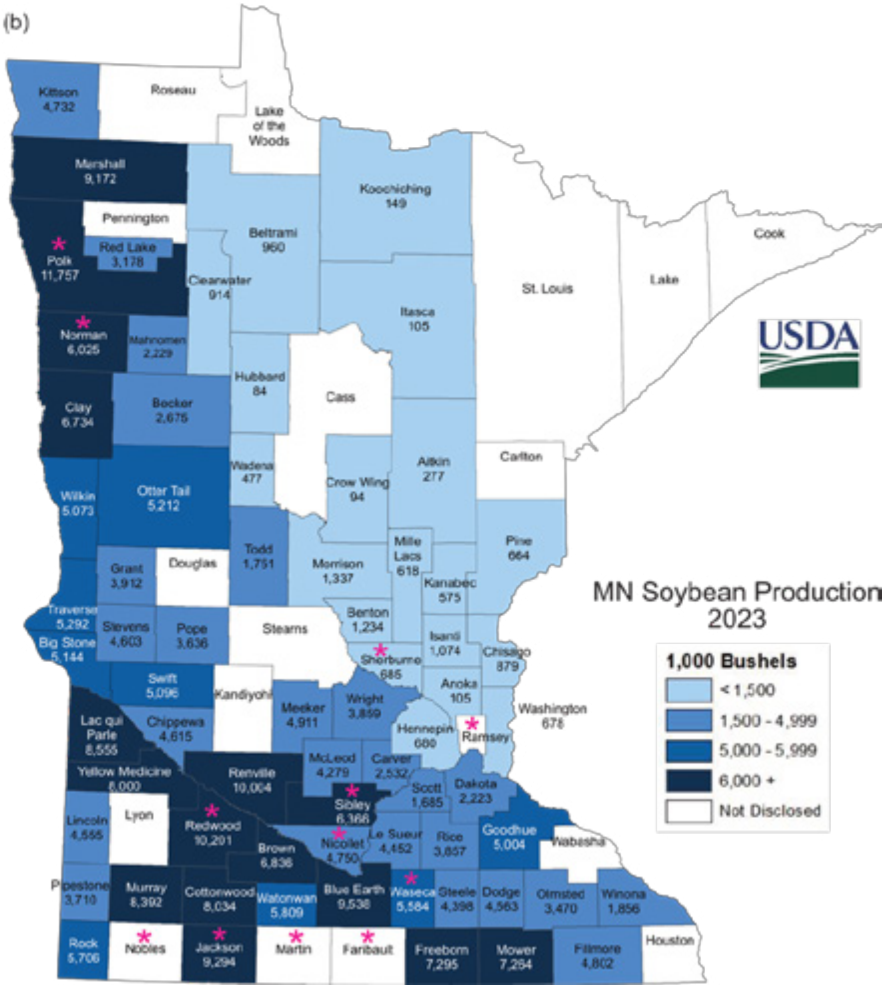


Figure 1. Soil samples collected from various MN fields in 2023 from which *Phytophthora* species will be isolated. **(a)** List of soil samples our lab gathered in the 2023 growing season. **(b)** Map of MN soybean production in 2023, showing number of bushels produced per county (source: USDA). Pink asterisk represents counties from which we have soil samples.

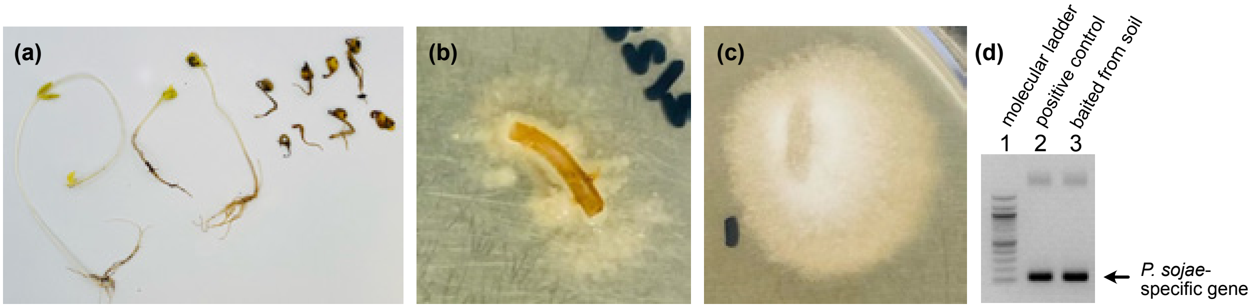


Figure 2. In experimental trials, we successfully isolated *P. sojae* from soil. **(a)** Soil that was artificially infested with *P. sojae* was allowed to infect a susceptible soybean cultivar (Sloan). Infected soybean seedlings (right) versus non-infected seedlings (left) are shown. **(b)** A piece of infected tissue was plated on *Phytophthora*-selective media and *Phytophthora* was allowed to grow. **(c)** Mycelia from (b) was sub-cultured on new growth media. **(d)** DNA was extracted from (c) and a molecular method (PCR) was performed to confirm that the identity was *P. sojae* (lane 3).

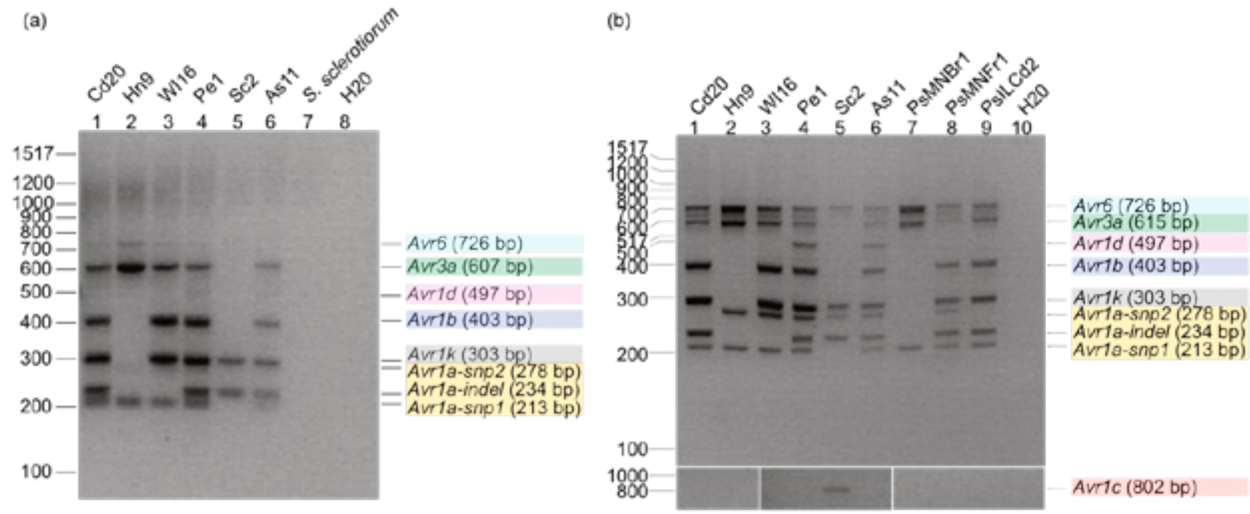
Sample_ID	County	Sample_type	Soil baiting (Y/N)	DNA extraction	PCR for *P.Sojae* (Y/N)
GRW001	Norman	soil	Y		
GRW003	Martin	soil	Y		
GRW004	Jackson	soil	Y		
GRW005	Nobles	soil	Y		
GRW006	Sherburne	soil	Y		
GRW007	Redwood	soil	Y		
GRW008	Redwood	soil	Y		
GRW009	Redwood	soil	Y	Y	
GRW010	Crookston	soil	Y	Y	
GRW011	Ramsey	soil	Y		
GRW012	Ramsey	soil	Y		
GRW013	Crookston	soil	Y		
GRW014	Dakota	soil	Y		
GRW016	Rice	soil	N		
GRW036	Rice	soil	Y		
GRW038	Waseca	soil	N		

Table 1: List of soil samples processed and the current status of soil baiting and *P.sojae* detection from these samples.

<u>Objective 2</u>: To enhance the efficiency of pathotype identification.

Traditional *Phytophthora sojae* pathotyping methods, which involve inoculating soybean plants with the pathogen, are labor-intensive and prone to inaccuracies. A new PCR-based molecular method developed by Dussault-Benoit et al. (2020) detects *P. sojae Avr* genes, achieving 97% accuracy in determining pathotypes when cross-validated with a refined plant pathotyping approach. This molecular method offers a faster and more reliable alternative to traditional techniques.

We successfully tested Dussault-Benoit *et al.*'s molecular method on 23 total *P. sojae* isolates that were previously pathotyped in 2004 by Dean Malvick via a plant inoculation method. After we optimized the molecular pathotyping method on few isolates (Fig. 3a-b), we performed the method on 23 total *P. sojae* isolates and were able to determine the PCR-based pathotyped based on the *Avr* genes that were absent (Fig. 3c). However, when we compare the PCR-based pathotypes to the plant inoculation-based pathotypes performed by Dean Malvick in 2004, we see inconsistencies between the two pathotyping methods (Table 2). Based on our communications with other researchers testing the molecular method, many others are also seeing inconsistencies. We are presently re-pathotyping the isolates using a plant inoculation method to determine the current plant-based pathotype, as old isolates could change pathotypes while in culture (Fig 4). The progress on the molecular re-pathotyping is shown below (Table 3). Our results from re-pathotyping using uniplex PCR differed from the results from the previous pathotyping using multiplex PCR. For example, we had detected *Avr6* in nearly all of the 23 samples except one. However, using our newer method, we detected *Avr6* in 12 out of the 23 isolates. Similar results were obtained for *Avr3a* (Table 3). We will repeat these experiments to confirm our results. We will continue our pathotyping using primers for the remaining *Avr* genes. Our results may help us design a better assay for *P.Sojae* detection that is more discerning and selective, avoiding false positives in pathotyping.



(c)

Isolate	Avr1a-indel	Avr1a-snp1	Avr1a-snp2	Avr1b	Avr1c	Avr1d	Avr1k	Avr3a	Avr6	PCR-based pathotype (2024)
Hk5		+	+				+	+	+	1a, 1b, 1c, 1d
Hn9		+	+					+	+	1a, 1b, 1c, 1d, 1k
Wi5	+	+						+	+	1a, 1b, 1c, 1d, 1k
PsMNBr1		+						+	+	1a, 1b, 1c, 1d, 1k
Sc2	+		+		+		+		+	1a, 1b, 1d, 3a
Pa9	+	+		+		+	+	+	+	1a, 1c
Cd20	+	+		+			+	+	+	1a, 1c, 1d
PsMNNi1	+	+		+			+	+	+	1a, 1c, 1d
PsMNMa1	+	+		+			+	+	+	1a, 1c, 1d
PsILCd2	+	+		+			+	+	+	1a, 1c, 1d
Wi16		+	+	+			+	+	+	1a, 1c, 1d
PsMNBr2	+		+	+			+	+	+	1a, 1c, 1d
Hn20	+	+		+				+	+	1a, 1c, 1d, 1k
PsMNOL1	+	+		+				+	+	1a, 1c, 1d, 1k
Hn27	+	+		+				+	+	1a, 1c, 1d, 1k
Sn2	+	+		+				+	+	1a, 1c, 1d, 1k
Is6				+						1a, 1c, 1d, 1k, 3a, 6
Wi13	+	+	+			+		+	+	1b, 1c, 1k
Pe1	+	+	+	+		+	+	+	+	1c
As11	+	+	+	+		+	+	+	+	1c
My1	+	+	+	+			+	+	+	1c, 1d
PsMNFr1	+	+	+	+			+	+	+	1c, 1d
Is4	+	+	+	+		+		+	+	1c, 1k

Figure 3. The molecular pathotyping method developed by Dussault-Benoit *et al.* (2020) was successfully tested in our lab using 23 *P. sojae* isolates collected in 2004 from Illinois by Dean Malvick. Dark bands at the appropriate size indicate presence of a specific *Avr* gene. *S. sclerotiorum* and *H20* are negative controls. **(a)** One of our early successful trials of the multiplex PCR suffered from faint and unresolved bands. **(b)** These issues were addressed in our later iterations of the molecular method, in which we were able to get distinct and well-resolved bands. **(c)** Summary of *Avr* genes detected in 23 *P. sojae* isolates using the molecular pathotyping method. Plus (+) sign denotes that we detected an *Avr* gene in the isolate. Blank denotes we did not detect an *Avr* gene. For *Avr1a*, all three genes (*Avr1a-indel, Avr1a-snp1, Avr1a-snp2*) must be detected in order for *Avr1a* to be considered present. We were then able to determine the pathotype of the isolate based on which *Avr* genes were absent in the isolate (last column).

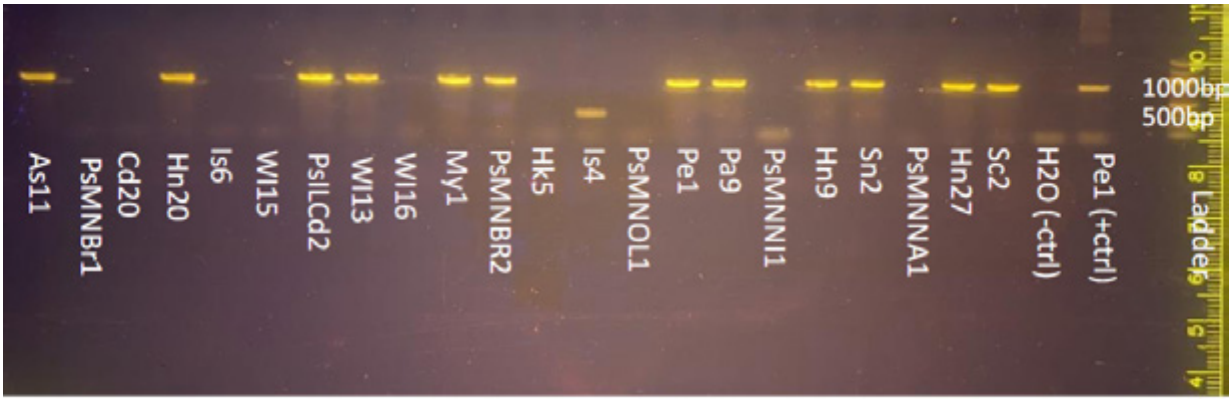


Fig 4: Gel electrophoresis showing results from uniplex PCR for detection of *Avr6* using DNA extracted from the different samples shown. The presence of the bright yellow band around 100bp indicates the presence of *Avr6* gene in these samples.

Isolate	Avr1a-indel	Avr1a-snp1	Avr1a-snp2	Avr1b	Avr1c	Avr1d	Avr1k	Avr3a	Avr6
Hk5								+	-
HN9								+	+
Wi5									-
PsMNBr1								+	-
Sc2								-	+
Pa9								+	+
Cd20								-	-
PsMNNI1								-	-
PsMNMA1								-	-
PsILCd2								+	+
Wi16								+	-
PsMNBr2								+	+
Hn20								+	+
PsMNOL1								-	-
Hn27								+	+
Sn2								+	+
Is6								-	-
WI13								+	+
Pe1									+
As11								+	+
MY1								+	+
PsMNFR1									
Is4								-	-

Table 3: Results from the molecular re-pathotyping using uniplex PCR. The *Avr* genes detected in 23 *P. sojae* isolates using the molecular pathotyping method where plus (+) sign denotes that we detected an *Avr* gene in the isolate. Blank denotes we did not detect an *Avr* gene.

Application/Use:
This research provides insights into the diversity and distribution of *Phytophthora sojae* affecting soybeans in Minnesota. By identifying the specific pathotypes of *P. sojae* present in fields through molecular methods and soil baiting, growers can select soybean varieties with resistance genes that better match the local pathogen profile, thereby reducing yield losses due to incompatible resistance. Furthermore, integrating these findings with commercial cultivar data enables a more strategic deployment of soybean varieties with effective *Rps* genes, aligning management practices with pathogen diversity in the region.

Materials and Methods:
Soil Baiting: Soil samples were ground, sieved, and placed into small cups or pots, then set in flats within a grow room or greenhouse and flooded for 24–48 hours. After draining, the pots were enclosed in plastic bags and incubated at a constant 77°F for 14 days. Following incubation, the cups were seeded with 3–5 soybean seeds per pot of the *Sloan* variety, known for universal susceptibility to *Phytophthora*. Seeds were covered with vermiculite, reflooded for 24 hours, then drained and incubated in a growth chamber at 77°F with a 16-hour photoperiod. Germinating seedlings were monitored for symptoms of *Phytophthora* infection, and symptomatic seedlings were harvested for pathogen isolation using *Phytophthora*-selective media in the lab.

Isolation and Pathotype Identification of *P. sojae*: *Phytophthora* isolates identified through soil baiting underwent DNA extraction as described previously (Zelaya-Molina et al., 2011) and following the established McCaghey Lab protocol. PCR protocols and primers, provided by Ohio State University and sourced from recent studies (Dussault-Benoit et al., 2020; Hu et al., 2021), were employed to amplify selected *Avr* genes if present in the isolates. Additionally, a separate PCR reaction targeted a *P. sojae*-specific gene unrelated to the *Avr* genes (Bienapfl et al., 2011) as a positive control to confirm *P. sojae* DNA. The PCR products were then analyzed by gel electrophoresis to determine which genes were present in each isolate, based on product size.

Economic Benefit to a Typical 500 Acre Wheat Enterprise: This work will assist growers to select varieties that will be the most effective at managing and avoiding yield losses from *P. soaje*.

Related Research: Additional research in the lab aims to improve resistance to Sclerotinia stem rot by developing pathogen panels to screen varieties and by identifying architectural traits that might be associated with disease escape. We have also collaborated with a researcher in Bioproducts and Biosystems Engineering to develop a LAMP assay as a rapid and early *P. sojae* detection method.

Recommended Future Research: Helpful future work could identify and characterize the virulence- associated genes and the genetic variability of *P.sojae* to predict the overcoming of resistance before it occurs. It would also be useful to explore quantitative resistance (many small genes that contribute to resistance) that can complement pathotype-specific resistance to build variety resistance-durability.

References:
Bienapfl, John C., Dean K. Malvick, and James A. Percich. "Specific molecular detection of Phytophthora sojae using conventional and real-time PCR." *Fungal biology* 115.8 (2011): 733-740.

Dussault-Benoit, Chloé, et al. "Discriminant haplotypes of avirulence genes of Phytophthora sojae lead to a molecular assay to predict phenotypes." *Molecular Plant Pathology* 21.3 (2020): 318-329.

Zelaya-Molina, Lily X., Maria A. Ortega, and Anne E. Dorrance. "Easy and efficient protocol for oomycete DNA extraction suitable for population genetic analysis." *Biotechnology letters* 33 (2011): 715-720.

Publications: This work is currently unpublished, but we aim to have the LAMP detection assay and molecular pathotyping validation published in spring, 2025.

Enhancing Sclerotinia stem rot (SSR) research capacity and exploring new avenues of disease management through soybean canopy architecture traits

Principal Investigator(s): Alisha Mildenberger, Suma Sreekanta, Aaron Lorenz, Megan McCaghey

Project Period: May 1, 2024- November 14, 2024

***<u>Research Question/Objectives</u>*:** In addition to physiological resistance, plant architecture may be important for avoiding soybean infection by *Sclerotinia sclerotiorum* in the field. Apothecia (the mushrooms required for infection of the pathogen) production is influenced by moisture, temperature and light (quality and quantity). In soybean production systems, 50% canopy coverage and greater favors apothecia development, and in a laboratory, UVB light (276-319 nm) are the most important wavelengths needed for apothecia development. Additionally, plant characteristics (leaf area, branch angle, etc.) may impact the plant and soil microenvironments that are important for disease development including UVB light penetration, soil moisture, and soil temperature. The purpose of this study is to explore the relationship between soybean canopy architecture, the soybean microenvironment, and Sclerotinia stem rot (SSR) development. We aim to inform breeding efforts to improve SSR avoidance and management. The research objectives are as follows:

Image 1 Apothecium of S. sclerotiorum

1) Characterize architectural traits and canopy closure of select lines in the field
2) Monitor microclimate conditions that are important for SSR development
3) Monitor apothecia and SSR development, in the field and greenhouse, under varied architectures
3) Assess apothecia and SSR development of commercial varieties with bushy vs. upright architectures

Results:
Preliminary results from 2024 are as follows:

Objective 1: Characterize architectural traits and canopy closure of select lines in the field

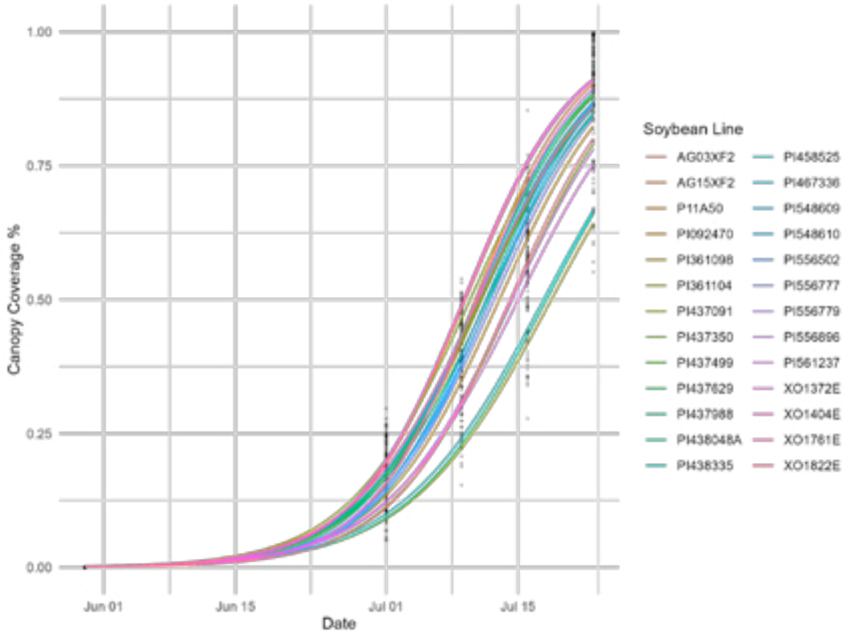


Figure 1. Logistic regression of % canopy coverage in 2024 in St. Paul showing from the planting date of 05.30.24 through 07.23.24. These dates were chosen based on peak apothecia production which based on figure 2 appears to occur between **07.16.24 and 07.25.24**.

Objective 2: Monitor microclimate conditions that are important for SSR development

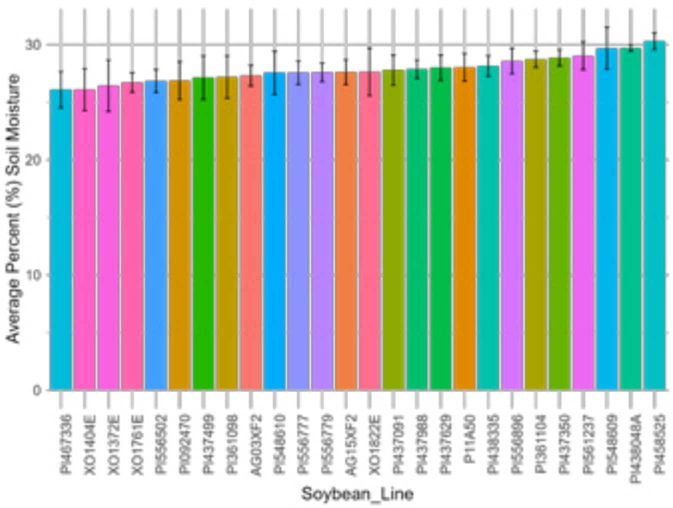


Figure 2. Mean % soil moisture from 07.12.24 in St. Paul replicated 5 times in an RCBD.

Objective 3: Monitor apothecia and SSR development, in the field and greenhouse, under varied architectures & Objective 4: Assess apothecia and SSR development of commercial varieties with bushy vs. upright architectures

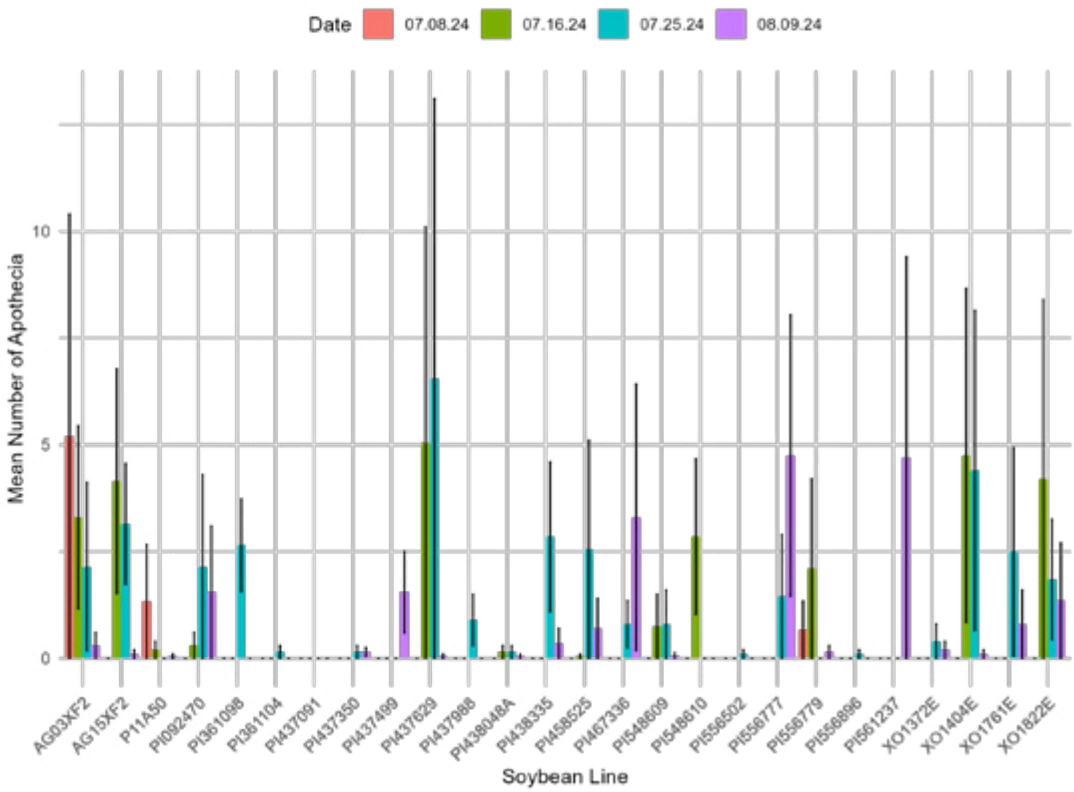


Figure 3. Mean number of apothecia found per soybean line in St. Paul on 4 different dates 07.08.24 (V4/V5, red), 07.16.24 (R, green), 07.25.24 (R2, teal), and 08.09.24 (R3/R4, purple) for 5 replicates in an RCBD.

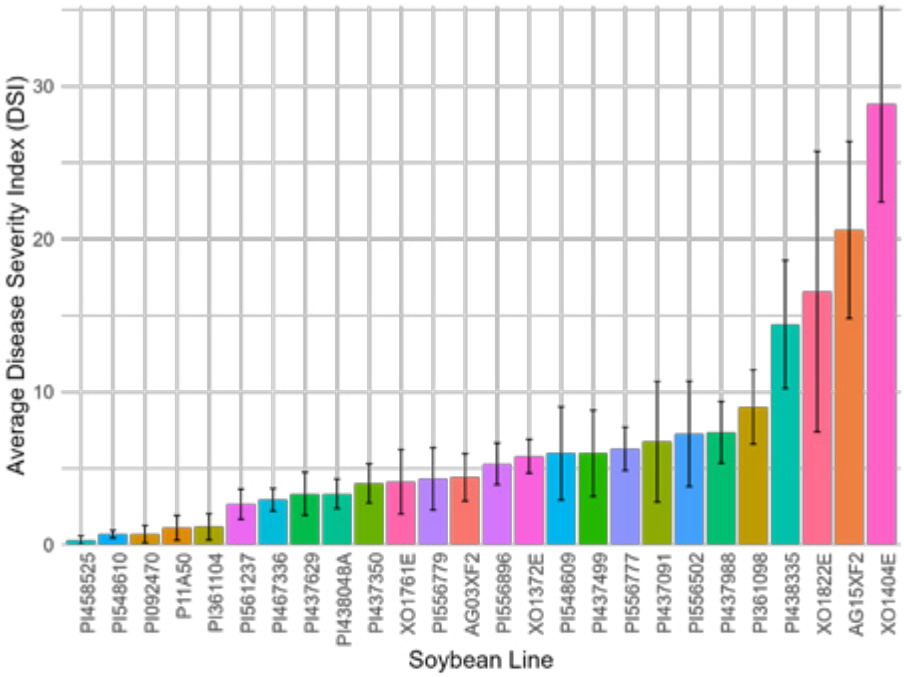


Figure 4. Mean disease severity index for 2024 in St. Paul observed at R6 with 5 replicates in an RCBD.

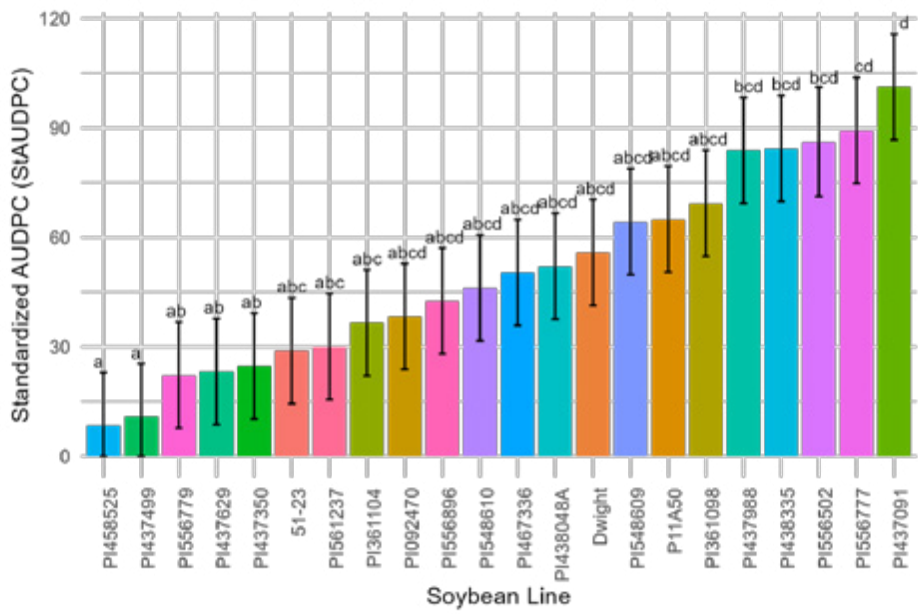


Figure 5. Mean standardized AUDPC (StAUDPC) for greenhouse petiole inoculation by soybean line challenged by one of each low, medium and highly aggressive *Ss* isolates with four biological replicates in an RCBD and three technical replicates per pot. Means with the same letter(s) are not significantly different at α=0.05 using Tukey's HSD.

Application/Use: This project will give insight into canopy architecture traits that may help inhibit SSR development which could be useful to breeders. It will also help us to understand what microclimate under the canopy is conducive to disease. Additionally, this can help us to consider how fungicide use could be combined with using soybean lines that have architecture traits as an additional management strategy.

Materials and Methods:

Obj. 1) Characterize architectural traits and canopy closure of select lines in the field (continuing)

Imaging for phenotyping of the traits mentioned above took place during the R4 stage and was conducted from four replicates and with six plants per plot. We conducted imaging in St. Paul on 8/12 and 8/14. In Waseca, imaging took place on 8/20, 8/22, 8/23, and 8/26. Analysis of the images is in progress. Average leaflet areas from 2023 are summarized in Figure 3. This fall, we will also aim to assess correlations between phenotypic traits and disease and apothecia development.

Obj. 2) Measure microclimate conditions that are important for SSR development

Light measurements were taken using a UVB meter at the end of vegetative stages to complete canopy closure. Canopy closure corresponded to R4 for most lines. UVB captures the spectrum of wavelengths considered to be the most important for apothecia production. Measurements were conducted in the morning starting between 9:00 and 10am and ending around 12:30pm on days with little to no cloud cover, waiting if clouds passed over, that might block the UVB penetration to the ground. Measurements were captured in the center of each two rows facing east at 0", 7.5", and 15" from the base of the plant to the center of the row for St. Paul and Waseca due to row spacing being 30". In St. Paul light measurements were completed on 7/12, 7/25, and several plots were assessed on 8/9 but rating ended early due to cloud cover. In Waseca, UVB light data were collected on 7/17 and the full field on 8/24.

Image 2 Light detection under the soybean canopy with a

Spectroradiometer readings to capture a complete light spectrum were collected from lines with very different levels of light interferences: 3 with high light, 3 with low light, 1 with medium light based on 2022 data. Spectra were also captured from the two industry check lines (bushy and upright). The same distances were used for the spectroradiometer measurements. Full spectrum was captured in St. Paul on 7/12 for all plots and on 8/9/24 for some plots.

Soil and canopy moisture are also important for the development of apothecia and white mold. Moisture was measured using a handheld sensor 7.5" from the soybeans in the middle rows. Soil moisture was measured in all blocks in St. Paul on 7/12 and block 5 on 7/25/24. In Waseca soil moisture was measured on 7/24 and 8/2/24 in all plots. Humidity and soil moisture and temperature sensors were established in industry bushy and industry upright lines in St. Paul at the late vegetative, V8 growth stage.

Obj. 3) Monitor apothecia and SSR development, in the field and greenhouse, under varied architectures & Obj. 4) Assess apothecia and SSR development of commercial varieties with bushy vs. upright architectures.

We scouted for apothecia in the middle two rows of each plot from 3–4 1m areas each side of a row prior to flowering and at early flowering stages in St. Paul through canopy closure, when apothecia begin to develop. Scouting in St. Paul took place on 7/8, 7/16, 7/25, and 8/9/24. Apothecia were found on all dates in St. Paul and data are currently undergoing analysis. Scouting was also completed in Waseca on 7/17, 7/24, and 8/2/24, but unfortunately no apothecia were observed in Waseca.

Bromophenol blue plates were used to detect the presence of ascospores, the spores that infect senescing flowers and lead to disease in soybean. Plates were put into the field at a 45-degree angle upwind for 1-3 hours in the morning (as dew evaporates) and incubated at room temperature for 2-3 days. If spores are present, the blue plates develop a yellow halo around spores due to a change in pH induced by the fungus. In St. Paul, plates were put out in the select lines that spectroradiometer readings were taken from on 7/12 and checked on 7/15 and 7/16. In Waseca plates were put out on 7/17 and checked on 7/20 and 7/22. Ascospores were frequently detected and data will be analyzed this fall.

Final disease incidence and severity ratings were completed at R6 using an established rating scale of 0 (no infection), 1 (infection on branches), 2 (infection on, but not girdling stem), 3 (infection on main stem resulting in death or poor pod fill, McCaghey et al., 2017). Lodging scores were taken at harvest and yield data collected for the industry lines.

Additionally, the subset of 20 soybean lines evaluated in the field, along with commercial lines, and susceptible and moderately resistant lines developed as check lines by Dr. Damon Smith's Lab were inoculated with *S. sclerotiorum* in the greenhouse this past winter to assess their genetic resistance. Three MN isolates with a range of aggressiveness were used. A cut petiole method was used to challenge plants and lesion progress was measured for 14 days post inoculation. Differential genetic susceptibility was observed among the lines as indicated by the area under the disease progress curve (a metric of disease progression across time, figure 4).

This winter, data from 2024 will continue to be analyzed. Correlations and relationships between architecture, disease and apothecia, and soybean microclimates will be assessed.

Economic Benefit to a Typical 500 Acre Wheat Enterprise: This work is intended to ultimately inform breeding efforts to reduce yield losses from SSR. Conceptually, breeding for architectures with disease avoidance paired with genetic resistance could improve plant protection from *S. sclerotiorum* infection.

Related Research: In addition to field-based assays, the lab is conducting complementary lab-based work to refine the wavelengths of light that are needed for apothecia production. We are also conducting various projects to understand and improve SSR management. Projects include the efficacy and discovery of biological control agents; the impact of cover crops on disease development, and the development of isolate panels to screen for resistance of soybean to Sclerotinia stem rot.

Recommended Future Research: Future research might explore the relationship between light and apothecia production in the lab; investigate the relationship between industry line architectures and disease; or might consider breeding efforts that combine avoidant architectures with genetic resistance to SSR.

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NOTES

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