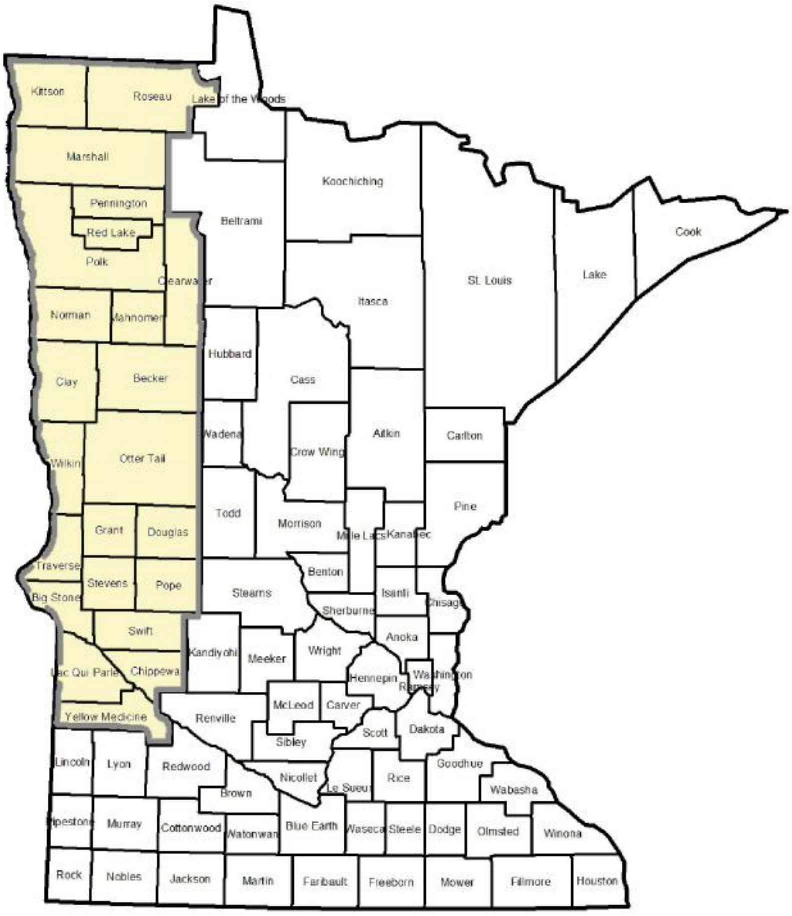
On-Farm Cropping Trials Northwest & West Central Minnesota and 2021 Minnesota Wheat Research Review



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2021 On-Farm Trials | UMN Extension On-Farm Cropping Trials

The mission of the UMN Extension and 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, with application to the knowledge base of the United States and World. Within this framework, major emphasis is placed on research and education that is relevant to the needs of northwest Minnesota, and which 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, Crookston; Dr. Jared Goplen, Extension Regional Office, Morris; Dr Daniel Kaiser, Soil, Water, and Climate, University of Minnesota; Arthur Vieira Ribeiro, Robert Koch and Bruce Potter, Extension Integrated Pest Management, University of Minnesota, SWROC; Andrew Leuck, Owner/Research Lead, Next Gen Ag, Renville; Maykon Jr. da Silva and Seth Naeve, Dept. of Agonomy and Plant Genetics, University of Minnesota; Dr. Dean Malvick, Dept. of Plant Pathology, Univeristy of Minnesota.

These projects were made possible thanks to the hard work of many people. This includes farmers, County and Regional Extension Educators, and specialists who conducted or cooperated with these trials.

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

2021 Wheat Research Review

In 2021 the Minnesota Wheat Research and Promotion Council allocated about $649,000 of the total $1,582,000 check-off income to wheat research projects. The 2021 reports from these projects are printed in this book.

Wheat Research Project Funding Process:
Each year in September, the Minnesota Wheat Research and 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 v.s. Benefit?

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

In addition to the projects reports being printed and distributed through this booklet, some of the project researchers give 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 the Prairie Grains Magazine. The Minnesota Wheat Research Committee is made up of wheat growers, agronomists, unbias 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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Wheat Research Reports - Funded in part by the Minnesota Wheat check-off

European corn borer survey – 2017-2021: Northwest Minnesota

Cooperators: Cooperating producers and crop advisors in Becker, Beltrami, Clay, Kittson, Mahnomen, Marshall, Norman, Pennington, Polk, Red Lake and Roseau Counties.

Purpose of Study:
European corn borer (ECB) larvae tunnel into stalks and ear shanks (**Figure 1**). Feeding affects the transfer of water and nutrients within the plant and can directly affect yield by reducing kernel weight and number. ECB feeding can indirectly affect yield when tunnels cause stalk breakage, ear drop, or allow the entry of stalk rot and ear mold fungi.

Figure 1. European corn borer (*Ostrinia nubilalis*). Clemson University, USDA Cooperative Extension Slide Series, Bugwood.org.

ECB and Bt corn. More than 25 years ago scientists found a way to transfer a gene from a soil-borne bacterium called *Bacillus thuringiensis* (Bt) into the corn genome. Bt corn was approved for commercial use in 1996. Within the corn plant tissues, this gene produces a protein toxic to corn borer larvae. When ingested by larvae, the protein breaks down to a toxin which kills larvae by allowing mid-gut contents to leak into the rest of the body cavity. Additional Bt traits that target different above- and below-ground insect pests have since been incorporated into some hybrids.

The only way to manage ECB before Bt corn was developed, was to closely monitor ECB moth flights and scout for larvae and egg laying. If ECB populations warrant, foliar insecticide applications can provide control if they are carefully timed as the larvae are only susceptible to insecticides for 10 to 14 days. After that time, 3rd instar larvae begin to tunnel into the stalk, ear or ear shank where they are protected from insecticide applications. This timing can be difficult particularly in areas of the state where both a single generation and multiple generation biotypes of ECB exist. Historically, the single generation (univoltine strain) has predominated in NW Minnesota.

Even the best-timed insecticide application is less effective than growing a hybrid with the Bt trait. Depending on the hybrid and trait package Bt corn can cost up to $20/acre more than conventional seed. In the current economic environment, $20/acre is a big deal and is a major driver of non-Bt corn hybrid seed purchases. During the past 4 years in MN, Bt corn use for above-ground traits for stalk and ear pests has ranged from 85-88% (USDA average). High adoption of Bt corn has also occurred in NW MN. This has resulted in area-wide suppression of ECB populations, protecting even the non-Bt acres.

Study Objectives. Some objectives of the MN Corn Research & Promotion Council-sponsored 2017-2021 fall ECB survey in NW MN are to answer the following questions:

1) Are there changes in ECB population densities over time?
2) To what extent does the areawide suppression effect occur in the NW?
3) Have any population shifts taken place? ie. is the Bt trait still effective (Bt-resistant corn borer have been found in eastern Canada but fortunately they are a different strain than occurs in MN) and does ECB in NW MN continue to only produce a single generation of larvae each year? Understanding the number of generations per year is essential for managing ECB in non-Bt corn.

Results:
During 2017, 2018, 2019, 2020 and 2021 a total of 13, 30, 55, 28 and 43 commercial fields were surveyed in NW MN, respectively (**Figure 2, Table 1**). Among the randomly surveyed fields there were also 3 known non-Bt fields in 2017, 21 in 2018, 36 in 2019, 8 in 2020 and 29 in 2021. The data presented in Table 1 summarize the per plant average number of ECB larvae in surveyed fields by year and Bt status. In 1995, before the 1996 release of ECB Bt hybrids, an average of 1.16 ECB larvae per plant were found in NW MN corn plants. In 2017 through 2019, randomly surveyed corn fields (likely a mix of Bt and non-Bt fields) had an average of 0 to 0.020 larvae per plant, while the average number of larvae per plant in non-Bt corn fields ranged from 0.0190 to 0.1472 larvae per plant. When compared to randomly surveyed fields, in 2017 there were more than 3.3 times the number of larvae per plant in the non-Bt fields; similarly, when compared to randomly surveyed fields, in 2019 there were more than 14 times the number of larvae per plant in the non-Bt fields.

ECB population densities were very low in all surveyed fields in 2020 and 2021. This may indicate that, even though overall ECB populations are low, they still follow the historical cycle entomologists believe is related to a fungal disease and other parasites causing dramatic declines in high ECB populations every 6-7 years. An additional factor that might have impacted population densities of larvae within plants, is the historic extreme drought conditions that prevailed in NW MN in 2021, as mortality of both eggs and early larval instars has been associated with uninterrupted periods of hot, dry weather. Another key factor is likely the high Bt use rates in NW MN.

For Additional Information: Angie Peltier, Bruce Potter, Eric Burkness and Bill Hutchison

Project Funding Provided by: Minnesota Corn Research and Promotion Council

European corn borer survey – 2017-2021: Northwest Minnesota, pg 2

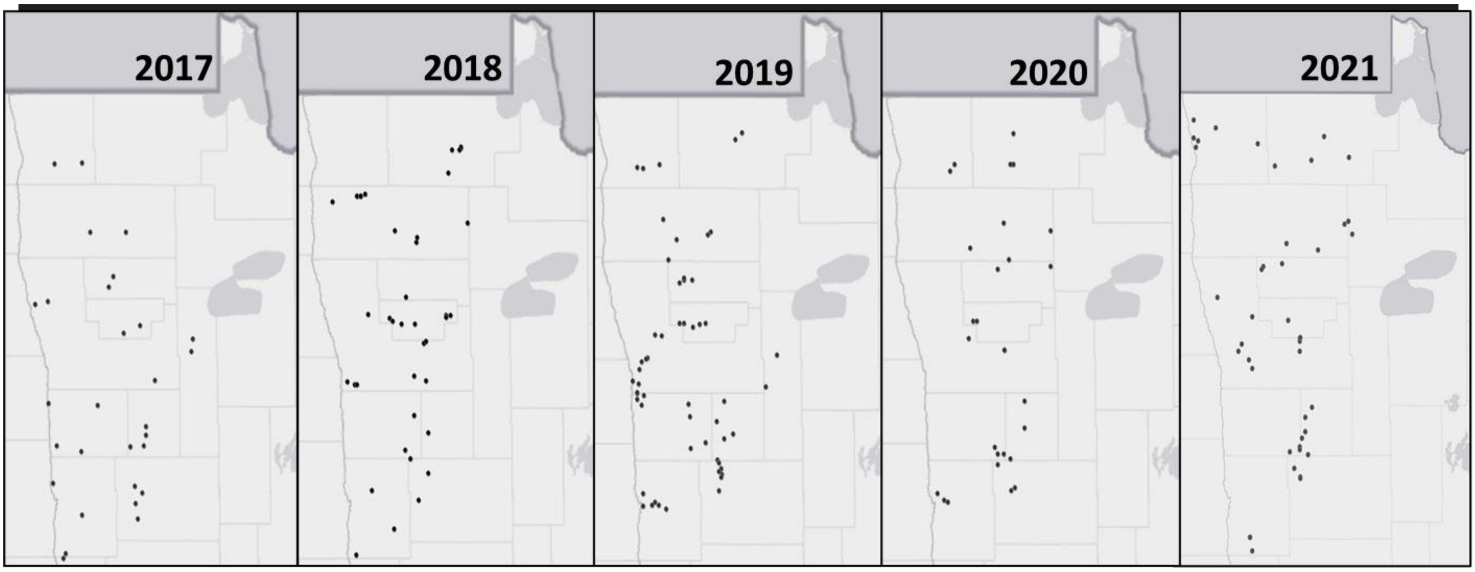


Figure 2. Fields in the northwest crop reporting district surveyed for European corn borer in 2017-2021.

It is interesting to note that among the non-Bt fields sampled in 2020-2021, only 0.0 to 9.3 percent were infested with one or more larvae. This trend continues to indicate that the "halo effect" of Bt corn protection is still active in protecting non-Bt fields from ECB (Hutchison, unpublished data). Briefly, the halo effect is attributed to ECB moth dispersal and behavior, where the number of moths dispersing out of non-Bt fields each spring/summer is greater than moths immigrating back to non-Bt fields. Thus, fewer eggs are laid in non-Bt corn. Because ECB moths cannot distinguish between Bt and non-Bt fields, the majority of eggs will be laid in Bt fields (via current high Bt use), and virtually all larvae emerging in Bt fields will die (assuming ECB remains susceptible to Bt). While higher than the number of larvae per plant in fields surveyed at random, the average number of larvae per plant in non-Bt fields is much lower than the traditional economic threshold levels for ECB (typically estimated at 0.5 larvae/plant).

<u>Bottom line.</u>

While this information provides a '30,000 ft view' of ECB in the region, remember that these are region-wide averages and do not replace scouting of individual fields for making informed, in-season pest management decisions. One positive for those planting non-Bt corn in NW MN, the larvae collected in this region reflect the single-generation type of ECB, meaning that scouting and insecticide management can be confined to a shorter time each year.

Each farmer has a different tolerance for risk. While low populations mean that there is less risk associated with planting corn hybrids without Bt for ECB protection, the risk is not zero, and varies from year to year.

Table 1. NW MN crop reporting district data for ECB larvae and percentage of fields infested in field corn, Minnesota 2017-21. Baseline data for 1995, prior to Bt corn commercialization is also shown (non-Bt fields)*

	Mean #ECB larvae/plant (n)		Fields Infested (%)
Year	**Random fields**	**Known non-Bt fields only**	**All fields (Only non-Bt fields)**
1995	**1.16***	**1.16***	**. (.)**
2017	**0.0200 (10)**	**0.0667 (3)**	**15.4 (33.3)**
2018	**0.0000 (9)**	**0.0190 (21)**	**10.0 (14.3)**
2019	**0.0105 (19)**	**0.1472 (36)**	**25.5 (33.3)**
2020	**0.0000 (20)**	**0.0000 (8)**	**0.0 (0.0)**
2021	**0.0000 (14)**	**0.0344 (29)**	**9.3 (13.8)**

<u>Want to learn more?</u>

For additional information about the European corn borer and ECB management, visit:

https://extension.umn.edu/corn-pest-management/european-corn-borer-minnesota-field-corn

For Additional Information: Angie Peltier, Bruce Potter, Eric Burkness and Bill Hutchison

Project Funding Provided by: Minnesota Corn Research and Promotion Council

A new way of managing white mold in soybean

Purpose of Study: White mold in soybeans has always been difficult to manage. The fungus that causes this disease produces long-lived survival structures and has a wide host range, causing economic losses in many crops important to NW MN, including soybean, edible beans, sunflower and canola. Partial resistance in soybean varieties means that in years in which weather favors disease, some yield loss is still likely to occur. Similarly, while there are several protectant fungicides labeled for white mold management, sub-optimal canopy penetration and coverage at the site of infection (flower buds at leaf axils) means that some yield loss likely occurs even with a well-timed application.

While the connection may not initially be apparent, the convergence of recent economic and environmental concerns and the availability of equipment that allows farmers to spoon-feed nitrogen (N) to their crops, paved the way for this soybean white mold management project. With corn producers feeling both an internal pressure to make sure that every last bit of N at least pays for itself and an external pressure to reduce N lost to the environment, some split their N, applying a baseline in the spring and coming back later on to side-dress the remaining N into a standing crop. It is the equipment that allows this in-season side-dressing to take place (think y-drop applicators) that provides an opportunity to research different fungicide application techniques.

In an effort to improve fungicide coverage, we compared coverage and efficacy when fungicides were applied either within the canopy between rows or in the typical over-the-top fashion. Personnel built a spray boom to position multiple nozzles between rows and within the canopy (**Figure 1**). Chemical-resistant hose, plumbing and sprayer fixtures and junctions were used to fashion the body onto which to affix the nozzle filters and nozzles. Zip ties were used to connect the nozzle body onto the bottom of a square, hollow steel pipe that would ride within the canopy and between rows. Plastic skid plates were bent and riveted to the steel pipe so that the pipe and nozzle body could easily glide through the canopy, minimizing potential plant injury. Details regarding the over-the-top and between-the-row sprayer setups can be found in **Table 1**. Note that while fungicides work best to protect plants when droplet size is small and more plant surfaces are covered, some fungicide labels suggest increasing droplet size for white mold management to ensure sufficient canopy penetration.

Figure 1. Configuration of the tractor-mounted hydraulic-powered plot sprayer used to apply fungicides in this experiment. Note that two different within-the-canopy booms were built to allow application down the center of both 22 (Crookston study site) and 30 inch (Staples study site)-spaced soybean rows. The within-the-canopy nozzle body (black circle/square) rode approximately 12“ from the soil surface and the over-the-top nozzles (white circle/square) rode approximately 8“ above the soybean canopy.

Table 1. Details regarding the nozzle type and details, spray volume, speed, pressure and droplet size of fungicides applied over the top of the canopy and within the canopy. See **Figure 1** for a picture of what both look like.

	Over-the-top	Within-the-canopy
Spray nozzle	TeeJet AI XR11002	TeeJet 110015
Nozzle details	Flat fans riding above the canopy	3 nozzles: 2 flat fans spray vertically toward rows & 1 sprays up at 45° angle under the canopy
Gallons/Acre	10	10
mph	5	5
Pressure	40 psi	40 psi
Droplet size	Very course	Medium

For additional information: Angie Peltier, Jeff Nielsen, Michael Leiseth, Hannah Barrett, Dean Malvick

Project funding provided by:
Minnesota Soybean Research & Promotion Council

A new way of managing white mold in soybean (continued)

Results:

Treatments. To improve the chance of white mold occurring, some plots were infested with the fungus that causes white mold (*Sclerotinia sclerotiorum, Ss*) and all plots were periodically irrigated after fungicide application. Experimental treatments included an untreated control that was neither infested with *Ss* nor treated with fungicide, a positive control in which plots were infested with *Ss*, but not treated with fungicide, and over-the-top and within-the-canopy fungicide treatments that were infested with *Ss*.

Assessing spray coverage and deposition. Prior to applying fungicides, short (18”-tall, installed) pieces of metal fencing material were pounded into soybean rows in plots that were to have over-the-top or within-the-canopy applications; and small spring-loaded two-sided alligator-type clips were attached to them at 6” and 12” above the soil line. Just before fungicide application, water-sensitive paper was attached to the clips and oriented to sit within the canopy. After application and time for the water-sensitive paper to dry, personnel put on appropriate PPE and retrieved the papers, placing them into pre-labeled Ziplock-type bags to shield them from additional moisture or humidity. A scanner and USDA-developed software program called “Deposit Scan” were used to objectively analyze spray coverage on the water sensitive paper.

Data collected. At the beginning flowering (R1) growth stage, 8 oz/A of Endura was applied to the center four rows of six 22 inch-row soybean plots at the Northwest Research and Outreach Center in Crookston and to the center four rows of six 30 inch-row soybean plots at the Central Lakes College Ag and Energy Center in Staples. Data that was collected from these plots included: fungicide coverage, white mold incidence and severity and harvest moisture and yield.

Yield. Despite doing our best to initiate disease in these experiments, in 2020 warm temperatures prevailed after treatment and the growing season was dominated by historically severe drought conditions, resulting in no disease. Data from 2020 and 2021 differed significantly from one another (Staples: yield: $P < 0.0001$, moisture: $P < 0.0001$; Crookston: yield: $P < 0.0001$, moisture: $P < 0.0001$) and so yield and moisture data were analyzed separately by year. With the environmental conditions that prevailed after treatment, it was not a surprise that there were no differences observed among treatments for soybean yield in either year (2020: 66.7 bu/A average, $P = 0.2869$; 2021: 43.5 bu/A average, $P = 0.2395$) and moisture (2020: 12.0% average, $P = 0.2307$; 2021: 16.0% average, $P = 0.2732$) at the Staples site and yield (2020: 29.8 bu/A average, $P = 0.9644$; 2021: 15.9 bu/A average, $P = 0.7894$) and moisture (2020: 8.8% average, $P = 0.1882$; 2021: 11.7% average, $P = 0.9218$) at the Crookston site.

Fungicide coverage. Fungicide coverage data from the two research locations for water sensitive paper placed 6 inches and 12 inches above the soil line were first analyzed to determine whether years differed or whether data from both years could be combined; analysis indicated that data did not differ between years (Staples, 6-inch: $P = 0.2498$, 12-inch: $P = 0.9375$; Crookston, 6-in: P 0.2498, 12-inch: $P = 0.7385$) and so data from 2020 and 2021 were combined for analysis. The within-the-canopy application resulted in significantly better fungicide coverage within the soybean row at both 6 and 12 inches above the soil line than the over-the-top application in the 22 inch rows in Crookston (**Table 2, Figure 2**). In 30 inch rows at Staples, the within-the-canopy application resulted in numerically better fungicide coverage at 6 inches above the soil line (**Table 3**) and statistically better coverage at 12 inches above the soil line compared to an over-the-top application. We speculate that at the CLC in Staples the thick canopy may have interfered with fungicide penetration at the 6-inch height regardless of application method.

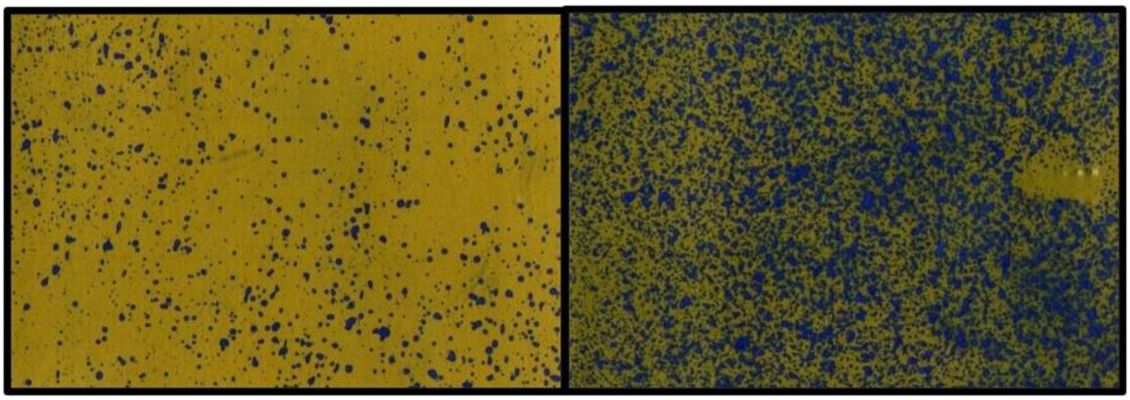


Figure 2. Water sensitive paper that had been placed 6 inches above the soil line in the soybean row before fungicide was applied using either the traditional over-the-top method (left) or the experimental within-the-canopy method (right). A document scanner and the Deposit Scan software was used to impartially assess spray coverage and fungicide deposition. Note that darker areas indicate where fungicide droplets fell on the water sensitive paper.

For Additional Information: Angie Peltier, Jeff Nielsen, Michael Leiseth, Hannah Barrett, Dean Malvick

Project Funding Provided by: Minnesota Soybean Research and Promotion Council

Table 2. Coverage (%) of fungicides applied over-the-top or within-the-canopy captured by water-sensitive paper placed within the R1 soybean canopy at 6 inches above the soil line in 22 inch rows at the NWROC in Crookston and in 30 inch soybean rows at the CLC in Staples. Treatment means within a column followed by different letters are statistically significantly different from one another.

	Fungicide Coverage (%)		
Nozzle configuration	NWROC, Crookston		CLC, Staples
Over-the-top	19.3 a		16.0
Within-the-canopy	55.3 b		24.5
P =	< 0.0001		0.2889

Table 3. Coverage (%) and deposition (microL/cm^2) of fungicides applied over-the-top or within-the-canopy captured by water-sensitive paper placed within the R1 soybean canopy at 12 inches above the soil line in 22 inch rows at the NWROC in Crookston and in 30 inch soybean rows at the CLC in Staples. Treatments means within a column followed by different letters are statistically significantly different from one another.

	Fungicide Coverage (%)		
Nozzle configuration	NWROC, Crookston		CLC, Staples
Over-the-top	33.0 a		18.4 a
Within-the-canopy	47.6 b		27.5 b
P =	0.0318		0.0743

Corn stalk rot survey – 2021: Northwest Minnesota

Cooperators: Personnel visited fields of cooperating producers in Becker, Beltrami, Clay, Kittson, Mahnomen, Marshall, Norman, Pennington, Polk, Red Lake and Roseau Counties.

Purpose of Study:
During a fall survey of 43 corn fields in Becker, Beltrami, Clay, Kittson, Mahnomen, Marshall, Norman, Pennington, Polk, Red Lake and Roseau counties in NW MN for European corn borer, personnel also assessed stalk strength using a "standard" push-test. Briefly, 20 random plants in each field were pushed at ear height more than 30 degrees from vertical. Plants 'failed' this test by permanently bending or breaking and not returning upright, indicating poor stalk strength.

This survey was not designed to differentiate between stalk quality issues caused by disease or other stressors but rather to assess standability of the 2021 corn crop.

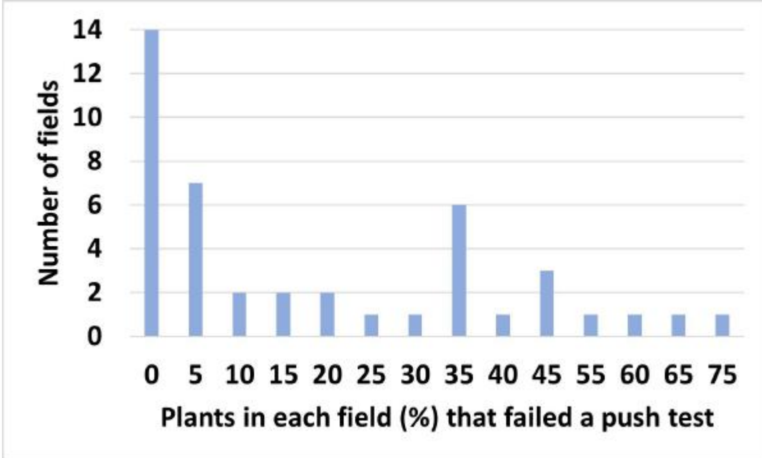


Fig. 1. The percentage of plants failing the push test.

Results:
Developing corn kernels place a high demand on the plant for sugars. Stress slows photosynthesis, reducing the amount of sugar the plant can produce. Different stresses can reduce the rate of photosynthesis: too much or too little moisture, nutrient imbalances, plant injury (ex.: hail, insects, diseases), excessive plant populations, and even long-periods of cloudy weather.

Hybrid genetics and/or high yield potential combined with stress during grain fill can increase the probability of stalk quality issues. Stalk quality tends to decrease the longer the crop remains in the field unharvested.

If a plant is unable to keep up with kernel sugar demand, it can rob sugars from stalk tissue, deteriorating stalk integrity and predisposing it to stalk rotting fungi.

In NW MN, the percentage of plants suffering from stalk rot ranged from a low of 0 percent (14 fields) to a high of 75 percent (1 field; Figures 1 and 2); 51% of the fields had stalk quality issues that might have impacted harvestability, more than the 46% of fields in 2020.

Crop stressors in 2021 included the historic drought throughout much of the region, with between 8 and 14 inches less precipitation than normal between Sep 1, 2020 and Aug 30, 2021. Those areas that received some rain had more kernels and so required more sugars, some of which was likely to be redistributed from and weaken stalks. Without adequate soil moisture, plants also struggled to take up sufficient nutrients or as efficiently photosynthesize and produce and accumulate the sugars needed for grain-fill with rolled leaves.

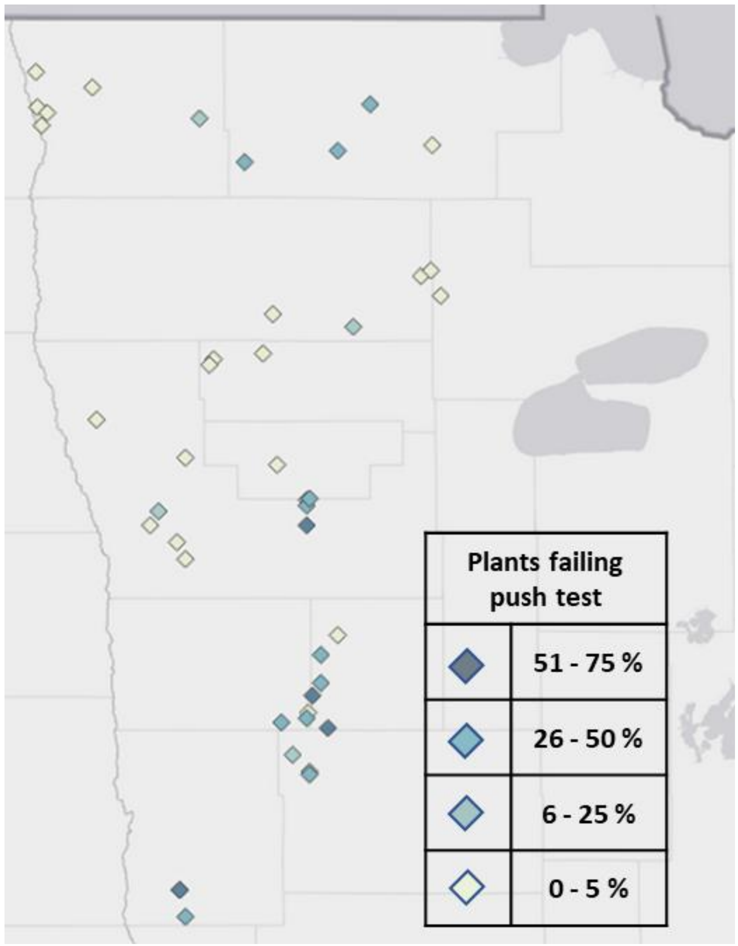


Fig 2. The location of fields surveyed and the percentage of plants failing the push test in 43 fields in 2021.

For Additional Information: Angie Peltier, Bruce Potter, Eric Burkness or Bill Hutchison

Project Funding Provided by: Minnesota Corn Research and Promotion Council

2021 Western Minnesota Soybean Crop & Pest Survey

Cooperators: Minnesota Soybean Research & Promotion Council, NDSU IPM Survey

Purpose of Study:
The soybean crop and pest survey was designed to provide in-season data about regional pest pressure to assist farmers and consultants in making pest management decisions. The 2021 growing season was the sixth that UMN Extension undertook this MSR&PC-sponsored survey.

This project was coordinated with a similar survey undertaken by the NDSU IPM team. Bi-state survey maps were made by NDSU IPM and are available on the NDSU Pest Management website: https://www.ag.ndsu.edu/ndipm/ipm-survey-archives/

Results:
Field surveys of randomly selected Minnesota soybean fields were initiated on June 21. A total of 822 fields were surveyed from June 7 through August 13 in MN and ND (Fig 1).

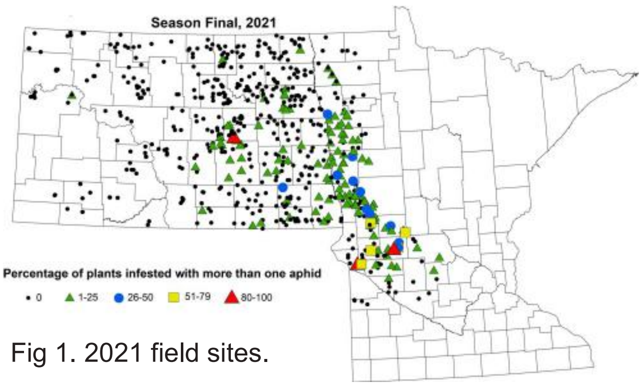


Fig 1. 2021 field sites.

The above-normal temperatures that prevailed throughout the 2021 growing season (Fig 2) accelerated soybeans to grow and develop faster than in 2019 (Fig 3), the last year of this IPM survey.

A total of 283 field visits occurred in Minnesota in 2021.

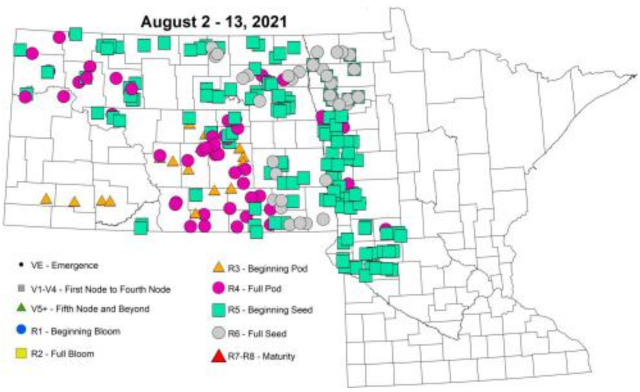


Fig 2. Growth stages, Aug 2-13, 2021.

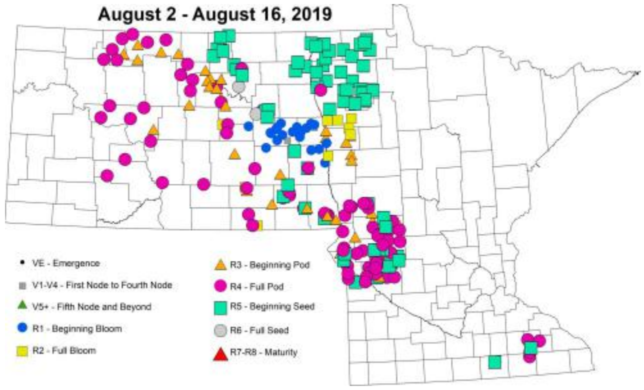
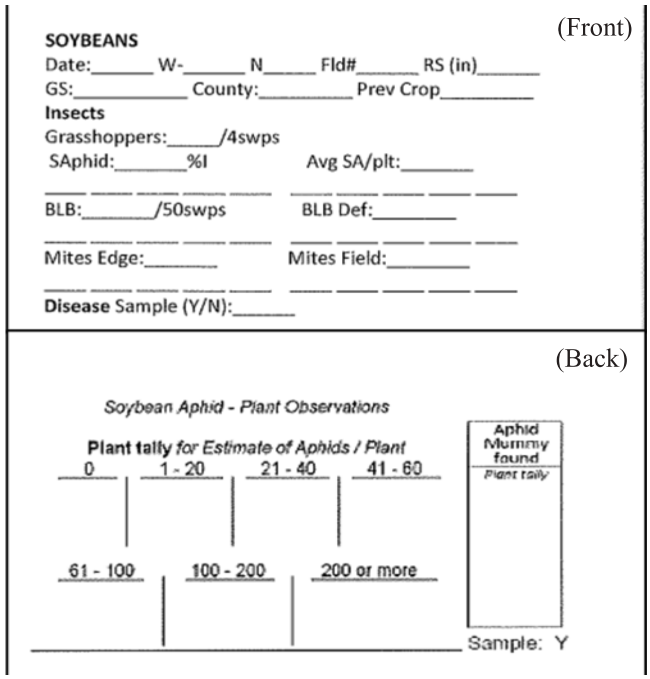


Fig 3. Growth stages, Aug 2-16, 2019.

A primary focus of the survey was documenting soybean aphid population dynamics. Surveys used a protocol based on the "Speed Scouting" procedure which bases treatment decisions for soybean aphid on the treatment threshold of 250 aphids per plant. Scouts inspected a minimum of 31 plants at random from randomly selected soybean fields; plants with aphids were noted and used to determine the percentage of plants with at least one aphid. Aphid population densities on individual plants were visually estimated and tallied on field cards (Fig 4) by the numerical range estimated.


(Front)

SOYBEANS
Date:______ W-______ N_____ Fld#______ RS (in)______
GS:__________ County:_________ Prev Crop_________
Insects
Grasshoppers:_____/4swps
SAphid:_______%I Avg SA/plt:_______
BLB:_______/50swps BLB Def:________
Mites Edge:________ Mites Field:________
Disease Sample (Y/N):______

(Back)

Soybean Aphid - Plant Observations

Plant tally for Estimate of Aphids / Plant

0 | 1 - 20 | 21 - 40 | 41 - 60

61 - 100 | 100 - 200 | 200 or more

Aphid Mummy found
Plant tally

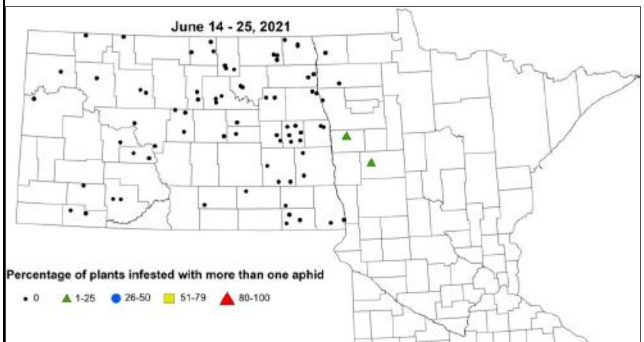
Sample: Y

Fig 4. Pocket-sized card used for data collection. Soybean fields were scouted for crop growth stage and spider mites and 31 plants within each field were scouted for soybean aphid population estimates.

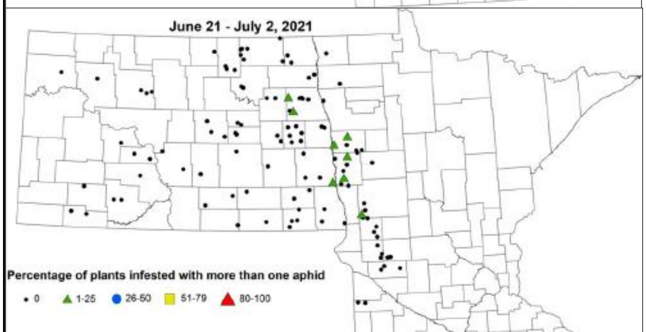
For Additional Information:
Angie Peltier, Jared Goplen, or Anthony Hanson

Funding Provided by:
Minnesota Soybean Research & Promotion Council

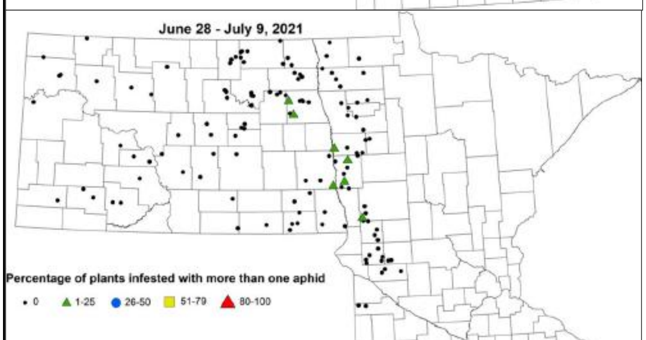
Although incidence and severity remained low throughout 2021, detectable aphid infestations were found in WC Minnesota between June 7 through 18 (Fig 5). Although soybean aphid incidence (the percentage of plants within a field that were infested) continued to grow throughout the growing season in WC MN, the population density or average number of soybean aphids per plant of these infestations remained well below the soybean aphid treatment threshold of 250 aphids per plant, averaging less than 20 aphids per plant (Fig 6).



June 14 - 25, 2021

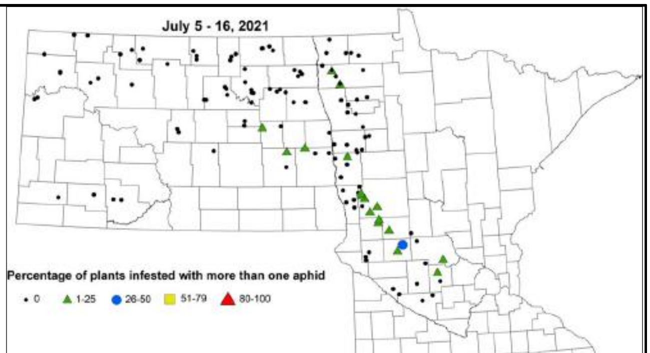


June 21 - July 2, 2021

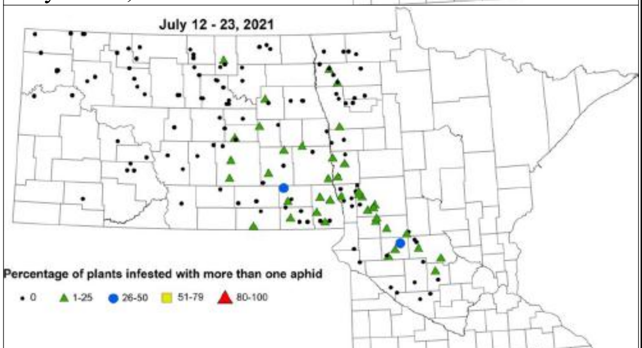


June 28 - July 9, 2021

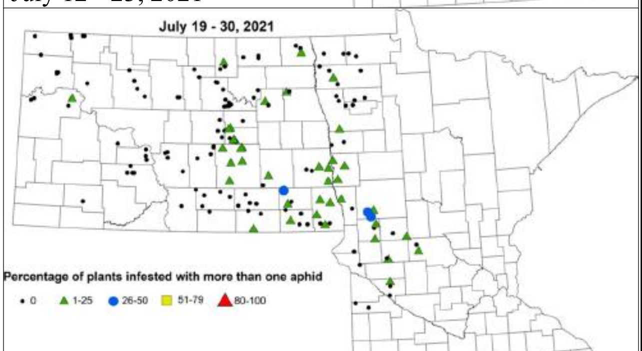
Figure 5. Percentage of surveyed soybean plants with at least one soybean aphid.



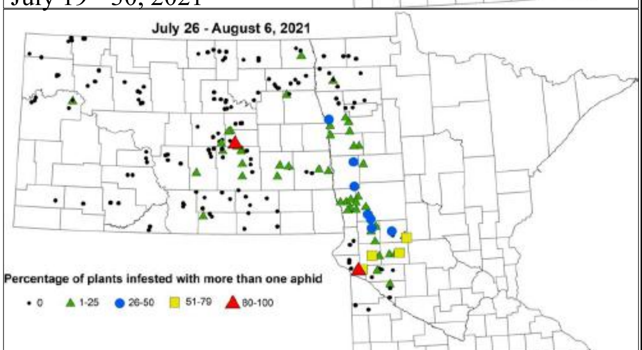
July 5 - 16, 2021



July 12 - 23, 2021



July 19 - 30, 2021



July 26 - August 6, 2021

Figure 5. Percentage of surveyed soybean plants with at least one soybean aphid.

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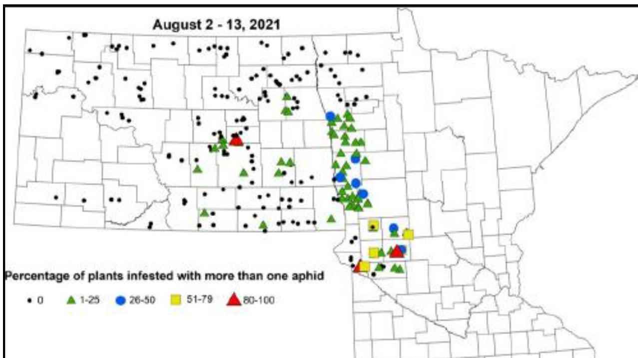
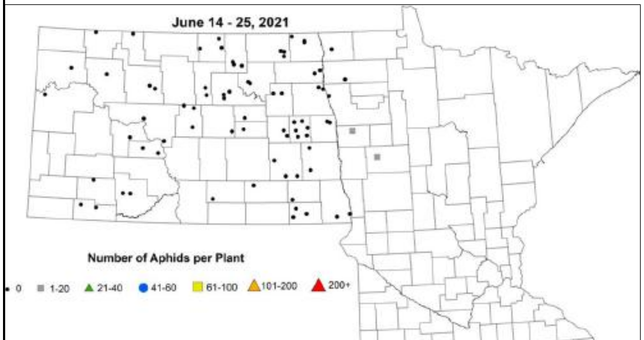
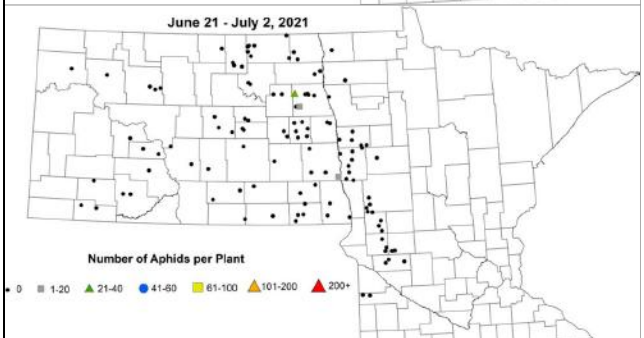


August 2 - 13, 2021

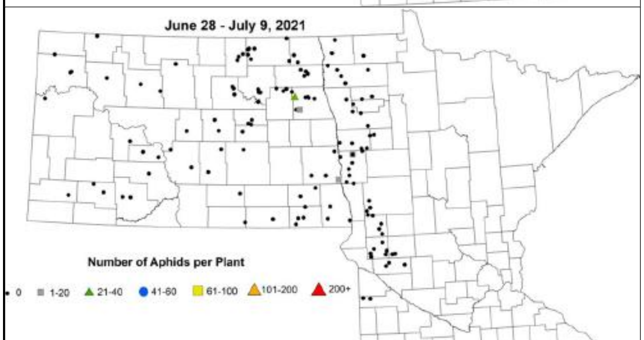
Figure 5. Percentage of surveyed soybean plants with at least one soybean aphid.



June 14 - 25, 2021

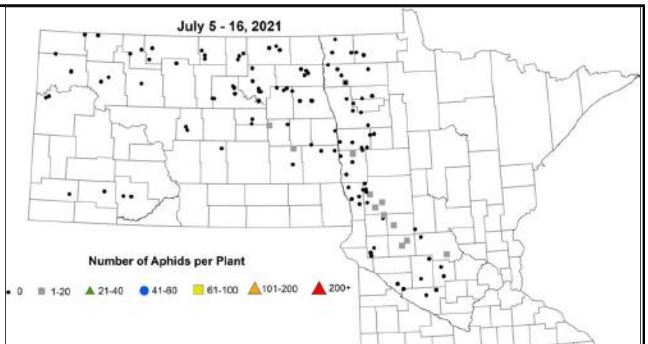


June 21 - July 2, 2021

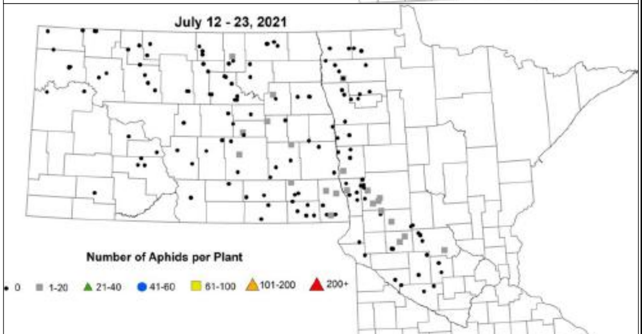


June 28 - July 9, 2021

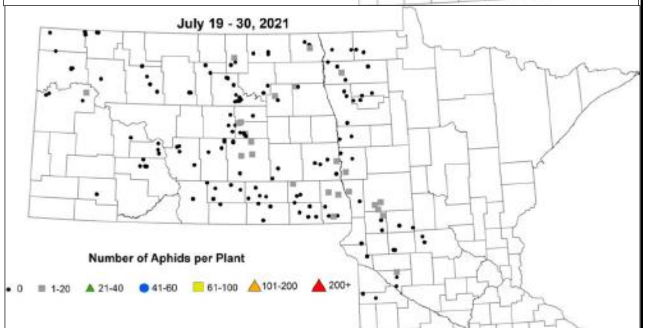
Figure 6. Average number of soybean aphids estimated per surveyed plant.



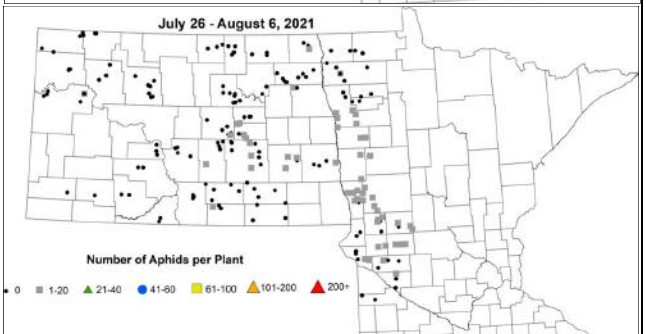
July 5 - 16, 2021



July 12 - 23, 2021



July 19 - 30, 2021



July 26 - August 6, 2021

Figure 6. Average number of soybean aphids estimated per surveyed plant.

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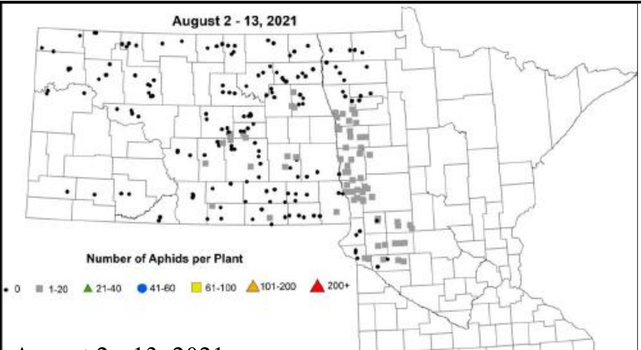
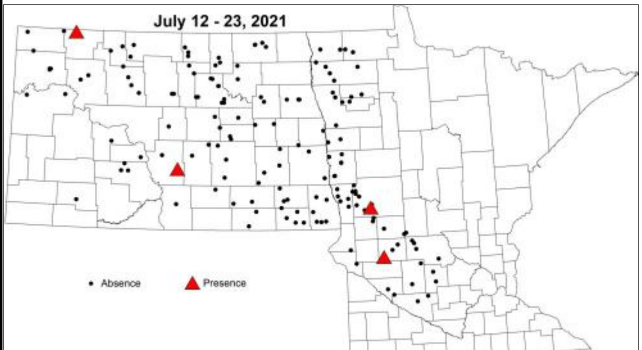


August 2 - 13, 2021

Figure 6. Average number of soybean aphids surveyed plant.

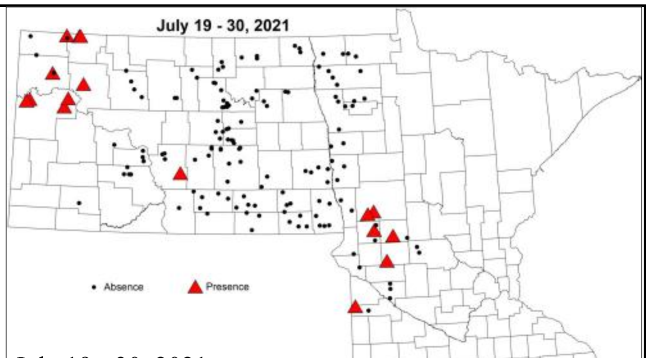
Of concern in any drought year are two-spotted spider mite infestations (Fig 7), which tend to begin at the outer edge of fields. Edge-of-field spider mite infestations began to appear in multiple WC MN fields in the middle of July, peaking towards the end of the survey (Fig 8).

Fig. 7. Two spotted spider mites (red arrows) and eggs (blue arrows) on a soybean leaf.

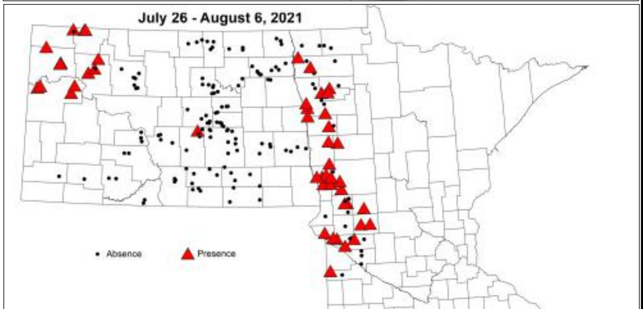


July 12 - 23, 2021

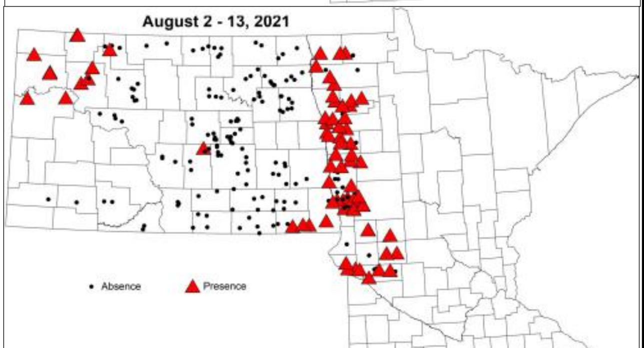
Fig. 8. Edge of field two-spotted spider mite infestations (red triangles).



July 19 - 30, 2021



July 26 - August 6, 2021



August 2 - 13, 2021

Fig. 8. Edge of field two-spotted spider mite infestations (red triangles).

Lagging just behind edge-of-field infestations, spider mite (SM) infestations also spread to colonize plants within soybean fields in WC MN in the middle of July (Fig 9). Both edge-of-field and in-field spider mite infestations in NW MN lagged behind those in WC MN, becoming more evident toward the end of July (Figs. 8 & 9).

Plant injury and treatment thresholds and economic losses (lower leaf yellowing is apparent and loss is common; SM injury, webbing and mites are common; mites and minor feeding injury present in upper canopy) were met in many fields. Whether or not one chose to treat depended upon one's sense of whether or not there was yield potential to protect, whether to spend more to….

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produce an already poor crop, and whether rainfall was likely to fall in a timely enough manner to “save” the crop if one acted to save it.

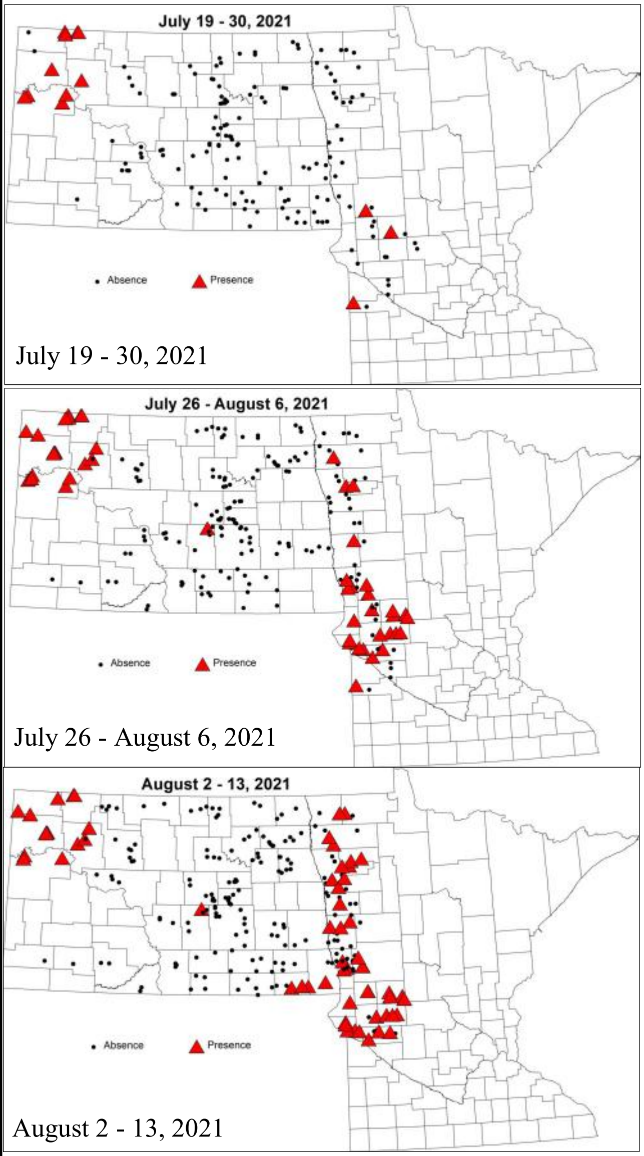

Fig 9. Within-field two-spotted spider mite infestations (red triangles).

Soybean aphid. Scouting can lead one to understand whether aphid population densities in a field have reached all three aspects of the treatment threshold:

- More than 80% of plants are infested with aphids
- There is an average of 250 aphids per plant
- The aphid population is growing.

In 2021, the understanding that aphids had not reached treatment thresholds could help producers.. to both avoid unnecessary insecticide applications and save a farmer between $9.12 and $35.49 per acre in insecticide and application costs.

- For additional information about biology, scouting and management of soybean aphid search “soybean aphid” on the University of Minnesota Extension website or visit: https://extension.umn.edu/soybean-pest-management/soybean-aphid

Two-spotted spider mite. Scouting can also lead one to understand whether spider mites and the injury that they cause have reached treatment thresholds. Years ago, UMN IPM Specialist Bruce Potter developed spider mite infestation-based treatment thresholds that are designed to balance minimizing yield losses, not waiting to treat until infestations have already affected yield potential and not treating too early and avoid having to re-treat a field:

- **0**: No spider mites or injury observed.
- **1**: Minor stippling on lower leaves. No premature yellowing observed.
- **2**: Stippling common on lower leaves. Small areas with yellowing on scattered plants.
- **3:** Spray threshold: Heavy stippling on lower leaves with some stippling progressing into the middle canopy. Mites present in the middle canopy, with scattered colonies in the upper canopy. Lower leaf yellowing is common, and there’s some lower leaf loss.
- **4**: Economic loss: Lower leaf yellowing is readily apparent. Leaf drop is common. In the middle canopy, stippling, webbing, and mites are common. Mites and minor stippling present in the upper canopy.
- **5**: Lower leaf loss is common, with yellowing or browning moving up the plant into the middle canopy. Stippling and distortion of the upper leaves are common. Mites are present in high levels in the middle and lower canopy.

It is recommended that in addition to noting spider mite injury, one determine whether mites are still present before spraying. When scouting, carry a white piece of paper to place underneath plants. To make mites easier to see than when they are camouflaged on leaves, place the paper underneath leaves and then tap the plants and look for moving mites on the paper.

Good canopy coverage through using adequate carrier volume is key. Because there is always the risk of pesticide resistance and different pesticides have more or less effect on specific spider mite developmental stages (Table 1; ex. only effective against adults), it is important to evaluate how effective a treatment was 5 to 7 days afterward.

Preserving a.i.’s efficacy. Insecticides have been widely used in soybean production, often without consideration of treatment thresholds, as ‘cheap and easy insurance’ when added to the...

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...spray tank when making post-emergence herbicide or fungicide applications. Avoiding unnecessary applications can also help to preserve a.i. efficacy. Each time that an insecticide or miticide is used, it selects those insects or mites that are resistant to that active ingredient(s) (a.i.) to survive and reproduce, killing those that are sensitive to the a.i. Over time this results in a population shift from one that is largely a.i.-sensitive to one that is largely a.i.-resistant.

Do your best to avoid unnecessary pesticide applications. Insecticide and fungicide applications can adversely affect biological control conferred by natural predators or entomopathogenic fungi and may actually cause spider mite populations to flare up.

Table 1. Pesticides labeled for control of two-spotted spider mite (TSSM) and soybean aphid (SBA) on soybean (Adapted from Potter, Koch and Ostlie, 2021).

Insecticide group	Common name	Trade name	Label for TSSM	TSSM stage controlled	Label for SBA	Resistance concerns
1B-organophosphate	dimethoate	Several* (e.g. Dimethoate 4E, 4EC, 400, Dimate 4E, 4EC)	X	adults/ immature	X	TSSM resistance concerns
3A-pyrethroid	bifenthrin	Several* (e.g. Bifenture 2E, Brigade 2E, Discipline 2E, Fanfare 2E, Sniper 2E, Tundra 2E)	X	adults/ immature	X	SBA resistance concerns
6-chlorine channel activators	abamectin	Agri-Mek SC*	X	adults/ immature		
10A-Hexythizox	hexythiazox	Onanger		egg/ immature		
10b-etoxazole	etoxazole	Zeal SC, Zeal WDG (corn only)	X	egg/ immature		
12C-propargite	propargite	Comite*, Comite II*		egg/ immature		
23-tetranic and tetramic acid derivatives	spiromesifen	Oberon 2SC		egg/ immature		
Mixtures						
3A + 3A	zeta-cypermethrin + bifenthrin	Hero*	X	adult/ immature	X	SBA resistance concerns
3A + 44 (fungicide)	bifenthrin + *Bacillus sp.*	EthosXB*	X	adult/ immature	X	SBA resistance concerns

* Restricted use pesticide

Always read and follow label directions. Products are mentioned for illustrative purposes only. Their inclusion does not mean endorsement and their absence does not imply disapproval.

- For more information about two-spotted spider mites, visit the University of Minnesota Extension Managing spider mite on soybean webpage (https://extension.umn.edu/soybean-pest-management/managing-spider-mite-soybean)

What is the Deal With Chloride and Soybean?

By Daniel E. Kaiser – University of Minnesota, St. Paul

Long term trials were established at four locations in Spring 2017 [Crookston, Lamberton, Morris, and Waseca (Table 1)]. Two-year cropping rotations were established at each site in two blocks, one for each crop. A two-year corn-soybean rotation was established at Lamberton, and Waseca. A two year hard red spring wheat-soybean rotation was established at Morris and Crookston. Treatments are a combination of fertilizer rate, timing, and source. Fertilizer is based on a K application at a K rate of 100 and 200 lbs K_2O per acre which is roughly 1 and 2 times expected crop removal for the rotations (Kaiser et al., 2020a, 2020b, 2013). Two sources of K, KCl and K_2SO_4, are compared with a non-fertilized control. An additional source treatment includes $CaCl_2$ (calcium chloride) applied at a rate which supplies an identical amount of Cl as applied in the KCl treatments. The $CaCl_2$ treatment is used to determine if any impacts from KCl may be due to the Cl. Soil Ca content at the beginning of the study will be measured, but the Ca applied is not anticipated to have a significant impact on yield. Gypsum will be applied to balance S applied with the K_2SO_4 so all plots will receive a relatively high rate of S and Ca annually. Timing will consist of all fertilizer applied before soybean or before wheat or corn. A split plot design will be used where main plots will consist of a factorial combination of rate and time while the sub-plots will consist of fertilizer source (none, KCl, K_2SO_4, and $CaCl_2$).

A second set of soybean trials were established at 3 sites (Becker, Morris, and Waseca, MN) in 2020 and 2021 comparing or four varieties which vary in IDC/salt tolerance to determine if salt tolerance is an indicator of potential tolerance of excess Cl. The variety sets varied by year and consisted of Asgrow 14X7, 14X8, 17X7, and 17X8 in 2020, and Asgrow 13XF0, 14X8, 17X8, and Gold Country 1827X in 2021. Three Cl treatments, no Cl and 500 lb/ac of Cl applied either as KCl or $CaCl_2$ were applied. A strip plot design was utilized where varieties were planted as strips over top the fertilizer treatment. Soil test results are not shown for the second study. Soil types for Morris and Waseca were similar as those given in Table 1. The soil type at Becker was a Hubbard loamy sand. Becker was the only site which supplemental irrigation was applied. Average chloride content in the irrigation water was 32 ppm measured in 2020 at Becker.

A summary of source main effects is given in Table 1 across four cropping years for each crop at each location. Rate and timing main effects were seldom, if ever, significant and are not included. Fertilizer source affected corn and hard red spring wheat yield at one of two locations and at three of four soybean locations. Single degree of freedom contrasts were used to determine response to K and Cl. Potassium almost always increased yield in situations where source main effects were significant. The exception was Crookston where the source main effect was not significant but single degree of freedom contrasts indicated a small response to potassium. Overall soybean yields were relatively low at Morris and Crookston along

Table 1. Summary of corn, hard red spring wheat, and soybean grain yield data across four growing years at four locations averaged for fertilizer source main effects across two fertilizer application rates and application timing where fertilizer was applied in the fall directly ahead of the soybean crop or in the fall ahead of the rotational crop. Response to K and Cl is given from results of single degree of freedom contrasts when the contrast indicated a significant effect of K or Cl. Small letters following numbers indicate significance among treatments at the $P \leq 0.10$ probability level.

		Source Main Effect				Response to	
Crop	Location	None	$CaCl_2$	KCl	$K2SO_4$	+K	+Cl
		---------------------------------------bushels per acre-----------------------------					
Corn	Lamberton	175c	176bc	181a	179ab	4.2	2.4
	Waseca	204	206	206	204	0	0
Wheat	Crookston	62b	62b	64a	64a	1.9	0
	Morris	36	36	37	36	0	0
Soybean	Crookston	38	38	39	39	0.7	0
	Lamberton	52b	51c	53bc	54a	1.3	-1.0
	Morris	25b	23c	26ab	27a	2.3	-1.7
	Waseca	67a	66ab	65b	67a	0	-0.8

with hard red spring wheat yield at Morris due to generally dry conditions and relatively high levels of soybean cyst nematode at Morris (not shown). Corn grain yield was increased at Lamberton but not at Waseca while hard red spring wheat yield was increased by K at Crookston but not at Waseca. Current fertilizer guidelines for corn and soybean in Minnesota suggest a response to K is more likely when soil test K is less than 200 ppm. All sites tested less than 200 ppm but not all sites responded to K. No K is suggested for wheat when the soil test is 160 ppm or greater.

Rate and timing main effects are not shown as they were seldom significant except for the timing main effect which differed for soybean at Lamberton and Waseca. In both cases soybean yield was 1.5 bushels per acre greater when fertilizer was applied for soybean ahead of the corn crop. The fact that the timing by source interaction was not significant for soybean at Lamberton and Waseca is odd as soybean grain yield was greater when fertilizer was applied ahead of the corn crop, the negative impact of Cl on soybean grain yield did not seem to be affected by time of application. Additional data has shown that application ahead of the crop in rotation with soybean greatly reduces the risk of a reduction in grain yield (not shown). In the current study the reductions appear to be consistent regardless of fertilizer timing.

Chloride only increased yield at one location, Lamberton Corn. When impacted, soybean grain yield was always less when Cl was applied regardless of rate. The increases were generally small and likely would not be noticeable to soybean growers. When K was deficient K did increase yield, but the increase was typically greatest when potassium sulfate was the K source.

High rates of Cl were applied to study 2 in order to induce a negative soybean response to the nutrient. Data were analyzed by year across most sites as the variety sets differed between the years. Variety main effect grain yield data are not given in this article. Soybean grain yield did vary by variety but there was no interaction between variety and fertilizer source indicating consistent effects of K or Cl among the four varieties used. Yield data for Morris in 2020 was analyzed separately from Becker and Waseca due to greater impact on soybean grain yield from the fertilizer treatments at Morris (Table 3). Soybean grain yield was decreased by Cl by 18 bushels per acre at Morris in 2020 while the reduction was much smaller at Becker and Waseca which is consistent with the long-term study results. All sites responded similarly to fertilizer application in 2021. Average yield for the KCl and $CaCl_2$ treatments did not differ in 2021 and averaged a 4 bushel per acre reduction in grain yield. There was a tendency in 2021 for soybean grain yield to be numerically higher for KCl but the difference was not significant. The data in study 2 further indicates a general risk of yield reduction from Cl and that more work is needed to determine which soybean varieties could be considered Cl excluders.

CONCLUSIONS

Soybean grain yield can be reduced by chloride contained in KCl fertilizer. These studies were not designed to determine the exact rate of KCl that would result in a reduction in yield. Research on rate of application is needed to determine whether rates lower than what would be applied to supply expected crop removal for a two-year corn-soybean or wheat-soybean rotation would not result in a reduction in grain yield. Potassium can increase yield and should be applied if soil tests indicate a potential deficiency. The reduction in soybean grain yield was less when fertilizer was applied ahead of the rotational crop. If higher application rates need to be applied as KCl it should be applied of the preceding crop. More research is needed to determine exact tolerance of soybean to Cl and whether alternative sources of K fertilizer should be considered if K is needed for soybean production.

Table 2. Summary of soybean grain yield data averaged across four soybean varieties when 500 lbs of Cl per acre were applied as either KCl or $CaCl_2$. Small letters following numbers indicate significance among treatments at the $P \leq 0.10$ probability level.

Year	Location	None	KCl	$CaCl_2$
		--------------------bushels per acre--------------------		
2020	Becker, Waseca	67a	64b	65ab
	Morris	68a	49b	50b
2021	Becker, Morris, Waseca	45a	42b	39b

Soybean Insect Research Update – 2021

By Arthur Vieira Ribeiro, Robert Koch and Bruce Potter, University of Minnesota

This update provides an overview of two research projects on soybean insects that have been supported by the Minnesota Soybean Research & Promotion Council. The first project is focused on improving management of and remote sensing for soybean aphid. In particular, research is being performed to examine the individual and combined effects of soybean aphid and defoliation (Japanese beetle and artificial) on soybean spectral reflectance and yield. The second project is focused on identifying alternate crop and non-crop hosts of the soybean gall midge.

Effects of soybean aphid in combination with Japanese beetle feeding or artificial defoliation on soybean canopy reflectance

Soybean aphid is an invasive insect pest of soybean production in the Midwest region of the U.S. Soybean aphid populations can quickly grow to damaging levels and cause significant yield losses. For this reason, the management of this pest currently relies mainly on insecticides. Previous works have shown that remote sensing using near infra-red reflectance can accurately identify and classify soybean aphid populations. Field trials with caged soybean plants were conducted in Saint Paul, Rochester and Rosemount during the summers of 2019, 2020 and 2021. Each cage had a combination of soybean aphid with Japanese beetle feeding or artificial defoliation. Data on aphid abundance, Japanese beetle feeding and artificial defoliation, yield and yield components, and hyperspectral readings were collected. Low levels of soybean aphid (~ 100 aphids/plant) and Japanese beetle defoliation did not reduce yield or seed quality. However, high levels of soybean aphid (upwards of 1000 aphids/plant) reduced seed weight, and intense defoliation (33%) decreased total yield, and the weight and number of seeds. Low levels of Japanese beetle defoliation (≤ 5%) were found to increase red-edge, but not near infra-red reflectance of soybean plants. However, Japanese beetle defoliation close to 10% increased red-edge and reduced near infra-red. Thus, typical levels of Japanese beetle defoliation in the field are unlikely to affect the detection of soybean aphids with remote sensing. However, intense defoliation (≥ 10%) decreased reflectance at near infra-red and therefore could affect remote sensing for aphids. Yield and yield components from 2021 trials are still being analyzed.

Preliminary investigations on host preference of the soybean gall midge in Minnesota

During 2018, the soybean gall midge (SGM) was identified as a new pest of Midwestern soybeans and confirmed in Rock County, MN, in that same year. Each year since then, this insect pest has been found in additional Minnesota counties. The twelve new counties confirmed in 2020 brings the total to 28 counties, most of these are in the southwest part of the state. To help understand the potential impact of SGM on crops other than soybean and possibly provide clues to its geographic area of origin, a sentinel plant approach with fifteen annual legume cultivars was used. Plants of eight crop species with origins in the eastern and western hemisphere were greenhouse-grown in 4-inch pots plastic pots containing potting mix and thinned to 2 plants /pot after emergence. During the period of 1st and 2nd generation SGM adult activity, potted plants were placed at a border of a soybean field in Rock County that had a history of yield-limiting soybean gall midge infestations. After one week in the field, the plants were brought back to the greenhouse and maintained for one week to allow time for larval development. When the lower stems of these sentinel plants were dissected, SGM larvae were found only within the stems of soybean.

Dry bean fields in Cottonwood, Kandiyohi, Lac Qui Parle, Renville, Stevens, and Swift counties that were encountered during surveys for SGM were also examined. No SGM larvae or signs of infestation were found in dry bean in these counties with histories of SGM. In Minnesota, SGM larvae have been observed in Alfalfa (Rock County) and sweet clover (Kandiyohi, Lac Qui Parle, Rock, Yellow Medicine counties), but only when nearby soybeans have also been infested. No other legume hosts were observed in August 2021 observations of native prairie legumes in WC and SW MN.

Summary of Comprehensive Waterhemp Control from Micro-Rate Combinations of Soil Residual Herbicides

By Andrew Lueck,
Research Lead and Owner, Next Gen AG LLC:
Independent Agricultural Contract Research

Rainfall of greater than 0.40 inches within 30 days of pre-emergent (PRE) application is required for effective (>85% waterhemp control) activation of most soil residual herbicides. A single rainfall event of 1.0 inches is likely to achieve that goal. A single, effective rainfall event increased residual herbicide activity on small emerged or emerging waterhemp by 19.6%. Micro-rate treatments receiving Flexstar early post emergent (EPOST) at V2 soybean verses PRE provided a 14.1% increase in waterhemp control in addition to the 19.6% provided by PRE residual herbicide activation following a single, effective rainfall event for a total increase of 33.7% waterhemp control. The 1.00 micro-rate ratio includes Blanket (8) + Valor SX (*2) + Warrant (40) + Flexstar (10) applied PRE only achieved 93% or greater end of season waterhemp control. However, there are data in other 2021 supporting studies that suggest the 0.75 micro-rate ratio may also provide acceptable waterhemp control.

PRE only micro-rate treatments provided greater waterhemp control compared to PRE fb EPOST treatments at all evaluation timings. Waterhemp control averages of PRE vs. PRE fb EPOST were 3.4% greater at A+14 (14 days after PRE application), 15.8% greater at A+27, 0.7% greater at A+40, 3.5% greater at A+53, and 0.4% greater at A+68 or soybean crop canopy. Despite a "worst case" drought impacted environment for residual herbicide activation and intense waterhemp pressure, all micro-rate treatments averaged 93.1% waterhemp control at soybean canopy. A one-pass PRE only micro-rate application was just as effective as a two-pass PRE fb EPOST application. The micro-rate treatments were evaluated against conventional industry standard entries.

Seven different industry partners submitted three treatments each to be compared to nine different Next Gen Ag LLC developed residual micro-rate treatments in a large industry trial. Only three treatments appeared in both the top 15 waterhemp control and top 15 treatment cost lists, one being a micro-rate treatment. Growers should consider these three treatments to be the best "bang for their buck" in relation to the entries within the study. These treatments include: Warrant (64) + Metribuzin (5.33) fb Warrant Ultra (64) which provided 89% waterhemp control (#9/40) at an estimated cost of $31.40 (#8/40); Valor SX (1.5) + Warrant (30) fb Zidua (2) + Flexstar (7.5) which provided 85% waterhemp control (#15/40) at an estimated cost of $32.85 (#12/40); and, Warrant (48) fb Warrant Ultra (64) provided 85% waterhemp control (#15/40) at an estimated cost of $25.41 (#4/40). Crop safety was not an issue.

Crop safety of micro-rate PRE combinations will continue to be evaluated, however, at the reduced product rates the program should logically be considered safe in soybean. Crop safety of the most affordable 0.75 ratio micro-rate treatment ($21.43) has the products being applied at 50% (Blanket at 6), 50% (Valor SX at *1.5), 47% (Warrant at 30), and 47% (Flexstar at 7.5) of max single application rates for a fine textured soil (clay loam) with greater than 3% organic matter (4.5%). However, the grower should be aware that the micro-rates combination product rates may fall below the recommended label threshold in a similar environment. One label restrictions related to micro-rate treatments is that Valor SX can only be applied with Warrant at 2 ounces per acre according to label, however be aware "splash up" rain events that may result in some crop injury, a synergistic phenomenon which may also be the reason for increased waterhemp control from the tank mix at reduced rates. Growers on more coarse soils with reduced organic matter, although rates of the four tank mix products are on label for that respective environment, should experiment on reduced acres in year one in the event of synergistic crop injury.

Growers should consider applying the residual micro-rates approach PRE as a potential cost and time saving one-time application in years with average early rainfall. A PRE only micro-rate application of Blanket (6) + Valors SX (1.5) + Warrant (30) + Flexstar (7.5) provided 94% waterhemp control under intense environment and waterhemp pressure. The PRE only residual micro-rates program is affordable and may provide the necessary season long waterhemp control for $21.43/A in ideal environmental conditions compared to the cost of a multiple post-emergent application, herbicides, and adjuvants. However, in years with below average early rainfall the grower must be prepared to utilize a glufosinate or 2, 4-D EPOST as a rescue on glyphosate-resistant waterhemp populations. Volunteer corn control or fungicide applications may also require a second trip over the field, however, these applications, although optional, should be more affordable without the need to tank mix additional residual herbicides. The PRE only residual micro-rates program allows the grower an opportunity to "wait-and-see" what other necessary inputs will be required rather than trying to predict the unknown. This program is also universal across all soybean genetics minimizing tank cleanout events for operations that grow multiple herbicide tolerant soybean genetics. Next Gen Ag LLC is responsible for conducting and summarizing information, but is not liable for any decisions made on the basis of this study or publication.

Management Strategies for Iron Deficiency Chlorosis in Soybeans from a Systems Approach: Variety Selection, Iron Chelates and Seeding Rate

Maykon Jr. da Silva and Seth Naeve, Dept. of Agronomy & Plant Genetics, U of M, St. Paul

Introduction

- Iron Deficiency Chlorosis (IDC) is one of the most yield damaging maladies of soybean in western Minnesota.
- Iron Deficiency Chlorosis is a soil-borne abiotic stress caused by a lack of soluble iron (Fe II) to the plants.
- IDC symptoms include interveinal chlorosis and stunting of the plants.
- Crop rotations, variety selection, seeding rates, rows spacing, iron chelates, and even cover crops or companion crops are utilized today. However, each of these strategies comes at some cost.

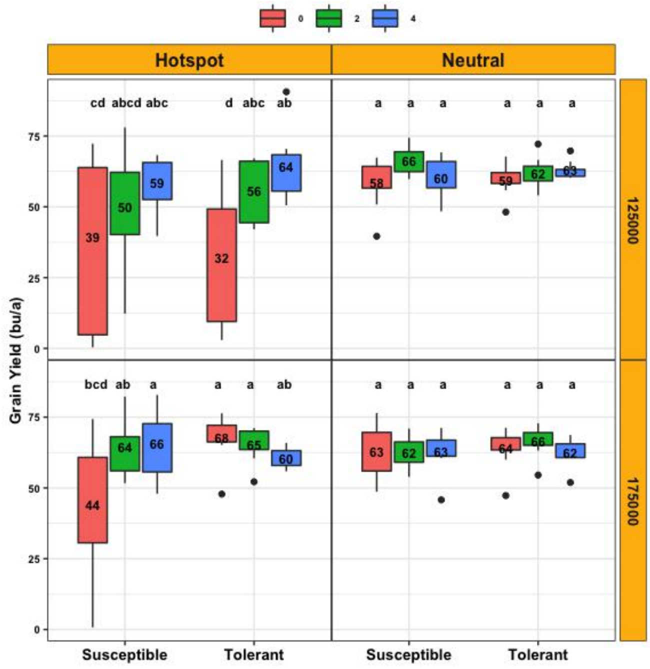
Objectives

1. Examine yield response to the interactive effects between varieties, populations, and iron chelate rates across a range of IDC levels.
2. Develop an economic model informing producers about ROI for each management strategy individually or collectively to maximize economic returns across fields and farms.
3. Develop a model to predict grain yield based on timing and intensity of IDC using drone imagery.

Materials and Methods

1. Field Sites:
   a. Three locations: Danvers, Foxhome and Graceville, MN
   b. To vary the intensity of IDC, plots were placed in two areas within each producer field: a “hot-spot” and a “neutral-spot”
2. Experimental Design:
   a. Randomized complete blocks with split plot treatment design
   b. Four replications
   c. Plot size: 30’x 10’ in 4 x 30” rows
3. Treatments: 24 Treatments
   a. Iron Chelates (Soygreen): 0, 2 and 4 lb/acre
   b. Varieties: Moderately Tolerant (AG12XF1) vs Tolerant (AG13XF0)
   c. Population: 125,000 and 175,000 plants/a
   d. Nitrogen application to increase IDC intensity: Nitrogen (75# / acre) vs No N
4. Data collection: Weekly after emergence
   a. Visual Scores (Greenness Scores)
   b. Ground-based NDVI (crop canopy sensor)
   c. Drone Imagery (DJI Inspire 2 + Micasense Red Edge-MX)
   d. After harvest, sample weight was adjusted to yield (at 13% moisture)
5. Statistical Analysis: Data were analyzed in R 4.0.3
   a. The lmer function in the *lme4* package was used to create a linear mixed model
   b. Analysis of Variance (ANOVA) was used to test the fixed effects of the factorial arrangements of treatments and environments and their interactions
   c. Means separation assessment using Tukey’s HSD ($P < 0.05$)

Results



At Danvers, a four-way interaction was found between Type, Soygreen, Variety, and Population. Therefore, a separate analysis was performed within each Type to test for treatment effects.

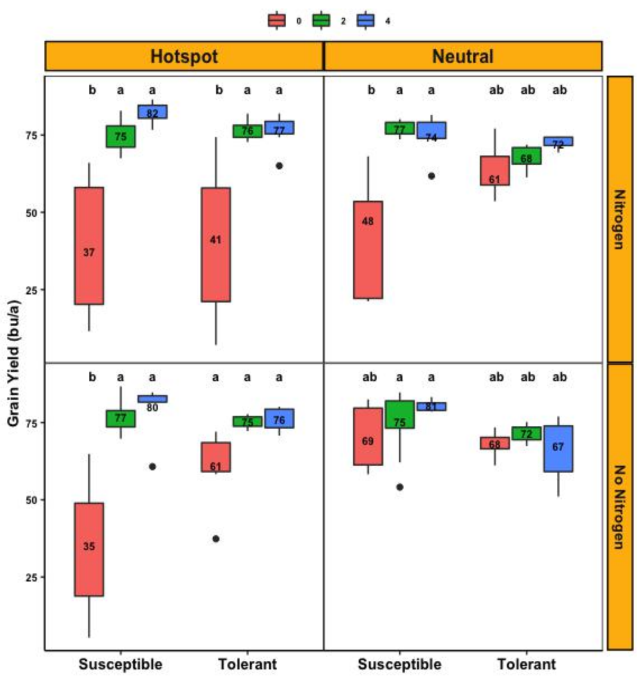
Neutral:

- There were no differences in grain yield between treatments.

Hotspot:

- Without Soygreen applied, higher seeding rates increased yield of the tolerant variety.
- In the susceptible variety, an increased rate of Soygreen from 0 to 4 lbs/acre significantly increased yield, but only in higher seeding rate treatments.
- At increased seeding rates without Soygreen, the tolerant variety produced 52% more than the susceptible variety.

Figure 1 – Danvers



At Graceville, a four-way interaction was found among Type, Soygreen, Variety, and N. Therefore, a separate analysis was performed within each Type to test for treatment effects.

Neutral:

- Application of Soygreen increased soybean yield by 54 to 60% in the susceptible variety where IDC was amplified by N addition.

Hotspot:

- Regardless of variety, Soygreen application increased yield when N was applied.
- Where N was not applied and no Soygreen was added, a tolerant variety yielded 72% more than a susceptible variety.

Figure 2 – Graceville

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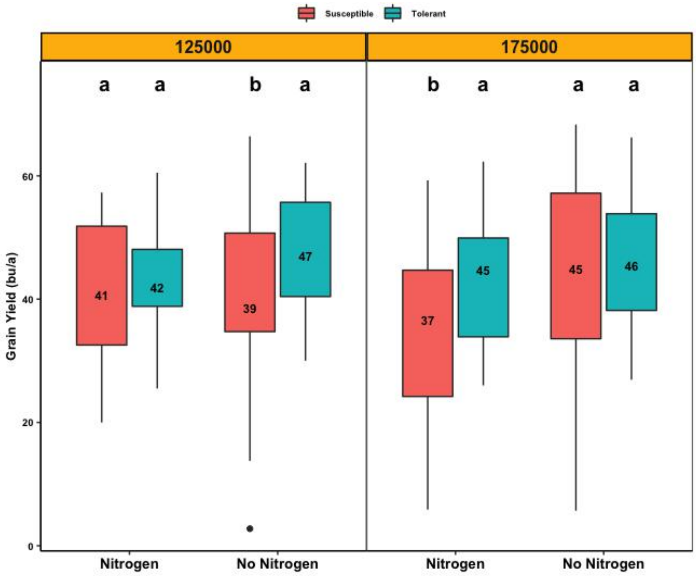


At Foxhome, a three-way interaction was verified between Population, Variety, and Nitrogen. A separate analysis was performed within N and Population to test for the Variety effect.

- At low seeding rates and no N application, the tolerant variety outyielded the susceptible variety by 22%.
- The tolerant variety produced significantly more yield than the susceptible variety with increased seeding rates where N was applied.

Figure 3 -- Foxhome

Preliminary Conclusions

- **Preliminary results suggest different management strategies should be recommended depending on the location and intensity of IDC.**
- **In Neutral spots, where lower intensities of IDC are found, treatments have less effect on soybean yield.**
- **In Hotspots, where IDC is severe, treatments varied in their effect on IDC.**

Acknowledgements

This research is supported by the Minnesota Soybean Research and Promotion Council and the University of Minnesota.

NOTES

Assessing Management Options & Inputs for Soybean Sudden Death Syndrome (SDS)

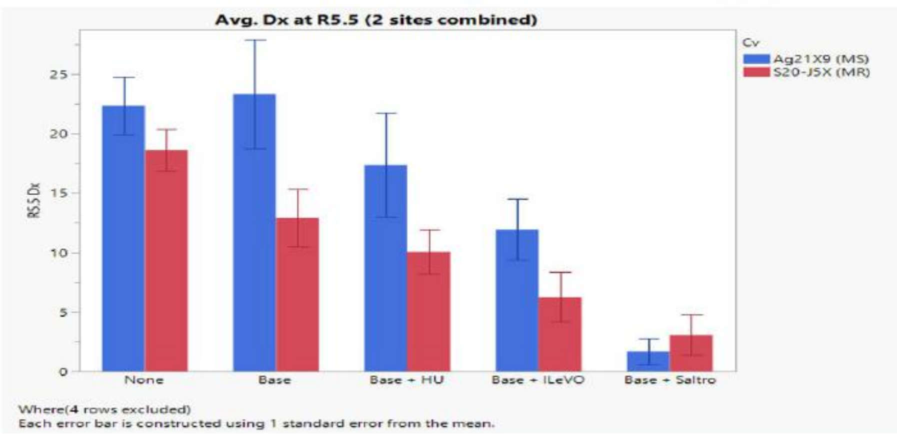
Dean Malvick, University of Minnesota, St Paul

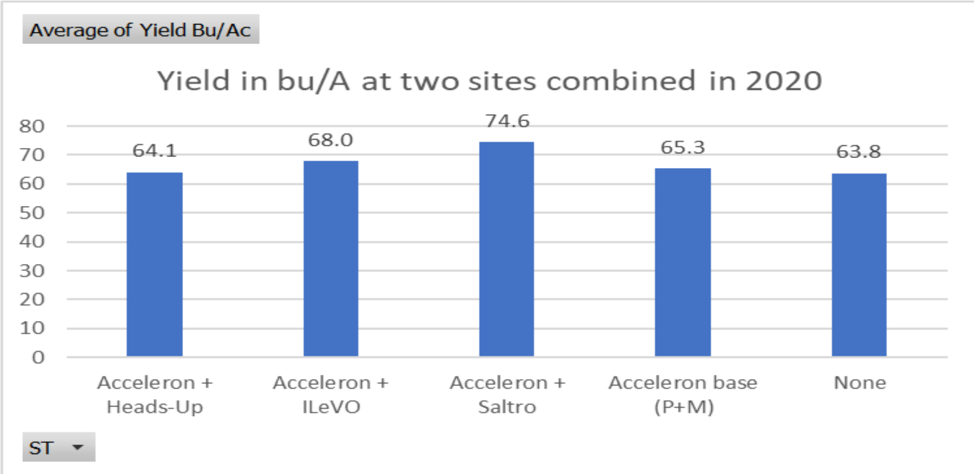
Purpose of Study: Soybean sudden death syndrome (SDS) is among the most important soybean diseases in the NC Region and Minnesota based on USB-sponsored yield loss estimates. SDS is spreading west and north in Minnesota (as well as in North Dakota) into areas where it was previously uncommon. Thus, SDS is becoming a bigger problem in more areas, including areas where high levels of resistance in locally adapted varieties is limited or absent. Several seed treatments that have been developed and marketed in the past few years for management of SDS. There is a need to understand and compare management options for SDS in Minnesota. The primary goal is to determine the benefits of four seed treatments (ILeVO®, Saltro®, base fungicide treatment, and Heads-Up®) alone and in combination with resistant soybean varieties for management of SDS in different field environments

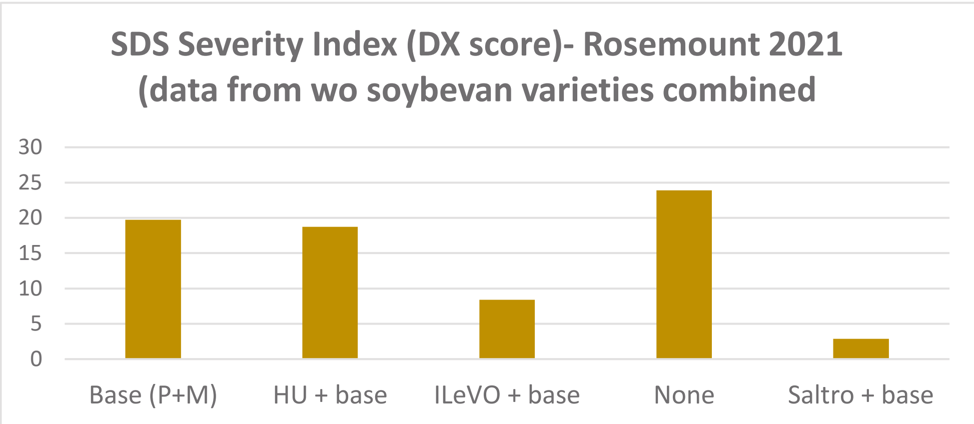
Project Methodology: Field studies were conducted at inoculated and irrigated fields in Rosemount and Waseca, MN in 2020 and 2021. The studies include two soybean varieties with different levels of resistance to SDS and five seed treatments (untreated, Acceleron base ILeVO®+base, Saltro®+base, and Heads-Up®+base). The studies were planted and inoculated in May, and were irrigated weekly as needed so the plots received at least 1.5" of rain and irrigation combined to increase SDS. SDS developed in all studies, although it was at low levels in 2021. We rated disease development at R5.5 and R6 growth stages and plots were harvested for yield in both years, although data from 2021 was not available in time for this report.

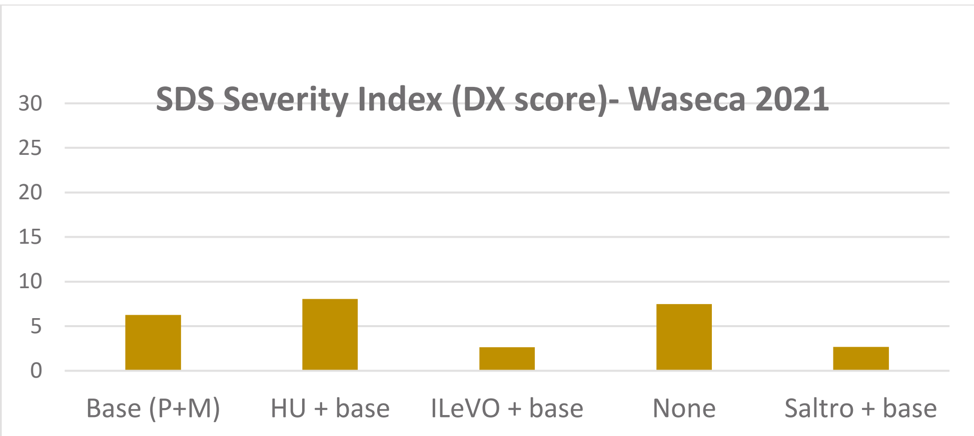
Results summary. In 2020, foliar disease index (DX) scores ranged from @42 to 66 (on a 100 pt scale) at Waseca, and at Rosemount the DX scores ranged from @2 to 66 across the two soybean varieties and seed treatments. Ix 2021, DX scores were below 8 for all treatments at Waseca, and between 4 and 24 at Rosemount. The more SDS-resistant soybean variety generally had lower levels of SDS and greater yield than the more susceptible variety under SDS pressure, as expected. The ILeVO and Saltro seed treatments both consistently reduced SDS and increased yield relative to the untreated controls in both locations. The Heads-Up treatment had inconsistent effects on SDS and yield. The results demonstrate the relative efficacy of seed treatments and variety resistance on management of SDS. Preliminary data summaries are shown below.

Results of 2020 MN SDS Management Study *(D. Malvick et al.)*









Conclusion: Resistant soybean varieties and ILeVO® and Saltro® seed treatments were effective alone and in combination for managing SDS. .

For additional information: contact Dean Malvick (dmalvick@umn.edu)

Project funding provided by the Minnesota Soybean Research & Promotion Council

Combining Key Resistance and Agrotype Genes for the Improvement of Hard Red Winter Wheat Germplasm

G. Francois Marais, Dept. of Plant Services, NDSU, Fargo

Research Question/Objectives

The NDSU winter wheat breeding program was initiated in 2011 to breed new varieties for the northern Prairies. Annually, winterkill and diseases such as Fusarium head blight, wheat rust, bacterial leaf streak, tan spot and Septoria nodorum blotch cause significant production losses. To establish a productive breeding population, useful disease resistance genes were obtained from un-adapted sources, including spring wheat. The newly acquired genes are often associated with yield-detrimental traits and occur (mostly singly) in highly related, lower yielding winter wheat backgrounds that now need to be systematically combined into more diverse, higher yielding combinations that are resistant to multiple pathogens. The project therefore aimed to: (a) develop semi-dwarf inbred lines from eight crosses to combine significant FHB, leaf-, stem- and stripe rust resistance with improved yield and cold tolerance. Greenhouse based single seed descent (SSD) inbreeding with phenotypic and marker selection steps was used to expedite line development. A field trial identified the nine best yielding F_4 families and from these a large number of F_5 plants were grown for individual marker analyses. Hundred and forty-three F_5 plants had favorable resistance gene pyramids and are being increased for continued yield testing. (b) Since stripe rust is a growing threat to winter wheat production and the level of resistance in the NDSU winter wheat breeding pool was unknown, an assessment of the variation for resistance in current germplasm was done employing genome-wide association mapping (GWAS).

Results

<u>Single Seed Descent Inbreeding</u>: In January 2019, crosses were made among eight parents and SSD inbreeding/selection was initiated with 150-200 F_2 seedlings per cross. Following selection for seedling resistance to a mix of six leaf rust and four stem rust races (greenhouse), the most resistant plants were also selected based on height and fertility to reduce the group to about 345 lines. The F_3 was planted (greenhouse) in March 2020 for further inbreeding and phenotypic selection. Finally, 100 F_3-derived F_4 families were planted in an un-replicated field trial at Casselton in September, 2020. In 2021, the trial was evaluated for winter-survival, plant height, agrotype, and disease resistance and nine superior families were identified. Four single spikes were selected from each of the nine families and were harvested separately. Five seeds from each selected spike were then planted (greenhouse) for marker screening of targeted resistance genes. Hundred and forty-three plants that derive from seven of the nine best yielding plots were selected. Each selection had *Fhb1* plus additional resistance gene pyramids summarized in Table 1. The selections had (average) 93% homozygosity and will continue to be evaluated in field trials. The *Yr17* translocation occurred with *Fhb1* in 101 lines and is expected to contribute to stripe rust resistance in the material.

<u>GWAS of stripe rust resistance in NDSU germplasm</u>. The phenotyping results revealed very little resistance to the leading stripe rust race, PSTv-37. Only 8.7% of the lines tested in 2018 had the resistant infection type, and 23% of lines had disease severities less than 40%. In 2019, 7.9% of the lines had the resistant infection type, and 58% of lines were partially resistant. The GWAS analyses failed to identify genes that provide significant resistance to stripe rust race PSTv-37 in the NDSU winter wheat breeding germplasm. Previous marker screening has shown that the race-nonspecific, resistance genes *Yr29* and *Yr18* do occur in NDSU hard red winter wheat germplasm and would provide a low level of resistance to stripe rust race PSTv-37 (Cobo, 2019; Wu, 2015). The race-specific resistance gene *Yr17* also occurs in the germplasm but is not effective against stripe rust race PSTv-37 (Wan et al., 2016). Possible reasons why *Yr29* and *Yr18* were not identified in this study could be that their individual contributions to stripe rust resistance was not big enough to be identified by GWAS, or the frequency at which the two QTL occur in the germplasm is too low.

Application and Use

The transfer of resistance genes from spring wheat greatly improves the ability of winter wheat to combat diseases such as FHB, the wheat rusts, bacterial leaf streak, tan spot, etc. However, following transfer, inbred lines with the new resistance are frequently lower yielding than their susceptible counterparts. This suggests that yield-detrimental genes get co-introduced that requires pre-breeding (crossbreeding and selection) to restore productive winter wheat genetic backgrounds. This project aimed to develop FHB resistant lines that are simultaneously high yielding, winter-hardy, and resistant to other major diseases. Such breeding material will greatly aid the breeding program. The accumulation of multiple favorable genes (disease resistance, yield, adaptation and processing quality) in a breeding line is a formidable task achieved through numerous cycles of un-interrupted, meticulous crosses; strict phenotypic and statistical evaluation and selection. Smaller, targeted pre-breeding projects using accelerated pure line development and marker-facilitated selection can help to pre-assemble subsets of favorable genes, which facilitates the process. The genetic material and gene pyramids developed in the course of this project will not only help the breeding program reach maximum productivity sooner; it also has commercial potential.

Clearly, there is a need to introgress additional stripe rust resistance genes into the breeding population. Race specific stripe rust genes that are currently effective against PSTv-37 include *Yr5* and *Yr15* among others and sources with the genes have been included among the 2021 cross parents. Additional new resistance that will be employed, include a B_1F_5 line 17YR251-4-1 (10X028-0-0-34-103L/2*Jerry) recently produced by Dr. Campbell, USDA-ARS, WSU, USA. Another four selections from the NDSU 2020 inbred lines showed strong stripe rust resistance in Washington and were therefore included as additional parents.

Materials and Methods

<u>SSD inbreeding</u>: The project utilized crosses among eight winter wheat parents, each of which contributed specific desirable traits. Inbreeding and selection were initiated with 150-200 F_2 plants/cross. These were infected with mixed leaf- and stem rust inoculum and 25% were selected. During SSD inbreeding, plants that were too tall or lacked in vigor, seed set, and phenotype were removed. $F_{3:4}$ inbred lines were obtained and evaluated in an un-replicated yield trial at Casselton for winter survival, agrotype, disease resistance, and yield. The nine best lines/plots in the trial were identified and with respect to each, four selected spikes were individually threshed. Five $F_{4:5}$ seeds per selected spike were used for marker screening (*Fhb1, Qfhs.ifa-5A, Lr34, Lr46, Lr67, Lr56, Sr24, Lr35/Sr39, Yr17,* and the 1B.1R translocation) in order to select the most promising plants for continued testing in replicated yield trials.

<u>Assessment of the available stripe rust resistance</u>: Annually since 2016, new NDSU HRWW breeding lines are submitted for stripe rust resistance screening in replicated field trials conducted at Central Ferry and Pullman, Washington (care of Dr K. Campbell, USDA-ARS at Washington State University). In 2018 and 2019, respectively, two different sets of 162 and 270 NDSU inbred lines were evaluated for infection type, disease severity, and disease index. Genotyping by sequencing of the two sets of lines was performed by Dr. X. Li's laboratory at North Dakota State University using tissue samples of both sets of lines. In an attempt to identify previously mapped single nucleotide polymorphism (SNP) loci that correlate with resistance measured in the two winter wheat populations, a genome wide association study (GWAS) was done.

Economic Benefit to a Typical 500 Acre Wheat Enterprise

The disease-causing pathogens targeted in the project annually cause significant wheat yield losses in the Northern Great Plains and even modest changes in the average level of resistance in new cultivars will be of considerable benefit to producers. The targeted diseases include some that are notoriously difficult to breed resistance for (for example tan spot, bacterial leaf streak, SNB and FHB) since resistance/ insensitivity is based on numerous quantitative trait loci each making only a small contribution to the total resistance phenotype.

Related Research

The project supports the NDSU hard red winter wheat pedigree-breeding program. Many of the known genes for resistance to the rusts, FHB, tan spot, SNB and BLS are not available in winter-hardy germplasm that is adapted to North Dakota. Furthermore, the resistance genes often occur singly in poorly adapted backgrounds making it even more difficult to combine multiple favorable genes in a single line. This pre-breeding program aims to improve the diversity and utility of the pool of breeding parents and therefore directly supplements and facilitates the main pedigree breeding effort.

Recommended Future Research

Incorporate additional FHB resistance genes such as *Fhb6, Fhb7, Qfhb.rwg-5A.1*, and *Qfhb.rwg-5A.2* from HRSW to supplement the currently employed *Fhb1* and *Qfhs.ifa-5A* resistance in the breeding program.

References

Bakhsh A., N. Mengistu, P.S. Baenziger et. al. 2013. Effect of Fusarium head blight resistance gene *Fhb1* on agronomic and end-use quality traits of hard red winter wheat. Crop Sci. 53:793-801.
Bai G., Z. Su, and J. Cai. 2018. Wheat resistance to Fusarium head blight. Canadian Journal of Plant Pathology, 40:3, 336-346, DOI: 10.1080/07060661.2018.1476411.
Cobo, N., H. Wanjugi, E. Lagudah, J. Dubcovshy. 2019. A high-resolution map of wheat *QYr.ucw-1BL*, an adult plant stripe rust resistance locus in the same chromosomal region as *Yr29*. The Plant Genome. 12:1-15.
Friskop, A, and M. Acevedo. 2015. Rust diseases of wheat in North Dakota. NDSU Extension Publications. PP1361.
Gupta P.K., R.K. Varshney, P.C. Sharma, and B. Ramesh. 1999. Molecular markers and their applications in wheat breeding. Plant Breeding. 118: 369-390.
Poehlman J.M. and D.A. Sleper 1995. Breeding Field Crops. Iowa State University Press.
»

Steiner B., M. Buerstmayr, S. Michel, et al. 2017. Breeding strategies and advances in line selection for Fusarium head blight resistance in wheat. Trop. Plant pathol. 42: 165-174.
USDA-ARS Cereal Disease Lab. 2017. Resistance Genes. St. Paul, MN. *https://www.ars.usda.gov/midwest-area/stpaul/cereal-disease-lab/docs/resistance-genes/resistance-genes/*.
Wan, A., X.C. Chen, J. Yuen. 2016. Races of *Puccinia striiformis* f. *sp. tritici* in the United States in 2011 and 2012 and comparison with races in 2010. Plant Diseases. 100:966-975.
Wu, L. X. Xia, G.M. Rosewarne, H. Zhu, S. Li, Z. Zhang, Z. He. 2015. Stripe rust resistance gene *Yr18* and its suppressor gene in Chinese wheat landraces. Plant Breeding. 134:634-640.

Publications

The results formed part of an MS thesis

Table 1. Inbred lines produced.

Cross	Pedigree	Lines	Markers detected
19K89-1	Norstar-*Fhb1*/Jerry//TX09D1119/Buteo/3/Broadview/SD07W083-4	20	*Fhb1, Lr34, Lr46, Yr17*
19K89-3	Norstar-*Fhb1*/Jerry//TX09D1119/Buteo/3/Broadview/SD07W083-4	13	*Fhb1, Lr34, Lr46, Yr17*
19K89-3	Norstar-*Fhb1*/Jerry//TX09D1119/Buteo/3/Broadview/SD07W083-4	7	*Fhb1, Lr46, Yr17*
19K94-6	Norstar-*Fhb1*/Jerry//TX09D1119/Buteo/3/Monument	8	*Fhb1, Lr46, 1B1R, Yr17*
19K94-6	Norstar-*Fhb1*/Jerry//TX09D1119/Buteo/3/Monument	1	*Fhb1, Lr46, Yr17*
19K94-6	Norstar-*Fhb1*/Jerry//TX09D1119/Buteo/3/Monument	9	*Fhb1, 1B1R, Yr17*
19K94-6	Norstar-*Fhb1*/Jerry//TX09D1119/Buteo/3/Monument	2	*Fhb1, Yr17*
19K132-1	Norstar-*Fhb1*/Jerry//TX09D1119/Buteo/4/CM82036/Jerry/3/Jerry-*Lr50*/Falcon//Moats	4	*Fhb1, Lr46, 1B1R, Yr17*
19K132-1	Norstar-*Fhb1*/Jerry//TX09D1119/Buteo/4/CM82036/Jerry/3/Jerry-*Lr50*/Falcon//Moats	16	*Fhb1, Lr46, Yr17*
19K365-4	Norstar-*Fhb1, Sr39*//Monument	12	*Fhb1, Lr34, Lr68, 1B1R*
19K365-4	Norstar-*Fhb1, Sr39*//Monument	6	*Fhb1, Lr34, Lr68*
19K368-8	Norstar-*Fhb1, Sr39*//Keldin	9	*Fhb1, Lr46, Lr68*
19K368-8	Norstar-*Fhb1, Sr39*//Keldin	1	*Fhb1, Lr68*
19K368-8	Norstar-*Fhb1, Sr39*//Keldin	7	*Fhb1, Lr34, Lr46, Lr68*
19K368-8	Norstar-*Fhb1, Sr39*//Keldin	7	*Fhb1, Lr34, Lr68*
19K438-9	Broadview/SD07W083-4 /3/Radiant/RCATL33//Ideal	16	*Fhb1, Lr34, Yr17*
19K438-9	Broadview/SD07W083-4 /3/Radiant/RCATL33//Ideal	5	*Fhb1, Lr34, Lr46, Yr17*
	Total:	**143**	

Acceleerated Breeding for Resistance to Fusarium Head Blight

Karl Glover, Plant Science Dept. SDSU, Brookings

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 2021 AYT are presented in Table 1. Thirty-eight experimental breeding lines were tested along with ten check cultivars during the 2021 growing season. Of the thirty-eight experimental lines, twenty had FHB disease index (DIS) values that were lower than the test average. Among these entries, fourteen produced more grain than average. Among the fourteen, test weight of ten entries was higher than average, and protein content of two (SD4894 and SD4949) were also greater than average. Although protein content of SD4873 was slightly less than average, it will likely be released in November 2021 along with SD4843. Certified seed production will take place during the 2022 growing season.

Application and 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 F_2 populations
Year 1	Fall greenhouse	$F_{2:3}$ hills
Year 1	Spring greenhouse	$F_{3:4}$ hills
Year 2	Field	$F_{4:5}$ progeny rows
Year 2	Off-season Nursery	$F_{5:6}$ progeny rows
Year 3	Field	$F_{5:7}$ Yield Trials (1 replication, 2 locations)
Year 4	Field	$F_{5:8}$ Yield Trials (2 replications, 5 locations)
Year 5	Field	Advanced Yield Trials (3 reps, 10 locations)

F_2 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 $F_{2:3}$ 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 $F_{3:4}$ 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 $F_{4:5}$ 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 $F_{5:6}$ 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 $F_{5:6}$ 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 2021 AYT are presented in Table 1.

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Economic Benefit to a Typical 500 Acre Wheat Enterprise

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.

Publications

Glover K. D., J. L. Kleinjan, C. Graham, S. Ali, E. Byamukama, Y. Jin, J. A. Ingemansen, E. B. Turnipseed, and L. Dykes. 2021. Registration of 'Driver' Hard Red Spring Wheat. Journal of Plant Registrations. https://doi.org/10.1002/plr2.20165

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 ten test environments in 2021.

ENTRY	DIS INDEX	YIELD (BU/AC)	TW (LB/BU)	PROTEIN (%)	HEADING (D > 6/1)	HEIGHT (INCHES)
BRICK	7.6	34.1	62.6	15.8	12.1	25
SD4893	11.9	35	62.2	16.8	14	24.5
DRIVER	13.2	40.2	62.6	15.5	16.6	27
SD4949	13.5	38.3	61.8	17	18.3	27.2
SURPASS	14.5	36.4	61.3	15.9	13.3	24.3
SD4998	14.7	37.3	61.1	15.4	16.7	24.5
SD4894	14.8	36.2	61.7	16.3	13.2	24.4
SD4905	14.8	36.7	61	16.4	15.1	24.7
SD4873	14.9	39.1	61.4	15.8	17.5	26.5
SD4903	14.9	35.7	61.7	15.7	15	22.7
SD4924	15.3	37	61.8	15.4	12.5	25.2
SD4934	15.4	35.1	61.3	15.5	17.3	24.4
SD4914	15.6	35.7	60.5	16.3	15.1	24.1
SD5017	15.6	33.5	60.3	16	16.7	23.9
SD4855	15.7	37	62.1	15.7	16	24.7
SD5001	15.7	35.3	61.2	15.5	13.5	21.8
ADVANCE	15.8	36.3	61.7	15.1	17.2	23.5
SD4848	15.8	33	62.1	17.1	16.5	23.1
FOREFRONT	15.9	35.3	61.5	16	13.4	26.9
LCS-TRIGGER	15.9	37.9	61.1	14.6	20	25.6
SD4915	16	37.4	60.4	16.1	14.7	23.9
SD4925	16	35.3	61.6	16.4	14.1	24.8
SD4951	16.1	36.3	61.5	15.4	14.8	23.5
SD4991	16.2	35.9	61.3	16.1	14.7	22.4
SD5008	16.4	35.4	61	15.6	17.5	21.8
SD4843	16.6	41.2	63.2	14.7	16.5	24.4
PREVAIL	16.7	35.6	61.2	15.8	15.1	22.8
SD4981	17	36.2	60.5	15.5	16.3	24
SD4957	17.3	37.1	62	15.6	17.1	25.7
SD4937	17.4	34	60.1	17.4	20	25.4

Table 1 continued

ENTRY	DIS INDEX	YIELD (BU/AC)	TW (LB/BU)	PROTEIN (%)	HEADING (D > 6/1)	HEIGHT (INCHES)
BOOST	17.9	36.2	61.1	16.2	18	26.4
SD4976	18.2	36.1	60.8	15.9	13.7	23.2
SD5010	18.2	34.8	60.8	15.4	18.1	21.9
SY-VALDA	18.2	36.9	61.2	15.5	16.5	24
SD4975	18.4	36.3	60.6	16	14.3	23.6
SD5021	18.4	33.5	60.1	17.7	20.6	25.1
SD4944	18.5	35	60.7	16.8	19.6	25.2
SD5020	18.6	34.3	60.1	16.5	18.5	24
SD4985	18.9	34.5	61	16.7	16.1	22.2
SD4904	19.1	39.7	61	15.8	16.3	25
SD4994	19.2	36.3	62.5	14.4	16.8	24.4
SD4940	19.3	34.1	60.1	17.2	19.8	25.7
SD4972	19.7	34	60.4	15.5	14.6	23.3
SD4913	20.4	35.4	60.7	16.3	14.9	23.2
SD4930	21.1	41.2	61	15.2	17.6	25.2
TRAVERSE	22.2	35.3	59.5	15	15.7	24.9
SD4945	24.6	33.5	60.1	16.6	18.4	22
SD4960	26.4	38.1	61.5	15	17.8	23.5
MEAN	16.97	36.14	61.19	15.92	16.21	24.28
LSD (0.05)	2.84	1.35	0.35	0.25	0.64	0.65
cv	14.75	7.36	1.13	3.08	5.43	4.7

Southern Minnesota Small Grains Research & Outreach Project

Jared Goplen, Morris Regional Extension Office, Morris

Research Question/Objectives

The objectives of this grant were to:

1. Evaluate variety performance for Hard Red Spring Wheat (HRSW) and Hard Red Winter Wheat (HRWW) varieties across southern Minnesota with locations at Becker, Benson, and Le Center.
2. 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 was held virtually in 2021 due to restrictions surrounding Covid-19. Three virtual workshops were held using the Zoom platform on February 15, 17, and 19th. Each workshop had a regional focus. Participation in the online workshops was good, with 138 participants attending the live sessions in Minnesota and surrounding states (Figure 1). Of the participants, nearly 45% had not been to a UMN small grain extension program before, indicating that the virtual meetings helped reach a new audience. There were an additional 51 views of the recorded workshops, totaling 189 total participants / views, which is a similar number of farmers and crop consultants typically reached with in-person meetings held in previous years. The meetings were well received, with 100% of attendees responding that they would recommend the program to others. All of the workshop attendees also reported having a deeper understanding of the subject matter as a result of attending the sessions, while 89% of attendees planned to change production practices due to attending a workshop.

The summer field days for 2021 were held despite additional regulations surrounding Covid-19. Field days were held from June 21st – June 25th at Benson, Becker, Lamberton, Le Center, New Ulm and Rochester to showcase variety trials. Attendance at field days totaled 99, averaging over 16 attendees per location.

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 all southern Minnesota locations was 87 bu/ac for HRWW (4 locations) and 57 bu/ac for HRSW (6 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 and 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 21 and 13 entries, respectively. The spring wheat, oats, and barley variety trials had 39, 16, and 12 entries, respectively. Trials were all a randomized complete block design with 3 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 the 2021 on-farm trials, there was a 19 bu/ac difference between the highest-yielding 10% of varieties and the lowest-yielding 10% of varieties. This 19 bu/ac difference in yield could increase returns by over $180 per acre, or over $ 90,000 in gross returns for a 500 acre wheat enterprise. All while only changing variety selection. When wheat prices are high, increasing yield by just 5% can increase gross returns by nearly $50 per acre. 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. The rye variety trials also link with this project with funding from other sources.

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 trend 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.

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 on-line publication '2021 Minnesota Field Crop Trials' (Also available at https://www.maes.umn.edu/publications/field-crop-trials). The 2020 trial results were published in:

1. Anderson J.A, J.J. Wiersma, S. Reynolds, N. Stuart, H. Lindell, R. Dill-Macky, J. Kolmer, M. Rouse, Y. Jin, and L. Dykes. 2020. 2020 Spring Wheat Field Crop Trials Results. *In*: 2020 Minnesota Field Crop Trials. Minnesota Agricultural Experiment Station Publication. University of Minnesota, St. Paul, MN.
2. Smith, K., R. Dill-Macky, J.J. Wiersma, B. Steffenson, K. Beaubien, and E. Schiefelbein. 2020. 2020 Barley Field Crop Trials Results. *In*: 2020 Minnesota Field Crop Trials. Minnesota Agricultural Experiment Station Publication. University of Minnesota, St. Paul, MN.
3. Heuschele, J., R. Dill-Macky, D. von Ruckert, K. Beaubien, J.J Wiersma, and K. Smith. 2020. 2020 Oat Field Crop Trials Results. *In*: 2020 Minnesota Field Crop Trials. Minnesota Agricultural Experiment Station Publication. University of Minnesota, St. Paul, MN.
4. Wiersma, J.J. and J.A. Anderson. 2020. 2020 Winter Wheat Field Crop Trials Results. *In*: 2020 Minnesota Field Crop Trials. Minnesota Agricultural Experiment Station Publication. University of Minnesota, St. Paul, MN.
5. Wiersma, J.J., S. Wells, and A. Garcia y Garcia. 2020. 2020 Winter Rye Field Crop Trials Results. *In*: 2020 Minnesota Field Crop Trials. Minnesota Agricultural Experiment Station Publication. University of Minnesota, St. Paul, MN.

Table 1 – Preliminary summary of grain yield of spring wheat varieties tested in performance evaluations in 6 locations across southern Minnesota in 2021

Entry	Becker	Benson	Lamberton	Le Center	Morris	St. Paul	**Average**
	------------------------------------- bu/acre -------------------------------------						
AP Gunsmoke CL2	43.9	58.2	63.7	78	57.1	42.6	57.3
AP Murdock	43.9	54.4	59.4	65.7	49.8	52.8	54.3
AP Smith	38.9	62.8	62.2	72.1	57.1	50.7	57.3
Bolles	33.5	61.8	53.9	62.8	54.9	48.7	52.6
CAG Justify	37	68.1	59.3	62.3	70.1	51.1	58
CAG Reckless	52.8	60.3	59.4	67.9	56.3	52.6	58.2
CP3099A	43.7	68.9	71.3	64	73.9	44.1	61
CP3119A	52.1	65.9	66.2	74.7	68.5	43.6	61.8
CP3188	45.7	66.9	73	77.3	68.4	51.6	63.8
CP3530	40.2	61.6	59.8	77.5	52.1	49.6	56.8
CP3915	46.3	60	60.4	67.5	52.8	37.2	54
Driver	44.3	66	71	71.2	58	49.3	60
Dyna-Gro Ambush	38.6	63	56.8	78.1	35.4	56.6	54.8
Dyna-Gro Ballistic	47.6	57.1	58.2	73.9	58.4	40.5	56
Dyna-Gro Commander	47.6	67.3	57.8	75.2	55.3	57.1	60.1
Lang-MN	41.4	54.6	57.4	70.2	53.6	55.3	55.4
LCS Buster	53.1	62.9	61.6	70	52.1	53.3	58.8
LCS Cannon	42.9	67.5	60.7	78.9	37.2	55.3	57.1
LCS Rebel	40.7	62.8	62.6	68.8	61.5	51.3	57.9
LCS Trigger	49	64.2	70.1	82.4	67.6	58.5	65.3
Linkert	41.4	55.9	56.3	71	49.7	48.7	53.8
MN-Torgy	44.7	62.3	57.1	74.6	56.7	54.1	58.2
MN-Washburn	39.7	58.7	58	70.9	60.8	49	56.2
MS Barracuda	39.6	58.1	59.6	77.5	38.9	55.7	54.9
MS Cobra	40.7	57.4	60.2	74.4	55	55	57.1
MS Ranchero	39	67.8	58	72.3	49.3	49.6	56
ND Frohberg	42.6	66.1	58.2	72.7	56.1	48.9	57.4
PFS-Buns	42.5	64.2	59.7	72	61	40.9	56.7
Prosper	47.2	64.1	58.2	73.7	65.7	42.3	58.5
Shelly	41.1	62.7	61.4	74.3	59.5	56.3	59.2
SY 611 CL2	44	64.3	61.3	68.4	50.6	42.9	55.3
SY Longmire	45.3	60.3	64.5	68.3	62.4	30.2	55.2
SY McCloud	35.3	58.4	58.9	73.3	44.2	44.2	52.4
SY Valda	40.1	59	62.3	74.8	53.9	48.4	56.4
TCG-Heartland	38.9	53.8	58.2	69	48.2	44	52
TCG-Spitfire	45.4	67.7	70.7	74.9	57	45.6	60.2
TCG-Wildcat	45.7	58.2	68.4	72.8	58	52.7	59.3
WB9479	37.6	58.2	51.8	73.4	47	44.4	52.1
WB9590	36.6	58.8	62.6	72	46.9	46.2	53.8
Mean (bu/acre)	42.8	61.8	61.3	72.3	55.4	48.7	57.1
LSD (0.10)	8.1	6.7	10.5	5.7	10.2	4.3	5

Table 2 - Preliminary summary of grain yield of winter wheat varieties tested in performance evaluations in six locations across Minnesota in 2021.

Entry	Becker (Irrigated)	Crookston	Le Center	St. Paul
	---------------------------- bu/acre ----------------------------			
AAC Goldrush	65.9	49.9	89.7	96.6
AC Emerson	62.2	46.4	72.7	94
Bobcat	63.5	52.4	80.1	93
Flathead	67.6	48.5	94.9	121.5
FourOSix	74.5	41.5	85	118.7
Ideal	76.6	49.2	85.3	100.7
Jerry	67.2	63.2	80.6	81.9
Jupiter	77.4	31.5	100.1	134.3
Keldin	84.5	44.7	98	124.9
LCS Helix AX	63.5	43	92.2	107.5
ND Noreen	67.1	59.2	86.8	96.4
Ray	74.7	54.6	86	99.4
Redfield	64.7	57.3	85.7	111.6
Ruth	71.2	36	88.6	111.3
SD Andes	73.9	59.8	91.8	121.2
SY Wolf	72.9	54.2	92.1	111.4
SY Wolverine	77.8	32.8	90.8	109.9
Thompson	77	55.1	92.7	102.6
WB4309	77.6	43.9	94.6	125.8
WB4462	82.3	44.8	84.8	101.3
Winner	80.3	54.2	97.1	124.5
LSD(0.1)	10.9	9.8	8.5	9.3

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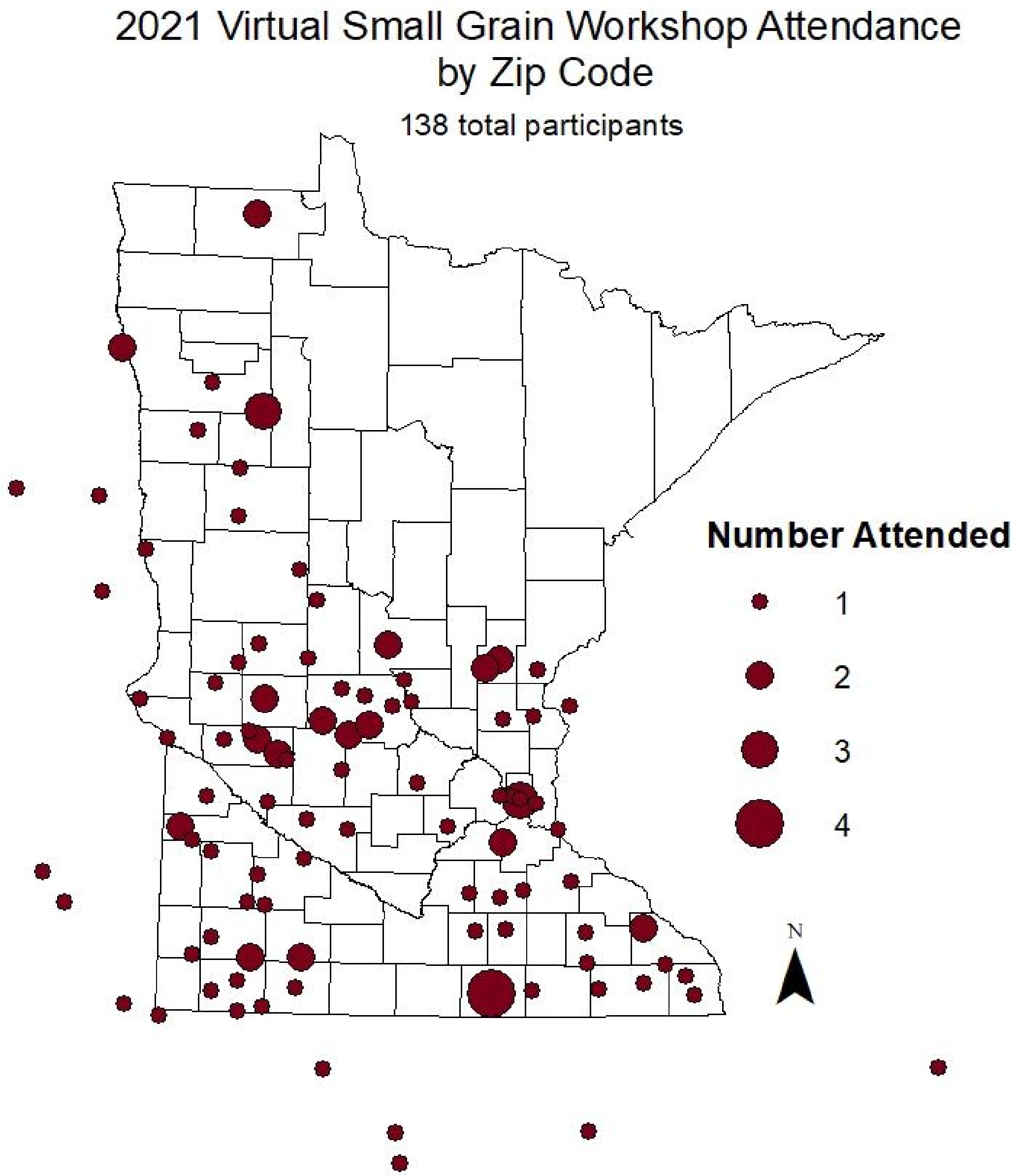
Figure 1: Virtual small grain workshop attendance by zip code for 2021 small grain workshops.



Wheat Stem Sawfly Resistance Screening

Jochum Wiersma, Dept. of Agronomy & Plant Genetics, NWROC, Crookston

Research Question/Objectives

Evaluate current, adapted HRSW varieties for resistance to stem cutting by wheat stem sawfly.

Results

Emergence of WSS adults was monitored using four emergence cages in the WSS resistance screening nursery at the Northwest Research and Outreach Center in 2021. The emergence cages were placed on May 29 and monitoring started three days later. After the initial sampling date on June 1, cages were sampled every Monday, Wednesday, and Friday throughout the month of June. Emergence of the adult males had just started on the first sampling date. Overall emergence numbers were just a tenth of the counts of the previous two seasons. The emergence of females, normally peaking two to three weeks after the first males emerge, was conspicuously low (data not shown). Salt (1947) mentions that WSS larvae can enter a secondary diapause if conditions are extremely dry, something we experienced this past growing season.

Little to no stem clipping was observed in the dedicated WSS screening nursery. Results of the stem dissection indicate that, on average, less than 20% of the stems had evidence of wheat stem sawfly feeding and thus successful oviposition (Table 1). Less than 16% of the infested stems showed signs that the WSS larvae had been parasitized. There was a statistically significant negative correlation of -0.59 between the presence of WSS larvae in the stems and heading date, meaning that varieties that headed later escaped WSS infestations.

WB Gunnison, Dagmar, and Duclair were used as solid stemmed check varieties. WB Gunnison was developed by WestBred and released in Montana in 2011. WB Gunnison expresses the stem solidness early in the season and re-absorbs the pith prior to heading. Both Duclair and Dagmar were released by Montana State University and maintain their stem solidness throughout the grainfill period.

Application and Use

A number of adapted HRSW varieties performed as good as or better than the solid stem checks WB Gunnison, Dagmar, and Duclair. This year's results, however, are likely overestimating the level of resistance to WSS of later maturing varieties as successful ovipositioning declined over the month of June.

Materials and Methods

A duplicate of the HRSW variety performance evaluation trial was seeded on April 30 , 2021 near Crookston, MN in a field that has been continuous wheat for the past three years. Wheat Stem Sawfly emergence was monitored in the trial using soil emergence traps (BugDorm Model BT2003, BioQuip Products, CA 90220). The collection bottle was filled with approximately 50 ml of pre-diluted automotive antifreeze/coolant solution (SuperTech Extended Life Antifreeze/Coolant, WalMart, AR). Four emergence traps were placed on bare soil and secured to the soil surface using tent stakes in the WSS resistance screening nursery on the Northwest Research and Outreach Center in Crookston, MN.

The number of adult male or female WSS were counted every Monday, Wednesday and Friday for six weeks starting on June 1, 2021. To aid identification and counting of WSS males and female specimens, the collection bottle was removed from individual emergence traps and the contents were emptied on a piece of white cheesecloth held over a 200 ml glass beaker with a sink strainer. The collected antifreeze solution was recycled and poured back into the sample collection bottle. Additional antifreeze solution was added to the bottles when necessary and before sample collection bottles were placed back in the emergence traps. The insects caught on the cheesecloth were separated and individual WSS were identified and counted.

All stems from three linear feet of row were harvested by hand at harvest ripe stage of the crop and fifty randomly selected stems from each hand-harvested sample were dissected longitudinally to determine presence of frass on or near the nodes to evaluate whether WSS oviposition was successful (Photo 1). The incidence of parasitism by Bracon cephi (Gahan) and other parasitoids was scored by determining the percentage of WSS-infested stems that had an emergence hole or a parasitoid cocoon (Photo 2).

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.

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Recommended Future Research

The next step is to combine the three years of field screening and share the results with producers in extension meetings. In addition, the PIs would like to determine the absence/presence of the Qss.msub-3BL.c QTL associated with the WSS resistance expressed in WB Gunnison as the timing of the determination of presence of a pith at the 6 to 7 leaf stage of spring wheat is precarious (Cook, 2019). The PIs would also like to continue the screening of adapted HRSW varieties for resistance to WSS as the extreme drought of the past growing screening probably caused the negative correlation between the heading date and the emergence of female WSS resulting in a lower success of ovipositioning on later heading HRSW varieties.

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

Salt, R.W. 1947. Some Effects of Temperature on the Production and Elimination of Diapause in the Wheat Stem Sawfly *Cephus Cintus* Nort.. Canadian Journal of Research 25 (2): 66-86 https://doi.org/10.1139/cjr47d-004

Table 1. Days to heading and the percentage of stems of HRSW varieties adapted to Minnesota that were infested by wheat stem sawfly (WSS) (*Cephus cintus* Norton) in a dedicated screening nursery at the Northwest Research & Outreach Center near Crookston in 2021. Varieties that do not share the same group letters are, with a 95% confidence, statistically different from one another for the number of stems infested by WSS.

Variety	Days to Heading	WSS Infected Stems	Group	Entry	Days to Heading	WSS Infected Stems	Group
	(days)	(%)			(days)	(%)	
LCS Buster	60.0	0	R	WB9479	54.3	15	GHIJK
LCS Trigger	60.2	0	R	Dyna-Gro Ambush	54.5	18	FGHIJ
Gunnison[1]		1	QR	MS Ranchero	54.8	20	EFGHI
PFS-Buns	62.0	1	QR	CP3188	56.1	21	EFGHI
CP3119A	61.0	1	PQR	MS Cobra	55.3	21	DEFGH
Dagmar[1]		1	PQR	Dyna-Gro Ballistic	57.0	23	CDEFGH
CAG Reckless	56.3	2	OPQR	Dyna-Gro Commander	54.9	28	BCDEFG
Duclair[1]		2	OPQR	SY 611 CL2	56.1	28	CDEFGH
SY Longmire	56.9	4	MNOPQR	Prosper	57.8	29	BCDEFG
MN-Torgy	55.7	6	KLMNOPQR	AP Murdock	55.3	30	BCDEFG
CP3915	57.2	7	JKLMNOPQR	AP Gunsmoke CL2	55.6	30	BCDEFG
Bolles	58.4	8	IJKLMNOPQ	TCG-Heartland	54.3	31	BCDEFG
TCG-Spitfire	59.2	8	IJKLMNOP	CAG Justify	57.5	32	BCDEF
CP3099A	60.9	9	IJKLMNOP	Driver	57.7	32	BCDEF
MN-Washburn	57.3	10	HIJKLMNO	SY Valda	56.9	32	BCDEF
TCG-Wildcat	57.7	12	HIJKLMNO	LCS Rebel	55.0	37	BCDEF
AP Smith	58.1	13	HIJKLMN	MS Barracuda	53.3	38	BCDEF
Shelly	57.9	14	HIJKLM	Linkert	55.2	40	BCDE
Lang-MN	56.9	14	HIJKLM	SY McCloud	55.4	44	ABC
WB9590	54.7	14	HIJKL	CP3530	58.1	45	AB
ND Frohberg	56.8	15	GHIJK	LCS Cannon	53.5	65	A

[1] Checks

All stems from three linear feet of row were harvested by hand at harvest ripe stage of the crop and fifty randomly selected stems from each hand-harvested sample were dissected longitudinally to determine presence of frass on or near the nodes to evaluate whether WSS oviposition was successful (Photo 1). The incidence of parasitism by *Bracon cephi* (Gahan) and other parasitoids was scored by determining the percentage of WSS-infested stems that had an emergence hole or a parasitoid cocoon (Photo 2).

Photo 1 Frass and a parasitized wheat stem sawfly (*Cephus cinctus* Nort.) in a longitudinal dissected stem of a hollow-stemmed HRSW variety.

Photo 2 Parasitoid emergence hole on a stem of a hollow stemmed HRSW variety.

Minnesota Small Grains Pest Survey

Jared Goplen, Morris Regional Extension Office, Morris

Research Question/Objectives

1) Identify insect and disease issues in small grains as they develop throughout Minnesota
2) Provide timely alerts about small grain pest and disease issues for small grains producers so that sound economic control options can be implemented.

Results

The 2021 small grain scouting program had over 380 unique field visits during the 2021 small grain scouting season in approximately 80 fields. These fields were volunteered by producers in early spring and scouted throughout spring and early summer by three different survey scouts. Areas scouted focused on Western Minnesota but ranged from Kittson County in the North to Olmstead County in the south, spanning over 400 miles. Scouting started in May and continued until the crop had reached maturity in late July. Data was collected on severity and incidence of the major cereal diseases in Minnesota as well as some of the important insect pests. Data was submitted each week to the NDSU IPM team who 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/ and the US wheat/Barley Scab Initiative scab prediction website http://www.wheatscab.psu.edu for state commentary on disease development. There was a total of 11 pest updates posted to the Minnesota Crop News Blog, with a total of over 2700 views, averaging nearly 250 views per post.

In general, 2021 was a quiet year for small grain diseases. Very few diseases were found throughout the growing season, largely due to lack of moisture in many parts of the state which did not provide conditions conducive for many of the fungal diseases to develop. Insects were the most prevalent pest issues found this year, with grasshoppers and cereal aphids being the predominate issues. Cereal aphids were found in southern Minnesota by early June, and became relatively widespread throughout much of the state by late June. Some fields reached levels warranting treatment. Barley yellow dwarf virus, which is vectored by cereal aphids, was the most notable disease this year given how widespread cereal aphids were. In fact, the oat variety trial at Rochester exhibited some of the "dwarfing" phenotype caused by barley yellow dwarf virus when infection occurs very early. This phenotype is rarely found in Minnesota as aphids typically aren't present early enough in crop development to cause this response. Grasshoppers appeared in the sweep net sample from early-June onward, reaching treatable levels in some areas of the state. The Season Summary maps by disease or insect are provided as a reference in an appendix at the end of the report (Appendix 1)

Application and Use

Results from this scouting project are used widely by farmers, crop consultants, and Extension educators throughout Minnesota. The in-season commentary published to the Minnesota crop news blog and the US wheat and barley scab initiative scab prediction website provides Minnesota farmers with real-time pest issues and recommendations to make informed pest management decisions.

Materials and Methods

Three scouts operating throughout western Minnesota scouted approximately 20-30 small grains fields per week during the small grain growing season. Scouts underwent training at the beginning of the season with the NDSU IPM scouts 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 a regional effort. 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/ insect pest. Fields were scouted by walking out past the headland in each field and walking a "w" pattern and taking observations of 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 FHB. Incidence only data was collected for Bacterial leaf streak, Barley yellow dwarf, 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 and the national Fusarium Head Blight Prediction Center. The commentaries were not shared on the Minnesota

Association of Wheat Growers disease forecasting site as it was under construction this growing season.

Economic Benefit to a Typical 500 Acre Wheat Enterprise

A follow-up survey to the users of the Minnesota Crop News blog and the disease risk assessment websites is necessary to fully assess whether the timely disease and pest updates and commentary altered producer decisions for their disease and pest management in 2021. Each update posted to the Minnesota Crop News Blog had an average of nearly 250 page visits, 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.

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 ties with the Minnesota Soybean Scouting project funded by the Minnesota Soybean Research and Promotion Council, as these programs complement each other, providing a full summer scouting experience for our crop scouts, who are able to scout small grains in the spring and early summer while shifting to soybeans mid-summer.

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.

Publications

11 Minnesota Crop News posts (https://blog-crop-news.extension.umn.edu/)
Commentaries posted to the US wheat/Barley Scab Initiative scab prediction website http://www.wheatscab.psu.edu

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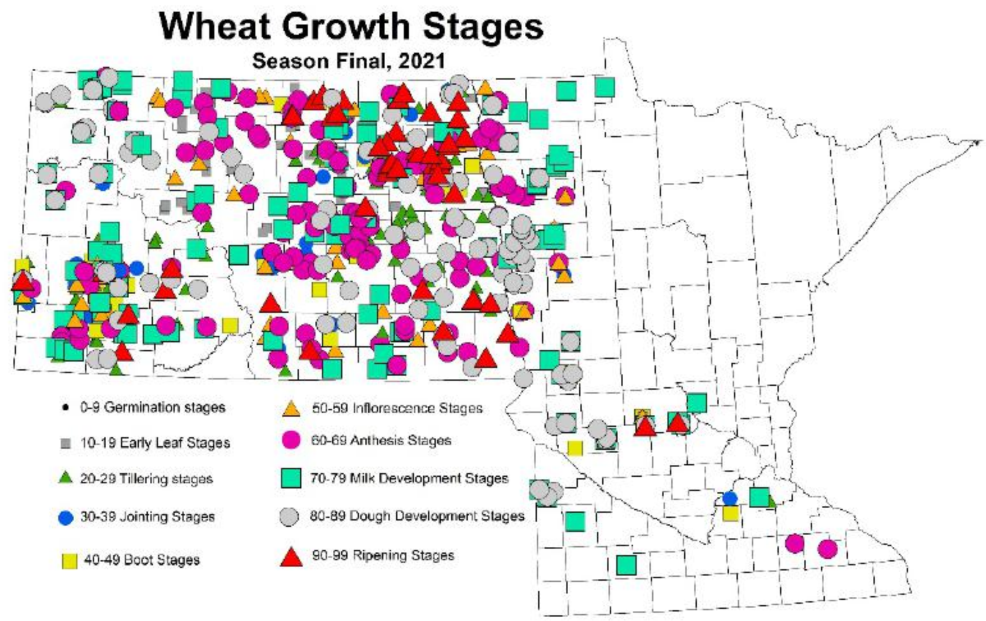
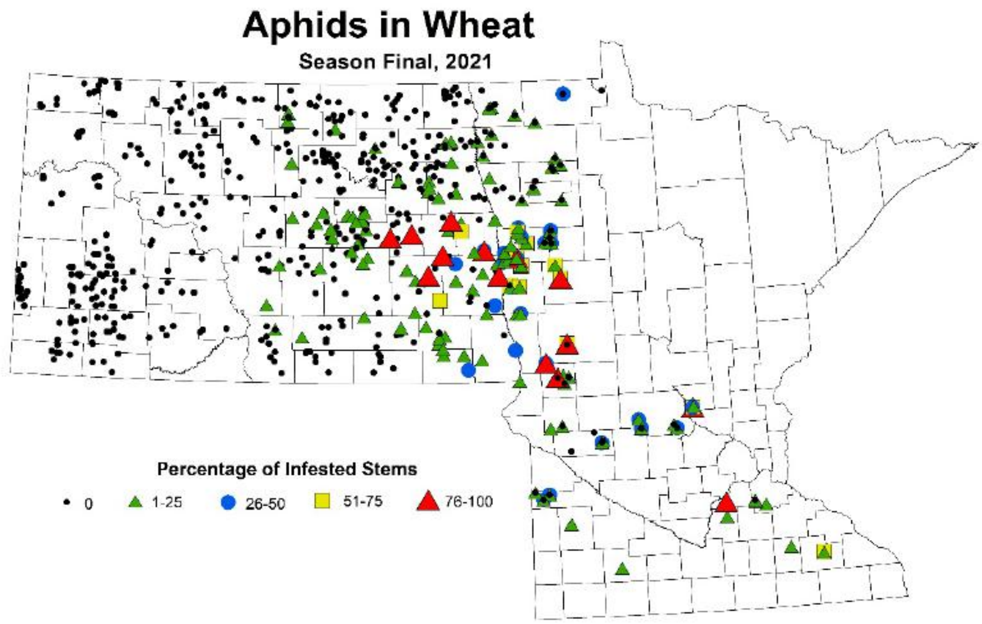
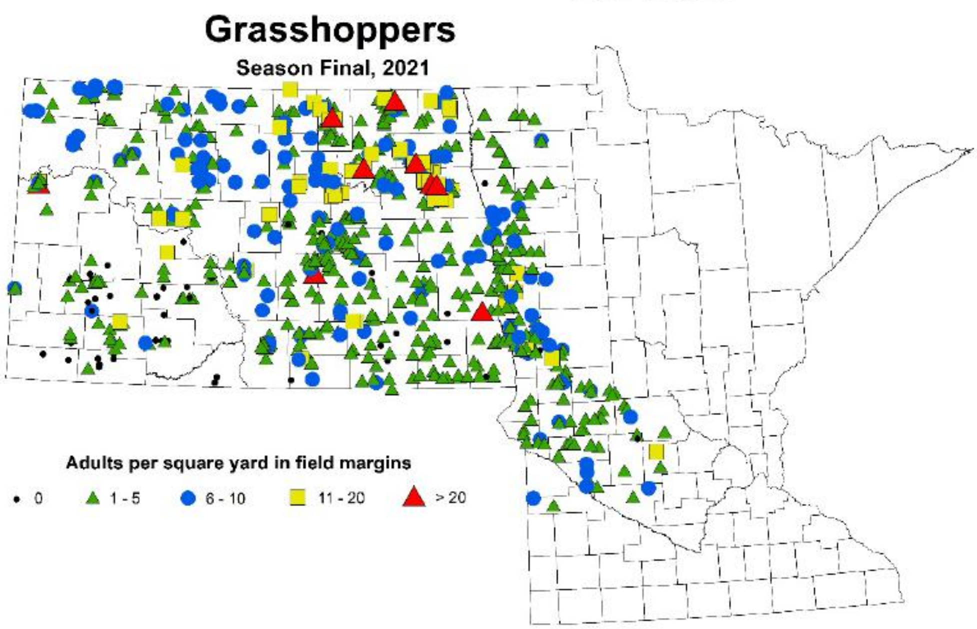
Appendix I:

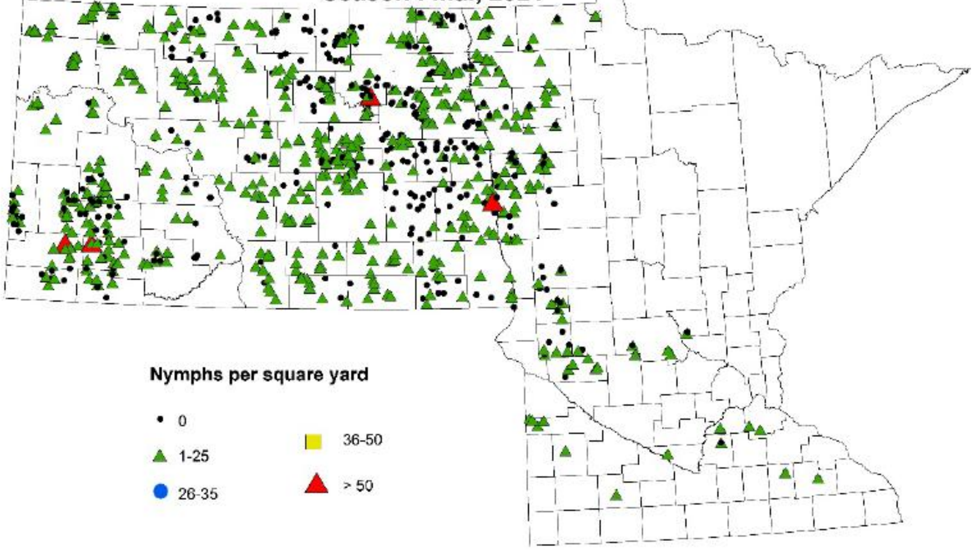

Wheat Growth Stages
Season Final, 2021
0-9 Germination stages
10-19 Early Leaf Stages
20-29 Tillering stages
30-39 Jointing Stages
40-49 Boot Stages
50-59 Inflorescence Stages
60-69 Anthesis Stages
70-79 Milk Development Stages
80-89 Dough Development Stages
90-99 Ripening Stages


Aphids in Wheat
Season Final, 2021
Percentage of Infested Stems
0
1-25
26-50
51-75
76-100


Grasshoppers
Season Final, 2021
Adults per square yard in field margins
0
1 - 5
6 - 10
11 - 20
> 20

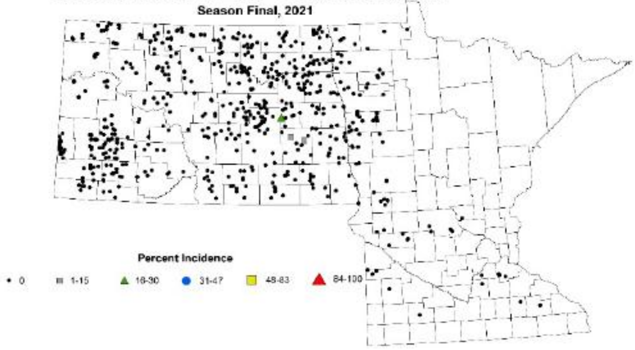
Grasshoppers

Season Final, 2021



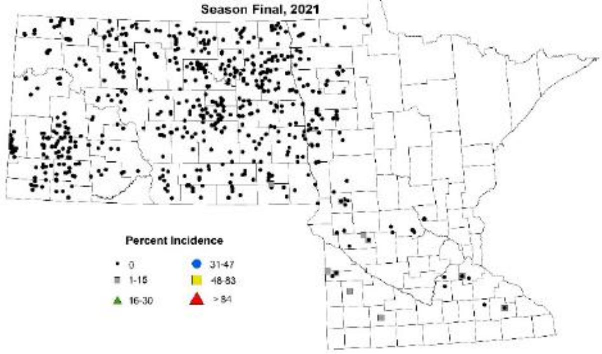
Wheat Bacterial Leaf Streak Incidence

Season Final, 2021



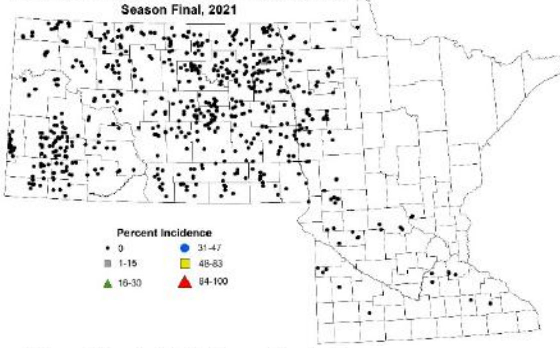
Wheat Barley Yellow Dwarf Virus

Season Final, 2021



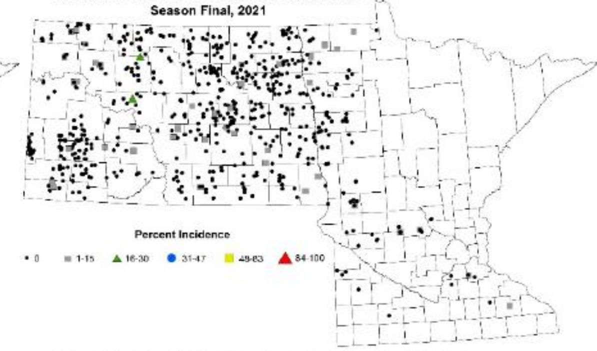
Wheat Ergot Percent Incidence

Season Final, 2021



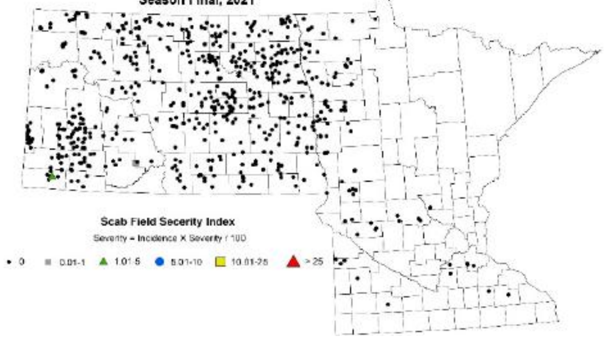
Wheat Loose Smut Incidence

Season Final, 2021



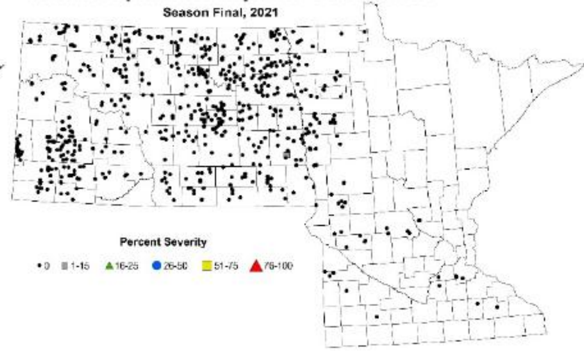
Wheat Scab Field Severity Index

Season Final, 2021



Wheat Septoria Complex SC Incidence

Season Final, 2021



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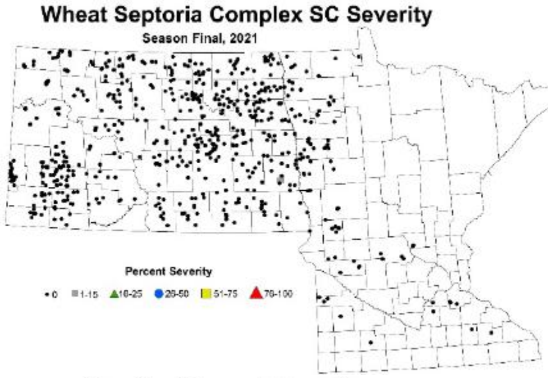
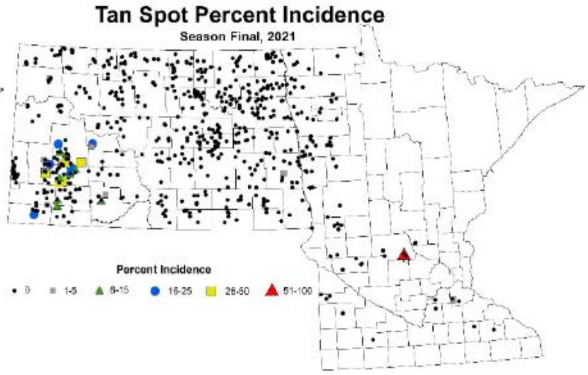
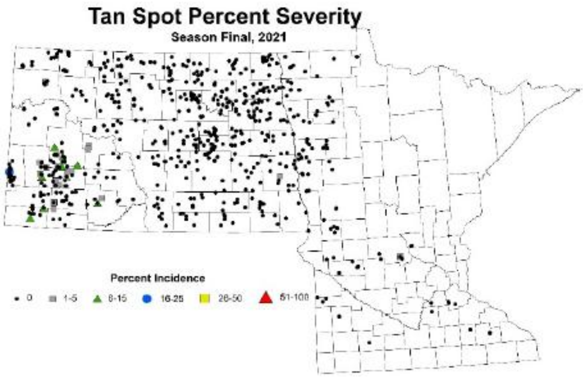
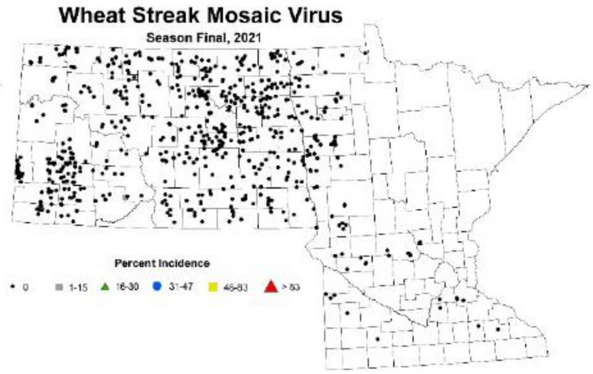
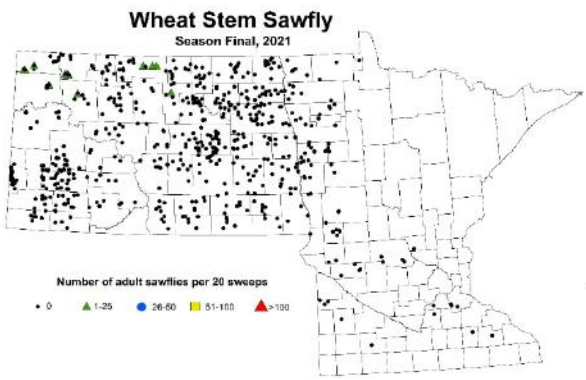
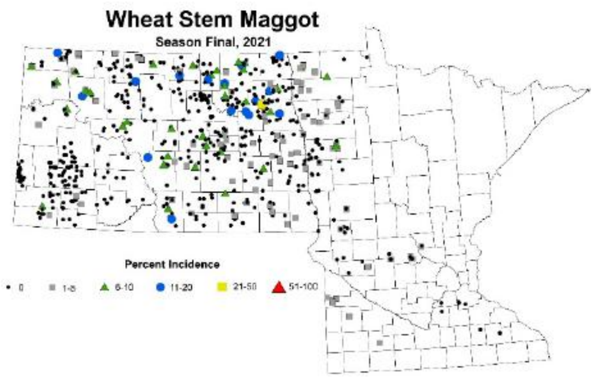

Wheat Septoria Complex SC Severity
Season Final, 2021
Percent Severity
0 1-15 16-25 26-50 51-75 76-100


Tan Spot Percent Incidence
Season Final, 2021
Percent Incidence
0 1-5 6-15 16-25 26-50 51-100


Tan Spot Percent Severity
Season Final, 2021
Percent Incidence
0 1-5 6-15 16-25 26-50 51-100


Wheat Streak Mosaic Virus
Season Final, 2021
Percent Incidence
0 1-15 16-30 31-47 48-63 > 63


Wheat Stem Sawfly
Season Final, 2021
Number of adult sawflies per 20 sweeps
0 1-25 26-50 51-100 >100


Wheat Stem Maggot
Season Final, 2021
Percent Incidence
0 1-5 6-10 11-20 21-50 51-100

A Novel High-Throughput Phenotyping Pipeline to Deliver More Productive and Stress Resilient Minnesota Wheat Varieties

M. Walid Sadok, Dept. of Agronomy & Plant Genetics, U of M, St Paul

Research Question/Objectives

By capturing light, nitrogen and other nutrient resources from the roots, wheat canopies are the engine that fuels reproductive growth and therefore grain yields. While a highly productive and healthy canopy is a very desirable trait for a breeder, a challenge is that such canopies are nearly impossible to detect with the naked eye, which is not equipped to detect certain wavelengths that varieties emit when they are under-performing or stressed. For a breeding program, this challenge has to be addressed to enable rapid screening of hundreds if not thousands of breeding lines. To address this problem, we are developing a drone-based remote-sensing technology that is based on thermal imaging which is being tested to support the U of M wheat breeding program. This method differentiates between productive and underperforming canopies based on their thermal 'signatures'.

While there are existing drone-based approaches to monitor crops, our method is unique as it relies on advanced thermal imaging technology coupled with energy balance modeling, and informed by physiology-based ground truthing techniques. This combination of physiology-based techniques and remote-sensing methods ensures that differences in thermal images among genotypes actually captures differences in cultivar physiology rather than differences due to weather changes. This distinction is critical to any breeding program, because traits that are 'masked' by the environment will tend to have low heritability and are more difficult to genetically improve.

For this first year, the main objective of our research was to deploy, test and validate our technology on a population of 508 breeding lines (plus 4 checks) that are part of the U of M wheat Preliminary Yield Trials (PYT). The specific goals were to resolve scaling challenges that arise as a result of a such a large trial and test if the technology could detect differences between genotypes and stress conditions.

Results

Yield results from this year's PYTs are plotted in Figure 1. The preliminary results indicate that there is a large variability in yields, with 80 breeding lines out-yielding the best performing check by up to 16 bu/a. These are, of course, preliminary results, and need to be confirmed in multi-location yield trials.

While we are still analyzing data from our remote-sensing pipeline, our preliminary findings indicate that our technology was able to capture differences in canopy temperature responses to the hot and dry summer season as exemplified in Figure 2. More specifically, we were able to detect differences in canopy temperature among genotypes, under both normal and stressful (droughty) conditions, confirming that our technology could potentially help breeders rapidly identify stress-resilient and productive breeding lines. In the example outlined in Figure 2, cooler canopies indicate genotypes that are coping well under the hot conditions of the day since they are able to cool themselves, while the hotter ones indicate genotypes that are likely to be heat-stressed. The ones that are better at cooling themselves do so by maintaining water loss by transpiration, which means that they are actively taking up water and nutrients. Consistently with this hypothesis, the 'cooler' MN-Washburn out-yielded MN-Torgy by about 6 bu/A in this trial, representing a significant 11-12% increase.

Application and Use

As exemplified above, this research aims to develop a remote-sensing technology that enables rapid screening of breeding lines for canopy temperature, a trait directly related to yield performance. The development of this technology is expected to support the U of M breeding program by making it possible for the breeder to more rapidly screen a larger number of breeding lines and identify promising ones at lower costs. Additionally, this technology could work in farmers' fields, potentially enabling them to monitor in real time the health status of their crop.

Materials and Methods

The experimental design was an augmented incomplete block design with 4 checks in each block (14 blocks). A total of 512 genotypes including 4 checks were planted in (4.5 ft x 8 ft) yield plots at the U of M St Paul campus on 4/22 and harvested on 7/30 and 8/2. After planting, aerial thermal images were collected weekly from [5/12] (emergence) to [7/23] (physiological maturity) with a thermal camera (Vue Pro R 640) mounted on an unmanned aerial system (UAS; Inspire 2, DJI) using a specialized gimbal (VuIR Tab HD gimbal). Flights always took place on sunny days around solar noon, i.e., between 13:00 and 13:30 hours. Along with the thermal images, RGB (Red-Green-Blue) images were collected using the drone RGB camera and gimbal (Zenmuse X5S, DJI). These RGB images

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were needed to align with the thermal images to differentiate soil from crop temperature and estimate the change in canopy cover over time, and to obtain an estimation of plant height.

To ensure that the remote-sensing approach effectively captures canopy temperature, we deployed ground-truthing temperature sensors (thermocouples) which were installed physically on plants so that we have an estimate of temperature as experienced by the plants. At flag leaf appearance, a total of 24 T-type thermocouples were installed throughout the trial in the flag leaves, with one mounted on a stick to measure air temperature at canopy height.

Economic Benefit to a Typical 500 Acre Wheat Enterprise

The ability to deliver more productive and resilient varieties for the farmer depends on new technologies such as the one being developed in the proposal. By being able to rapidly screen breeding lines for their canopy health and performance under normal and stressful conditions, this new technology will support and strengthen the ability of the U of M wheat breeding program to deliver more rapidly better yielding varieties to growers. The proposal directly aims at increasing the yield potential, and therefore the profitability of the crop for the farmer.

Related Research

This research is directly linked to the U of M wheat breeding program. In addition, the technology being developed is expected to be directly translatable to other small grain crops including barley and oats. In the future, it is also expected that this work will benefit efforts to enhance resistance not only to climate stressors (drought, heat, etc) but also to pathogens such as rusts and FHB. This research directly connects to Dr. Sadok's international research program which aims to help breeders develop wheat cultivars equipped with canopy traits that maximize yield gains under different water availability regimes in collaboration with colleagues in the Middle-East and Australia (Schoppach et al. 2017; Sadok et al. 2019; Tamang et al. 2019; Sadok and Schoppach 2019; Schoppach et al. 2020; Monnens and Sadok 2020).

Recommended Future Research

Future research will focus on further developing a data analytics pipeline with the goal of enabling the detection of genetic loci associated with desirable canopy temperature traits. Favorable alleles at these genetic loci will be integrated in the U of M breeding pipeline and pyramided with other favorable genes to improve the yield potential of the next generation of varieties that will be released by the breeding program.

Publications

- Monnens, D., & Sadok, W. (2020). Whole-plant hydraulics, water saving, and drought tolerance: a triptych for crop resilience in a drier world. Annual Plant Reviews, 3(4), 661-698.
- Sadok, W., Schoppach, R., Ghanem, M. E., Zucca, C., & Sinclair, T. R. (2019). Wheat drought-tolerance to enhance food security in Tunisia, birthplace of the Arab Spring. European Journal of Agronomy, 107, 1-9.
- Schoppach, R., Fleury, D., Sinclair, T. R., & Sadok, W. (2017). Transpiration sensitivity to evaporative demand across 120 years of breeding of australian wheat cultivars. Journal of Agronomy and Crop Science, 203(3), 219-226.
- Tamang, B. G., Schoppach, R., Monnens, D., Steffenson, B. J., Anderson, J. A., & Sadok, W. (2019). Variability in temperature-independent transpiration responses to evaporative demand correlate with nighttime water use and its circadian control across diverse wheat populations. Planta, 250, 115-127.

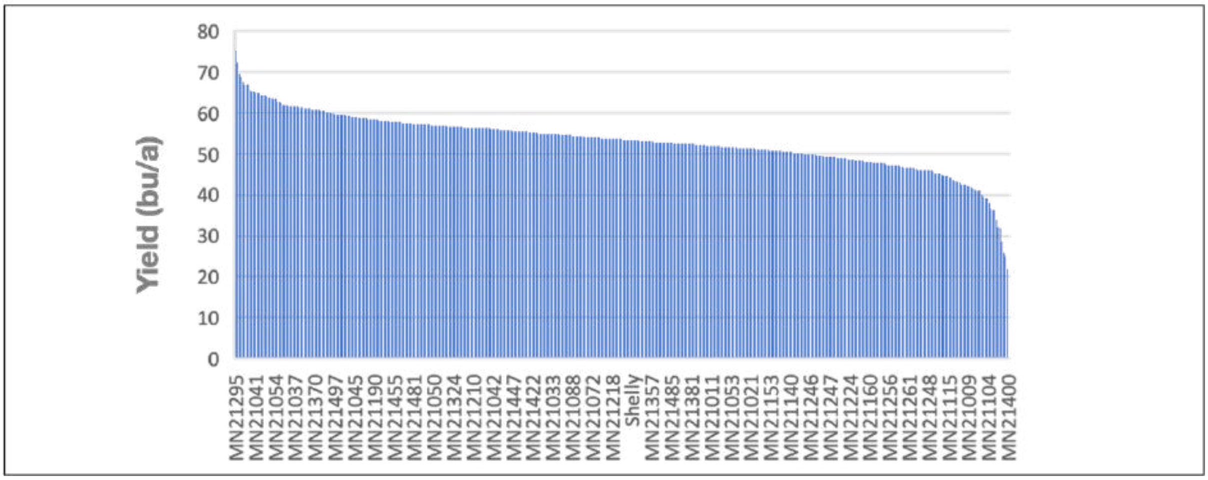


Figure 1. Yield performance of the 508 breeding lines and the 4 checks in the PYT conducted at the St. Paul campus of the U of M. Breeding lines are ranked from the highest to the lowest-yielding. Due to the lack of space, only a fraction of genotype names are indicated.

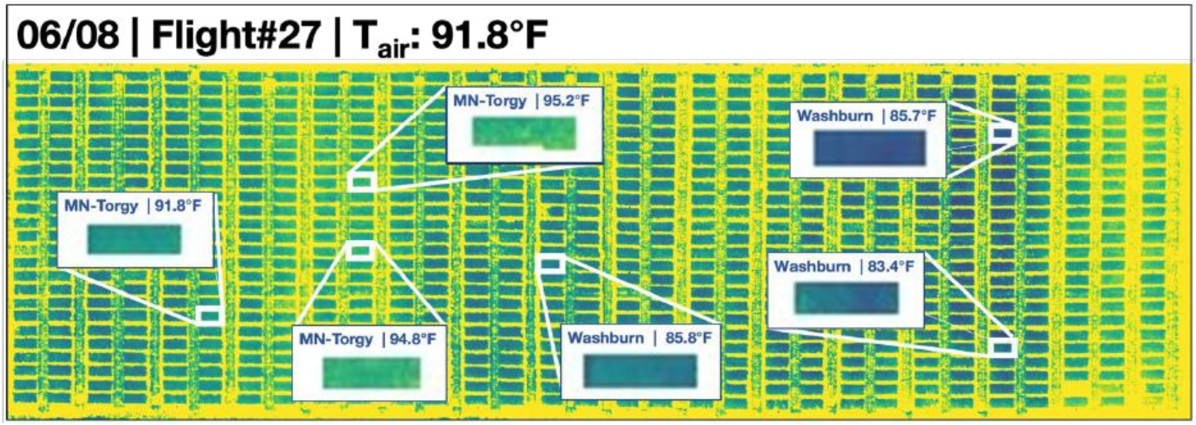


Figure 2. A composite color-coded thermal image showing consistent differences in canopy temperature between two check cultivars, MN-Torgy and MN-Washburn, measured on June 8th under hot and droughty conditions. Cultivar MN-Washburn consistently exhibited a cooler canopy (dark blue plots, compare to green-yellow plots) indicating a better ability to protect itself from excessive heat stress. The image spans the entire yield trial, which involves 508 breeding lines and four checks.

University of Minnesota Wheat Breeding Program

James Anderson, Dept. of Agronomy & Plant Genetics, U of M, St Paul

Research Question/Objectives

This is a continuation of the U of MN 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

During the 2020/2021 crossing cycle, 218 crosses were made. The 2021 State Variety Trial, which contained 39 released varieties, 11 University of Minnesota experimental lines, 2 experimental lines from other programs, and 3 long term checks was grown at 15 locations. Another 186 advanced experimental lines were evaluated in advanced yield trials at 10-11 locations and 504 lines were evaluated in preliminary yield trials at 3 locations. A total of 7,019 yield plots were harvested in 2021. 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 2,725 pre-yield trial lines and their FHB resistance and dough mixing properties were predicted based on a training set of 197 lines and their 71 parents. The predictions based on DNA sequence information were used to help select the 504 preliminary yield trial lines from the 2,725 candidate lines, therefore avoiding more expensive and time-consuming field-based evaluations on more than 2,000 lines with low genetic potential. Data from the yield and disease nurseries are summarized and published in Prairie Grains and the MAES's 2021 *Minnesota Field Crop Variety Trials* (https://varietytrials.umn.edu).

Experimental line MN15005-4 (Prosper/MN08301-6//Norden) is a candidate for release. MN15005-4 has grain yields comparable to Shelly, straw strength comparable to Linkert, and average grain protein. Disease resistance and baking quality are acceptable. See Table 1 for comparison of MN15005-4 with other varieties

Application and 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 rust 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 10-11 locations. All yield nurseries are grown as 50-80 sq. ft. plots. Misted, inoculated Fusarium head blight 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. 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 4% higher will produce 3 extra bushels/acre in a field that averages 75 bu/A. At $8.75/bushel that equates to more than $13,000 in additional gross revenue for a 500 acre wheat enterprise.

Related Research

Related Research: These funds provide general support for our breeding & genetics program. Additional monetary support for breeding activities in 2021 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

This is an ongoing project and we expect to deploy drone-based phenotyping and expand our use of genomic prediction in 2022.

Publications

Anderson, J.A., J.J. Wiersma, S.K. Reynolds, E.J. Conley, R. Caspers, G.L. Linkert, J.A. Kolmer, Y. Jin, M.N. Rouse, R. Dill-Macky, M.J. Smith, L. Dykes, and J.-B. Ohm. 2021. Registration of 'Lang-MN' hard red spring wheat. J. Plant Registrations, https://doi.org/10.1002/plr2.20099.

Anderson, J.A., J.J. Wiersma, S.K. Reynolds, E.J. Conley, R. Caspers, G.L. Linkert, J.A. Kolmer, Y. Jin, M.N. Rouse, R. Dill-Macky, M.J. Smith, L. Dykes, and J.-B. Ohm. 2021. Registration of 'MN-Washburn' Hard Red Spring Wheat Containing Barley Yellow Dwarf Virus Resistance Gene bdv2. J. Plant Registrations, https://doi.org/10.1002/plr2.20130.

Bajgain, P. A.H. Sallam G. Annor, E. Conley, B.J. Steffenson, G..J Muehlbauer, and J.A. Anderson. 2020. Genetic characterization of flour quality and bread-making traits in a spring wheat nested association mapping population. Crop Sci. https://doi.org/10.1002/csc2.20432

Kolmer J, M.K .Turner, M.N. Rouse, and J.A. Anderson. 2021. Adult plant leaf rust resistance in AC Taber wheat maps to chromosomes 2BS and 3BS. Phytopathol. doi: 10.1094/PHYTO-03-20-0074-R.

Table 1. Comparison of MN15005-4, MN-Torgy and the other seven most popular spring wheat varieties grown in MN. Entries are sorted based on grain yield (% of mean) over 43 environments. For traits scored on a 1-9 scale, 1 is best and 9 is worst.

			Grain Yield					Straw	Test Wt	Protein	Baking		Leaf	Bacterial	
	Release	% of MN	(% of mean)			HD	HT	Str.	(lbs/bu)	(%)	Quality	PHS	Rust	Leaf Str.	Scab
Variety	Yr.	Acreage	2021	2 Yr	3 Yr	d	in.	1–9	2021	2021	1–9	1–9	1–9	1–9	1–9
SY Valda	2015	12.8	102	103	105	56.9	25.4	5	62.0	14.2	6	2	1	3	4
AP Murdock	2020	8.4	94	101	104	55.3	25.2	5	60.9	14.8	5	1	3	4	7
MN15005-4	**–**	**–**	**103**	**104**	**104**	**57.9**	**25.8**	**2–3**	**61.8**	**14.7**	**5**	**2**	**2**	**5**	**4–5**
Shelly	2016	4.2	103	103	104	57.9	26.3	5	62.2	14.1	5	1	3	6	4
MN-Torgy	2020	9.7	101	102	103	55.7	25.6	4	62.4	15.3	4	1	3	3	4
WB9590	2017	18.0	96	101	–	54.7	23.6	3	61.9	15.4	4	1	6	6	7
MN-Washburn	2019	4.0	97	95	97	57.3	25.3	3	61.6	14.4	3	1	1	3	4
WB9479	2017	10.3	94	95	–	54.3	24.3	3	62.0	15.7	2	1	6	6	7
Linkert	2013	11.9	95	93	92	55.2	25.8	2	62.6	15.9	1	1	3	5	5

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

George Annor, Dept. of Food Science & Nutrition, U of M, St Paul

Research Question/Objectives

How does breeding activities by the University of Minnesota Breeding Program affect end-use Quality of Wheat?

Results

Activities during the reporting period were significantly impacted by the COVID-19 pandemic. Despite effects of the pandemic, we were still able to analyze 253 wheat samples for their protein aggregation kinetics using the Brabender Gluto Peak Tester (GPT). The samples were grown in Crookston and St. Paul in 2020. Based on the peak maximum time, torque maximum, torque before maximum, torque after maximum, startup energy, plateau energy and aggregation energy of the samples generated from the GTP, the water absorption of the samples were calculated. The calculations were done using regression equations developed earlier with funding from the MWRPC. The calculated water absorption of the samples analyzed are shown in Fig 1. The water absorption of samples ranged from 56.1% to 80.2% with an average of 64.4%. The mean of the water absorption of the samples grown in St. Paul was 64.2% while those grown in Crookston was 65.5%. The ability to calculate these water absorptions using the GPT is very important in screening large amounts of samples at a very early stage of the breeding process.

Application and Use

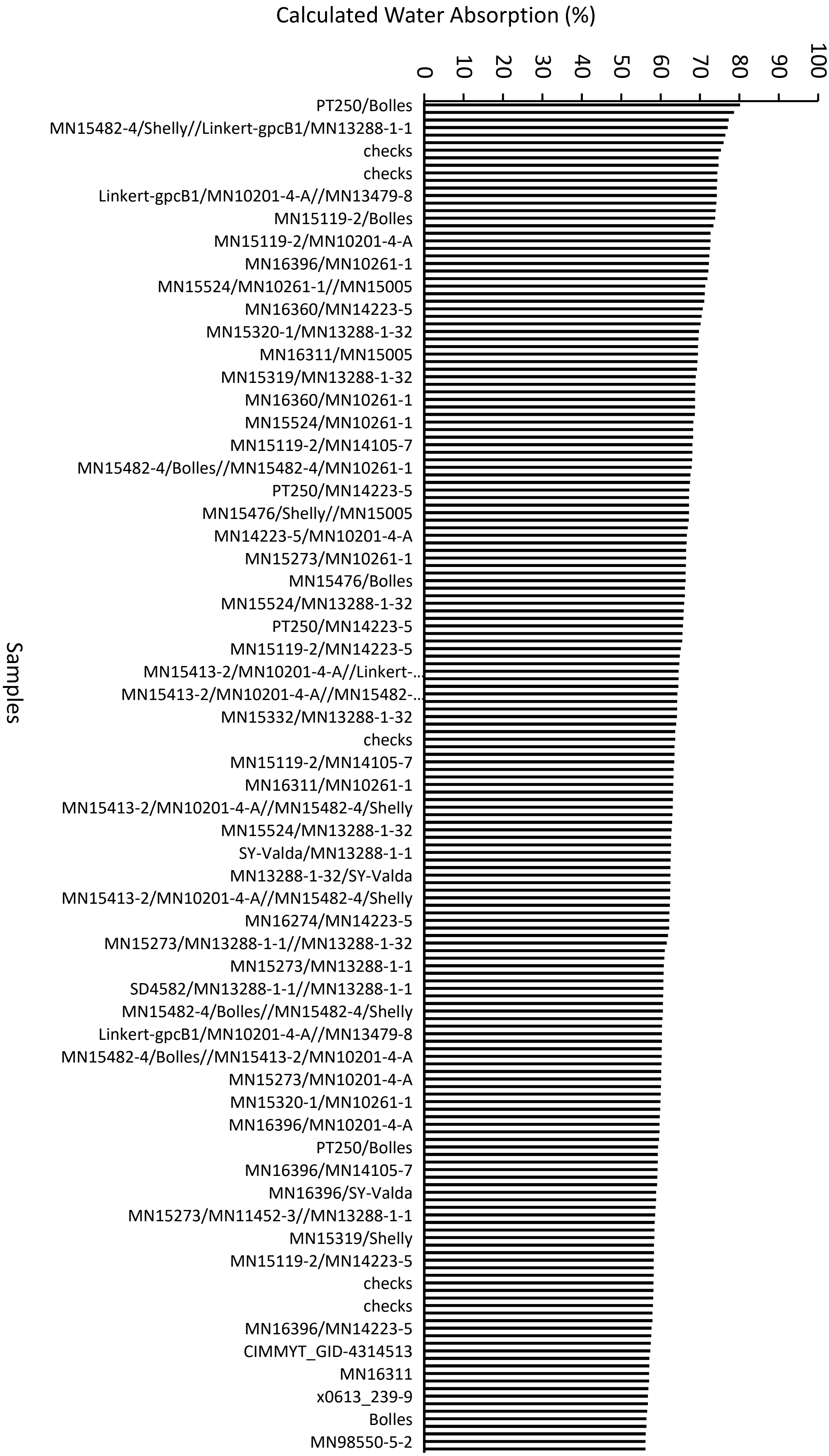
These calculated water absorptions, along with grain protein and test weight data are the only end-use quality data the breeding program will have to help decide which of these entries will be advanced for yield trials in 2022.

Materials and Methods

Grain from 253 2020 F_5 cohort samples harvested from St. Paul and Crookston were milled into flour and their protein aggregation kinetics 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.



Calculated Water Absorption (%)
0
10
20
30
40
50
60
70
80
90
100
Samples
PT250/Bolles
MN15482-4/Shelly//Linkert-gpcB1/MN13288-1-1
checks
checks
Linkert-gpcB1/MN10201-4-A//MN13479-8
MN15119-2/Bolles
MN15119-2/MN10201-4-A
MN16396/MN10261-1
MN15524/MN10261-1//MN15005
MN16360/MN14223-5
MN15320-1/MN13288-1-32
MN16311/MN15005
MN15319/MN13288-1-32
MN16360/MN10261-1
MN15524/MN10261-1
MN15119-2/MN14105-7
MN15482-4/Bolles//MN15482-4/MN10261-1
PT250/MN14223-5
MN15476/Shelly//MN15005
MN14223-5/MN10201-4-A
MN15273/MN10261-1
MN15476/Bolles
MN15524/MN13288-1-32
PT250/MN14223-5
MN15119-2/MN14223-5
MN15413-2/MN10201-4-A//Linkert-…
MN15413-2/MN10201-4-A//MN15482-…
MN15332/MN13288-1-32
checks
MN15119-2/MN14105-7
MN16311/MN10261-1
MN15413-2/MN10201-4-A//MN15482-4/Shelly
MN15524/MN13288-1-32
SY-Valda/MN13288-1-1
MN13288-1-32/SY-Valda
MN15413-2/MN10201-4-A//MN15482-4/Shelly
MN16274/MN14223-5
MN15273/MN13288-1-1//MN13288-1-32
MN15273/MN13288-1-1
SD4582/MN13288-1-1//MN13288-1-1
MN15482-4/Bolles//MN15482-4/Shelly
Linkert-gpcB1/MN10201-4-A//MN13479-8
MN15482-4/Bolles//MN15413-2/MN10201-4-A
MN15273/MN10201-4-A
MN15320-1/MN10261-1
MN16396/MN10201-4-A
PT250/Bolles
MN16396/MN14105-7
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Bolles
MN98550-5-2

The Role of Water in Fertilizer Loss in Northwest Minnesota Wheat Production

Lindsay Pease, Dept. of Soil, Water & Climate, U of M, Crookston

Research Question/Objective

1. Establish one fully instrumented, water monitoring research site to improve our ability to capture fertilizer loss in surface runoff and subsurface drainage discharge at the field scale.

2. Collect grab samples of tile discharge and soil samples from four satellite on-farm locations to broaden the interpretation and applicability of findings across Northwest Minnesota's wheat growing region.

3. Bring a greater understanding of the role that water and soil moisture plays in the movement of fertilizer both within and out of the soil profile for farmers who grow wheat rotations in the greater North Central region.

Results

Throughout the 2020 growing season, observed nitrate (NO3) and total nitrogen (TN) concentrations varied by sampling location, but in general, were lower than 15 ppm. A summary of the distribution for subsurface tile drainage samples is presented in Table 1 and a summary for surface runoff is presented in Table 2.

Total N losses were significantly greater from tile outlets than from surface runoff, but the opposite was true for total P losses (Figure 1). This is typical because N moves easily with water and leaches into the soil profile. Because it leaches into the soil, it does not move as easily in surface runoff. P tends to adhere to soil particles as it leaches. It can attach relatively easily to clay particles or calcium carbonates (both of which are very common in Red River Basin soils). This means P is less likely to move into subsurface drainage water, but it is more likely to be lost in surface runoff due to soil erosion. The dissolved form of P (which was suspended in water that leached through the soil profile) moved along with NO3. It was greater at tile outlets than in surface runoff.

Other significant factors in N and P concentration were rainfall and landscape position (beach ridge or valley floor). Concentrations of Total N, Total P, and Dissolved P were all significantly greater when high rainfall was observed in the week before the sample was taken. Sites on the beach ridge tended to have slightly higher soluble nutrient losses than sites on the valley floor. This is likely because water moves more readily through the soil profile in sandy soils than clayey soils.

Nitrogen concentrations were relatively low across on-farm sites in 2020. More than half of the samples were below

Table 1: Summary of Measured Tile Discharge Concentrations in parts per million (ppm)

	N	Minimum	Median	Maximum	Standard Deviation
Total Nitrogen	105	1.0	8.5	17.7	4.1
Nitrate	55	1.4	9.4	14.7	3.4
Total Phosphorus	104	<0.01	0.1	1.6	0.3
Dissolved Phosphorus	105	<0.01	0.1	0.3	0.1

Table 2: Summary of Measured Surface Runoff Concentrations in parts per million (ppm)

	N	Minimum	Median	Maximum	Standard Deviation
Total Nitrogen	75	0.7	2.3	10.7	1.6
Nitrate	43	0.7	2.6	10.0	1.8
Total Phosphorus	76	<0.01	0.1	0.7	0.2
Dissolved Phosphorus	76	<0.01	0.1	0.9	0.2

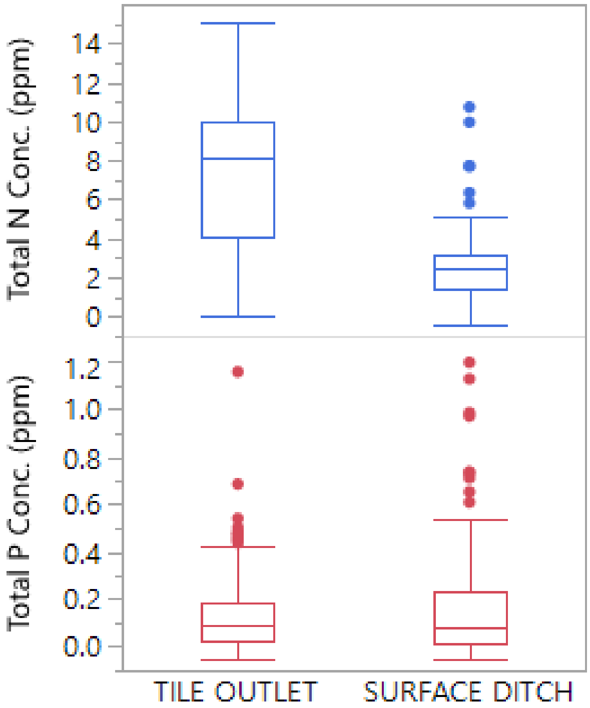

Figure 1: Concentrations of Total Nitrogen (N) and Total Phosphorus (P) in parts per million (ppm) collected in 2020

the recommended drinking water standard for NO3, which is 10 ppm. This is a very good water quality result, especially considering the extreme rainfall experienced in the summer of 2020.

Median P concentrations were similar between tile discharge and surface runoff. Two factors, (1) higher than average rainfall and (2) extreme ground disturbance at NWROC due to subsurface tile installation likely led to greater observed P losses in 2020 than may be typical. Additional monitoring over time will determine whether P losses generally pose a water quality risk in the Red River Basin.

Application and Use

Heavy rainfall years likely mean higher N and P losses in subsurface tile drainage systems and in surface runoff. Nitrogen losses were low from a water quality perspective, indicating that farmers are doing a good job matching nitrogen fertilizer to crop needs. Due to the heavy rainfall in 2020 followed by a drought with little to no runoff in 2021, it is difficult to say whether P losses are high or low for the Red River Basin. This is an area that needs further research over time. Practices that minimize soil erosion will likely minimize loss of P risk.

Materials and Methods

In 2020, water samples were collected approximately daily from a continuously monitored subsurface drainage system at the Northwest Research & Outreach Center. Additionally, grab samples were collected throughout the growing season from four on-farm locations. These water samples were analyzed for total nitrogen (N), nitrate (NO3), total phosphorus (P), and dissolved P in Dr. Pease's lab at the Northwest Research & Outreach Center.

Because water quality data tends to be non-normal in its distribution, water samples were statistically analyzed using non-parametric methods and multiple linear regression to detect significant differences. This approach was previously used by Pease et al. (2018a) and Pease et al. (2018b) to evaluate nutrient losses in subsurface drainage systems in Ohio.

Recommended Future Research

Further monitoring over time is recommended to help determine how different crops in wheat rotations and management practices influence nutrient use efficiency and losses with rainfall.

References

Pease, L.A., N.R. Fausey, J.F. Martin, and L.C. Brown. 2018. Weather, landscape, and management effects on nitrate and soluble phosphorus concentrations in subsurface drainage in the Western Lake Erie Basin. Transactions of the ASABE 61(1):223–232.

Pease, L.A., K.W. King, M.R. Williams, G.A. LaBarge, E.W. Duncan, and N.R. Fausey. 2018. Phosphorus export from artificially drained fields across the Eastern Corn Belt. Journal of Great Lakes Research 44(1):43–53.

Bacterial Seed Inoculation to Improve Nitrogen Uptake and Use Efficiency in Wheat

Paluo Pagliari and Lindsay Pease, Dept. of Soil, Water and Climate, NWROC, Crookston

Research Question/Objectives

Determine if inoculation of wheat with plant growth promoting bacteria has a positive impact on wheat growth and yield;
Assess nitrogen uptake in plots inoculated with plant growth promoting bacteria.

Results

2021 was very atypical year with very limited rainfall during critical grain filling stages. Yields at both locations, Crookston and Lamberton, was about two thirds to half of expected yield, in most cases. At Crookston, wheat following sugar beet was only 12 bushels per acre on average; while yield after soybean averaged 43 bushels per acre. At Lamberton, wheat yield after corn averaged 54 bushels per acre; and after soybean it averaged 45 bushel per acre. Inoculation had a significant effect on wheat grain yield only at Lamberton. Inoculation increased wheat grain yield by about 22% (51 bushels in the inoculated plots compared with 42 bushels in the non-inoculated) in the plots without any nitrogen application (control plots) see Figure 1. No significant differences were observed due to inoculation for the other nitrogen application rates in the wheat following corn treatment. For wheat following soybeans at Lamberton, there was a significant increase in wheat grain yield of 11% for the 0 N treatment (control) and also 16% for the nitrogen rate of 120 lbs per acre (figure 2).

Although the 2021 season was very challenging, the results are very positive and show the potential for the use of *Azospirillum* as a management practice that could minimize the amount of N required for maximum wheat growth and yield. Future work is needed so that a better understanding of this management can be developed under different weather conditions.

Soil nitrogen levels were also measured for nitrate and ammonium. No significant results were observed for both N forms at the Crookston location. However, there were significant differences in soil nitrate levels at the Lamberton location for both wheat after corn and wheat after soybean. Figures 3 (wheat after corn) and 4 (wheat after soybean) show soil nitrate as a function of N application rate in plots that were inoculated and also non-inoculated plots. Soil nitrate levels tended to be greater in plots that were inoculated than in plots that were not inoculated starting at the application rate of 60 lb N acre^{-1} (Figures 3 and 4). Figures 5 and 6 show soil nitrate levels as a function of inoculation rate. Soil nitrate levels for the 45 lbs N acre^{-1} were greater than soil nitrate levels for the 0 N acre^{-1} for all inoculation rates, except the recommended 1.37 oz acre^{-1} for wheat following corn and also soybean (Figures 5 and 6).

In conclusion this first year research trial to assess the potential for using Azospirillum brasilense as a nitrogen fixer to help improve wheat productivity and decrease the reliance on synthetic fertilizer shows great potential. The extreme dry conditions likely hindered our ability to fully assess how effective Azospirillum was at fixing atmospheric N. More trials are needed to determine how to best use this management practice in wheat to help wheat growers in Minnesota.

Application and Use

Our main goal with this project is to improve nitrogen fertilizer use and help wheat growers be more profitable. Nitrogen fixing bacteria can remove N from the atmosphere and convert it into ammonium or nitrate in the soil which is available for plant uptake. Finding management practices that reduces the cost of production to farmers could lead to significant savings improving overall profits.

Materials and Methods

Replicated field studies were conducted at two of the University of Minnesota research and outreach center at Lamberton (SWROC) and Crookston (NWROC). To test the effects of seed inoculation on wheat grain yield, wheat was planted after soybean and corn, at Lamberton, and soybean and sugarbeets, at Crookston. Treatments tested were inoculation and nitrogen rates. For the inoculation rate portion of the study a fixed N rate was used (45 lbs N ac^{-1}) and the levels of inoculation were 0x, 0.5x, 1x, 2x, and 3x, with x being the recommended inoculation rate (10 gallons per acre). For the N rate portion of the study, there were plots which were inoculated at the 1x inoculum rate and also plots which were not inoculated; nitrogen rates were 0, 30, 60, 90, and 120 lbs of N / acre. Each study was replicated four times for a total of 100 plots in each location. Having equivalent N rates with and without inoculation could allow us to determine the true potential for N fixation from the seed treatments and if a reduction in N fertilization is possible with this seed treatment. Wheat was harvested using plot combine and wheat grain samples were saved for N uptake analysis which is currently being performed at Lamberton in Dr. Pagliari labs.

Economic Benefit to a Typical 500 Acre Wheat Enterprise

The benefit to wheat growers would be increased wheat yield with lower N application rates. By reducing the amount of N needed for maximum wheat yield growers would save on fertilizers, specially when fertilizer prices are as high as they are going to be in the 2022 growing season. In addition, lower amounts of N applied to cropping fields will also reduce the amount of N that can potentially cause environmental problems to aquatic systems and drinking water.

Related Research

Nitrogen (N) fertilization is one of the highest costs in the production process of non-leguminous crops such as wheat (*Triticum aestivum*). Developing management practices which minimize the reliance on chemical N inputs are critical for global food security and environmental sustainability. Recent research has shown the potential for utilization of plant growth promoting bacteria (PGPB) to enhance nutrient use efficiency in non-leguminous cropping systems (Galindo et al., 2021a). This has the potential to reduce both costs associated with fertilizer purchases and N loss to the environment. Microorganisms such as *Azospirillum brasilense* and *Bacillus subtilis*, are PGPB known to have a significant effect on the nutrient balance in the soil-plant ecosystem. The mutualism relationship between PGPB, soil microflora, and plants could lead to better plant nutrition and development and increased productivity, while minimizing the needs for external inputs. The PGPB are nonpathogenic residents of plants or/and soil who act directly to promote growth or indirectly as biological control agents of plant diseases (Mariano et al., 2004). The use of inoculation in non-leguminous crops with non-symbiotic PGPB is increasing in Latin America, in particular for wheat and corn crops (Marks et al., 2015; Salvo et al., 2018; Galindo et al., 2021b). The use of PGPB can significantly reduce the amount of chemical N needed for optimum wheat productivity (Galindo et al., 2021a,b). Therefore, the overall hypothesis of this study is that *A. brasilense* and *B. subtilis* could promote plant growth by increasing biological N fixation (BNF), N use efficiency, overall nutrient uptake, and reduce biotic and abiotic stress.

Recommended Future Research

This was the first and only trial conducted in the USA using this specific *Azospirillum* strain. 2021 was a very challenging growing season and water stress limited plant yield. Future research needs to be conducted to assess the true potential for the use of this organism at supplying wheat with N from atmospheric N gas under different weather conditions.

References

Galindo, F.S., Pagliari, P.H., Buzetti, S., Rodrigues, W.L., Fernandes, G.C., Biagini, A.L.C., Tavanti, R.F.R. and Teixeira Filho, M.C.M., 2021a. Nutrient availability affected by silicate and Azospirillum brasilense application in corn–wheat rotation. *Agronomy Journal*.

Galindo, F.S., da Silva, E.C., Pagliari, P.H., Fernandes, G.C., Rodrigues, W.L., Biagini, A.L.C., Baratella, E.B., da Silva Junior, C.A., Neto, M.J.M., Silva, V.M. and Muraoka, T., 2021b. Nitrogen recovery from fertilizer and use efficiency response to Bradyrhizobium sp. and Azospirillum brasilense combined with N rates in cowpea-wheat crop sequence. *Applied Soil Ecology, 157*, p.103764.

Mariano RLR, Silveira EB, Assis SMP, Gomes AMA, Nascimento ARP, Donato VMTS. 2004. Importance of plant growth-promoting rhizobacteria for a sustainable agriculture. (In Portuguese, with English abstract). Anais Acad. Pernamb. Ci. Agron. 1:89-111.

Marks BB, Megías M, Ollero FJ, Nogueira MA, Araujo RS, Hungria M. 2015. Maize growth promotion by inoculation with *Azospirillum brasilense* and metabolites of *Rhizobium tropici* enriched on lipo-chitooligosaccharides (LCOs). Amb Express 5:71-82. doi: 10.1186/s13568-015-0154-z.

Salvo LP, Ferrando L, Fernandéz-Scavino A, Salamone IEG. 2018. Microorganisms reveal what plants do not: wheat growth and rhizosphere microbial communities after *Azospirillum brasilense* inoculation and nitrogen fertilization under field conditions. Plant Soil 424:405-417. doi: 10.1007/s11104-017-3548-7.

Figure 1. Wheat yield as affected by inoculation and N application rate for wheat following corn.

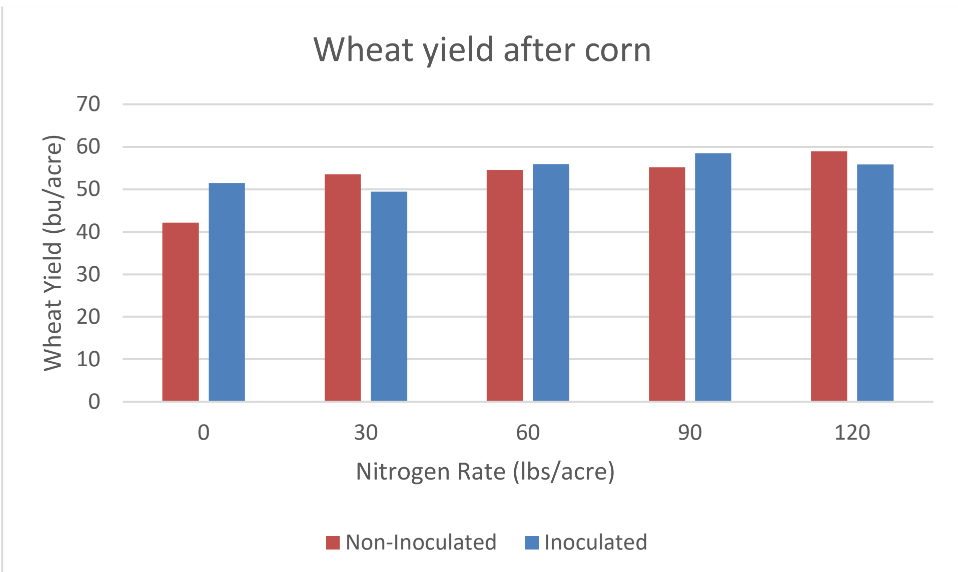

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Figure 2. Wheat yield as affected by inoculation and N application rate for wheat following soybean.

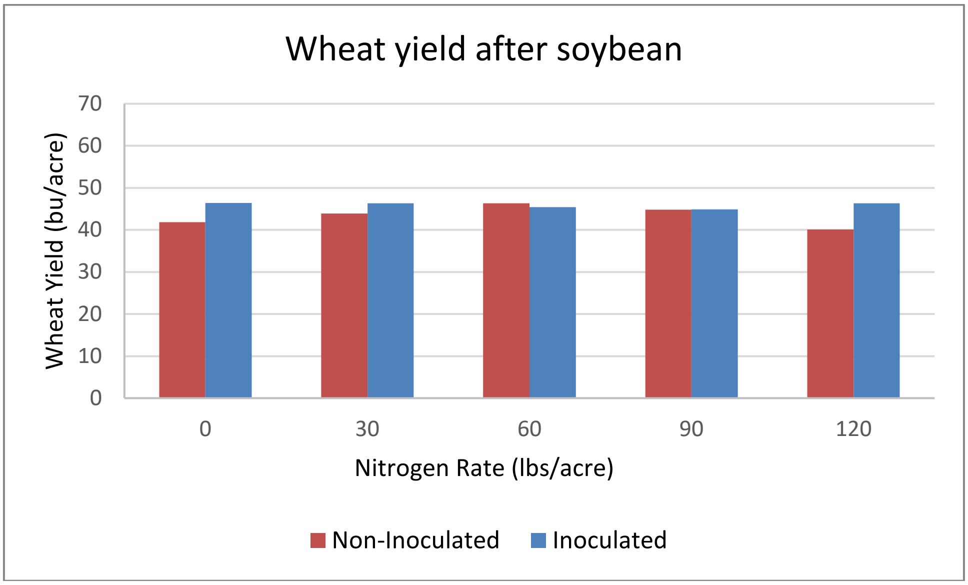


Figure 3. Soil nitrate levels after wheat harvest.

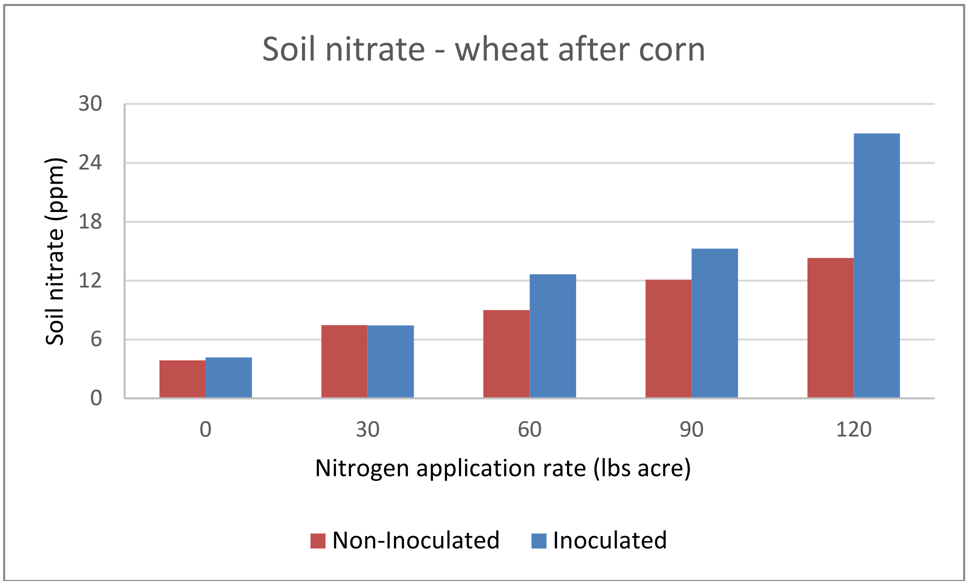


Figure 4. Soil nitrate levels after wheat harvest.

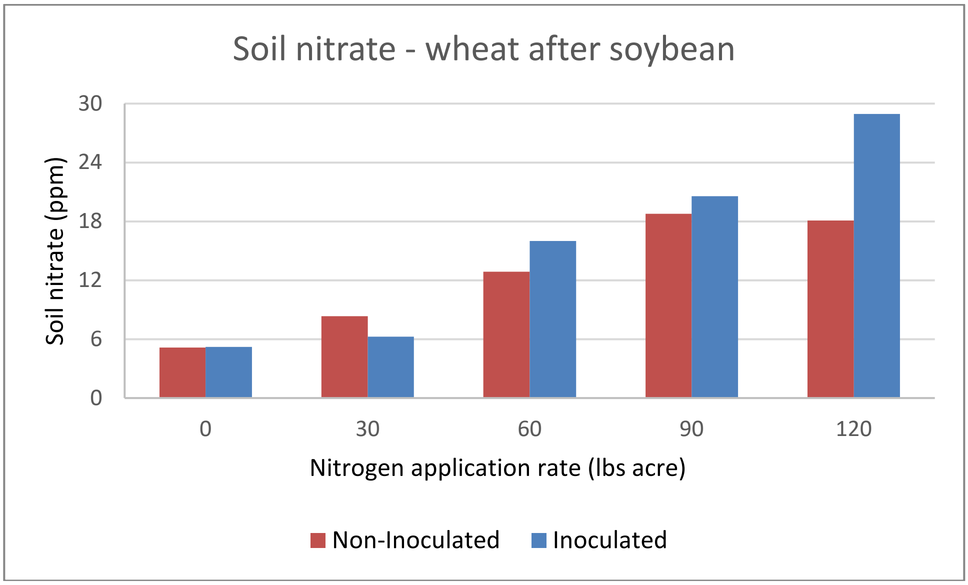


Figure 5. Soil nitrate levels after wheat harvest as a function of inoculation rate.

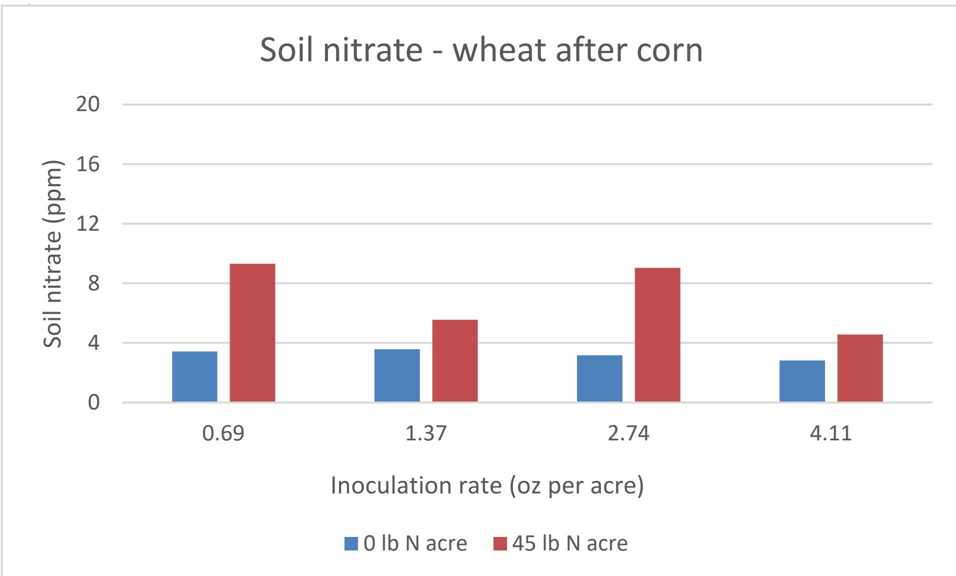
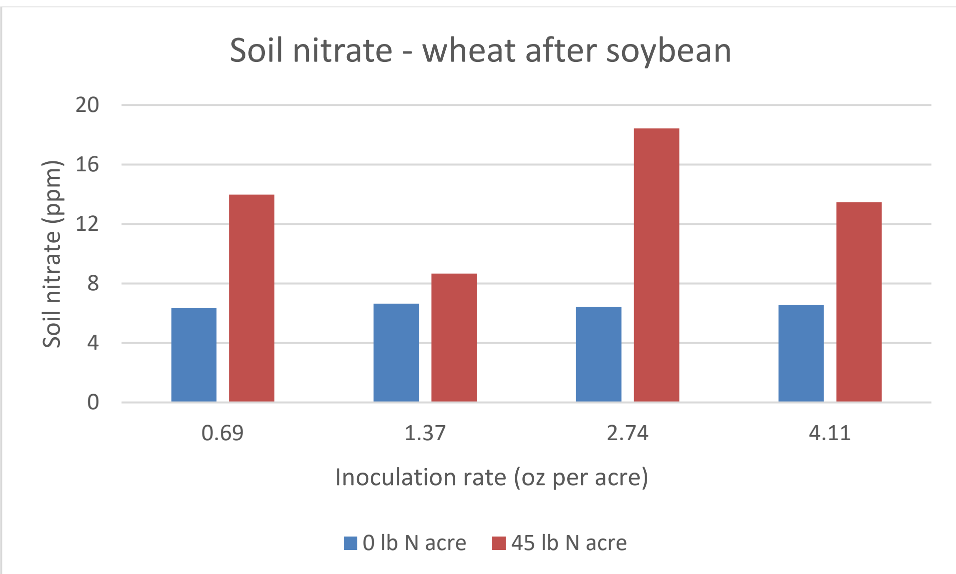


Figure 6. Soil nitrate levels after wheat harvest as a function of inoculation rate



Research on Bacterial Leaf Streak of Wheat

Ruth Dill-Macky, Dept. of Plant Pathology, U of M, St. Paul

Research Question/Objectives

Bacterial leaf streak (BLS) of wheat continues to cause significant economic damage to wheat in Minnesota, though there was little disease development in 2021, because of the dry season. The ultimate goal of this project was to deliver economic disease control measures for growers. Our work examined the biology of the BLS pathogen with the aim of uncovering avenues of disease control and examined disease management strategies that may complement host resistance. Outcomes, of practical value to the wheat grower, stem from our work understanding the pathogen. The development and validation of tools for the identification and/or quantification of BLS infection within seed lots, crop debris and soil were started in this project. These tools, once fully validated, will be useful in identifying seed lots and specific fields that are at higher risk of BLS. In addition, we examined the efficacy of seed treatments in disinfesting seed infected by the pathogen. In response to inquiries from wheat growers we also examined the efficacy of foliar sprays, containing copper, in reducing BLS development. As the *Xanthomonads* that cause BLS are known for their ability to rapidly develop resistance to copper, we also examined the sensitivity of the strains in our collection to provide an understanding of the baseline sensitivity of this pathogen to copper.

In conjunction with the use of varieties with improved resistance, the implementation of the tools we are developing in this project may provide additional options to the grower in the management of this economically important disease.

The specific objectives of this research project were to:

- Validate molecular assays as tools to rapidly and reliably identify *Xanthomonas translucens* pv. *undulosa (Xtu)* on wheat seed, plant tissues, and soil samples for use in a commercial setting.
- Determine where in the wheat seed the bacterium is surviving to aid understanding of seed transmission.
- Examine the efficacy of seed treatments in reducing *Xtu* in association with seed to determine if seed is important in driving bacterial leaf streak (BLS) development in wheat crop planted using infested seed.
- Conduct field trials to examine the efficacy of commercial foliar treatments on the control of BLS.
- Examine the baseline sensitivity of the Minnesota *Xtu* population to copper.

Results

- *Validate molecular assays as tools to rapidly and reliably identify Xtu on wheat seed, plant tissues, and soil samples.*

We tested two molecular assays; the loop mediated isothermal amplification (LAMP) assay and a polymerase chain reaction (PCR) assay for detecting the bacterial pathogen. The LAMP assay, using the protocol described by Langlois et al. (2017), proved successful in detecting *X. translucens* in artificially inoculated wheat and barley seed. A multiplex PCR, designed by the Jacob's lab, at the Ohio State University, was also successful in detecting *X. translucens* and was able to also differentiate the pathovars *X. translucens* pv. *undulosa* and *X.translucens* pv. *translucens*, that cause BLS in wheat and barley, respectively.

These molecular assays were used to test seed that was harvested from artificially inoculated wheat (varieties: Apogee and Mayville) and barley (varieties: Lacey and Pinnacle). In addition, the assays have been used on wheat and barley seed that was artificially inoculated in the lab using a vacuum infiltration method. We were unable to test field seed from 2021 as we had planned. We had planned to use seed from the on-farm variety trials but there was no BLS development this season in any of these trials, likely because of the dry conditions.

In addition to the work using these two assays (LAMP and PCR), we have also been working on developing a quantitative PCR (qPCR) protocol. This protocol has the advantage that it should detect and quantify viable *X. translucens cells*, as opposed to the other methods that detect cells but are unable to determine of those bacteria cells are dead or alive. We expect to get this qPCR test working this winter and expect it may be very helpful in determining the efficacy of any treatments that work by killing bacteria cells.

- *Determine where in the wheat seed the bacteria are surviving.*

We have an experiment, still underway, that is testing a method to artificially inoculate seed heads in the greenhouse with the goal of developing black chaff. Black chaff is caused by the same bacterium that causes BLS, however when the bacterium invades the head, the disease is called black chaff. We plan to use this experimental technique to inoculate heads and later examine the pathogen in association with the seed harvested from these symptomatic heads. This inoculation method will be necessary if we are to use *X. translucens* strains tagged with a fluorescent protein. The fluoresence can then be visualized using microscopy, allowing us to determine where in the seed the bacteria are residing.

This experiment currently underway, is evaluating dipping, spraying, and point-inoculating seed heads with a bacterial suspension. After the seeds have formed and the heads are dried down, serial dilutions to determine bacterial recovery and also the molecular assays we have already validated, to detect bacterial DNA in the seed.

In addition, we have an experiment underway to evaluate the transmission of *X. translucens* from artificially inoculated seed (seed inoculated by vacuum infiltration) into growing tissue within a sterile environment. Our preliminary findings suggest that *X. translucens* is able to move from an infected seed into the coleoptile tissue of wheat and barley after planting. This suggests that there is a pathway for the bacterium to get from the contaminated seed to the seedling. These findings suggest that seed may play a bigger role in the survival of the pathogen and/or BLS development than we previously thought.

- *Examine the efficacy of seed treatments in reducing Xtu in association with seed to determine if seed is important in driving BLS development in a subsequent wheat crop.*

An experiment was undertaken to test the efficacy of dry heat on artificially inoculated wheat and barley seed. Seeds were subject to 72 °C dry heat for 4 days. After the treatment no bacteria was recovered compared to non-heat-treated seed, from which bacteria were readily recovered. Unfortunately, the heat treatment significantly impacted the rate of germination of the seed. We are now examining a greater range of temperatures, along with adjusting the time a seed is treated at a given temperature, to evaluate the effectiveness of dry heat treatments aimed at reducing the contamination of the seed by X*anthomonas* bacteria.

- *Conduct field trials to examine the efficacy of commercial foliar treatments on the control of BLS.*

We conducted a trials examining foliar applications aimed at reducing BLS. While we were able to generate BLS in the inoculated field trials, our findings from the 2021 trials indicated that none of the copper-based treatments had a significant impact on the development of BLS. Further no significant differences in yield, test weight or thousand kernel weights were observed among the treatments. We plan to repeat this trial in 2022, and expand to examine additional treatments.

- *Examine the baseline sensitivity of the Minnesota Xtu population to copper.*

A collection of 230 *Xanthomonas translucens* strains were screened for their capacity to grow on media amended with 150 ug/mL copper sulfate, alongside a positive control. The positive control was a strain of *Xanthomonas campestris* with known copper resistance. *Xanthomonas campestris* is a bacterium that causes plant diseases including; black leg of cruciferous vegetables, bacterial wilt of turfgrass, and bacterial leaf spot of peppers and tomato. Of the 230 *Xanthomonas translucens* strains tested, 81 strains were *X. translucens* pv. *translucens* and 149 were *X. translucens* pv. *undulosa*, the causal agents of BLS on barley and wheat, respectively.

Two *X. translucens* pv. *undulosa* exhibited growth on copper amended media, demonstrating a resistance rate of 1.3% in the population. In addition, five *X. translucens* pv. *translucens* strains exhibited growth on copper amended media, yielding a resistance rate of 6.2%. While the rate of resistance is low that we were able to detect resistance suggests that the pathogen has the capacity to develop resistance to copper. Strains with suspected copper resistance were plated multiple times, with growth on copper amended media only being observed some of the time. This indicated that the resistance we observed may not be stable. Further studies are in progress to examine growth of these copper-resistant strains on media using a wider range of copper sulfate concentrations to help determine the stability of the observed copper resistance in the BLS pathogen.

Applications/Use

Developing effective and durable resistant germplasm to the diseases of economic importance to wheat in Minnesota relies in the development of effective screening methods to identify sources of resistance, to introgress the resistance into adapted germplasm, an understanding of the epidemiology and biology of the pathogens and the use of additional mitigation strategies that can complement host resistance.

Materials and Methods

Bacterial leaf streak (BLS) of wheat, caused by *Xanthomonas translucens* pv. *undulosa* (Xtu), is presently the most important foliar disease of wheat in Minnesota. Managing BLS is difficult as fungicides are ineffective against bacterial pathogens thus host resistance provides the principal disease control strategy. Although host resistance is critical to disease control, there is no known immunity in wheat to the pathogen that incites BLS. This project aimed to develop additional tools that can be used by the grower in the management of BLS.

Validate molecular assays (LAMP and PCR) as tools to rapidly and reliably identify Xtu on wheat seed, plant tissues, and soil samples.

We conducted studies to validate molecular tools (PCR and LAMP assays) that have been developed to identify *Xtu* and determine if these can be used to identify *Xtu*- »

contaminated seed lots. These assays will be corroborated using dilution plating that will determine the bacterial load and confirm if the bacterial DNA detected using the molecular assays is indeed detecting viable bacteria. Initially we used seed from the 2020 field season to complete the preliminary work. The dry conditions of 2021 prevented us from validating the usefulness of this data, as none of the on-farm yield trials developed a significant level of BLS. We hope to be able to validate the data on seed in 2022 and to be able to adapt the technique to detect the bacteria in other matrices (plant tissues and soil). Our goal from this work is to be able to effectively detect contaminated seed lots, plant debris, and soil in commercial settings, such as samples submitted to Plant Disease Clinics or for seed lots that breeding programs ship internationally.

Determine where in the wheat seed the bacteria are surviving.

In this goal we examined where in the wheat seed the bacteria (*Xanthomonas translucens* pv. *undulosa*) are surviving. It is thought that the wheat pathogen *Xtu* is not vascular, meaning it is not able to colonize the vascular tissues of wheat. It has long been assumed that *Xtu* and the closely related bacteriun *Xanthomonas translucens* pv. *translucens (Xtt)*, the causal agent of BLS in barley, are seed-borne and that these pathogens were similar in their abilities to colonize grain. In the project we proposed examining how *Xtu* colonizes wheat seed to determine if the *Xtu* bacterium is surviving inside and/or on the surface of wheat seed.

This information will improve our understanding of *Xtu* survival in seed and provide an indication of the role of seed in driving BLS epidemics. If *Xtu* lacked the ability to enter the interior vascular tissues of the seed, antibacterial seed treatments, such as copper compounds, or physical seed treatments such as the applications of heat, may be useful in reducing seed transmission of this pathogen. We planned to use strains of the bacterium tagged with a fluorescent protein that will allow us to visualize the bacterium in association with the wheat seed. Once we inoculated plants with the tagged strain, we used microscopy to visualize the bacterium in the seed. This work should confirm if *Xtu* is inside the wheat seed and associated with the embryo, or *Xtu* is surviving only on the seed exterior.

Examine the efficacy of seed treatments in reducing Xtu in association with seed to determine if seed is important in driving BLS development in a subsequent wheat crop.

To determine where in the wheat seed the bacteria are surviving, we used naturally infested seed to examine the efficacy of seed treatments in reducing *Xtu* in association with seed. In this project we planned to expand the work to test naturally infected seed from the Minnesota on-farm variety trials and to examine the efficacy of seed treatments in reducing *Xtu* in association with seed.

In addition, we selected a naturally occurring isolate of *Xtu*, with a known sequence type, inoculated seed, using seed infiltration, and then attempted to recover bacteria from the developing seedling/plant, using dilution plating. Once we recovered the bacterium, we identified the recovered strains using Multi Locus Sequence Typing (MLST). Recovery of the same sequence type that we used to inoculate the seed provides evidence that seed is contributing to the development of BLS in the crop grown from infected seed. It does appear that we have demonstrated that Xtu is seedborne. The next step in control is using the molecular assays we have developed to identify infested seed lots. This is useful in reducing the carry forward of the disease from one season to the next and indicated that seed treatments may be efficacious in disease control.

Conduct field trials to examine the efficacy of commercial foliar treatments in the control of BLS.

We undertook field trials in conjunction with Dr Andrew Friskop (NDSU) to examine the impact of commercially available chemical treatments (a.i. copper, applied at flag leaf, heading, and at heading and 10 days after heading) and two biologicals (*Streptomyces* and *Bacillus*; applied both early [at the 3-4 leaf stage] and at the flag leaf stage). In addition, untreated control treatments were included. The trials were inoculated, treated and then BLS development was assessed visually. Yield and test weight was examined in the harvest plots.

Examine the baseline sensitivity of the Minnesota Xtu population to copper.

Copper is the most widely recognized bactericide used to control plant diseases, but is problematic because of its toxicity to the plants, ability to accumulate in the environment. There are also numerous reports of the development of copper resistance strains of *Xanthomonas* in other pathosystems. Using our collection of *Xtu* isolates we determined their baseline sensitivity to copper. We have a sizable *Xtu* collection, and we know that the *Xtu* population on wheat in Minnesota is quite diverse and we have isolates that are representative of that diversity. We selected strains that were representative of the population of *Xtu* found in association with wheat and determined the baseline sensitivity by growing the pathogen on media containing copper, at a range of concentrations. Information on the current sensitivity of the *Xtu* population to copper should allow us to determine if the pathogen already has some resistance to copper and may thus be able to readily adapt to the deployment of copper-based products in the control of BLS. Given the history of many closely related bacteria developing rapid resistance to copper we think this is advisable ahead of recommending any copper-based treatments in the control of BLS.

Economic Benefit to a Typical 500 Acre Wheat Enterprise

We have demonstrated that bacterial leaf streak (BLS) is of economic importance to the wheat industry. Our data on the response of varieties would allow a grower to select wheat varieties for production that are less susceptible to BLS. The development and introgression of host resistance provides economic and environmentally sustainable control of wheat diseases. We have evidence that copper-based products are not likely to provide any reduction in BLS.

The work in this project has contributed to our understanding of the development of BLS and indicates that seed may play an important role in the survival of the pathogen. We expect that in the long term, tools to detect the level of the bacterium in seed lots used in conjunction with treatments to reduce the viability of the bacterium in the seed will provide additional tools in the control of this disease.

Related Research

We have established close relationships with research and extension plant pathologists and the wheat breeding programs (public and private) in Minnesota and in neighboring states.

Recommended Future Research

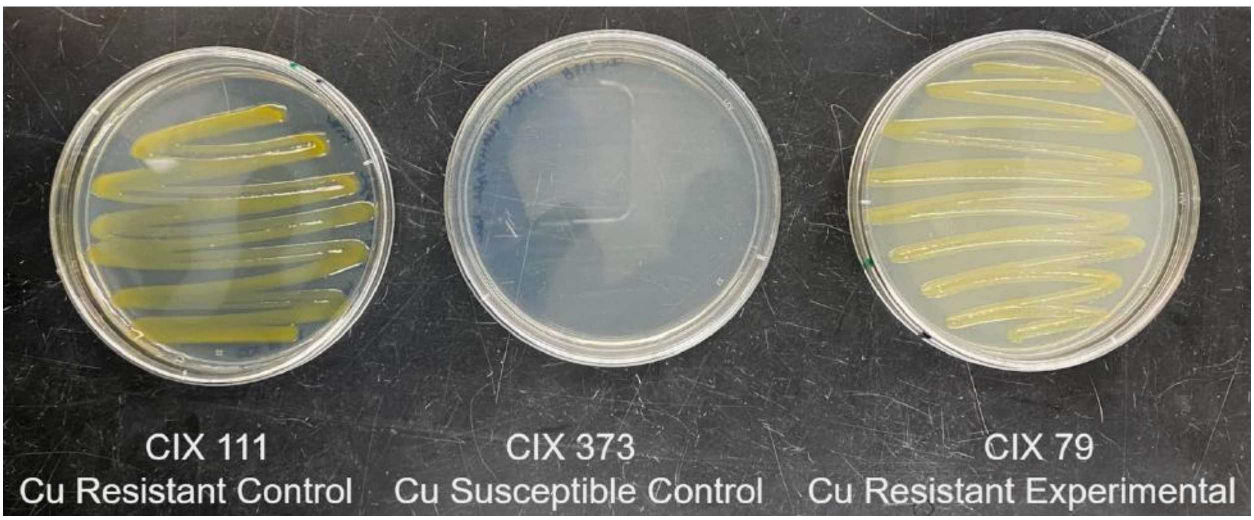
While our initial results suggest that copper-based foliar applications do not reduce BLS we plan to examine additional formulations that we hope may have some efficacy. As we have evidence that seed transmission is important in initiating BLS, we plan to validate this work and examine seed treatments aimed at reducing the viable bacterial cells in association with the seed.

References

Langlois, P. A., Snelling, J., Hamilton, J. P., Bragard, C., Koebnik, R., Triplett, L. R., … Leach, J. E. (2017). Characterization of the *Xanthomonas translucens* complex using draft genomes, comparative genomics, phylogenetic analysis, and diagnostic LAMP assays. *Phytopathology, 107*, 519–527.

Publications

Ledman, K.E., Curland, R.D., Ishimaru, C.A. and Dill-Macky, R., 2020. *Xanthomonas translucens* pv. *undulosa* identified on common weedy grasses in naturally infected wheat fields in Minnesota. Phytopathology, In Press [accepted Nov 13, 2020; Currently available in *Phytopathology, First Look*]
Curland R.D., Gao, L., Hirsch, C.D., and Ishimaru, C.A. 2020. Localized genetic and phenotypic diversity of *Xanthomonas translucens* associated with bacterial leaf streak on wheat and barley in Minnesota. *Phytopathology* 110:257-266.



As part of our work on Bacterial Leaf Streak (BLS) of wheat, we examined resistance to copper in a collection of 230 *Xanthomonas translucens* strains housed at the University of Minnesota. Two strains of *X. translucens* pathovar undulosa, the pathovar that causes BLS of wheat, exhibited growth on a copper amended media. While the rate of resistance to copper was only 1.3%, our findings indicated that there is already resistance to copper in the pathogen population. The detection of copper resistant strains suggests that foliar applications of copper to control BLS may lead to the selection of copper resistance in the pathogen population.
The picture above shows one of the copper resistant strains (right) growing, along with copper resistant (left) and susceptible (middle) controls, on a copper-amended growth media.

Elevated levels of Phosphorus and Potassium in a Long Term Wheat-Soybean Rotation

Dave Grafstrom, Dept. of Agronomy & Plant Genetics, U of M, St. Paul
and Melissa Carlson, Minnesota Wheat Research & Promotion Council

Research Question/Objectives

To compare the effects of elevated P and K fertility over four years of a wheat-soybean rotation.

Treatments

Control - Farmer practice (FP) rate of P and K fertility
Treatment - FP rate of P and K; + 50 additional units of P and K

Methods

The large on-farm large trials were conducted at four wheat sites and one soybean site in NW MN in 2021. The small-plot research conducted at the U of MN Magnusson Research Farm near Roseau, MN. The small plot treatment rates included 0, 20, 40, 60, 80 and 100 units of P and K and combination of P and K. The total number of treatments will be 15 plus an untreated for a total of 16. Wheat results can be found in Table 3 and soybeans in Table 4. The results from the small plot P&K trial can be used to help interpret findings in the large-plot on-farm trials as we continue with this project.

Large-plot Results

Table 1. Yield at large On-Farm P&K fertility trials at four wheat locations in 2021

	Roseau-1	Roseau-2	Roseau-3	Baudette	2021 Mean
Treatment	--------------------Yield/bu/acre ----------------------				
FP	41.9	51.7	61.1	78.0	58.2
FP Plus 50	47.4	57.9	63.8	78.9	62
LSD (0.05)	0.4	NS	NS		
LSD (0.1)	0.3	5.3	NS	NS	
CV (%)	1.0	4.0	10.0	8.6	
FP = P&K rate selected by the farmer cooperator FP Plus 50 = P&K rate selected by farmer cooperator plus an additional 50 units of P&K					

Table 2. Protein at large On-Farm P&K fertility trials at four wheat locations in 2021

	Roseau-1	Roseau-2	Baudette	2021 Mean
Treatment	-------------------Protein % ------------------------			
FP	14.2	16.8	11.8	14.0
FP Plus 50	14.4	17	11.7	14.0
LSD (0.05)	0.1	NS		
LSD (0.1)	0.1	NS	NS	
CV (%)	1.0	6.0	0.9	
FP = P&K rate selected by the farmer cooperator FP Plus 50 = P&K rate selected by farmer cooperator plus an additional 50 units of P&K				

Table 3. Soybean yield and quality at Elbow Lake, MN in 2021

Treatment	Yield (bu/ac)	Protein (%)	Oil (%)	Moisture (%)	TW (lbs/bu)
Control	46.0 -	35.2 a	18.4 -	10.7 b	56.3 a
Treated	47.7 -	34.5 b	16.1 -	10.9 a	54.4 b
LSD (0.10)	NS	0.4	NS	0.1	1.8
CV (%)	3.3	0.6	20.7	0.4	1.9

Table 4. Agronomic Information for Three On-Farm Sites in 2021

	Roseau-1	Roseau-2	Roseau-3	Baudette	Elbow Lake
Crop	Wheat	Wheat	Wheat	Wheat	Soybean
Variety	MN-Washburn	Linkert	MN-Washburn	MN-Washburn	LGS0701XF
Planting Date	4/28/21	4/30/21		5/7/21	5/6/21
Harvest Date	7/30/21	7/31/21		8/14/21	9/18/21
Organic Matter	5.7	3.9	4.4	2.89	4.7
Soil Type	Loam	Sandy Loam	Clay Loam	Clay Loam	Clay Loam
2020 - P ppm	6.5	6	20	17.8	
2020 - K ppm	113	111	379	120.1	

Large Plot Observations

- At the (0.05%) confidence level, there was a 5.5 bu/ac yield advantage from the Plus 50 compared to the farmer practice at the Roseau-1 location. The soil P at this location was 6.5 (low). In 2021, one of three wheat sites (33%) gave a positive response to additional P&K.
- The combined analysis did not show significant differences between treatments at the (0.05) confidence level.
- This trial will be conducted again in 2022. Several more years of research in various environments at additional locations are needed before any conclusions can be drawn from this elevated P&K fertility trial.

Small-plot Results

Wheat-2021					Soil Test Results[4]		Tissue Test Results[5]	
	Added[1]	Yield[2]	Test		P	K	P	K
Trt#	P & K	Bu/Acre	Wt./Bu	Protein[3]	ppm	ppm	%	%
1	0-20-0	72.6	61.9	16.9	5.5	130	0.36	2.9
2	0-40-0	79.6	62.0	16.8	8.5	125	0.39	3.1
3	0-60-0	78.6	62.0	17.0	9.5	125	0.41	2.8
4	0-80-0	80.0	62.0	16.6	12.5	128	0.45	3
5	0-100-0	79.0	61.4	17.0	16.8	119	0.45	2.7
6	0-0-20	64.3	62.2	17.0	4.0	121	0.33	3
7	0-0-40	63.2	61.9	17.3	5.0	127	0.32	3.3
8	0-0-60	60.3	62.1	17.3	4.5	132	0.32	3.6
9	0-0-80	60.7	62.3	17.4	4.8	147	0.3	3.7
10	0-0-100	59.0	62.2	17.1	3.8	136	0.32	4
11	0-20-20	75.9	62.2	17.1	6.0	126	0.35	3.2
12	0-40-40	80.5	61.8	16.8	10.8	135	0.39	3.3
13	0-60-60	82.4	62.2	17.1	12.5	125	0.43	3.5
14	0-80-80	82.8	62.3	17.1	19.5	130	0.43	3.4
15	0-100-100	84.8	62.0	17.1	19.8	139	0.44	3.5
16	0-0-0	60.0	61.7	17.0	3.7	120	0.33	3
LSD @5%level	7	0.6	0.7	3.8	12	0.05	0.3	
LSD @10%level	5.8	0.5	0.6	3.1	10	0.04	0.2	
CV(%)	6.7	0.6	3.0	28	6	9	7	

Experimental Design: RCB with 4 reps
Plots harvested on 07/31/21
Yield[2] - Yields correct to 12% moisture
Soil test results[4] - Soil samples taken after harvest on 08/17/21
Background soil test spring of 2019 - OM-2.8%; pH 8.2; P (Olsen) 6 ppm; K 154 ppm
Soil type - Borup silt loam
Tissue samples[5] - Wheat late tillering on 06/14/21
Plot size= 6' x 15' Harvest area= 5' x 12'
160 pounds of nitrogen applied and incorporated prior to planting

Linkert wheat seeded at 120#/ac on 5/06/21
Added[1] - P source 0-46-0 and K source 0-0-60
Protein[3] - Dry matter basis

Table 4. Soybean - Spring Wheat Fertility Rotation Trial
U of MN, Magnusson Research Farm Roseau, MN

Soybean-2021						Soil Test Results[4]		Tissue Test Results[5]	
	Added[1]	Yield[2]	Test			P	K	P	K
Trt#	P & K	Bu/Acre	Wt./Bu	Protein[3]	Oil[3]	ppm	ppm	%	%
1	0-20-0	46.0	59.7	37.7	20.6	17.0	117	0.48	1.9
2	0-40-0	44.3	59.4	37.9	20.9	17.0	112	0.48	1.7
3	0-60-0	46.3	59.4	37.6	20.8	17.2	120	0.5	1.9
4	0-80-0	48.3	59.5	36.5	21.3	20.5	115	0.5	1.9
5	0-100-0	50.9	59.5	38.5	20.6	27.8	129	0.47	2
6	0-0-20	48.3	59.5	37.3	20.2	10.5	113	0.47	1.9
7	0-0-40	50.7	59.3	36.9	20.9	11.5	137	0.45	2.1
8	0-0-60	54.1	59.4	35.5	21.1	10.8	133	0.48	2.3
9	0-0-80	47.2	59.4	37.4	21.1	12.7	129	0.48	2.2
10	0-0-100	51.7	59.2	37.9	20.7	10.0	125	0.49	2.3
11	0-20-20	48.0	59.3	36.4	21.0	13.0	108	0.49	2.1
12	0-40-40	46.4	59.5	38.6	20.9	14.5	118	0.5	2.1
13	0-60-60	48.2	59.3	35.8	21.1	22.2	131	0.5	2.1
14	0-80-80	51.1	59.5	37.6	20.9	20.5	126	0.47	2.1
15	0-100-100	48.2	59.2	36.9	21.3	27.3	124	0.5	2.2
16	0-0-0	46.0	59.4	38.0	21.2	12.5	110	0.49	1.9
LSD @5%level	7.5	0.4	1.4	0.8	6.0	11	0.03	0.2	
LSD @10%level	6.2	0.3	2.0	0.6	5.0	9	0.02	0.1	
CV(%)	10.8	0.5	3.5	2.6	26	6	5	6	

Experimental Design: RCB with 4 reps
Soybean variety - AG005x1 seeded at 1.4 units/ac; 172,000 PLS/ac on 05/13/21
Plots harvested on 09/13/21
Added[1] - P source 0-46-0 and K source 0-0-60
Yield[2] - Yields correct to 13% moisture
Protein and oil[3] - Dry matter basis
Soil test results[4] - Soil samples taken after harvest on 09/14/21
Soil type - Zippel very fine sandy loam
Background soil test taken -spring of 2019: OM 2.8%; pH 7.8; P (Olsen) 23 ppm: K 166 ppm
Tissue samples[5] - Soybeans early flower on 07/05/21
Plot size= 6' x 15'
Harvest area= 5' x 12'

Background Soil Test Information at Small Plot Sites in 2019

0-6" sample	Site 1	Site 2
	2021 Wheat	2021 Soybeans
OM %	2.8	2.8
PH - 8.2	8.2	7.8
P (Olsen) ppm	6 ppm	23 ppm
K ppm	154 ppm	166 ppm
S ppm	14 lbs/ac	34 lbs/ac
Soluble salts (mmho/cm)	0.23	0.4

Wheat Small Plot Summary

- Soil test values after harvest (untreated) in 2021 for P = 3.7 ppm and K = 120 ppm
- Yields ranged from 60 to 84.8 bu/ac
- All P rates applied alone or in combination with K gave higher wheat yields (0.05% confidence level) than the untreated
- Wheat yields in bu/ac averaged over all P rates = 78, all K rates = 61.5 and the combination of P&K = 81.2 bu/ac compared to the untreated of 60 bu/ac
- Wheat yields from all K treatments applied alone gave similar yields at the untreated
- Test weight ranged from 61.1 to 62.3 #/bu with no treatment difference
- Wheat protein ranged from 16.6 to 17.1% with no treatment differences
- P applied alone or in combination with K increased soil test levels of P
- P soil test increased from 5.5 ppm at 0-20-0 to 16.8 ppm at 0-100-0
- Soil test levels for P tended to increase as the rate of increased from 20 to 100
- K soil test levels tended to increase only with the highest applied rates of K
- All rates of P increased the levels of P in wheat tissue vs untreated
- K rates of 60, 80 and 100 increased K tissue test levels vs untreated
-

Soybean Small Plot Summary

- Soil test values after harvest (untreated) in 2021 for P = 12.5 ppm and K = 110 ppm
- Yields ranged from 46 to 54.1 bu/ac
- Yields generally similar from all treatments compared to the untreated
- Yields in bu/ac averaged over all P rates = 47.2, all K rates = 50.4 and the combination of P&K = 48.4 bu/ac compared to the untreated of 46 bu/ac
- No treatment difference in test weight, protein and oil vs untreated
- P applied alone or in combination generally increased soil test levels for P
- P soil test levels increased with rate
- K soil test levels tended to or increased with all K rates
- No treatment effect in P tissue test levels vs untreated
- Applied K generally increased K tissue levels in the plants

2021 Wheat, Barley, and Oats Variety Performance in Minnesota
- Preliminary Report 24

Preface by Jochum Wiersma

Arid, parched, sere, desertic, xerothermic are a few of the words Merriam-Webster lists to describe Minnesota's 2021 growing season. The moderate drought of the 2020 summer that cut a swath across the state from Lake Traverse to Duluth has spread across much of the state by early winter. By the New Year's eve the whole state was either already abnormally dry or in a moderate drought. Early spring rains partially relieved the drought in the central and northeast part of the state only to immediately worsen again. By the end of June over three quarters of the state was in a moderate drought and already a tenth of the state was in a severe drought. A month later, the situation had further deteriorated with a quarter of the state being classified as in an extreme drought and another half of the state in a severe drought. The Northwest Research & Outreach Center weather records illustrate how parched especially the Red River Valley was with the second driest first half of the year and the driest first nine months of the year ever recorded since record keeping started in 1890. The NWROC weather station also recorded 21 days with daytime high temperatures above 90°F, sharing it's fifteenth overall rank with 2012, 1932, 1929, and 1894.

Stored soil moisture was the saving grace for most of this past season and allowed for a small grains harvest. Both the water holding capacity of the soil and the previous crop's water usage had a tremendous effect on this year's grain yield and probably explains much of the extreme variability in grain yield experienced by individual producers across their farms and between neighbors.

The dry conditions across much of the state allowed for an early start of the field season. By April tenth already a fifth of Minnesota's oat acreage had been seeded. Three weeks later three quarters of the state's spring wheat acreage, oats, and barley had been seeded and just about a quarter of the spring wheat and oats had emerged. All the while temperatures in that same period were well below normal. By mid-May seeding of wheat, barley and oats had all but been completed, and the earliest seeded fields had reached the jointing stage. Both metrics were about a week to two weeks ahead of both 2020 and the 5-year average for each of the three commodities.

The dry conditions allowed for some temperature records to be broken in the last days of May and the first days of June with frost and record lows being reported on May 29th followed by triple digit heat and record highs on June 5th. The widespread frost was of little consequence to the spring cereals but caused some sterility in winter rye that had just started to head. The persistence of the drought and the accompanying low dew points resulted in very little ergot in spite of the increased risk for infections. The lack of moisture meant that not just ergot but most fungal diseases were all but absent. The relative cool start of the season and the dry conditions did, however, allow cereal aphids to reach economic threshold prior to heading in southern and west central Minnesota. Further north the populations exploded in many cases not until after anthesis when economic losses are unlikely. We probably had not seen such high numbers of aphids after anthesis in more than two decades. Tank mixing an insecticide with the fungicide application at anthesis has become routine. The decision not to spray the fungicide meant that those same acres did not receive an insecticide either. This in turn allowed already established populations to explode exponentially during the grain fill period.

Data from US Wheat Associates' US Hard Red Spring Wheat Regional Quality Report indicate an average test weight of nearly 63 lbs./bu, an average grain protein content of 14.0%, and an average vitreous kernel count over 80%, resulting in an average grade of #1 DNS. Values more often seen in western North Dakota than in Minnesota and again a testament to the very unusual growing season. Morever, due to the dry conditions during flowering time, deoxinivananol (DON) was undetectable in the samples collected.

I felt very much on thin ice the whole season when asked about the potential of the crop simply because of the severity of the drought. I felt that the crop could do reasonably well as long as the crop kept its toes in enough water to avoid reaching its wilting point. The low dew points meant that nighttime temperatures and thus respiration losses were low enough that they offset some of decline in photosynthetic output due to photorespiration brought on by temporary heat and drought stress during the heat of the day.

USDA-NASS' initial spring wheat yield forecast for Minnesota on July 1st was 40 bu/acre or 17 bu/acre less than their 2020 forecast. USDA-NASS corrected their forecast upwards with 2 bu/acre one month later. In the September Small Grains Summary USDA-NASS reported Minnesota's average spring wheat yield as 48 bu/acre, 4 bushels lower than last year's state average. The state's average barley yield increased 15% year-over-year to 55.0 bu/acre, while the state average for oat dropped 15% year-over-year to 57 bu/acre. The increase in the average barley yield is probably a testament to the fact that barley uses less water overall than either oats or wheat over the course of the growing season. Acreage of all three commodities dropped to near historic lows with only 55,000, 180,000, and 1.2 million acres of barley, oats, and spring wheat, respectively.

INTRODUCTION

Successful small grain production begins with selection of the best varieties for a particular farm or field. For that reason, varieties are compared in trial plots on the Minnesota Agricultural Experiment Station (MAES) sites at St. Paul, Rosemount, Waseca, Lamberton, Morris, and Crookston. In addition to the six MAES locations, trials are also planted with a number of farmer cooperators. The cooperator plots are handled so factors affecting yield and performance are as close to uniform for all entries at each location as possible.

The MAES 2021 Wheat, Barley, and Oat Variety Performance in Minnesota Preliminary Report 24 is presented under authority granted by the Hatch Act of 1887 to the Minnesota Agricultural Experiment Station to conduct performance trials on farm crops and interpret data for the public.

VARIETY CLASSIFICATIONS

Varieties are listed in the tables alphabetically. Seed of tested varieties can be eligible for certification, and use of certified seed is encouraged. However, certification does not imply a recommendation. The intellectual property rights of the breeders or owners of the variety are listed as either PVP, PVP(pending), PVP(94), patent, or none. PVP protection means that the a variety is protected under the Plant Variety Protection Act for a period of 20 years, while PVP(94) means that the variety is protected for 20 years with the additional stipulation that seed of the variety can only be sold as registered and certified classes of seed. PVP(pending) indicates that the PVP application has been made and that you should consider the variety to have the same intellectual property rights as those provided by PVP(94). The designation 'Patent' means that the variety is protected by a utility patent and that farm-saved seed may be prohibited by the patent holder. The designation 'None' means that the breeder or owner never requested any intellectual property protection or that legal protection has expired. Registered and certified seed is available from seed dealers or from growers listed in the 'Minnesota Crop Improvement Association 2021 Directory', available through the Minnesota Crop Improvement Association office in St. Paul or online at http://www.mncia.org

INTERPRETATION OF THE DATA

The presented data are the preliminary variety trial information for single (2021) and multiple year (2019-2021) comparisons in Minnesota. The yields are reported as a percentage of the location mean, with the overall mean (bu/acre) listed below. Two-year and especially one-year data are less reliable and should be interpreted with caution. In contrast, averages across multiple environments, whether they are different years and/or locations, provide a more reliable estimate of mean performance and are more predictive of what you may expect from the variety the next growing season. The least significant difference or LSD is a statistical method to determine whether the observed yield difference between any two varieties is due to true, genetic differences between the varieties or due to experimental error. If the difference in yield between two varieties equals or exceeds the LSD value, the higher yielding one was indeed superior in yield. If the difference is less, the yield difference may have been due to chance rather than genetic differences,and we are unable to differentiate the two varieties. The 5% or 10% unit indicates that, with either 95% or 90% confidence, the observed difference is indeed a true difference in performance. Lowering this confidence level will allow more varieties to appear different from each other, but also increases the chances that false conclusions are drawn.

THE AUTHORS AND CONTRIBUTORS

This report is written, compiled, and edited by Dr. Jochum Wiersma, Small Grains Specialist. The contributing authors/principal investigators are:

Dr. James Anderson, Wheat Breeder, Department of Agronomy & Plant Genetics, St. Paul. Dr. Kevin Smith, Barley Breeder, Department of Agronomy & Plant Genetics, St. Paul. Dr. Ruth Dill-Macky, Plant Pathologist, Department of Plant Pathology, St. Paul. Dr. James Kolmer, USDA-ARS, Cereal Disease Laboratory, St. Paul. Dr. Matt Rouse, USDA-ARS, Cereal Disease Laboratory, St. Paul. Dr. Brian Steffenson, Plant Pathologist, Department of Plant Pathology, St. Paul. Dr. Yue Jin, USDA-ARS, Cereal Disease Laboratory, St. Paul.

Matt Bickell, Dave Grafstrom, Tom Hoverstad, Michael Leiseth, Houston Lindell, Steve Quiring, Curt Reese, Susan Reynolds, Dimitri von Ruckert, Edward Schiefelbein, Nathan Stuart, Donn Vellekson, and Joe Wodarek supervised fieldwork at the various sites. Special thanks are also due to all cooperating producers.

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SPRING WHEAT

James Anderson, Jochum Wiersma, Susan Reynolds, Nathan Stuart, Houston Lindell, Ruth Dill-Macky, James Kolmer, Matt Rouse, and Yue Jin.

After having been the top acreage variety in Minnesota 5 years running, Linkert dropped to third place with just under 12% of Minnesota's spring wheat acreage. WB9590 was the most widely grown variety this past growing season with 18% of the acreage followed by SY Valda with nearly 13% of the acreage. WB9479 maintained its fourth overall rank. Newcomer NW-Torgy jumped to fifth place with just under 10% of the acreage.

First-time entrants in the 2021 trials were AP Smith, CAG Justify, CAG Reckless, CP3099A, CP3199A, CP3188, MS Cobra, and PFS Buns. Data for AP Gunsmoke CL2 and AP Smith are presented for the first time, but both varieties were tested as experimentals in 2020, so 2 year data is available. Testing of CP3055, CP3903, CP3910, Dyna-Gro Velocity, MS Chevelle, Rollag, SY Ingmar, and WB-Mayville was discontinued. WestBred continues to not test any HRSW varieties in the University of Minnesota variety trial system. WB9479, WB9590, however, were included in the testing in 2021 as they occupied more than 5% of the acreage in 2020.

The results of the variety performance evaluations for spring wheat are summarized in Tables 1 through 7. The varietal characteristics are presented in Tables 1 through 3. Tables 4, 5, and 6 present the relative grain yield of tested varieties in 1, 2, and 3-year comparisons. Table 7 presents the grain yield when fungal pathogens are controlled to the maximum extent possible compared to the same trials without the use of fungicides. The average yield across the six southern testing locations was 56 bu/acre in 2021. This average compares to a southern average of 66 bu/acre in 2020 and a three-year average of 62 bu/acre. The eight northern locations averaged 72 bu/acre in 2021 compared to 75 bu/acre last year and 75 bu/acre for the three-year average. Newcomers CP3099A, CP3119A, and CP3188 were among the highest yielding varieties in single year comparisons in both the north and southern portions of the state. LCS Trigger once again held the top spot for grain yield in the multiple year comparisons. Higher yielding cultivars tend to be lower in grain protein. Variety selection is one approach to avoid discounts for low protein, but N fertility management remains paramount to maximize grain yield and grain protein.

While not seen this past growing season, lodging remains a serious production risk. Varieties with a lodging score of 2 and 3 are considered exceptionally good and will only lodge in extreme cases, while varieties with a rating of 4 or 5 have adequate straw strength most years. Increasing seeding rates generally increases the risk of lodging for all but the strongest and shortest semi-dwarf HRSW varieties. Conversely, lower seeding rates will lower the risk of lodging, but commonly results in lower grain yield potential. Linkert continues to be rated superior for straw strength at a 2, while MS-Washburn is the only public release with a lodging rating of 3. Private releases that have a lodging rating of 3 include AP Smith, MS Barracuda, and all entries in the variety trials of both 21st Century Genetics (TCG) and WestBred.

Varieties with disease ratings of 4 or lower are considered the best defense against a particular disease. Varieties that are rated 7 or higher are likely to suffer significant economic losses under even moderate disease pressure. The foliar disease rating represents the total complex of leaf diseases other than the rusts, and includes the Septoria complex and tan spot. Although varieties may differ from their response to each of those diseases, the rating does not differentiate among them. Therefore, the rating should be used as a general indication and only for varietal selection in areas where these diseases historically have been a problem or if the previous crop is wheat or barley. Control of leaf diseases with fungicides may be warranted, even for those varieties with an above average rating.

Bacterial leaf streak (BLS) cannot be controlled with fungicides. Variety selection of more resistant varieties is the only recommended practice at this time if you have a history of problems with this disease. CP3915, Dyna-Gro Ballistic, Lang-MN, LCS Rebel, LCS Trigger, MN-Torgy, MN-Washburn, ND Frohberg, SY Longmire, SY Valda, and TCG-Spitfire provide the best resistance against BLS.

Lang-MN, LCS Buster, and LCS Trigger provide the best resistance against FHB while another thirteen varieties have a rating of 4 for FHB. Combined, this group of varieties includes some of the top yielders and varieties with higher grain protein.

BARLEY

Kevin Smith, Ruth Dill-Macky, Jochum Wiersma, Brian Steffenson, Karen Beaubien and Ed Schiefelbein

The results of the variety performance evaluations for spring barley are summarized in Tables 8 through 12. The varietal characteristics and disease reactions are presented in Tables 8 and 9. Tables 10 through 12 present the relative grain yield of the tested varieties in single and multiple year comparisons.The average yield across the 13 testing locations was 80 bu/acre in 2021 (Table 12). This is down from a state average of 95 bu/A in 2020. No doubt this is at least in part due to the extreme heat in June and subsequent drought in many parts of the state. The highest yields this year were recorded in Stephen with 114 bu/A (Table 10) while the lowest grain yields were recorded in Becker with 29 bu/A (Table 11).

This year's report contains several new entries that have only been tested in 2021. As always, one should exercise caution interpreting data from a single year. This is particularly true for this past year with extreme weather which may not be representative of future years.
Given that caveat, BC Ellinor and BC Leandra were the highest yielding varieties based on the 2021 state average (Table 12). In general, the six-row varieties, with the exception of Quest, had lower stem breakage. Grain protein content varied between 11.2% and 12.9% with values not available for newer entries in the trial. Brewers in general require low grain protein with all-malt brewers desiring less protein than adjunct brewers.

Table 9 describes the reaction of this year's entries to four major diseases in the region. Disease reaction is based on data from at least two experiments and scored from 1–9; where 1 is most resistant and 9 is most susceptible. Net blotch can be an important disease, however we have only obtained useful data in 2020 which is not presented since it is only a single year of data. It is notable that Pinnacle is highly susceptible to net blotch. Conlon continues to be the variety with the best resistance to Fusarium head blight expressed as lower concentrations of vomitoxin or DON. All the varieties tested are susceptible to the QCC race of stem rust which has not been identified as a threat in the Midwest yet. All listed varieties carry stem rust resistance to the predominate Puccinia graminis f. sp. tritici race (MCCF). Most varieties possess pre-heading resistance to stem rust; thus, they will not likely incur much damage unless the disease epidemic is severe. Bacterial Leaf Streak (BLS) cannot be controlled by fungicides and there are some differences in resistance among the current varieties.

OATS

Kevin P. Smith, Ruth-Dill-Macky, Dimitri von Ruckert, Karen Beaubien, Jochum Wiersma

Entries in the state oat variety trial were evaluated in 14 locations. In addition, entries were evaluated for disease resistance to crown rust, barley yellow dwarf virus (BYDV), and smut in dedicated, inoculated nurseries. This past summer, we observed no crown rust in our nursery in St. Paul due to extreme heat and drought. Therefore, the crown rust ratings are based on data from previous years. The results of the variety evaluations are summarized in Tables 13 to 17. The origin and agronomic characteristics of the tested oat varieties are listed in Table 13. Maturity, height, and test weight data are presented as statewide averages from 2019-2021 except where noted. Lodging data is also a statewide average from the same period, but only from locations where lodging was present. Maturity, height, and lodging are important considerations for variety selection based on the intended location and expected end use of the crop.

Crown rust continues to be a major limiting factor to oat production in Minnesota that must be managed to achieve optimal yield. Buckthorn (Rhamnus cathartica L.), the alternate host of crown rust is widespread in Minnesota, allowing for a persistent and particularly aggressive pathogen population. Rust in all yield trials was managed through treatment with a propiconazole-based fungicide when the flag leaf was fully extended (Feekes 9) to evaluate the yield potential with little to no disease. Crown rust and other disease resistance ratings are listed in Table 14. All disease scores were converted to a 1- 9 scale. A score of 1 is very resistant and a score of 9 is very susceptible. The most economical way of controlling crown rust is through resistant varieties; however, application of fungicide to a variety with rating of 4 or greater is prudent if crown rust is present in the lower canopy at Feekes 9. Deon,Saddle and Warrior appear to be the best varieties for crown rust resistance.

Other important diseases include BYDV and smut which were evaluated in inoculated nurseries at the University of Illinois and the University of Minnesota, respectively. We observed little difference among the tested varieties for resistance to BYDV. A seed treatment and certified seed should be used to manage smut. Choose the varieties with the lowest disease ratings in an organic production system and plant as early as possible to reduce the risk of yield losses caused by BYDV or crown rust.

For grain production, lodging and grain quality traits should be considered when choosing a variety (Table 13). Oat varieties with high protein and low oil are preferred in the food market. High test weight, as a proxy for milling yield, is very important in both the food and feed markets. Contact your local elevator or buyer and ask whether they prefer particular varieties.

Tables 15 through 17 present the relative grain yield of the tested varieties in single and multiple year comparisons. For 2021, the highest yields were in Crookston and the lowest yields in Waseca. Hayden followed by Deon and MN-Pearl were the top yielding varieties in statewide averages for 2021. These same three varieties performed well in both the northern and southern regions in 2021. However, some varieties perform differently in the north and south. In general, earlier maturing varieties perform better in southern Minnesota because flowering can occur when it is cooler. Similarly, later performing varieties tend to perform better in northern Minnesota.

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Tables # 1 - 17 can be found on pages 70 - 95 »

Table 1. Origin and agronomic characteristics of hard red spring wheat varieties in Minnesota in single-year (2021) and multiple-year comparisons.

Entry	Origin[1]	Legal Status	Desired Stand (Plants/Acre)[2]	Days to Heading[3]	Height Inches[3]	Straw Strength[4]
AP Gunsmoke CL2[5]	2021 AgriPro/Syngenta	PVP (94) (pending)	1.3	55.6	26.2	4–5
AP Murdock	2020 AgriPro/Syngenta	PVP (94) (pending)	1.3	55.3	25.2	5
AP Smith	2021 AgriPro/Syngenta	PVP (94) (pending)	1.3	58.1	24.7	2–3
Bolles	2015 MN	PVP (94)	1.3	58.4	28.3	4
CAG Justify	2021 Champions Alliance Group	PVP (94) (pending)	1.3	57.5	26.8	–
CAG Reckless	2021 Champions Alliance Group	PVP (94) (pending)	1.3	56.3	27.3	–
CP3099A	2020 CROPLAN by WinField United	PVP (94) (pending)	1.3	60.9	27.0	–
CP3119A	2021 CROPLAN by WinField United	PVP (94) (pending)	1.3	61.0	26.3	–
CP3188	2020 CROPLAN by WinField United	PVP (94) (pending)	1.3	56.1	27.7	–
CP3530	2015 CROPLAN by WinField United	Patented	1.3	58.1	28.3	5
CP3915	2019 CROPLAN by WinField United	PVP (94) (pending)	1.3	57.2	26.3	4
Driver	2020 SDSU	PVP (94) (pending)	1.3	57.7	28.2	4
Dyna-Gro Ambush	2016 Dyna-Gro	PVP (94)	1.4	54.5	26.9	4
Dyna-Gro Ballistic	2018 Dyna-Gro	PVP (94)	1.1	57.0	26.3	5
Dyna-Gro Commander	2019 Dyna-Gro	PVP (94)	1.4	54.9	25.9	4
Lang-MN	2017 MN	PVP (94)	0.9	56.9	26.6	4
LCS Buster	2020 Limagrain Cereal Seeds	PVP (94) (pending)	1.3	60.0	27.7	5
LCS Cannon	2018 Limagrain Cereal Seeds	PVP (94)	1.3	53.5	25.5	4
LCS Rebel	2017 Limagrain Cereal Seeds	PVP (94)	1.3	55.0	27.8	6
LCS Trigger	2016 Limagrain Cereal Seeds	PVP (94)	1.3	60.2	26.4	5
Linkert	2013 MN	PVP (94)	1.3	55.2	25.8	2
MN-Torgy	2020 MN	PVP (94) (pending)	1.3	55.7	25.6	4
MN-Washburn	2019 MN	PVP (94)	1.3	57.3	25.3	3
MS Barracuda	2018 Meridian Seeds	PVP (94)	1.3	53.3	26.0	3
MS Cobra	2022 Meridian Seeds	PVP (94) (pending)	1.3	55.3	26.9	–
MS Ranchero	2020 Meridian Seeds	PVP (94) (pending)	1.3	54.8	26.1	4–5
ND Frohberg	2020 NDSU	PVP (94) (pending)	1.3	56.8	28.2	4–5
PFS-Buns	2021 Peterson Farms Seed	PVP (94) (pending)	1.3	62.0	24.7	–
Prosper	2011 NDSU	PVP (94)	1.3	57.8	28.5	6
Shelly	2016 MN	PVP (94)	1.3	57.9	26.3	5
SY 611 CL2[5]	2019 AgriPro/Syngenta	PVP (94)	1.3	56.1	24.9	4
SY Longmire[6]	2019 AgriPro/Syngenta	PVP (94)	1.3	56.9	26.1	4
SY McCloud	2019 AgriPro/Syngenta	PVP (94)	1.3	55.4	26.1	4
SY Valda	2015 AgriPro/Syngenta	PVP (94)	1.3	56.9	25.4	5
TCG-Heartland	2019 21st Century Genetics	PVP (94), Patent pending	1.6	54.3	24.9	3
TCG-Spitfire	2016 21st Century Genetics	PVP (94)	1.5	59.2	26.4	3
TCG-Wildcat	2020 21st Century Genetics	PVP (94) (pending), Patent pe	1.5	57.7	26.9	3
WB9479	2017 WestBred	Patented, PVP (94)	1.3	54.3	24.3	3
WB9590	2017 WestBred	Patented, PVP (94)	1.3	54.7	23.6	3
Mean				57.0	26.2	

[1] Abbreviations: MN = Minnesota Agricultural Experiment Station; NDSU = North Dakota State University Research Foundation; SDSU = South Dakota Agricultural Experiment

[2] Our standard seeding rate is designed to achieve a desired stand of 1.3 million plants/acre, assuming a 10% stand loss and adjusting for the germination percentage and seed weight of each variety.

[3] 2021 data

[4] 1-9 scale in which 1 is the strongest straw and 9 is the weakest. Based on 2014-2021 data. The rating of newer entries may change by as much as one rating point as more data are collected.

[5] AP Gunsmoke CL2 and SY 611 CL2 have tolerance to Beyond® herbicide.

[6] SY Longmire has solid stems.

Table 2. Grain quality of hard red spring wheat varieties in Minnesota in single-year (2021) and multiple-year comparisons.

	Test Weight (lb/Bu)		Protein (%)[1]		Baking	Pre-Harvest
Entry	**2021**	**2 yr**	**2021**	**2 yr**	**Quality[2]**	**Sprouting[3]**
AP Gunsmoke CL2	60.8	60.0	15.0	15.3	–	3
AP Murdock	60.9	60.3	14.8	14.8	5	1
AP Smith	61.5	60.5	15.0	15.2	–	4
Bolles	61.2	60.1	16.5	16.6	1	1
CAG Justify	59.3	–	14.0	–	–	3
CAG Reckless	62.3	–	14.9	–	–	4
CP3099A	59.2	–	12.8	–	–	1
CP3119A	57.1	–	13.3	–	–	3
CP3188	59.6	–	13.3	–	–	3
CP3530	60.8	60.1	15.0	15.1	3	1
CP3915	62.2	61.4	15.0	15.0	4	1
Driver	63.1	61.8	14.0	14.4	–	3
Dyna-Gro Ambush	62.4	61.9	14.9	15.0	2	3*
Dyna-Gro Ballistic	61.1	60.2	14.0	14.1	5	3*
Dyna-Gro Commander	62.1	61.0	14.7	14.9	6	1
Lang-MN	61.8	61.1	15.0	15.2	3	1
LCS Buster	59.1	58.2	12.8	12.8	–	4
LCS Cannon	63.4	62.1	14.6	14.6	4	3*
LCS Rebel	63.0	62.1	15.0	15.1	3	5
LCS Trigger	61.0	60.5	13.4	13.1	7	1
Linkert	62.6	61.4	15.9	15.8	1	1
MN-Torgy	62.4	61.2	15.3	15.2	4	1
MN-Washburn	61.6	60.7	14.4	14.6	3	1
MS Barracuda	62.1	61.0	14.9	15.1	4	3
MS Cobra	62.3	–	14.8	–	–	4
MS Ranchero	61.1	59.7	14.0	14.4	–	4
ND Frohberg	62.1	61.3	14.8	14.9	–	4
PFS-Buns	58.8	–	14.4	–	–	4
Prosper	61.1	60.3	14.2	14.3	5	1
Shelly	62.2	60.9	14.1	14.2	5	1
SY 611 CL2	62.3	61.3	14.7	15.0	6	2*
SY Longmire	62.0	60.8	14.9	15.1	3	2*
SY McCloud	63.0	62.0	15.6	15.6	3	2*
SY Valda	62.0	61.1	14.2	14.5	6	2
TCG-Heartland	62.6	61.8	15.3	15.5	2	2
TCG-Spitfire	60.8	60.3	14.2	14.2	3	3*
TCG-Wildcat	62.2	61.4	14.7	15.1	–	1
WB9479	62.0	61.2	15.7	15.8	2	1
WB9590	61.9	60.9	15.4	15.5	4	1
Mean	61.5	60.9	14.6	14.9		
No. Environments	11	21	11	21		

[1] 12% moisture basis.

[2] 2014-2020 crop years, where applicable

[3] 1-9 scale in which 1 is best and 9 is worst. Values of 1-2 should be considered as resistant. Falling number data was collected from nine 2019 locations. Varieties with an * following their pre-harvest sprouting rating had lower than expected falling numbers based on their PHS rating.

Table 3. Disease reactions[1] of hard red spring wheat varieties in Minnesota in multiple-year comparisons.

Entry	Leaf Rust	Stripe Rust[2]	Stem Rust[3]	Bacterial Leaf Streak[4]	Other Leaf Diseases[5]	Scab
AP Gunsmoke CL2	3	–	1	7	6	4
AP Murdock	3	–	1	4	6	7
AP Smith	6	–	1	4	4	6
Bolles	2	1	2	4	3	5
CAG Justify	–	–	2	–	–	–
CAG Reckless	–	–	1	–	–	–
CP3099A	–	–	8	–	–	–
CP3119A	–	–	2	–	–	–
CP3188	–	–	6	–	–	–
CP3530	3	3	1	4	4	4
CP3915	1	–	1	2	5	4
Driver	3	–	1	3–4	5	4
Dyna-Gro Ambush	2	–	2	5	4	4
Dyna-Gro Ballistic	3	–	3	3	5	5
Dyna-Gro Commander	2	–	1	4	6	5
Lang-MN	1	–	2	3	4	3
LCS Buster	2	–	1	4	3	3
LCS Cannon	3	–	2	5	7	4
LCS Rebel	6	–	2	3	4	4
LCS Trigger	1	–	2	2	3	3
Linkert	3	1	1	5	4	5
MN-Torgy	3	–	1	3	3	4
MN-Washburn	1	2	1	3	3	4
MS Barracuda	6	–	2	7	5	5
MS Cobra	–	–	1	–	–	–
MS Ranchero	1	–	1	6–7	3	4
ND Frohberg	3	–	1	3	4	5
PFS-Buns	–	–	1	–	–	–
Prosper	6	5	2	4	4	5
Shelly	3	1	2	6	4	4
SY 611 CL2	3	–	5	4	4	4
SY Longmire	5	–	1	3	5	7
SY McCloud	3	–	1	5	5	5
SY Valda	1	2	1	3	4	4
TCG-Heartland	3	–	2	5	5	6
TCG-Spitfire	4	–	2	3	4	5
TCG-Wildcat	3	–	3	6–7	7	6
WB9479	6	–	2	6	5	7
WB9590	6	–	2	6	6	7

[1] 1-9 scale where 1=most resistant, 9=most susceptible.

[2] Based on natural infections in 2015 at Kimball, Lamberton, and Waseca.

[3] Stem rust levels have been very low in production fields in recent years, even on susceptible varieties.

[4] Bacterial leaf streak symptoms are highly variable from one environment to the next. The rating of entries may change as more data is collected.

[5] Combined rating of tan spot and septoria.

NOTES

Table 4. Relative grain yield of hard red spring wheat varieties in northern Minnesota locations in single-year (2021)

	Crookston			Fergus Falls			Hallock			Oklee		
Entry	**2021**	**2 Yr**	**3 Yr**	**2021**	**2 Yr**	**3 Yr**	**2021**	**2 Yr**	**3 Yr**	**2021**	**2 Yr**	**3 Yr**
AP Gunsmoke CL2	107	106	–	100	101	–	102	101	–	107	113	–
AP Murdock	92	100	104	89	94	97	92	95	101	86	100	103
AP Smith	99	98	–	106	101	–	100	95	–	101	98	–
Bolles	90	92	96	99	96	95	88	91	94	91	91	92
CAG Justify	89	–	–	111	–	–	109	–	–	106	–	–
CAG Reckless	113	–	–	107	–	–	105	–	–	103	–	–
CP3099A	87	–	–	120	–	–	113	–	–	140	–	–
CP3119A	110	–	–	115	–	–	100	–	–	116	–	–
CP3188	112	–	–	107	–	–	102	–	–	106	–	–
CP3530	74	84	91	99	98	100	93	102	102	90	96	96
CP3915	86	95	100	95	98	102	108	99	99	94	91	96
Driver	99	99	–	108	107	–	103	108	–	121	114	–
Dyna-Gro Ambush	118	111	108	107	103	103	96	100	100	89	98	100
Dyna-Gro Ballistic	96	101	105	106	107	110	102	102	105	116	110	112
Dyna-Gro Commander	104	98	100	98	100	101	96	99	101	96	98	100
Lang-MN	104	101	100	91	97	97	98	100	98	89	93	96
LCS Buster	90	97	–	107	112	–	106	108	–	111	120	–
LCS Cannon	87	93	97	92	95	99	103	96	100	101	103	104
LCS Rebel	94	96	100	101	102	99	92	99	99	119	105	104
LCS Trigger	96	106	111	96	109	110	102	114	113	102	111	115
Linkert	111	100	98	92	94	93	104	100	99	78	86	89
MN-Torgy	104	105	103	98	103	104	99	96	100	94	101	102
MN-Washburn	89	94	97	88	95	98	101	99	100	96	97	100
MS Barracuda	81	88	93	94	95	95	102	98	97	111	106	107
MS Cobra	99	–	–	109	–	–	101	–	–	89	–	–
MS Ranchero	127	113	–	95	95	–	101	104	–	100	102	–
ND Frohberg	119	105	–	97	101	–	89	88	–	104	101	–
PFS-Buns	105	–	–	98	–	–	98	–	–	116	–	–
Prosper	94	102	105	109	110	110	102	103	102	103	107	107
Shelly	98	102	105	109	109	112	103	106	108	102	104	105
SY 611 CL2	92	97	100	113	108	107	106	98	101	102	107	106
SY Longmire	92	94	98	101	99	102	95	94	96	98	95	99
SY McCloud	109	99	98	95	98	98	104	103	100	99	101	99
SY Valda	94	98	102	96	101	99	105	106	108	109	105	106
TCG-Heartland	101	101	100	92	97	96	93	90	90	95	94	94
TCG-Spitfire	95	102	103	118	112	110	106	98	98	92	99	101
TCG-Wildcat	88	95	–	107	104	–	100	98	–	101	99	–
WB9479	97	104	–	89	94	–	90	96	–	96	101	–
WB9590	98	106	–	102	102	–	93	106	–	90	98	–
Mean (Bu/Acre)	57.8	64.1	68.6	74.9	78.3	79.7	72.0	68.8	74.3	69.7	74.7	71.0
LSD (0.10)	24.2	14.0	9.4	11.0	8.7	6.7	9.8	12.6	7.9	17.6	14.0	9.9

and multiple-year comparisons (2019-2021).

Perley			Roseau			Stephen			Strathcona		
2021	**2 Yr**	**3 Yr**	**2021**	**2 Yr**	**3 Yr**	**2021**	**2 Yr**	**3 Yr**	**2021**	**2 Yr**	**3 Yr**
107	100	–	101	100	–	102	101	–	108	100	–
98	103	106	95	101	104	89	105	105	95	109	109
98	97	–	95	99	–	103	105	–	106	95	–
104	102	98	99	97	94	89	91	94	90	87	89
107	–	–	102	–	–	103	–	–	100	–	–
103	–	–	105	–	–	108	–	–	105	–	–
103	–	–	110	–	–	121	–	–	98	–	–
92	–	–	122	–	–	128	–	–	99	–	–
107	–	–	106	–	–	111	–	–	104	–	–
95	99	102	106	100	101	108	102	102	100	105	102
100	98	96	93	105	107	88	95	102	103	92	95
108	109	–	101	99	–	103	106	–	105	98	–
103	105	98	104	98	95	90	99	98	105	105	104
98	102	101	102	110	110	106	107	108	100	96	99
101	97	103	104	101	104	98	103	103	111	106	103
96	96	97	88	95	96	105	97	98	94	105	105
108	113	–	103	112	–	109	113	–	99	106	–
104	108	111	110	101	103	109	101	104	110	105	103
93	100	102	103	107	106	85	91	96	111	107	106
103	113	113	96	107	111	108	110	111	99	106	110
88	89	88	88	89	89	101	92	93	98	89	89
104	100	100	93	98	101	101	108	106	102	103	103
99	98	99	103	88	92	90	94	97	94	82	88
101	92	96	105	96	97	94	93	96	112	110	108
102	–	–	104	–	–	95	–	–	104	–	–
102	101	–	105	108	–	91	104	–	100	114	–
96	94	–	100	96	–	96	91	–	104	100	–
111	–	–	107	–	–	113	–	–	85	–	–
109	105	100	106	107	105	114	113	110	93	95	100
91	92	94	100	95	101	103	99	103	105	109	107
98	98	96	101	103	102	95	99	104	103	97	100
100	98	91	95	92	93	106	103	105	99	83	89
95	96	95	106	102	101	93	85	92	100	101	100
96	101	99	107	102	109	110	115	116	102	105	106
78	94	98	101	98	96	87	98	98	99	93	92
116	111	111	98	99	104	106	101	102	106	101	100
107	104	–	101	104	–	92	104	–	111	106	–
99	92	–	92	92	–	89	96	–	103	102	–
98	103	–	101	103	–	87	90	–	100	105	–
85.3	76.4	73.8	90.7	89.5	87.9	68.6	70.6	73.8	60.2	65.4	68.0
10.4	11.8	10.8	9.0	14.2	11.0	12.6	14.8	9.9	6.3	15.9	10.5

Table 5. Relative grain yield of hard red spring wheat varieties in southern Minnesota

	Becker[1]		Benson			Le Center		
Entry	**2021**	**2 Yr**	**2021**	**2 Yr**	**3 Yr**	**2021**	**2 Yr**	**3 Yr**
AP Gunsmoke CL2	104	–	96	100	–	110	106	–
AP Murdock	104	112	89	93	99	93	101	106
AP Smith	92	–	103	104	–	102	98	–
Bolles	79	83	102	100	100	89	87	87
CAG Justify	87	–	112	–	–	88	–	–
CAG Reckless	125	–	99	–	–	96	–	–
CP3099A	103	–	113	–	–	90	–	–
CP3119A	123	–	108	–	–	105	–	–
CP3188	108	–	110	–	–	109	–	–
CP3530	95	103	101	107	111	109	106	110
CP3915	109	102	99	94	99	95	96	95
Driver	104	–	109	103	–	100	98	–
Dyna-Gro Ambush	91	103	104	104	99	110	107	109
Dyna-Gro Ballistic	112	109	94	105	105	104	104	103
Dyna-Gro Commander	112	109	111	112	105	106	104	102
Lang-MN	98	98	90	95	95	99	97	99
LCS Buster	125	–	103	105	–	99	103	–
LCS Cannon	101	111	111	101	96	111	111	110
LCS Rebel	96	101	103	101	100	97	99	98
LCS Trigger	116	111	106	118	118	116	112	114
Linkert	98	100	92	97	93	100	94	91
MN-Torgy	105	102	102	102	104	105	106	106
MN-Washburn	94	92	96	93	93	100	102	100
MS Barracuda	93	106	95	95	94	109	108	107
MS Cobra	96	–	94	–	–	105	–	–
MS Ranchero	92	–	111	102	–	102	96	–
ND Frohberg	101	–	109	104	–	102	99	–
PFS-Buns	100	–	106	–	–	102	–	–
Prosper	111	104	105	105	104	104	106	104
Shelly	97	100	103	107	103	105	106	103
SY 611 CL2	104	105	106	98	102	96	91	93
SY Longmire	107	90	99	94	97	96	94	92
SY McCloud	83	92	96	93	91	103	100	96
SY Valda	95	102	97	102	106	105	105	110
TCG-Heartland	92	100	88	95	97	97	96	93
TCG-Spitfire	107	103	111	109	114	106	103	105
TCG-Wildcat	108	–	96	96	–	103	103	–
WB9479	89	–	96	92	–	103	99	–
WB9590	86	–	97	98	–	101	105	–
Mean (Bu/Acre)	42.4	60.1	60.8	72.7	81.2	70.9	74.8	69.8
LSD (0.10)	19.2	16.0	11.0	10.8	10.4	8.0	8.4	8.0

[1] 2020 Becker was discarded due to drought. 2 yr data is the mean of 2021 Becker and 2019 Kimball

[2] 2021 Waseca was discarded due to excessive within trial variation. 2 year is the mean of 2019 and 2020.

locations in single-year (2021) and multiple-year compaisons (2019-021).

Lamberton			Morris			St. Paul			Waseca[2]
2021	2 Yr	3 Yr	2021	2 Yr	3 Yr	2021	2 Yr	3 Yr	2 Yr
106	91	–	105	103	–	89	94	–	–
99	100	104	91	98	99	110	109	112	123
103	101	–	104	108	–	105	99	–	–
90	96	91	101	100	99	101	99	100	99
99	–	–	128	–	–	106	–	–	–
99	–	–	103	–	–	109	–	–	–
119	–	–	135	–	–	92	–	–	–
110	–	–	125	–	–	91	–	–	–
121	–	–	125	–	–	107	–	–	–
100	99	102	95	95	102	103	103	106	103
100	103	104	97	100	104	77	82	86	84
118	113	–	106	106	–	103	102	–	–
95	94	99	65	87	91	118	112	113	114
97	103	106	107	107	111	84	97	98	108
96	99	98	101	109	111	119	111	110	114
96	94	99	98	101	98	115	106	105	106
102	109	–	95	106	–	111	105	–	–
101	102	100	68	91	94	115	118	115	113
104	106	105	113	105	103	107	106	100	109
117	119	121	124	129	123	122	111	109	116
94	92	91	91	91	91	101	101	99	91
95	104	103	104	107	108	112	105	104	106
96	100	97	111	102	100	102	95	101	101
99	100	91	71	81	84	116	114	113	101
100	–	–	101	–	–	114	–	–	–
97	95	–	90	96	–	103	109	–	–
97	98	–	103	106	–	102	103	–	–
99	–	–	112	–	–	85	–	–	–
97	107	109	120	112	115	88	99	98	95
102	101	95	109	112	109	117	106	107	102
102	97	95	92	93	98	89	96	92	96
107	109	106	114	105	96	63	78	81	71
98	90	94	81	86	91	92	100	99	94
104	100	102	99	100	101	101	99	100	110
97	96	91	88	87	90	91	97	101	101
118	122	124	104	117	116	95	96	100	94
114	110	–	106	103	–	110	104	–	–
86	88	–	86	89	–	92	95	–	–
104	103	–	86	91	–	96	103	–	–
60.1	61.6	49.1	54.7	50.7	55.8	48.1	61.3	64.8	44.3
17.5	14.3	13.6	18.7	18.3	14.5	8.9	10.6	8.8	15.6

Table 6. Relative grain yield of hard red spring wheat varieties in Minnesota in single-year (2021) and multiple-year comparisons (2019-2021).

	State			North			South		
Entry	**2021**	**2 Yr**	**3 Yr**	**2021**	**2 Yr**	**3 Yr**	**2021**	**2 Yr**	**3 Yr**
AP Gunsmoke CL2	103	101	–	104	102	–	102	100	–
AP Murdock	94	101	104	92	101	103	97	101	106
AP Smith	101	99	–	101	98	–	102	101	–
Bolles	94	94	94	94	93	94	94	95	95
CAG Justify	104	–	–	104	–	–	103	–	–
CAG Reckless	105	–	–	106	–	–	104	–	–
CP3099A	111	–	–	112	–	–	109	–	–
CP3119A	110	–	–	110	–	–	110	–	–
CP3188	109	–	–	107	–	–	114	–	–
CP3530	98	100	102	96	98	99	101	101	106
CP3915	96	96	98	96	97	99	96	95	97
Driver	106	105	–	106	105	–	107	104	–
Dyna-Gro Ambush	100	102	102	101	102	100	97	102	104
Dyna-Gro Ballistic	102	104	106	103	105	106	100	104	105
Dyna-Gro Commander	103	103	103	101	100	102	107	108	106
Lang-MN	96	98	99	95	98	98	99	99	99
LCS Buster	105	109	–	104	110	–	105	108	–
LCS Cannon	102	102	103	103	100	102	102	106	105
LCS Rebel	101	102	101	100	101	101	103	103	102
LCS Trigger	106	113	113	100	109	111	116	118	116
Linkert	95	93	92	94	92	92	96	95	94
MN-Torgy	101	102	103	99	101	102	104	104	105
MN-Washburn	97	95	97	96	93	96	100	99	98
MS Barracuda	99	98	99	100	97	98	98	100	99
MS Cobra	101	–	–	101	–	–	102	–	–
MS Ranchero	101	103	–	102	105	–	100	99	–
ND Frohberg	101	99	–	100	97	–	102	102	–
PFS-Buns	103	–	–	104	–	–	101	–	–
Prosper	104	105	105	104	105	105	104	105	105
Shelly	103	103	104	101	102	104	105	105	103
SY 611 CL2	100	99	100	101	101	102	98	95	97
SY Longmire	98	95	95	98	95	96	98	95	92
SY McCloud	98	96	96	100	98	97	93	93	94
SY Valda	102	103	105	103	104	105	100	101	104
TCG-Heartland	93	95	95	93	96	95	93	95	96
TCG-Spitfire	106	105	106	105	103	103	107	108	109
TCG-Wildcat	103	102	–	101	102	–	106	103	–
WB9479	94	95	–	94	97	–	93	93	–
WB9590	96	101	–	96	102	–	96	100	–
Mean (Bu/Acre)	65.4	68.1	69.0	72.4	73.6	74.9	56.2	60.9	61.6
LSD (0.10)	5.1	3.5	2.8	6.2	4.5	3.3	8.9	5.4	4.7
No. Environments	14	28	43	8	16	24	6	12	19

NOTES

Table 7. Grain yield (bushels per acre) of hard red spring wheat varieties grown under

	North						South	
	2021		2-year		3-year		2021	
Entry	Conv	Int	Conv	Int	Conv	Int	Conv	Int
AP Gunsmoke CL2	76.6	83.5	78.8	83.9	–	–	60.4	70.6
AP Murdock	69.7	71.2	77.2	81.3	81.3	84.2	54.6	61.6
AP Smith	71.6	73.7	75.7	75.4	–	–	59.6	68.0
Bolles	70.9	74.9	72.6	73.9	74.1	74.9	54.4	61.3
CAG Justify	71.7	88.8	–	–	–	–	64.7	70.2
CAG Reckless	80.5	81.9	–	–	–	–	57.9	61.1
CP3099A	75.0	88.2	–	–	–	–	72.6	87.6
CP3119A	87.3	101.0	–	–	–	–	67.3	77.7
CP3188	80.4	89.2	–	–	–	–	70.7	73.7
CP3530	69.3	75.9	71.6	80.9	75.5	84.1	56.0	64.5
CP3915	66.9	81.4	77.3	83.9	81.2	85.3	56.6	67.7
Driver	74.4	88.1	76.1	80.6	–	–	64.5	65.7
Dyna-Gro Ambush	81.0	78.4	79.3	77.5	78.9	76.6	46.1	64.4
Dyna-Gro Ballistic	73.7	87.3	81.5	84.3	84.5	88.9	58.3	66.8
Dyna-Gro Commander	77.3	83.0	76.8	80.2	80.0	83.1	56.6	64.8
Lang-MN	69.8	73.3	74.8	76.6	76.7	80.0	55.5	65.0
LCS Buster	72.4	87.8	81.2	87.2	–	–	56.9	78.6
LCS Cannon	75.1	82.3	74.9	80.4	78.4	82.9	49.0	71.6
LCS Rebel	73.9	82.2	78.4	79.7	80.9	80.1	62.1	61.8
LCS Trigger	71.3	82.8	81.7	83.8	87.0	90.2	68.9	77.2
Linkert	71.9	69.6	71.9	74.6	72.6	76.7	53.0	66.3
MN-Torgy	72.0	73.7	77.3	77.3	79.6	82.3	56.9	66.6
MN-Washburn	72.4	74.6	69.5	82.5	73.5	83.8	59.4	66.0
MS Barracuda	70.8	80.0	71.1	75.5	74.8	78.2	49.2	61.4
MS Cobra	75.9	80.5	–	–	–	–	57.6	66.6
MS Ranchero	84.5	81.6	84.3	79.7	–	–	53.7	63.8
ND Frohberg	79.8	80.9	76.7	77.2	–	–	57.2	62.0
PFS-Buns	78.9	91.0	–	–	–	–	60.4	72.1
Prosper	75.1	83.6	80.3	84.8	82.4	88.8	62.0	71.7
Shelly	73.5	82.7	75.2	85.5	80.4	87.6	60.4	73.4
SY 611 CL2	72.5	79.6	77.3	81.4	79.1	86.2	56.0	65.7
SY Longmire	69.6	76.7	71.5	78.3	74.7	81.2	63.5	69.2
SY McCloud	79.6	73.0	77.3	75.5	77.7	78.4	51.6	63.7
SY Valda	75.8	84.0	77.2	84.3	82.7	88.3	58.1	71.8
TCG-Heartland	75.2	75.4	76.5	79.0	76.4	80.5	53.2	69.0
TCG-Spitfire	72.0	85.9	77.0	87.7	81.2	89.7	63.9	74.9
TCG-Wildcat	71.0	81.7	77.4	83.5	–	–	63.2	63.0
WB9479	70.1	73.3	74.3	75.3	–	–	49.4	62.7
WB9590	74.4	83.0	80.2	85.2	–	–	54.7	60.3
Mean (Bu/Acre)	74.3	80.1	76.8	79.8	78.5	82.6	57.4	67.6
LSD (0.10)	11.7	9.9	7.8	7.7	5.9	6.0	8.7	9.1
No. Environments	2	2	4	4	6	6	2	2

conventional and intensive management.

South *(continued)*				State					
2-year		3-year		2021		2-year		3-year	
Conv	Int	Conv	Int	Conv	Int	Conv	Int	Conv	Int
54.1	61.3	–	–	68.5	77.1	66.5	72.6	–	–
55.7	58.3	55.2	60.2	62.2	66.4	66.4	69.8	68.2	72.2
58.5	59.7	–	–	65.6	70.9	67.1	67.6	–	–
54.7	58.7	52.1	56.9	62.6	68.1	63.7	66.3	63.1	65.9
–	–	–	–	68.2	79.5	–	–	–	–
–	–	–	–	69.2	71.5	–	–	–	–
–	–	–	–	73.8	87.9	–	–	–	–
–	–	–	–	77.3	89.3	–	–	–	–
–	–	–	–	75.6	81.5	–	–	–	–
54.6	60.6	54.6	60.7	62.6	70.2	63.1	70.7	65.1	72.4
57.2	61.8	53.8	59.9	61.7	74.6	67.2	72.9	67.5	72.6
61.7	60.2	–	–	69.4	76.9	68.9	70.4	–	–
51.5	59.5	51.1	60.1	63.5	71.4	65.4	68.5	65.0	68.3
58.9	65.2	57.9	65.0	66.0	77.0	70.2	74.7	71.2	76.9
58.1	61.1	56.3	59.3	66.9	73.9	67.4	70.6	68.2	71.2
54.6	60.6	53.3	60.2	62.6	69.2	64.7	68.6	65.0	70.1
60.8	70.7	–	–	64.6	83.2	71.0	79.0	–	–
54.6	64.4	52.6	60.9	62.1	77.0	64.8	72.4	65.5	71.9
59.2	59.2	55.8	59.0	68.0	72.0	68.8	69.4	68.4	69.6
69.1	74.4	64.3	71.6	70.1	80.0	75.4	79.1	75.7	80.9
51.5	58.7	48.7	54.8	62.4	67.9	61.7	66.7	60.7	65.7
59.3	59.8	57.4	59.0	64.4	70.1	68.3	68.6	68.5	70.6
56.9	59.3	55.0	59.2	65.9	70.3	63.2	70.9	64.2	71.5
51.6	56.0	47.7	53.5	60.0	70.7	61.3	65.8	61.3	65.9
–	–	–	–	66.7	73.6	–	–	–	–
53.8	54.9	–	–	69.1	72.7	69.1	67.3	–	–
57.5	58.7	–	–	68.5	71.4	67.1	68.0	–	–
–	–	–	–	69.7	81.5	–	–	–	–
61.4	66.7	60.0	66.3	68.5	77.7	70.8	75.7	71.2	77.5
59.4	62.2	55.6	61.2	67.0	78.1	67.3	73.9	68.0	74.4
53.5	58.9	51.9	56.8	64.2	72.7	65.4	70.2	65.5	71.5
60.0	62.3	54.9	58.9	66.5	73.0	65.7	70.3	64.8	70.0
49.6	55.3	48.9	53.9	65.6	68.3	63.4	65.4	63.3	66.2
56.3	62.8	54.6	60.9	67.0	77.9	66.7	73.6	68.7	74.6
51.6	57.7	49.3	56.0	64.2	72.2	64.0	68.3	62.8	68.3
67.7	71.1	63.6	67.5	67.9	80.4	72.3	79.4	72.4	78.6
60.2	60.2	–	–	67.1	72.4	68.8	71.8	–	–
49.5	55.5	–	–	59.7	68.0	61.9	65.4	–	–
55.1	58.0	–	–	64.5	71.7	67.7	71.6	–	–
56.3	60.6	53.9	59.4	65.8	73.8	66.5	70.2	66.2	71.0
5.8	6.0	4.8	4.8	7.6	6.5	5.0	4.8	3.8	3.8
4	4	6	6	4	4	8	8	12	12

Table 8. Origin and agronomic characteristics of barley varieties in multiple-year comparisons (2019-2021).

Variety	Origin[1]	Year of Release	Legal Status	Days to Heading	Plant Height	Stem Breakage	Plump[4]	Protein[4]
				(days)	(inches)	(%)	(%)	(%)
2-row								
AAC Connect[1]	AAFC	2017	Yes	59	28	13	-	-
AAC Synergy	AAFC	2012	Yes	60	28	16	92	11.4
ABI Cardinal[2]	ABI	NA	Yes	61	28	9	-	-
BC Ellinor[2]	LCS/BC	NA	NA	61	29	11	-	-
BC Leandra[2]	LCS/BC	NA	NA	62	26	22	-	-
BC Lexi2	LCS/BC	NA	NA	61	27	22	-	-
Conlon	ND	1996	Yes	56	27	56	92	12.3
KWS Fantex[1]	KWS	NA	Pending	62	26	25	-	-
ND Genesis	ND	2015	Yes	59	29	20	96	11.2
6-row								
Lacey	MN	2000	Yes	57	30	0	92	12.4
Quest[1]	MN	2010	Yes	57	30	63	-	-
Rasmusson[1]	MN	2008	Yes	57	28	0	92	11.3
Robust	MN	1984	Expired	57	32	7	92	11.8
Tradition	ABI	2003	Yes	56	30	0	91	12.9
No. Environments				**8**	**8**	**6**	**3**	**3**

[1] Line tested in 2020 and 2021
[2] Line tested in 2021 only
[3] Agriculture and Agri-Food Canada (AAFC), Anheuser-Busch InBev (ABI), Limagrain Breun (LCS/BC), North Dakota State University (ND), KWS Lochow GmbH (KWS), University of Minnesota (MN)
[4] Data available from 3 locations in 2019 only.

Table 9. Disease reactions of barley varieties in multiple year comparisons (2019-2021).

Variety	DON [3,4]	Spot Blotch [3,4]	Stem Rust [3,5]	Bacterial Leaf Streak [3]
	---------- (1-9) ----------			
2-row				
AAC Connect[1]	3	1	4	3
AAC Synergy	8	1	5	3
ABI Cardinal[2]	-	-	4	4
BC Ellinor[2]	-	-	7	3
BC Leandra[2]	-	-	7	4
BC Lexi[2]	-	-	6	2
Conlon	2	7	3	5
KWS Fantex[1]	3	9	4	6
ND Genesis	4	2	6	5
6-row				
Lacey	5	0	5	5
Quest	3	4	4	5
Rasmusson	7	0	6	5
Robust	7	0	4	4
Tradition	3	1	4	6
No. Environments	**4**	**2**	**3**	**4**

[1] Line tested in 2020 and 2021
[2] Line tested in 2021 only
[3] Trait measured on a scale from 0-9 where 1=resistant and 9=susceptible, NA=not available. Deoxynivalenol (DON) is the mycotoxin produced by the Fusarium head blight pathogen.
[4] Data for 2019 and 2020 only.
[5] Data is for stem rust pathogen QCCJ. All lines were resistant to stem rust pathogen MCCF in years tested.

Table 10. Relative grain yield of barley varieties in northern Minnesota locations in a single-year (2021) and

Variety	Crookston			Hallock					Oklee		
	2021	3 yr[3]		2021	2 yr	3 yr		2021	2 yr	3 yr	
	--(% of mean)--										
2-row											
AAC Connect[1]	102	-		108	113	-		98	98	-	
AAC Synergy	96	102		100	107	106		95	106	102	
ABI CaBrdinal[2]	109	-		114	-	-		98	-	-	
BC Ellinor[2]	114	-		102	-	-		110	-	-	
BC Leandra[2]	111	-		101	-	-		114	-	-	
BC Lexi[2]	97	-		102	-	-		106	-	-	
Conlon	82	92		97	97	99		101	92	94	
KWS Fantex[1]	110	-		102	103	-		97	95	-	
ND Genesis	105	112		97	94	103		111	110	109	
6-row											
Lacey	98	104		88	86	87		109	101	99	
Quest[1]	92	-		91	87	-		92	97	-	
Rasmusson[1]	102	-		114	108	-		102	100	-	
Robust	92	92		90	94	97		79	92	93	
Tradition	89	98		94	111	108		89	108	104	
Mean (bu/acre)	90	104		101	97	85		61	90	90	
LSD (0.05)	15	12		21	22	19		18	20	16	

[1] Line tested in 2020 and 2021
[2] Line tested in 2021 only
[3] Trial data is from 2019 and 2021

multiple-year comparisons (2019-2021).

Perley			Stephen		Stephen			Strathcona		
2021	2 yr	3 yr	2021	3 yr[3]	2021	2 yr	3 yr	2021	2 yr	3 yr
---(% of mean)---										
116	109	-	95	-	99	97	-	104	130	-
103	103	101	104	104	112	110	103	93	123	127
97	-	-	106	-	98	-	-	92	-	-
104	-	-	114	-	117	-	-	104	-	-
119	-	-	99	-	102	-	-	101	-	-
99	-	-	114	-	99	-	-	112	-	-
87	91	89	105	99	99	110	104	102	67	67
84	89	-	101	-	95	92	-	94	123	-
116	115	109	104	104	97	101	100	106	88	108
99	96	98	101	108	99	103	101	100	96	107
91	94	-	78	-	93	95	-	96	100	-
104	97	-	109	-	83	87	-	99	109	-
85	95	96	80	91	101	102	95	95	78	92
96	112	108	90	94	105	102	98	102	87	98
111	102	98	74	86	114	97	105	89	75	75
14	26	18	19	16	24	17	14	9	55	35

Table 11. Relative grain yield of barley varieties in southern Minnesota locations in single-year (2021) and

Variety	Becker	Fergus Falls			Lamberton		Le Center		
	2021[3]	2021	2 yr	3 yr	2021	2 yr[4]	2021	2 yr	3 yr
	----------(% of mean)----------								
2-row									
AAC Connect[1]	93	100	108	-	102	102	110	101	-
AAC Synergy	142	98	103	100	101	109	89	99	101
ABI Cardinal[2]	131	115	-	-	114	-	83	-	-
BC Ellinor[2]	112	105	-	-	96	-	101	-	-
BC Leandra[2]	113	107	-	-	120	-	108	-	-
BC Lexi[2]	106	95	-	-	88	-	104	-	-
Conlon	61	94	91	89	86	83	106	95	97
KWS Fantex[1]	88	85	97	-	68	77	82	99	-
ND Genesis	120	96	101	105	102	99	105	107	108
6-row									
Lacey	96	104	98	99	109	111	103	99	99
Quest[1]	125	99	96	-	122	97	104	104	-
Rasmusson[1]	89	102	106	-	112	117	102	103	-
Robust	63	98	96	99	89	96	97	90	92
Tradition	60	101	104	108	90	108	104	105	103
Mean (bu/acre)	29	81	96	79	58	62	70	88	86
LSD (0.05)	8	11	16	10	13	2	10	20	12

[1] Line tested in 2020 and 2021
[2] Line tested in 2021 only
[3] Trial data is from 2021 only.
[4] Trial data is from 2021 and 2020 only.

multiple-year comparisons (2019-2021).

New Ulm			Rochester				St. Paul		
2021	2 yr[4]		2021	2 yr	3 yr		2021	2 yr	3 yr
--------------------------------------(% of mean)--									
108	107		111	88	-		102	111	-
73	90		95	100	100		100	115	117
96	-		68	-	-		94	-	-
103	-		96	-	-		123	-	-
101	-		101	-	-		130	-	-
108	-		111	-	-		122	-	-
89	91		91	83	79		82	73	72
76	88		85	81	-		137	125	-
114	107		109	101	102		91	105	111
116	109		107	110	112		77	100	107
107	100		109	104	-		75	89	-
109	111		126	120	-		101	105	-
99	93		89	103	98		64	84	92
100	104		104	109	108		101	94	102
99	84		84	95	90		57	71	66
11	32		10	29	16		14	23	18

Table 12. Relative grain yield of barley varieties in a single-year (2021) and multiple year comparisons (2019-2021)

	State				North				South		
Variety	2021	2yr	3yr		2021	2yr	3yr		2021	2yr	3yr
	---(% of mean)---										
2-row											
AAC Connect[1]	104	105	-		104	108	-		105	102	-
AAC Synergy	98	106	105		101	108	106		94	103	104
ABI Cardinal[2]	100	-	-		102	-	-		96	-	-
BC Ellinor[2]	107	-	-		109	-	-		104	-	-
BC Leandra[2]	108	-	-		107	-	-		110	-	-
BC Lexi[2]	104	-	-		103	-	-		105	-	-
Conlon	93	90	89		96	93	92		90	86	85
KWS Fantex[1]	93	98	-		97	101	-		87	94	-
ND Genesis	105	104	106		105	103	106		105	104	106
6-row											
Lacey	101	101	102		98	97	100		104	104	106
Quest[1]	97	97	-		91	94	-		105	100	-
Rasmusson[1]	104	105	-		101	101	-		108	110	-
Robust	90	93	94		90	92	94		89	93	94
Tradition	97	103	103		96	103	102		98	103	105
Mean (bu/acre)	80	84	84		92	91	92		68	78	75
LSD (0.05)	6	7	5		8	11	8		10	8	6
No. Environments	14	25	36		7	12	19		7	13	17

[1] Line was tested for yield in 2021 only. Refer to 2018 and prior years' reports for additional data.
[2] Line tested in 2021 only

NOTES

Table 13. Origin and agronomic characteristics of oat varieties in Minnesota in multiple-year comparisons (2019-2021).

Variety	Origin	Year of Release	Legal Status	Seed Color	Days to Heading
					(days)
Antigo	WI	2017	PVP(94)	Yellow	55.8
CS Camden[1]	Meridian Seeds	2013	PVP(94)	White	61.2
Deon	MN	2014	PVP(94)	Yellow	59.5
Esker 2020	WI	2020	PVP(94)	Yellow	57.2
Hayden	SD	2015	PVP(94)	White	59.3
MN-Pearl	MN	2018	PVP(94)	White	58.9
ND Heart[2]	ND	2020	PVP(94)	White	59.2
Reins	IL	2016	PVP(94)	White	56.0
Rushmore	SD	2020	Pending	White	57.4
Saddle	SD	2018	PVP(94)	White	55.4
Shelby 427	SD	2011	PVP(94)	White	56.7
Streaker[3]	SD	2016	PVP(94)	Hulless	57.4
Sumo	SD	2017	PVP(94)	White	54.1
Warrior	SD	2019	PVP(94)	White	57.8

[1] Line tested in 2020 and 2021; developed by Lantmannen Seed in Sweden.
[2] Line tested in 2020 and 2021
[3] Hulless oat
[4] 1-9 scale where 1=most resistant, 9=most susceptible
[5] 12% Grain moisture
[6] Trait measured for 3 locations in 2019 and 3 locations in 2020

Plant Height	Straw Strength [3]	Test Weight	Grain Protein [4,5]	Grain Oil [4,5]	Grain Beta-glucan [4,5]
(inches)	(1-9)	(lbs/bu)	(%)	(%)	(%)
30.4	2.6	36.9	17.3	7.1	5.2
31.0	2.2	31.5	14.2	6.5	5.1
31.4	2.8	35.4	14.3	6.8	4.8
30.6	2.9	33.6	14.9	5.8	5.3
32.7	3.4	34.0	13.4	7.4	5.1
33.9	2.9	35.8	12.8	7.4	4.6
32.6	3.1	34.5	15.7	6.6	5.6
29.3	1.5	35.7	14.9	6.2	4.8
30.8	2.6	36.6	15.0	6.0	4.9
30.3	1.4	35.2	14.9	6.1	4.5
32.0	3.1	36.1	14.1	7.0	4.6
30.0	3.7	42.5	14.9	7.1	5.1
30.7	2.6	34.9	16.4	5.8	4.5
28.8	1.6	35.4	14.7	6.4	4.5

Table 14. Disease characteristics of oat varieties.

Variety	Crown Rust[2]	Loose Smut[3]	BYDV[4]
	(1-9)	(1-9)	(1-9)
Antigo	4	3	4
CS Camden[1]	5	1	4
Deon	3	1	4
Esker 2020	4	1	3
Hayden	5	1	3
MN-Pearl	4	1	4
ND Heart[1]	5	5	4
Reins	6	1	4
Rushmore	4	1	4
Saddle	3	1	4
Shelby 427	5	1	4
Streaker	5	1	4
Sumo	4	2	4
Warrior	3	1	4

[1] Line tested in 2020 and 2021
[2] Tested in 2019, 2020, and 2021 with a mixed race population of crown rust; 1 = most resistant, 9 = most susceptible. Data is from 2019 and 2020 only; 2021 trial failed due to drought
[3] Tested in 2019 and 2020; 1 = most resistant, 9 = most susceptible
[4] Tested in 2021; 1 = most resistant, 9 = most susceptible

Table 15. Relative grain yield of oat varieties in northern Minnesota locations in single-year (2021) and multiple-year comparisons (2019-2021).

Variety	Crookston			Fergus Falls[4]			Roseau			Stephen	
	2021	3yr		2021	2 yr		2021	3yr		2021	3yr
	---(% of mean)--										
Antigo	100	102		89	96		65	88		85	85
CS Camden[1]	116	-		110	-		99	-		113	-
Deon	105	100		90	100		116	114		113	115
Esker 2020	107	-		83	-		105	-		101	-
Hayden	119	121		111	115		123	109		106	108
MN-Pearl	111	110		120	126		112	120		116	118
ND Heart[2]	96	-		102	-		98	-		107	-
Reins	98	96		101	92		106	104		101	108
Rushmore	113	-		115	-		117	-		125	-
Saddle	89	99		93	91		100	106		105	105
Shelby 427	98	102		95	95		99	98		94	95
Streaker[3]	75	84		101	101		72	75		68	75
Sumo	75	69		61	76		84	92		81	90
Warrior	97	-		116	-		121	-		99	-
Mean (bu/acre)	165	132		146	143		101	118		155	138
LSD (0.05)5	27	19		38	33		35	25		26	20

[1] Data presented from 2020 and 2021, see previous years' reports for additional data
[2] Line was tested in 2020 and 2021 only
[3] Hulless oat
[4] Location was tested in 2020 and 2021
[5] A large LSD suggests large variability from year to year for the specific location

Table 16. Relative grain yield of oat varieties in southern Minnesota locations in single-year (2021) and multiple-year comparisons (2019-2021).

Variety	Becker[4]	Kimball[5]	Lamberton		Le Center		Rochester		St. Paul[6]	Waseca	
	2021	2019	2021	3 yr	2021	3 yr	2021	3 yr	2020	2021	3 yr
	(% of mean)										
Antigo	84	104	81	94	102	101	109	107	84	101	95
CS Camden[1]	113	-	107	-	106	-	78	-	99	147	-
Deon	96	99	114	120	105	103	110	109	109	126	117
Esker 2020	114	98	117	106	87	101	98	101	100	116	107
Hayden	119	102	110	93	110	109	116	109	118	115	102
MN-Pearl	104	104	119	120	106	110	94	104	128	140	123
ND Heart[2]	97	-	93	-	95	-	100	-	91	56	-
Reins	93	98	92	89	103	98	96	103	102	87	101
Rushmore	101	108	98	114	104	112	115	113	98	102	114
Saddle	93	112	80	88	100	107	103	102	97	53	89
Shelby 427	111	99	99	84	103	105	115	103	104	89	88
Streaker[3]	72	78	85	71	77	71	79	70	77	87	74
Sumo	97	90	104	106	98	91	82	90	79	94	92
Warrior	106	107	102	115	103	94	106	90	113	89	98
Mean (bu/acre)	81	154	95	101	123	139	126	127	127	46	82
LSD (0.05)[7]	18	38	21	22	22	24	19	22	13	13	19

[1] Data presented from 2020 and 2021, see previous years' reports for additional data
[2] Line was tested in 2020 and 2021 only
[3] Hulless oat
[4] Location was tested in 2021 only
[5] Location was tested in 2019 only
[6] Location was tested in 2020 only
[7] A large LSD suggests large variability from year to year for the specific location

Table 17. Relative grain yield of oat varieties in Minnesota in single year (2021) and multiple-year comparisons (2019-2021).

Variety	North				South				State		
	2021	2yr	3yr		2021	2yr	3yr		2021	2yr	3yr
	---(% of mean)--										
Antigo	85	86	89		97	96	98		91	91	94
CS Camden[1]	111	111	-		104	101	-		107	106	-
Deon	116	110	110		109	109	109		112	109	110
Esker 2020	101	100	102		104	102	103		102	101	102
Hayden	112	113	112		114	111	106		113	112	109
MN-Pearl	116	115	116		108	112	113		112	114	114
ND Heart[2]	103	102	-		92	94	-		97	98	-
Reins	85	94	95		96	98	98		91	96	97
Rushmore	106	112	112		105	109	111		105	111	112
Saddle	93	95	98		91	94	99		92	94	98
Shelby 427	98	97	97		106	101	98		102	99	98
Streaker[3]	76	78	81		79	77	72		78	78	76
Sumo	88	80	81		94	94	93		91	88	87
Warrior	110	108	106		103	102	100		106	105	103
Mean (bu/acre)	108	125	119		94	110	114		100	117	116
LSD (0.05)	16	13	11		14	10	9		11	8	7
No. Environments	4	8	11		5	10	15		9	18	26

[1] Data presented from 2020 and 2021, see previous years' reports for additional data
[2] Line was tested in 2020 and 2021 only
[3] Hulless oat

North Dakota Hard Red Spring Wheat Variety Trial Results for 2021 and Selection Guide

Clair Keene, Andrew Green, Senay Simsek, Andrew Friskop, Matt Breiland, Tim Friesen, Zhaohui Liu and Shaobin Zhong (NDSU Main Station); John Rickertsen (Hettinger Research Extension Center); Eric Eriksmoen (North Central Research Extension Center, Minot); Bryan Hanson (Langdon Research Extension Center); Glenn Martin (Dickinson Research Extension Center); Gautam Pradhan (Williston Research Extension Center); Mike Ostlie (Carrington Research Extension Center)

Hard red spring (HRS) wheat was planted on 5.5 million acres in 2021, down from 5.7 million in 2020. The average yield of HRS wheat was 34 bushels/acre (bu/a), down approximately 31% from 49 bu/a in 2020. Lower yields were common across the state due to a wide-spread and severe drought. A greater-than-average number of HRS wheat acres were hayed or abandoned due to the drought.

SY Ingmar was the most popular HRS wheat variety in 2021, occupying 13.2% of the planted acreage, followed by SY Valda (9.5%), WB9590 (7.5%), AP Murdock (4.7%), Glenn (4.4%) and Faller (4.2%). SY Ingmar, SY Valda, and AP Murdock were released by Syngenta/AgriPro. WB9590 was released by Westbred/Monsanto. Glenn and Faller are NDSU releases.

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.

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).

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 2020. 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, it means that with 95% or 90% confidence (LSD probability 0.05 or 0.10), the higher-yielding variety has a significant 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. NS is used to indicate no significant difference for that trait among any of the varieties at the 95% or 90% level of confidence. The CV stands for coefficient of variation and is expressed as a percentage. The CV is a measure of variability in the trial. Large CVs mean a large amount of variation could not be attributed to differences in the varieties. Yield is reported at 13.5% moisture, while protein content is reported at 12% moisture content. 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, appropriate footnotes are given and the order of the data is not rearranged. Additional data from county sites are available from each Research Extension Center at https://vt.ag.ndsu.edu/.

North Dakota State University Spring Wheat
Tables # 1 - 5 can be found on pages 97 - 101

Table 1. North Dakota hard red spring wheat variety descriptions, agronomic traits, 2021.

						Reaction to Disease[5,6]			
Variety	Agent or Origin[1]	Year Released	Height (inches)[2]	Straw Strength[3]	Days to Head[4]	Leaf Rust	Tan Spot	Bact. Leaf Streak	Head Scab
Ambush	Dyna-Gro	2016	24	5	60	4	4	6	5
AP Gunsmoke CL2	Syngenta/AgriPro	**2021**	**23**	**6**	**60**	**NA**	**4**	**8**	**3**
AP Murdock	Syngenta/AgriPro	2019	22	4	60	NA	4	6	6
AP Smith	Syngenta/AgriPro	**2021**	**21**	**3**	**61**	**NA**	**3**	**4**	**4**
Ballistic	Dyna-Gro	2018	25	3	61	5	6	5	3
Bolles	MN	2015	26	4	62	3	4	6	5
CAG-Justify	**Champions Alliance Grp**	**2021**	**25**	**6**	**62**	**NA**	**8**	**6**	**3**
CAG-Reckless	**Champions Alliance Grp**	**2021**	**25**	**4**	**60**	**NA**	**6**	**6**	**4**
Commander	Dyna-Gro	2019	23	3	59	4	3	5	5
CP3099A	**Croplan**	**2020**	**25**	**5**	**64**	**NA**	**4**	**6**	**4**
CP3119A	**Croplan**	**2021**	**24**	**3**	**64**	**NA**	**6**	**5**	**3**
CP3188	**Croplan**	**2020**	**25**	**6**	**61**	**NA**	**6**	**5**	**4**
CP3530	Croplan	2015	27	5	62	2	6	5	5
CP3915	Croplan	2019	23	3	61	1	7	4	5
Dagmar[7]	MT	2019	24	6	59	7	4	7	7
Driver	SD	2019	26	4	61	1	7	7	3
Faller	ND	2007	27	5	62	7	7	5	4
Glenn	ND	2005	25	4	59	6	6	4	4
Lang-MN	MN	2017	24	5	61	2	4	3	3
Lanning	MT	2017	23	4	60	7	4	8	6
LCS Buster	**Limagrain**	**2020**	**24**	**4**	**63**	**NA**	**4**	**4**	**5**
LCS Cannon	Limagrain	2018	23	4	58	7	5	7	6
LCS Rebel	Limagrain	2017	26	6	59	7	3	4	5
LCS Trigger	Limagrain	2016	24	5	64	1	6	3	3
MN-Torgy	MN	2020	23	3	61	4	3	3	3
MN-Washburn	MN	2019	22	3	61	1	6	5	5
MS Barracuda	Meridian Seeds	2018	22	4	58	2	7	7	6
MS Cobra	**Meridian Seeds**	**2022**	**23**	**3**	**60**	**NA**	**4**	**8**	**5**
MS Ranchero	Meridian Seeds	2020	24	5	61	4	5	6	6
ND Frohberg	ND	2020	25	4	61	5	8	4	5
ND VitPro	ND	2016	24	3	59	4	6	5	4
PFS Buns	**Peterson Farms Seed**	**2021**	**23**	**3**	**65**	**NA**	**6**	**4**	**5**
SY 611CL2	Syngenta/AgriPro	2019	22	5	60	6	4	6	5
SY Ingmar	Syngenta/AgriPro	2014	NA	3	NA	3	6	4	5
SY Longmire[7]	Syngenta/AgriPro	2019	23	4	61	7	2	6	7
SY McCloud	Syngenta/AgriPro	2019	24	4	60	5	7	8	5
SY Soren	Syngenta/AgriPro	2011	22	3	60	2	2	7	7
SY Valda	Syngenta/AgriPro	2015	22	4	61	2	6	6	5
TCG-Heartland	21st Century Genetics	2019	22	3	59	2	5	7	6
TCG-Spitfire	21st Century Genetics	2015	24	3	63	5	6	4	6
TCG-Wildcat	21st Century Genetics	2020	21	3	61	5	6	7	NA
WB9479	WestBred	2017	21	2	59	1	4	8	6
WB9590	WestBred	2017	20	3	59	3	8	8	6

[1]Refers to agent or developer: MN = University of Minnesota; MT = Montana State University; ND = North Dakota State University; SD = South Dakota State University. Bold varieties are those recently released, so data are limited and rating values may change.

[2]Height data averaged from multiple locations in 2021; note, state-wide drought conditions generally resulted in shorter wheat.

[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 several locations in 2021.

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

[6]All wheat varieties are resistant to moderately resistant to stem rust when screened using *Puccinia graminis* f. sp. *tritici* races TPMK, TMLK, RTQQ, QFCQ and QTHJ.

[7]Solid stemmed or semisolid stem, imparting resistance to sawfly.

Table 2. Yield of hard red spring wheat varieties grown at six locations in eastern North Dakota, 2019-2021.

	Carrington		Casselton		Grand Forks		Forman	Langdon		Prosper	Average	
Variety	2021	3 Yr.	2021	3 Yr.	2021	3 Yr.	2021	2021	3 Yr.	2021	2021	3 Yr.
	(bu/a)											
Ambush	60.1	--	93.5	74.7	81.7	65.1	39.2	16.7	53.7	90.3	63.6	--
AP Gunsmoke CL2	57.7	--	103.1	--	84.8	--	46.1	23.5	--	96.2	68.6	--
AP Murdock	53.9	49.0	100.3	--	80.4	--	31.2	20.8	63.2	84.2	61.8	--
AP Smith	55.0	--	92.9	--	77.7	--	39.6	24.4	--	86.6	62.7	--
Ballistic	54.9	52.1	105.8	--	95.3	--	38.8	24.4	62.6	93.1	68.7	--
Bolles	57.7	48.3	89.2	71.0	75.3	55.7	36.7	14.6	51.7	81.4	59.1	56.7
CAG-Justify	60.5	--	111.4	--	84.3	--	40.4	23.1	--	91.5	68.5	--
CAG-Reckless	54.3	--	107.0	--	83.2	--	40.0	24.3	--	92.0	66.8	--
Commander	58.1	46.2	96.0	82.2	85.4	72.2	36.2	17.4	57.1	95.3	64.7	64.4
CP3099A	57.4	--	106.7	--	--	--	39.8	31.4	--	98.4	66.7	--
CP3119A	50.4	--	85.2	--	91.2	--	33.0	30.7	--	75.2	60.9	--
CP3188	57.8	--	102.9	--	90.1	--	47.3	27.4	--	90.5	69.3	--
CP3530	59.6	52.5	97.3	84.8	88.8	69.6	44.8	31.6	64.3	76.7	66.5	67.8
CP3915	54.1	50.0	95.7	80.0	81.8	69.9	36.2	28.7	62.1	87.6	64.0	65.5
Dagmar	59.3	--	99.2	--	80.0	--	35.4	24.0	--	81.9	63.3	--
Driver	62.2	--	102.7	--	88.5	--	45.9	28.8	--	95.6	70.6	--
Faller	57.0	54.0	95.1	81.8	86.4	72.9	45.3	28.4	64.2	91.0	67.2	68.2
Glenn	54.6	44.6	82.7	69.5	73.9	63.5	36.1	27.2	58.5	81.3	59.3	59.0
Lang-MN	57.8	52.1	94.2	80.0	80.2	65.2	44.7	26.1	58.5	84.7	64.6	64.0
Lanning	56.7	--	102.2	--	77.5	--	42.8	27.9	--	82.0	64.8	--
LCS Buster	48.7	--	111.4	--	90.9	--	43.6	22.2	--	87.1	67.3	--
LCS Cannon	52.3	42.6	109.6	88.3	85.6	67.8	35.9	23.4	59.2	--	61.4	64.5
LCS Rebel	58.0	47.9	98.2	78.0	86.6	73.6	40.5	21.8	59.5	89.1	65.7	64.8
LCS Trigger	58.8	52.6	108.4	87.8	88.7	82.5	39.2	23.0	63.6	93.6	68.6	71.6
MN-Torgy	63.2	--	96.0	--	81.8	--	31.9	28.0	60.8	86.1	64.5	--
MN-Washburn	54.4	45.5	95.4	79.1	79.2	64.2	36.2	21.6	58.4	86.4	62.2	61.8
MS Barracuda	56.6	44.1	92.4	80.1	78.5	63.6	31.9	14.8	54.6	78.6	58.8	60.6
MS Cobra	56.6	--	97.4	--	83.0	--	35.3	20.4	--	85.7	63.1	--
MS Ranchero	60.0	--	102.8	--	85.2	--	41.3	32.7	--	74.2	66.0	--
ND Frohberg	62.6	53.3	100.8	79.4	76.9	64.7	37.2	13.6	56.0	85.5	62.8	63.3
ND VitPro	52.5	43.3	86.7	73.4	74.3	62.4	30.5	21.1	56.7	78.0	57.2	58.9
PFS-Buns	59.8	--	105.6	--	90.2	--	40.0	32.8	--	95.3	70.6	--
SY 611CL2	59.5	46.3	95.8	81.8	81.7	64.7	42.9	23.4	61.5	94.0	66.2	63.6
SY Ingmar	54.2	45.2	93.8	78.5	75.8	66.5	44.8	21.3	59.8	84.9	62.5	62.5
SY Longmire	62.3	--	101.2	81.6	79.4	63.6	36.7	26.2	61.0	87.1	65.5	--
SY McCloud	62.7	47.1	90.5	77.9	82.4	62.8	36.4	22.5	58.9	88.0	63.7	61.7
SY Soren	49.8	45.6	90.0	77.4	76.5	56.5	27.1	18.3	55.6	83.1	57.5	58.8
SY Valda	57.7	53.5	102.1	84.9	84.1	69.8	35.3	27.6	62.2	91.7	66.4	67.6
TCG-Heartland	50.6	45.2	87.7	75.2	77.8	62.2	20.6	23.1	54.8	81.3	56.8	59.3
TCG-Spitfire	59.6	52.5	98.5	81.5	88.5	76.2	43.5	25.2	61.2	99.4	69.1	67.9
TCG-Wildcat	50.9	--	96.5	--	83.8	--	38.9	22.5	--	89.6	63.7	--
WB9479	60.6	--	85.9	--	76.2	--	25.1	18.1	--	77.1	57.2	--
WB9590	56.3	--	91.6	--	82.2	--	16.5	22.2	--	86.7	59.3	--
Mean	56.4	48.4	97.7	79.5	82.7	66.7	37.5	24.1	59.2	86.8	64.1	63.5
CV%	12.7	--	2.9	--	5.3	--	8.4	9.3	--	8.4	7.3	--
LSD 0.05	NS	--	6.8	--	4.9	--	7.9	2.0	--	8.3	5.4	--
LSD 0.10	8.3	--	5.7	--	4.1	--	6.6	1.7	--	7.0	4.5	--

Table 3. Yield of hard red spring wheat varieties grown at five locations in western North Dakota, 2019-2021.

	Dickinson		Hettinger		Mandan		Minot		Williston		Average	
Variety	2021	3 Yr.	2021	3 Yr.	2021	3 Yr.	2021	2 Yr.[1]	2021	3 Yr.	2021 [2]	3 Yr.[2]
	(bu/a)											
Ambush	17.6	34.9	43.1	42.6	16.6	31.9	13.5	64.1	16.6	37.5	23.5	36.7
AP Gunsmoke CL2	22.7	--	48.4	--	19.8	--	8.3	--	16.2	--	26.8	--
AP Murdock	15.9	--	39.5	44.1	16.7	34.0	8.1	--	14.3	--	21.6	--
AP Smith	19.5	--	38.0	--	23.7	--	10.9	--	14.4	--	23.9	--
Ballistic	17.6	--	45.7	44.3	21.3	35.3	11.8	--	16.7	--	25.3	--
Bolles	14.3	30.4	42.7	41.3	18.4	31.6	14.3	62.2	13.3	34.3	22.2	34.4
CAG-Justify	16.1	--	48.0	--	20.8	--	9.5	--	14.9	--	24.9	--
CAG-Reckless	19.0	--	49.9	--	19.0	--	19.1	--	20.7	--	27.1	--
Commander	18.8	35.6	48.4	45.7	19.1	32.9	17.0	--	16.7	37.9	25.7	38.0
CP3099A	12.6	--	41.9	--	15.1	--	10.5	--	19.8	--	22.4	--
CP3119A	17.4	--	42.8	--	26.2	--	21.5	--	20.4	--	26.7	--
CP3188	24.4	--	43.7	--	24.3	--	17.8	--	18.5	--	27.7	--
CP3530	19.8	38.7	40.3	45.0	19.1	34.6	12.0	69.0	15.8	35.9	23.7	38.6
CP3915	21.7	39.2	43.4	46.4	19.4	34.5	11.4	--	17.7	37.4	25.5	39.4
Dagmar	22.3	--	48.4	--	18.8	--	6.8	--	21.5	--	27.8	--
Driver	21.0	--	45.9	--	23.3	--	15.3	--	19.0	--	27.3	--
Faller	18.1	38.7	45.1	48.3	23.4	37.9	17.9	74.5	17.7	39.6	26.1	41.1
Glenn	19.6	33.9	41.6	40.7	19.1	32.0	7.4	59.1	20.2	36.4	25.1	35.7
Lang-MN	18.3	37.4	49.4	47.1	21.8	36.9	13.0	62.1	19.3	37.3	27.2	39.7
Lanning	19.4	37.6	48.6	44.7	22.4	35.5	8.0	66.2	21.6	38.1	28.0	39.0
LCS Buster	12.2	--	43.5	--	22.2	--	10.2	--	15.7	--	23.4	--
LCS Cannon	21.0	37.5	48.5	45.3	18.1	32.2	7.0	61.3	17.1	34.9	26.2	37.5
LCS Rebel	23.2	38.8	49.4	46.2	17.1	33.6	9.5	61.0	16.1	39.5	26.4	39.5
LCS Trigger	14.7	37.8	43.1	48.0	22.2	38.0	20.7	75.1	16.9	39.8	24.2	40.9
MN-Torgy	17.3	--	45.2	46.1	21.4	36.8	18.8	--	16.3	--	25.1	--
MN-Washburn	19.5	36.1	39.8	43.7	20.8	32.2	15.2	60.8	16.0	34.4	24.0	36.6
MS Barracuda	23.0	32.1	45.0	44.0	12.1	30.1	11.9	68.7	19.7	36.3	25.0	35.6
MS Cobra	20.3	--	42.3	--	17.1	--	15.0	--	14.0	--	23.4	--
MS Ranchero	19.3	--	49.3	--	27.0	--	7.5	--	16.0	--	27.9	--
ND Frohberg	16.8	35.4	46.0	43.7	18.8	32.0	11.0	60.5	16.4	35.8	24.5	36.7
ND VitPro	19.2	34.2	39.4	40.7	16.8	33.3	10.8	56.2	17.3	35.3	23.2	35.9
PFS-Buns	5.0	--	39.9	--	22.2	--	21.5	--	15.2	--	20.6	--
SY 611CL2	20.8	38.3	44.6	47.8	20.0	35.0	15.6	68.9	15.6	--	25.2	--
SY Ingmar	16.2	35.4	42.6	41.2	21.5	31.5	17.2	58.4	19.0	36.3	24.8	36.1
SY Longmire	15.0	35.9	40.2	45.1	19.6	32.4	13.6	63.8	17.5	38.7	23.1	38.0
SY McCloud	16.9	34.3	46.5	43.2	17.5	30.5	6.9	61.7	17.8	37.3	24.7	36.3
SY Soren	12.6	33.9	44.2	43.1	18.3	29.4	8.4	65.0	19.2	36.3	23.6	35.7
SY Valda	15.5	36.3	43.3	46.1	21.4	38.1	12.8	61.8	14.4	38.2	23.6	39.7
TCG-Heartland	15.6	33.5	45.7	44.0	15.4	29.5	8.2	--	16.9	37.6	23.4	36.1
TCG-Spitfire	13.0	37.8	42.6	47.4	25.5	37.6	11.9	68.1	18.8	40.3	25.0	40.8
TCG-Wildcat	19.0	--	44.9	--	21.6	--	19.5	--	16.4	--	25.5	--
WB9479	13.4	--	45.9	--	15.4	--	5.8	--	16.4	--	22.8	--
WB9590	19.8	--	43.2	--	17.5	--	8.3	--	18.1	--	24.6	--
Mean	17.9	36.0	44.2	44.7	20.3	33.7	13.1	64.2	17.4	37.2	24.9	37.7
CV%	20.9	--	7.4	--	7.2	--	45.7	--	17.9	--	11.6	--
LSD 0.05	5.2	--	3.8	--	3	--	9.7	--	5	--	4	--
LSD 0.10	4.4	--	3.0	--	2.5	--	8.1	--	4.2	--	3.4	--

[1]Two-year average includes 2019 and 2020.

[2]Averaged across four locations, Minot data excluded due to low yields and high variability caused by drought conditions.

Table 4. Quality data from 2017-2020. The Wheat Quality Index (WQI) is a weighted average developed to summarize the relative milling and baking quality of lines in the trial. Data below are from 2017-2020 for all varieties which were tested in a minimum of two years (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	
Bolles	60.6	76.6	16.8	64.9	64.8	23.7	1031.7	1
ND Frohberg	62.0	71.3	15.5	66.8	66.2	12.1	996.5	2
Glenn	63.3	83.0	15.6	64.9	65.9	15.1	1008.9	3
CP3915	62.2	74.5	15.2	64.2	69.5	12.4	991.0	4
MS Barracuda	61.3	67.9	15.6	64.8	67.0	11.5	999.7	5
ND VitPro	62.9	81.7	15.6	65.2	67.4	9.2	978.9	6
WB9479	62.1	67.5	15.8	62.8	66.4	20.9	952.4	7
SY McCloud	62.2	63.4	15.3	65.9	66.3	10.6	981.2	8
LCS Rebel	62.5	68.7	15.1	64.5	68.6	11.9	982.2	9
Lang-MN	61.9	84.0	15.4	64.9	66.8	12.0	949.6	10
SY 611CL2	62.3	69.7	15.2	67.9	65.6	8.5	916.4	11
TCG-Heartland	62.3	66.7	15.5	63.8	67.7	14.3	941.8	12
SY Longmire	61.6	67.4	15.4	64.7	66.8	10.2	985.4	13
Ballistic	60.7	73.0	14.9	64.5	67.7	12.2	979.1	14
SY Soren	61.7	60.6	15.6	63.8	66.4	9.7	1007.4	15
SY Ingmar	61.8	69.8	15.3	63.2	67.7	10.8	996.0	16
AP Murdock	61.0	51.9	14.9	64.9	67.3	13.4	949.7	17
Ambush	62.1	70.6	15.3	62.7	66.1	13.7	996.3	18
Lanning	60.6	76.6	15.6	63.9	65.0	10.0	1008.1	19
LCS Cannon	62.3	62.8	14.8	63.2	68.7	12.1	964.4	20
Faller	60.6	63.6	14.6	63.9	68.1	10.2	985.9	21
CP3530	61.0	59.9	14.7	64.7	67.0	9.3	984.5	22
MN-Washburn	61.0	81.7	14.6	61.1	69.4	14.9	973.6	23
TCG-Spitfire	61.0	63.8	14.3	64.4	65.1	13.5	966.4	24
Commander	61.3	65.0	15.3	63.5	66.9	9.1	948.3	25
WB9590	61.6	64.7	15.4	63.4	66.3	13.4	900.2	26
MN-Torgy	61.5	58.0	15.2	62.5	65.4	14.6	927.9	27
SY Valda	61.3	78.5	14.5	62.8	66.5	8.1	929.5	28
LCS Trigger	60.8	74.0	13.4	64.6	67.5	8.6	814.4	29
Mean	61.6	69.5	15.2	64.2	66.9	12.3	967.2	

[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 U.S. No. 1.

[2]Vitreous kernels - Expressed as a percentage of seeds having a vitreous-colored endosperm. A high percentage is desirable. US No. 1 DNS requires greater than 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]Adjusted means across locations were calculated for each trait. These means were standardized (mean=0 and standard deviation=1) to remove effect of scale, which varies between traits. The standardized means were used to calculate the Wheat Quality Index (WQI). The WQI is a weighted index using 7 key traits with the following weights: Test Weight (5%); Vitreous kernel (5%); Wheat Protein (15%); Flour Extraction (10%); Farinograph Absorption (21.66%); Farinograph Stability (21.66%); Loaf Volume (21.66%).

Table 5. Quality data from 2020. The Wheat Quality Index is a weighted average developed to summarize the relative milling and baking quality of lines in the trial. Data below are from 2020 for all varieties which were tested in the 2021 trial. Data were collected from Gwinner, Langdon, Minot and Williston.

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	
Bolles	59.8	75.3	17.1	63.6	62.6	22.6	953.8	1
Glenn	62.4	72.9	15.6	63.8	64.2	12.8	930.5	2
ND Frohberg	61.4	56.0	15.0	65.2	65.3	11.2	932.3	3
ND VitPro	62.2	66.3	15.4	64.4	66.4	9.2	928.6	4
Sy Ingmar	61.6	58.6	15.6	63.0	66.0	10.8	920.2	5
Lang-MN	61.0	74.5	15.8	63.7	65.0	10.3	903.5	6
SY McCloud	61.5	59.4	15.3	64.9	64.6	9.2	927.7	7
CP3915	61.7	53.5	15.1	63.9	66.8	9.9	921.2	8
Lanning	59.8	64.4	16.1	63.0	62.8	8.7	972.4	9
LCS Rebel	61.9	54.8	15.3	64.1	66.4	10.2	904.4	10
MS Barracuda	60.4	56.3	15.5	63.9	64.9	10.0	927.7	11
MN-Washburn	61.0	68.1	14.8	60.4	67.8	13.2	937.0	12
Dagmar	60.7	75.7	15.8	63.6	64.3	9.8	900.7	13
TCG-Heartland	61.7	60.2	15.6	62.9	65.8	11.0	885.8	14
Ballistic	60.2	63.8	14.9	63.7	65.9	10.4	916.5	15
SY Soren	61.0	50.6	15.8	63.2	63.8	9.4	913.7	16
Faller	60.2	50.7	14.8	63.2	67.0	8.9	930.5	17
MS Ranchero	58.9	60.4	15.1	64.4	62.7	11.8	896.0	18
AP Murdock	60.6	45.9	14.8	64.1	66.4	11.1	876.4	19
SY Longmire	61.0	62.8	15.5	63.9	64.8	7.8	900.7	20
SY 611CL2	61.5	56.9	15.2	66.7	64.3	7.2	865.3	21
Ambush	61.4	68.0	15.4	62.1	64.4	9.9	906.3	22
CP3530	61.1	52.1	14.7	64.1	65.7	7.8	916.5	23
Commander	60.9	61.9	15.6	62.9	65.0	8.8	889.5	24
TCG-Wildfire	61.5	59.6	15.3	63.4	64.8	8.8	888.5	25
LCS Cannon	61.5	52.7	14.6	61.9	66.5	10.6	881.1	26
TCG-Spitfire	60.7	54.3	14.7	63.6	62.2	10.8	892.3	27
MN-Torgy	61.0	46.7	15.3	61.2	63.1	11.3	894.1	28
Driver	61.2	62.8	15.2	61.0	64.4	9.2	849.4	29
SY Valda	61.1	68.7	14.7	62.4	63.8	7.2	865.3	30
LCS Trigger	61.5	68.3	13.5	65.1	65.8	6.9	815.9	31
LCS Buster	58.8	54.5	13.7	58.7	66.6	12.9	839.2	32
Mean	61.0	60.5	15.2	63.3	65.0	10.3	902.6	

[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 U.S. No. 1.

[2]Vitreous kernels - Expressed as a percentage of seeds having a vitreous-colored endosperm. A high percentage is desirable. US No. 1 DNS requires greater than 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]Adjusted means across locations were calculated for each trait. These means were standardized (mean=0 and standard deviation=1) to remove effect of scale, which varies between traits. The standardized means were used to calculate the Wheat Quality Index (WQI). The WQI is a weighted index using 7 key traits with the following weights: Test Weight (5%); Vitreous kernel (5%); Wheat Protein (15%); Flour Extraction (10%); Farinograph Absorption (21.66%); Farinograph Stability (21.66%); Loaf Volume (21.66%).

North Dakota Durum
Variety Trial Results for 2021 and Selection Guide

Clair Keene, Elias Elias, Andrew Friskop, Tim Friesen, Zhaohui Liu, Shaobin Zhong and Frank Manthey (NDSU Main Station); Blaine Schatz and Mike Ostlie (Carrington Research Extension Center); Glenn Martin (Dickinson Research Extension Center); Bryan Hanson (Langdon Research Extension Center); John Rickertsen (Hettinger Research Extension Center); Eric Eriksmoen (North Central Research Extension Center, Minot); Gautam Pradhan (Williston Research Extension Center).

Durum was planted on 880,000 acres in North Dakota in 2021, down 3.4% from 2020. The average yield was 24 bushels per acre (bu/a), down from 39 last year. Lower yields were the result of the widespread and severe drought that persisted throughout the growing season across most of the state. The most commonly grown varieties in 2021 and the percent of the acreage they occupied were Joppa (27%), ND Riveland (23%), Divide (10%), Alkabo (6%), VT Peak (5%), Carpio (5%) and ND Grano (4%).

Durum varieties are tested each year at multiple sites throughout North Dakota. The relative performance of these varieties is presented in table form. Variety performance data are used to provide recommendations to producers. Some varieties may not be included in the tables due to insufficient testing or lack of seed availability, or they offer no yield or disease advantage over similar varieties. Yield is reported at 13.5% moisture, while protein content is reported at 12% moisture.

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 significant or if they might be due to error inherent in the experimental process.

The LSD (least significant difference) numbers beneath the columns in tables are derived from these statistical analyses and only apply to the numbers in the column in which they appear. If the difference between two varieties exceeds the LSD value, it means that with 95% or 90% confidence (LSD probability 0.05 or 0.10), the higher-yielding variety has a significant yield advantage. When the difference between two varieties is less than the LSD value, no significant difference occurs between those two varieties under those growing conditions.

The abbreviation NS is used to indicate no significant difference for that trait among any of the varieties at the 95% or 90% level of confidence. The CV is a measure of variability in the trial. The CV stands for coefficient of variation and is expressed as a percentage. Large CVs mean a large amount of variation that could not be attributed to differences in the varieties.

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, appropriate footnotes are given and the order of the data is not rearranged. Additional data from county sites are available from each Research Extension Center at https://vt.ag.ndsu.edu/. Use data from multiple locations and years when selecting a variety.

North Dakota State University Durum Tables # 1 - 5 can be found on pages 103 - 106

Table 1. Descriptions and agronomic traits of durum wheat varieties grown in North Dakota, 2021.

						Reaction to Disease[5]				
	Agent or Origin[1]	Year Released	Height (inches)[2]	Straw Strength[3]	Days to Heading[4]	Stem Rust	Leaf Rust	Foliar Disease	Bact. Leaf Streak	Head Scab
AC Commander	Can.	2002	19	5	62	1	1	6	NA	NA
Alkabo	ND	2005	21	2	63	1	1	5	7	6
Alzada	WB	2004	20	6	62	1	1	8	NA	9
Ben	ND	1996	22	4	63	1	1	4	7	8
Carpio	ND	2012	22	5	64	1	1	5	6	5
CDC Verona	Can.	2010	22	5	64	1	1	4	NA	8
Divide	ND	2005	22	5	65	1	1	5	7	5
Grenora	ND	2005	22	5	64	1	1	5	7	6
Joppa	ND	2013	22	5	64	1	1	5	7	5
Lebsock	ND	1999	21	3	63	1	1	5	7	6
Maier	ND	1998	20	5	63	1	1	5	NA	8
Mountrail	ND	1998	20	5	63	1	1	5	7	8
ND Grano[6]	ND	2017	20	5	64	1	1	8	7	6
ND Riveland[6]	ND	2017	23	4	63	1	1	4	7	5
ND Stanley[6]	**ND**	**2021**	**21**	**4**	**64**	**1**	**1**	**5**	**NA**	**5**
Pierce	ND	2001	21	5	63	1	1	6	7	8
Rugby	ND	1973	22	5	63	1	1	4	NA	8
Strongfield[6]	Can.	2004	23	6	64	1	1	6	NA	8
Tioga	ND	2010	23	4	63	1	1	5	7	6
VT Peak	Viterra	2010	22	6	64	1	NA	NA	NA	NA

[1]Refers to agent or developer: Can. = Agriculture Canada, WB = Westbred, ND = North Dakota State University. Bold varieties are those recently released, so data are limited and rating values may change.

[2]Plant height was obtained from the average of six locations in 2021.

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

[4]Days to Heading = the number of days from planting to head emergence from the boot. Averaged from six locations in 2021.

[5]Disease reaction scores from 1-9, with 1 = resistant and 9 = very susceptible. NA = Not adequately tested. Foliar Disease = reaction to tan spot and septoria leaf spot complex.

[6]Low cadmium accumulating variety.

Table 2. Yield of durum wheat varieties at six Research Extension Centers in North Dakota, 2019-2021.

	Carrington		Langdon		Dickinson		Hettinger		Minot		Williston		Average	
Variety	**2021**	**3 Yr.**	**2021**	**3 Yr.**	**2021**	**3 Yr.**	**2021**	**3 Yr.**	**2021**	**2 Yr.[1]**	**2021**	**3 Yr.**	**2021 [2]**	**3 Yr.[3]**
	(bu/a)													
AC Commander	49.3	39.1	42.3	55.2	12.0	34.9	28.4	36.4	9.3	56.6	18.8	37.2	30.2	43.2
Alkabo	47.0	38.7	48.6	64.9	13.9	33.4	25.7	40.5	15.1	58.3	15.5	35.6	30.1	45.2
Alzada	50.4	34.9	39.4	48.8	13.4	33.0	29.5	31.5	12.8	46.1	16.0	31.8	29.8	37.7
Ben	51.1	38.8	45.5	62.5	11.1	33.3	25.5	35.4	12.5	59.3	14.0	34.6	29.4	44.0
Carpio	46.8	45.4	50.0	65.6	12.9	32.1	23.3	35.8	13.6	65.1	18.5	35.9	30.3	46.6
CDC Verona	50.6	44.1	51.7	60.1	8.0	33.1	22.9	38.8	19.4	55.2	15.1	37.2	29.7	44.7
Divide	47.1	41.0	50.7	65.7	12.4	33.4	24.0	38.1	12.2	62.3	13.4	36.2	29.5	46.1
Grenora	52.0	42.1	49.3	67.6	14.8	35.3	27.5	39.4	18.1	59.9	17.7	38.7	32.3	47.2
Joppa	53.3	42.4	43.5	64.8	11.5	34.7	25.8	37.9	14.7	66.8	15.7	34.8	30.0	46.9
Lebsock	45.4	38.7	45.1	63.3	16.6	36.2	29.2	38.1	16.1	62.9	13.8	34.0	30.0	45.5
Maier	43.9	36.1	40.0	56.8	13.5	32.1	30.4	37.1	9.5	58.9	13.6	34.1	28.3	42.5
Mountrail	56.0	41.9	48.7	62.3	11.4	34.8	26.6	39.1	10.5	68.0	15.9	36.5	31.7	47.1
ND Grano	47.6	41.8	49.8	65.0	11.3	34.6	25.2	39.3	13.3	68.1	15.3	35.2	29.8	47.3
ND Riveland	50.6	48.5	45.2	65.3	15.3	33.1	30.3	41.9	15.9	61.6	15.5	37.8	31.4	48.0
ND Stanley	53.9	43.8	50.0	65.8	13.8	35.5	30.1	41.2	10.8	68.8	13.6	--	32.3	49.1
Pierce	42.6	39.0	44.9	63.3	13.3	32.8	28.6	39.9	10.6	60.7	13.0	33.6	28.5	44.9
Rugby	53.4	43.9	40.7	55.3	12.7	31.4	25.5	36.1	11.2	56.7	13.1	35.0	29.1	43.1
Strongfield	55.0	43.3	45.7	57.0	9.9	32.0	25.7	37.9	12.3	59.2	15.4	34.8	30.3	44.0
Tioga	50.1	41.7	47.6	64.6	15.3	35.0	27.9	37.6	16.2	63.5	15.9	35.4	31.4	46.3
VT Peak	53.8	41.9	48.7	67.0	11.6	33.3	26.7	41.1	16.6	64.8	16.1	35.9	31.4	47.3
Mean	51.3	41.4	48.1	62.0	12.7	33.7	27.6	38.7	13.7	61.1	15.2	35.5	30.3	45.3
CV %	13.7	--	7.1	--	19.0	--	13.3	--	50.4	--	19.7	--	9.6	5.9
LSD 0.05	NS	--	3.1	--	3.4	--	4.3	--	NS	--	4.8	--	3.7	3.1
LSD 0.10	NS	--	2.6	--	2.8	--	3.3	--	NS	--	4.1	--	3.1	2.6

[1]Two-year data includes 2019 and 2020.; 2021 data not included due to low yields and high variability caused by drought conditions.

[2]2021 state-wide average does not include Minot data.

[3]Averages calculated with three-year averages from all sites except Minot, for which two-year averages were used.

Table 3. Test weight and protein of durum wheat varieties at six Research Extension Centers in North Dakota, 2021.

Variety	Carrington		Langdon		Dickinson		Hettinger		Minot		Williston		Average	
	Test Wt.	Protein	Test Wt.	Protein	Test Wt.	Protein	Test Wt.	Protein	Test Wt.	Protein	Test Wt.	Protein	Test Wt.	Protein[1]
	lb/bu	%	lb/bu	%	lb/bu	%	lb/bu	%	lb/bu	%	lb/bu	%	lb/bu	%
AC Commander	63.8	16.4	58.7	15.2	58.6	18.8	57.7	16.6	58.9	17.2	61.4	19.8	59.9	16.4
Alkabo	64.6	15.6	59.5	14.7	59.3	17.1	58.1	16.1	59.9	14.8	61.2	19.0	60.4	15.3
Alzada	64.0	16.6	57.3	15.2	58.9	16.5	56.3	15.0	58.8	15.6	61.4	18.6	59.5	15.6
Ben	64.3	16.9	59.8	15.8	58.7	18.7	57.4	16.8	59.5	16.5	60.9	20.0	60.1	16.5
Carpio	63.4	16.5	59.8	14.4	57.1	18.4	55.1	16.5	57.9	15.8	60.0	18.5	58.9	15.8
CDC Verona	64.3	16.3	59.4	15.7	58.1	20.0	54.8	17.4	59.8	16.0	60.2	20.4	59.4	16.4
Divide	63.6	16.6	59.7	15.2	58.5	18.4	56.2	16.9	59.8	15.7	59.9	19.7	59.6	16.1
Grenora	63.9	15.8	59.1	14.9	59.1	17.8	56.8	15.8	59.5	14.7	60.9	18.9	59.9	15.3
Joppa	64.6	15.7	60.2	14.3	59.3	17.3	57.1	15.9	59.0	15.6	61.2	18.8	60.2	15.4
Lebsock	64.7	16.3	60.0	15.3	59.3	16.9	56.8	15.6	60.1	15.5	61.0	19.2	60.3	15.7
Maier	64.5	17.8	59.4	16.0	58.6	19.4	57.1	16.6	58.3	17.4	61.0	20.1	59.8	17.0
Mountrail	63.0	15.9	59.3	14.6	58.1	18.2	56.8	16.2	58.6	16.0	60.2	19.4	59.3	15.7
ND Grano	64.5	16.6	61.0	14.9	58.6	18.5	58.0	16.5	60.5	15.9	60.0	19.8	60.4	16.0
ND Riveland	64.1	16.4	59.5	14.8	59.2	17.1	57.4	15.5	59.3	15.8	60.1	19.1	59.9	15.6
ND Stanley	63.6	16.3	60.4	15.2	60.0	18.2	57.1	16.3	60.1	16.4	61.3	19.4	60.4	16.1
Pierce	64.6	16.4	59.7	14.8	59.1	17.7	58.0	15.9	58.9	16.0	60.6	19.1	60.1	15.8
Rugby	64.3	16.2	59.8	15.6	59.1	17.6	57.4	16.3	59.2	16.3	60.3	20.0	60.0	16.1
Strongfield	63.3	17.0	58.8	16.3	58.1	20.6	54.4	17.2	58.8	17.1	60.5	20.4	59.0	16.9
Tioga	64.5	16.8	59.3	14.7	59.4	18.3	57.5	16.9	59.9	15.8	61.3	18.7	60.3	16.0
VT Peak	65.0	16.1	60.8	15.4	59.8	18.1	57.7	15.8	61.2	16.0	61.7	19.5	61.0	15.8
Mean	64.1	16.4	59.8	15.0	59.0	18.1	57.2	16.3	59.2	16.1	60.7	19.4	59.9	16.0
CV %	0.8	1.8	0.5	1.5	0.8	2.5	1.8	3.7	1.9	5.2	0.8	1.9	1.0	2.5
LSD 0.05	0.7	0.4	0.2	0.2	0.7	0.6	1.2	0.7	1.8	1.4	0.7	0.6	0.7	0.6
LSD 0.10	0.6	0.3	0.2	0.2	0.5	0.5	0.9	0.4	1.5	1.1	0.6	0.5	0.6	0.5

[1]Average protein does not include data from Dickinson and Williston due to abnormally high values caused by drought conditions.

Table 4. Durum wheat variety quality descriptions, milling and processing data averaged for five years (2016-2020) from drill strips (32 locations/years).

Variety	Test Weight	Vitreous Kernels	Large Kernels	Falling Number	Wheat Protein[1]	Gluten Index[2]	Pasta Color[3]	Spaghetti Firmness[4]	Overall Quality[5]
	(lb/bu)	(%)	(%)	(sec)	(%)		(1-12)	(g-cm)	
Alkabo	61.3	83	59	397	13.9	48	8.3	3.9	good
Alzada	60.1	86	68	499	14.5	85	8.1	4.4	good
Carpio	61.6	80	67	471	14.0	92	8.4	4.1	good
Divide	61.0	86	59	460	14.3	76	8.0	3.9	good
Joppa	61.4	87	51	445	13.7	84	8.6	4.0	good
Maier	60.7	89	55	425	15.0	57	8.1	4.2	good
Mountrail	60.7	90	50	446	14.2	27	7.6	3.8	fair
ND Grano	61.5	85	55	458	14.3	68	8.4	4.1	good
ND Riveland	61.1	88	63	453	14.4	82	8.2	4.1	good
ND Stanley	62.1	83	62	470	14.5	74	8.3	4.0	good
Strongfield	60.6	88	58	455	14.9	68	7.9	4.2	good
Tioga	61.0	84	66	398	14.2	75	7.8	4.1	good
Average	61.1	86	59	448	14.3	70	8.1	4.1	

For all numbered footnotes, refer to bottom of Table 5.

Table 5. Durum wheat variety quality descriptions, milling and processing data for 2020 at all locations from drill strips.

Variety	Test Weight	Vitreous Kernels	Large Kernels	Falling Number	Wheat Protein[1]	Gluten Index[2]	Pasta Color[3]	Spaghetti Firmness[4]	Overall Quality[5]
	(lb/bu)	(%)	(%)	(sec)	(%)		(1-12)	(g-cm)	
Alkabo	61.0	88	58	386	14.0	53	8.1	3.9	good
Carpio	61.7	85	66	481	14.1	94	8.4	4.1	good
Divide	60.3	90	59	466	15.0	84	7.3	3.9	good
Joppa	61.3	93	52	414	13.9	88	8.6	3.9	good
Maier	60.4	94	57	402	15.6	64	7.7	4.2	good
Mountrail	60.4	94	49	421	14.3	25	7.6	3.7	fair
ND Grano	61.7	92	62	439	14.8	68	8.1	4.1	good
ND Riveland	61.2	94	62	433	14.4	88	7.9	4.0	good
ND Stanley	62.3	91	68	475	14.9	77	8.1	3.8	good
Strongfield	60.6	94	59	472	15.7	71	7.9	4.4	good
Tioga	60.8	90	74	359	14.6	77	7.3	4.3	good
Average	61.0	91	61	432	14.6	72	7.9	4.0	

[1]Wheat protein is reported on a 12% moisture basis.

[2]Gluten index is unitless. Numbers less than 15 = very weak and greater than 80 = very strong gluten proteins.

[3]Pasta Color Score: Higher number indicates better color, with 8.5+ typically considered good.

[4]Work required to cut through a strand of spaghetti.

[5]Overall Quality is determined based on agronomic, milling and spaghetti processing performance.

North Dakota Hard Winter Wheat Variety Trial Results for 2021 and Selection Guide

Clair Keene, Joel Ransom, Francois Marais, Senay Simsek and Andrew Friskop (NDSU Main Station); Eric Eriksmoen (North Central Research Extension Center, Minot); John Rickertsen (Hettinger Research Extension Center); Glenn Martin (Dickinson Research Extension Center)

During the 2019-20 growing season, 85,000 acres of winter wheat were planted and 55,000 acres were harvested. The state's winter wheat yield was estimated at 35 bushels per acre (bu/a), which was down from last year's yield of 49 bu/a. The dry fall in 2020 reduced plantings and impacted stand establishment in parts of the state. The very dry conditions during the spring and summer months of 2021 resulted in reduced yields and in some cases the abandonment of the crop.

SY Wolf was the most popular variety in 2020-21, occupying 27% of the acres planted. Jerry followed SY Wolf in popularity with 12% of the acreage. Most growers (61%) surveyed did not identify the variety they used. Successful winter wheat production depends on numerous production practices, including selecting the right variety for a particular area. The information included in this publication is meant to help growers choose that variety or group of varieties. Characteristics to consider when selecting a variety are winter hardiness, yield potential in your area, test weight, protein content when grown with proper fertility, straw strength, plant height, reaction to important diseases and maturity.

The recommended seeding dates for winter wheat are Sept. 1-15 north of North Dakota Highway 200 and Sept. 15-30 in southern regions. Planting after the recommended dates reduces winter survival and grain yield. Planting prior to the recommended date may deplete soil moisture reserves unnecessarily. It also increases the risk of wheat streak mosaic virus and may reduce winter survival.

Winter wheat should be seeded at a rate of 1 million to 1.2 million viable seeds per acre. The higher seeding rates of this recommended range should be used for late seeding or with poor seedbed conditions. Producers should consider only the most winter-hardy varieties available when growing winter wheat in North Dakota. Relative ratings for winter hardiness are found in Table 1.

Phosphorus aids winter survival by stimulating root growth and fall tillering. The secondary root system that develops during tillering is essential for a healthy, deep-rooted plant capable of withstanding stress. If winter wheat is planted on bare soil, an application of phosphorus is recommended if soil phosphorous levels are low. While important, the contribution of phosphorus to winter survival is secondary to varietal hardiness.

Data from several years and locations should be used when selecting varieties. The idea that data from a single location nearest your farm will indicate which variety will perform the best for you next year is incorrect. You should select varieties that, on average, perform the best at multiple trial locations near your farm across several years.

North Dakota State University Hard Winter Wheat Tables # 1 - 5 can be found on pages 108 - 112

Table 1. 2021 North Dakota hard red winter wheat variety description and agronomic traits.

Variety	Agent or Origin[2]	Year	Reaction to Disease[1] Stripe Rust	Leaf Rust	Stem Rust	Scab	Tan Spot	Days to Heading[3]	Straw Strength[4]	Height[5] (inches)	Winter[6] Hardiness
AAC Wildfire	FP Genetics	2015	1	5	8	NA	NA	1	3	29	3
AC Emerson	Meridian	2011	1	6	1	3	5	1	2	32	4
Draper	**SD**	**2019**	**4**	**7**	**4**	**4**	**5**	**-2**	**NA**	**28**	**NA**
Ideal	SD	2011	4	1	3	8	4	-1	4	28	4
Jerry	ND	2001	8	3	1	8	8	0	5	34	3
Keldin	WB	2011	2	3	3	5	3	0	3	29	5
MS Iceman	**Meridian**	**2021**	**7**	**8**	**5**	**6**	**8**	**0**	**NA**	**26**	**NA**
ND Noreen	ND	2020	3	3	1	3	5	0	4	29	3
Northern	MT	2015	1	8	1	8	6	2	4	29	5
Ray[7]	**MT**	**2018**	**1**	**8**	**NA**	**NA**	**NA**	**4**	**NA**	**33**	**NA**
SD Andes	**SD**	**2020**	**2**	**6**	**NA**	**5**	**6**	**0**	**NA**	**29**	**NA**
SY Monument	Agripro	2014	3	3	1	6	5	-2	4	27	3
SY Wolf	Agripro	2010	3	3	1	6	1	-2	3	27	6
SY Wolverine	Agripro	2019	4	3	1	4	5	-5	4	25	4
TCG-Boomlock	TCG	2019	NA	NA	NA	NA	NA	-1	4	29	6
Thompson	SD	2017	5	3	3	3	6	-1	3	30	5
WB 4309	**WB**	**2019**	**4**	**6**	**4**	**7**	**7**	**-2**	**NA**	**29**	**NA**
WB4462	WB	2016	7	3	NA	8	6	-5	4	31	4
Winner	SD	2019	NA	NA	NA	NA	NA	-2	NA	29	NA

[1]Disease reaction scores from 1-9, with 1 = resistant and 9 = very susceptible, NA = not available.
[2]MT = Montana State University; ND = North Dakota State University; SD = South Dakota State University;
TCG = Twenty-first Century Genetics; WB = WestBred.
[3]Days to heading relative to Jerry.
[4]Straw strength: 1 = strongest, 9 = weakest. Based on field observations in limited sites in 2020.
[5]Based on the average of several environments, and should be used for comparing varieties. The environment can impact the height of varieties.
[6]Relative winter hardiness rating: 1 = excellent, 10 = no survival. These values are subject to change as additional information becomes available.
[7]Developed primarily for use as a forage winter wheat.
Bold varieties are those recently released or the first time tested, so data are limited and rating values may change.

Table 2. Yield of winter wheat varieties grown at four locations in North Dakota in 2021, with three-year averages (2019-21).

	Casselton		Dickinson		Hettinger		Minot		Avg. N.D.	
Variety	2021	3-Yr. Avg.	2021	3-Yr. Avg.	2021	3-Yr. Avg.	2021	3-Yr. Avg.	2021	3-Yr. Avg.
	(bu/a)									
AAC Wildfire	122.8	--	21.9	--	26.6	--	21.8	--	48.3	--
AC Emerson	97.3	84.4	17.4	33.5	27.1	39.5	14.1	48.9	39.0	51.6
Draper	122.7	--	19.8	--	29.4	--	16.7	--	47.2	--
Ideal	116.6	91.8	18.8	37.9	25.5	39.4	18.7	54.4	44.9	55.9
Jerry	115.9	89.4	21.2	37.7	28.0	40.8	26.5	51.2	47.9	54.8
Keldin	121.8	90.4	22.1	38.0	30.0	45.9	29.1	59.5	50.8	58.5
MS Iceman	99.6	--	13.9	--	28.7	--	16.8	--	39.8	--
ND Noreen	119.4	--	22.6	38.7	27.5	--	21.1	54.1	47.7	--
Northern	126.7	88.6	25.5	41.3	31.6	46.6	21.4	48.0	51.3	56.1
Ray	115.6	--	22.3	--	30.1	--	22.6	--	47.7	--
SD Andes	122.9	--	26.4	--	30.3	--	21.5	--	50.3	--
SY Monument	115.1	88.8	20.8	38.9	30.4	43.2	17.3	53.5	45.9	56.1
SY Wolf	107.8	89.0	12.9	38.5	25.9	38.0	19.3	47.0	41.5	53.1
SY Wolverine	116.6	92.6	12.6	--	28.2	--	11.7	42.8	42.3	--
TCG-Boomlock	121.4	90.7	19.6	38.5	30.8	--	21.7	50.3	48.4	44.9
WB4309	119.1	--	16.0	--	32.7	--	16.0	--	46.0	--
WB4462	110.3	89.6	18.5	37.7	30.5	40.0	17.4	46.9	44.2	53.6
Winner	120.3	--	23.2	--	30.8	--	18.3	--	48.2	--
Mean	115.9	89.5	19.3	38.1	29.1	41.8	19.4	50.6	46.2	53.8
CV (%)	4.4	--	18.1	--	7.5	--	17.7	--	8.7	5.2
LSD 0.05	5.9	--	5.7	--	2.6	--	5.6	--	5.7	4.2
LSD 0.10	4.9	--	4.8	--	2.0	--	4.7	--	4.8	3.5

Table 3. Test weight of winter wheat varieties grown at four locations in North Dakota in 2021.

Variety	Casselton	Dickinson	Hettinger	Minot	Average[1]
	-----	-----	(lb/bu)	-----	-----
AAC Wildfire	62.8	55.9	52.0	55.7	56.6
AC Emerson	61.9	57.4	54.1	55.4	57.2
Draper	62.1	56.4	53.6	59.0	57.8
Ideal	62.7	56.7	53.6	58.4	57.9
Jerry	61.3	56.6	53.6	58.1	57.4
Keldin	62.4	57.0	52.5	58.3	57.6
MS Iceman	63.6	60.2	54.8	60.3	59.7
ND Noreen	63.6	59.8	56.1	59.9	59.9
Northern	62.3	58.0	54.2	57.4	58.0
Ray	61.1	57.0	51.5	56.3	56.5
SD Andes	63.6	57.8	53.7	59.0	58.5
SY Monument	61.6	53.9	52.1	57.1	56.2
SY Wolf	62.7	58.1	53.2	58.9	58.2
SY Wolverine	62.4	57.2	53.7	57.6	57.7
TCG-Boomlock	62.7	57.3	54.8	59.6	58.6
WB4309	62.2	56.6	52.1	56.7	56.9
WB4462	61.8	54.5	53.4	56.5	56.6
Winner	62.3	56.9	53.8	58.8	58.0
Mean	62.3	57.0	53.7	58.0	57.7
CV (%)	0.6	1.5	2.1	1.4	1.4
LSD 0.05	0.4	1.4	1.6	1.4	1.2
LSD 0.10	0.3	1.2	1.3	1.1	1.0

[1]Mean values have been estimated using statistical techniques if there were missing values.

Table 4. Grain protein content at 12% grain moisture content of winter wheat varieties grown at four locations in North Dakota in 2021.

Variety	Casselton	Dickinson	Hettinger	Minot	Average
	----------------------	----------------------	(%)	----------------------	----------------------
AAC Wildfire	12.6	16.4	17.3	14.3	15.2
AC Emerson	13.9	16.2	16.3	15.5	15.5
Draper	12.7	14.8	15.7	13.5	14.2
Ideal	12.3	15.3	16.7	13.8	14.5
Jerry	13.0	15.6	16.9	13.8	14.8
Keldin	12.4	15.4	16.5	13.3	14.4
MS Iceman	14.4	15.3	16.3	15.4	15.4
ND Noreen	13.0	15.5	16.9	14.1	14.9
Northern	12.7	15.4	16.8	13.7	14.7
Ray	13.2	15.8	17.1	13.4	14.9
SD Andes	12.3	15.2	16.5	13.6	14.4
SY Monument	12.5	14.3	15.6	13.5	14.0
SY Wolf	13.0	15.3	16.2	14.3	14.7
SY Wolverine	13.0	14.8	15.6	15.1	14.6
TCG-Boomlock	12.8	15.3	16.4	14.2	14.7
WB4309	13.0	15.0	16.3	14.6	14.7
WB4462	12.7	14.9	15.4	14.1	14.3
Winner	12.7	14.5	15.2	14.5	14.2
Mean	12.9	15.2	16.2	14.1	14.7
CV (%)	2.5	2.5	3.2	3.3	3.4
LSD 0.05	0.4	0.6	0.7	0.8	0.7
LSD 0.10	0.3	0.5	0.6	0.6	0.6

Table 5. Analytical milling and baking characteristics of selected varieties evaluated at two locations (Casselton and Dickinson), in 2020.

	Kernel				Flour					Farinograph				Loaf	
Variety	Test Weight[1]	1,000 Kernel Weight[2]	Whole Wheat Protein 12 MB[3]	Falling Number[4]	Flour Protein 14 MB	Flour Ash 14 MB	Milling Extraction[5]	Wet Gluten	Gluten Index	Abs[6]	Peak Time	Stability[7]	Mixing Tolerance Index	Loaf Volume[8]	Crumb Color
	(lb/bu)	(gram)	(%)	(seconds)	(%)	(%)	(%)	(%)		(%)	(min)	(min)	(BU)	(cc)	(1-10)[9]
AAC-Wildfire	59.8	29.7	13.7	384	13.2	0.6	73.7	33.7	88.6	58.3	6.3	9.0	32.5	1025	8.0
AC Emerson	60.2	25.7	15.0	337	14.0	0.6	73.2	33.3	98.0	56.5	7.3	14.8	26.5	1038	7.5
Ideal	60.1	30.8	12.4	357	11.7	0.6	74.8	26.0	99.0	55.9	5.4	11.0	25.5	925	7.0
Jerry	58.6	31.6	14.0	354	13.0	0.5	73.1	29.6	92.5	57.9	5.5	5.0	51.0	945	7.0
Keldin	60.3	36.0	13.4	360	12.6	0.6	74.9	31.0	92.6	58.2	4.6	8.5	33.5	970	7.0
ND Noreen	61.0	33.5	13.9	377	12.9	0.6	73.1	34.5	77.4	57.8	5.5	5.4	47.5	995	8.0
Northern	57.8	27.9	14.7	386	14.0	0.6	72.2	36.2	84.7	62.4	5.9	6.0	39.5	1048	8.5
Oahe	60.2	34.5	13.0	382	12.0	0.6	75.2	31.8	80.1	59.3	4.0	4.0	50.0	870	6.0
Peregrine	60.0	28.7	12.7	313	12.0	0.5	76.3	29.2	94.5	56.5	5.2	6.3	47.0	920	6.5
SY Monument	58.0	29.7	12.9	387	12.2	0.5	70.3	27.0	99.3	56.9	4.4	15.4	15.0	838	6.0
SY Sunrise	58.6	30.0	12.4	382	11.5	0.5	71.7	28.1	97.5	56.4	5.0	6.3	45.5	935	7.0
SY Wolf	59.8	30.1	13.6	298	12.8	0.5	70.8	31.0	87.2	57.7	6.9	7.9	35.0	930	7.0
SY Wolverine	59.6	32.0	12.6	362	11.8	0.5	71.7	29.1	88.8	56.1	7.1	10.8	29.0	910	6.0
TCG-Boomlock	60.2	28.6	13.8	391	13.0	0.6	73.3	32.5	87.5	58.8	6.0	6.3	38.5	955	7.5
Thompson	60.2	28.5	13.7	371	12.8	0.5	73.1	33.8	66.6	56.4	5.2	5.2	48.5	885	6.5
WB4462	58.8	35.2	12.6	335	12.2	0.6	74.2	29.5	88.1	55.6	4.9	5.4	46.5	903	6.5
WB4595	61.3	29.7	13.0	303	12.3	0.6	73.0	31.6	71.0	59.8	4.3	4.6	45.0	903	7.0
Mean	59.7	30.7	13.4	357.4	12.6	0.6	73.2	31.0	87.9	57.6	5.5	7.7	38.6	941	7.0

[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 U.S. No. 1.

[2]1,000 KWT - Estimate of weight of 1,000 seeds based on a clean 10g sample. Expressed in grams and used to approximate seed size.

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

[4]Falling Number - Expressed in seconds at a 14% moisture basis. It is used as an indicator of sprouting based on elevated enzyme activity.
A high falling number is desirable, preferably greater than 400 seconds.

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

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

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

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

[9]Scale 1-10, with 1 being low and 10 being superior.

North Dakota Barley, Oat and Rye Variety Trial Results for 2021 and Selection Guide

Clair Keene, Rich Horsley, Mike McMullen, Paul Schwarz, Andrew Friskop and Thomas Baldwin (NDSU Main Station); Blaine Schatz, Steve Zwinger and Mike Ostlie (Carrington Research Extension Center); Glenn Martin (Dickinson Research Extension Center); John Rickertsen (Hettinger Research Extension Center); Eric Eriksmoen (North Central Research Extension Center, Minot); Bryan Hanson (Langdon Research Extension Center); and Gautam Pradhan (Williston Research Extension Center)

Barley, oat and rye varieties currently grown in North Dakota are described in the following tables. Successful production of these crops depends on numerous factors, including selecting the right variety for a particular area. Characteristics to evaluate in selecting a variety are: yield potential in your area, test weight, straw strength, plant height, reaction to problematic diseases and maturity.

Selecting varieties with good quality also is important to maintain market recognition. Because malting barley usually is purchased on an identity-preserved basis, producers are encouraged to determine which barley varieties are being purchased by potential barley buyers before selecting a variety. When selecting a high-yielding and good-quality variety, use data that summarize several years and locations. Additional data from county sites are available at https://vt.ag.ndsu.edu and from each Research Extension Center.

Yield is reported on a 14.5%, 14% and 14% moisture basis for barley, oats and rye respectively. Protein is reported on a 0% moisture basis for all crops in this report. The agronomic data presented in this publication are from replicated research plots using experimental designs that enable the use of statistical analysis. The LSD (least significant difference) numbers beneath the columns in tables are derived from these statistical analyses and apply only to the numbers in the column in which they appear. Differences between two varieties exceeding the LSD value mean that with 95% or 90% confidence (LSD probability 0.05 or 0.10), the higher-yielding variety has a significant yield advantage.

The abbreviation NS is used to indicate that no statistical difference occurs between varieties. The CV is a measure of variability in the trial. The CV stands for coefficient of variation and is expressed as a percentage. Large CVs mean a large amount of variation could not be attributed to differences in the varieties.

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 this publication only if no portion is deleted, appropriate footnotes are given and the order of the data is not rearranged.

North Dakota State University Barley, Oat and Rye Tables # 1 - 10 can be found on pages 114 - 120

Table 1. 2021 North Dakota barley variety descriptions.

Variety	Use[1]	Origin[2]	Year Released	Awn[3] Type	Rachilla Hair[4] Length	Aleurone Color	Height (inch)	Days to Head	Straw[5] Strength	Reaction to Disease[6]: Stem Rust	Spot-form Net Blotch	Spot Blotch	Net Blotch
Six-rowed													
Tradition	M/F	BARI	2003	S	L	White	29	28	3	8	6	3	7
Two-rowed													
AAC Connect	M/F	Meridian	2017	R	L	White	27	31	4	4	5	4	5
AAC Synergy	M/F	Syngenta	2015	R	L	White	27	32	4	4	3	4	4
ABI Cardinal	**M/F**	**BARI**	**2019**	**R**	**S**	**White**	**27**	**31**	**4**	**NA**	**NA**	**4**	**6**
Brewski	**M**	**ND**	**2021**	**S**	**L**	**White**	**27**	**32**	**4**	**NA**	**NA**	**4**	**4**
CDC Austenson	**F**	**CDC**	**2009**	**R**	**S**	**White**	**27**	**35**	**2**	**NA**	**NA**	**2**	**2**
CDC Bow	M/F	CDC	2016	R	L	White	27	33	2	NA	NA	6	NA
CDC Churchill	**M/F**	**CDC**	**2019**	**R**	**L**	**White**	**26**	**31**	**3**	**NA**	**NA**	**NA**	**NA**
CDC Fraser	**M/F**	**CDC**	**2016**	**R**	**L**	**White**	**27**	**32**	**2**	**NA**	**NA**	**4**	**4**
Conlon[7]	M/F	ND	1996	S	L	White	27	27	4	8	4	6	3
Esma	**F**	**Ackermann**	**NA**	**R**	**L**	**White**	**26**	**30**	**2**	**NA**	**NA**	**NA**	**NA**
Explorer	M	Secobra	NA	R	L	White	24	31	3	NA	NA	8	4
ND Genesis	M/F	ND	2015	S	L	White	28	30	4	8	4	4	6
Pinnacle	M/F	ND	2006	S	L	White	27	29	3	8	8	5	6

Bolded varieties were tested for the first time this year, so some ratings may change as new data become available.

[1]M = malting; F = feed.

[2]BARI = Busch Agricultural Resources Inc.; CDC = Crop Development Centre, University of Saskatchewan; ND = North Dakota State University Ackermann = Saatzucht Ackermann, Germany.

[3]R = rough; S = smooth.

[4]L = long S = short.

[5]Straw Strength scores from 1-9, with 1 = strongest and 9 = weakest.

[6]Disease reaction scores from 1-9, with 1 = resistant and 9 = very susceptible, NA – not available.

[7]Lower DON accumulations than other varieties tested.

Table 2. Yield and test weight of barley varieties at three locations in eastern North Dakota, 2019-2021.

	Casselton[1]			Carrington			Langdon			Avg. eastern N.D.		
	Test	Yield		Test	Yield		Test	Yield		Test	Yield	
Variety	Wt.	2021	3 Yr.	Wt.	2021	3 Yr.	Wt.	2021	3 Yr.	Wt.	2021	3 Yr.
	(lb/bu)	-----(bu/a)-----		(lb/bu)	-----(bu/a)-----		(lb/bu)	-----(bu/a)-----		(lb/bu)	-----(bu/a)-----	
Six-rowed												
Tradition	54.0	131.0	108.8	52.2	53.1	73.8	47.2	79.3	106.3	51.1	87.8	96.3
Two-rowed												
AAC Connect	53.4	134.1	96.6	53.1	52.1	66.9	47.1	89.5	112.2	51.2	91.9	91.9
AAC Synergy	53.5	120.0	93.3	52.7	52.4	65.8	48.2	92.3	115.6	51.5	88.2	91.6
ABI Cardinal	54.1	125.3	93.3	51.1	57.9	--	46.9	82.7	103.9	50.7	88.6	98.6
Brewski	53.4	115.2	--	52.0	50.9	--	48.3	90.9	--	51.2	85.7	--
CDC Austenson	--	112.6	--	51.9	53.0	--	--	--	--	--	--	--
CDC Bow	52.5	116.2	--	51.5	47.2	57.9	47.8	81.7	--	50.6	81.7	--
CDC Churchill	--	134.1	--	51.8	52.4	--	--	--	--	--	--	--
CDC Fraser	52.4	105.2	--	50.7	51.5	--	46.3	81.5	--	49.8	79.4	--
Conlon	53.3	105.6	86.5	52.9	44.2	57.7	49.9	57.4	92.0	52.0	69.1	78.7
Esma	--	132.9	--	52.5	55.9	--	--	--	--	--	--	--
Explorer	54.3	118.4	86.5	53.4	50.8	61.0	48.2	80.3	100.8	52.0	83.2	82.8
ND Genesis	53.3	121.5	101.2	51.8	50.7	59.5	48.8	91.0	115.1	51.3	87.7	91.9
Pinnacle	54.7	113.8	91.1	53.1	50.3	61.1	50.2	84.3	105.8	52.7	82.8	86.0
Mean	53.5	119.9	94.7	51.7	50.4	63.0	47.7	84.6	106.5	51.3	84.2	89.7
CV %	--	8.9	--	1.1	13.8	--	1.5	9.9	--	1.4	7.4	5.7
LSD 0.05	--	14.6	--	0.8	NS	--	0.8	9.9	--	1.2	10.6	8.8
LSD 0.10	--	12.2	--	0.7	8.2	--	0.6	7.7	--	1.0	8.8	7.2

[1]Data from Casselton were used because of non-uniform plots in Fargo due to poor plot emergence.

Table 3. Plump and protein of barley varieties at three locations in eastern North Dakota, 2020.

	Casselton		Carrington		Langdon		Avg. eastern N.D.	
Variety	Plump	Protein	Plump	Protein	Plump	Protein	Plump	Protein
	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
Six-rowed								
Tradition	87.4	11.9	93.1	15.0	92.9	13.5	91.1	13.5
Two-rowed								
AAC Connect	91.3	12.3	91.6	15.5	89.8	14.5	90.9	14.1
AAC Synergy	94.0	11.8	93.0	14.9	94.3	13.6	93.8	13.4
ABI Cardinal	90.5	11.3	92.7	15.1	93.1	14.2	92.1	13.5
Brewski	95.2	11.7	93.5	14.5	97.8	13.0	95.5	13.1
CDC Austenson	--	--	85.0	15.6	--	--	--	--
CDC Bow	94.1	12.2	92.6	15.2	96.4	14.2	94.4	13.9
CDC Churchill	--	--	90.2	15.0	--	--	--	--
CDC Fraser	89.8	12.2	92.2	15.1	95.4	13.7	92.5	13.7
Conlon	96.2	13.1	96.7	15.0	98.3	14.1	97.1	14.1
Esma	--	--	93.4	15.2	--	--	--	--
Explorer	93.1	12.6	94.9	15.5	96.0	13.9	94.7	14.0
ND Genesis	94.0	10.6	93.8	13.5	98.1	12.5	95.3	12.2
Pinnacle	95.8	10.5	93.9	13.6	98.7	13.7	96.1	12.6
Mean	93.3	11.5	93.1	14.5	95.8	13.2	93.9	13.5
CV %	--	--	2.5	2.4	2.8	3.7	1.6	2.8
LSD 0.05	--	--	3.3	0.5	3.2	0.6	2.6	0.7
LSD 0.10	--	--	2.8	0.4	2.4	0.4	2.2	0.5

Table 4. Yield and test weight of barley varieties at four locations in western North Dakota, 2019-2021.

	Dickinson			Hettinger			Minot			Williston			Avg. western N.D.		
	Test	Yield		Test	Yield		Test	Yield		Test	Yield		Test	Yield	
Variety	Wt.	2021	3 Yr.	Wt.	2021	3 Yr.	Wt.	2021	3 Yr.[1]	Wt.	2021	3 Yr.	Wt.	2021 [2]	3 Yr.[3]
	(lb/bu)	---(bu/a)---		(lb/bu)	---(bu/a)---		(lb/bu)	---(bu/a)---		(lb/bu)	---(bu/a)---		(lb/bu)	---(bu/a)---	
Six-rowed															
Tradition	44.5	22.2	43.4	43.8	50.4	66.0	46.1	31.9	--	49.8	25.7	42.3	46.0	36.3	50.6
Two-rowed															
AAC Connect	48.0	10.9	44.7	45.2	46.4	66.4	46.0	20.6	--	48.3	13.7	49.0	46.9	28.7	53.4
AAC Synergy	48.5	11.4	45.2	44.0	47.5	68.7	46.0	36.7	107.9	47.4	15.8	52.5	46.5	29.4	55.5
ABI Cardinal	48.7	12.3	46.5	45.1	50.3	66.9	47.6	29.8	--	49.0	22.4	--	47.6	31.3	56.7
Brewski	46.7	23.8	--	44.5	60.1	--	43.6	35.6	--	49.0	29.4	--	46.0	42.0	--
CDC Austenson	--	--	--	46.5	44.7	--	46.4	33.1	--	49.4	19.0	--	--	--	--
CDC Bow	48.5	11.3	--	43.8	46.4	--	47.1	36.6	--	46.8	14.5	49.5	46.6	28.9	--
CDC Churchill	--	--	--	44.2	55.7	--	47.3	36.0	--	49.2	20.2	--	--	--	--
CDC Fraser	47.4	9.2	--	43.5	45.9	--	45.1	34.7	--	46.4	16.4	--	45.6	27.6	--
Conlon	46.5	21.5	42.6	44.1	43.9	53.1	45.4	30.4	90.5	50.6	22.8	50.3	46.6	32.7	48.7
Esma	--	--	--	44.7	57.3	--	48.9	37.5	--	50.5	37.0	--	--	--	--
Explorer	45.8	20.1	53.2	44.9	54.3	62.5	46.5	27.7	106.8	50.5	25.7	56.4	46.9	37.2	57.4
ND Genesis	46.3	19.2	46.3	45.0	57.5	76.6	45.8	37.6	109.0	47.3	18.8	56.4	46.1	38.3	59.8
Pinnacle	49.0	22.0	49.2	46.0	54.8	58.3	48.1	41.4	106.8	49.3	20.0	56.5	48.1	38.4	54.7
Mean	47.3	18.9	46.4	44.5	53.1	64.8	46.4	30.2	104.2	48.7	23.9	51.6	46.6	33.7	54.6
CV %	1.5	13.1	--	2.1	9.4	--	3.7	24.2	--	1.7	25.8	--	2.4	--	--
LSD 0.05	1.0	3.5	--	1.3	5.9	--	NS	14.6	--	1.4	10.1	--	NS	--	--
LSD 0.10	0.9	2.9	--	1.1	4.6	--	NS	12.3	--	1.2	8.4	--	1.4	--	--

[1]Three-year average does not include 2021 data.

[2]Excludes Minot and Williston data due to high variability caused by drought conditions.

[3]Excludes Minot 3 Yr. data.

Table 5. Plump and protein of barley varieties at four locations in western North Dakota, 2021.

	Dickinson		Hettinger		Minot		Williston		Avg. western N.D.	
Variety	Plump	Protein	Plump	Protein	Plump	Protein	Plump	Protein	Plump	Protein
	---(%)---									
Six-rowed										
Tradition	48	17.2	56	16.7	89	14.5	68	14.1	65.2	15.6
Two-rowed										
AAC Connect	72	18.2	80	17.4	93	18.0	90	16.0	83.7	17.4
AAC Synergy	82	17.5	80	17.1	96	15.4	88	16.0	86.5	16.5
ABI Cardinal	74	18.9	84	17.0	96	15.4	91	15.4	86.2	16.7
Brewski	63	16.2	80	15.7	96	14.8	80	13.4	79.9	15.0
CDC Austenson	--	--	76	16.7	93	14.8	78	14.8	82.3	15.4
CDC Bow	90	17.1	83	17.3	97	14.7	93	15.4	90.8	16.1
CDC Churchill	--	--	61	17.8	96	14.7	89	15.3	81.9	15.9
CDC Fraser	91	17.3	85	17.4	96	15.2	91	14.8	90.6	16.2
Conlon	86	17.4	93	16.3	96	15.6	95	15.0	92.4	16.1
Esma	--	--	68	17.7	96	13.8	84	13.9	82.7	15.1
Explorer	64	18.5	79	17.0	96	15.9	88	16.4	81.6	17.0
ND Genesis	60	15.2	85	14.3	95	13.2	83	13.2	80.8	14.0
Pinnacle	82	16.3	86	15.2	97	12.5	86	12.5	87.8	14.1
Mean	74	16.7	78	15.9	95	14.7	86	14.0	83.7	15.8
CV %	12.1	2.6	7.4	4.9	2.0	8.7	3.5	5.6	7.6	4.0
LSD 0.05	12	0.6	8.2	0.9	4.0	2.6	4.9	1.3	9.1	0.9
LSD 0.10	11	0.5	6.9	0.6	3.0	2.1	4.1	1.1	7.6	0.7

Table 6. 2021 North Dakota oat variety descriptions.											
							Reaction to Diseases				
		Year	Grain	Height	Straw	Days to	Stem	Crown	Barley	Test	
Variety	Origin[1]	Released	Color	(inch)	Strength	Heading[2]	Rust[3]	Rust[3]	Y.Dwf[4]	Weight	Protein[5]
Beach	ND	2004	White	22	M.strg.	61	8	4	6	V.good	M
CDC Minstrel	Sask.	2006	White	21	M.strg.	62	8	8	8	Good	M
CS Camden	Meridian	2016	White	21	Strong	64	8	6	NA	Good	M
Deon	MN	2013	Yellow	22	Strong	63	8	2	2	V.good	M
Hayden	SD	2014	White	20	Med.	62	8	6	NA	V.good	M
HiFi	ND	2001	White	22	Strong	64	4	8	2	Good	M
Hytest	SD	1986	White	23	M.strg.	62	8	6	8	V.good	H
Jury	ND	2012	White	23	M.strg.	62	1	8	4	V.good	M
Killdeer	ND	2000	White	21	Strong	62	8	6	4	Good	M
Leggett	AAFC	2005	White	21	Strong	64	3	1	8	Good	M
ND Heart	ND	2020	White	22	Strong	62	3	6	4	Good	H
Newburg	ND	2011	White	20	Med.	65	1	8	4	Good	M
Otana	MT	1977	White	23	M.weak	64	8	8	8	V.good	M/L
Paul[6]	ND	1994	Hull-less	23	Strong	65	1	4	2	V.good	H
Rockford	ND	2008	White	22	Strong	63	8	8	4	V.good	M
Warrior	SD	2018	White	20	Strong	62	6	1	NA	V.good	M

Bolded varieties were tested for the first time this year, so some ratings may change as new data become available.

[1]AAFC = Agriculture & Agri-Food Canada; MN = University of Minnesota; ND = North Dakota State University; SD = South Dakota State University; Sask. = University of Saskatchewan; MT = Montana State University.

[2]Days after planting.

[3]Disease reaction scores from 1-9, with 1 = resistant and 9 = very susceptible.

[4]Disease reaction scores from 1-9, with 1 = resistant and 9 = very susceptible, NA – not available.

[5]H = high; M = medium; L = low.

[6]Hull-less variety.

Table 7. Yield and test weight of oat varieties at three locations in eastern North Dakota, 2019-2021.

	Fargo			Casselton			Carrington (organic)			Average Eastern N.D.		
	Test	Yield		Test	Yield		Test	Yield		Test	Yield	
Variety	Wt.	2021	3 Yr.	Wt.	2021	3 Yr.	Wt.	2021	3 Yr.	Wt.	2021	3 Yr. Avg.
	(lb/bu)	---(bu/a)---		(lb/bu)	---(bu/a)---		(lb/bu)	-----(bu/a)-----		(lb/bu)	--------(bu/a)--------	
Beach	40.4	143.3	111.9	43.3	104.8	92.1	37.2	42.7	--	40.3	96.9	102.0
CDC Minstrel	--	--	--	--	--	--	35.1	59.6	93.1	--	--	--
CS Camden	33.4	147.2	113.3	39.3	128.5	93.5	34.4	58.4	99.1	35.7	111.4	102.0
Deon	38.7	136.4	119.5	42.3	105.2	96.6	37.4	62.2	94.2	39.5	101.3	103.4
HiFi	37.0	139.6	103.1	39.5	111.7	83.0	34.6	56.3	83.2	37.0	102.5	89.8
Hytest	--	--	--	--	--	--	37.5	53.0	--	--	--	--
Jury	37.0	163.8	107.0	42.2	129.6	89.5	35.7	60.9	90.6	38.3	118.1	95.7
Killdeer	34.6	132.3	97.1	40.0	120.9	87.2	35.9	61.4	89.9	36.8	104.9	91.4
Leggett	37.6	143.8	124.6	40.6	99.0	103.8	36.4	53.0	86.0	38.2	98.6	104.8
ND Heart	37.5	146.3	--	41.1	100.2	--	35.3	56.2	82.0	38.0	100.9	--
Newburg	37.2	149.7	101.5	41.5	100.1	69.3	33.8	60.2	87.3	37.5	103.3	86.0
Otana	35.8	150.0	96.0	40.6	115.3	80.8	37.2	55.3	--	37.9	106.9	88.4
Paul[1]	42.4	114.3	63.8	45.2	69.4	50.0	44.4	39.6	51.2	44.0	74.4	55.0
Rockford	39.5	142.9	91.9	41.9	117.4	77.5	36.8	54.6	85.0	39.4	105.0	84.8
Warrior	37.5	142.9	126.0	41.2	110.0	101.6	36.3	56.7	81.2	38.3	103.2	102.9
Mean	37.6	142.5	104.6	41.4	108.6	85.4	37.0	52.9	85.2	38.5	102.1	92.2
CV %	6.2	8.0	--	3.9	14.4	--	2.4	12.9	--	2.9	7.8	7.7
LSD 0.05	1.3	18.0	--	1.2	21.9	--	1.3	9.7	--	1.9	13.1	12
LSD 0.10	0.9	11.7	--	1.0	17.0	--	1.1	8.1	--	1.6	10.9	10

[1]Hull-less varieties. When comparing yield of hull-less oat varieties with varieties with hulls, multiply the yield of the hull-less oats by 1.35 (the hull of a hulled kernel comprises 35% of the weight).

Table 8. Yield and test weight of oat varieties at four locations in western North Dakota, 2019-2021.

	Dickinson			Hettinger			Minot			Williston			Average Western N.D.		
	Test	Yield		Test	Yield		Test	Yield		Test	Yield		Test	Yield	
Variety	Wt.	2021	3 Yr.	Wt.	2021	3 Yr.	Wt.	2021	2 Yr.[1]	Wt.	2021	3 Yr.	Wt.	2021 [2]	3 Yr.
	(lb/bu)	----(bu/a)----		(lb/bu)	----(bu/a)----		(lb/bu)	----(bu/a)----		(lb/bu)	----(bu/a)----		(lb/bu)	----(bu/a)----	
AAC Douglas	--	--	--	33.5	96.0	--	28.7	31.4	--	41.0	29.8	--	--	--	--
Beach	37.1	18.4	72.4	32.9	63.0	87.3	31.2	14.7	119.0	39.9	21.0	73.8	35.3	42.0	77.8
CDC Minstrel	36.7	18.3	79.9	34.2	72.6	101.3	24.1	19.3	115.4	39.2	18.8	85.6	33.6	45.7	88.9
CS Camden	30.9	15.3	72.1	29.2	88.1	106.1	26.8	31.4	127.2	41.7	34.2	100.3	32.1	61.2	92.8
Deon	35.8	18.5	87.6	31.8	81.0	93.9	30.8	25.7	113.2	43.2	31.7	89.5	35.4	56.4	90.3
Hayden	36.4	22.0	81.5	34.5	81.3	101.2	29.5	21.3	121.4	--	--	--	--	--	--
HiFi	32.0	13.6	75.0	31.7	68.7	93.7	27.0	17.9	109.1	36.9	13.2	79.5	31.9	40.9	82.7
Hytest	36.2	19.1	65.5	33.6	74.6	89.9	28.3	17.1	113.8	36.2	14.0	65.7	33.6	44.3	73.7
Jury	34.6	27.5	81.2	31.6	80.5	97.0	29.7	19.5	105.7	39.7	21.2	91.1	33.9	50.9	89.8
Killdeer	34.6	21.7	83.3	32.7	78.4	92.5	30.8	22.0	107.4	41.8	24.4	98.0	35.0	51.4	91.3
Leggett	36.4	15.6	67.3	32.8	67.2	92.5	25.5	20.5	116.4	40.6	16.5	90.4	33.8	41.8	83.4
ND Heart	33.9	25.1	72.4	31.4	67.6	88.2	27.5	12.0	112.7	41.9	28.9	--	33.7	48.3	--
Newburg	34.3	16.0	74.9	33.2	78.2	92.6	26.1	14.1	99.3	41.6	27.1	81.6	33.8	52.7	83.0
Otana	33.8	17.0	73.2	33.8	81.9	94.7	28.7	21.7	106.9	38.1	31.6	89.5	33.6	56.8	85.8
Paul[3]	42.1	9.5	53.1	39.7	44.3	60.9	29.7	7.9	87.6	--	4.8	55.3	37.2	24.6	56.4
Rockford	35.3	17.1	77.0	35.1	86.7	103.4	30.0	18.5	120.2	42.0	32.9	95.3	35.6	59.8	91.9
Warrior	35.5	22.1	70.2	34.2	91.1	102.2	29.6	17.1	--	41.8	29.2	85.7	35.3	60.2	86.0
Mean	35.5	20.2	74.2	33.4	77.1	93.6	29.2	18.9	111.7	38.9	20.5	84.4	34.2	49.1	83.9
CV %	4.2	30.5	--	4.2	7.9	--	5.2	32.5	--	3.9	14.8	--	5.2	--	--
LSD 0.05	2.1	8.6	--	2.0	7.2	--	2.5	10.0	--	2.5	5.0	--	2.5	--	--
LSD 0.10	1.7	7.2	--	1.6	5.6	--	2.1	8.4	--	2.1	4.1	--	2.1	--	--

[1]Two-year Average includes 2019 and 2020.

[2]Excludes Dickinson and Minot data due to high variability caused by drought conditions.

[3]Hull-less varieties. When comparing yield of hull-less oat varieties with varieties with hulls, multiply the yield of the hull-less oats by 1.35 (the hull of a hulled kernel is 35% of the weight).

Table 9. 2021 North Dakota winter rye variety descriptions.

Variety	Origin[1]	Year Released	Height (inches)	Straw Strength	Days to Head	Seed Color	Seed Size	Winter Hardiness
AC Hazlet	Canada	2006	35	Good	156	Bl-grn.	Small	Good
Aroostok	USDA	1981	35	Fair	153	Tan	Small	V.good
Bono[3]	KWS	2013	27	Good	158	Green	Med.	Good
Brasetto[3]	KWS	2007	28	V.good	159	Bl-grey	Large	Good
Danko	Poland	1976	31	Good	159	Green	Large	Poor
ND Dylan	ND	2016	36	Good	158	Blue	Med.	V.good
ND Gardner	ND	2019	35	Fair	154	Bl-grn.	Small	V.good
Rymin	MN	1973	33	V.good	158	Grn-gray	Large	Fair[4]
Serfanio[3]	KWS	2019	28	V.good	158	Green	Large	V.good
Spooner	WI	1993	34	V.good	156	Tan	Large	Good
Tayo[3]	KWS	2020	28	V.good	158	Green	Med.	Good

[1]ND = North Dakota State University; WI = University of Wisconsin; MN = University of Minnesota; MI = Michigan State University. KWS = KWS Cereals, USA

[2]NA = not available.

[3]Hybrid.

[4]Varieties with fair or poor winter hardiness should not be seeded in bare soil.

Table 10. Yield and test weight of winter rye varieties at four locations in North Dakota, 2019-2021.

	Carrington (organic)			Hettinger			Langdon			Minot			Average		
	Test	Seed Yield		Test	Seed Yield		Test	Seed Yield		Test	Seed Yield		Test	Seed Yield	
Variety	Wt.	2021	3-yr.	Wt.	2021	3-Yr.	Wt.	2021	3-Yr.	Wt.	2021	3-yr.	Wt.	2021[1]	3-yr.
	(lb/bu)	---(bu/a)---		(lb/bu)	---(bu/a)---		(lb/bu)	---(bu/a)---		(lb/bu)	---(bu/a)---		(lb/bu)	---(bu/a)---	
AC Hazlet	56.6	27.2	45.7	50.4	29.7	49.5	54.7	75.6	--	53.1	38.0	72.7	53.7	44.2	56.0
Aroostok	55.3	15.1	34.3	51.2	28.4	39.7	53.0	59.9	50.7	51.9	16.5	50.2	52.9	34.5	43.7
Bono	55.5	35.0	58.2	50.7	39.6	68.9	54.7	97.0	79.5	52.9	39.8	92.7	53.4	57.2	74.8
Brasetto	54.5	25.2	48.4	50.9	39.5	64.6	52.9	90.9	80.6	51.8	40.8	90.8	52.5	51.9	71.1
Danko	52.1	8.2	--	50.5	31.8	--	54.0	68.2	--	51.4	18.4	--	52.0	36.1	--
ND Dylan	54.9	26.4	45.9	49.6	28.4	49.5	53.3	67.1	66.1	52.3	26.1	67.4	52.5	40.6	57.2
ND Gardner	54.3	14.6	37.4	51.6	32.1	44.0	53.8	66.7	57.2	52.8	21.7	55.2	53.1	37.8	48.5
Rymin	53.3	14.5	40.8	50.6	29.7	46.4	53.6	66.7	62.3	52.0	18.7	57.5	52.4	37.0	51.8
Serfanio	54.3	28.1	--	48.2	43.0	--	54.0	94.8	--	52.6	36.7	--	52.3	55.3	--
Spooner	55.1	22.6	39.6	51.5	29.9	45.1	53.0	58.5	54.8	51.9	21.7	54.0	52.9	37.0	48.4
Tayo	--	--	--	48.4	37.3	--	53.5	111.8	--	52.5	43.2	--	--	--	--
Mean	54.6	21.7	43.8	50.1	32.7	51.0	53.7	77.1	64.5	52.3	29.2	67.6	52.8	43.2	56.4
CV %	1.1	10.9	--	2.3	9.0	--	0.9	9.5	--	1.8	30.3	--	1.7	18.1	--
LSD 0.05	0.9	3.4	--	1.4	3.5	--	0.7	10.5	--	NS	15.1	--	NS	14.0	--
LSD 0.10	0.7	2.8	--	1.1	2.7	--	0.6	8.8	--	1.3	12.5	--	NS	11.5	--

[1]Average does not include Minot data due to high variability caused by drought conditions.

Minnesota Wheat Research
& Promotion Council
2600 Wheat Drive • Red Lake Falls, MN 56750
Ph: (218) 253-4311
www.mnwheat.org

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