MCDC Annual Report

2021

www.mbpotatoresearch.ca/
www.mbdiversificationcentres.ca/

Manitoba Crop Diversification Centre

The Manitoba Crop Diversification Centre (MCDC) was established between the Government of Canada, the Government of Manitoba, and Manitoba Horticulture Productivity Enhancement Centre Inc. (MHPEC). The Centre's mission, in brief, is to facilitate the development and adoption of science-based solutions for agricultural crop production. This is accomplished through the design, development and adaptation of best management practices with a focus on water management, crop diversification and environmental stewardship. Its strategic areas include sustainable irrigation, sustainable potato production, improving the environmental sustainability of intensive crop production, and crop diversification. This partnership between MHPEC and Manitoba Agriculture provides a unique opportunity for a collaborative site which amplifies the scale and significance of research that can be done. Our goal is to provide leadership and vision through cooperation, coordination and strategic collaborations between local producers, industry members and the scientific community, resulting in the development of a research program that will ensure the long term sustainability of the potato and agricultural industry in Manitoba.

Message from Site Manager

Thank you for taking the time to read and review our 2021 report and looking forward to the 2022 year. The Manitoba Crop Diversification Centre (MCDC) was established between the Government of Canada, the Government of Manitoba, and Manitoba Horticulture Productivity Enhancement Centre Inc. (MHPEC). We are located at the north-east corner of the junction of highway number 1 and number 5 at Carberry Manitoba.

The Centre's mission, in brief, is to facilitate the development and adoption of science-based solutions for agricultural crop production. This is accomplished through the design, development, and adaptation of best management practices with a focus on water management, crop diversification and environmental stewardship. Its strategic areas include sustainable irrigation, sustainable potato production, improving the environmental sustainability of intensive crop production, and crop diversification. Here at the MHPEC site we are fortunate to have the support of our three industry members Keystone Potato Producers Association, Simplot Canada II Ltd., and McCain Foods Canada that allows us to operate and conduct research for the potato industry, as well as other trials on crops. The results of this collected data are then entered and published for distribution to all interested stakeholders in potato production. These reports and the full report are also available online at www.mbpotatoresearch.ca and https://mbdiversificationcentres.ca/.

Since March 2020, due to Covid-19 restrictions, our offices have been closed to the public and access can be granted by appointment only in response to the rapid spread of Omicron variant and rising COVID case counts, the Manitoba Potato Production Days 2022 had to be cancelled. We hope to host multiple outdoor extension and knowledge transfer activities such as field days and plot tours in 2022. In closing I would like to thank you for taking the time to read and review this publication. We welcome, any and all, researchers, commodity groups and interested industry parties to bring forward your research projects for discussion. We are always open to the possibility of new research and trials at our site.

Garth Christison
Site Manager
MCDC Carberry Manitoba

Potato Research

Zack received his Master of Science in Plant Pathology with a minor in fungal and Oomycete biology from Cornell University in 2013 Zack received his Doctor of Philosophy in Plant Pathology with a minor in fungal and Oomycete biology from Washington State University in 2017. Zack's advisers included Drs. Dennis Johnson, Mark Pavek, Debra Inglis, and Weidong Chen, and his research and extension program focused on disease management strategies for soilborne fungal diseases of potato in Washington State's Columbia Basin with a focus on Verticillium wilt. Zack was awarded the J. de Weerd Fellowship in Potato Research in both 2015 and 2016. Zack was also an ARCS scholar (Achievement Rewards for College Scientists) from 2013 to 2017.

Zack has been the principal investigator of a research and extension program from 2017 to the present day for the Manitoba Horticulture Productivity Enhancement Centre (MHPEC) Inc. Zack's efforts to study Manitoba's potato yield variability have highlighted the importance of Verticillium wilt identification and management, as well as nutrition optimization for regional nitrogen and sulfur programs. Additional research is currently underway to study black dot and powdery scab identification and management, the development of disease-suppressive soils, irrigation decision support tools, seed cutter disinfection, and the implementation of precision agriculture tools into research with UAVs and a remote sensing device called Soil Optix.

Zack Frederick
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Crop Diversification Research

I was born & brought up on a family farm. I have approximately 12 years of professional experience related to agricultural research and demonstration. I received a M.Sc. in Agricultural & Biosystems Engineering from the University of Manitoba (Soil and Water Engineering focus), and a B.Sc.in Agricultural Engineering (Irrigation & Drainage Engineering focus). I currently work as Diversification Specialist with Manitoba Agriculture and Resource Development, in Carberry at the Canada Manitoba Crop Diversification Centre, where I am supporting Manitoba Horticulture Productivity Enhancement Centre experience in executing a small plot research program with expertise in crop agronomy, soil and water engineering, experimental field plot design, and management of field research activities. Moreover, I have sound working experience of precision agriculture technologies such as GPS, Real Time Kinematic (RTK) guidance systems, operation and maintenance of farm scale equipment, and grain cleaning equipment. I am certified in WHMIS and Emergency First Aid/ CPR/ AED Level A from the Canadian Red Cross.

CMCDC's goals are to increase profitability, sustainability and adaptability of local farms; accelerate the adoption and commercialization of research innovation at the farm level; facilitate the adoption of technical innovation or practices from outside of the province or country; and improve the overall growth of the agriculture, agri-food and agri-product sectors. Transfer of knowledge is a priority and project results, technical information and emerging opportunities are accessible through annual reports, field days, tours and display booths at agriculture trade fairs. Financial support is provided through the Canadian Agricultural Partnership (CAP) program, a federal-provincial-territorial government initiative, as well as through the Provincial Agricultural Sustainability Initiative (ASI) grant.

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Characterization of Agronomic Practices for Mustard Cultivars Necessary to Achieve Maximum Biomass to Theoretically Maximize Glucosinolate Production

Project duration:	September 2018 – September 2021
Objective:	To develop agronomic recommendations for mustard cultivars necessary to achieve maximum biomass to theoretically maximize glucosinolate production
Collaborators:	Manitoba Horticulture Productivity Enhancement Centre Inc. (MHPEC)

Targets and Deliverables:

a. Practices to target: planting date, flea beetle control, minimum inputs (irrigation, N+S fertilization) needed to achieve max biomass, seedbed preparation (stubble type, chaff spreading, best seed-to-soil contact ratio)
b. Deliverables
    1. Develop list of recommended and experimentally verified practices to successfully use mustard biofumigants as part of program to manage Verticillium wilt in Manitoba
    2. Improve recommendations for the inevitable question of "does this process work with other mustards?"
    3. Develop experimental evidence to make the call for Canada-bred mustards for biofumigation (if existing mustards will not suffice)

Background:

Planting date, presence of cereal's stubbles and seed treatment significantly impacted mustard yield and characteristics. The early seeded mustard planting date had the highest yield, population, height, and early season vigor. On the other hand, the late seeded mustard planting date had the lowest yield, population, height, and early season vigor. The mustard grown in this trial did not produce as much biomass as commonly seen in producers' field in the Carberry area, where mustard has become a popular biofumigant. It is possible that more mustard biomass is needed to have a stronger impact on subsequent potato plantings. In addition, growers have experimented with rolling, packing, or irrigating freshly incorporated mustard to help create a seal over the soil surface and increase release of biofumigants in the soil. It is possible that other techniques may be more effective at using mustard as a biofumigant. Additional research is needed to continue developing best agronomic practices for this pest control measure.

When managed properly mustard offers another tool to help growers control soilborne pests and diseases. It is important to strictly follow the outlined cultural practices to have any chance of success using mustard as a biofumigant. A high infestation rate of flea beetles was observed in the study areas which effected the capacity of biomass production of mustard varieties, highlighting a potential change that needs to be made for growing mustards in Manitoba. Proper chopping of plant material and soil incorporation is of utmost importance. Although mustard is a remarkable biofumigant, it could have other benefits that is expected from any other cover crop such as; prevention of soil erosion, recycling of soil nutrients, improved soil structure and maintaining soil organic matter. Interestingly, there are other crops that show possible biofumigation effect such as but not limited to; buckwheat, pearl millet, Sorghum-Sudan grass, rape seed and oil seed radish.

MCDC tested the biomass production from treated mustard varieties planted at four seeding dates (June 1, June 15, June 29, and July 13) during the 2021 planting year. For this purpose, cereal crops of fall rye, and winter wheat were seeded as a stubble crop in the fall of 2020.

Materials & Methods:

Pest Control

When using mustard or any other crop as a biofumigant, it is important to know the targeted pest(s) and its life cycle. The biofumigant crop should be incorporated when the pest is present in the upper soil profile (15 to 20 cm).

Seeding Date

Seeding date should be based on the targeted pest. Mustard should be seeded about 60 days before pest will be present in the field as mustard should be incorporated into the soil before seed production begins. Seeding date should be planned accordingly in order for the crop to have reached maximum biomass at time of incorporation. Depending on variety and growing conditions, it takes about 60 to 70 days to attain maximum biomass production.

Varieties

Mustard comes in many varieties but not all are equally as effective when it comes to biofumigation. Some mustard varieties produce more glucosinolates compared to others. In fact, some varieties have been bred for the sole purpose of biofumigation, for example, the “Caliente”. Caliente grows quickly and is typically used in spring or late summer, bred specifically for biofumigation as it contains very high levels of glucosinolates. At CMCDC, we are testing all varieties i.e. ‘AC Volcan’, ‘Caliente Rojo’, and ‘Cutlass’.

For The Best Results

- **(i)** **pH** of the soil should be above 5.5. If the field has a pH lower than 5.5 the biofumigation process might not be successful. For optimal results, the pH of soil should be as close to 7 as possible.
- **(ii)** **Biomass and glucosinolates** are factors that are fundamental to the success of biofumigation.
- **(iii)** **Fertilizer** Nitrogen is important to the production of biomass and sulfur is crucial for the production of glucosinolates. Nitrogen is applied depending on the field’s history.

The rate of sulfur should be adjusted in relation to the chosen nitrogen rate in a 6:1 ratio. For example, if 100 lbs/ac of nitrogen is applied then the suggested amount of sulfur to be applied would be 17lbs/ac.

Soil Incorporation

The following considerations should be taken into account, when incorporating the mustard crop into the soil.

- Mustard crop should be incorporated into the soil before it has reached full bloom.
- Incorporation process should be done when soil has a good level of moisture. Do not incorporate mustard when the soil is dry.
- Mustard must be incorporated immediately after mowing, 80% of the fumigant gas will be released in the first 20 minutes after mowing.

After incorporation, the field should be rolled and packed to trap the fumigant gas in the soil. Finally, once the incorporation process is complete, leave the field undisturbed for 14 days to ensure that all the plant material can break down.

In the fall of 2020, fall rye (variety: Bono), and winter wheat (variety: wildfire) were seeded to produce stubble crop prior to mustard seeding. Plot area was kept 6 m^2 with a plot length of 5 m, and width of 1.2 m. After harvesting the grain material of fall rye and winter wheat crop, three different mustard varieties were seeded at four different dates with an interval of two weeks. In the 2021 growing season, June 1, June 15, June 29, and July 13 were seeding dates for mustard. The mustard seed was treated with a seed treatment product called ‘Gaucho 600’ ensuring protection of the mustard plant against pests from the time of sowing well into the growing period. Herbicides and insecticides were applied when needed. All the other agronomic practices were carried out in accordance with standard mustard production guidelines.

Results:

A significant flea beetles’ infestation rate was observed throughout the grown season. An area of 1 m^2 was harvested to analyze biomass production in each variety. In addition to CMCDC, four more local sites were selected to collect data points from off-site for observation purpose.

Mustard Seeded on Fall Rye Stubble:

Mustard biomass, plant counts, and plant heights are shown in Figure 1, 2, and 3. All parameters were significantly higher in Caliente Rojo varieties within same dates. Highest biomass, plant counts, and plant heights were observed in seeding 1 of all varieties.

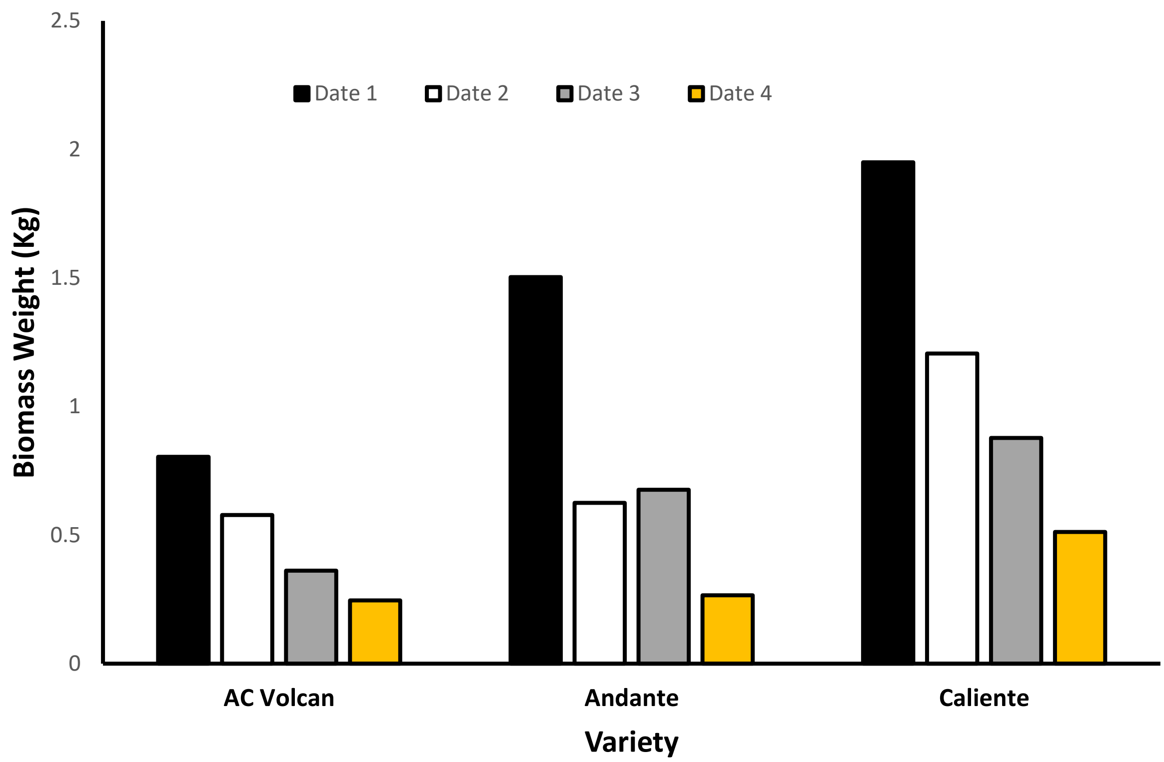


Figure 1. Biomass of mustard varieties seeded on fall rye (Variety: Bono) stubbles

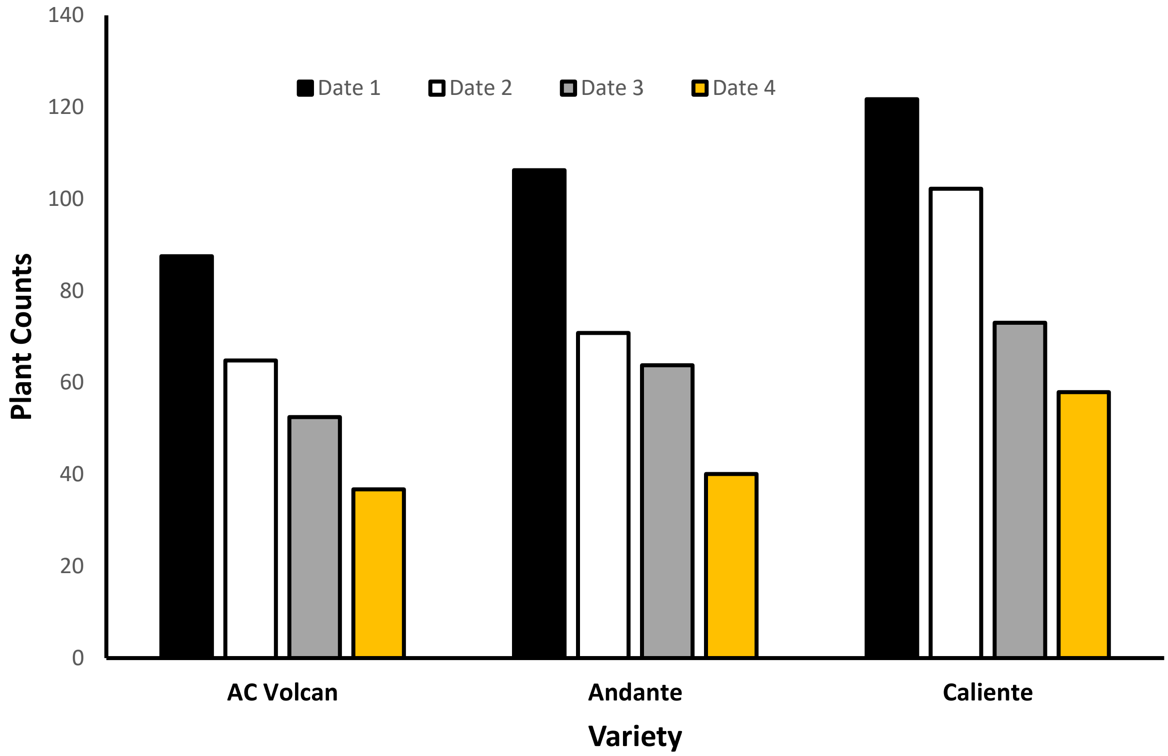


Figure 2. Plant counts of mustard varieties seeded on fall rye (Variety: Bono) stubbles

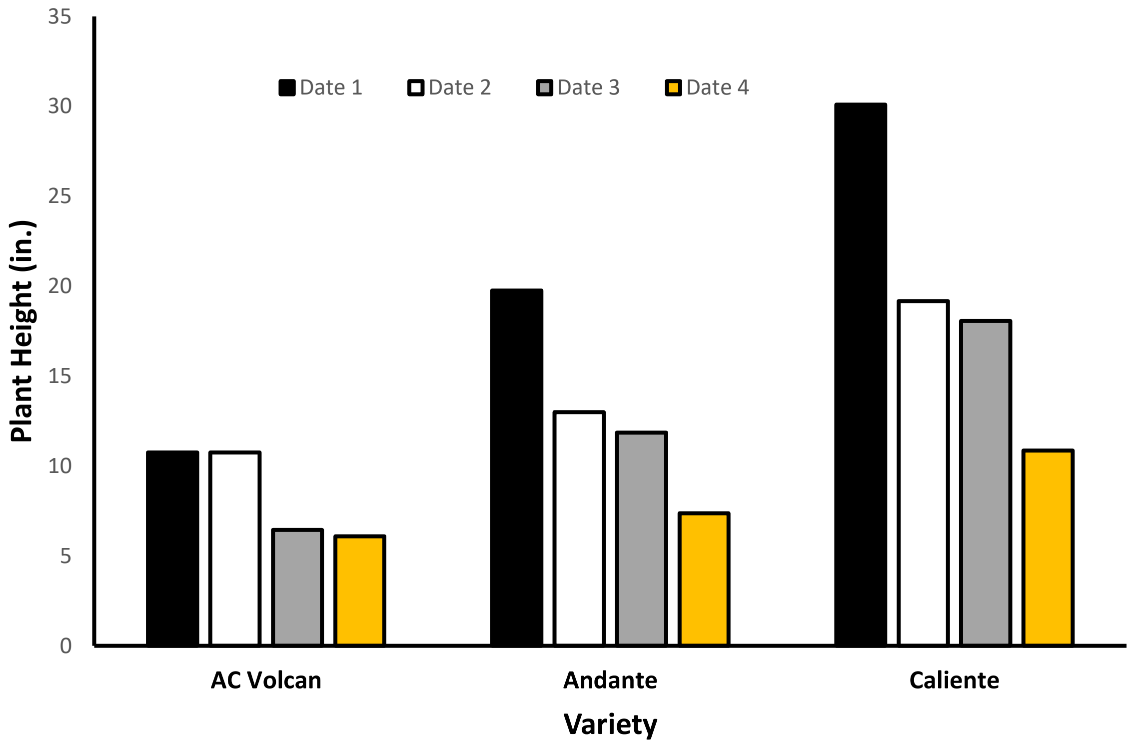


Figure 3. Plant height of mustard varieties seeded on fall rye (Variety: Bono) stubbles

Mustard Seeded on Winter Wheat Stubble:

Mustard biomass, plant counts, and plant heights are shown in Figure 4, 5, and 6. All parameters were significantly higher in Caliente Rojo varieties within same dates. Highest biomass, plant counts, and plant heights were observed in seeding 1 of all varieties.

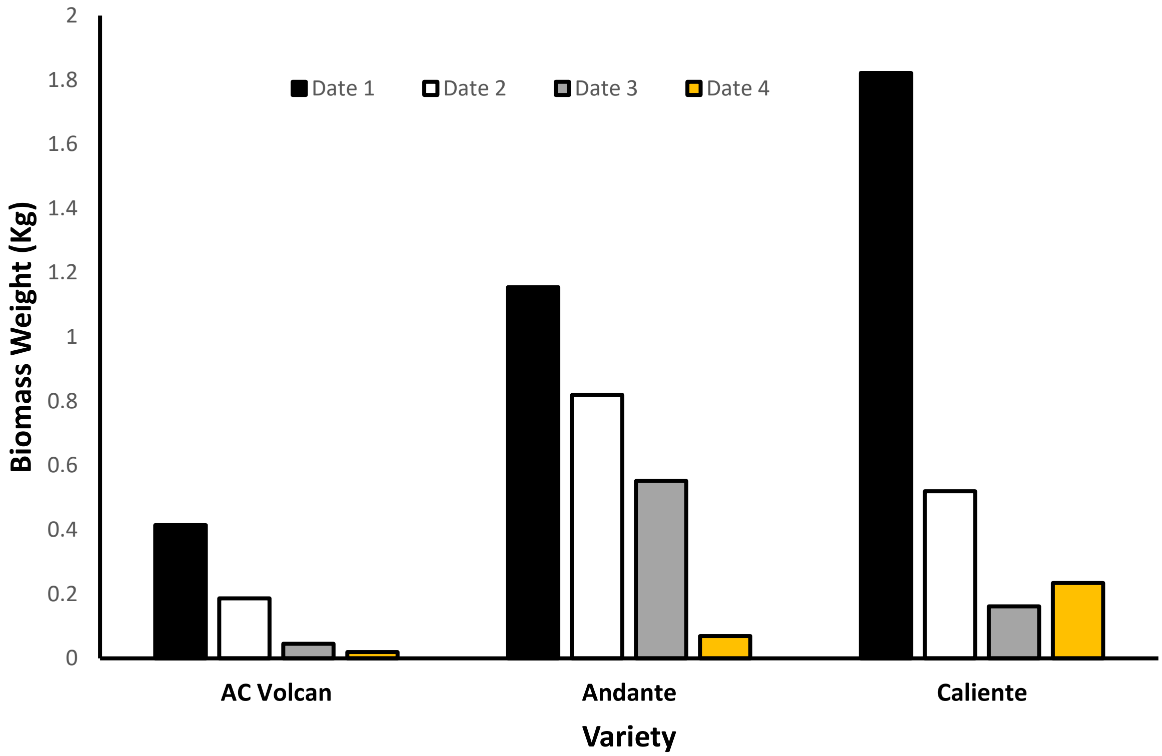


Figure 4. Biomass of mustard varieties seeded on winter wheat (Variety: Wildfire) stubbles

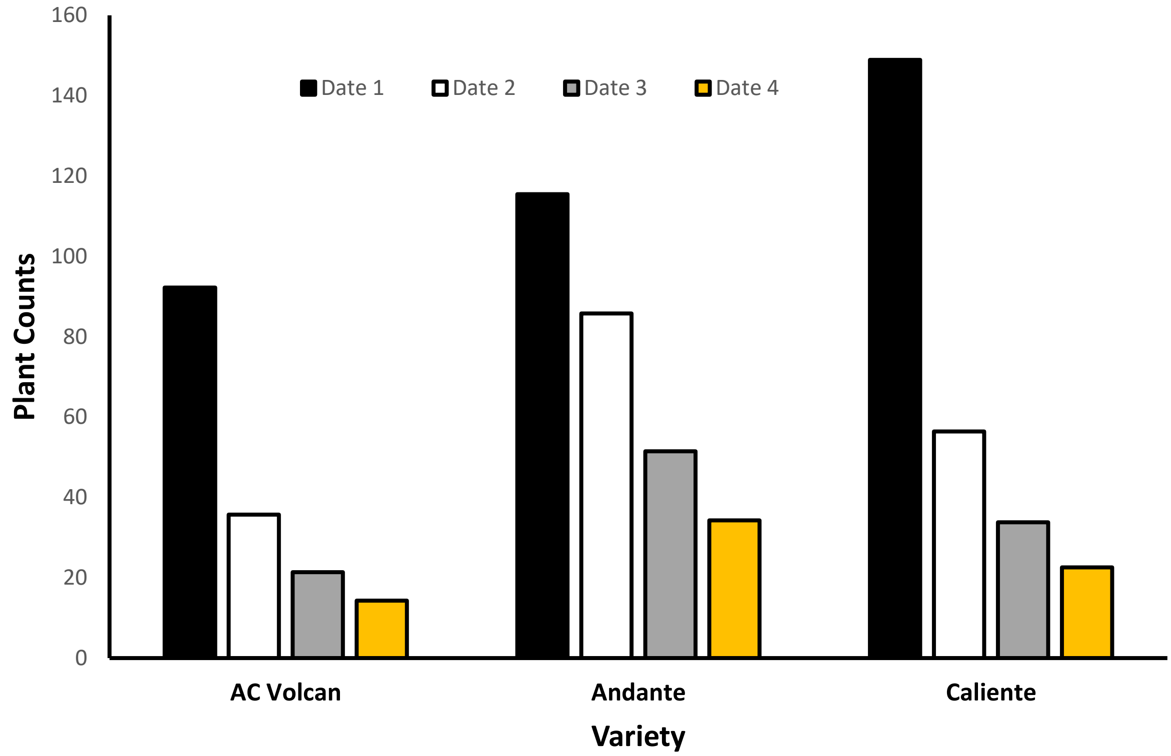


Figure 5. Plant counts of mustard varieties seeded on winter wheat (Variety: Wildfire) stubbles

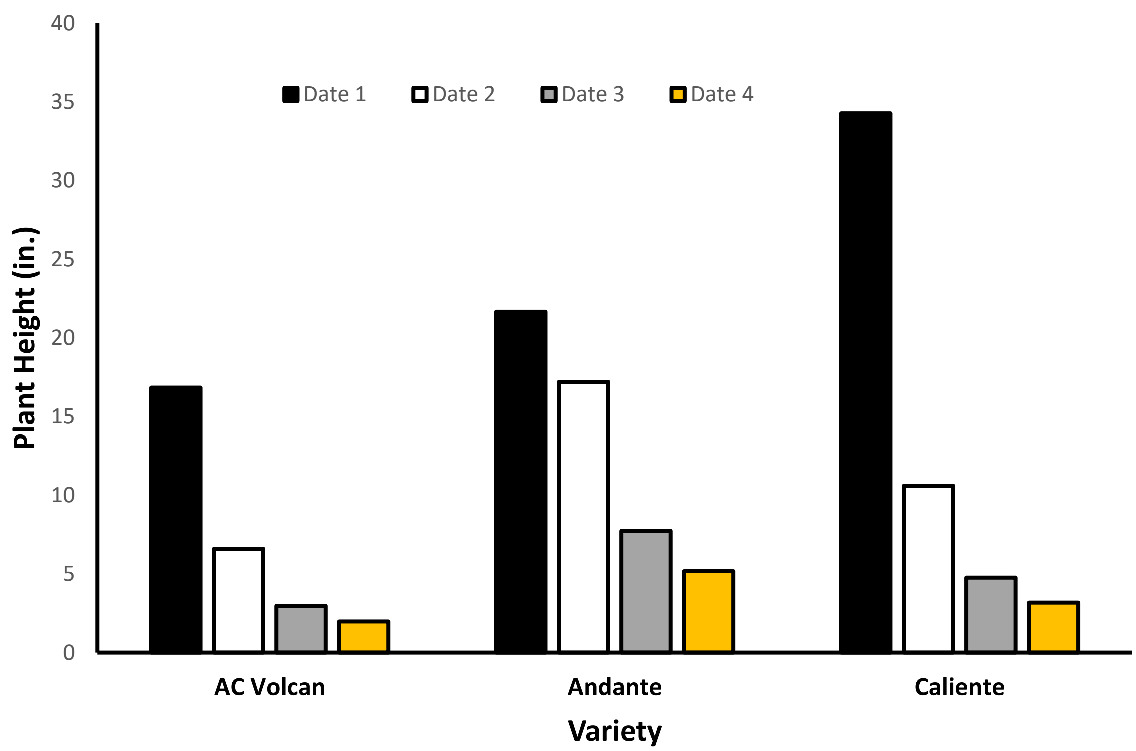


Figure 6. Plant heights of mustard varieties seeded on winter wheat (Variety: Wildfire) stubbles

Mustard Seeded on Non-stubble Land:

Mustard biomass, plant counts, and plant heights are shown in Figure 7, 8, and 9. All parameters were significantly higher in Caliente Rojo varieties within same dates. Highest biomass, plant counts, and plant heights were observed in seeding 1 of all varieties.

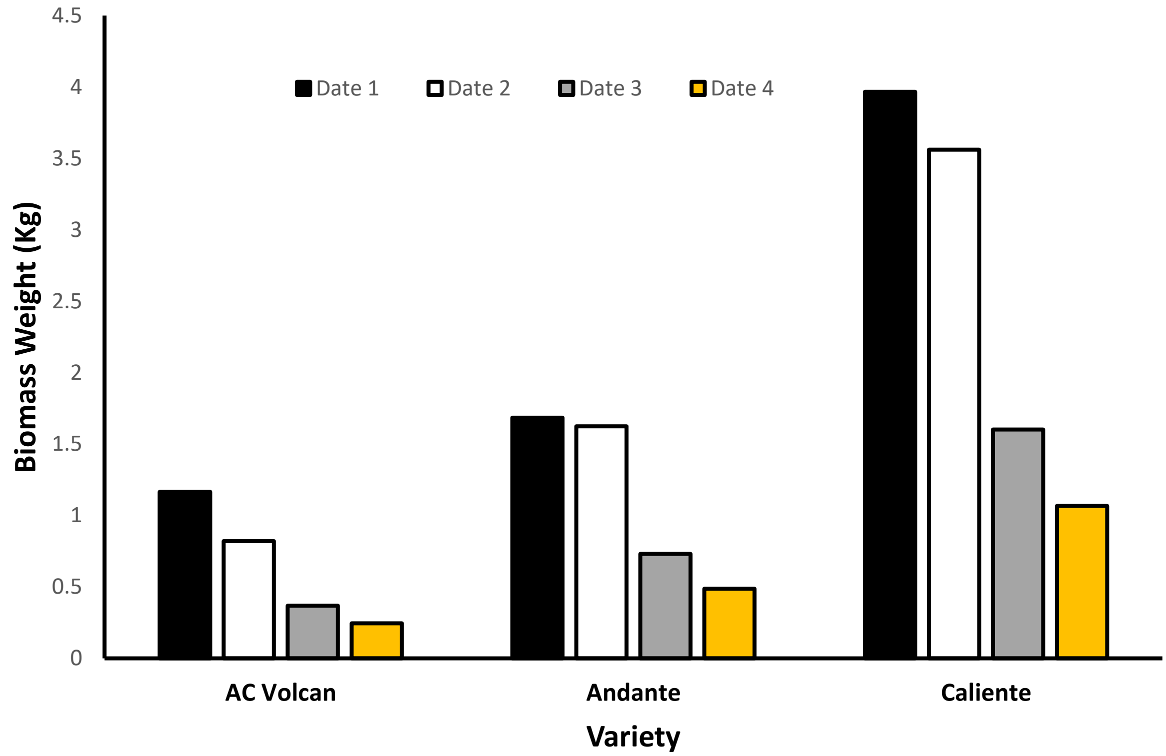


Figure 7. Biomass of mustard varieties seeded on non-stubble land

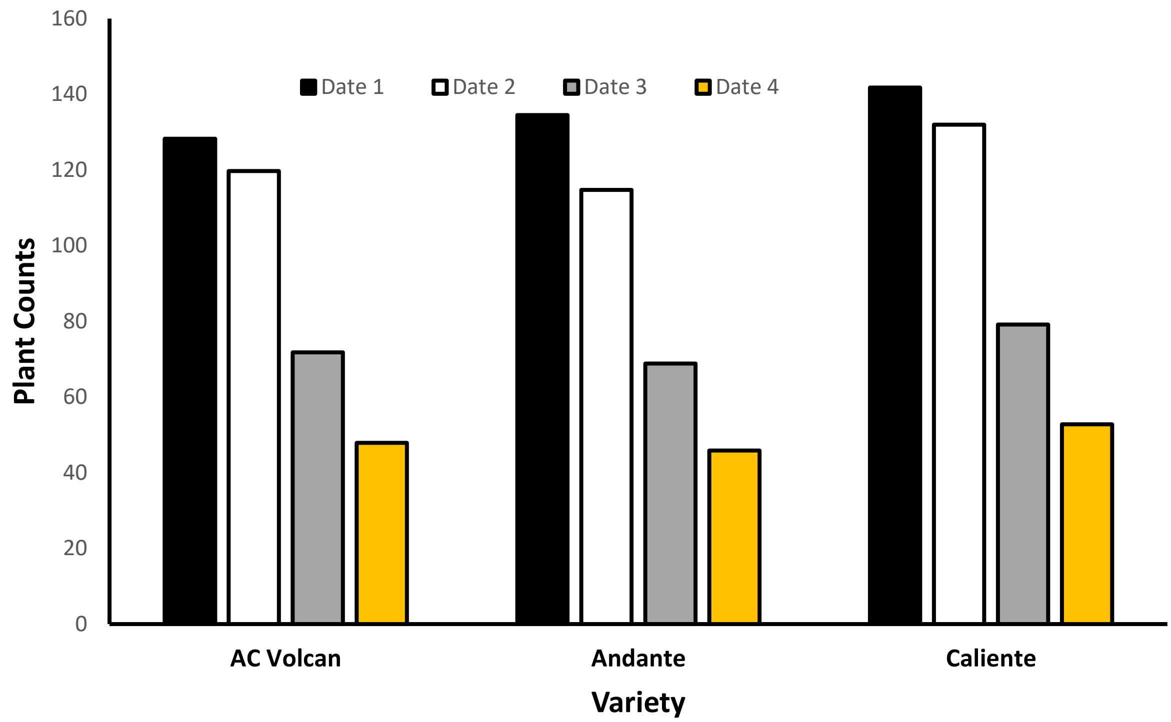


Figure 8. Plant counts of mustard varieties seeded on non-stubble land

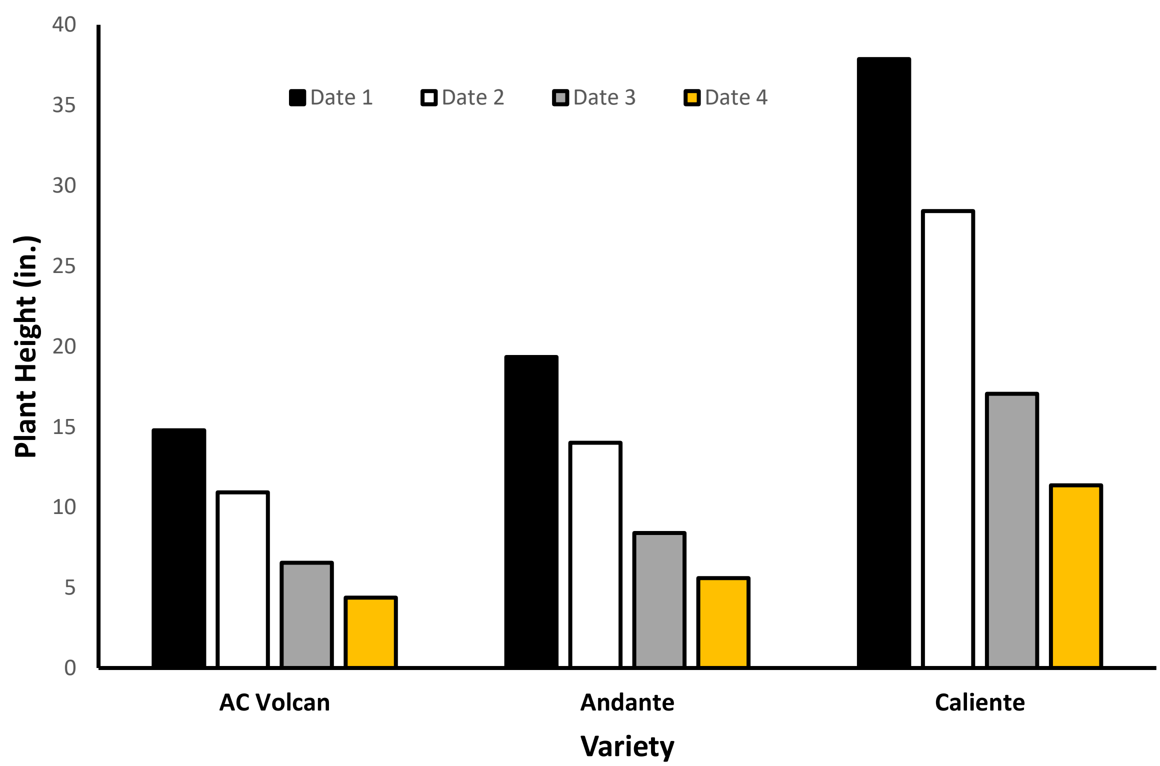


Figure 9. Plant height of mustard varieties seeded on non-stubble land

Field Scale Study:

Figures 10 to 13 show biomass, plant counts, and plant height data collected in producer's field at four different sites having same treatments but different land features.

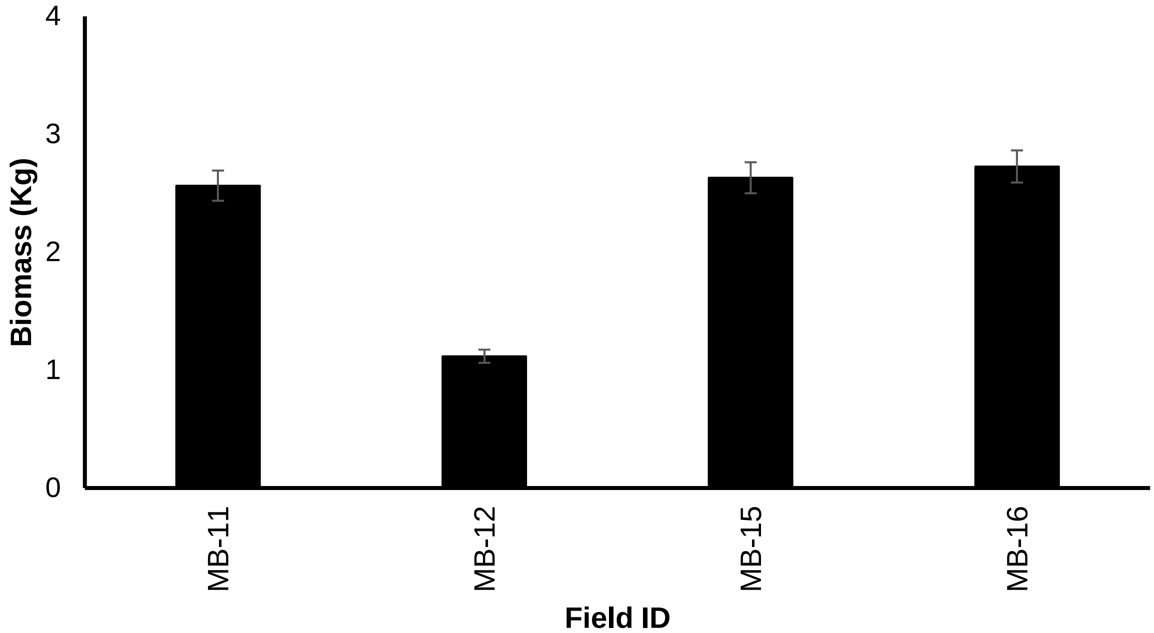


Figure 10. Biomass data collected (wet weight) in producer's field – single seeding date

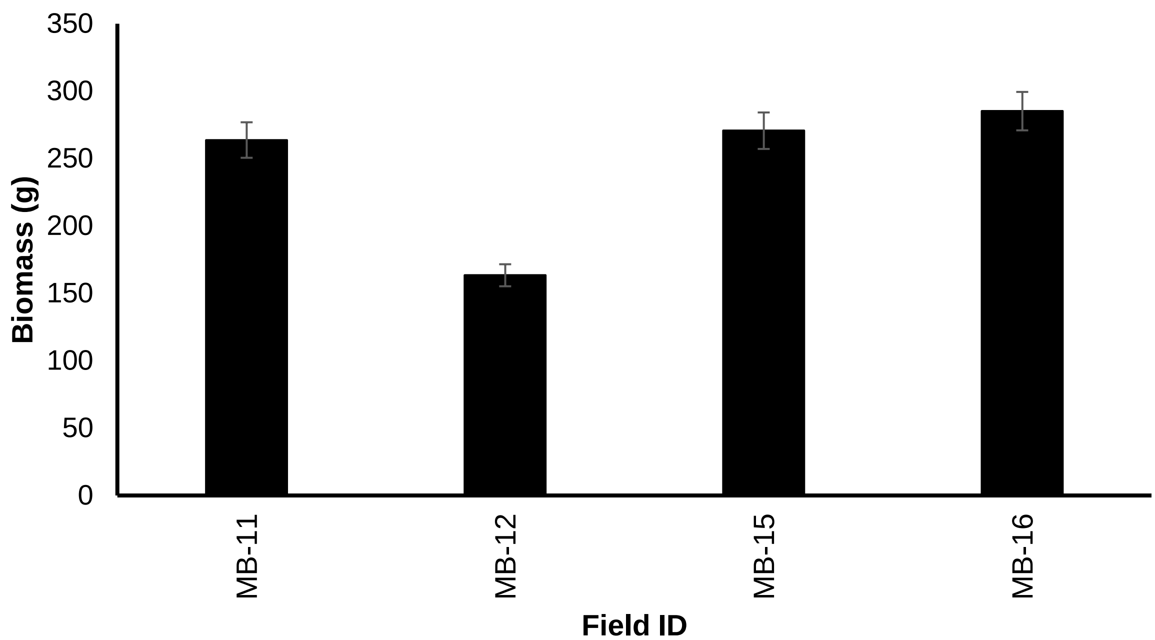


Figure 11. Biomass data collected (dry weight) in producer's field – single seeding date

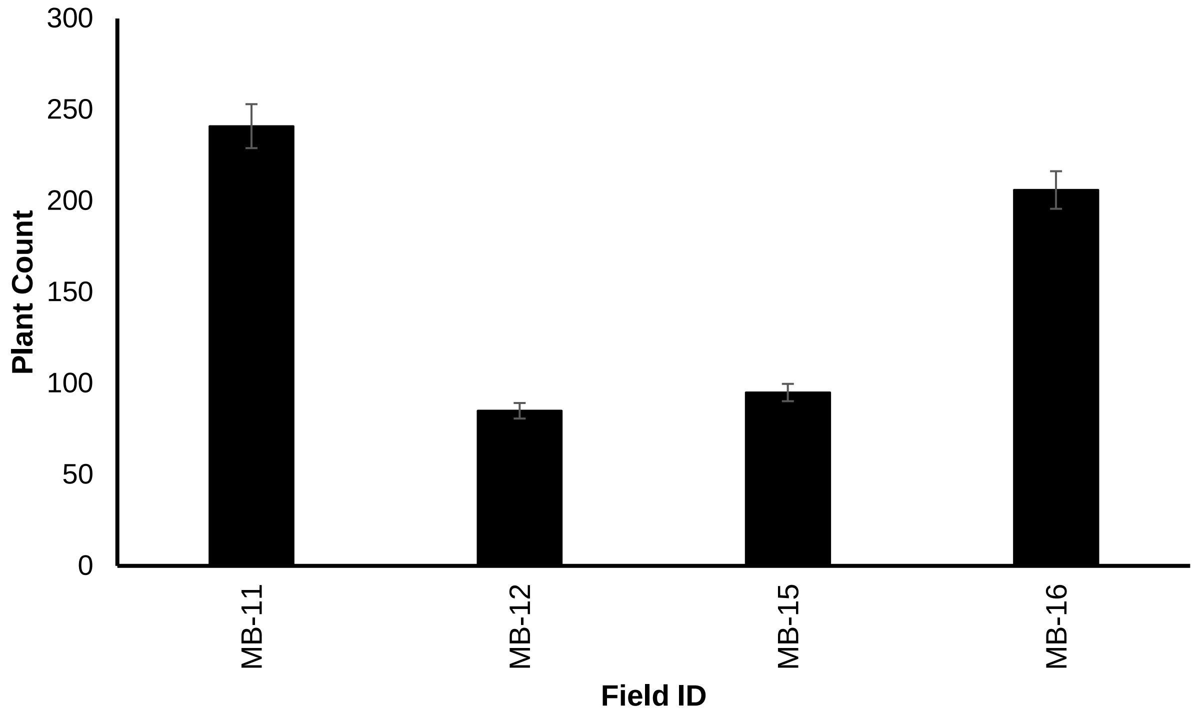


Figure 12. Plant count data collected (dry weight) in producer's field – single seeding date

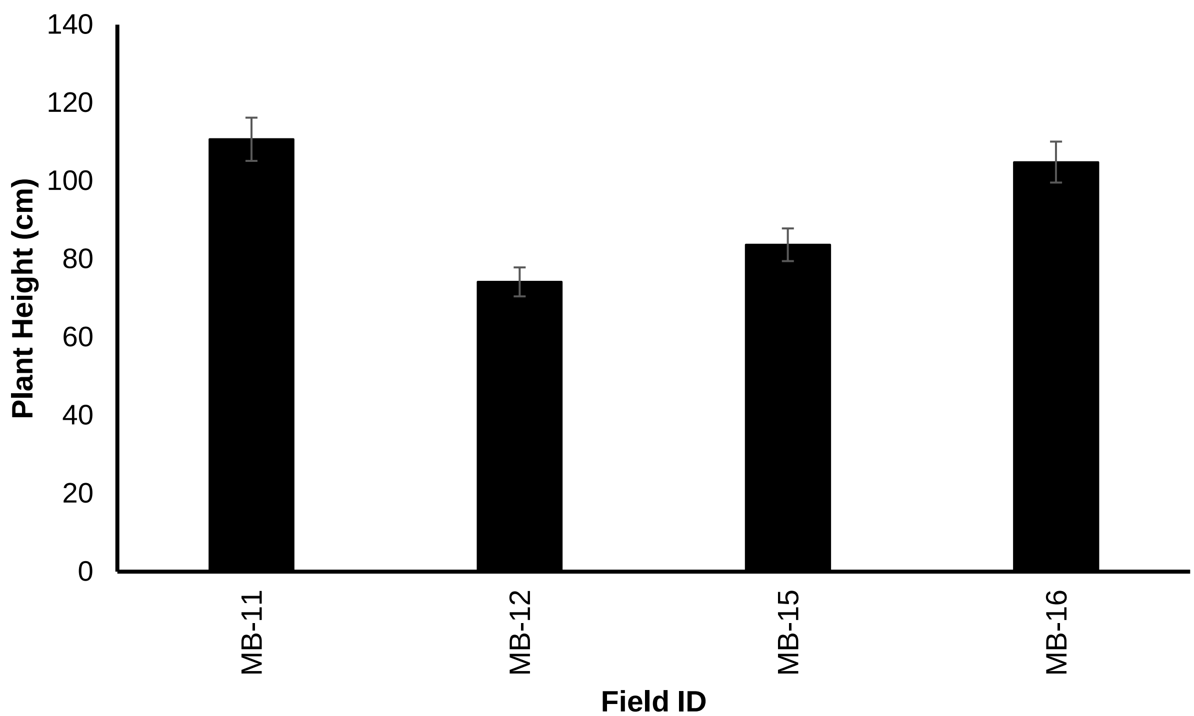


Figure 13. Plant height data collected (dry weight) in producer's field – single seeding date

Project findings:

This study demonstrates the necessity for planting the mustard crop in the early growing season if the goal is to maximize biomass production prior to late fall incorporation. Biofumigant mustard varieties planted early in the season (date 1) produced substantially more biomass than mustard planted late in the growing season (date 2 to date 4). Moreover, plant counts and plant height were higher in biofumigant mustard varieties planted on date 1 compared to mustard planted late in the growing season. When using mustard as a biofumigant tool in the potato production systems, mustard should be planted as soon as the soil can be worked to maximize biomass production.

Biomass production is important, even when a cover crop is selected for a specific function. A mustard cover crop grown for its bio-fumigation properties or a legume cover crop grown for its nitrogen contribution is more likely to perform its intended function if it produces maximum amounts of biomass. Biomass production can be optimized by selecting the ideal cultivar and planting date.

Development of Best Management Practices for Brown Mustard to Achieve Maximum Biomass for Biofumigation in Potatoes

Project duration:	May 2021 – August 2021
Objective:	To develop best management practices for brown mustard to achieve maximum biomass for biofumigation in potatoes
Collaborators:	Manitoba Horticulture Productivity Enhancement Centre Inc. (MHPEC), Mustard 21 Canada Inc.

Background:

Biofumigation is the suppression of soil born pests and diseases through the use of plants that produce inhibitory chemicals, also known as secondary metabolites. In most cases these biofumigant plants are chopped and incorporated into the soil so they can release their inhibitory chemicals. Mustard is a well understood biofumigant. Its biofumigation properties have been studied for a number of years and scientists have developed a method to fully use these properties. Mustard and most other plants from the brassica family produce chemicals called "glucosinolates". When glucosinolates come in contact with water and a family of enzyme myrosinase, contained in plant cells, they are transformed in another group of compounds called "isothiocyanate". It is these isothiocyanates that give mustard its biofumigation power.

Isothiocyanates are also responsible for giving plants from the brassica family their bitter/hot/spicy taste. The isothiocyanate that is produced by mustard is called "Allyl isothiocyanate" (AITC). AITC is a compound that is very similar to the compound that is contained in the commercial fumigant Vapam®.

AAC Brown 18 is the first brown mustard [Brassica juncea (L.) Czern.] hybrid variety developed using an improved Ogura cytoplasmic male sterility hybrid system at Agriculture and Agri-Food Canada – Saskatoon Research and Development Centre (AAFC-SRDC). AAC Brown 18 has significantly higher (24%) yield than the check variety Centennial Brown. It is resistant to white rust race 2a, whereas Centennial Brown is susceptible to race 2a. AAC Brown 18 is well adapted to all mustard growing areas of western Canada.

Materials & Methods:

During the 2021-planting year, two mustard varieties Caliente Rojo, and AAC Brown 18 (brown mustard) were seeded to develop best management practices for brown mustard to achieve maximum biomass for biofumigation in potatoes. Plot area was kept 6 m^2 with a plot length of 5 m, and width of 1.2 m. Both mustard varieties were seeded on June 1. The mustard seed was treated with a seed treatment product ensuring protection of the mustard plant against pests from the time of sowing well into the growing period. Three nitrogen treatments were applied at the rate of 90 lb/A, 135 lb/A, and 180 lb/A. Sulphur was applied at the ratio of 6:1 in accordance with nitrogen application. All treatments were tested under irrigated and non-irrigated conditions. Herbicides and insecticides were applied when needed. All the other agronomic practices were carried out in accordance with standard mustard production guidelines.

Results:

A significant flea beetles' infestation rate was observed throughout the grown season. An area of 1 m^2 was harvested to analyze biomass production in each variety. However, plant counts data was collected from entire plot area.

Irrigated (IR) conditions:

Mustard biomass, plant counts, and plant heights collected from plots under irrigated conditions are shown in Figure 1, 2, and 3. All parameters were relatively higher in AAC Brown 18 variety. A significantly lower biomass, plant counts, and plant heights were observed in 90 lb/A nitrogen application treatment in both varieties. In both varieties, the difference between 135 lb/A and 180 lb/A nitrogen application treatment was not significant for all parameters.

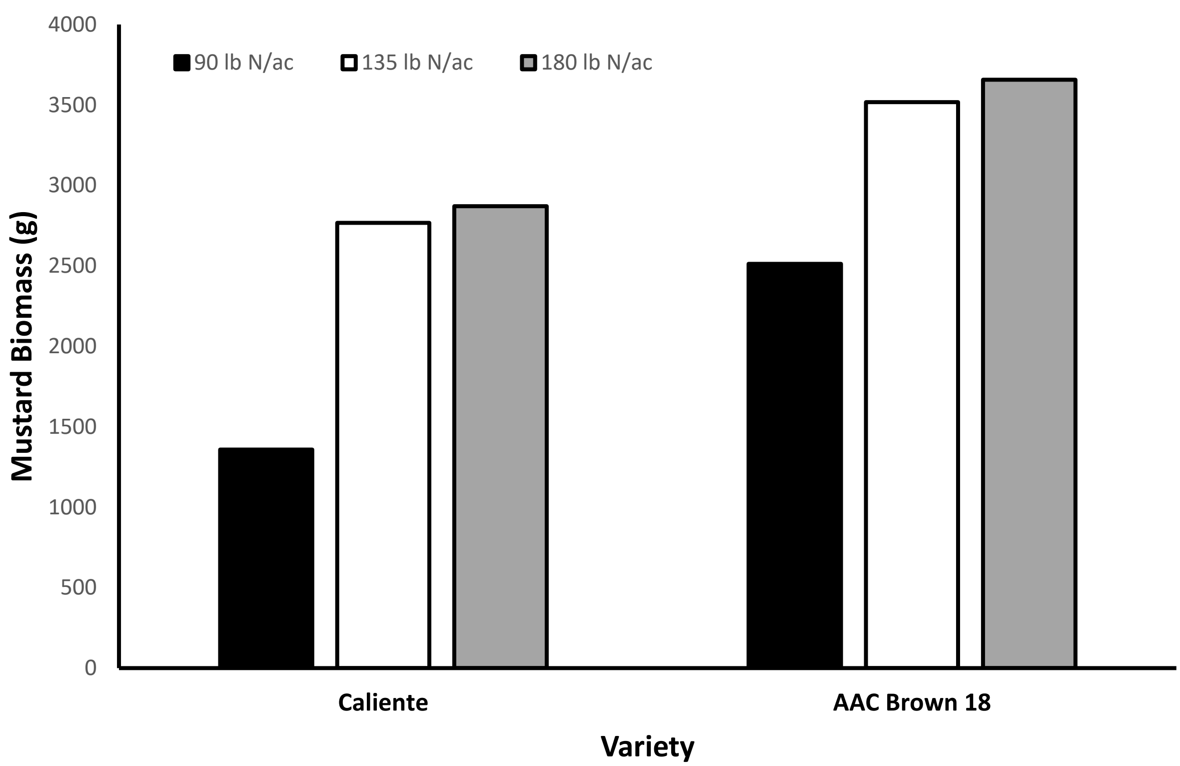


Figure 1. Mustard Biomass (under irrigated conditions)

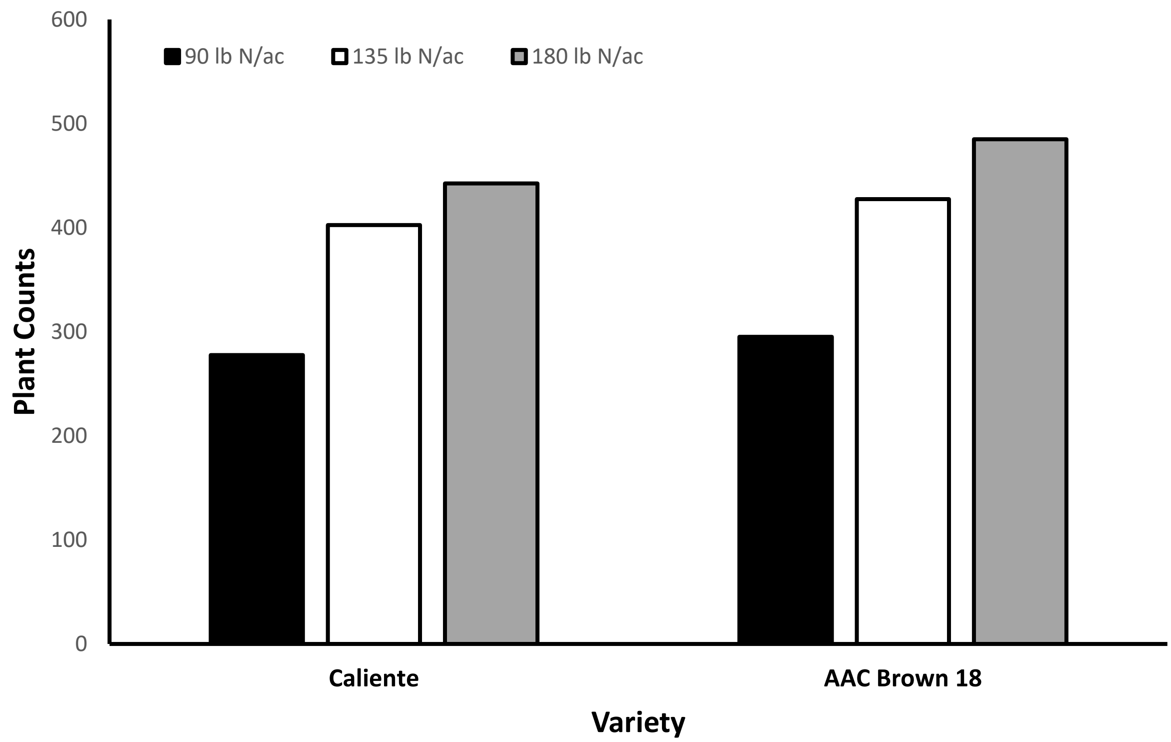


Figure 2. Mustard plant counts (under irrigated conditions)

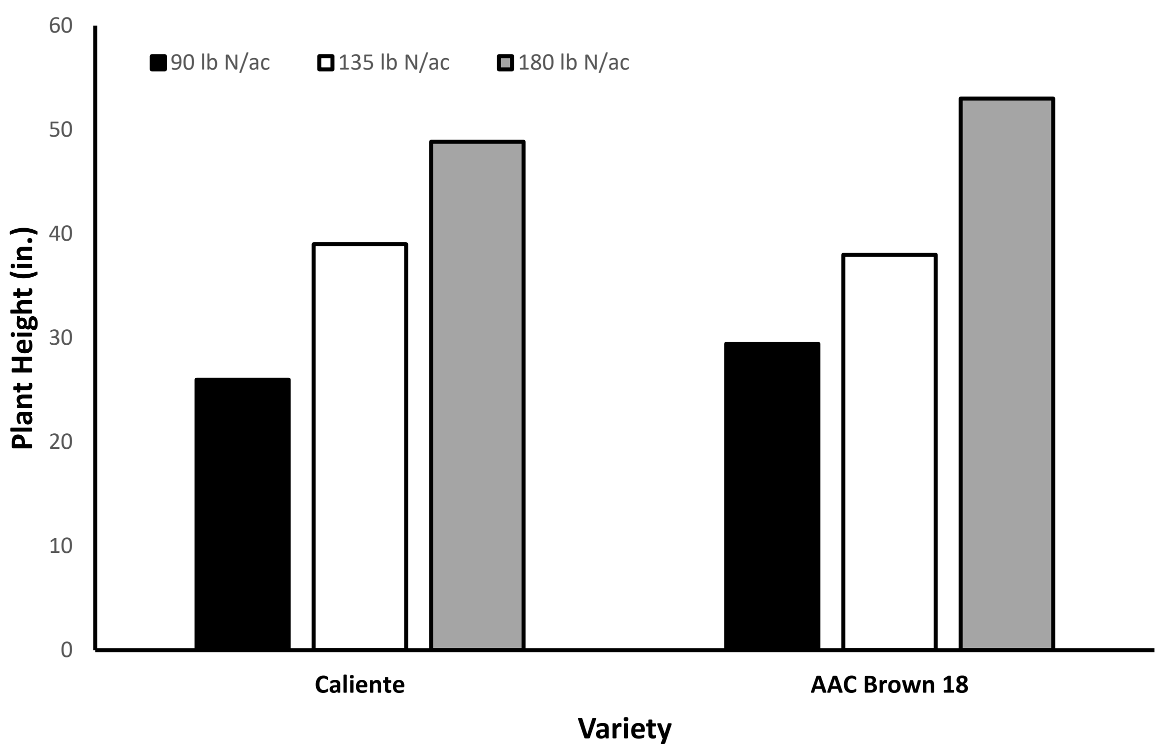


Figure 3. Mustard heights (under irrigated conditions)

Non-irrigated (IR) conditions:

Mustard biomass, plant counts, and plant heights collected from plots under non-irrigated conditions are shown in Figure 4, 5, and 6. All parameters were relatively higher in AAC Brown 18 variety. A significantly lower biomass, plant counts, and plant heights were observed in 90 lb/A nitrogen application treatment in both varieties. In both varieties, the difference between 135 lb/A and 180 lb/A nitrogen application treatment was not significant for all parameters.

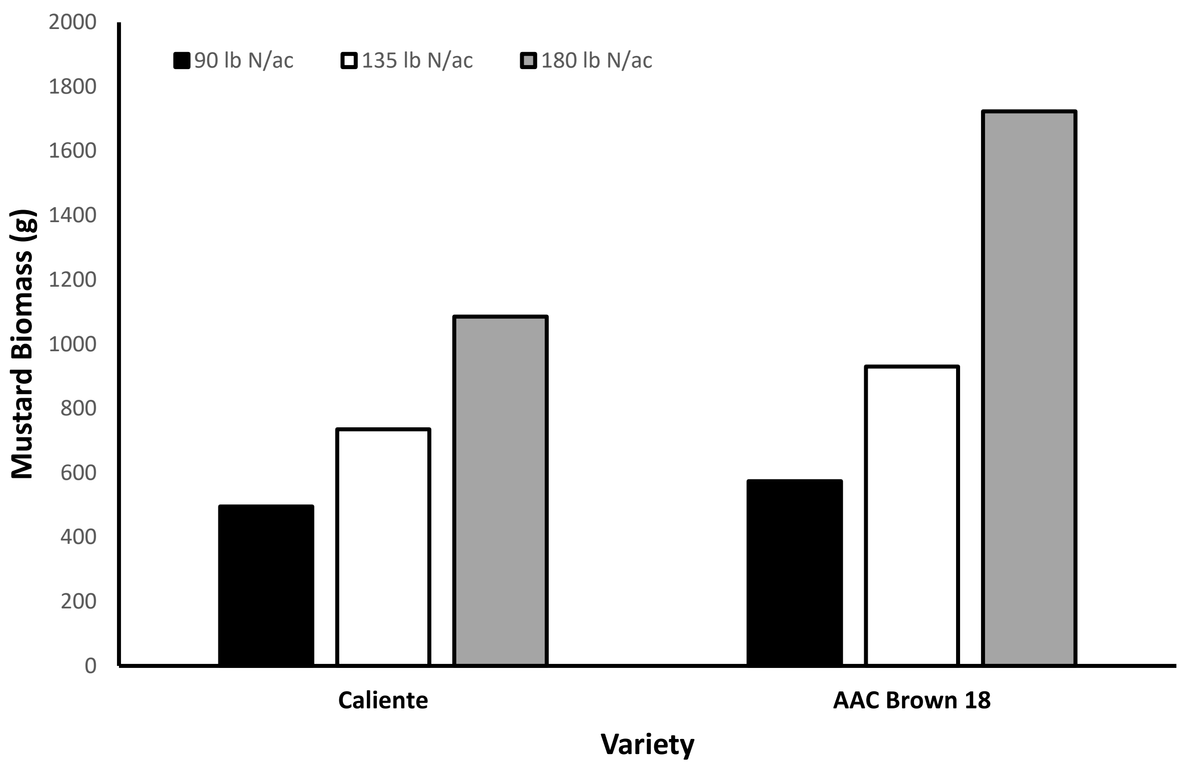


Figure 4. Mustard Biomass (under non-irrigated conditions)

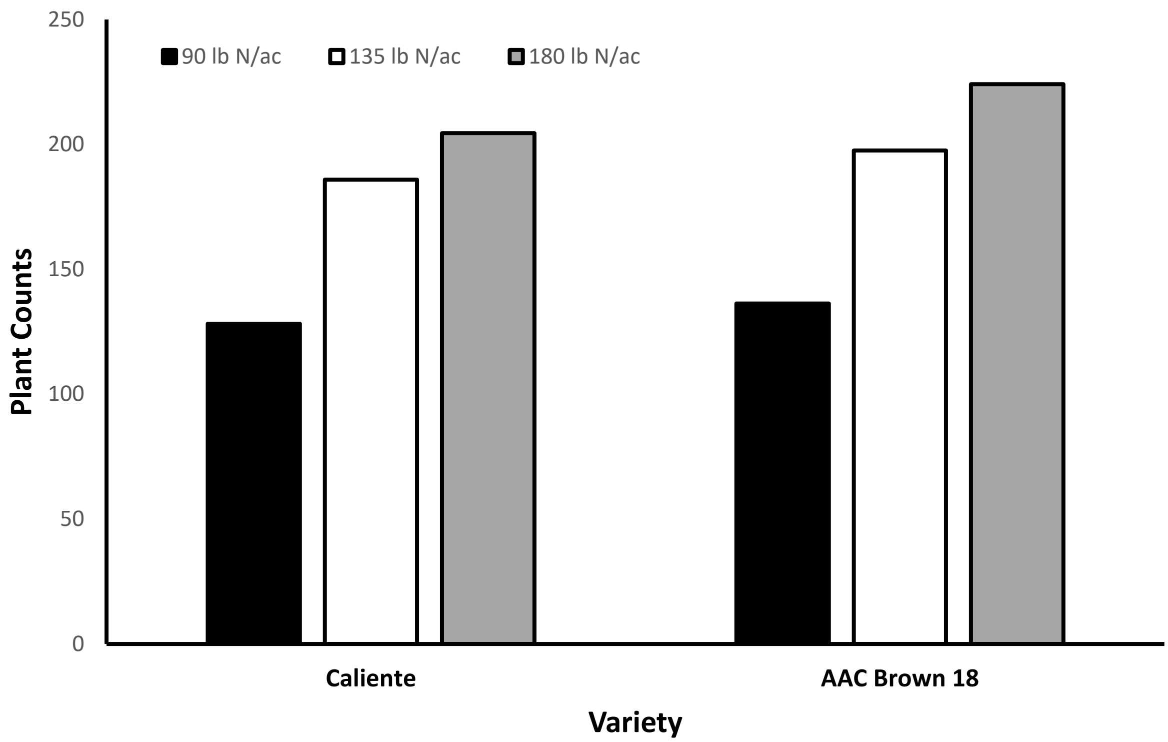


Figure 5. Mustard plant counts (under non-irrigated conditions)

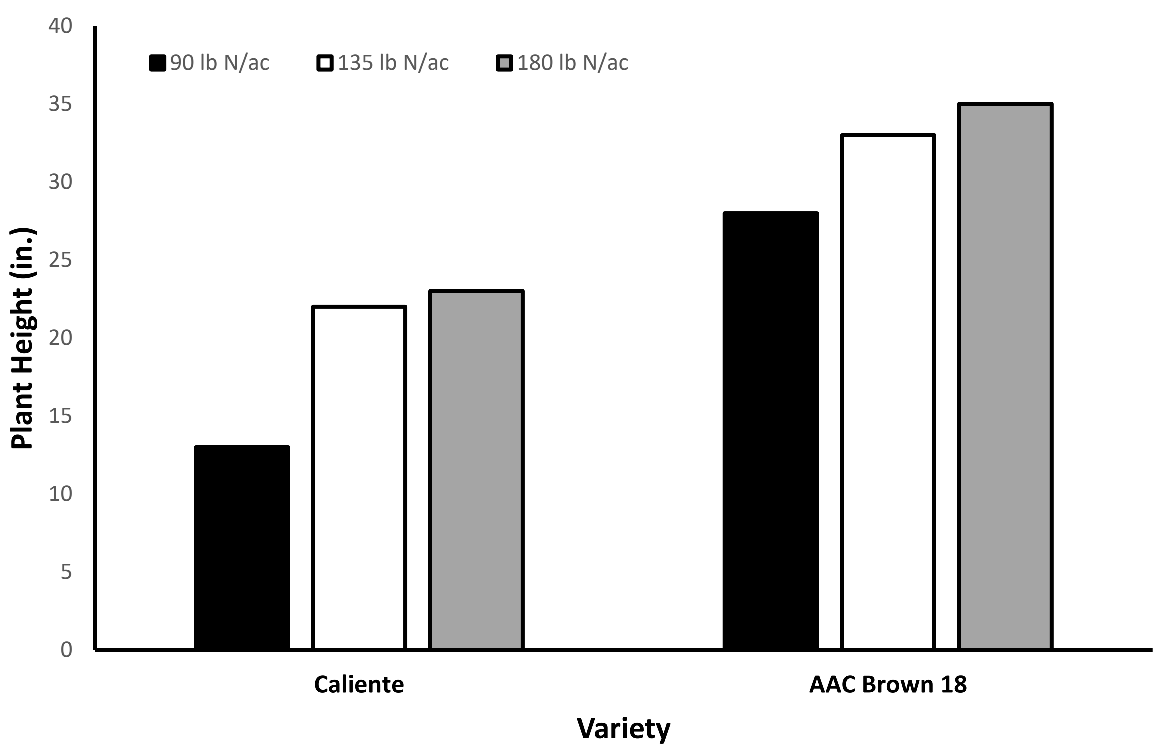


Figure 6. Mustard heights (under non-irrigated conditions)

Project findings:

This study demonstrates the importance of nutrients and irrigation requirement in growing a mustard crop if the goal is to maximize biomass production prior to late fall incorporation. For maximum bio-fumigation potential, 120-180 units of available N are needed. Apply up to 90 units at seeding. For maximum growth, 25-30 units Sulphur are also recommended (adjust to 6:1 ratio nitrogen to sulfur).

The best results in Manitoba to date have been with 8 inches of water in the Carberry area. 4-5 inches should be applied in the first month to keep the seedbed moist. Shortly after seeding, multiple 1/4" shots of water are required to allow seeds to germinate. In season, these bio-fumigant crops can use up to 2" or more per week. When these plants are stressed for water, they will bolt and flower early (not what we want). In this study, higher biomass production potential was observed in the irrigated treatment. This study shows that application of 90 lb/A of nitrogen is not adequate to achieve targeted biomass. However, there was no significant difference in biomass production between 135 lb/A and 180 lb/A nitrogen application treatments.

Biomass production is important, even when a cover crop is selected for a specific function. A mustard cover crop grown for its bio-fumigation properties or a legume cover crop grown for its nitrogen contribution is more likely to perform its intended function if it produces maximum amounts of biomass. Biomass production can be optimized by selecting the ideal cultivar and planting date.

Impact of Increasing Soil Nitrogen at Row Closure on Yield and Root Zone Dynamics of 'Russet Burbank' in Manitoba

Introduction:

Objective 1:

The Field Variability Study (FVS) was conducted from 2015 to the present day with the overall goal of identifying and remediating factors responsible for variable processing potato yield. Approximately 55 soil, plant, and environmental factors have been identified in 23 grower fields and each factor has been ranked according to impact on potato yield. Lower petiole nitrate and soil nitrogen at row closure are both associated with total yield negatively (i.e. lower petiole nitrate and/or lower soil nitrogen at row closure is associated with the lowest yielding sampling points). These yield associations were found at the mid-bulking and row closure growing stages of ‘Russet Burbank’ in Manitoba, which roughly approximates to early August and early July, respectively.

The FVS also offered insight into the amount of soil nitrogen typically seen in grower fields at row closure, which ranged from 4-to-320-lb from samples 0-30 cm in depth. In a cursory examination of the data set, 130 to 180-lb of nitrogen appeared to be the beneficial amount of available soil nitrogen (N), and compromised yields were observed when nitrogen test above or below this amount. The lowest yields appeared to be associated with sampling sites with under 50-lb of nitrogen at row closure. This cursory examination did not have the benefit of any statistical test or association. **The goal of this study was to identify the exact range of lb of soil nitrogen needed by row closure and possible products and rates needed to accomplish the task. Outcomes of this study are set in the context of small, controlled research plots to demonstrate the importance of a unique nitrogen fertilizer regime to potato growers in order to justify field-scale validation studies that are necessary for industry adoption.**

Objective 2:

The addition of nitrogenous fertilizers to the agricultural systems has an impact on the composition of air which is 79% nitrogen. The N in the air is present in the form of N_2 molecules, which is not directly available to the plants. That is why inorganic or mineral fertilizers are supplied to the plants to meet the crop nutrients demand. These fertilizers supply a form of N, called fixed nitrogen, that plants can easily uptake. In an inorganic fertilizer, N in the form of ammonium ion (NH_4^+) is converted into nitrite ions (NO_2^-) by soil bacteria of the Nitrosomonas species through biological oxidation (Nitrification). The nitrite ions are further converted into nitrate ions (NO_3^-), the plant available form, at soil temperature above 10 ºC by the Nitrobacter species. Nitrate is highly soluble and eventually leaches down into the deeper soil layers because of its low adsorption capacity in the soil. If soil becomes water saturated causing anaerobic conditions, Nitrate-Nitrogen (NO_3-N) may be lost to the atmosphere through a reduction process called denitrification. Complete conversion from NH_4^+ to NO_3^- takes place within a month of application.

$$NH_4^+ \leftrightarrow NO_2^- \leftrightarrow NO_3^-$$

Like all other crops, a substantial amount of fertilizer-N is required to get the optimum yield and quality of potato tuber and to tolerate the diseases as well. In addition to nitrogenous fertilizers, irrigation management also plays a significant role in improving the crop yield. Potato tubers are very sensitive to water stress. Yield may be significantly reduced by water deficit. On the other hand, excessive water application may result in respiration stress and denitrification. Maximum potato production is achieved when the soil moisture is sustained at an optimum level and N is frequently available during the peak demand period within the potato root-zone. In order to achieve high potato yield with minimum water quality impact, both nitrogen and water management should be taken into account.

A combination of fertilizer application and irrigation management during the early growth stages of potato affects the tuber yield. Both over- and under-application of irrigation water and nitrogenous fertilizers, affect the nitrogen dynamics within the potato root-zone. The highly soluble NO_3-N will be leached below the root-zone due to excessive water application. That is why over-application of irrigation water causes contamination of ground water and surface water by leaching and surface run off, respectively. However, the total N uptake by plants is also substantially restricted by water deficits.

Intensive over-application of fertilizer is one of the main contributors to lower yield and elevated NO_3-N concentrations in groundwater. If the excess N is not utilized by the crop, N may accumulate within the root-zone in the form of NO_3-N which can leach below with a rainfall or supplemental irrigation event causing an increase in the NO3-N concentrations in the groundwater. If the soil becomes saturated, this nitrogen may be lost to the atmosphere in the form of nitrous oxide (N_2O) gas by denitrification, which destroys the stratospheric ozone contributing to global warming.

Nitrate leaching in the agricultural soil is influenced by many factors such as the irrigation system/applicator, irrigation management, N fertilizer management (N rate, application method, and splitting), soil characteristics, and rainfall patterns. Soil thickness and distance between the bottom of the root-zone and groundwater table also plays a role in determining the potential for ground water contamination. If the plant roots are closer to the water table, nitrate leaches into the groundwater more easily.

The results from numerous studies have proven that excessive irrigation and heavy rainfall are the main drivers of NO_3-N losses from plant root-zone. This loss can be controlled by irrigation management (that subsequently governs the volume of subsurface drainage water) and fertilizer management. The timing and scheduling of irrigation directly affects nitrate leaching. A proper water management can minimize N losses from the plant root-zone and improve the N uptake. If there is a significant difference between the irrigation supplies and the evapotranspiration demand of the crop, the application of N fertilizers assessed for full irrigation may result in “unintentional” over application of N fertilizers causing the potential for N losses. Soil type and soil physical properties also affect nitrate leaching potential.

Impact of different nitrogen application treatments on nitrate dynamics within the potato root-zone was studied in Carberry, Manitoba. The objective of this study was to examine the effects of different nitrogen application rates on nitrogen dynamics within the potato root-zone in a loamy sand soil, and to analyze the nitrate leaching potential below the root-zone.

Conclusions:

Objective 1:
MHPEC's 2018 to 2020 small plot nitrogen study was based upon statistical associations created from the larger field variability study that encompassed observations from 23 grower fields over five years. The goal of this study was to identify the exact range of lb of soil nitrogen needed by row closure and possible products and rates needed to accomplish the task to ultimately improve yield and quality of processing potatoes. It is suspected that larger tuber size profiles are found when 130-to-180-lb of nitrogen are found in the top 0-30 cm of soil at row closure based on this initial study, but this statistical association needs to be verified as cause and effect through further study.

While statistically significant observations were made for differences between fertilizer rates on available nitrogen at row closure, the targets for row closure soil tests were not met. Any discussion of statistically significant results does not encompass the biological phenomenon because treatment goals were not met.

In general, the treatments of ESN and urea where 40-or-130-lb were expected by row closure ended up having far more soil nitrogen than anticipated. Treatments of ESN and urea where 180-lb were targeted by row closure appeared to be on target on average between all the replicates, but the large error bar indicates that some individual plots could be off from the target by 50-lb or more. Neither fertilizer treatment could achieve targets of 280-lbs. of nitrogen in a soil test by row closure. An unexpected, unrepeated observation came from the urea 180-lb treatment, which had more >12-oz percentage of tubers than urea treatments with either more or less nitrogen (280-and-40-lb, respectively). More study on this subject would be required to identify if this was a spurious event or something more meaningful, but the results are muted by the fact that soil targets by row closure were generally not met.

While negative results are generally undesirable in applied research, this study indicates that on this lighter soil type, unblended ESN and urea cannot possibly meet nitrogen goals by row closure at any of the rates evaluated.

The original research question remains unanswered using these four rates of ESN and Urea. Grower feedback has indicated that a blend of nitrogen fertilizers is often employed on-farm, and the exact blend varies by field needs and the consultant. **Answering the original research question requires going back to the community to monitor a wide range of nitrogen programs in order to select promising candidates to use in a study formatted much like the present study**. It is anticipated that other treatments may yield the desired result and can overcome the deficiencies outlined in the first two years of this study.

MHPEC's 2020 and 2021 field study was an observational study to achieve just such a goal of identifying promising candidate treatments and practices to address deficiency of row closure soil nitrogen. Some low nitrogen points were connected to the soil organic matter and texture where there was high leaching potential.

Based off average of all 8 points in 2021:
3/11 growers were above 200 lbs N at row closure
4/11 growers were between 120 and 180 lbs N hitting 130 lb target at row closure
1/11 growers were between 100 and 110 lbs
3/11 growers were under 100 lbs of N
2 growers top dressed to hit target or were above target using a dry or liquid product (ESN & UAN)
The lowest fields at row closure had an average of 35 lbs and 47 lbs. Lowest point was 16 lbs at row closure.
The highest fields at row closure had an average of 243 lbs and 227 lbs. The highest point was 390 lbs. at row closure.

Nitrogen Fertilizer Info:
Some were just general spring dry blends with no specifics on N products
2 growers used just urea for preplant
1 grower did a mixture of urea and ESN
2 growers did just liquid fertilizer 1 just UAN and 1 UAN/ATS 2:1 mixture
2 did just ESN
1 grower relied heavily on fertigation with 60% of applied N and all upfront was with N containing P & S fertilizer applied in the fall or in the planter

General Fertilizer Info
All producers used 10-34-0 at planting
Most used ammonium sulfate and MAP for dry blends

Fertigation Info
Avg fertigation passes was 4. Most 7 and least 2. *This is for info given
Most fertigaton programs used both UAN and ATS. Some mixed together others different passes.

Objective 2:
The importance of fertilizers in improving the crop yield and quality can never be underestimated. Nitrogen (N), potassium (P) and phosphorus (K) are the predominant fertilizers, generally applied to meet the crop nutrients demand, if the native soil supplies of these nutrients are limited. Nitrogen (N) is one of the essential fertilizers that affects plant growth and plays a significant role in optimizing the crop yield. Like all other crops, a substantial amount of fertilizer-N is required to get the optimum yield and quality of potato tuber and to tolerate the diseases as well. In addition to nitrogenous fertilizers, irrigation management also plays a significant role in improving the crop yield. Potato tubers are very sensitive to water stress. Yield may be significantly reduced by water deficit. On the other hand, excessive water application may result in respiration stress and denitrification. Maximum potato production is achieved when the soil moisture is sustained at an optimum level and N is frequently available during the peak demand period within the potato root-zone. In order to achieve high potato yield with minimum water quality impact, both nitrogen and water management should be taken into account.

Intensive over-application of fertilizer is one of the main contributors to lower yield and elevated NO3-N concentrations in groundwater. If the excess N is not utilized by the crop, N may accumulate within the root-zone in the form of NO3-N which can leach below with a rainfall or supplemental irrigation event causing an increase in the NO3-N concentrations in the groundwater.

Potatoes require comparatively less N during the early part of the growing season i.e., sprout development, and vegetative growth stages compared to the later part i.e., tuber initiation, and tuber bulking stages. Excessive N application during the early part of the growing season leads to delay onset of the tuber initiation stage and decrease the yield. Potato requires an adequate and steady supply of N from tuber formation to bulking. Therefore, potato growers apply approximately 25 to 50 % of the total recommended N at the beginning of the growing season and the remainder is applied at the tuber initiation stage. Although this scheduling improves the yield and quality of tuber, it is costly and labor intensive. Controlled release nitrogen (CRN), also known as polymer coated urea (PCU), and environmentally smart nitrogen (ESN) is a cost effective N application source. A micro-thin polymer coat facilitates the release of N at a controlled rate and minimizes N losses from the soil. The rate of N release from PCU is controlled by soil temperature and soil water content. When water is applied to the soil by supplemental irrigation and/or rainfall, it enters into the polymer coated fertilizer granule and dissolves the N into soluble form within the granule. As temperature increases, this nitrogen solution moves out through the polymer coated fertilizer granule into the soil solution in the plant available form.

Methods:

Objective 1:

CMCDC small plot experiment 2018-2020: A factorial randomized complete block design was enacted with four blocks in 2020. The soil at the site was a Halboro series Orthic Black Chernozem with a loamy sand texture. The site has a typical crop rotation of potato-wheat-canola and is irrigated. All of these factors are a reasonable representation of lighter soils that potatoes are grown on in Carberry, Manitoba, except the black chernozem exhibits greater organic matter content typical of lighter soils. Regardless of the organic content, the crop rotation resulted in low preseason soil nitrogen tests with approximately 8 to 26-lb of soil nitrogen available at the start of each season.

Plot scale experimental size and fertilizer calculations: The entire experiment was 57869.28-ft^2 (1.33-acres). Each plot was 3.6-m wide and 24-m long, or 86.4-m^2 (approximately 0.022-acres). The experiment was constructed with two fertilizer treatments: urea and Environmentally Smart Nitrogen (ESN, Redfern Farm Services, Brandon, Manitoba). Each fertilizer treatment, except the negative control, was applied preplant at the equivalent of 40, 130, 180 and 280-lb of nitrogen expected in the soil by row closure (approximately early July). The total amount of each fertilizer needed to achieve the goal by row closure varied based on nitrogen content, with exact application rates displayed in Table 1 below:

Formulation (NPKS)	Fertilizer	Target lb by row closure (lb/acre)	lb/acre fertilizer rate applied preplant	Fertigation Fertilizer and Formulation	Fertigation rate (lb)
46-0-0	Urea	40	180	UAN-28	60 lb
46-0-0	Urea	130	325	UAN-28	60 lb
46-0-0	Urea	180	400	UAN-28	60 lb
46-0-0	Urea	280	500	UAN-28	60 lb
44-0-0	ESN	40	180	UAN-28	60 lb
44-0-0	ESN	130	325	UAN-28	60 lb
44-0-0	ESN	180	400	UAN-28	60 lb
44-0-0	ESN	280	500	UAN-28	60 lb
No Preplant Nitrogen			0	UAN-28	60 lb

Table 1. Nitrogen fertilizer products employed in the study are listed to display the amount of each product necessary to achieve the goal lb of nitrogen available at row closure, as determined at a 0-30 cm soil test conducted by Agvise, Inc. (Northwood, North Dakota). Fertigation was applied at 20 lb N/acre (6.67 gals UAN 28 lb/acre). Two fertigation events were required in 2020, as determined by petiole testing from Agvise Inc. All plots received 115 lb/acre of mono-ammonium phosphate (MAP, 11-52-0-0) and a Kmag mixture of 32% 0-0-60-0 and 68% 0-0-22-22 at 132 lb/acre.

Small plot experimental design: Only the cultivar Russet Burbank was used for the study. Experimental plots were prepared by cultivating on April 22nd 2020 and preplant fertilized on April 29th. Fertilizers were applied with a custom-modified R-tech Terra Mater fertilizer applicator that was set up to apply up to three different fertilizers in a single pass. Two sets of three-Gandy Boxes were arranged in rows, and a single box of amazon cups was set up at the front in order to accommodate the three different types of fertilizer at possible rates of 6 lb/acre to 584 lb/acre (depending on fertilizer pellet size, vehicle speed, and gear combinations selected). The machine was set to broadcast all fertilizers over four potato rows at 36-inches between the rows. Each row of fertilizer applicators was calibrated for each pelleted formulation of fertilizer employed in the experiment and for every fertilizer rate in the treatment structure. Pre-plant fertilizer was immediately mixed into soil post-application with a Lely Rotterra 350-33 (Lely, Maassluis, Netherlands) to a depth of up to 10-inches. Burbank seed (2 to 3 oz, average 2.5 oz (data not shown)) was planted on May 5th, 2020, with no gaps between plots, 36 inches between rows, 13 inches between seed pieces within row, and 6-to-7-inches deep (from top of hill). Seed was treated with Titan Emesto (Bayer, Leverkusen, Germany) at a rate of 20.8 mL/100 kg of seed. Pesticide applications and irrigation schedule were typical for the potato growing region in Carberry, Manitoba (data not shown).

Hills were created as plants emerged on June 2nd using a power hiller attached to a tractor. Row closure was observed on June 30th and five 0-15 cm soil and 30-petiole samples per plot were collected on the same day. Thirty-petioles were collected weekly on every Friday in July from one replicate of each treatment to determine if a fertigation event was required the following week. The need for fertigation was determined by examining 130-and-180-lb treatments for both Urea and ESN, and fertigation was conducted when these treatments were deficient in petiole nitrate as determined by Agvise Inc standards (Northwood, North Dakota). The exact determination of sufficient soil nitrogen and petiole nitrate can be found in the supplemental materials at the end of this document.

Fertigation was conducted through a Hardi (Davenport, IA, USA) NL 80-26' SB PT sprayer with three inline filters, triple nozzle bodies, and three boom controls using a minidrift 03-blue nozzle at approximately 41 PSI at 2 to 4 miles per hour. Applications were done in the early morning and diluted as quickly as possible to limit fertilizer burn. Thirty-liters of UAN (28-0-0) was mixed with 35-imperial gallons of water and applied evenly to the entire experiment. This application was immediately diluted with ¼-inch of water from a linear irrigator (see Fig. 1 below). Fertigation was applied to entire experiment, negative controls included, because studying the impact of fertigation as an impact on final yield was not the intended purpose of the study because fertigation occurs after row closure, the key period identified in the field variability study. A flat rate of fertigation was selected instead of a variable rate due to technical limitations of the irrigation equipment onsite and the desire to have as minimal impact of fertigation as a factor on final yield. Likewise, fertigation was not applied through the linear irrigation system because an equipment limitation preventing fertigation of all potato experiments on the same site, including other fertigation experiments.

Fig 1. An example fertigation event demonstrating concentrate is applied directly to foliage and then immediately diluted to the correct ratio by a linear irrigator on a cloudy morning to prevent fertilizer burn.

Harvest occurred on September 14th and was completed using a 1-row digger on a 10m section of a designated harvest row that was unsampled and untrampled during the season. This harvest row was the innermost part of each plot to buffer it as much as possible from edge effects. The total yield of each plot was recorded as lb harvested, as well as the lb of each tuber size category (less than 3-oz, 3-to-5.9 oz, 6-to-9.9 oz, 10-to-11.9 oz, 12 oz and greater) and quality metrics were recorded (weight of rotted tubers, green tubers, hollow heart tubers in grams, as well as specific gravity). This information was used to calculate an approximate Canadian dollar value using these metrics to determine bonuses and deductions for a mid-season shipment of Burbank potatoes from a demonstration processor contract (data not shown).

Small plot statistical methods: Statistical tests were conducted with SAS v9.4 (SAS, Cary, NC). More specifically, proc mixed was employed to construct a linear regression model to compare the variables of fertilizer treatment and desired rate by row closure to a yield parameter (e.g. fertilizer and treatment effect determined for the 6-to-10-oz yield category). This analysis was completed for each yield parameter separately. In each case a Satterthwaite approximation is used to delineate limits for all variables that had a lower boundary constraint of zero. The blocking factor was used as a random effect as a vector for the mixed model. Because assumptions for the normal distribution of errors and homogeneity of variances were not met (data not shown), the repeated statement was used to model the variance. Finally, the lsmeans statement was used to determine significance of pairwise comparisons of a yield parameter between two fertilizer treatments (provided the type III test of fixed effects from the mixed model was significant with $P \leq 0.05$). Familywise type I error was controlled for the multiple comparisons in the lsmeans statement using a Tukey adjustment, with all subsequent reported *P*-values between specific treatments referring to this Tukey-adjusted *P*-value.

MHPEC's 2020-2021 observational study: This study was based in grower fields consisted of selections that were chosen for exhibiting yield or quality limitations due to soil type, topography, limited water holding capacity, compaction, or for unknown reasons. Fields destined for French fry processing were planted with potato cultivar 'Russet Burbank'. Eight sampling points were established in each study field each May of the study year. Sampling points were determined in consultation with each grower and their consultants using all available information: aerial imagery, variability, Veris, and yield maps, as well as producer and agronomist knowledge of the field. The sampling points will be chosen to represent the range of field conditions and capture the areas of historical potato yield and/or quality variability within a 30-to-50-acre section of the field. Sample sites were recorded with a Trimble receiver with a 5-to-9-cm variance.

Determining Verticillium propagule levels. Soil samples were collected in the spring at row closure for each of the sampling points. Row closure was anticipated to occur by early July of each year. Sampling at each collection date for all fields in the project did not vary by more than two weeks. Composite soil samples (Seven cores per sampling point) were taken from 0-10 cm depths from the centre each collection point. The soil samples were ground to fine powder to prepare them for DNA extraction and eventual *V. dahliae* quantification. Two sub-samples of 0.25-g each were taken from each ground soil sample after it was well mixed between each sub-sampling. DNA was extracted from the sub-samples using DNeasy PowerSoil Kit (QIAGEN) following the manufacturer's instruction. Two extracted DNA samples were combined and mixed as the stock DNA to represent the original soil sample for the next step. The target DNA was amplified using the qPCR markers developed by Wei et al. (2015) http://dx.doi.org/10.1094/PHYTO-05-14-0139-R for *V. dahliae*. A model was developed and validated based on the relation of the numbers of microsclerotia per gram soil and threshold cycle threshold (Ct) of DNA amplification. Both parties of Pest Sustainability Initiative (PSI) labs and MHPEC were satisfied the model validation and agreed to their application on the real soil samples. The model was MSVd = 4*10^(9.019 – 0.2721*Ct) for *V. dahliae*.

Soil and plant nutrient evaluation: Soil and petiole samples were collected at row closure to determine in-season nutrient availability. Soils were collected from each of the 8-sampling points per field. Soils were sampled five times with a probe at 0-15 cm and 15-30 cm, and composite soil samples from both depths at each sampling point were tested through Agvise for N, P-Olsen, K, and S. Soil samples in the project were generally taken a 'V' pattern from sampling rows 1 to 3, and soil samples in the project were taken from within 6-inches of the plant, but never where the consultant had banded fertilizer (if fertilizer was not broadcast or fertigated). These samples were not dried before submission.

Potato petiole samples were collected on the same day as soils at row closure for analysis of percentage NO_3, P, K and S levels in plants. The data were used to assess the nutrient status of the plants at the various field sampling points through the season. Thirty-petioles were collected from sampling rows 1-to-3-in each collection site of each field. Petiole collection was done through the following method:

- Fields should not have been sprayed with pesticides or foliar nutrients for 3 to 5 days before sampling whenever possible.

- Sample from all 8-sites using rows 1 and 2 and 3, 30-petioles per site, go in a zig zag pattern down the rows.
- Select plants without an inflorescence if possible.
- Attempt to maintain similar sizes of petiole throughout sample, attempt to maintain petiole length of a minimum of three inches after stripping leaves
- Do not include snapped, torn, crushed, or otherwise damaged petioles
- Select 4th petiole from the top of the meristem, samples should not come in contact with dirt.
- Samples must be maintained in as cool temperatures as possible and not be exposed to sunlight.
- Samples should be delivered for processing immediately.

Objective 2:
Water level sensors (WLS) (Solinst Levelogger Junior 3001, Solinst Canada, Ltd., Georgetown, Ontario, Canada) were used to monitor the groundwater level in each plot throughout the season. These sensors were set to take a reading at half an hour interval. These sensors were hung inside the piezometers installed at the center of each plot. The piezometers were made from 2.5-m long steel pipes with an inner diameter of 41-mm. In order to avoid any hindrance to farming operations, such as hilling and spraying, all the piezometers were installed along the crop rows. The piezometers were mechanically installed using a mechanical auger. Manual readings of ground water level were also taken using a water level sensing tape as a check. A barometric pressure sensor (Solinst Barologger Gold) was used for subsequent barometric correction of the water level sensor data.
The stage of plant growth and rooting depth were the main factors considered in determining the nitrogen dynamics within the potato root-zone. Representative soil samples within 1.0-m below the ground surface were taken at 0.2-m intervals to determine the soil nitrate concentration (NO_3-N) at the beginning of each growth stage. Soil samples were stored in a refrigerator before sending them to soil testing lab (Agvise Laboratories Inc.) for analysis.

Results:

The 2020 nitrogen study indicated that the amount of available soil nitrogen, in lb, at row closure form 0-6 inches (P = 0.0666) and 6-12 inches (P = 0.0883) trended towards significance between treatments (Figs 2 and 3). There was a significant difference between the lb of nitrogen found in the soil prior to nitrogen fertilizer application at the start of the season (P = 0.9615, data not shown) with 10-to-18-lb of residual nitrogen in October of 2019. In general, the treatments of ESN and urea where 40-or-130-lb were expected by row closure ended up having far more soil nitrogen than anticipated. Treatments of ESN and urea where 180-lb were targeted by row closure appeared to be on target on average between all the replicates, but the large error bar indicates that some individual plots could be off from target by 50-lb or more. Neither fertilizer treatment could achieve targets of 280-lb of nitrogen in a soil test by row closure.

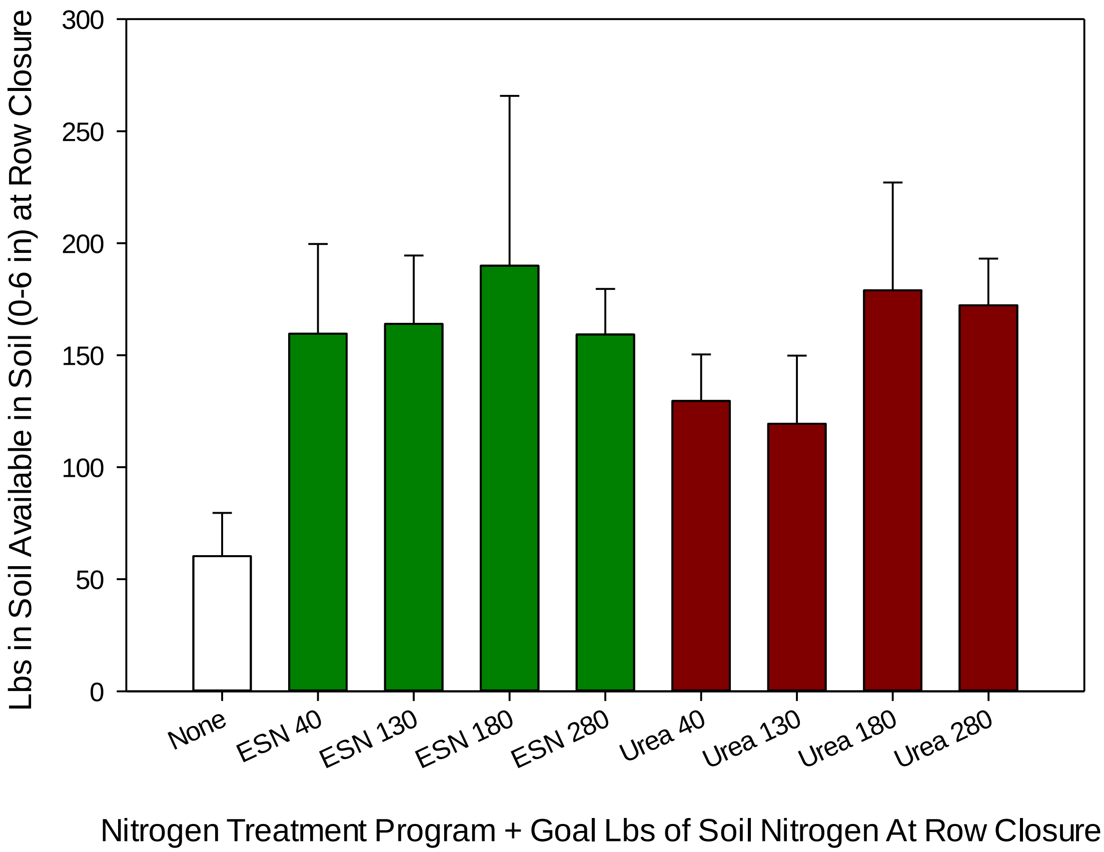

Lbs in Soil Available in Soil (0-6 in) at Row Closure
0
50
100
150
200
250
300
None
ESN 40
ESN 130
ESN 180
ESN 280
Urea 40
Urea 130
Urea 180
Urea 280
Nitrogen Treatment Program + Goal Lbs of Soil Nitrogen At Row Closure

Fig. 2

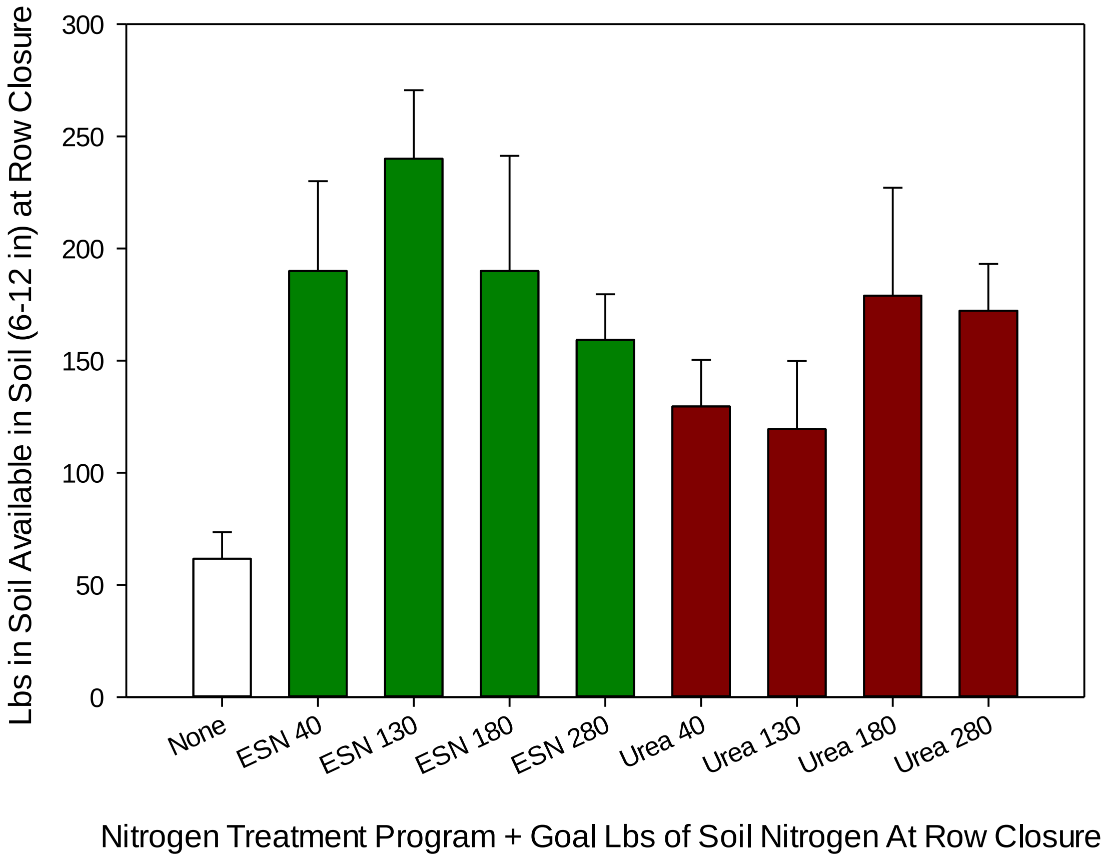

Lbs in Soil Available in Soil (6-12 in) at Row Closure
300
250
200
150
100
50
0
None
ESN 40
ESN 130
ESN 180
ESN 280
Urea 40
Urea 130
Urea 180
Urea 280
Nitrogen Treatment Program + Goal Lbs of Soil Nitrogen At Row Closure

Fig. 3

There was a significant effect of soil nitrogen treatment on the percentage of petiole nitrate at row closure ($P < 0.0001$, Fig. 4). Any nitrogen treatment significantly improved petiole nitrate availability compared to the negative control. There were no differences in petiole nitrate between any nitrogen fertilizer and/or treatment.

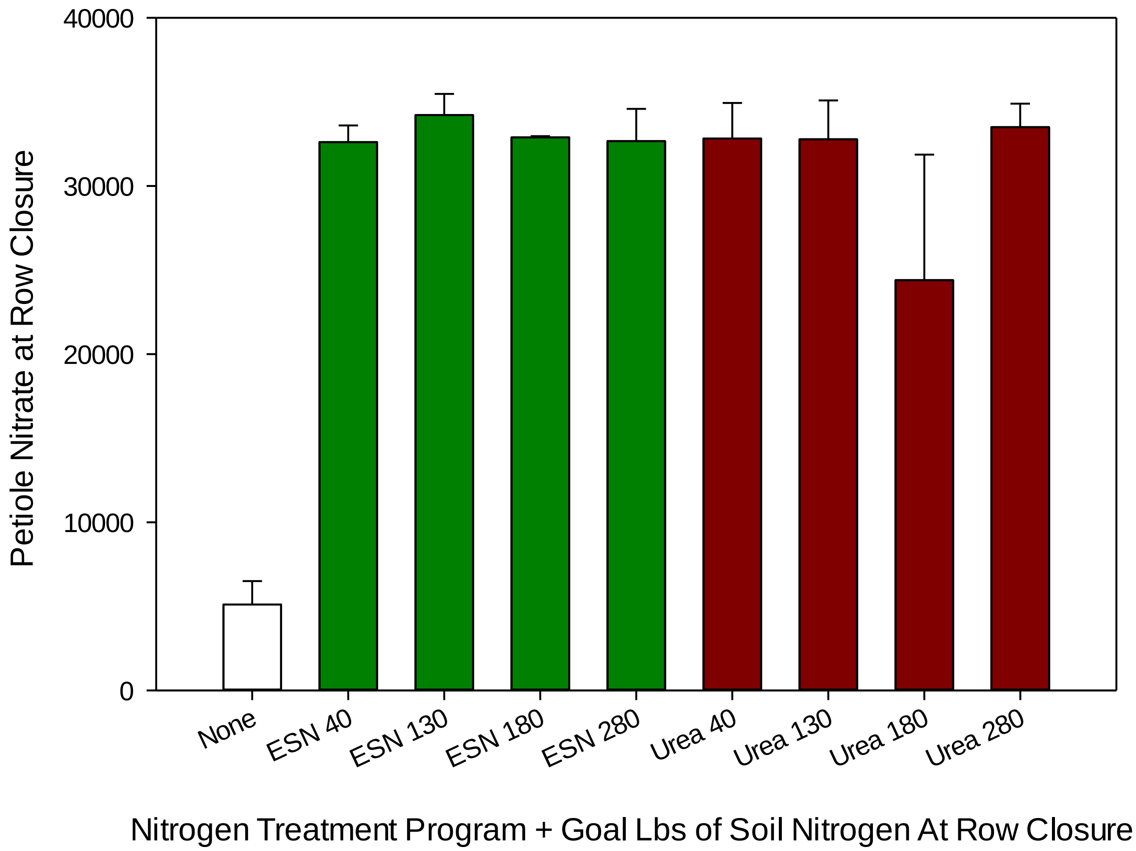


Fig. 4

Greater Fertilizer Treatment	Lesser Fertilizer Treatment	*P*- value
ESN 40	No added nitrogen	$P < 0.0001$
ESN 130	No added nitrogen	$P < 0.0001$
ESN 180	No added nitrogen	$P < 0.0001$
ESN 280	No added nitrogen	$P < 0.0001$
Urea 40	No added nitrogen	$P < 0.0001$
Urea 130	No added nitrogen	$P = 0.0021$
Urea 180	No added nitrogen	$P < 0.0001$
Urea 280	No added nitrogen	$P < 0.0001$

Table 2: The specific pairwise comparisons from proc mixed listed by the treatment with more petiole nitrate first, the lesser treatment second, and the P-value third. All other pairwise comparisons that are listed are nonsignificant ($P > 0.05$).

There was a nonsignificant effect of nitrogen treatment on total yield (P = 0.1549, Fig. 5). A curious observation is that the extreme ESN treatment (ESN 280-lb, where 500-lb of ESN were applied preplant with the intent of having 280-lb residual by row closure) has a numerical decrease in total yield when compared to the ESN 40-lb treatment or the treatment with no additional nitrogen.

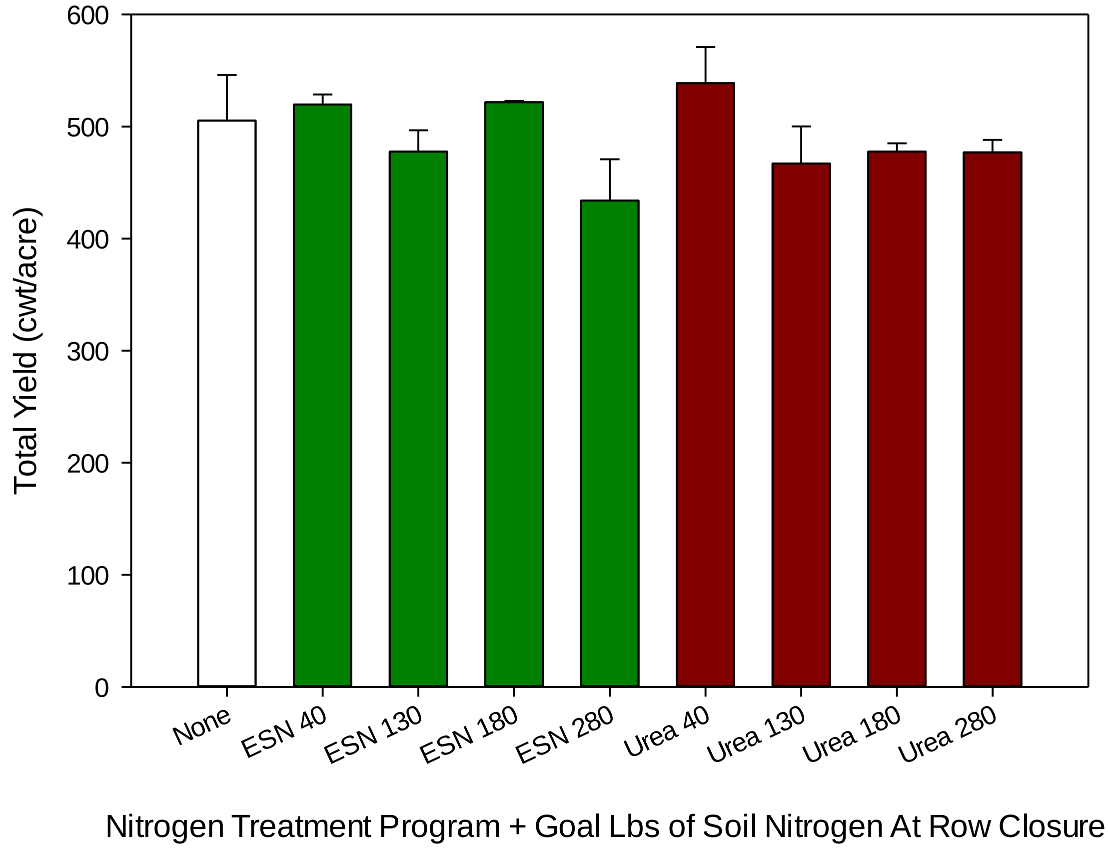


Fig. 5

There was nearly a significant trend (*P* = 0.1017) of nitrogen treatment and rate upon specific gravity (Fig. 6). While not technically significant, most nitrogen treatments appeared to numerically decrease specific gravity, albeit most of these decreases would not have incurred a penalty for low specific gravity by most French fry processors by being below 1.08. The most consistent trend is that the extreme rates of ESN and urea, where 500-lb were applied preplant with the intent to have 280-lb by row closure, dropped the specific gravity compared to lower rates of each fertilizer or the plots that received no supplemental nitrogen preplant.

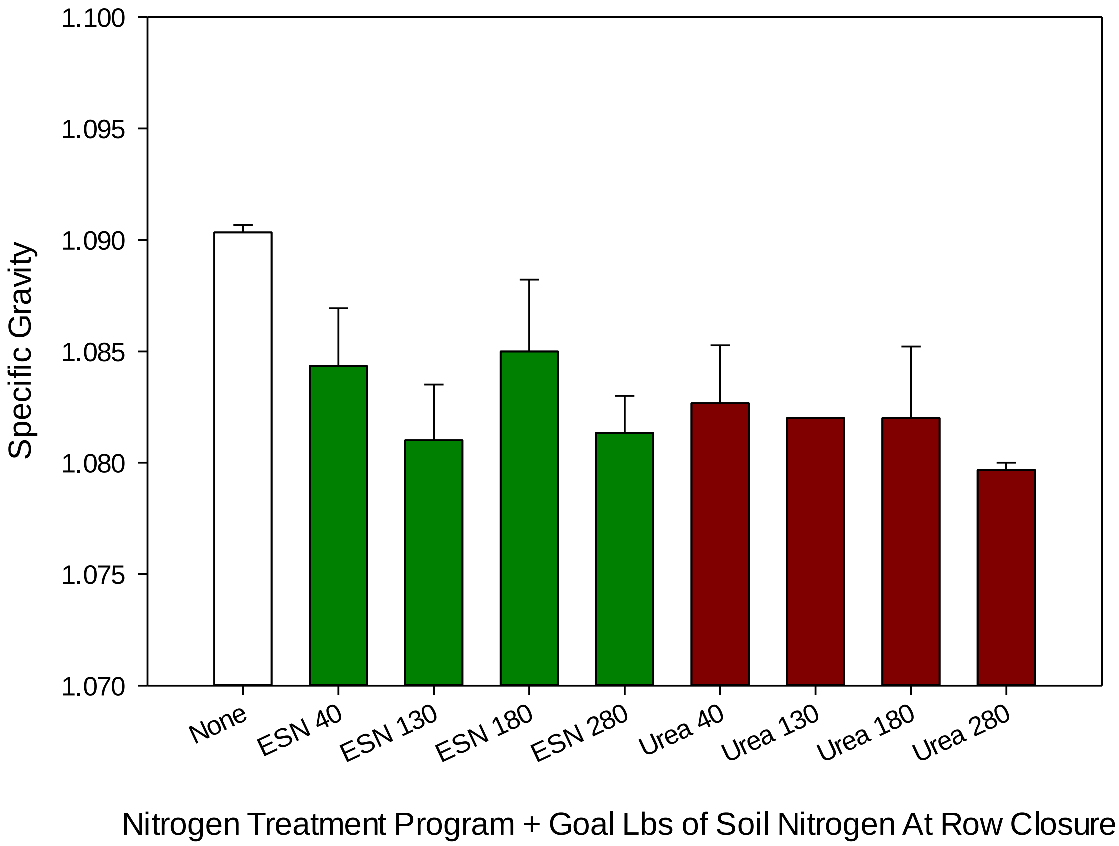


Fig. 6

There was a significant impact ($P < 0.0001$) of nitrogen treatment and rate on the cwt/acre of 3-to-6-oz tubers harvested from the experiment (Fig. 7). All fertilizer treatments decreased 3-to-6-oz yield compared to the negative control regardless of fertilizer rate or source (Table 3). There were no differences between the 3-to-6-oz yield between any of the fertilizer treatments and rate.

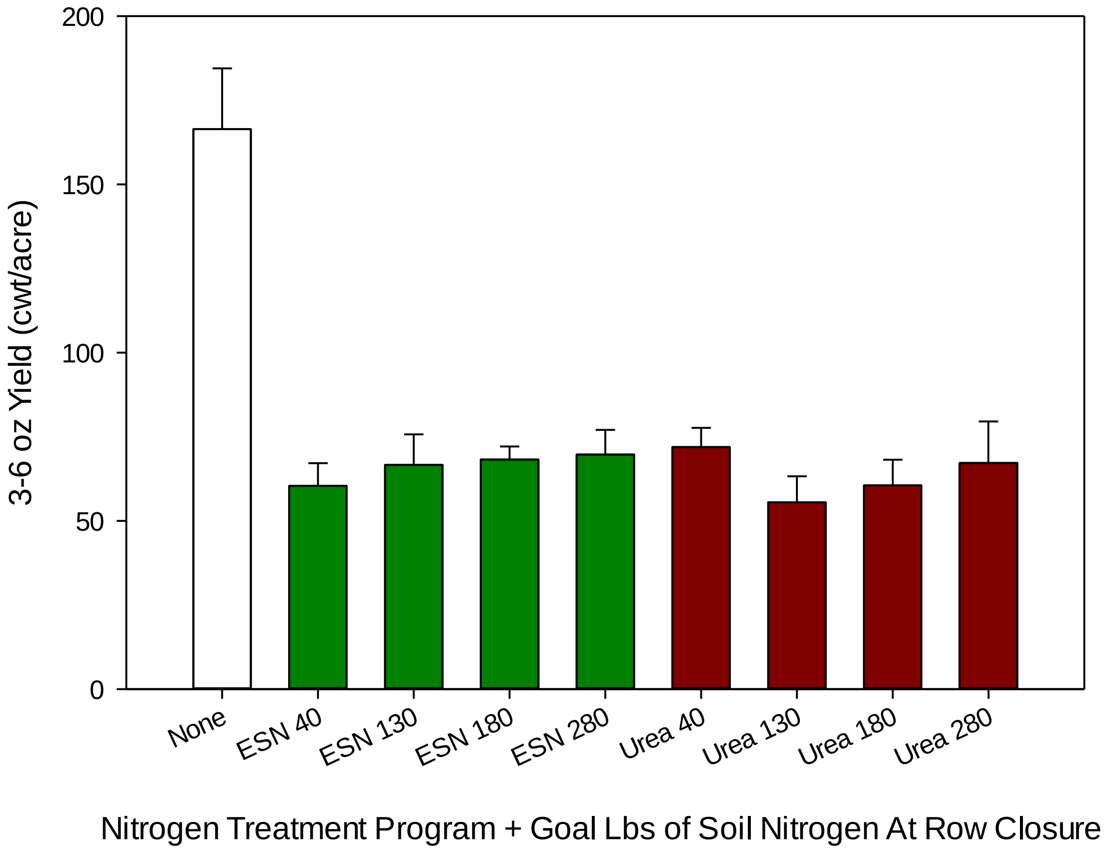


Fig. 7

Greater Fertilizer Treatment	Lesser Fertilizer Treatment	*P*- value
ESN 40	No added nitrogen	$P < 0.0001$
ESN 130	No added nitrogen	$P < 0.0001$
ESN 180	No added nitrogen	$P < 0.0001$
ESN 280	No added nitrogen	$P < 0.0001$
Urea 40	No added nitrogen	$P < 0.0001$
Urea 130	No added nitrogen	$P < 0.0001$
Urea 180	No added nitrogen	$P < 0.0001$
Urea 280	No added nitrogen	$P < 0.0001$

Table 3: The specific pairwise comparisons from proc mixed listed by the treatment with greatest 3-to-6-oz yield first, the lesser treatment second, and the *P*-value third. All other pairwise comparisons that are listed are nonsignificant ($P > 0.05$).

There was a significant impact ($P < 0.0001$) of nitrogen treatment and rate on the percentage of 10-to-12-oz tubers harvested from the experiment (Fig. 8). The treatments where 40-lb of nitrogen were targeted by row closure had the greatest percentage of 10-to-12-oz tubers when compared to the negative controls or higher rates of fertilizer, such as 280-lb of nitrogen by row closure.

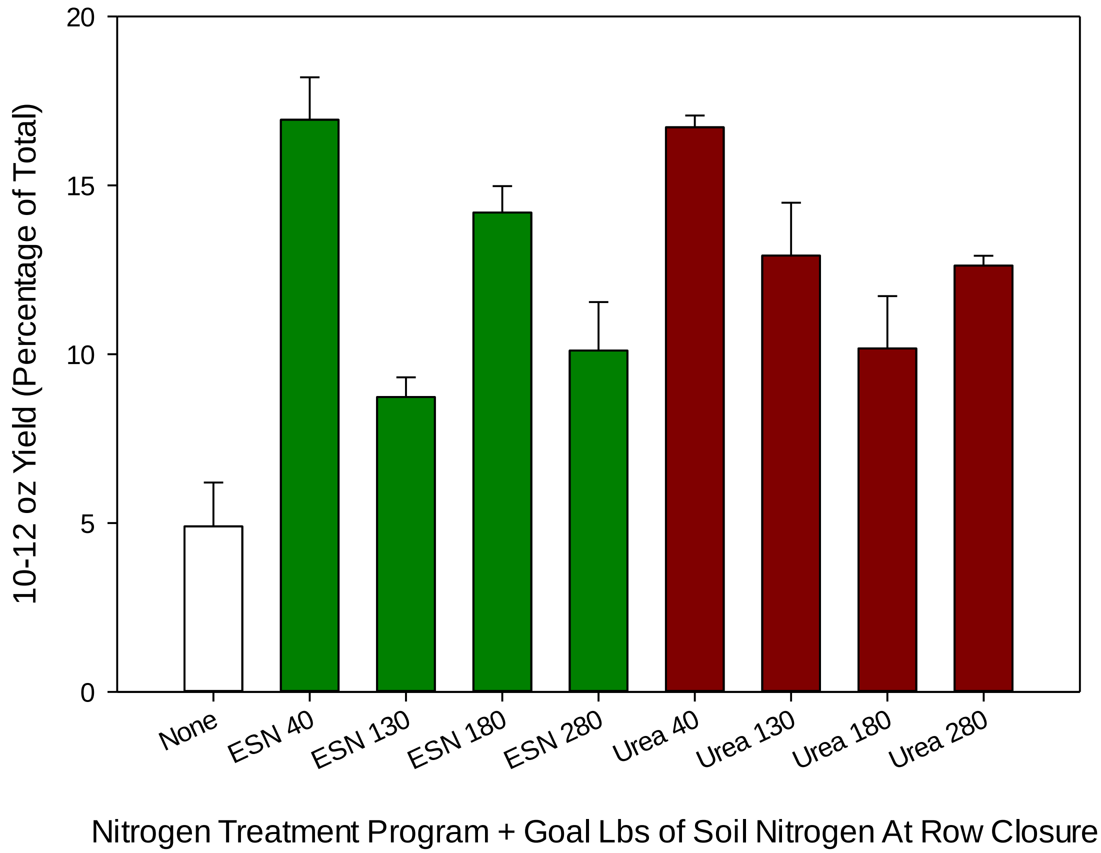


Fig. 8

10-to-12-oz %

Greater Fertilizer Treatment	Lesser Fertilizer Treatment	*P*- value
ESN 40	ESN 280	$P = 0.0104$
ESN 40	ESN 130	$P = 0.0018$
ESN 40	No added nitrogen	$P < 0.0001$
ESN 40	Urea 180	$P = 0.0112$
ESN 180	No added nitrogen	$P = 0.0005$
Urea 40	Urea 180	$P = 0.0148$
Urea 40	ESN 130	$P = 0.0024$
Urea 40	ESN 130	$P = 0.0137$
Urea 40	No added nitrogen	$P < 0.0001$
Urea 130	No added nitrogen	$P = 0.0023$
Urea 280	No added nitrogen	$P = 0.0034$

Table 4: The specific pairwise comparisons from proc mixed listed by the treatment with greatest 10% to 12% of yield first, the lesser treatment second, and the *P*-value third. All other pairwise comparisons that are listed are nonsignificant ($P > 0.05$).

There was a significant impact ($P = 0.0007$) of nitrogen treatment and rate on the percentage of 10 to 12-oz tubers harvested from the experiment (Fig. 9). All treatments improved >12-oz percentage yield compared to the negative control that had no additional nitrogen. There were no differences in >12-oz percentage yield between ESN fertilizer treatments. Conversely, the urea 180 treatment had more >12-oz tubers than urea treatments with more or less nitrogen (280 and 40, respectively).

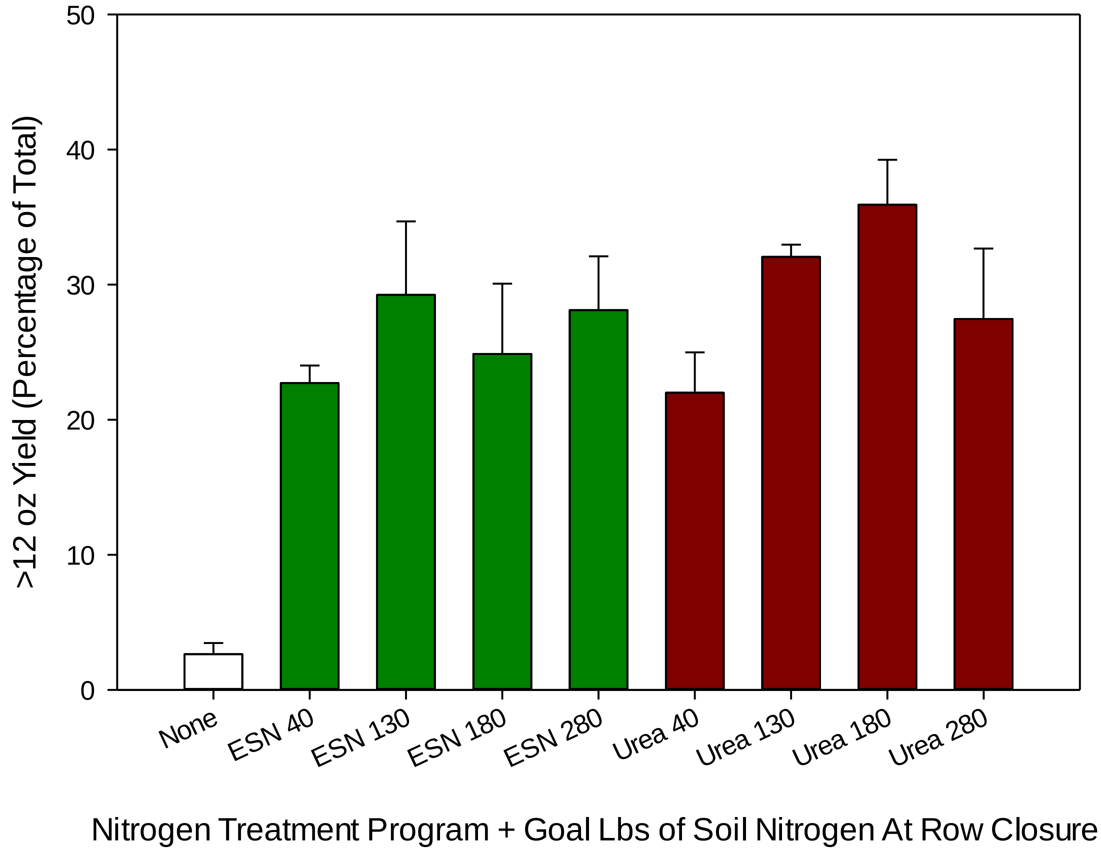


Fig. 9

Greater Fertilizer Treatment	Lesser Fertilizer Treatment	*P*- value
ESN 40	No added nitrogen	$P = 0.0016$
ESN 130	No added nitrogen	$P = 0.0074$
ESN 180	No added nitrogen	$P = 0.0156$
ESN 280	No added nitrogen	$P = 0.0285$
Urea 40	No added nitrogen	$P = 0.0176$
Urea 130	No added nitrogen	$P = 0.0074$
Urea 180	No added nitrogen	$P = 0.0156$
Urea 180	Urea 40	$P = 0.0355$
Urea 180	Urea 280	$P = 0.0022$
Urea 180	ESN 40	$P = 0.0480$
Urea 280	No added nitrogen	$P = 0.0349$

Table 4: The specific pairwise comparisons from proc mixed listed by the treatment with greatest >12-oz percentage of yield first, the lesser treatment second, and the *P*-value third. All other pairwise comparisons that are listed are nonsignificant ($P > 0.05$).

Tracking of Nitrogen Dynamics within the Potato Root-Zone

Objective:

The addition of nitrogenous fertilizers to the agricultural systems has an impact on the composition of air which is 79% nitrogen. The N in the air is present in the form of N_2 molecules, which is not directly available to the plants. That is why inorganic or mineral fertilizers are supplied to the plants to meet the crop nutrients demand. These fertilizers supply a form of N, called fixed nitrogen, that plants can easily uptake. In an inorganic fertilizer, N in the form of ammonium ion (NH_4^+) is converted into nitrite ions (NO_2^-) by soil bacteria of the Nitrosomonas species through biological oxidation (Nitrification). The nitrite ions are further converted into nitrate ions (NO_3^-), the plant available form, at soil temperature above 10 °C by the Nitrobacter species. Nitrate is highly soluble and eventually leaches down into the deeper soil layers because of its low adsorption capacity in the soil. If soil becomes water saturated causing anaerobic conditions, Nitrate-Nitrogen (NO_3-N) may be lost to the atmosphere through a reduction process called denitrification. Complete conversion from NH_4^+ to NO_3^- takes place within a month of application.

$$NH_4^+ \leftrightarrow NO_2^- \leftrightarrow NO_3^-$$

Like all other crops, a substantial amount of fertilizer-N is required to get the optimum yield and quality of potato tuber and to tolerate the diseases as well. In addition to nitrogenous fertilizers, irrigation management also plays a significant role in improving the crop yield. Potato tubers are very sensitive to water stress. Yield may be significantly reduced by water deficit. On the other hand, excessive water application may result in respiration stress and denitrification. Maximum potato production is achieved when the soil moisture is sustained at an optimum level and N is frequently available during the peak demand period within the potato root-zone. In order to achieve high potato yield with minimum water quality impact, both nitrogen and water management should be taken into account.

A combination of fertilizer application and irrigation management during the early growth stages of potato affects the tuber yield. Both over- and under-application of irrigation water and nitrogenous fertilizers, affect the nitrogen dynamics within the potato root-zone. The highly soluble NO_3-N will be leached below the root-zone due to excessive water application. That is why over-application of irrigation water causes contamination of ground water and surface water by leaching and surface run off, respectively. However, the total N uptake by plants is also substantially restricted by water deficits.

Intensive over-application of fertilizer is one of the main contributors to lower yield and elevated NO_3-N concentrations in groundwater. If the excess N is not utilized by the crop, N may accumulate within the root-zone in the form of NO_3-N which can leach below with a rainfall or supplemental irrigation event causing an increase in the NO3-N concentrations in the groundwater. If the soil becomes saturated, this nitrogen may be lost to the atmosphere in the form of nitrous oxide (N_2O) gas by denitrification, which destroys the stratospheric ozone contributing to global warming.

Nitrate leaching in the agricultural soil is influenced by many factors such as the irrigation system/applicator, irrigation management, N fertilizer management (N rate, application method, and splitting), soil characteristics, and rainfall patterns. Soil thickness and distance between the bottom of the root-zone and groundwater table also plays a role in determining the potential for ground water contamination. If the plants roots are closer to the water table, nitrate leaches into the groundwater more easily.

The results from numerous studies have proven that excessive irrigation and heavy rainfall are the main drivers of NO_3-N losses from plant root-zone. This loss can be controlled by irrigation management (that subsequently governs the volume of subsurface drainage water) and fertilizer management. The timing and scheduling of irrigation directly affects nitrate leaching. A proper water management can minimize N losses from the plant root-zone and improve the N uptake. If there is a significant difference between the irrigation supplies and the evapotranspiration demand of crop, the application of N fertilizers assessed for full irrigation may result in “unintentional” over application of N fertilizers causing the potential for N losses. Soil type and soil physical properties also affect nitrate leaching potential.

Impact of different nitrogen application treatments on nitrate dynamics within the potato root-zone was studied in Carberry, Manitoba. The objective of this study was to examine the effects of different nitrogen application rates on nitrogen dynamics within the potato root-zone in a loamy sand soil, and to analyze the nitrate leaching potential below the root-zone.

Conclusion

The importance of fertilizers in improving the crop yield and quality can never be underestimated. Nitrogen (N), potassium (P) and phosphorus (K) are the predominant fertilizers, generally applied to meet the crop nutrients demand, if the native soil supplies of these nutrients are limited. Nitrogen (N) is one of the essential fertilizers that affects plant growth and plays a significant role in optimizing the crop yield. Like all other crops, a substantial amount of fertilizer-N is required to get the optimum yield and quality of potato tuber and to tolerate the diseases as well. In addition to nitrogenous fertilizers, irrigation management also plays a significant role in improving the crop yield. Potato tubers are very sensitive to water stress. Yield may be significantly reduced by water deficit. On the other hand, excessive water application may result in respiration stress and denitrification. Maximum potato production is achieved when the soil moisture is sustained at an optimum level and N is frequently available during the peak demand period within the potato root-zone. In order to achieve high potato yield with minimum water quality impact, both nitrogen and water management should be taken into account. Intensive over-application of fertilizer is one of the main contributors to lower yield and elevated NO_3-N concentrations in groundwater. If the excess N is not utilized by the crop, N may accumulate within the root-zone in the form of NO_3-N which can leach below with a rainfall or supplemental irrigation event causing an increase in the NO_3-N concentrations in the groundwater.

Potatoes require comparatively less N during the early part of the growing season i.e. sprout development, and vegetative growth stages compared to the later part i.e. tuber initiation, and tuber bulking stages. Excessive N application during the early part of the growing season leads to delay onset of the tuber initiation stage, and decrease the yield. Potato requires an adequate and steady supply of N from tuber formation to bulking. Therefore, potato growers apply approximately 25-50 % of the total recommended N at the beginning of the growing season and the remainder is applied at the tuber initiation stage. Although this scheduling improves the yield and quality of tuber, it is costly and labor intensive. Controlled release nitrogen (CRN), also known as polymer coated urea (PCU), and environmentally smart nitrogen (ESN) is a cost effective N application source. A micro-thin polymer coat facilitates the release of N at a controlled rate and minimizes N losses from the soil. The rate of N release from PCU is controlled by soil temperature and soil water content. When water is applied to the soil by supplemental irrigation and/or rainfall, it enters into the polymer coated fertilizer granule and dissolves the N into soluble form within the granule. As temperature increases, this nitrogen solution moves out through the polymer coated fertilizer granule into the soil solution in the plant available form.

Method

Water level sensors (WLS) (Solinst Levelogger Junior 3001, Solinst Canada, Ltd., Georgetown, Ontario, Canada) were used to monitor the groundwater level in each plot throughout the season. These sensors were set to take a reading at half an hour intervals. These sensors were hung inside the piezometers installed at the center of each plot. The piezometers were made from 2.5 m long steel pipes with an inner diameter of 41 mm. In order to avoid any hindrance to farming operations, such as hilling and spraying, all the piezometers were installed along the crop rows. The piezometers were mechanically installed using a mechanical auger. Manual readings of ground water level were also taken using a water level sensing tape as a check. A barometric pressure sensor (Solinst Barologger Gold) was used for subsequent barometric correction of the water level sensor data.

The stage of plant growth and rooting depth were the main factors considered in determining the nitrogen dynamics within the potato root-zone. Representative soil samples within 1.0 m below the ground surface were taken at 0.2 m intervals to determine the soil nitrate concentration (NO_3-N) at the beginning of each growth stage. Soil samples were stored in a refrigerator before sending them to soil testing lab (Agvise Laboratories Inc.) for analysis.

In the 2021 growing season, treatments of ESN 280 lb/A, ESN 180 lb/A, and No Supplemental Nitrogen under adequate irrigation application were compared to track nitrogen dynamics within the potato root-zone under adequate irrigation application.

Results

Impact of different nitrogen application treatments on nitrate dynamics within the potato root-zone was studied in Carberry, Manitoba. The objective of this study was to examine the effects of different nitrogen application rates on nitrogen dynamics within the potato root-zone in a loamy sand soil, and to analyze the nitrate leaching potential below the root-zone.

The nitrate concentrations at 0.2, 0.4, 0.6, 0.8 and 1.0 m depths from ground surface at vegetative growth, tuber initiation, tuber bulking, and maturation stages during the 2021 growing season is shown in figure 1 and 2. The plots with supplemental nitrogen application showed a trend of higher nitrate content within the potato root-zone compared to the no-supplemental nitrogen application treatment. Nitrogen was applied in the form of Urea and ESN also called as polymer-coated urea (PCU). ESN is a controlled release nitrogen fertilizer source. It has nitrogen granules covered in a thin/semi-permeable polymer coating. Soil water is absorbed by the granule which dissolves the nitrogen inside to releases it at a specific temperature and soil moisture level. About 80% of the nitrogen is released from PCU/ESN urea between 40 and 90 days after application. This period spans over the beginning of tuber initiation stage to mid of tuber bulking stage.

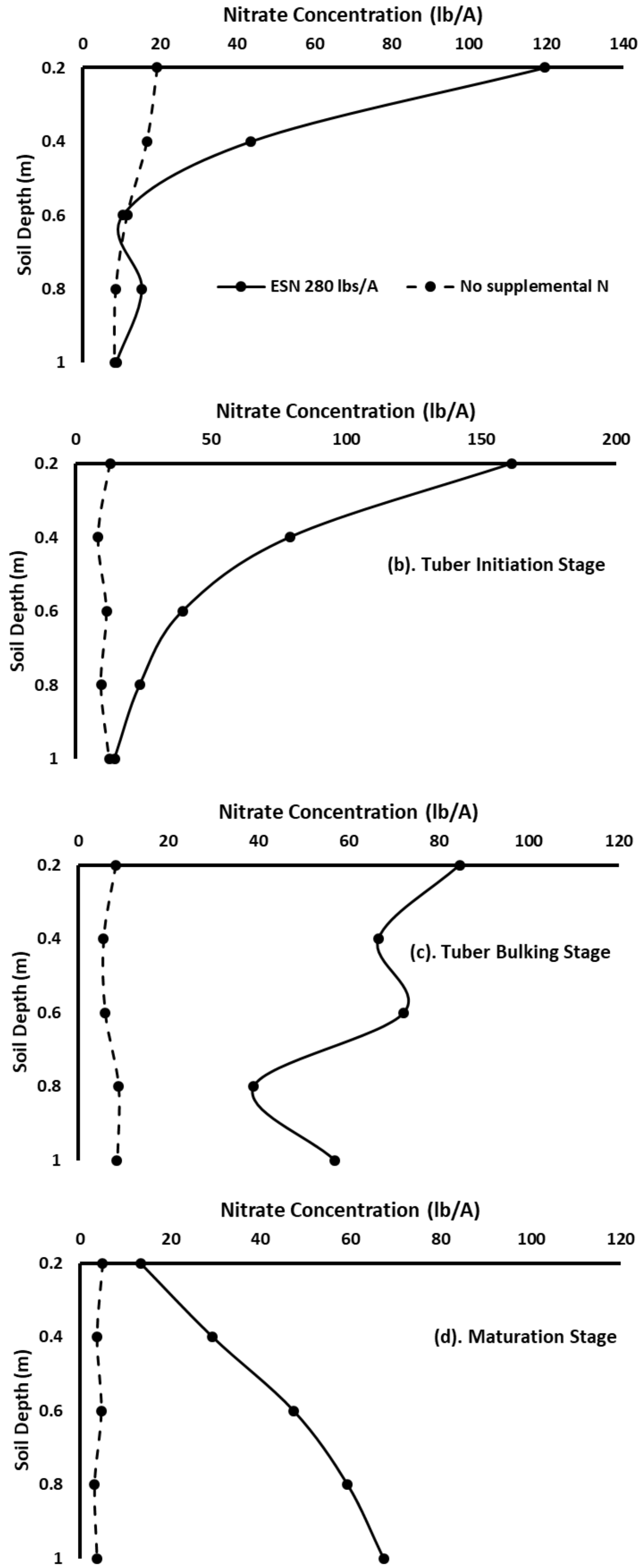


Fig. 1 Comparison of N application rate of ESN = 280 lb/A and no-supplemental N

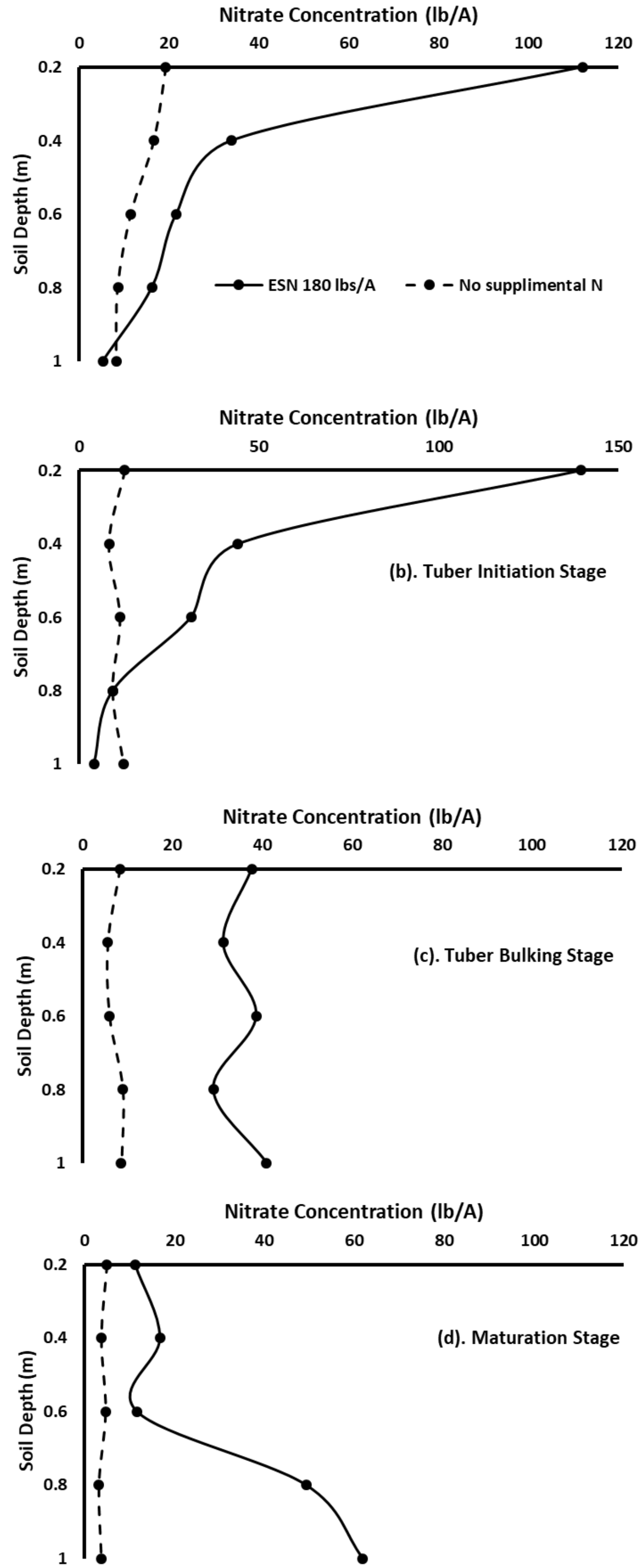


Fig. 2 Comparison of N application rate of ESN = 180 lb/A and no-supplemental N

Potato requires modest nitrate and soil moisture in the beginning of the growing season i.e. at sprout development and vegetative growth stages compared to the subsequent growth stages. An adequate amount of supplemental irrigation was applied during tuber initiation, and tuber bulking stages which facilitated the release of nitrogen from ESN. A comparatively higher nitrate content within the 0.2 m depth shows an adequate application of nitrogenous fertilizers. However, a trend of nitrate leaching was observed within the potato root-zone with the progression of growth stages. It resulted in higher nitrate contents in the deeper depths compared to shallow depths in some ESN applied treatments.

Polymer coated urea may release a maximum of 80% of the total nitrogen during the period of sprout development to mid-bulking stage and remaining is released after that. Since the potatoes do not need as much water during the maturation stage, no supplemental irrigation was applied during this stage. About 20% of the total PCU nitrogen may have been released during this stage. The decrease in nitrate content at 0.2 m depth and increase at 1.0 m depth in ESN = 280 lb/A treatment may be attributed to leaching down of unutilized nitrogen with percolation caused by irrigation and rainfall. As nitrates are readily soluble in water, nitrate leaching potential is directly linked to soil water dynamics within the effective root-zone. The potential risk of nitrate leaching increases with the accumulation of excessive nitrates within the root-zone combined with excessive irrigation and/or intense rainfall on well-drained sandy soils having low water-holding capacity.

Fig. 3 and 4 show that a higher amount of nitrogen application in sandy loam soil system facilitate the availability of nitrogen for plant growth. However, the application of a higher rate of slow released nitrogen is comparatively beneficial than Urea for better nitrogen use efficiency. Nitrate leaching potential from the effective root-zone was found significantly higher at tuber initiation stage, and tuber bulking stage. Tuber initiation and tuber bulking stages are sensitive to irrigation and nutrients stress. In 2021, supplemental irrigation was applied to the irrigated treatment during the tuber initiation, and tuber bulking stages. Overhead irrigation and rainfall coupled with favorable temperature facilitated the release of nitrogen from PCU/ESN granules in the plant-available-form. This accumulated nitrate may have been available to leach below the root-zone with the irrigation and rainfall events.

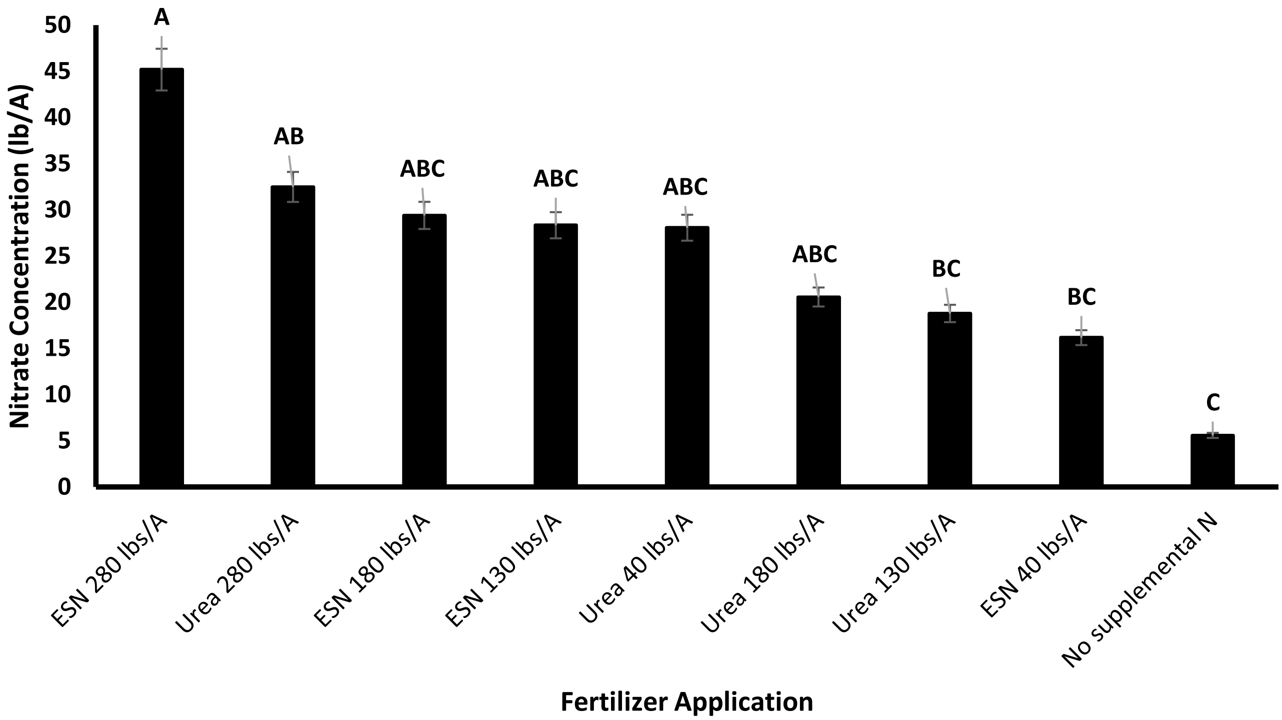


Fig. 3 Nitrogen availability within the potato root-zone throughout the growing season (2020)

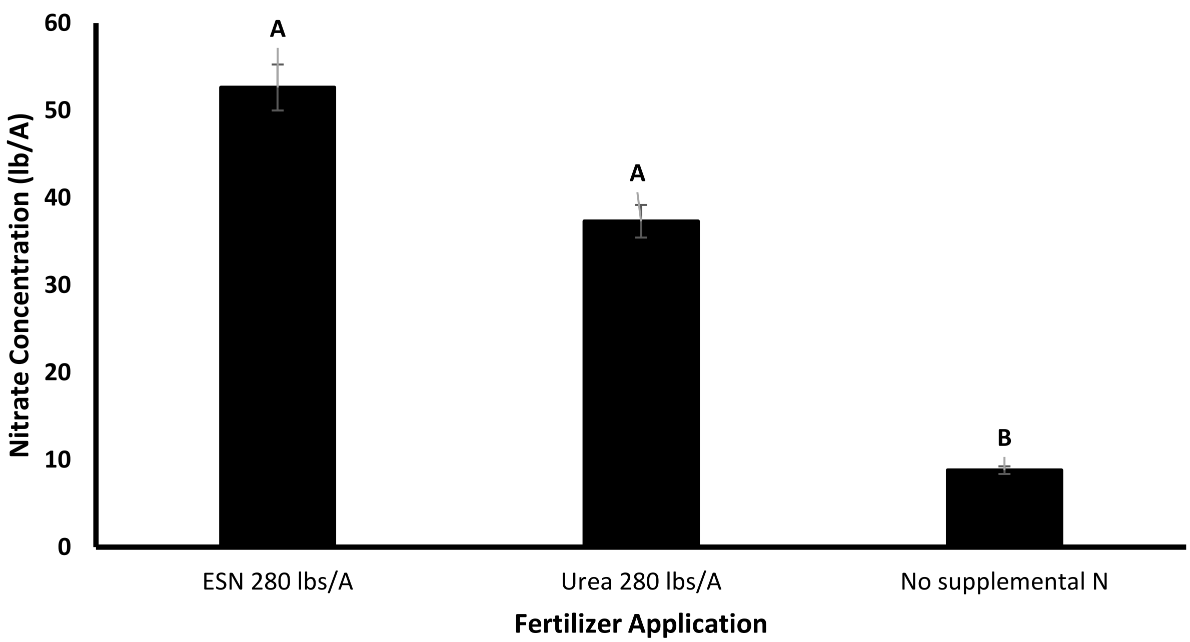


Fig. 4 Nitrogen availability within the potato root-zone throughout the growing season (2021)

Project findings:

Nitrate leaching can have a direct impact on groundwater quality. Nitrate is very mobile and easily leaches with water. Heavy rains and supplemental irrigation applications can cause nitrates to leach downward in the soil below the potato root zone. Whether nitrates continue to leach downward, and into groundwater, depends on underlying soil and/or bedrock conditions, as well as depth to groundwater. If depth to groundwater is shallow and the underlying soil is sandy, the potential for nitrates to enter groundwater is relatively high. However, if depth to groundwater is deep and the underlying soil is heavy clay, nitrates will not likely enter groundwater. In some cases where dense hardpans are present, nitrate leaching will not progress beyond the depth of the hardpan. The unavailability of nitrogen within the potato root-zone, due to nitrates leaching effect, causes negative impacts on potato yield and quality.

Optimizing Soil Sulphur at Row Closure and Characterizing Impacts on Yield of 'Russet Burbank' in Manitoba

Introduction

The Field Variability Study (FVS) was conducted from 2015 to the present day with the overall goal of identifying and remediating factors responsible for variable processing potato yield. Fifty-five soil, plant, and environmental factors were identified in 23 grower fields and each factor was ranked according to impact on potato yield in a new partial least squares model generated in 2020. Soil sulphur availability has been identified as the fourth most influential variable responsible for differences in total yield at row closure, which is approximately late June to Early July. Soil sulphur availability at all sampled soil depths throughout the growing season swept the top nine most influential variables responsible for variation in the 6-to-10-oz, 10-to-12-oz, and 12-oz and greater yields. The assumed ideal soil sulphur test is 40-lb in potato (as published by the University of Manitoba in Agvise's soil sulphur guidelines at https://www.agvise.com/wp-content/uploads/2017/03/Sulphur-Magnesium-and-Chloride-guidelines.pdf).

The FVS also offered insight into the amount of soil sulphur typically seen in grower fields, which ranged from 0-to-120-lb, regardless of sampling date. In a cursory examination of the data set, 40-to-60-lb of sulphur appeared to be the beneficial amount of available soil sulphur, where compromised yields were observed outside of this range. The lowest yields appeared to be associated with sampling sites with virtually no soil sulphur, which was especially prevalent in sandy soils. This cursory examination was done by hand did not have the benefit of any statistical test or association. **The goal of this study was to identify the exact range of soil sulphur needed by row closure and possible products and rates needed to accomplish the task in order to achieve desired benefits to total yield and larger tuber size categories (greater than 6-oz). Outcomes of this study were set in the context of small, controlled research plots to demonstrate the importance of a unique sulphur fertilizer regime to potato growers in order to justify field-scale validation studies that are necessary for industry adoption.**

Methods

A factorial randomized complete block design was enacted with four-blocks in 2019, 2020, and 2021. The soil at the site was a Halboro series Orthic Black Chernozem with a loamy sand texture. The site has a typical crop rotation of potato-wheat-canola and is irrigated. All of these factors were a reasonable representation of lighter soils that potatoes are grown on in Manitoba, except the black chernozem exhibits greater organic matter content typical of lighter soils. Regardless of the organic content, the crop rotation resulted in low preseason soil sulphur tests with approximately 4-to-14-lbs of soil sulphur available (data not shown), and all plots would be considered sulphur deficient without additional treatment.

Experimental plots were individually fertilized on May 2nd 2019, April 30th 2020, and April 27th 2021. Fertilizers were applied with a custom-modified R-tech Terra Meter fertilizer applicator that was set up to apply up to three different fertilizers in a single pass. Two sets of three-Gandy Boxes were arranged in horizontal rows, and a single box of amazon cups was set up at the front in order to accommodate the three different types of fertilizer at possible rates of 6 lbs/acre (A) to 584 lbs/A (rates varied depending on fertilizer pellet size, vehicle speed, and gear combinations selected). The machine was set to broadcast all fertilizers over four potato rows at 36 inches between the rows. Each row of fertilizer applicators was calibrated for each pelleted formulation of fertilizer employed in the experiment and for every fertilizer rate in the treatment structure. Pre-plant fertilizer was immediately mixed into soil post-application with a Lely Roterra 350-33 (Lely, Maassluis, Netherlands) to a depth of up to 10-inches. Russet Burbank seed (2-to-3-oz, average 2.5-oz (data not shown)) was planted on May 6th 2019, May 5th 2020, May 4th 2021 with no gaps between plots, 36-inches between rows, 13-inches between seed pieces within row, and 6-inches deep (from top of hill). The seed treatment, pesticide applications and irrigation schedule were typical for the potato growing region in Carberry, Manitoba (data not shown). Hills were created as plants emerged on June 7th 2019, June 2nd 2020 and 2021 using a power hiller attached to a tractor. Row closure was observed on July 15th 2019, June 30th 2020 and July 7th 2021 and five 0-6 in. and 6-12 in. soil and 30-petiole samples per plot were collected on the same day. Thirty petioles were collected weekly on every Friday in July from four ammonium sulphate treatments to determine if a fertigation event was required the following week. Finally, five 0-6 in. and 6-12 in. soil samples were taken from every plot for late bulking soil sulphur assessment on the August 20th 2019, August 18th 2020, and August 19th 2021. The pounds of sulphur available in soils and the percentage of sulphur in petioles were determined by Agvise Inc (Northwood, North Dakota, USA).

Fertigation events were to be conducted in July as determined by low petiole percentage sulphur in the ammonium sulphate treatment only, regardless ammonium sulphate of rate applied to the plot preplant. Low petiole percentage sulphur was observed once in each year on July 15th 2019, July 23rd 2020, and July 9th 2021. Fertigation was conducted through a Hardi (Davenport, Iowa, USA) NL 80-26' SB PT sprayer with three inline filters, triple nozzle bodies, and three boom controls using a minidrift 03-blue nozzle at approximately 41 PSI at 2-3 miles per hour. Applications were done in the early morning and diluted as quickly as possible to limit fertilizer burn. One-gallon of ammonium thiosulphate was mixed with 10-imperial gallons of water and applied only to the ammonium sulphate treatment. This application was immediately diluted with ¼-inch of water from a linear irrigator (see Fig. 1 below). There was a frost on September 8th 2020 where the temperature reached -2 ºC at night, which was not anticipated to significantly impact any yield results and resulted in moderate foliar damage right before harvest.

Fig 1. An example fertigation event demonstrating concentrate is applied directly to foliage and then immediately diluted to the correct ratio by a linear irrigator on a cloudy morning to prevent fertilizer burn.

The entire experiment was 2,282.34-m^2 (approximately 0.57-acre). Each plot was 3.6-m wide and 12-m long, or 43.2-m^2 (approximate 0.011-acre). Harvest calculations were based upon a 10-m harvest row, which was left undisturbed in each plot throughout the season until harvest. The experiment was constructed with five fertilizer treatments: Tiger XP (Tiger-Sul Inc, Shelton, Connecticut, USA), Tiger Combo (Tiger-Sul Inc), no sulphur amendment (negative control), magnesium sulphate ($MgSO_4$, Redfern Farm Services, Brandon, Manitoba), ammonium sulphate ($(NH_4)_2SO_4$) as a soil amendment with ammonium thiosulphate ($(NH_4)_2S_2O_3$, Redfern Farm Services, Brandon, Manitoba, the treatment will henceforth be abbreviated ATS) through fertigation. Each fertilizer treatment, except the negative control, was applied at the equivalent of 20,-60,-and 100-lb of sulphur expected in the soil by row closure (approximately early July). The total amount of each fertilizer needed to achieve the goal by row closure varied based on sulphur content along with exact application rates displayed in Table 1 below:

Formulation (NPKS)	Fertilizer	Goal lb by row closure	lb/A of product required to achieve goal	lb product applied preplant per replicate(Per 4 plots)	Fertigation Fertilizer and Formulation	Sulphur Fertigation rate (lb)
0-0-0-85	Tiger XP	20	24	1.2	None	None
0-0-0-85	Tiger XP	60	71	4	None	None
0-0-0-85	Tiger XP	100	118	6	None	None
12-0-0-50	Tiger Combo	20	40	2	None	None
12-0-0-50	Tiger Combo	60	120	6	None	None
12-0-0-50	Tiger Combo	100	200	10	None	None
0-0-0-16	Magnesium Sulphate	20	125	7	None	None
0-0-0-16	Magnesium Sulphate	60	375	19	None	None
0-0-0-16	Magnesium Sulphate	100	625	32	None	None
21-0-0-24	Ammonium Sulphate	20	68	4	Ammonium Thiosulphate 12-0-0-26	3
21-0-0-24	Ammonium Sulphate	60	188	10	Ammonium Thiosulphate 12-0-0-26	3
21-0-0-24	Ammonium Sulphate	100	313	16	Ammonium Thiosulphate 12-0-0-26	3
Negative Control (no additional sulphur)			0	0	None	None

Table 1. Sulphur fertilizer products employed in the study are listed by sulphur content to display the amount of each product necessary to achieve the goal lb of sulphur available at row closure, as determined at a soil test conducted by Agvise, Inc. (Northwood, North Dakota). The fertigation rate assumes three-lb sulphur is in approximately one-gallon of ammonium thiosulphate (ATS) per fertigation event. One fertigation event was required in 2019, as determined by petiole testing from Agvise Inc. All plots received 115 lb/acre (A) of mono-ammonium phosphate (MAP, 11-52-0-0), 42.24 lb/A of Kmag blend (0-0-60-0), and 466.6 lb/A of ESN (polymer coated urea named Environmentally Smart Nitrogen, 44-0-0) from Redfern Farm Services, Brandon, Manitoba.

Harvest occurred on September 17th 2019, September 14th 2020, and September 13th 2021 and was completed using a 1-row digger on a 10-m section of a designated harvest row that was unsampled and untrampled during the season. This harvest row was the innermost part of each plot to buffer it as much as possible from edge effects. The total yield of each plot was recorded as lb harvested, as well as the lb of each tuber size category (less than 3-oz, 3-to-5.9-oz, 6-to-9.9-oz, 10-to-11.9-oz, 12-oz and greater) and quality metrics were recorded (weight of rotted tubers, green tubers, and hollow heart tubers in grams, as well as specific gravity). The size profile used to calculate an approximate Canadian dollar value to determine bonuses and deductions for a mid-season shipment of Burbank potatoes from a demonstration processor contract (data not shown).

Statistical tests were conducted with SAS v9.4 (SAS, Cary, NC). More specifically, the mixed procedure (proc mixed) was employed to construct a linear regression model to compare the variables of fertilizer treatment, year, and desired soil test (lb/acre) by row closure to a yield parameter (for example: the fertilizer Tiger XP at 60-lb by row closure impact on the 6-to-10-oz yield category). This analysis was completed for each yield parameter separately (e.g. 6-to-10-oz yield was run separately from total yield). In each case a Satterthwaite approximation is used to delineate limits for all variables that had a lower boundary constraint of zero. The blocking factor was used as a random effect as a vector for the mixed model. Because assumptions for the normal distribution of errors and homogeneity of variances were not met (data not shown), the repeated statement was used to model the variance of the fertilizer used. Finally, the lsmeans statement was used to determine significance of pairwise comparisons of a yield parameter between two fertilizer treatments (provided the type III test of fixed effects from the mixed model was significant with $P \leq 0.05$). Familywise type I error was controlled for the multiple comparisons in the lsmeans statement using a Tukey adjustment, with all subsequent reported *P*-values between specific treatments referring to this Tukey-adjusted *P*-value.

Sulphur Fertilizer Conversions and Cost Estimate Analysis

All of the following conversions and calculations are taken from Manitoba Soil Fertility Guide. (https://www.gov.mb.ca/agriculture/crops/soil-fertility/soil-fertility-guide/calculating-fertilizer-rates.html)

Fertilizer Product Applied to Actual Nutrient Applied Conversion Process

To convert lb of fertilizer product per acre to lb of actual nutrient per acre, the total lb of product was multiplied by the percentage of the plant nutrient content that is within the product. This percentage was found within the chemical breakdown of each product. For example: Tiger Combo is 12-0-0-50 (Nitrogen-Phosphorous-Potassium-Sulphur). This means there is 12% nitrogen and 50% sulphur within the product. Multiplying the total weight of the fertilizer product by the percentage of each nutrient within the product produces the total nutrient value in lb within that fertilizer product. This calculates the rate of actual nutrient that is being applied per acre. If the conversion is opposite and the product amount is needing to be found the actual nutrient needs to be divided by the percentage. This is shown below.
Tiger Combo (TC) (12-0-0-50)

$$\left(\frac{\text{x lb S}}{\text{ac}}\right)\left(\frac{\text{100 lb TC}}{\text{50 lb S}}\right) = \frac{\text{x lb TC}}{\text{ac}} \qquad \left(\frac{\text{x lb TC}}{\text{ac}}\right)\left(\frac{\text{50 lb S}}{\text{100 lb TC}}\right) = \frac{\text{x lb S}}{\text{ac}}$$

$$\left(\frac{\text{x lb N}}{\text{ac}}\right)\left(\frac{\text{100 lb TC}}{\text{12 lb N}}\right) = \frac{\text{x lb TC}}{\text{ac}} \qquad \left(\frac{\text{x lb TC}}{\text{ac}}\right)\left(\frac{\text{12 lb N}}{\text{100 lb TC}}\right) = \frac{\text{x lb N}}{\text{ac}}$$

Converting Fertilizer Prices into Price per Unit of Nutrient

Example 1. Single Nutrient Fertilizers

There was just one set of calculations for single nutrient containing products which is shown the in the Urea section. The first step is converting the price per tonne to price per lb. The cost per tonne of urea was $1,295.00 as of December 2021 and there are 2204-lb per tonne. Therefore, dividing $1,295.00 per tonne of urea by 2204-lb of urea equaled $0.588 per lb. This total was then divided by the percent of actual plant nutrient that is within the fertilizer for urea, or 46%. These calculations yielded a price per lb of actual nitrogen that is being applied and, in this case, was $1.28 per lb. This method was used for all single nutrient fertilizers by interchanging the product with the appropriate amount of nutrient within that fertilizer amendment.

$$\left(\frac{\$1{,}295.00}{tonne\ urea}\right)\left(\frac{tonne\ urea}{2204\ lb\ urea}\right)\left(\frac{100\ lb\ urea}{46\ lb\ N}\right)=\frac{\$1.28}{\text{lb N}}$$

Example 2. Multiple Nutrient Fertilizers

When there were two nutrients within a fertilizer product, the most common nutrient or the nutrient that is not being compared the total value of that nutrient was subtracted. In the case of ammonium sulphate (AS) (21-0-0-24), there was nitrogen (21%) and sulphur (24%) within the fertilizer product so the total value of nitrogen must first be subtracted. One tonne of AS is converted to lb AS using 2204-lb/tonne. Then this is converted to the lb of actual nitrogen that is within the fertilizer product by multiplying 21%. This yields 462.84-lb within that 1-tonne is actual nitrogen. To find the total N value this is multiplied by the price per pound of nitrogen that was calculated in the urea calculation which is $1.28/lb N. The total value of the nitrogen within AS is $591.20. The total value of AS is $835.00 as of December 2021 therefore $591.20 needs to be subtracted from $835.00 which equals $243.80 per tonne AS without the N value. This is then converted to cost per lb by dividing it by 2204-lb per tonne which equals $0.11 per lb. To yield the cost per actual sulphur this divided by the 24% which is the actual plant nutrient amount. This makes the cost of sulphur in ammonium sulphate $0.46 per lb sulphur. This method can be used for all multiple nutrient fertilizers just interchanging the products with the appropriate amount of each nutrient within that fertilizer amendment.

$$1\ \text{tonne AS}\left(\frac{2204\ lb\ AS}{1\ tonne\ AS}\right)\left(\frac{21\ lb\ N}{100\ lb\ AS}\right)\left(\frac{\$1.28}{lb\ N}\right)=\$591.20\ N\ value$$

$$\frac{\$835.00}{tonne\ AS}-\frac{\$591.20\ N\ value}{tonne\ AS}=\frac{\$243.80}{tonne\ of\ S\ in\ AS}$$

$$\left(\frac{\$243.80}{tonne\ AS}\right)\left(\frac{tonne\ AS}{2204\ lb\ AS}\right)\left(\frac{100\ lb\ AS}{24\ lb\ S}\right)=\frac{\$0.46}{\text{lb S}}$$

Nitrogen value of multi-nutrient fertilizers

Urea and ESN are two very common granular nitrogen fertilizers used by Manitoba processing potato growers. Urea is the baseline nitrogen amendment used in the Manitoba community and this is why it was selected for deciding base value of nitrogen within the multi-nutrient fertilizers. ESN has become part of growing practice on many farms, but since it has properties that make it a slow-release product, it has extra value when compared to urea and was not chosen as the baseline for these reasons.

Liquid urea-ammonium nitrate (UAN) is commonly used as a liquid nitrogen fertilizer to help top up nutrients throughout the growing season. Due to the addition of water, the concentration of nutrients is lower, mimicking what happens with the ATS fertilizer treatment, which is why this treatment has a different value of nitrogen within the cost breakdown.

The magnesium sulphate treatment ($MgSO_4$) became unavailable in the spring of 2021. Due to the most common magnesium amendments being foliar standalone products and micronutrient combination products, the costs of magnesium use could be skewed when determining a baseline. The method chosen to determine actual nutrient amounts for the sake of fertilizer cost comparisons was the same as other multi nutrient fertilizer breakdowns previously outlined. This will show the sulphur amount being the same amount as ammonium sulphate and using that as the value subtracted to find the magnesium value to know how much that micronutrient was within that fertilizer.

Calculate Cost of Fertilizer Product Applied

The first step is converting the price per tonne of fertilizer to price per lb of fertilizer. The cost per tonne of Tiger XP is $745.00 as of December 2021 and there are 2204-lb per tonne. For example to reach the goal of 60-lb sulphur per acre 71-lb of product will need to be applied per acre. That means that 71-lb XP will have to be divided by 2204 lb to convert into tonne of XP product which is 0.032 tonne XP per ac applied. This is then multiplied by the price per tonne which is $745.00. This means that the value of the 71-lb XP applied would be $24.00 per acre. This method doesn’t change with multi-nutrient fertilizers just interchange the lb of product applied and the value of that product.

$$\left(\frac{71\ lb\ XP}{ac}\right)\left(\frac{1\ tonne\ XP}{2204\ lb\ XP}\right)\left(\frac{\$745.00}{tonne\ XP}\right) = \frac{\$24.00}{ac}$$

Results

Nutrient results for 2019-2021:

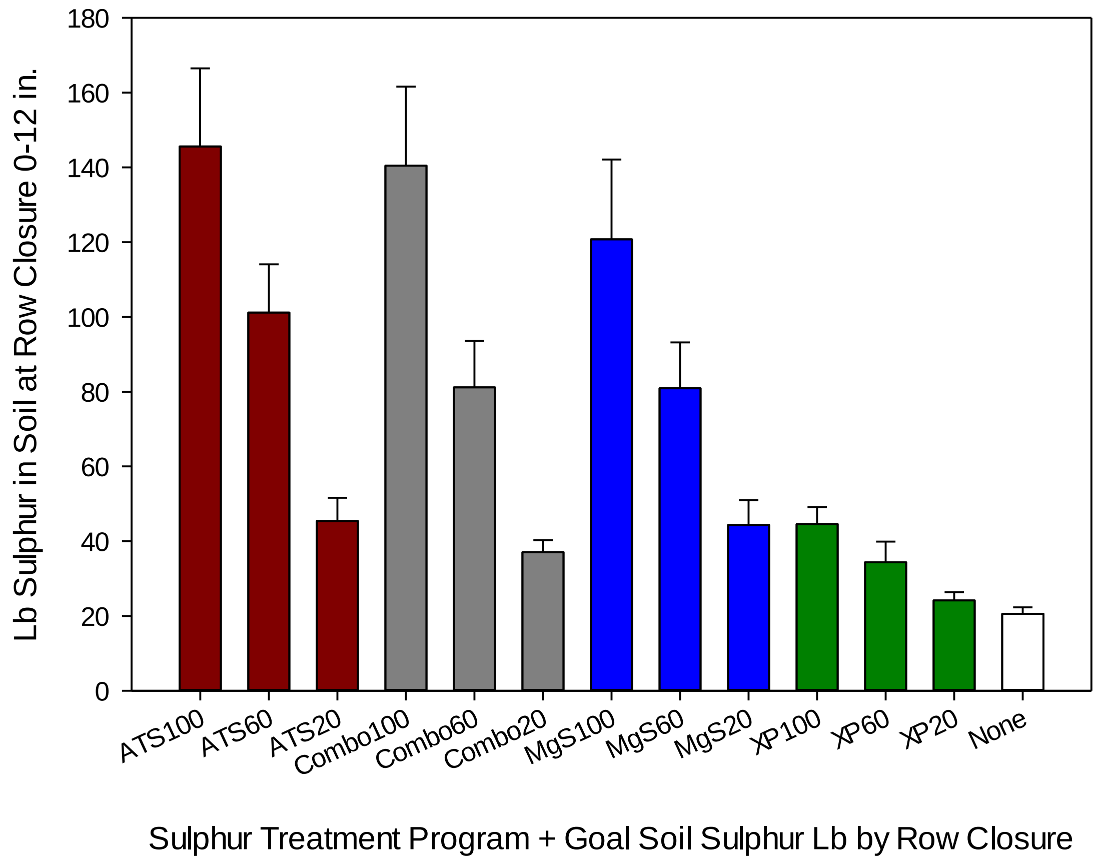


Figure 1 (above): The effect of sulphur treatment program (x-axis) on the availability of soil sulphur (y-axis) at row closure. Bars indicate mean lb of sulphur and the standard error is above each bar. MgS signifies magnesium sulphate, while ATS stands for ammonium sulphate + ammonium thiosulfate fertigation. Combo represents Tiger-Sul's Combo product, as XP stands for Tiger-Sul's XP product. None represents the negative control, where no additional sulphur fertilizers/fertigation events were added. The number 20, 60, and 100 refer to the fertilizer targets for row closure (i.e. all 60 treatments target 60-lb on the Y-axis of this figure). All fertilizer rates for each treatment can be found in Table 1.

In general, across three years of small plot experiments, increasing amount of fertilizer (such as targeting 100-lb soil sulphur by row closure compared to 20-lb) resulting in increasingly variable responses in levels of soil sulphur, as indicated by increasing whisker length on the highest rates of all treatments. Bearing in mind that the assumed ideal soil sulphur test is 40-lb in potato (as published by the University of Manitoba in Agvise's soil sulphur guidelines at https://www.agvise.com/wp-content/uploads/2017/03/Sulphur-Magnesium-and-Chloride-guidelines.pdf), each 100-lb rate for every fertilizer treatment was well above the 40-lb goal. Each 60-lb rate for every fertilizer treatment was at or above the 40-lb goal, albeit with a much smaller margin for error in specific cases such as Tiger XP and the ammonium sulphate 60-lb. An unexpected result was observed where the 20-lb rates of magnesium sulphate and ammonium sulphate actually achieved a result over the 40-lb threshold by row closure, whereas Tiger XP and Combo 20-lb did not.

There was a significant effect of soil sulphur treatment on the amount of available soil sulphur at row closure ($P < 0.0001$). In general, all 100-lb fertilizer treatments provided significantly more soil sulphur than the negative controls ($P \leq 0.05$, Table 2). Similarly, all 60-lb and 20-lb fertilizer treatments provided more soil sulphur than negative controls except Tiger Combo, which trended towards significance ($P = 0.1142$), and Tiger XP, which was nonsignificant ($P \geq 0.05$, Table 2). In the cases of ammonium sulfate and Tiger Combo treatments their respective 100-lb treatments provided significantly more soil sulphur than 60-lb treatments, and 60-lb treatments provided significantly more soil sulphur than 20-lb treatments. An unexpected observation with the magnesium sulphate treatment was that 100-lb treatments did not have significantly more soil sulphur than the 60-lb treatments, but the 60-lb treatments did have significantly more soil sulphur. Tiger XP treatments did not differ from one-another significantly other than the 100-lb treatment providing more soil sulphur than the 20-lb treatment.

Greater Fertilizer Treatment	Lesser Fertilizer Treatment	*P*-value
Ammonium sulphate 100-lb	Ammonium sulphate 20-lb	$P < 0.0001$
Ammonium sulphate 100-lb	Ammonium sulphate 60-lb	$P = 0.0239$
Ammonium sulphate 100-lb	None	$P < 0.0001$
Ammonium sulphate 60-lb	Ammonium sulphate 20-lb	$P = 0.0054$
Ammonium sulphate 60-lb	None	$P < 0.0001$
Ammonium sulphate 20-lb	None	$P = 0.0039$
Tiger Combo 100-lb	Tiger Combo 60-lb	$P < 0.0001$
Tiger Combo 100-lb	Tiger Combo 20-lb	$P < 0.0001$
Tiger Combo 100-lb	None	$P < 0.0001$
Tiger Combo 60-lb	Tiger Combo 20-lb	$P < 0.0001$
Tiger Combo 60-lb	None	$P < 0.0001$
Tiger Combo 20-lb	None	$P < 0.0001$
Magnesium sulphate 100-lb	Magnesium sulphate 60-lb	$P = 0.4178$ *NS
Magnesium sulphate 100-lb	Magnesium sulphate 20-lb	$P = 0.0002$
Magnesium sulphate 100-lb	None	$P < 0.0001$
Magnesium sulphate 60-lb	Magnesium sulphate 20-lb	$P = 0.9889$ *NS
Magnesium sulphate 60-lb	None	$P < 0.0001$
Magnesium sulphate 20-lb	None	$P = 0.1142$ *NS
Tiger XP 100-lb	Tiger XP 60-lb	$P = 0.9618$ *NS
Tiger XP 100-lb	Tiger XP 20-lb	$P = 0.0005$
Tiger XP 100-lb	None	$P < 0.0001$
Tiger XP 60-lb	Tiger XP 20-lb	$P = 0.8008$ *NS

Tiger XP 60-lb	None	*P* = 0.5928 *NS
Tiger XP 20-lb	None	*P* = 0.9999 *NS

Table 2 (above): Specific pairwise comparisons of sulphur treatments on available soil sulphur at row closure are listed with the numerically greatest treatment on the left and lesser column on the right. Combinations of fertilizers that are not present were either not significant ($P \leq 0.05$) or not of experimental interest. *P*-values above the 0.05 threshold on the Tukey test are denoted with *NS as nonsignificant in the *P*-value column and were included for completeness.

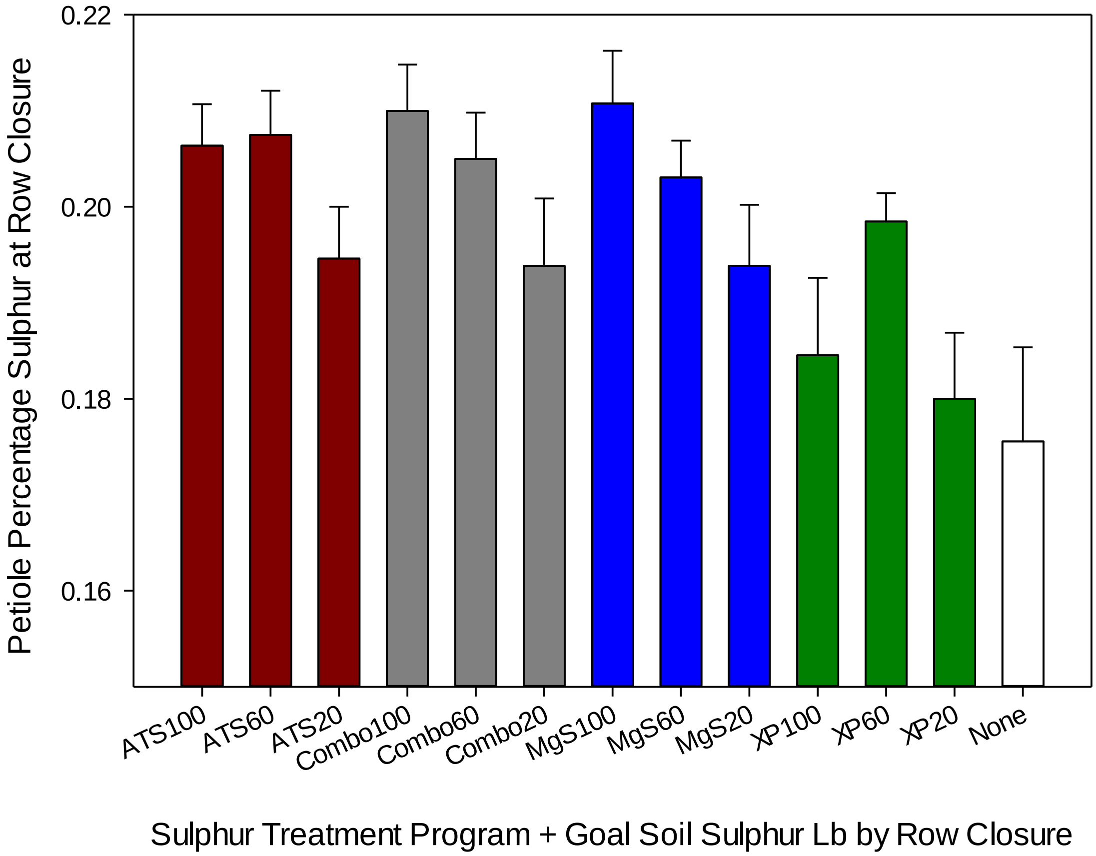


Figure 2 (above): The effect of sulphur treatment program (x-axis) on the availability of petiole sulphur (y-axis) at row closure. Bars indicate mean percent of sulphur, and the standard error is above each bar. MgS signifies magnesium sulphate, while ATS stands for ammonium sulphate + ammonium thiosulfate fertigation. Combo represents Tiger-Sul's Combo product, as XP stands for Tiger-Sul's XP product. None represents the negative control, where no additional sulphur fertilizers/fertigation events were added. The number 20, 60, and 100 refer to the fertilizer targets for row closure. All fertilizer rates for each treatment can be found in Table 1.

Agvise Inc specifies that row closure petiole sulphur sufficiency is 0.2% to 0.5%, whereas petioles low in sulphur are 0.01% to 0.19% and high sulphur 0.51% to 0.99% (data not shown). The petioles for every fertilizer's 60-lb treatment were at or above the 0.2% threshold for sufficiency.

In general, the petioles for every 100-lb treatment were above the 0.2% threshold and the 20-lb treatment was at or just below the same threshold. However, Tiger XP 100-and-20-lb treatments were generally low and below the 0.2% threshold.

There was a significant effect of soil sulphur treatment on the amount of available petiole sulphur at row closure ($P < 0.0001$). Generally, petiole sulphur levels within the same fertilizer but different rates (20, 60, 100) were statistically indistinguishable ($P \geq 0.05$, data not shown), but all fertilizer 100 and 60 rates provided significantly more petiole sulphur than the negative control ($P \leq 0.05$, Table 3) with the only exception of Tiger XP. The only fertilizer treatment where fertilizer rates had significantly different petiole sulphur was Tiger XP 60-lb vs 20-lb ($P = 0.0017$, Table 3).

Greater Fertilizer Treatment	Lesser Fertilizer Treatment	*P*-value
Ammonium sulphate 100-lb	None	$P = 0.0350$
Ammonium sulphate 60-lb	None	$P = 0.0509$
Tiger Combo 100-lb	None	$P = 0.0020$
Tiger Combo 60-lb	None	$P = 0.0063$
Magnesium sulphate 100-lb	None	$P = 0.0001$
Magnesium sulphate 60-lb	None	$P = 0.0450$
Tiger XP 100-lb	None	$P = 0.9999$*NS
Tiger XP 60-lb	None	$P = 0.8994$*NS
Tiger XP 60-lb	Tiger XP 20-lb	$P = 0.0017$

Table 3 (above): Specific pairwise comparisons of sulphur treatments on available petiole sulphur at row closure are listed with the numerically greatest treatment on the left and lesser column on the right. Combinations of fertilizers that are not present were either not significant ($P \leq 0.05$) or not of experimental interest. *P*-values above the 0.05 threshold on the Tukey test are denoted with *NS as nonsignificant in the *P*-value column and were included for completeness.

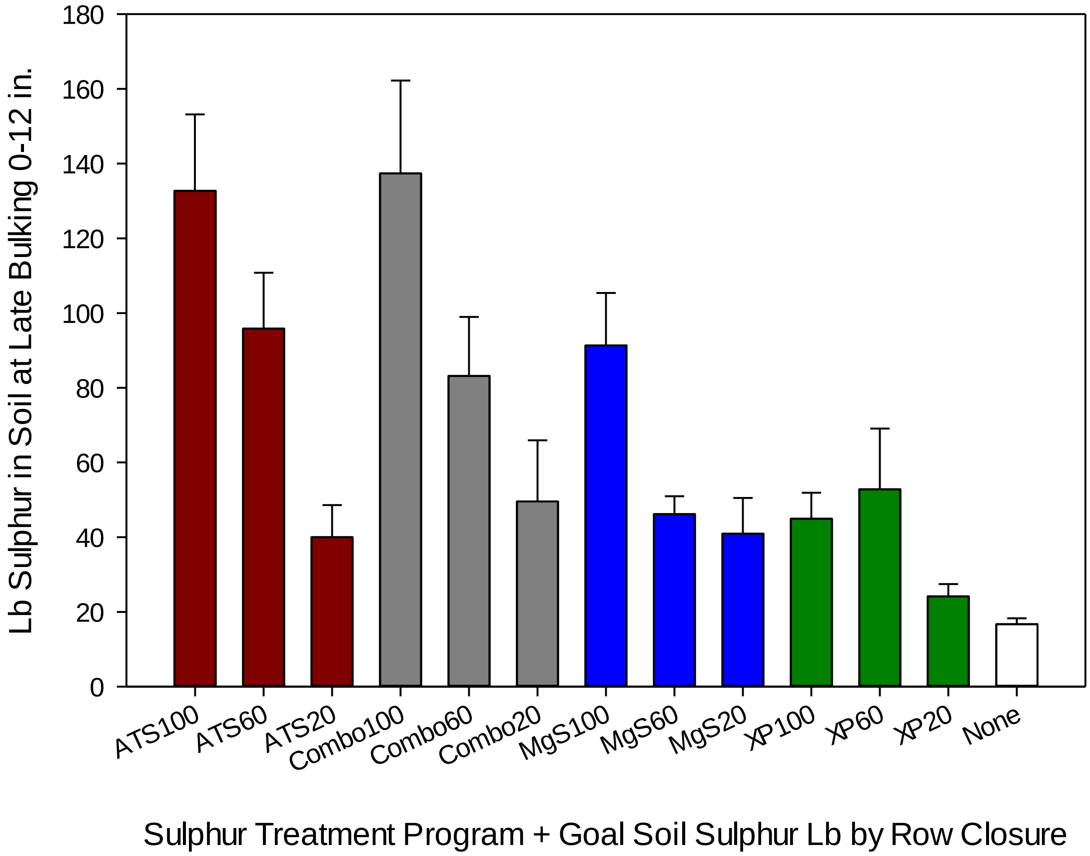


Figure 3 (above): The effect of sulphur treatment program (x-axis) on the availability of soil sulphur (y-axis) at late bulking. Bars indicate mean lb of sulphur and the standard error is above each bar. MgS signifies magnesium sulphate, while ATS stands for ammonium sulphate + ammonium thiosulfate fertigation. Combo represents Tiger-Sul's Combo product, as XP stands for Tiger-Sul's XP product. None represents the negative control, where no additional sulphur fertilizers/fertigation events were added. The number 20, 60, and 100 refer to the fertilizer targets for row closure, **NOT** the targets for late bulking. All fertilizer rates for each treatment can be found in Table 1.

Statistical analysis for late bulking soil sulphur availability was not possible using the same methods as the other soil, plant, and yield parameters because the convergence criteria wasn't being met and infinite likelihoods were being created by mixed models. Despite this setback, observations can be made about the persistence of sulphur products throughout the season with this data in Fig. 3. In general, ammonium sulfate and Tiger Combo levels soil sulphur were maintained between row closure (Fig. 1) and late bulking (Fig. 2) with numerically similar means regardless of fertilizer rate. Magnesium sulfate levels decreased between row closure (Fig. 1) and late bulking (Fig. 2) by approximately 40-lb of soil sulphur on average for higher 100-and-60-lb treatments. The magnesium sulfate 20-lb treatments did not appreciably decrease between row closure and late bulking (decrease by 3-lb on average). The Tiger XP 60 treatment increased in soil sulphur levels between row closure (Fig. 1) and late bulking (Fig. 2) by an average of 18-lb, whereas the 20-and-100-lb treatments did not appreciably change in the lb of soil sulphur available (average of 0.5-lb increase). An additional observation of note with Tiger XP is that virtually all fertilizer rates had the standard error on soil sulphur measurements double between row closure and late bulking, which stands out compared to the standard error on the other fertilizers remaining consistent between the sampling dates. Both the observations with the increase in total soil sulphur and the variability from plot-to-plot could be explained by the slow-release nature of Tiger XP as it is being converted to plant-available sulphates that can be used or leached.

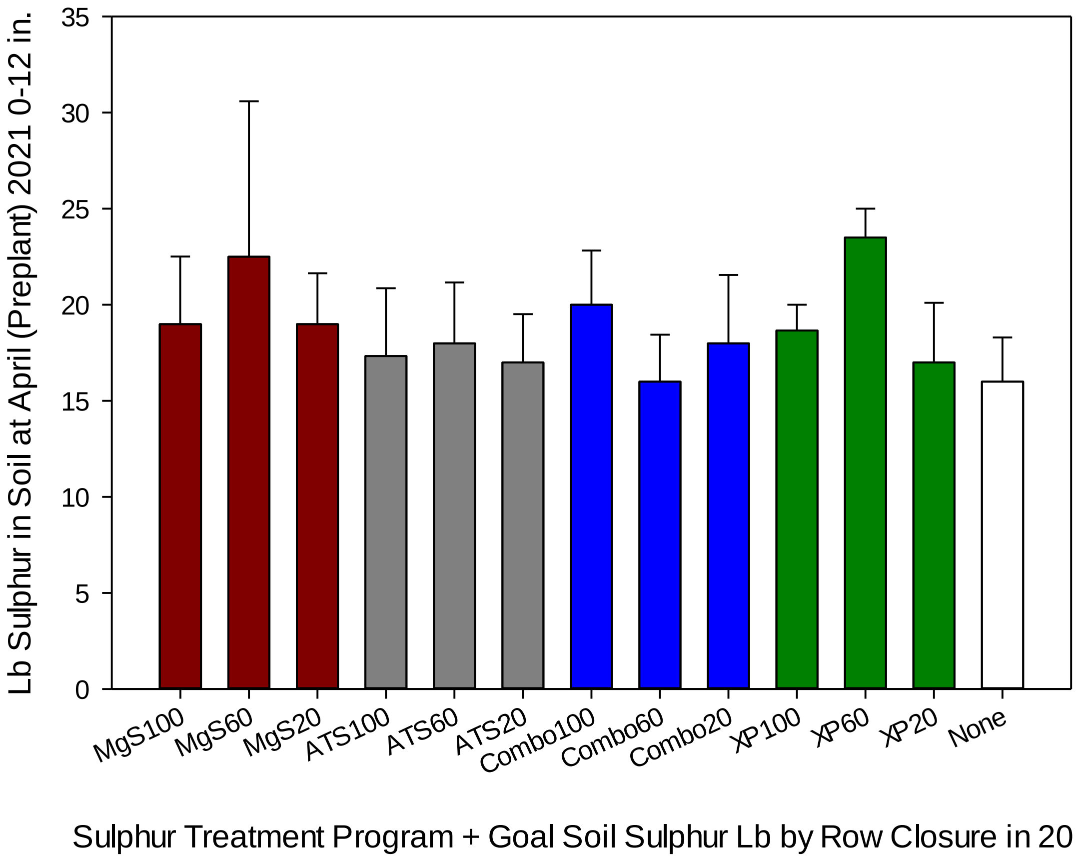


Figure 4 (above): The effect of sulphur treatment program (x-axis) **from 2019** on the availability of soil sulphur (y-axis) in **April 2021**. Bars indicate mean lb of sulphur and the standard error is above each bar. MgS signifies magnesium sulphate, while ATS stands for ammonium sulphate + ammonium thiosulfate fertigation. Combo represents Tiger-Sul's Combo product, as XP stands for Tiger-Sul's XP product. None represents the negative control, where no additional sulphur fertilizers/fertigation events were added. The number 20, 60, and 100 refer to the fertilizer targets for row closure **in 2019, <u>NOT</u> the targets for 2021**. All fertilizer rates for each treatment can be found in Table 1.

Because of the leaching potential associated with sulphur fertilizers and the sandy soil of the site, questions arose on the long-term potential of slow-release products to persist in plots years after the experiment was complete. The crop rotation on this site is typically potato-wheat-canola, which is typical of the Carberry growing area. Tillage typically precedes the potato year and occurs with plant and digging potatoes, which means the potential for soil movement between plots is low, but not impossible, in the years between 2019 research and 2021 sampling. In general, most fertilizers, regardless of rate, only had 15-to-25-lb of residual soil sulphur (Fig. 4). What is notable is that two years after Tiger XP was applied to soil, overall levels had moved from being below the other fertilizers to more-or-less equivalent. Another unusual observation was that the numerically greatest residual sulphur in soil observed with the magnesium sulfate and Tiger XP treatments at the 60-lb rate.

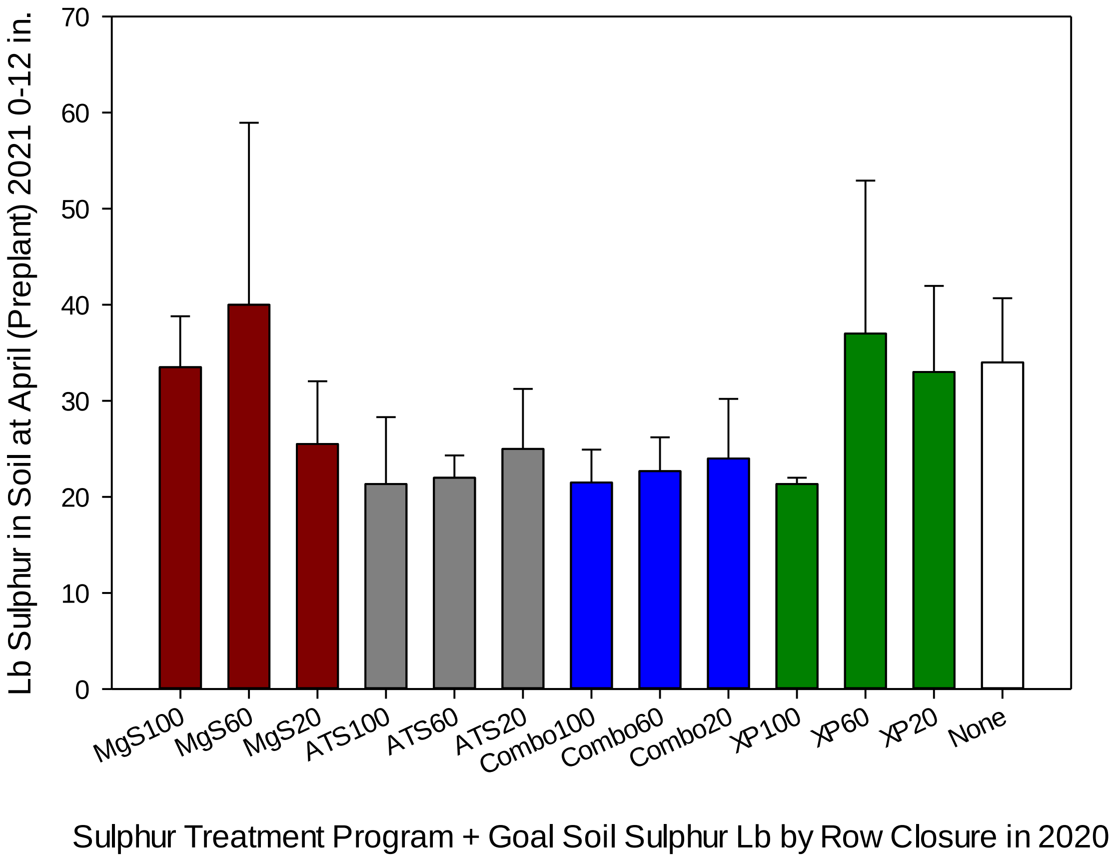


Figure 5 (above): The effect of sulphur treatment program (x-axis) **from 2020** on the availability of soil sulphur (y-axis) in **April 2021**. Bars indicate mean lb of sulphur and the standard error is above each bar. MgS signifies magnesium sulphate, while ATS stands for ammonium sulphate + ammonium thiosulfate fertigation. Combo represents Tiger-Sul's Combo product, as XP stands for Tiger-Sul's XP product. None represents the negative control, where no additional sulphur fertilizers/fertigation events were added. The number 20, 60, and 100 refer to the fertilizer targets for row closure **in 2020, <u>NOT</u> the targets for 2021** (although field variability study data suggests more soil sulphur throughout season is a positive yield attribute). All fertilizer rates for each treatment can be found in Table 1.

A similar interest extended in studying in the residual sulphur after only one year of experimentation. In the year after potato experimentation, wheat was grown on the site with a similarly limited potential for plot-to-plot soil transfer. The concern for plot-to-plot transfer should be noted as the negative control was found to have more soil sulphur than some of the other fertilizer treatments (Fig. 5). However, magnesium sulfate and Tiger XP plots appeared to have closer to 30-lb of soil sulphur, and again the 60-lb treatments had the most residual sulphur any fertilizer and rate evaluated (numerically). Ammonium sulfate and Tiger Combo treatments appeared to have an average of approximately 20-lb of soil sulphur one (Fig. 6) and two years (Fig. 5) after application, which displays a remarkable consistency across different sets of plots over time.

Yield Results for 2019-2021:

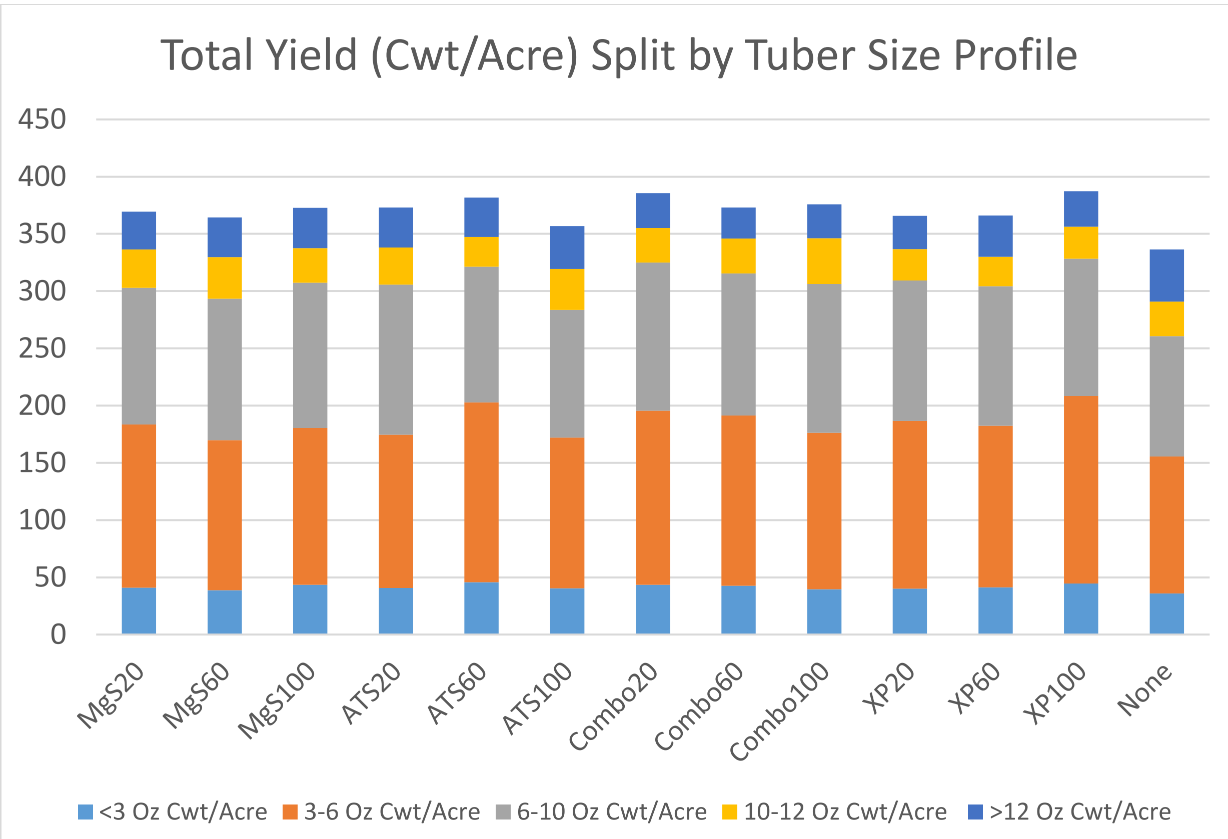


Fig. 6: The total yield (cwt/acre) of each fertilizer treatment and rate with each column separated by the tuber size profile (cwt/acre) average across 2019-2021. Bars indicate mean yield and standard errors were not shown to reduce the load of data in the figure. MgS signifies magnesium sulphate, while ATS stands for ammonium sulphate + ammonium thiosulfate fertigation. Combo represents Tiger-Sul's Combo product, as XP stands for Tiger-Sul's XP product. None represents the negative control, where no additional sulphur fertilizers/fertigation events were added. The number 20, 60, and 100 refer to the fertilizer targets for row closure in each year.

There was a significant impact of sulphur fertilizer and rate on total yield ($P = 0.0272$). None of the total yields from ammonium sulphate treatments were statistically distinguishable from each other or the negative control ($P \geq 0.05$, data not shown). None of the yields from plots subjected to Tiger Combo treatment, regardless of rate, were statistically distinguishable from one-another ($P \geq 0.05$), but plots from each treatment produced significantly more yield than the negative control (Table 4). Similarly, plots with magnesium sulphate treatment were not statistically distinguishable all treatments but trended ($P < 0.11$) towards significantly more yield than the negative control. Tiger XP treatments were also not statistically discernable from each other ($P \geq 0.05$), but the 100-lb rate generated significantly more yield than the negative control ($P = 0.0068$) and the 60-and-20-lb rates trended ($P < 0.11$) very closely towards significance compared to the negative control (Table 4).

Greater Fertilizer Treatment	Lesser Fertilizer Treatment	*P*-value
Tiger Combo 100-lb	Tiger Combo 60-lb	*P* = 0.9880*NS
Tiger Combo 100-lb	Tiger Combo 20-lb	*P* = 1.0000*NS
Tiger Combo 100-lb	None	*P* = 0.0055
Tiger Combo 60-lb	Tiger Combo 20-lb	*P* =0.9947*NS
Tiger Combo 60-lb	None	*P* = 0.0085
Tiger Combo 20-lb	None	*P* = 0.0124
Magnesium sulphate 100-lb	Magnesium sulphate 60-lb	*P* = 1.0000*NS
Magnesium sulphate 100-lb	Magnesium sulphate 20-lb	*P* = 1.0000*NS
Magnesium sulphate 100-lb	None	*P* = 0.1043*NS
Magnesium sulphate 60-lb	Magnesium sulphate 20-lb	*P* = 1.0000*NS
Magnesium sulphate 60-lb	None	*P* = 0.1070*NS
Magnesium sulphate 20-lb	None	*P* = 0.0752*NS
Tiger XP 100-lb	Tiger XP 60-lb	*P* = 0.9987*NS
Tiger XP 100-lb	Tiger XP 20-lb	*P* = 0.8993*NS
Tiger XP 100-lb	None	*P* = 0.0068
Tiger XP 60-lb	Tiger XP 20-lb	*P* = 1.0000*NS
Tiger XP 60-lb	None	*P* = 0.0537*NS
Tiger XP 20-lb	None	*P* = 0.0729*NS

Table 4 (above): Specific pairwise comparisons of sulphur treatments on total yield are listed with the numerically greatest treatment on the left and lesser column on the right. Combinations of fertilizers that are not present were either not significant ($P \leq 0.05$) or not of experimental interest. *P*-values above the 0.05 threshold on the Tukey test are denoted with *NS as nonsignificant in the *P*-value column and were included for completeness.

There was a nonsignificant impact of sulphur fertilizer and rate on the cwt/acre of tubers that were less than three ounces in weight ($P = 0.6231$, data not shown), three-to-six ounces in weight ($P = 0.1867$, data not shown), six-to-ten-ounce tubers ($P = 0.8021$, data not shown), and tubers over 12-ounces ($P = 0.7265$, data not shown).

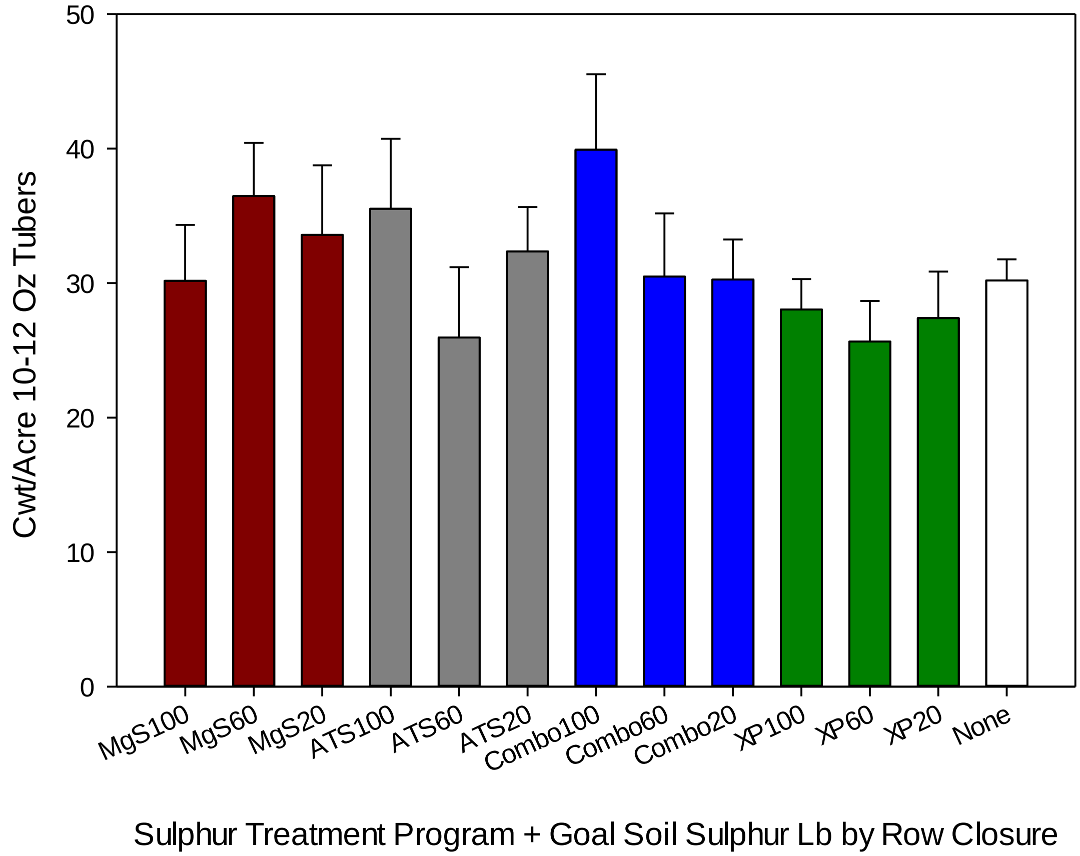


Fig. 7: The effect of sulphur treatment program (x-axis) on the 10-to-12-oz tuber yield (y-axis). Bars indicate mean lb of sulphur and the standard error is above each bar. MgS signifies magnesium sulphate, while ATS stands for ammonium sulphate + ammonium thiosulfate fertigation. Combo represents Tiger-Sul's Combo product, as XP stands for Tiger-Sul's XP product. None represents the negative control, where no additional sulphur fertilizers/fertigation events were added. The number 20, 60, and 100 refer to the fertilizer targets for row closure. All fertilizers and rates can be found in Table 1.

There was a significant impact on sulphur fertilizer treatment and rate on the cwt/acre of yield that was 10-to-12-oz in size ($P = 0.0422$). None of the total yields from ammonium sulphate, magnesium sulphate, or Tiger XP treatments were statistically distinguishable from each other or the negative control ($P \geq 0.05$, data not shown). However, the Tiger Combo 10-lb treatment produced more 10/12 oz tubers than the 20-lb treatment ($P = 0.0334$) and negative control ($P = 0.0105$, Table 5).

Greater Fertilizer Treatment	Lesser Fertilizer Treatment	*P*-value
Tiger Combo 100-lb	Tiger Combo 60-lb	*P* = 0.1807*NS
Tiger Combo 100-lb	Tiger Combo 20-lb	*P* = 0.0334
Tiger Combo 100-lb	None	*P* = 0.0105
Tiger Combo 60-lb	Tiger Combo 20-lb	*P* = 0.6192*NS
Tiger Combo 60-lb	None	*P* = 0.4610*NS
Tiger Combo 20-lb	None	*P* = 0.7617*NS

Table 5 (above): Specific pairwise comparisons of sulphur treatments on 10 to 12-oz yield are listed with the numerically greatest treatment on the left and lesser column on the right. Combinations of fertilizers that are not present were either not significant ($P \leq 0.05$) or not of experimental interest. *P*-values above the 0.05 threshold on the Tukey test are denoted with *NS as nonsignificant in the *P*-value column and were included for completeness.

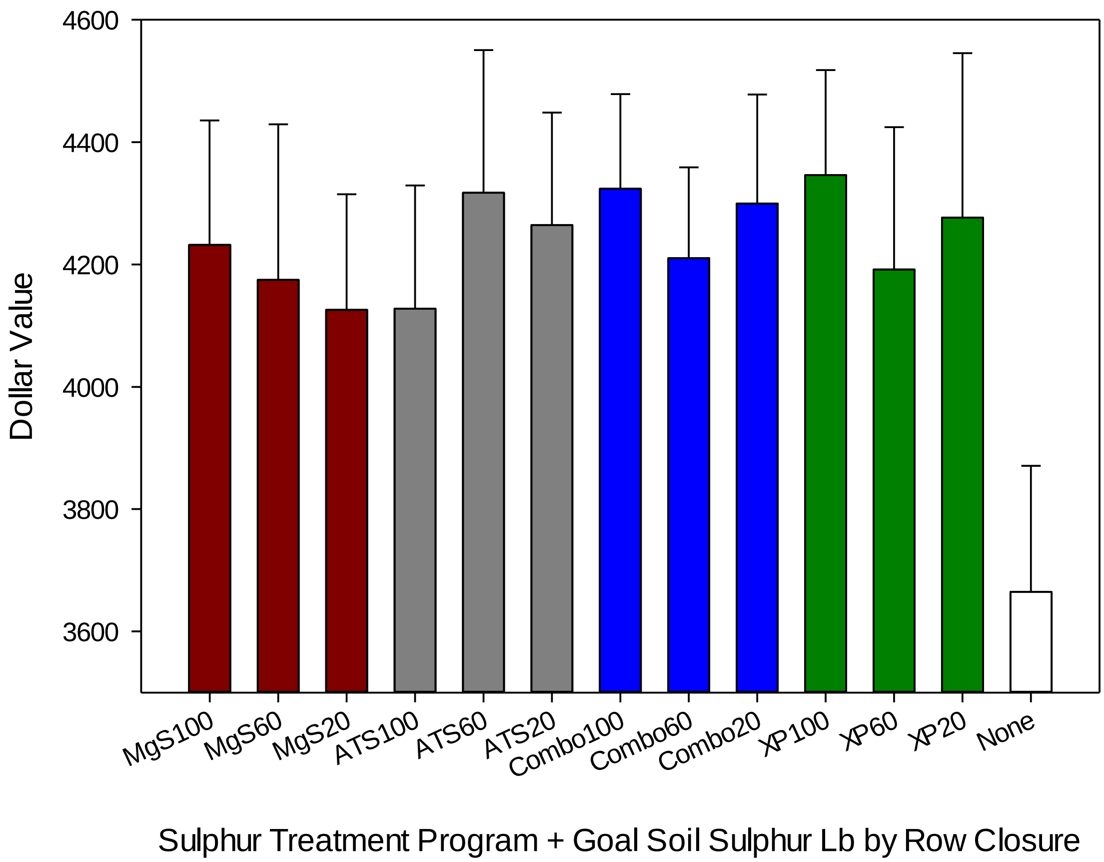


Fig. 8: The effect of sulphur treatment program (x-axis) on the estimated dollar value of plots scaled up to cwt/acre (y-axis). Bars indicate mean lb of sulphur and the standard error is above each bar. MgS signifies magnesium sulphate, while ATS stands for ammonium sulphate + ammonium thiosulfate fertigation. Combo represents Tiger-Sul’s Combo product, as XP stands for Tiger-Sul’s XP product. None represents the negative control, where no additional sulphur

fertilizers/fertigation events were added. The number 20, 60, and 100 refer to the fertilizer targets for row closure. All fertilizers and rates can be found in Table 1.

There was a significant (*P* = 0.0440) impact of sulphur fertilizer and rate on the estimated dollar value of plots (when scaled up to cwt/acre). None of the total yields from ammonium sulphate or magnesium sulphate treatments were statistically significant when compared to each other or the negative control ($P \geq 0.05$, data not shown). Both treatments of Tiger Combo and Tiger XP, regardless of rate, generally netted significantly more value than the negative control with the exception of Tiger XP 60-and-20-lb rates, which only trended ($P < 0.11$) towards significance (Table 6). There were no differences ($P \geq 0.05$) between the value of any rate of Tiger Combo or XP, but there was the beginning of a possible trend (*P* = 0.1386) with Tiger Combo 100-lb rate being more valuable than the Tiger Combo 20-lb rate (Table 6).

Greater Fertilizer Treatment	Lesser Fertilizer Treatment	*P*-value
Tiger Combo 100-lb	Tiger Combo 60-lb	*P* = 0.7631*NS
Tiger Combo 100-lb	Tiger Combo 20-lb	*P* = 0.1386*NS
Tiger Combo 100-lb	None	*P* = 0.0140
Tiger Combo 20-lb	Tiger Combo 60-lb	*P* = 0.2495*NS
Tiger Combo 60-lb	None	*P* = 0.0319
Tiger Combo 20-lb	None	*P* = 0.0009
Tiger XP 100-lb	Tiger XP 60-lb	*P* = 1.0000*NS
Tiger XP 100-lb	Tiger XP 20-lb	*P* = 1.0000*NS
Tiger XP 100-lb	None	*P* = 0.0026
Tiger XP 60-lb	Tiger XP 20-lb	*P* = 1.0000*NS
Tiger XP 60-lb	None	*P* = 0.0991*NS
Tiger XP 20-lb	None	*P* = 0.0519*NS

Table 6 (above): Specific pairwise comparisons of sulphur treatments on estimated dollar value are listed with the numerically greatest treatment on the left and lesser column on the right. Combinations of fertilizers that are not present were either not significant ($P \leq 0.05$) or not of experimental interest. *P*-values above the 0.05 threshold on the Tukey test are denoted with *NS as nonsignificant in the *P*-value column and were included for completeness.

Sulphur Fertilizer Cost Estimates

Fertilizer	Nitrogen value #1			Nitrogen value #2		
	$/lb N	$/lb S	$/lb Mg	$/lb N	$/lb S	$/lb Mg
Nitrogen						
Urea	$0.52	-	-	$0.63	-	-
UAN	$0.55	-	-	$0.55	-	-
Sulphur						
Ammonium Sulphate	$0.52	$0.37	-	$0.28	$0.28	-
Ammonium Thiosulphate	$0.55	$0.61	-		$0.61	-
Tiger Combo	$0.52	$0.42	-		$0.40	-
Tiger XP	-	$0.26	-		$0.26	-
Magnesium Sulphate	-	$0.37	$2.47	-	$0.37	$2.47

Table 7 (above): Sulphur fertilizer cost estimates for December 2020 are broken down by $/lb nitrogen (N), $/lb sulphur (S), and $/lb magnesium (Mg). No statistical analysis was completed on this table. Liquid urea-ammonium nitrate (UAN) and ammonium thiosulphate (ATS) are estimated amounts based on granular percent increase between 2020 and 2021. Urea increased 244% and ammonium sulphate increased 189%. Prices are estimates in Canadian dollars provided courtesy of the companies that provided the fertilizer products, and prices are subject to change in subsequent years after the study.

Fertilizer	Nitrogen value #1			Nitrogen value #2		
	$/lb N	$/lb S	$/lb Mg	$/lb N	$/lb S	$/lb Mg
Nitrogen						
Urea	$0.52	-	-	$0.63	-	-
UAN	$0.55	-	-	$0.55	-	-
Sulphur						
Ammonium Sulphate	$0.52	$0.37	-	$0.28	$0.28	-
Ammonium Thiosulphate	$0.55	$0.61	-		$0.61	-
Tiger Combo	$0.52	$0.42	-		$0.40	-
Tiger XP	-	$0.26	-		$0.26	-
Magnesium Sulphate	-	$0.37	$2.47	-	$0.37	$2.47

Table 8 (above): Sulphur fertilizer cost estimates for December 2021 are broken down by $/lb nitrogen (N), $/lb sulphur (S), and $/lb magnesium (Mg). Magnesium Sulphate is unavailable for purchase this year. No statistical analysis was completed on this table. Prices are estimates in

Pre-Plant Fertilizer	Fertigation Fertilizer	Actual Sulphur Pre-Plant Applied (lb/ac)	Actual Sulphur Fertigation (lb/ac)	Cost of Pre-Plant Application ($/lb S/ac)	Cost of Fertigation Application ($/lb S/ac)	Total cost of Sulphur Application ($/lb S/ac)
Negative Control (no additional sulphur)		0	0	$0.00	$0.00	$0.00
Tiger XP 0-0-0-85	None	20	0	$5.25	$0.00	$5.25
Tiger Combo 12-0-0-50	None	20	0	$7.97-8.47	$0.00	$7.97-8.47
Magnesium Sulphate 0-0-0-16-8Mg	None	20	0	$7.49	$0.00	$7.49
Ammonium Sulphate 21-0-0-24	Ammonium Thiosulphate 12-0-0-26	20	0.6	$5.68-7.49	$0.36	$6.04-7.85
Tiger XP 0-0-0-85	None	60	0	$15.76	$0.00	$15.76
Tiger Combo 12-0-0-50	None	60	0	$23.92-25.41	$0.00	$23.92-25.41
Magnesium Sulphate 0-0-0-16-8Mg	None	60	0	$22.46	$0.00	$22.46
Ammonium Sulphate 21-0-0-24	Ammonium Thiosulphate 12-0-0-26	60	0.6	$17.03-22.46	$0.36	$17.39-22.83
Tiger XP 0-0-0-85	None	100	0	$26.26	$0.00	$26.26
Tiger Combo 12-0-0-50	None	100	0	$39.87-42.35	$0.00	$39.87-42.35
Magnesium Sulphate 0-0-0-16-8Mg	None	100	0	$37.44	$0.00	$37.44
Ammonium Sulphate 21-0-0-24	Ammonium Thiosulphate 12-0-0-26	100	0.6	$28.38-37.44	$0.36	$28.74-37.80

Canadian dollars provided courtesy of the companies that provided the fertilizer products, and prices are subject to change in subsequent years after the study.

Table 9 (above): The breakdown per acre on sulphur fertilizer costs on a per lb sulphur/ac basis for December 2020. The range is created by using the two nitrogen values within table 7 affecting the sulphur base costs from table 7. Magnesium Sulphate has the same S cost as ammonium sulphate due to using ammonium sulphate as the base S price since there were no base Mg prices. No statistical analysis was completed on this table. Prices are estimates in Canadian dollars provided courtesy of the companies that provided the fertilizer products, and prices are subject to change in subsequent years after the study.

Pre-Plant Fertilizer	Fertigation Fertilizer	Actual Sulphur Pre-Plant Applied (lb/ac)	Actual Sulphur Rate Fertigation (lb/ac)	Cost of Pre-Plant Application ($/lb S/ac)	Cost of Fertigation Application ($/lb S/ac)	Total cost of Sulphur Application ($/lb S/ac)
Negative Control (no additional sulphur)		0	0	$0.00	$0.00	$0.00
Tiger XP 0-0-0-85	None	20	0	$7.95	$0.00	$7.95
Tiger Combo 12-0-0-50	None	20	0	$11.07-11.56	$0.00	$11.56
Magnesium Sulphate 0-0-0-16-8Mg	None	20	0	Unavailable		
Ammonium Sulphate 21-0-0-24	Ammonium Thiosulphate 12-0-0-26	20	0.6	$7.41-9.22	$0.42-0.55	$8.02-9.77
Tiger XP 0-0-0-85	None	60	0	$23.86	$0.00	$23.86
Tiger Combo 12-0-0-50	None	60	0	$33.20-34.69	$0.00	$33.20-34.69
Magnesium Sulphate 0-0-0-16-8Mg	None	60	0	Unavailable		
Ammonium Sulphate 21-0-0-24	Ammonium Thiosulphate 12-0-0-26	60	0.6	$22.22-27.65	$0.42-0.55	$22.83-28.20
Tiger XP 0-0-0-85	None	100	0	$39.77	$0.00	$39.77
Tiger Combo 12-0-0-50	None	100	0	$55.33-57.82	$0.00	$55.3357.82
Magnesium Sulphate 0-0-0-16-8Mg	None	100	0	Unavailable		
Ammonium Sulphate 21-0-0-24	Ammonium Thiosulphate 12-0-0-26	100	0.6	$37.03-46.09	$0.42-0.55	$37.64-46.64

Table 10 (above): The breakdown per acre on sulphur fertilizer costs on a per lb sulphur/ac basis for December 2021. The range is created by using the two nitrogen values within table 8 affecting the sulphur base costs from table 8. Magnesium Sulphate was unavailable for purchase this year. No statistical analysis was completed on this table. Prices are estimates in Canadian dollars provided courtesy of the companies that provided the fertilizer products, and prices are subject to change in subsequent years after the study.

Pre-Plant Fertilizer	Fertigation Fertilizer	Product Rate Pre-Plant Applied (lb/ac)	Product Rate Fertigation Applied (lb/ac)	Cost of Pre-Plant Application ($/lb product/ac)	Cost of Fertigation Application ($/lb product/ac)	Total cost of Sulphur Application ($/lb product/ac)
Negative Control (no additional sulphur)		0	0	$0.00	$0.00	$0.00
Tiger XP 0-0-0-85	None	24	0	$5.36	$0.00	$5.36
Tiger Combo 12-0-0-50	None	40	0	$10.98	$0.00	$10.98
Magnesium Sulphate 0-0-0-16-8Mg	None	125	0	$32.21	$0.00	$32.21
Ammonium Sulphate 21-0-0-24	Ammonium Thiosulphate 12-0-0-26	68	3	$13.58	$0.61	$14.19
Tiger XP 0-0-0-85	None	71	0	$15.85	$0.00	$15.85
Tiger Combo 12-0-0-50	None	120	0	$32.94	$0.00	$32.94
Magnesium Sulphate 0-0-0-16-8Mg	None	375	0	$96.64	$0.00	$96.64
Ammonium Sulphate 21-0-0-24	Ammonium Thiosulphate 12-0-0-26	188	3	$37.53	$0.61	$38.14
Tiger XP 0-0-0-85	None	118	0	$26.34	$0.00	$26.34
Tiger Combo 12-0-0-50	None	200	0	$54.90	$0.00	$54.90
Magnesium Sulphate 0-0-0-16-8Mg	None	625	0	$161.07	$0.00	$161.07
Ammonium Sulphate 21-0-0-24	Ammonium Thiosulphate 12-0-0-26	313	3	$62.49	$0.61	$63.10

Table 11 (above): The breakdown per acre on sulphur fertilizer costs on a per lb product/ac basis for December 2020. The range is created by using the two nitrogen values within table 7 affecting the sulphur base costs from table 7. No statistical analysis was completed on this table. Prices are estimates in Canadian dollars provided courtesy of the companies that provided the fertilizer products, and prices are subject to change in subsequent years after the study.

Pre-Plant Fertilizer	Fertigation Fertilizer	Product Rate Pre-Plant Applied (lb/ac)	Product Rate Fertigation Applied (lb/ac)	Cost of Pre-Plant Application ($/lb product/ac)	Cost of Fertigation Application ($/lb product/ac)	Total cost of Sulphur Application ($/lb product/ac)
Negative Control (no additional sulphur)		0	0	$0.00	$0.00	$0.00
Tiger XP 0-0-0-85	None	24	0	$8.11	$0.00	$8.11
Tiger Combo 12-0-0-50	None	40	0	$17.70	$0.00	$17.70
Magnesium Sulphate 0-0-0-16-8Mg	None	125	0	Unavailable		
Ammonium Sulphate 21-0-0-24	Ammonium Thiosulphate 12-0-0-26	68	3	$25.76	$1.16	$26.92
Tiger XP 0-0-0-85	None	71	0	$24.00	$0.00	$24.00
Tiger Combo 12-0-0-50	None	120	0	$53.09	$0.00	$53.09
Magnesium Sulphate 0-0-0-16-8Mg	None	375	0	Unavailable		
Ammonium Sulphate 21-0-0-24	Ammonium Thiosulphate 12-0-0-26	188	3	$71.23	$1.16	$72.38
Tiger XP 0-0-0-85	None	118	0	$39.89	$0.00	$39.89
Tiger Combo 12-0-0-50	None	200	0	$88.48	$0.00	$88.48
Magnesium Sulphate 0-0-0-16-8Mg	None	625	0	Unavailable		
Ammonium Sulphate 21-0-0-24	Ammonium Thiosulphate 12-0-0-26	313	3	$118.58	$1.16	$119.74

Table 12 (above): The breakdown per acre on sulphur fertilizer costs on a per lb product/ac basis for December 2021. The range is created by using the two nitrogen values within table 8 affecting the sulphur base costs from table 8. Magnesium Sulphate is unavailable for purchase this year. No statistical analysis was completed on this table. Prices are estimates in Canadian dollars provided courtesy of the companies that provided the fertilizer products, and prices are subject to change in subsequent years after the study.

Project findings:

The present study was based upon statistical associations created from the larger field variability study that encompassed observations from 23 grower fields over five years. The goal of this study was to identify the exact range of lb of soil sulphur needed by row closure and possible products and rates needed to accomplish the task to improve yield and quality of processing potatoes.

One resource of regional significance (as published by the University of Manitoba in Agvise's soil sulphur guidelines at https://www.agvise.com/wp-content/uploads/2017/03/Sulphur-Magnesium-and-Chloride-guidelines.pdf) has pointed to a preplant target 40-lb of soil sulphur, and the variability study suggested that recommendation should be extended to row closure to improve the size and value of tuber yield. An unexpected result was observed where the 20-lb rates of magnesium sulphate and ammonium sulphate actually achieved a result over the 40-lb threshold by row closure, whereas Tiger XP and Combo 20 did not (Fig. 1). An astute observer will note that the negative control plots still tested as having some soil sulphur despite the absence of treatment (Figs. 1 and 3). It is possible that residual sulphur pushed some of the 20-lb rates over the 40-lb target. Based on the evidence in this study, negative control plots that tested with an average of 20-lb by row closure did not improve the total yield (Fig. 6, Table 4), 10-to-12-oz yield (Fig. 7, Table 5), and estimated dollar value (Fig. 8, Table 6) - suggesting that 20-lb in the soil by row closure is insufficient soil sulphur and supporting the original target of at least 40-lb. In addition, assuming approximately 20-lb residual on average per plot prior to fertilization, and additional 20-lb of sulphur (totaling 40-lb) was often statistically indistinguishable from fertilizer treatments targeting 60-lb by row closure – which provides additional evidence that 40-lb of sulphur by row closure is a reliable target. Lastly, the only reliable tuber size increase within a fertilizer treatment occurred in 10-to-12-oz yield with Tiger Combo 100 when compared to Tiger Combo 20 (P = 0.0334, Table 5). This did not increase the total yield (P = 1.000, Table 4), but did net a better bonus on the estimated dollar value that large enough to trend towards significance (P = 0.1386, estimated average $60/cwt, Table 6). These three pieces of evidence support keeping the row closure soil sulphur target at 40-lb.

The observation that Tiger Combo at the 100-lb rate results in more 10-to-12-oz tubers and trends towards increased value provides more solid corroboration of the variability study results and that some sulphur products may require increased rates to manifest yield improvements. In the case of two of the other products evaluated (Tiger XP and magnesium sulfate), any rate provided yield and quality and value improvements over the negative control and low rates didn't present any advantage over higher rates (Figs 6, 7, 8; Tables 4, 5, 6). This result could indicate that in many cases, the lowest rates of sulphur are sufficient to reap the most benefit. Experimentation with each specific product would probably be required to discern which case prevails with which fertilizer product, as there are or will be sulphur products that could be used as fertilizer in potato production systems that were not part of the present study.

At row closure, each 100-lb rate for every fertilizer treatment was well above the 40-lb overall goal from the variability study. Each 60-lb rate for every fertilizer treatment was at or above the 40-lb goal, albeit with a much smaller margin for error in specific cases such as Tiger XP 60-lb and the ammonium sulphate 60-lb. In general, Tiger XP's slow-release nature and elemental sulphur ingredient are probably causes for why release was lower than expected targets by row closure (Fig. 1) and why the treatment appears to catch up with other fertilizer regimens in later years (Figs. 4 and 5).

In general, across three years of small plot experiments, increasing amount of fertilizer (such as targeting 100-lb soil sulfur by row closure compared to 20-lb) resulted in increasingly variable responses in levels of soil sulphur (Fig. 1). Part of this observation can be explained by increasing fertilizer levels, but there most likely is an interaction with leaching potential. The site that was selected was lighter, sandier soil with a propensity for leaching. When combined with large precipitation events in May or June, it is possible that the higher rates of sulphur fertilizers had more leaching potential.

A major part of grower acceptance of new products and practices is an understanding of the costs associated with the changes. A challenge in setting cost estimates between 2020-2021 is the approximately 180-250% change in price over a 12-month period (depending on product, Tables 7-8). In 2020 (Table 7), the estimated costs per lb of sulphur were $0.26 for Tiger XP, $0.37 for ammonium sulphate, $0.37 for magnesium sulphate, $0.42 for Tiger Combo, and $0.61 for ammonium thiosulphate. The estimate costs for sulphur per 20-lb rate of actual sulphur applied were $5.25 for Tiger XP, $7.97-8.47 for Tiger Combo, $7.49 for magnesium sulphate, and $6.04-7.85 for the mixture of ammonium sulphate and ammonium thiosulphate (table 9). The estimate costs for fertilizer product per 20-lb rate were $5.36 for Tiger XP, $10.98 for Tiger Combo, $32.21 for magnesium sulphate, and $14.19 for the mixture of ammonium sulphate and ammonium thiosulphate (Table 11). There is a large assumption that the 20-lb rate provides no statistical advantage in total yield, value, or tuber size profile only when there are an average 20-lb sulphur in the soil at the start of season, otherwise a higher rate of sulphur is needed to achieve the 40-lb minimum by row closure. The assumption that comparing prices on the basis of the actual nutrient the mixture is the normal practice in Manitoba when comparing fertilizer products (https://www.gov.mb.ca/agriculture/crops/soil-fertility/soil-fertility-guide/calculating-fertilizer-rates.html). Employing this practice, the mixture of ammonium sulphate and ammonium thiosulphate and magnesium sulphate product are the most cost effective. Due to the varied nitrogen and magnesium content in these products, which is more expensive, it sways the cost comparison in their favour. Due to the excess costs of magnesium as a micronutrient it increases the total cost of the product. This is also seen with the increased amount of nitrogen in ammonium sulphate compared to the other products. Given this assumption and the cost estimates, Tiger XP and Combo provide the most cost-effective means of achieving the row closure targets and net increased yields and tuber size profiles in soils that are deficient in soil sulphur at the start of season when looking at the cost of total product per acre being applied. The combined use of ammonium sulphate and thiosulphate has been employed in Manitoba processing potato industry, and the present study supports that this treatment effectively covers row closure soil sulphur products, but at a cost higher than the Tiger Combo and XP treatments. The use of magnesium sulphate is not widely employed in Manitoba and was the most expensive treatment. These trends carried over across the higher fertilizer rates for the same products.

The final piece of the puzzle to change sulphur recommendations and practices in potato production systems is to take the results of this plot scale study up to the field scale and verify the practice works on the large scale, is practical, and generates tangible profits for growers. If successful, these experiments should pave the way to changes in the blend of fertilizer that growers broadcast preplant in Manitoba in order to manage sulphur deficiency in the most cost-effective manner possible. If successful, this method can also provide a successful blueprint for nutrient research for consultants, agronomists, and researchers to conduct applied work on farm and in controlled plots to establish best, profitable practices.

Manitoba Crop Variety Evaluation Trials (MCVET)

MCVET Winter Wheat Variety Evaluation

Project duration: September 2020 – August 2021

Objectives: To evaluate the adaptation and performance of new and existing winter wheat varieties in regards to yield & quality potential.

Collaborators: Chami Amarasinghe (Innovation Specialist Crop – Manitoba Agriculture)
Anne Kirk (Crop Specialist Grains – Manitoba Agriculture)
Seed Manitoba

MCVET Fall Rye Variety Evaluation

Project duration: September 2020 – August 2021

Objectives: To evaluate the adaptation and performance of new and existing fall rye varieties in regards to yield & quality potential.

Collaborators: Chami Amarasinghe (Innovation Specialist Crop – Manitoba Agriculture)
Anne Kirk (Crop Specialist Grains – Manitoba Agriculture)
Seed Manitoba

MCVET Flax Variety Evaluation

Project duration: May 2021 – September 2021

Objectives: To evaluate the adaptation and performance of new and existing flax varieties in regards to yield & quality potential.

Collaborators: Chami Amarasinghe (Innovation Specialist Crop – Manitoba Agriculture)
Dane Froese (Crop Specialist Oilseeds – Manitoba Agriculture)
Seed Manitoba

MCVET Field Peas Variety Evaluation

Project duration: May 2021 – August 2021

Objectives: To evaluate the adaptation and performance of new and existing field peas varieties in regards to yield & quality potential.

Collaborators: Chami Amarasinghe (Innovation Specialist Crop – Manitoba Agriculture)
Dennis Lange (Crop Specialist Pulses – Manitoba Agriculture)
Seed Manitoba

MCVET Annual Forages Variety Evaluation

Project duration: May 2021 – August 2021

Objectives: To evaluate the adaptation and performance of new and existing field peas varieties in regards to yield & quality potential.

Collaborators: Chami Amarasinghe (Innovation Specialist Crop – Manitoba Agriculture)
Tim Clarke (Ag. Adaptation Specialist Livestock – Manitoba Agriculture)
Shawn Cabak (Ag. Adaptation Specialist Livestock – Manitoba Agriculture)
Seed Manitoba

Results:

CMCDC is one of the many contractors that are part of the Manitoba Crop Variety Evaluation Trials (MCVET) program, which facilitates variety evaluations of many different crop types in this province. The purpose of the MCVET variety evaluation trials are to grow both familiar (check varieties) and new varieties side by side in a replicated manner in order to compare and contrast various variety characteristics such as yield, maturity, protein content, disease tolerance, and many others aspects.

During the 2021 planting year, CMCDC conducted MCVET trials on winter wheat, fall rye, flax, field peas, and annual forages in Carberry. (See Table 1). From each MCVET site across the province, yearly data is collected, combined, and summarized in the 'Seed Manitoba' guide. Hard copies are available at most Manitoba Agriculture and Ag Industry offices. Seed Manitoba guide and the websites www.seedinteractive.ca and www.seedmb.ca, provide valuable variety performance information for Manitoba farmers.

Table 1. MCVET Trials at CMCDC

Crop type	# of plots	Site
Winter Wheat	24	Carberry
Fall Rye	24	Carberry
Flax	27	Carberry
Field Peas	63	Carberry
Annual Forages	42	
Total plots	**180**	**Carberry**

For MCVET trial results conducted by CMCDC, please see Seed Manitoba Guide or visit websites www.seedinteractive.ca or www.seedmb.ca.

Comparison of Traditional and Balanced Fertility Program and Potential of New Winter Wheat Varieties

Project duration: September 2020 – August 2021

Objective: To compare historical/standard "Producer Practice" (100% spring) fertility program to a balanced, "High Yield Practice" as determined by Western Ag Soil analysis and recommendations.

Collaborators: Ducks Unlimited Canada
Western Ag & Professional Agronomy

Background:

Following decades of extensive work in winter wheat production in North America, many researchers and producers have begun to implement best management practices to obtain higher grain yield and improve profitability in the crop. Management practices presently being implemented to improve winter wheat production include; increasing seeding rate, application of starter fertilizer by banding during seeding, variety selection, pest control (Anderson, 2008) and split application, during planting in fall and at tillering or stem elongation in spring (Schulz et al., 2015).

Fertility management, in particular nitrogen and phosphorus, remains an integral part of the overall management package aimed at achieving higher yields in winter wheat (Halvorson et al. 1987). Recommended fertilizer management, particularly nitrogen management, differs widely in winter wheat production, but the crop's nitrogen demand is correlated to yield potential and availability of moisture in dryland production systems (Beres et al., 2018). Compared to spring wheat, winter wheat presents more challenges in development as a result of its higher nitrogen demand during the long vegetative phase, hence the reason why it requires 25 to 50% more N than spring wheat in the Prairies (Fowler et al., 1989).

The ideal fertility management package would help counteract the escalating cost of winter wheat production per unit area, which is the main goal that producers aim to achieve. There is still a knowledge gap on the rates and timing of nitrogen fertilizer application, particularly in Western Canada, that result in improved yield without compromising grain quality and economic returns. Morris et al. (2018) suggested the implementation of adaptive use of nitrogen to help augment and improve nitrogen application rate decision making by farmers. Therefore, there is a great need to continue with research on the best management practices that can be availed to producers to improve economic returns in winter wheat production.

Nitrogen is most often the focus of crop fertility in field studies. However, having a balanced approach and considering other essential nutrients, such as, phosphorus, potassium and sulphur and micronutrients available in the soil, offers great yield potential when nitrogen needs of the crop are met. Perhaps more efficient returns on investment potential can be achieved as fertility management is optimized.

Materials & Methods:

This study was established at four locations, Melita, Arborg, Carberry and Roblin, Manitoba in the fall of 2020 (Table II). In Melita, wheat was seeded into canola stubble at a depth of 0.5" on September 14, 2020 using a 6-row dual knife seed hawk air seeder. The soil was characterized as Ryerson5Loam/Regent5Loam. No pre-emergent herbicide was necessary in 2020 at the Melita site. Post emergence weed control was done in spring to control flowering volunteer canola by application of Mextrol 450 at 0.5 L ac-1. No fungicide application was needed at the Melita site in 2021, but Prosaro or Folicur fungicides were applied at the Arborg, Carberry and Roblin sites.

The treatment structure consisted of a factorial arrangement of two fertilizer management practices and four to six winter wheat varieties in a randomized complete block design. The winter wheat varieties utilized at all sites were; Gateway, Goldrush, Elevate and Wildfire. At the Carberry site, AAC Network and W583 varieties were also incorporated into the trial. Fertilizer treatments included:

<u>Producer practice:</u>

100 lbs of nitrogen (urea plus agrotain) per acre applied in spring and 30 lbs phosphorus banded at seeding in fall and,

<u>Balanced fertility practice:</u>

Nitrogen was applied as per Western Ag recommendations based on soil test results, and application was split with 50% N banded at seeding and the other 50% N (urea plus Agrotain) broadcasted in spring. In addition, site specific P, K, S, and micronutrient recommendations were applied.

A summary of fall soil tests conducted at Melita, Roblin, Carberry and Arborg, and fertilizer treatments for the 2020/2021 trial are presented in Table I. Data were analyzed using Minitab 18.1 software, and means were separated using Fisher's mean separation method at 95% confidence.

Table 1. Fall Soil Test Results for all Sites

Fall Soil Test Results (lbs ac^{-1})				
Nutrient	**Location**			
	Melita	**Roblin**	**Carberry**	**Arborg***
N	11	53	31	93
P	10	71	27	44
K	306	410	48	660
S	36	22	15	582
Zn	1.4	1.1	0.04	0

* Farmers Edge sampling

Producer Practice Application (all N applied in Spring)				
N	100	100	100	100
P	30	30	30	30
K	0	0	0	0

Balanced Practice application recommendations (Western Ag Processional Agronomy Laboratory) 50% N applied in fall				
N	130	105	130	161
P	38	20	30	40
K	50	0	100	50
S	0	0	5	0
Zn	0	0	0	0

Table 2. Site Description and Agronomics for each Trial Site in the 2020/2021 Season

Location	Melita	Carberry	Roblin	Arborg
Cooperator	WADO	CMCDC	PCDF	PESAI
Legal	NW23-3-27W1	South ½ of 8-11-14 W1	NE 20-25-28 W1	NW 16-22-2 E1
Rotation (2 yr.)	Spring wheat – LL Canola	Soybean (2019), Canola (2020)	Barley silage (2019), Oat silage (2020)	Canola – Cereals
Soil Series	Ryerson Loam	Ramada Clay Loam	Erickson clay loam	Fyala heavy clay
Soil Test Done? (Y/N)	Yes	Yes	Yes	Yes
Field Prep	No till	No till	Vertical tilled	No till
Stubble	LL Canola	Canola	Oat	Canola
Burn off (Date/Rate per acre/Products)	None	09-Sep-20: Roundup 0.67 L + Heat 29 g + Water 40 L sprayed before seeding	None	None
Soil Moisture at Seeding	Very poor	Fair	Dry	Optimal
Seed Date	14-Sep-20	16-Sep-20	18-Sep-20	21-Sep-20
Seed depth (Inches)	0.5	1.0	0.75	1.0
Seeder (drill/planter?)	Knife drill	Knife drill	Disc drill	Disc drill
Errors at seeding	None	None	None	None
Topdressing	09-Apr-21	23-Apr-21	16-Apr-21	29-Apr-21
Herbicides (Date, Rate/ ac, Name)	08-Jul: 0.5 L Mextrol 450 on flowering canola	09-Sep: 0.7 L Glyphosate, 30 g Heat 15-Jun: 0.12 Fitness, 0.4 L Buctril M, 0.5 L Axial	14-Jun: 0.81 L Curtail M, 0.71 mL Puma	None
Fungicides	none	08-Jul: 0.325 L Prosaro	15-Jun: 0.202 L Folicur	22-Jun: 0.2 L Folicur
Insecticides	17-Jul: Coragen, aerial, hoppers	None	None	28-Jun: 0.325 L Prosaro
Harvest Date	16-Aug-21	12-Aug-21	25-August-21	3-Aug-21
Total Precipitation (mm) (Seeding > Harvest)	222			

Results:

Winter wheat variety was not found to have a significant effect on wheat yield at any of the individual trial sites (Table a). However, over all four site years, a significant ($P = 0.003$) grain yield trend was observed. Across all four site years, Wildfire winter wheat produced the greatest average yield, though this yield was not significantly different from that of Elevate winter wheat. AAC Network and W583 varieties were not included in multi-site analysis as these varieties were only included in the Carberry trial.

Winter wheat variety significantly influenced grain protein content at the Melita, Roblin and Arborg sites in the 2020/2021 growing season. At the Melita site, protein content of Gateway grain (15.8%) was significantly ($P < 0.001$) higher than that of Elevate, Goldrush and Wildfire varieties. In Roblin, Gateway winter wheat also resulted in the greatest protein content (16.7%), though this was not significantly different from that of Goldrush winter wheat (16.4%). At the Arborg site, no significant difference in protein content was observed among Wildfire (14.4%), Gateway (14.3%) or Goldrush (13.9%) varieties. Elevate winter wheat resulted in the lowest average grain protein content at the Melita, Roblin, and Arborg sites, indicating a potential protein content disadvantage of this variety in Manitoba compared to the other varieties used in this trail. Protein content data was not collected for Carberry grain in 2021.

Protein content of Elevate winter wheat was also demonstrated to be significantly ($P < 0.001$) lower than all other varieties when Melita, Roblin, and Arborg site data was combined (14.0%), while protein content of Gateway winter wheat (15.6%) was demonstrated to be greater than all other varieties grown at these sites. Test weight significantly varied across varieties at the Melita, Roblin, and Arborg sites, as well as across varieties over all four site years. At these sites, the greatest average test weight was observed from Gateway winter wheat.

Fertilizer management practice did not have a significant influence on grain yield at the Melita, Roblin, or Carberry sites. In Arborg, winter wheat grown with a balanced fertility practice (50% N in fall) had a significantly ($P = 0.034$) greater average yield than winter wheat grown with the current producer fertility practice (100% N in spring). No significant effect of fertility practice on winter wheat grain protein content was observed at the Melita or Arborg sites, but winter wheat grown using current producer fertility practice at the Roblin site had greater average protein content (16.1%) than winter wheat grown using the balanced fertility practice at this site (15.7%). However, when data from all sites was combined and analyzed, no significant influence of fertility management practice on winter wheat grain yield or protein content was observed. Fertility management practice had a significant influence on grain test weight at the Melita site, the Carberry site, and over all site years, with test weight of grain grown under the producer fertility practice significantly greater than that of grain grown under a balanced fertility practice.

Significant variety and fertility practice interactions (variety x fertility) were observed when yield data from all site years was combined, but no significant interactions were observed at individual sites. Over all four site years, Wildfire winter wheat grown under producer fertility practices had the greatest average yield (4176 kg ha^{-1}), though this yield was not significantly different from that of Goldrush winter wheat under balanced fertility practices (3895 kg ha^{-1}). No significant yield differences were observed between fertility practices for Elevate or Gateway winter wheat varieties over four site years.

A balanced fertility practice resulted in a greater average yield than the current producer fertility practice for Goldrush winter wheat, though the opposite was true for Wildfire winter wheat. This result may indicate that yields of some winter wheat varieties respond better to a balanced fertility practice than others. At the Melita site, Gateway winter wheat grown under balanced fertility practice resulted in the greatest average test weight (73.5 kg hL^{-1}), though this test weight was not significantly different from that of Elevate, Gateway, or Goldrush winter wheat grown under producer fertility practices. Protein content of winter wheat was not significantly different among variety and fertility management practice combinations (variety x fertility) at individual sites or when Melita, Roblin, and Arborg protein data was combined.

Table A. Analysis of variance for average winter wheat yield (kg ha^{-1}), protein content (%), and test weight at Melita, Roblin, Arborg, and Carberry Manitoba sites for the 2020/2021 growing season.

			Location														
			Melita			**Roblin**			**Arborg**			**Carberry**		**All Sites**		
Treatment			**Yield (kg ha^{-1})**	**Protein (%)**	**Test Wt. (kg hL^{-1})**	**Yield (kg ha^{-1})**	**Protein (%)**	**Test Wt. (kg hL^{-1})**	**Yield (kg ha^{-1})**	**Protein (%)**	**Test Wt. (kg hL^{-1})**	**Yield (kg ha^{-1})**	**Test Wt. (kg hL^{-1})**	**Yield (kg ha^{-1})**	**Protein* (%)**	**Test Wt. (kg hL^{-1})**
Variety	**Elevate**	**1**	2134	14.1**d**	72.1**ab**	3862	14.8**c**	60.4**c**	3216	13.0**b**	79.0**b**	5582	69.1	3699**ab**	14.0**c**	70.1**b**
	Gateway	**2**	1935	15.8**a**	73.0**a**	3377	16.7**a**	63.3**a**	2922	14.3**a**	81.5**a**	5582	70.2	3454**c**	15.6**a**	72.0**a**
	Goldrush	**3**	2299	15.4**b**	71.0**c**	3428	16.4**a**	62.2**b**	3103	13.9**a**	78.2**b**	5750	69.6	3645**bc**	15.2**b**	70.2**b**
	Wildfire	**4**	2456	14.9**c**	71.3**bc**	3661	15.7**b**	59.2**d**	2983	14.4**a**	76.9**c**	6597	70.0	3925**a**	15.0**b**	69.3**c**
	AAC Network	**5**	-	-	-	-	-	-	-	-	-	6545	69.6	-	-	-
	W583	**6**	-	-	-	-	-	-	-	-	-	5925	70.3	-	-	-
Fertility	**Balanced**	**1**	**2077**	**15.1**	71.4**b**	**3478**	15.7**b**	61.4	3167**a**	14.1	78.8	5829	69.3**b**	3628	15.0	70.2**b**
	100% Spring	**2**	**2335**	**15.0**	72.3**a**	**3686**	16.1**a**	61.1	2945**b**	13.7	79.0	6164	70.3**a**	3733	14.9	70.7**a**
Var x Fert		**1,1**	1855	14.3	71.2**cd**	3706	14.5	60.3	3365	13.4	79.2	5334	68.6	3565**bcd**	14.1	69.8
		1,2	2413	13.9	72.9**ab**	4018	15.0	60.4	3068	12.6	78.8	5831	69.6	3832**bc**	13.9	70.4
		2,1	1778	15.9	73.5**a**	3106	16.9	62.9	3025	14.6	81.5	5609	70.0	3379**d**	15.8	72.0
		2,2	2091	15.7	72.6**abc**	3648	16.5	63.6	2820	14.1	81.5	5555	70.4	3529**cd**	15.5	72.0
		3,1	2370	15.3	69.8**d**	3575	15.9	63.1	3340	14.0	77.8	6296	69.3	3895**ab**	15.1	70.0
		3,2	2227	15.4	72.2**abc**	3281	16.9	61.3	2866	13.7	78.7	5205	69.8	3395**d**	15.3	70.5
		4,1	2302	14.9	71.1**cd**	3526	15.4	59.4	2939	14.4	76.7	5923	69.0	3673**bcd**	14.9	69.0
		4,2	2610	14.9	71.5**cd**	3797	15.9	58.9	3027	14.4	77.2	7271	70.9	4176**a**	15.1	69.7
		5,1	-	-	-	-	-	-	-	-	-	5914	68.8	-	-	-
		5,2	-	-	-	-	-	-	-	-	-	7176	70.4	-	-	-
		6,1	-	-	-	-	-	-	-	-	-	5901	70.0	-	-	-
		6,2	-	-	-	-	-	-	-	-	-	5948	70.633	-	-	-
P values	**Variety**		0.082	**<0.001**	**0.006**	0.221	**<0.001**	**<0.001**	0.176	**0.011**	**<0.001**	0.066	0.113	**0.003**	**<0.001**	**<0.001**
	Fertilizer		0.075	0.158	0.021	0.252	**0.036**	0.265	**0.034**	0.197	0.493	0.18	**0.001**	0.223	0.824	**0.008**
	Var x Fert		0.353	0.297	**0.035**	0.405	0.115	0.072	0.248	0.721	0.533	0.072	0.482	**0.001**	0.181	0.605
	CV(%)		15	1	1	12	3	1	8	5	1	12	1	11	3	1

Values followed by the same letter are not significantly different by Fisher's mean separation method at 95% confidence.
*Does not include Carberry site

Overall, results from the 2020/2021 growing season indicate that yields of some winter wheat varieties respond better to a balanced fertility program than others. Additionally, yield results from the Arborg site demonstrate a potential yield benefit of a balanced fertility program, as wheat grown under a balanced fertility program at this site yielded significantly higher than wheat grown under a current producer fertility program. Winter wheat protein content was demonstrated to likely be more influenced by winter wheat variety than fertility management practices in the 2020/2021 growing season, as fertility management practice only had significant impact on winter wheat protein content at the Roblin site, while variety significantly influenced protein content at all sites.

Test weight of harvest grain was significantly greater in wheat grown under current producer fertility practices than in wheat grown under a balanced fertility practice at two sites indicating a potential test weight benefit of applying all nitrogen in spring. Continued field study is necessary to further evaluate the performance of new winter wheat varieties under both fertility management strategies, and to effectively develop fertilizer management recommendations that winter wheat producers can implement in their production systems.

Determining Optimum Target Plant Stands for Spring Cereal Crops in Manitoba

Project duration: May 2021 – August 2021

Objectives: Determine if target plant stand recommendations should be adjusted for spring wheat, oat, and barley.
Determine if optimum plant stands differ for individual varieties.
Assist producers with determining target plant stand and seeding rate for newer spring cereal varieties

Collaborators: Anne Kirk (Crop Specialist Grains – Manitoba Agriculture)
Manitoba Crop Alliance.

Background:

Yield of spring cereals is impacted by many agronomic practices, but starts with variety selection, seeding date, target plant stand, and the seeding rate needed to achieve those plant stands. Optimum plant population is determined by factors including crop management practices and growing conditions. Manitoba Agriculture currently recommends target plant stands of 23-28 plants/ft^2 for spring wheat, 18-23 plants/ft^2 for oat, and 22-25 plants/ft^2 for barley. With the introduction of semi-dwarf and higher yielding cultivars, target plant stands may need to be adjusted to maximize profitability. Pervious research has shown that optimum plant populations can differ by both crop type and variety. In a North Dakota study, Mehring et al. (2016) found that optimum seeding rates for spring wheat ranged from 14 to 46 plants/ft^2 depending on the characteristics of the variety.

Materials and Methods:

- Locations: Arborg, Carberry, Melita, and Roblin
- Year: 2021
- Experimental Design: Randomized complete block design with factorial treatments and replicated three times
- Treatments: Two cultivars of spring wheat, oat, and barley planted at six seeding rates. Target plant populations were 9, 15, 21, 27, 33, and 39 plants/ft^2. See Table 1 for a complete treatment list.
    - Experiments were separated by crop type
    - Seeding rates were calculated based on thousand kernel weight and assumed 15% seedling mortality
- Data Collection: Plant stand, mortality, heads per plant, and yield.

- Carberry oat plots had poor emergence and were terminated.
- Melita had hail on July 17. It is estimated that the hail resulted in 20% yield loss in the wheat, and 30% yield loss in the barley and oats.

Table 1. Crop Types, Varieties, and Target Plant Stands Studied

Crop Type	Variety	Target Plant Stand (pl/ft^2)
Spring Wheat	AAC Brandon	9, 15, 21, 27, 33, 39
	Faller	9, 15, 21, 27, 33, 39
Oat	CS Camden	9, 15, 21, 27, 33, 39
	Summit	9, 15, 21, 27, 33, 39
Barley	AAC Connect	9, 15, 21, 27, 33, 39
	CDC Austenson	9, 15, 21, 27, 33, 39

Table 2. Agronomic Information

	Arborg	Carberry	Melita	Roblin
Soil Series	**Peguis Clay**	**Wellwood Loam**	**Waskada Loam**	**Erickson Loamy Clay**
Wheat				
Seeding Date	07-May	3-May	4-May	6-May
Fertility (lb/ac)				
Residual	93 N, 44 P	12 N, 4 P, 158 ppm K, 12 S	10 N, 14 P, 364 K, 90 S	93 N, 46 ppm P, 709 ppm K
Applied	60 N, 20 P	78 N, 34 P, 15 K	105 N, 28 P, 20 K, 12 S	96 N, 15 P
Harvest Date	17-Aug	13-Aug	4-Aug	31-Aug
Oat				
Seeding Date	10-May	-	6-May	4-May
Fertility (lb/ac)				
Residual	93 N, 44 P	-	10 N, 14 P, 364 K, 90 S	162 N, 41 ppm P, 703 ppm K
Applied	60 N, 20 P	-	112 N, 28 P, 20 K, 12 S	10 N, 15 P
Harvest Date	18-Aug	-	6-Aug	15-Sep
Barley				
Seeding Date	10-May	30-Apr	4-May	6-May

Fertility (lb/ac)				
Residual	93 N, 44 P	12 N, 4 P, 158 ppm K, 12 S	10 N, 14 P, 364 K, 90 S	93 N, 46 ppm P, 709 ppm K
Applied	60 N, 20 P	78 N, 34 P, 15 K	105 N, 28 P, 20 K, 12 S	31 N, 15 P
Harvest Date	18-Aug	13-Aug	4-Aug	8-Sep

Table 3. Monthly and Growing Season (May 1 - September 30) Summaries

Data from Manitoba Agriculture Growing Season Report
web43.gov.mb.ca/climate/SeasonalReport.aspx

			Arborg			
	May	June	July	August	September	Growing Season
Precipitation (mm)	19	39	11	116	34	221
% of Normal precipitation[1]	36	51	20	147	71	69
Growing degree days (GDD)	163	412	502	397	291	1767
% of Normal GDD[1]	80	122	116	103	153	114
			Carberry			
	May	June	July	August	September	Growing Season
Precipitation (mm)	36	74	12	111	8	243
Normal precipitation[1]	75	106	17	158	16	79
Growing degree days (GDD)	156	419	496	389	308	1770
Normal GDD[1]	85	125	117	100	161	116
			Melita			
	May	June	July	August	September	Growing Season
Precipitation (mm)	28	87	35	125	13	289
Normal precipitation[1]	52	86	51	160	38	86
Growing degree days (GDD)	108	426	522	426	323	1878
Normal GDD[1]	88	121	115	103	153	115
			Roblin			
	May	June	July	August	September	Growing Season

Precipitation (mm)	50	62	37	82	16	249
Normal precipitation[1]	111	84	52	148	31	83
Growing degree days (GDD)	148	380	467	360	266	1623
Normal GDD[1]	86	121	119	102	163	116

[1]Based on 30-year averages

All sites has lower than normal precipitation over the entire growing season. Arborg had very low precipitation throughout May, June, and July, which resulted in short plants, few tillers, and low yields overall. Low precipitation was especially evident at all sites in July, where Arborg and Carberry had 20 and 17% or normal precipitation, respectively, and Melita and Roblin has 51 and 52% of normal precipitation, respectively. July was warmer than normal at all locations, and the warm and dry conditions affected plant growth and development.

Results and Discussion:

<u>Plant Stand</u>

Stand establishment increased as seeding rate increased at most site years. There was no significant difference in plant stand between seeding rate treatments for wheat at Roblin, results will not be shown for this site as a range of plant populations were not established. At many locations plant stands were lower than the target. The exception was Arborg where plant stands ranged from 18-57, 12-47, and 25-35 plants/ft^2 in the barley, oat, and wheat plots, respectively (Table 4).

Table 4. Plant Stand (plants/ft^2) for Barley, Oat, and Wheat at the Arborg (Arb), Carberry (Car), Melita (Mel), and Roblin (Rob) Locations

Barley varieties are CDC Austenson (A) and AAC Connect (B), oat varieties are CS Camden (A) and Summit (B), and wheat varieties are AAC Brandon (A) and Faller (B).

Least significant difference (LSD) values are shown for sites where there is a significant difference (Pr<0.05) between treatments. At sites with significant differences between treatments, means within the same site year followed by the same letter within a column are not significantly different.

	Barley				Oat			Wheat			
	Arb	Car	Mel	Rob	Arb	Mel	Rob	Arb	Car	Mel	Rob
	-- plants/ft^2 ---------------------------------										
Variety											
A	40	15	16.3b	18	33	17a	12	29	19	14	11
B	43	14	17.8a	18	29	13b	10	31	21	14	13
LSD	-	-	*1.3*	-	-	*2*	-	-	-	-	-
Target Plant Population (pl/ft^2)											
9	18e	6d	7f	8c	12e	6f	6f	25d	9e	6d	11
15	36d	10cd	12e	14b	23d	10e	9ef	27cd	15d	10c	12
21	40cd	13bc	15d	17b	29cd	14d	10de	30bc	20c	13b	11
27	47bc	14b	19c	21a	34bc	16c	12cd	33ab	23bc	16b	17
33	53ab	19ab	23b	23a	40b	21b	14bc	33ab	26b	19a	11
39	57a	24a	28a	23a	47a	24a	16a	35a	30a	19a	9
LSD	*9*	*5*	*2*	*3*	*7*	*3*	*3*	*5*	*3*	*3*	-

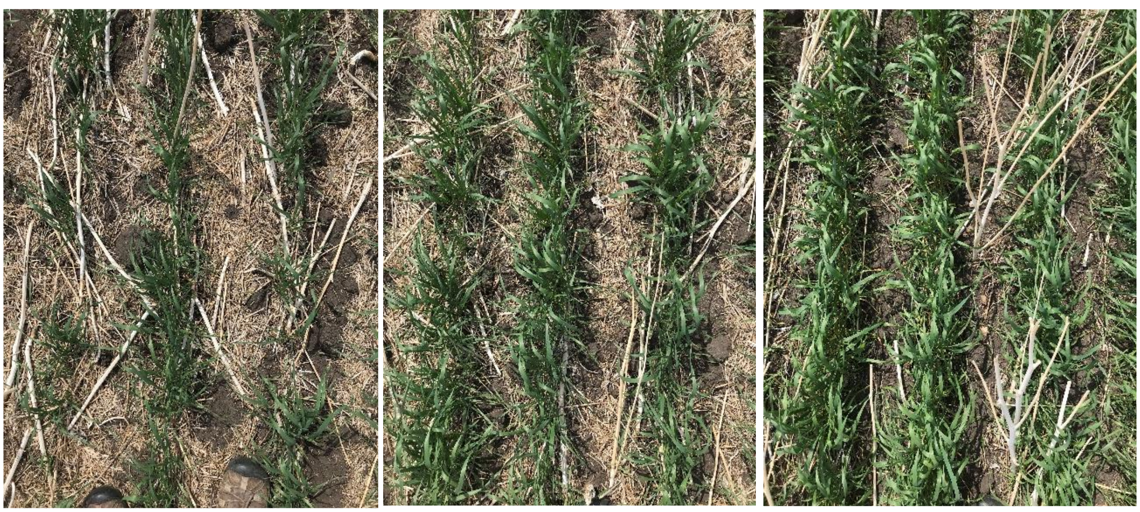


Figure 1. AAC Brandon wheat planted at target plant stands of 9, 21, and 33 plants/ft^2 at Melita in 2021.

Heading

Cereals can compensate for lower plant populations by increasing tillering. Research in which spring wheat plants were given ample room found that stems per plant ranged from 19 to 44 depending on the variety (Wiersma 2014). While cereal cultivars have differing abilities to tiller, at the majority of sites there was no difference in heads per plant between cultivars (Table 5). The actual number of spikes or panicles present at maturity depends on the number of tillers produced and the number that survive to maturity. The effect of drought stress on yield components depends on the timing of drought stress, and early season drought stress reduces yield potential through tiller death (Duggan et al. 2000). This is evident in the results from the Arborg location, where heads per plant were low across all crop types and treatments.

Heads per plant decreased as seeding rate increased, which demonstrates the ability of cereal crops to compensate for reduced plant populations by increasing tillering (Table 5). There was no significant difference in heads per plant at target plant populations ranging from 21-39 plants/ft^2 at five out of the eight sites where there were significant differences in heads per plant.

Table 5. Heads per Plant for Barley, Oat, and Wheat at the Arborg, Carberry, Melita, and Roblin Locations

Barley varieties are CDC Austenson (A) and AAC Connect (B), oat varieties are CS Camden (A) and Summit (B), and wheat varieties are AAC Brandon (A) and Faller (B). Least significant difference (LSD) values are shown for sites where there is a significant difference (Pr<0.05) between treatments. At sites with significant differences between treatments, means within the same site year followed by the same letter within a column are not significantly different. Roblin wheat data is not shown due to high coefficients of variation.

	Barley			**Oat**			**Wheat**		
	Arborg	Carberry	Roblin	Arborg	Melita	Roblin	Arborg	Carberry	Melita
	-- Heads/plant ------------------------------------								
Variety									
A	0.8	6.0	6.8	0.77	1.7b	6.03	1.1	5.8	2.7
B	0.8	5.7	6.7	0.89	2.2a	6.74	1.2	5.9	2.8
LSD	-	-	-	-	*0.2*	-	-	-	-
Target Plant Population (pl/ft^2)									
9	1.5a	6.5ab	10.2a	1.2a	3.2a	7.8	1.8a	6.7a	4.3a
15	0.9b	6.8a	7.9b	0.7b	2.2b	6.7	1.3b	5.9b	3.1b
21	0.7c	5.1c	7.2b	0.8b	1.8bc	6.9	1.2b	5.8b	2.6bc
27	0.6c	5.5c	5.7c	0.9b	1.7cd	6.0	0.9c	5.6b	2.3c
33	0.6c	5.7bc	4.5c	0.8b	1.4d	5.8	0.9c	5.5b	2.0c
39	0.5c	5.3c	4.9c	0.7b	1.4d	5.1	0.8c	5.8b	2.2c
LSD	*0.2*	*0.9*	*1.4*	*0.3*	*0.4*	-	*0.3*	*0.8*	*0.7*

<u>Yield</u>

Wheat

There were significant yield differences between the wheat varieties at the three locations where yields are reported, with AAC Brandon yielding significantly higher than Faller at two sites (Table 6). Yields were generally low at Arborg and Carberry due to drought conditions, with Carberry yields being further reduced as a result of hail.

When averaged across cultivars, there were no differences in wheat yield across plant densities at Melita. At the Carberry location yields increased as plant stand increased, with the highest yields being reported at target plant densities of 27 to 39 plants/ft^2 (Table 6, Figure 2). At Arborg, the 9 plants/ft^2 treatment had the lowest yield overall, with 33 plants/ft^2 yielding the highest (Table 6, Figure 2). Actual plant populations ranged from 9 to 30 plants/ft2 at Carberry, 6 to 19 plants/ft2 at Melita, and 25-35 plants/ft2 at Arborg. Figure 3 shows yield plotted against plant stand, giving context to the results. There was no interaction between seeding rate and cultivar, both cultivars responded similarly to increased seeding rates (data not shown).

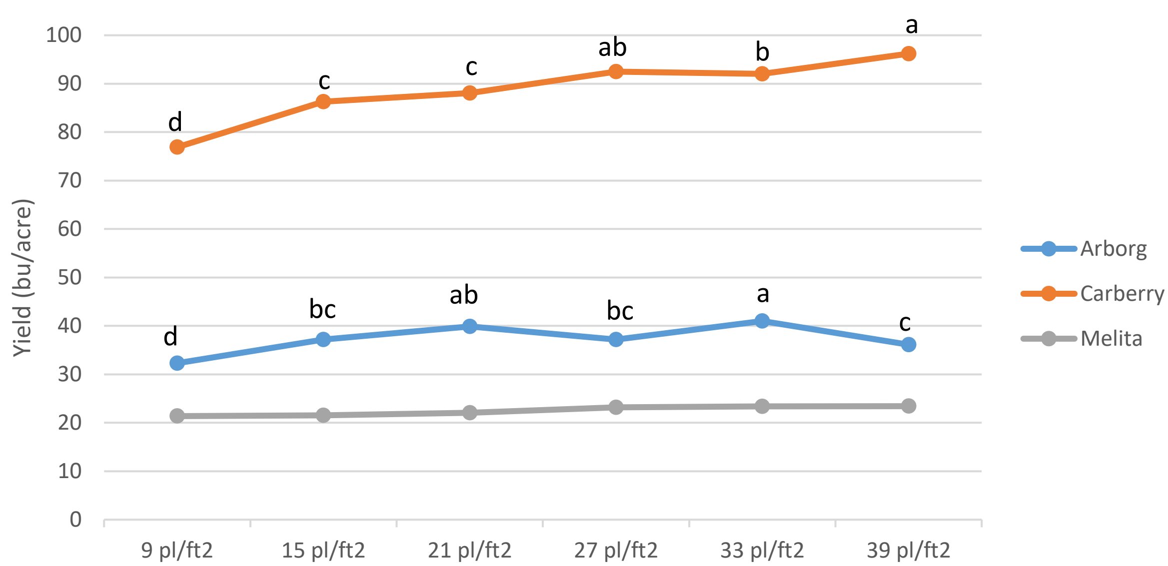


Figure 2. Wheat yield (bu/acre) at six target plant densities at Arborg, Carberry and Melita. Statistically significant differences are shown by letters above the line. Treatments within the same site with the same letter are not significantly different (P<0.05).

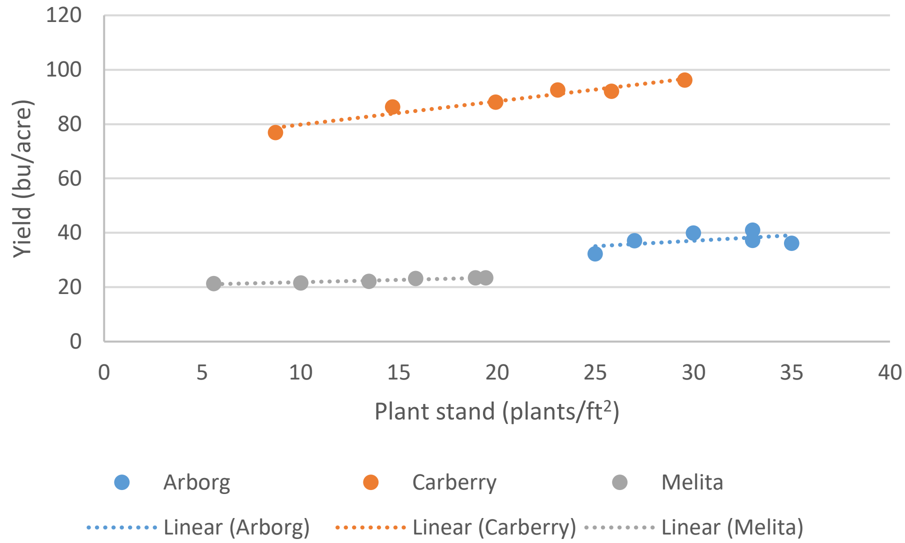


Figure 3. Wheat yield (bu/acre) plotted against actual plant density (plants/ft^2) at Arborg, Carberry and Melita. Statistically significant differences for plant stand and yield can be found in Tables 4 and 6, respectively.

Barley

There were no significant yield differences between barley varieties at three of four locations. At Arborg, CDC Austenson yielded significantly higher than AAC Connect (Table 6). When averaged across cultivars, there were no significant yield differences between target plant stands at three of the four locations. There were only significant yield differences between target plant densities at Arborg, with the 9 plants/ft^2 treatment yielding significantly lower than the higher target plant densities (Figure 4 and Table 6). Actual plant populations ranged from 6 to 28 plants/ft^2 at Carberry, Melita, and Roblin, and 18 to 57 plants/ft^2 at Arborg (Table 4). Figure 5 shows yield plotted against plant stand, giving context to the results and highlighting the higher plant populations at Arborg. There was no interaction between plant density and cultivar, both cultivars responded similarly to increased seeding rates (data not sown).

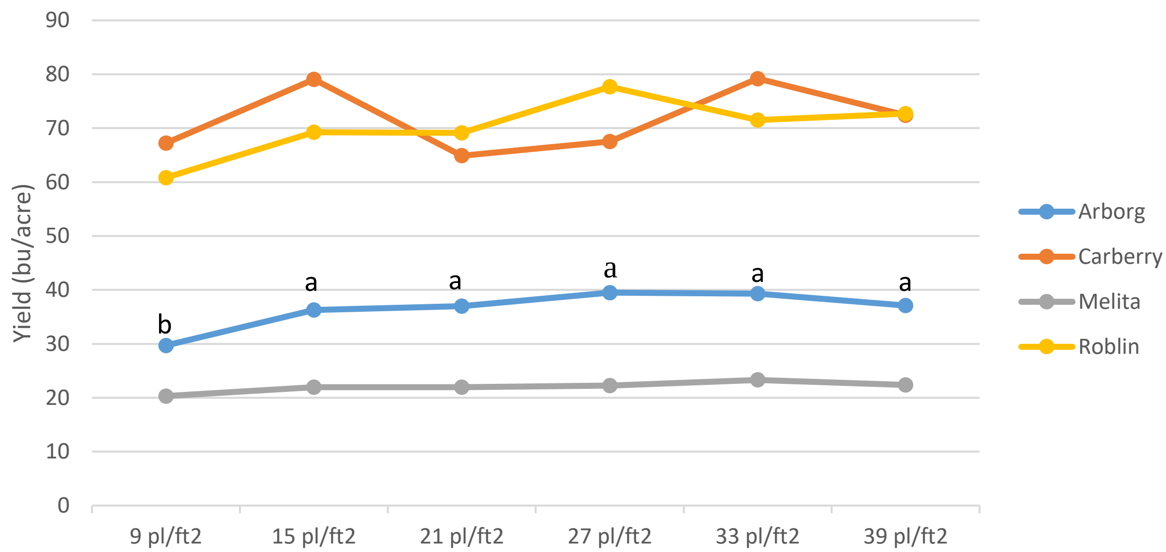


Figure 4. Barley yield (bu/acre) at six target plant densities at Arborg, Carberry, Melita, and Roblin. Statistically significant differences are shown by letters above the line. Treatments within the same site with the same letter are not significantly different (P<0.05).

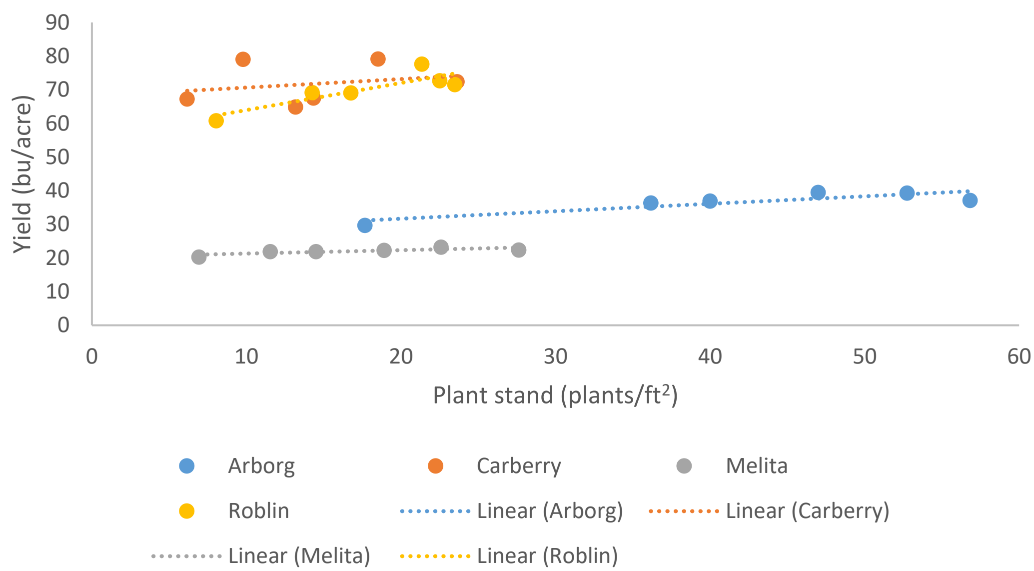


Figure 5. Barley yield (bu/acre) plotted against actual plant density (plants/ft^2) at Arborg, Carberry Melita, and Roblin. Statistically significant differences for plant stand and yield can be found in Tables 4 and 6, respectively.

Oat

There was a significant yield difference between the two oat varieties at two of the three locations, with CS Camden yielding higher than Summit in both cases (Table 6). Averaged across cultivars, there was no difference in oat yield across the range of target plant densities at two of the three locations. There were significant yield differences across target plant densities at the Arborg location, but no consistent trend (Figure 6). Oat yield plotted against plant stand is shown in Figure 7. There was no interaction between plant density and cultivar, both cultivars responded similarly to increased seeding rates (data not sown).

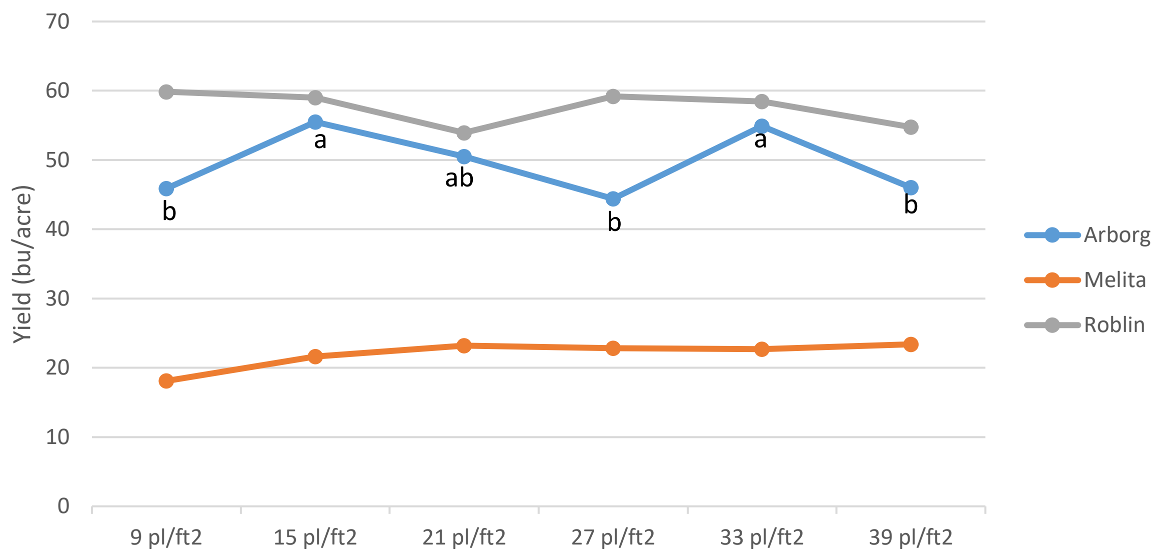


Figure 6. Oat yield (bu/acre) at six target plant densities at Arborg, Melita, and Roblin. Statistically significant differences are shown by letters below the line. Treatments within the same site with the same letter are not significantly different (P<0.05).

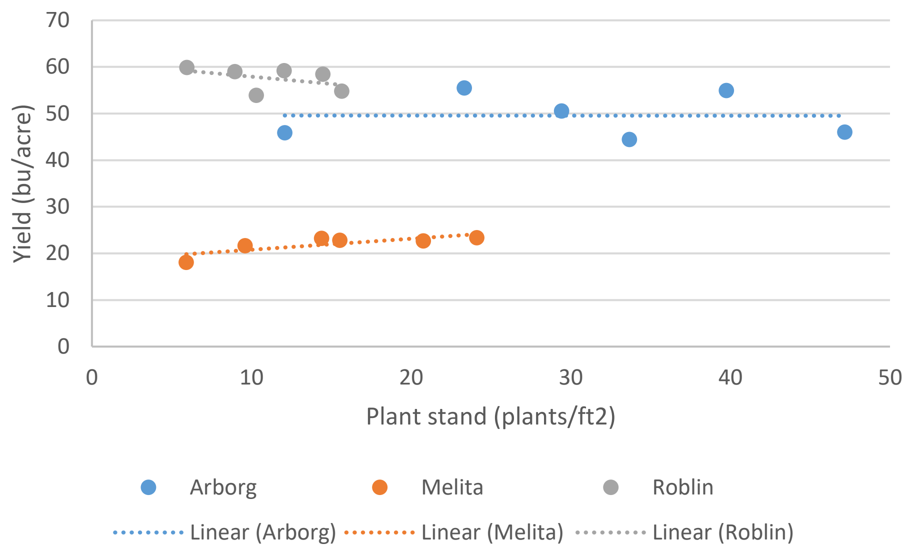


Figure 7. Oat yield (bu/acre) plotted against actual plant density (plants/ft^2) at Arborg, Melita, and Roblin. Statistically significant differences for plant stand and yield can be found in Tables 4 and 6, respectively.

Table 6. Yield (bushels/acre) for Barley, Oat, and Wheat at the Arborg, Carberry, Melita, and Roblin Locations

Barley varieties are CDC Austenson (A) and AAC Connect (B), oat varieties are CS Camden (A) and Summit (B), and wheat varieties are AAC Brandon (A) and Faller (B). Least significant difference (LSD) values are shown for sites where there is a significant difference (Pr<0.05) between treatments. At sites with significant differences between treatments, means within the same site year followed by the same letter within a column are not significantly different.

	Barley				**Oat**			**Wheat**		
	Arborg	Carberry	Melita	Roblin	Arborg	Melita	Roblin	Arborg	Carberry	Melita
	------------------- Yield (bu/acre) -------------------									
Variety										
A	38.5a	73.9	22.0	70.9	53.8a	21.1	86.9a	38.3a	84.9b	23.6a
B	34.4b	69.5	22.1	69.5	45.3b	22.8	28.1b	36.3b	92.4a	21.4b
LSD	*2.3*	-	-	-	*4.1*	-	*4*	*2.0*	*2.7*	*0.9*
Target Plant Population (pl/ft^2)										
9	29.7b	67.2	20.3	60.8	45.9b	18.1	59.9	32.3d	76.9d	21.4
15	36.3a	79.1	22.0	69.2	55.5a	21.6	59.0	37.2bc	86.3c	21.6
21	37.0a	64.9	21.9	69.1	50.5ab	23.2	53.9	39.9ab	88.1bc	22.1
27	39.5a	67.5	22.3	77.7	44.4b	22.8	59.2	37.2bc	92.5ab	23.2

33	39.3a	79.2	23.3	71.5	54.9a	22.7	58.4	41.0a	92.0b	23.4
39	37.1a	72.4	22.4	72.7	46.0b	23.4	54.8	36.1c	96.2a	23.4
LSD	*4*	-	-	-	*7*	-	-	*3.5*	*4.7*	-

This study is a continuation of a research project that took place at Arborg, Carberry, Melita, and Roblin in 2017 and 2018. The oat and barley sites in 2017 and 2018 showed similar yields across a range of plant stands, indicating that the current recommended target plant populations for barley and oat are sufficient. At the wheat sites in 2017 and 2018 there was a general trend of higher yields with increased plant stands, but no significant difference in yields between target plant stands of 21 to 39 plants/ft^2 at four of the five sites.

The 2021 results are similar, in that there were no significant yield differences across the range of plant densities at most sites. There was a general trend of higher yields with higher plant stands at the wheat, barley, and one of the oat sites, although the data indicates that these trends should be taken with caution. There were no significant difference in yields between target plant stands of 21 to 39 plants/ft^2 at nine out of the 10 sites. At all sites, both varieties tested responded similarly to each target plant stand, indicating that similar seeding rate recommendations could be made for both varieties of each crop type studied.

Development of Decision Support Tools for Fusarium Head Blight Management in Western Canada

Project duration: September 2020 – August 2021

Objectives: To increase understanding of resulting Fusarium Head Blight (FHB) infection for spring and winter wheat, barley and durum based on the current model.
To develop weather-based models to assess the risk of FHB infection and DON in spring wheat, winter wheat, barley and durum crops with different FHB resistance ratings.
To develop an interactive prairie-wide viewer and FHB/DON risk-mapping tool that is accessible to producers and industry to assist with fungicide application decisions.

Collaborators: Manasah Mkhabela (Research Associate – Department of Soil Science, University of Manitoba)

Results:

Grain samples were sent for Fusarium specific analysis, but no report for these results has yet been generated. CMCDC will post a link when this report is available. Average yields for the crops tested are shown in Figure. 1. The quality ratings for the crops are not included here.

Project Findings:

The 2021-planting year was the third year of testing at CMCDC site and data were handed over to U of M. Researchers are compiling data from all 15 sites (in three prairies provinces) and will report later on.

Background:

Fusarium head blight (FHB), also known as scab or tombstone, is a serious fungal disease of wheat (including durum), barley, oats and other small cereal grains and corn. It can also affect wild and tame grass species. However, the crops most affected are wheat, barley and corn. FHB affects kernel development, reducing yield and grade. It can also contaminate grain with a fungal toxin (mycotoxin) produced in infected seeds. Infection of the harvested grain and/or mycotoxin production negatively affects:

- livestock feed
- baking and milling quality of wheat

- biofuel (ethanol) production
- malting and brewing qualities of malt barley

Farmers need improved decision-making tools in order to assess the local risk of Fusarium Head Blight (FHB). Better tools would improve judgement on whether or not to use fungicide and how to time application. The project recognizes that the current model for predicting the presence of FHB is insufficient and is gathering data across the province for different treatment plans using both known fusarium resistant and fusarium susceptible varieties. This project design centred on learning more about how spore density in the air at specific times of plant maturation affected FHB infection. The specific window of interest is during flowering and up to five days before flowering.

Fusarium head blight is caused by several species of the fungal genus Fusarium. Fusarium graminearum (F. graminearum or Fg) is the species that causes the most serious damage to crops. FHB is favoured by warm, humid conditions during flowering and early stages of kernel development.

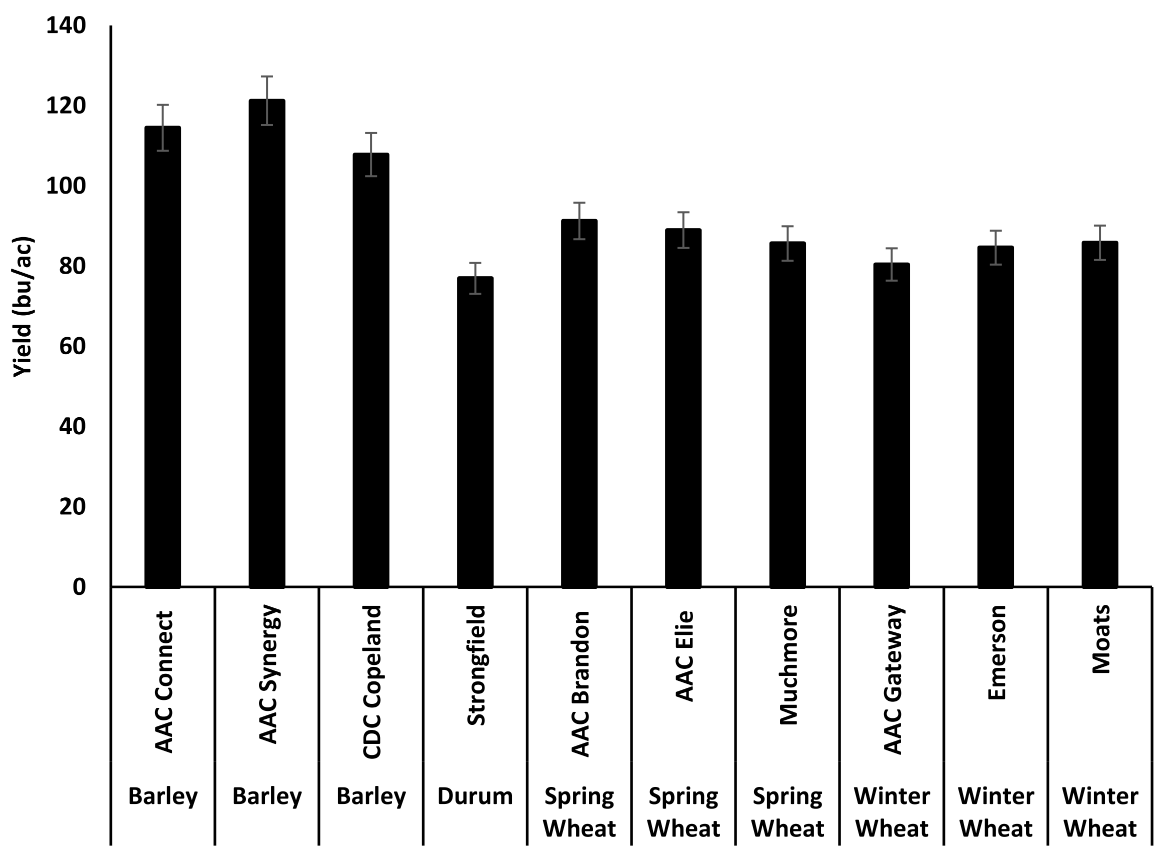


Figure. 1 Average yields for cereals tested

Materials & Methods:

Entries: 3 varieties for each winter wheat, spring wheat and barley; 1 variety for durum

Seeding: Winter Wheat seeded Sept 11 2020;
Barley, Spring Wheat and Durum seeded April 30, 2021

Harvest: Winter Wheat harvested Aug 13 2021

Varieties: Winter Wheat: Moats, AAC Gateway and Emerson
Spring Wheat: AAC Elie; AAC Brandon and Muchmore
Barley: CDC Copeland; AAC Connect; and AAC Synergy
Durum: Springfield

Data collected	**Date/Stage collected**
Plant Counts:	Three leaf stage (and spring emergence for winter wheat)
Plant Staging:	Weekly staging beginning at late booting through late flowering
Spore Collection:	Beginning just before winter wheat flowering spanning five weeks and covering all cereals flowering
FHB sampling & rating:	18-21 days after flowering – Enumeration of FHB afflicted kernels per head in a given sample size of fifty heads per plot
Heights:	Multiple
Yield:	Multiple
Moisture:	Multiple

Grain samples sent away to analyze for grading, fusarium species assessment, and mycotoxin analysis.

Agronomic info:

Standard recommended agronomic protocols were adopted for each crop. Fertilizers were applied according to soil test results. Herbicide were applied, when required.

Nutrient Uptake in Buckwheat

Project duration: May 2021 – September 2021

Objective: To better understand the nutrient uptake of buckwheat crop in Manitoba.

Collaborators: Rejean Picard (Agriculture Adaptation Specialist Crops – Manitoba Agriculture)
Manitoba Buckwheat Growers Association.

Background:

To better understand the nutrient uptake of buckwheat, the following study was undertaken based on protocol developed for sequential sampling of various other crops and nutrient analysis and develop nutrient uptake curves. Such data was collected for Manitoba corn and potato crops in 2003. These figures indicate the total amounts of nutrients taken up by the plant and when the uptake occurs

Procedure:

1. Establish a uniform planting of buckwheat – preferably on high fertility soil that will not suffer nutrient deficiencies.
2. Take a soil test – 0-6”, 6-24” – get a complete analysis.
3. Separate the plot area into randomized replicated individual plots minimum 3m long and 3 rows wide.
4. There will be seven sampling times, and 3 reps. Samples will also be split into plant parts as follows: leaves (including petioles), stems, flower clusters and seed.

Rep 1	1 V2 – 2 true leaves	2 V5 – 5 true leaves	3 R1- Beginning flowering	4 R3 – beginning seed set	5 R4 – beginning seed fill	6 R6 – mid seed set	7 R8 – full maturity

Plant Sampling Schedule:

Date collected	**Growth stage**	**Yields (g/3 m of row)**	**Analyses**
June 21	V2 – 2 true leaves	Leaves (includes petioles), stem	Complete nutrients
June 28	V5 – 5 true leaves	Leaves, stem	Same
July 5	R1- Beginning flowering	Leaves, stem	Same
July 26	R3 – beginning seed set	Leaves, stem, flower clusters	Same
August 5	R4 – beginning seed fill	Leaves, stem, flower clusters	Same
August 18	R6 – mid seed set and fill	Leaves, stem, flower clusters, seed	Same
September 29	R8 – full maturity	Fallen Leaves, stem, flower clusters, seed	Same

Method of Plant harvests:

- At appropriate growth stage (use growth stages rather than DAP days after plating to guide sampling), hand harvest 3 m of the centre row of each plot.
- Bag and bring entire samples to prep lab.
- Separate plant parts. Put in dryer to dry at 160^{O} F
- Remove dried samples, weigh.
- Grind entire samples. Submit sample to AgVise for complete analysis.
- Label plant part and stage.

Site Description:

The site selected was previously cropped by spring wheat. Soil sample was collected for the topsoil and analysis conducted to determine the availability of nutrients.

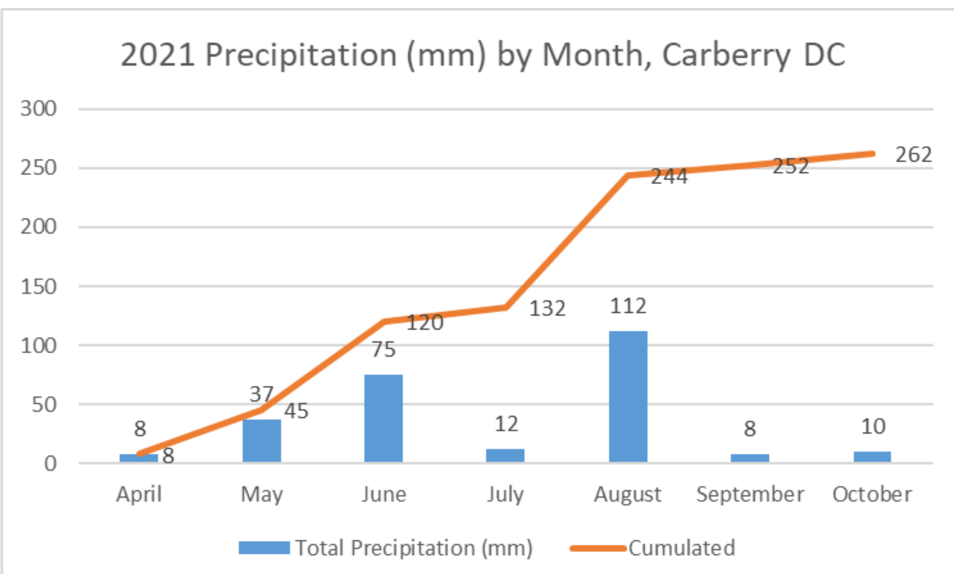
	Nitrogen	**Phosphorus**	**Potassium**	**Sulphur**	**Mg**	**Calcium**	**O.M.**	**pH**
Units	Lbs/a	ppm	ppm	Lbs/a	ppm	ppm	%	
0-6in	2	2	141	10	900	5461	1.8	8.1

Nitrogen was applied as a pre-seed broadcast application. 15 lbs/a of sulphur was added post seeding as a broadcast operation which added another 10 lbs/a of nitrogen.

Weather Information:

Temperature	Monthly mean (C)	**Precipitation**	Total Precipitation (mm)	Cumulated
April	3.0	April	8	8
May	10.0	May	37	45
June	19.0	June	75	120
July	21.0	July	12	132
August	18.0	August	112	244
September	16.0	September	8	252
October	8.0	October	10	262
Last frost in spring	20-May-21			
First Frost:	16-Sep-21			

Monthly and Cumulated Precipitation in 2021:



Last spring frost was May 20 and first fall frost September 16 but no visible damage to the plants.

Field Operations:

Seeding was done June 1st on parcels pre-treated May 21st with a glyphosate/Heat mixture as a broad-spectrum herbicide application to control all emerged weeds. The seedbed was firm and moist from recent rains. The variety Mancan was used for the trial. Seed row spacing was 9.25 inches wide. Emergence was rapid and uniform. Pre-seed burn off and in-crop graminicide was applied to control grassy weeds as well as an insecticide in later July to control grasshopper infestations.

Few broadleaf weeds were in the study area and the odd plants escaping were removed by hand. Otherwise, the crop competed well against late emerging weeds like Red Root pigweed and green foxtail.


June 14 (left) showing uniform plant emergence. July 5th (right), the begin flower stage was reached.

Growing conditions were warm and dry for extended periods of time but plants seemed to tolerate the conditions well. Grasshopper pressure was increasing and insects were visible on the edge of the plots in particular where leaves were notched by the feeding activity.


August 18th, mid seed set/fill. **September 29th, full maturity**

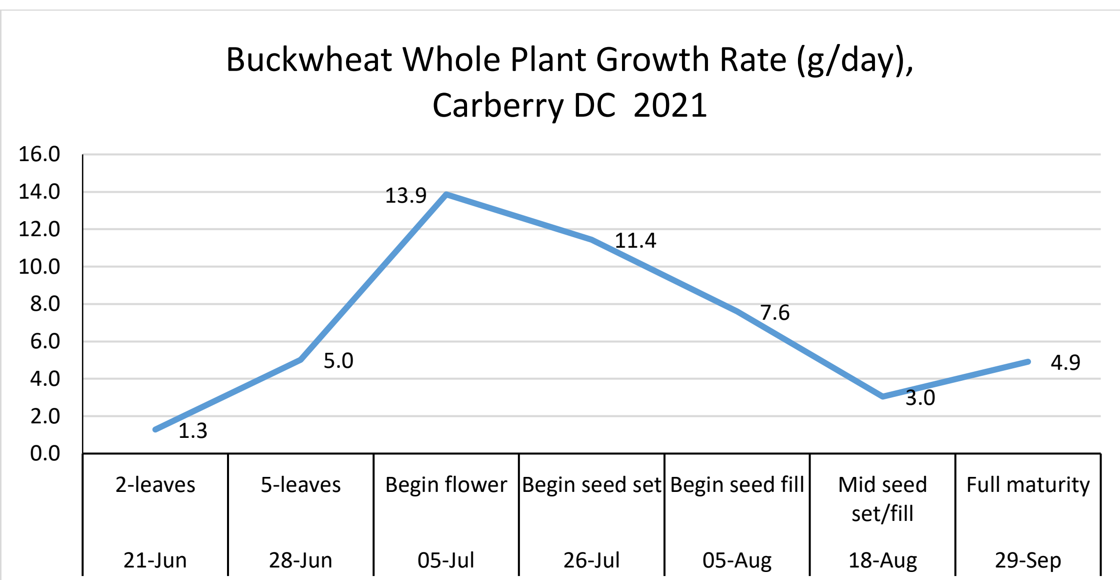
Ten feet of the mid-row of each replicated plot was sampled. Following harvest and separating the plant parts, the samples were oven dried for 5 to 7 days before weighing. Biomass was measured as dry samples were fresh out of the oven. Samples were bagged and kept in storage until sub-samples prepared for lab analysis.

Dry Matter Weight (g) at Different Stages:

	21-Jun	**28-Jun**	**05-Jul**	**26-Jul**	**05-Aug**	**18-Aug**	**29-Sep**
	2-leaves	5-leaves	Begin flower	Begin seed set	Begin seed fill	Mid seed set/fill	Full maturity
Stems		17.6	75.5	220.5	285.0	318.9	324.8
Fresh leaves	25.7	43.3	82.4	168.9	143.9	120.5	41.4
Dropped leaved							76.6
Flowers				8.8	45.5	50.9	76.6
Seed						23.7	201.1
Total	25.7	60.8	157.9	398.3	474.4	513.9	720.5
Growth rate g/d	1.3	5.0	13.9	11.4	7.6	3.0	4.9

Biomass Growth:

Buckwheat grows rapidly once emerged and has a strong ability to compete well with weeds. The growth rate increases most rapidly from the 5-leaves stage to the begin flower and then slows until full maturity.

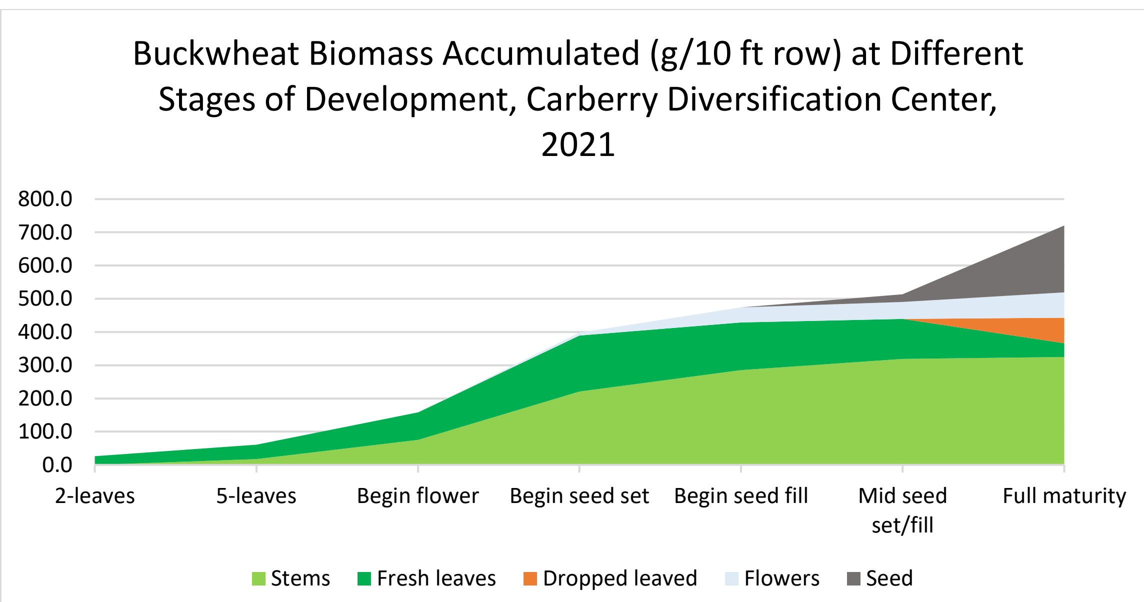


Separate samples collected were blended together by stage and a composite sub-sample taken for nutrient analysis.

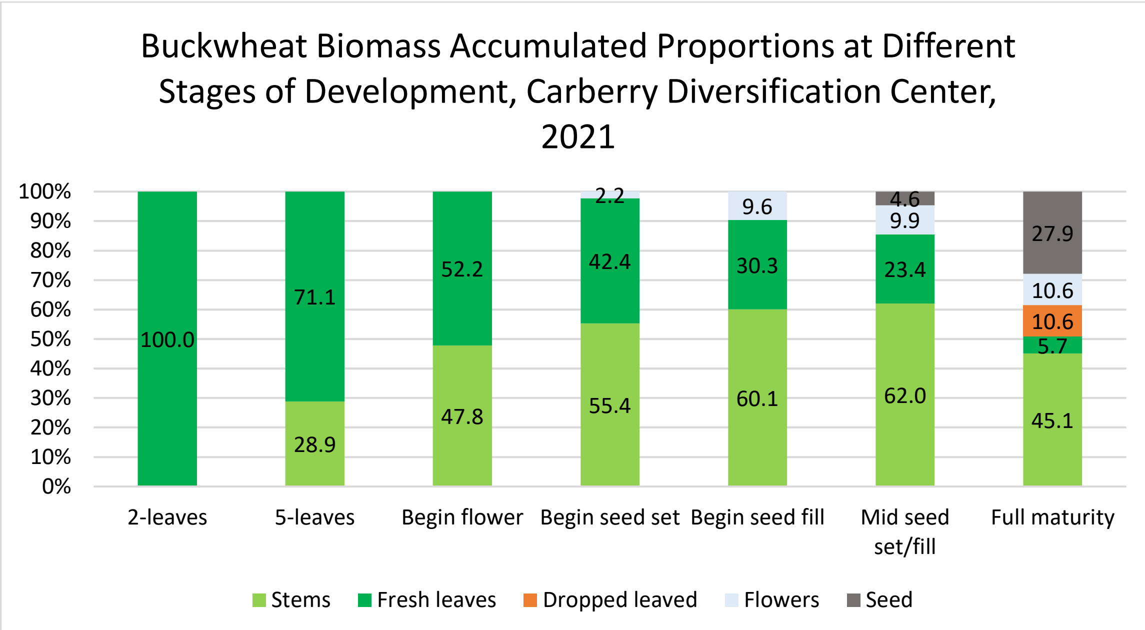
Nutrient Analysis Results:

Field Id	Sample ID	Total-N	P	K	S	Ca	Mg	Na	Zn	Fe	Mn	Cu	B
		%	%	%	%	%	%	%	ppm	ppm	ppm	ppm	ppm
2 LEAF SAMPLING	WHOLE PLANTS	5.03	0.33	2.59	0.28	2.27	1.55	0.01	58	204	172	5	24
5 LEAF SAMPLING	STEMS	3.76	0.18	5.64	0.18	1.77	1.36	0.01	29	109	48	4	21
5 LEAF SAMPLING	LEAVES	4.18	0.19	2.33	0.26	3.32	2.07	0.01	59	265	233	5	23
BEGIN FLOWER	STEMS	2.24	0.16	4.86	0.14	1.23	1.15	0.01	20	68	49	3	18
BEGIN FLOWER	LEAVES	3.79	0.24	1.90	0.24	3.90	2.37	0.01	55	170	349	6	31
BEGIN SEED SET	STEMS	1.66	0.10	3.03	0.09	0.97	1.19	0.01	12	62	38	3	19
BEGIN SEED SET	LEAVES	3.19	0.18	1.63	0.21	3.78	2.48	0.01	37	167	292	6	36
BEGIN SEED SET	FLOWERS	2.84	0.34	1.49	0.17	1.57	1.02	0.01	36	126	124	9	60
BEGIN SEED FILL	STEMS	0.80	0.09	2.31	0.07	0.48	0.70	0.01	10	36	28	1	15
BEGIN SEED FILL	LEAVES	2.57	0.15	1.27	0.17	2.88	2.18	0.01	29	174	284	5	31
BEGIN SEED FILL	FLOWERS	2.33	0.32	1.41	0.16	0.98	0.94	0.01	31	125	111	9	26
MID SEED SET/FILL	STEMS	1.09	0.12	2.47	0.08	0.52	0.85	0.01	12	26	42	2	15
MID SEED SET/FILL	LEAVES	2.69	0.25	1.71	0.20	2.54	1.97	0.01	32	160	305	6	40
MID SEED SET/FILL	FLOWERS	2.57	0.33	1.33	0.17	0.96	0.85	0.01	33	141	126	10	30
MID SEED SET/FILL	SEEDS	1.76	0.30	0.56	0.13	0.07	0.25	0.01	22	29	22	8	11
FULL MATURITY	STEMS	0.32	0.14	2.54	0.08	0.58	0.64	0.01	9	27	56	1	14
FULL MATURITY	FRESH LEAVES	1.75	0.19	1.77	0.15	3.02	1.92	0.01	23	345	506	4	43
FULL MATURITY	DROPPED LEAVES	1.33	0.14	1.13	0.11	3.99	2.27	0.01	30	1675	559	3	32
FULL MATURITY	FLOWERS	2.08	0.30	1.46	0.16	1.41	0.84	0.01	48	469	203	8	36
FULL MATURITY	SEEDS	1.69	0.35	0.65	0.13	0.07	0.27	0.01	26	40	33	6	12

Nutrient uptake is based on the biomass accumulated at various stages of development combined with the tissue analysis of each nutrient analyzed.



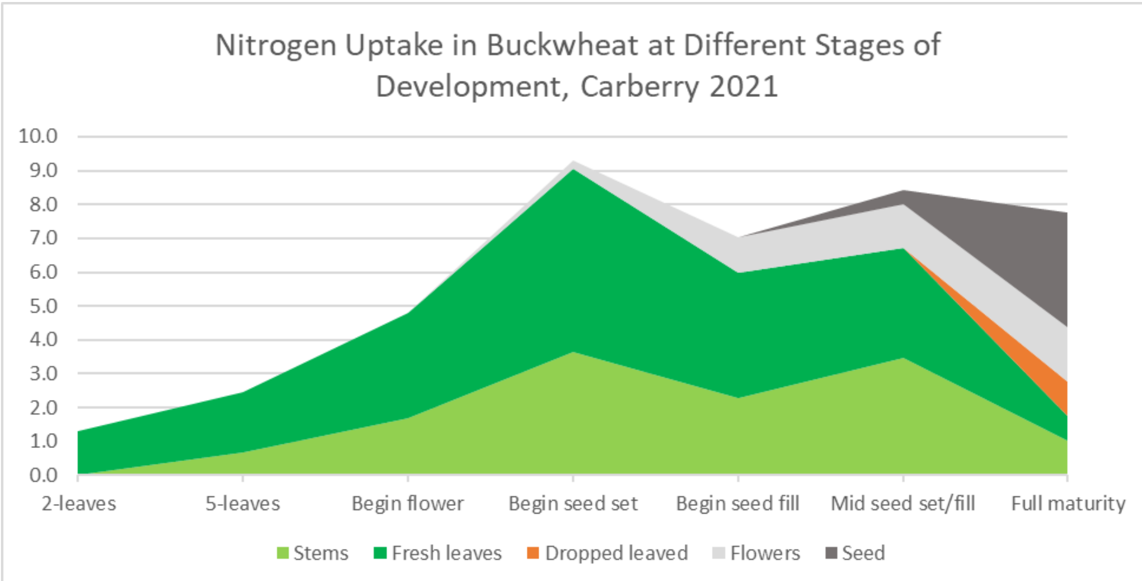
The above graph represents the dry weigh of biomass accumulated at each stage of development; leaves, stems, flower clusters and seed. As expected, the total weight increased at every stage of growth until the full maturity stage.



The above graph shows the proportion of the various plant components measured at different stages of development; leaves, stems, flower clusters and seed.

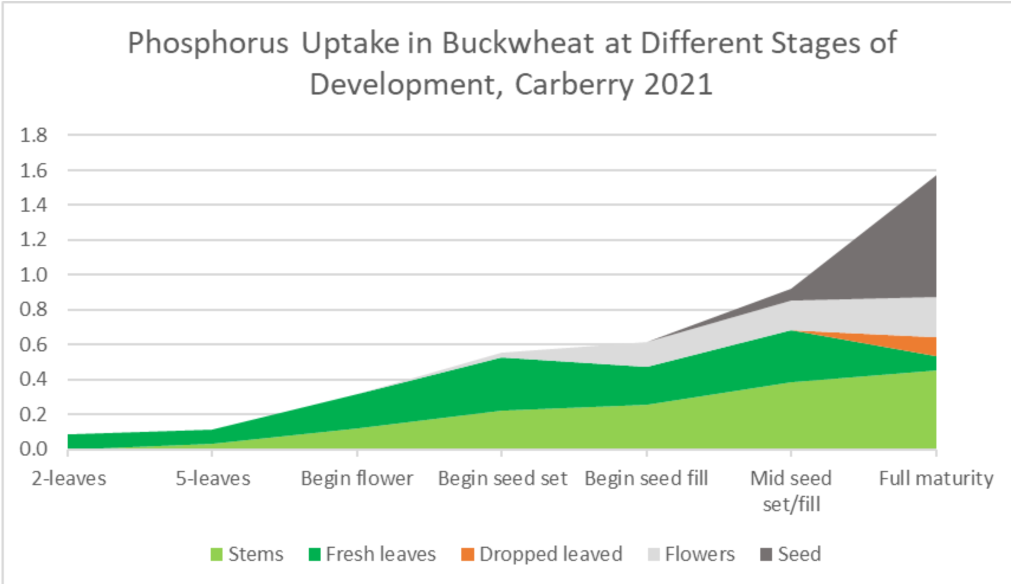
As seen from this data, as plants grew and developed the proportion of leaves declined while stems increased until mid-seed set and maintained a major share of plant biomass until full maturity. Seeds increase from begin seed set to reach a maximum at maturity. Favourable late August rains stimulated more flowering, seed set and seed fill of the stand. Overall seed yield was 52 bus/a for this trial which is well above the 10-year Manitoba average yield of 17 bus/a.

Nitrogen is a major nutrient required for plant growth and a major constituent of proteins. Plant uptake increased rapidly up to the reproductive stage of development. Maximum uptake was accomplished by the begin seed set stage in this trial and remained relatively stable until full maturity.

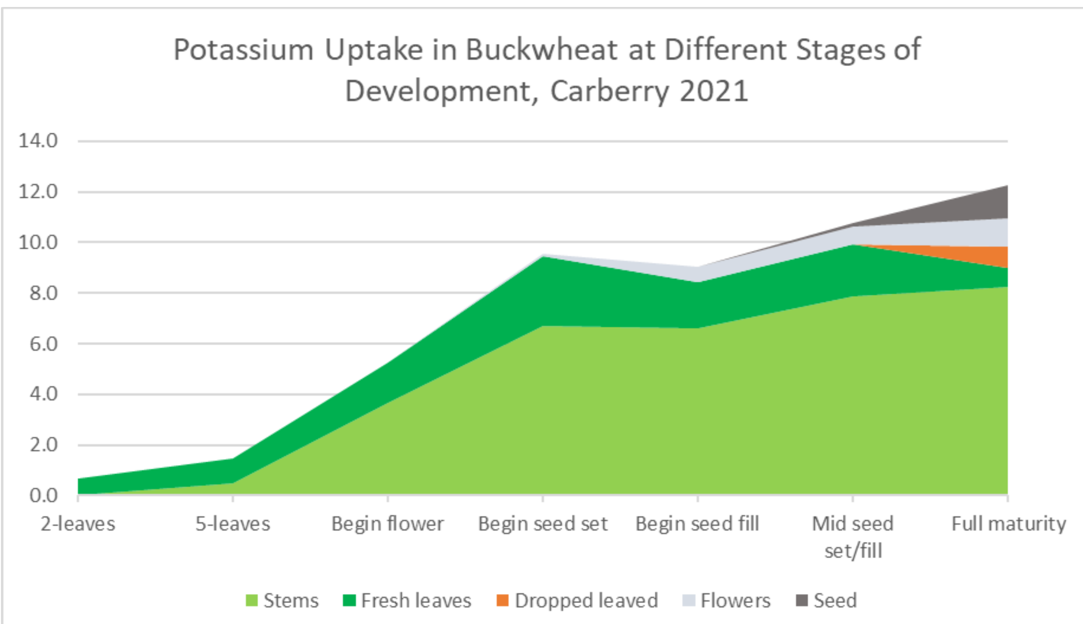


Phosphorus:

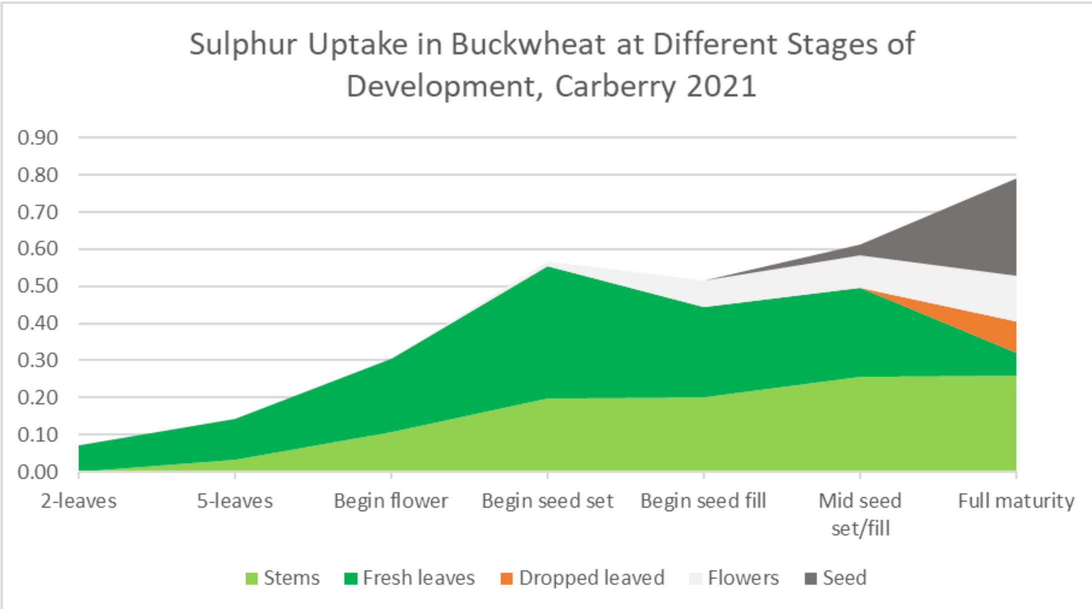
Buckwheat is considered an efficient plant at extracting phosphorus from the soil. The soil at the planting site of this trial tested very low in phosphorus (2 ppm). Plant growth was abundant during the vegetative and reproductive stages when seed development occurs and phosphorus accumulates. In this trial, almost 50% of the accumulated phosphorus ends up in the seed.



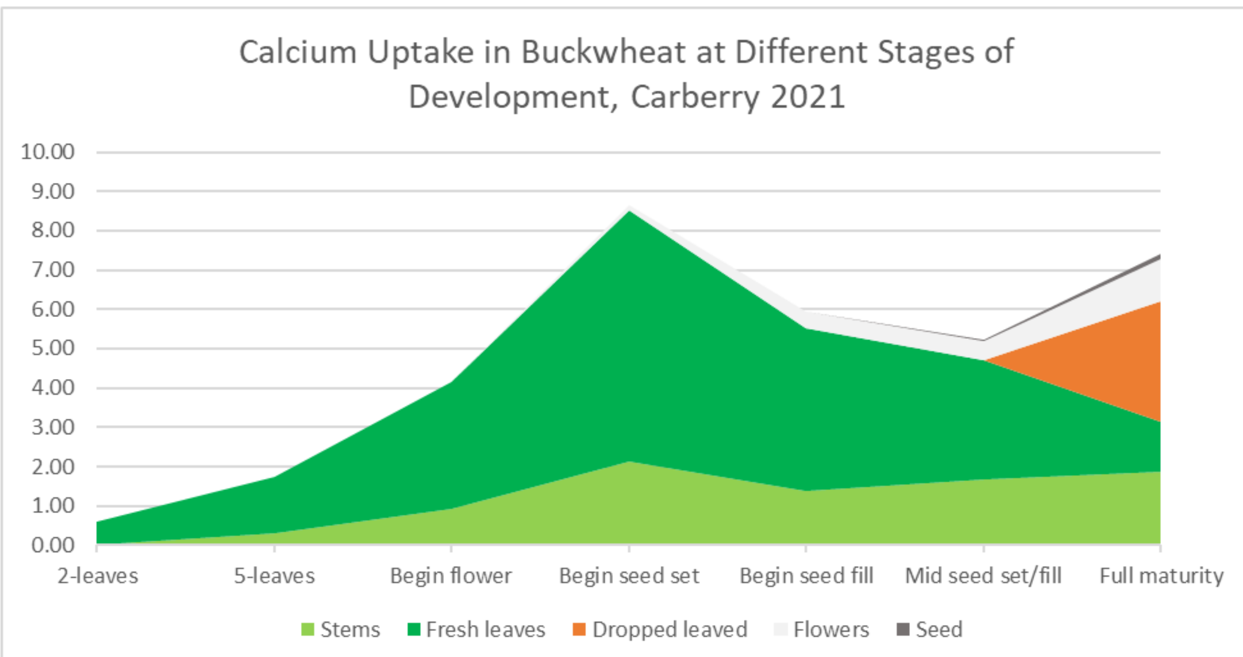
Potassium plays an important role in various functions of plant growth including water regulation, translocation of sugars and starch formation, grain quality and cell structure. Potassium uptake increased rapidly up to begin seed set to level off and then increase again in the seed development stage. Most of the potassium accumulated and remained in the vegetative parts of the plants.



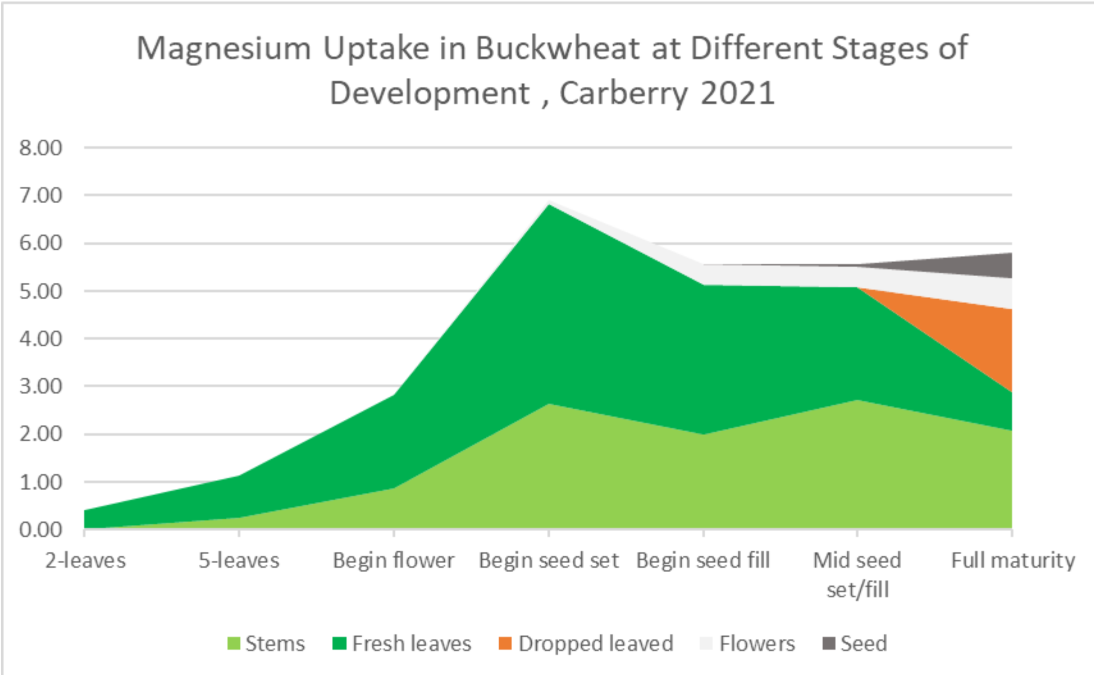
Sulphur is an important component of numerous proteins. It also aids in seed production and is needed to form chlorophyll. Sulphur increased in the plant up to begin seed set, then levelled off before accumulating in the seed.



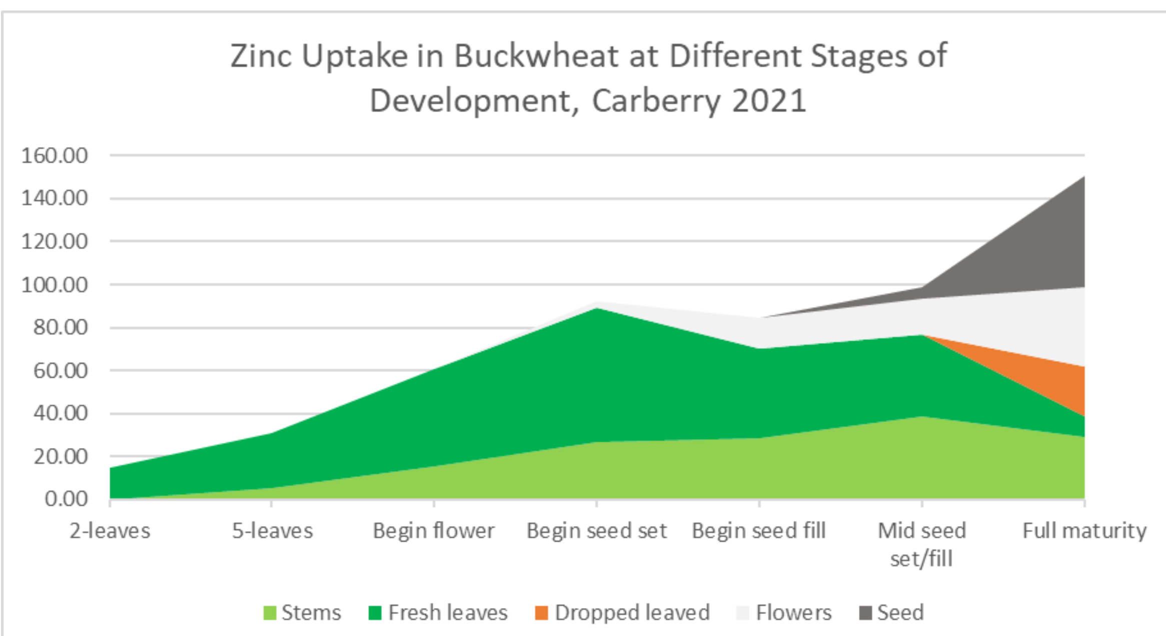
Calcium is important for cell growth and stabilizes the cell walls of plants. Calcium accumulated and remained in vegetative plant parts with little accumulation in the seed.



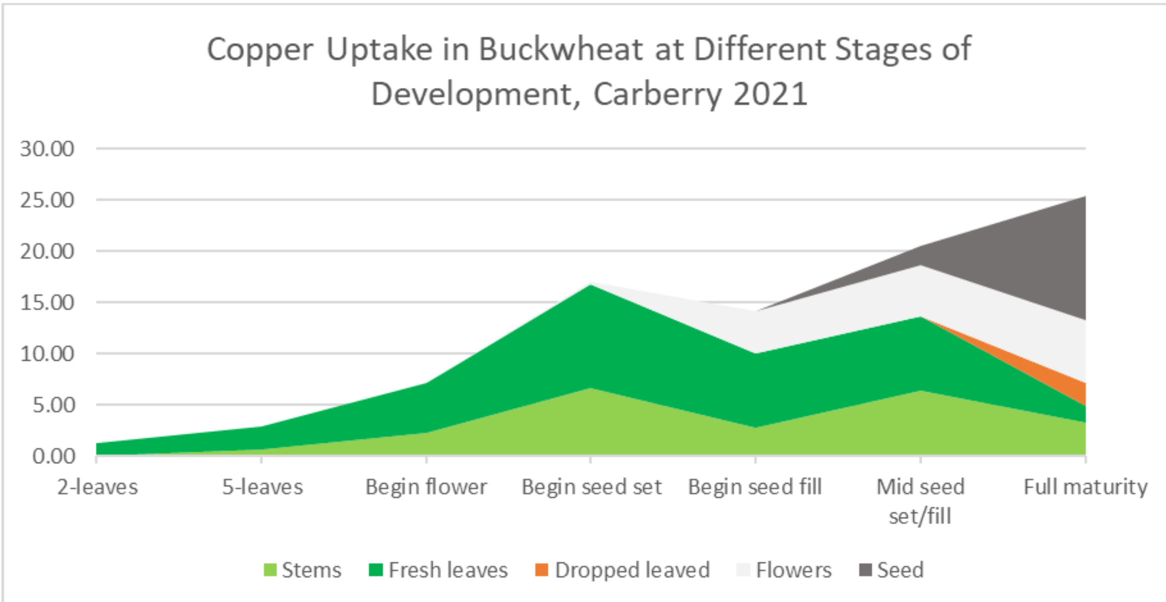
Magnesium is a component of chlorophyll and important for chlorophyll and protein synthesis. Magnesium increased up to the begin seed set and accumulated most in the leaves and stems of the plants.



Zinc is a metal activator of several enzymes and important for carbohydrate metabolism, protein synthesis and for stem elongation control. In this trial, zinc increased up to the reproductive stage, then leveled off to later increase and accumulate in the seed. In comparison with other cereals such as rice, wheat flour or corn, buckwheat contains higher levels of zinc, copper, and manganese (Ikeda et al, 1998; Steadman et al, 2001). The bio-availability of zinc, copper, and potassium from buckwheat is especially high.



Copper is a metal activator of several enzymes necessary for photosynthesis and aids in chlorophyll formation. As for zinc, a large proportion of copper accumulates in the seed.



Conclusions:

This study is unique in measuring how buckwheat grows and how nutrients accumulate at various stages of growth. As expected, buckwheat biomass accumulates rapidly allowing this plant to compete well with weeds. This confirms what growers observed that given a good start, even with limited weed control options in commercial production, buckwheat competes well with weeds. Macronutrients accumulate rapidly as the plants grow. A large proportion of Nitrogen, Phosphorus and Sulphur end up in the seed. Buckwheat is considered a good scavenger of soil phosphorus and this study shows that with very low starting phosphorus levels, the crop was able to yield well and accumulate much of the Phosphorus taken up by the plant into the seed.

Potassium and intermediate elements like Calcium and Magnesium tend to remain in the vegetative parts of the plants while micronutrients like zinc and copper accumulate in the seed.

Management Practices to Optimize Establishment and Early Growth of Soybean

Project duration: September 2017 – September 2021

Objective: To determine the effect of residue management on soybean planted in early versus later May.

Collaborators: Ramona Mohr and Aaron Glenn (Agriculture and Agri-Food Canada)

Background:

The Canadian prairies mark the northern fringe of soybean production in North America. Despite ongoing improvements in soybean genetics, soybean is inherently a cold-sensitive crop that requires a relatively long growing season. Frost, and near freezing temperatures in spring and fall can damage soybean. Early planting into cool and wet conditions can increase seedling disease and reduce plant stand, with soil temperature acting together with soil moisture to affect establishment (Helms et al. 1996a; Helms et al. 1996b; Wuebker et al. 2001). Residue management practices may influence soil temperature as well as soil moisture, and thus potentially affect early-season growth. Manitoba's soybean industry has grown rapidly over the past decade. The introduction of short-season cultivars adapted to this region has resulted in an expansion in production from traditional growing areas in the Red River Valley to shorter-season areas, leading to a record soybean acreage of 1.6 million acreas in 2016 (Statistics Canada 2016). Despite ongoing improvements in soybean genetics, soybean is inherently a cold-sensitive crop that can be prone to low-temperature damage in both the spring and the fall. As such, planting either too early or too late may pose a production risk.

Management practices that modify the micro-climate that soybeans are exposed to early in the growing season, and/or that give the crop a competitive advantage under stressful conditions, may help to create a set of conditions that are more conducive to soybean establishment, growth and yield and thereby potentially reduce production risk. A series of small-plot and controlled environment studies were initiated in fall 2017 to better understand the effect of management practices on temperature and moisture conditions and, in turn, on soybean establishment, growth, yield and quality. Based on preliminary results from the first year of field studies, planting date and previous residue management often influenced soil temperature and moisture at soybean planting; however, residue management influenced soybean yield at only 1 of 3 sites, while planting date (early vs late May) had no effect on yield in 2018. Seeding date and residue management had limited effects on soybean seed quality in 2018. These are preliminary results only from the first year of ongoing field experiments.

Treatments:

Main plots: two planting dates of soybean

Sub-plots: Six spring wheat stubble treatments:

1. Short stubble with straw removed (15 cm standing stubble)
2. Short stubble with straw chopped & retained (15 cm standing stubble)
3. Tall stubble with straw removed (30 cm standing stubble)
4. Tall stubble with straw chopped & retained (30 cm standing stubble)
5. Fall-tilled wheat residue (straw chopped and returned prior to tillage)
6. Fall-burned wheat stubble (straw chopped and returned prior to burn)

Agronomic Info:

Standard recommended agronomic protocols were adopted for each crop. Fertilizers were applied according to soil test results. Herbicide were applied, when required.

Study 1: Effect of Residue Management and Planting Date on Soybean.

A four-year study was initiated in 2017 near Brandon, MB (AAFC-Brandon), Carberry, MB (Canada-Manitoba Crop Diversification Centre), and Indian Head, SK (Indian Head Agricultural Research Foundation) to assess the effect of residue management practices on the following soybean crop. Treatments consisted of a factorial combination of six residue management treatments [fall-tilled; fall-burned; short stubble (+straw); tall stubble (+straw); short stubble (-straw); tall stubble (-straw)], and two soybean planting dates. A split plot design with four replicates was employed, with planting date assigned to main plots and residue treatments assigned to subplots (Fig. 1). Residue treatments were imposed on wheat (Brandon, Carberry) or canaryseed (Indian Head) stubble in fall 2017, and these plots planted to soybean in 2018. This will be repeated in 2018/19 and 2019/20. Immediately after residue treatments were imposed, self-logging temperature sensors (Model DS1922L, iButton Temperature Logger) were installed at a 5 cm depth in each plot to monitor soil temperature until spring.

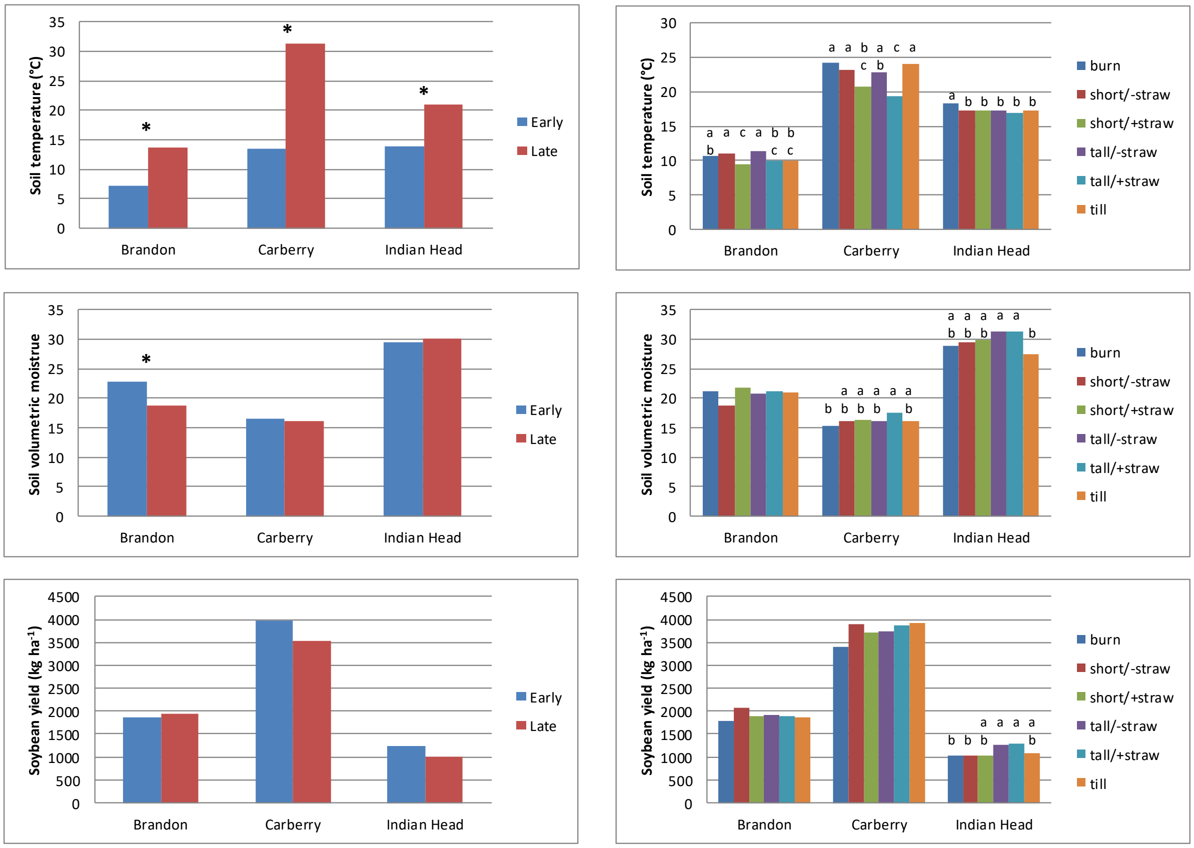


Figure 1. Experimental field design.

In 2018, soybean (R2, 00.3, 2375 CHU) was planted into residue treatments in early or late May (May 8-10 or 24-26). Yields varied considerably among sites as a function of growing season conditions (Fig. 2). Preliminary analysis indicated no date x residue management interactions, therefore main effects of date and residue management are reported herein. Soil temperature at soybean planting was higher for later seeding dates at all sites, and varied with residue management. Soil temperatures were higher for burned than all other treatments at Indian Head; for burned, tilled and short stubble (-straw) treatments than for short or tall stubble (+straw) at Carberry; and for burned and short and tall stubble (-straw) than for short stubble (+straw) at Brandon (Fig. 2). Soil moisture at planting was higher for tall stubble (+straw) than burned treatments at Carberry, and for tall stubble (+/- straw) than tilled treatments at Indian Head (Fig. 2).

Treatments had no effect on final plant density which ranged from an average of 35 to 41 plants m-2 across sites. Despite soil temperature and moisture differences observed at planting, neither seeding date nor residue treatments affected soybean yield except at Indian Head where the tall stubble treatments that had been associated with higher moisture at seeding resulted in higher yields than the burned and short stubble (-straw) treatments (Fig. 2). Treatments had limited effects on test weight, seed weight, and % protein. Early planting increased % oil at 2 of 3 sites, while residue management effects appeared to vary among sites in 2018.

Figure 2. Residue management treatments established near Carberry, MB at time of iButton installation (left) and near Brandon, MB (right).

Study 2: Temperature effects on soybean emergence under controlled conditions.

To complement the field studies, a series of controlled environment studies are ongoing to more closely assess temperature effects on early soybean development. Studies will be conducted during the winter over the duration of the project based on availability of the specialized controlled environment facility at AAFC-Saskatoon.

Preliminary testing of methodologies was done in 2017 to refine experimental protocols. In January 2018, a series of four studies were initiated to assess temperature effects on soybean germination and emergence. A completely randomized design with four replicates was employed to assess the effect of seven temperature treatments (ranging from 5 C to 20 C, in increments of 2.5 C) on small, medium and large size seed selected from one seedlot of untreated soybean seed. A subsequent study assessed the effect of temperature on the germination and emergence of two cultivars, each grown under varying growing conditions. To verify and augment results from these preliminary trials, a second set of experiments was initiated in January 2019. The first 2019 study assessed the effect of temperatures ranging from 5 C to 20 C, either held constant or adjusted by 5 C diurnally, on an untreated soybean seedlot; however, overall emergence was low in this trial although germination tests had indicated 100% germination. Preparations are now underway for a follow-up study to again assess a range of temperatures adjusted by 5 C diurnally using various sizes of soybean seed.

Effect of fertilizer management dry bean agronomic and economic performance on Pinto and Black Bean

Project duration: May 2021 – September 2021

Objective: To determine the effect of rate of fertilizer N, applied with and without inoculant, on the growth, yield and quality of solid-seeded dry bean in southwestern Manitoba.
To assess white mould incidence and severity under irrigation.
To determine the effect of fertilizer P rate and placement on dry bean performance.

Collaborators: Manitoba Pulse & Soybean Growers.

Results:

This project is part of a long-term, multi-site study led by Ramona Mohr. Research findings will be made available by Ramona Mohr and team.

Background:

In Manitoba, dry bean acreage has grown from 90,000 acres in 2015 to 168,300 acres in 2019, with total production ranging from 80,000 to 110,000 metric tonnes over this period (Statistics Canada 2020). Increasing interest in dry bean in southwestern Manitoba, which has not traditionally been a major bean-producing area, has generated questions as to optimum management practices for the growing conditions in this region. However, as a smaller acreage crop, comparatively little research has been done on dry bean production in Manitoba, particularly for the southwest region.

Nitrogen: While dry bean is a pulse crop, one of the key inputs in dry bean production systems is nitrogen (N) fertilizer. Unlike crops like pea and soybean which derive their N through symbiotic N fixation, dry bean is generally considered to be a poor N-fixer. As such, N fertilizer application remains the most common N management practice on-farm even though commercial inoculants are available. While recent studies in the Carman and Portage areas of Manitoba have assessed the effect of broadcast, incorporated N on pinto and navy bean grown on 15” row spacings (MacMillan 2018), information is lacking regarding crop responses to sidebanded N in solid-seeded dry bean and regarding the relative effectiveness of inoculant under Manitoba conditions as an N management strategy.

Phosphorus: While adequate P nutrition is important to optimize dry bean yield, little research has been conducted in Manitoba to assess crop P response under field conditions. In Manitoba studies conducted in the late 1990's, crop responses to fertilizer P were somewhat inconsistent (McAndrew, 2000).

Methodology:

Site Selection: A site with wheat (cereal) stubble with no recent history of dry bean was selected. A site with low soil test N that is expected to be responsive to fertilizer N application, was required. The study was conducted under rain-fed conditions. Study 1a was conducted at Brandon site under irrigated conditions to support disease development. A site with low soil test P (Olsen P) was required to increase the potential for a crop response to fertilizer P application.

Experimental design: Separate but otherwise identical trials were conducted for each of black and pinto bean at each site, for both the N and P experiments. Black and pinto bean trials were established adjacent to one another. Experimental design was RCBD with 4 reps; with treatments consisting of a factorial combination of five N rates, applied with or without inoculant and two additional treatments of 35, 105 kg N/ha, as sidebanded SuperU:

- N rate: 0, 35, 70, 105, 140 kg N/ha, as sidebanded urea
- Inoculants: +/- commercial inoculant, BOS self-adhering peat (BOS Inoculants – Nutriag)

Total plots per experiment = 48 (12 trt x 4 reps)

*ie. Two separate experiments – one consisting of 48 plots of pinto beans, and one consisting of 48 plots of black beans - will be established at each site.

Treatment	kg N/ha applied	+/- inoculant
1	0	+ inoc
2	0	- no inoc
3	35 kg N/ha	+ inoc
4	35 kg N/ha	- no inoc
5	70 kg N/ha	+ inoc
6	70 kg N/ha	- no inoc
7	105 kg N/ha	+ inoc
8	105 kg N/ha	- no inoc
9	140 kg N/ha	+ inoc
10	140 kg N/ha	- no inoc
11	35 kg N/ha as SuperU	+ inoc
12	105 kg N/ha as SuperU	+ inoc

RCBD with 4 reps; with treatments consisting of five N rates, with all treatments receiving commercial inoculant (BOS self-adhering peat inoculum as outlined above):

- N rate: 0, 35, 70, 105, 140 kg N/ha, in the form of an enhanced efficiency N fertilizer (to reduce leaching potential under irrigated conditions)

Total plots per experiment = 20 (5 trt x 4 reps)

*ie. Two separate experiments – one consisting of 20 plots of pinto beans, and one consisting of 20 plots of black beans - will be established at each site.

RCBD with 4 reps; with treatments consisting of a factorial combination of four P rates, seed-placed or side-banded:

- P rate: 0, 20, 40, 60 kg P_2O_5/ha, as monoammonium phosphate (11-52-0)
- Placement: seed-placed or side-banded

Total plots per experiment = 32 (8 trt x 4 reps)

*ie. Two separate experiments – one consisting of 32 plots of pinto beans, and one consisting of 32 plots of black beans - will be established at each site.

Treat	kg P_2O_5/ha	Placement
1	0	seed placed
2	0	sideband
3	20	seed placed
4	20	sideband
5	40	seed placed
6	40	sideband
7	60	seed placed
8	60	sideband

General Management:

Plot size: The plot size was 4 m wide and 10 m long.

Seeding: Direct seed into standing stubble; solid-seeded/narrow row spacing.

Seeder: Small plot Wintersteiger Victory Planter.

Cultivar: Cultivars with good agronomic characteristics well-adapted to the region:
Black bean: Blackstrap
Pinto bean: Windbreaker

Inoculant: For inoculated treatments, commercially-available rhizobia (BOS self-adhering peat, BOS Inoculants – Nutriag) was applied at recommended rates and using recommended methods, as appropriate for dry bean (*Rhizobium leguminosarium* biovar *phaseoli*).

Seeding rate: Pinto and Black: 90-120,000 plants/ac (22-30 live plants/m^2)

Adjusted seeding rate for germination and seed size to achieve goal plant density. Seeding rate (kg/ha) = Seed weight (g/1000 seeds) * Target plant population (plants per square metre) divided by % expected emergence (eg. 80).

Seeding date: Dry beans were seeded when soil temperature was consistently above 15°C. May 31 and June 01

Seeding Depth: 1.5"

Rolling: Beans were rolled after seeding and prior to emergence.

Agronomic Info:

Standard recommended agronomic protocols were adopted for each crop. Fertilizers were applied according to soil test results. Herbicide were applied, when required.

Evaluation of Corn Hybrids Adapted to Carberry Region

Project duration: May 2021 – October 2021

Objectives: Screening lines of parental corn for Western Canada corn development.

Collaborators: Aida Kebede – Agriculture and Agri-Food Canada

Results:

This project is part of a long-term, multi-site study led by Aida Kebede. Research findings will be made available by Aida Kebede and team.

Background:

The objective will be achieved using conventional corn breeding methodology enhanced by double haploid inbred production and specialized screening techniques for cold tolerance and disease resistance. The trial is being conducted at sites across five Canadian provinces. The anticipated impact of developing earlier maturing, cold tolerant corn will expand the acreage of corn production in Canada.

Project Findings:

These data were generated for AAFC; however, due to intellectual property issues pertaining to Plant Breeders' Rights, results for individual lines are not provided in this report. For more information on this variety trial

Materials & Methods:

Experimental Design	Random Complete Block Design
Entries	30 varieties
Replications	03
Seeding	May 10, 2021
Harvest	October 21, 2021
Data collected	**Date collected**
% Emergence	May 31
Tasseling Date	Jul 05 – Aug 02
Silking Date	Jul 12 – Aug 20
Ear Formation	Aug 02 – Aug 27
Heights	Aug 05

Lodging	October 21, 2021
Yield	October 21, 2021
Moisture	October 21, 2021

Agronomic Info:

Standard recommended agronomic protocols were adopted for each crop. Fertilizers were applied with respect to soil test results. Herbicide were applied, when required.

Evaluation/selection of Parent Lines Adapted to Carberry Region

Project duration	May 2021 – October 2021
Objectives	To evaluate parent lines adapted to Carberry region.
Collaborators	Aida Kebede – Agriculture and Agri-Food Canada

Background:

The objective will be achieved using conventional corn breeding methodology enhanced by double haploid inbred production and specialized screening techniques for cold tolerance and disease resistance. The trial is being conducted at sites across five Canadian provinces. The anticipated impact of developing earlier maturing, cold tolerant corn will expand the acreage of corn production in Canada.

Project findings:

This project is part of a long-term, multi-site study led by Aida Kebede. Research findings will be made available by Aida Kebede and team.

Materials & Methods:

Experimental Design	500 row observation nursery
Entries	500
Seeding	May 10, 2021
Termination	October 22, 2021

Data collected	**Date collected**
% Emergence	May 31
Tasseling Date	Jul 05 – Aug 02
Silking Date	Jul 12 – Aug 20
Ear Formation	Aug 02 – Aug 27
Heights	Aug 05

The nursery was terminated on October 22 after collecting required data and observations.

Agronomic info:

Standard recommended agronomic protocols were adopted for each crop. Fertilizers were applied with respect to soil test results. Herbicide were applied, when required.

Evaluation of Corn for Goss's Wilt Resistance

Project duration May 2021 – October 2021

Objectives Evaluation of hybrids adapted to Carberry region for Goss's Wilt Resistance.

Collaborators Aida Kebede – Agriculture and Agri-Food Canada

Background:

Goss's wilt has been in Western Canada for only a few years, but plant pathologists, agronomists and breeders are already working to learn more about this corn disease and enhance management options for Prairie growers. Goss's wilt is caused by the bacterium Clavibacter michiganensis subspecies nebraskensis. The bacteria overwinter on infected stubble, so the disease is a concern in fields with shorter corn rotations. But even in fields with longer rotations, it can be a problem because corn stubble is very mobile in the fall, blowing across the roadways and carrying the disease to new fields. The disease usually occurs in a non-systemic form in which the pathogen infects the plant's foliage. The bacterium enters the plant through a wound from hail or wind or sand blasting. The infection usually appears on the upper canopy at first. Then with high humidity and rain splash, the disease moves very rapidly throughout the plant, usually from the top down.

The disease also has a systemic form where the bacteria infect the corn plant's vascular tissues. A relatively new disease, Goss's wilt was first identified in Nebraska in 1969. In the 1970s and early 1980s, the disease spread through Nebraska and into some surrounding states. Then very little disease occurred until about 2006 when Goss's wilt resurged and began spreading into new areas. Goss's is continuing to expand. In the U.S., it has moved right across most of the Corn Belt as far south as Louisiana. It moved into the southwestern edge of Michigan, so it has moved east of the Mississippi River. In Western Canada, the disease was first found in Manitoba in 2009 and in Alberta in 2013.

In Manitoba, over the past five or six years, we've seen anything from an insignificant infection which doesn't have any yield loss all the way up to the most severe fields experiencing close to 50 to 60 per cent yield loss. So it can be very impactful. The severity of the disease depends on weather conditions, the amount of inoculum in the field and the susceptibility of the hybrid to Goss's wilt. Fortunately, late summer conditions in Manitoba didn't favour the disease. Manitoba corn producers have found the disease in many fields in mid to late July.

Managing Goss's wilt:

Symptoms of Goss's wilt may sometimes be confused with problems like drought, frost damage or sunscald, or with other diseases like Stewart's wilt or northern corn leaf blight. To identify Goss's wilt, look for greyish brown lesions with water-soaked margins when you are walking through your corn field. The telltale sign of Goss's wilt is the black freckling that shows up along the lesion edges. If you scout during drier conditions, you will see that black freckling. If conditions are damp, like a heavy dew in the early morning, you will sometimes see a glossy sheen on the lesion.

Fungicides are not effective for controlling Goss's wilt because it is a bacterial disease. Two main recommendations for managing the disease are:

1. Lengthen your crop rotation. However, that may not always be enough to prevent the disease if neighbouring fields have Goss's wilt.
2. The other key is to grow a resistant corn variety.

At this time there isn't any third-party testing to compare varieties from different companies, but most companies have a range of tolerances to Goss's wilt, so you can check with your seed supplier for information.

Fig. 1 The bacterium enters the corn plant through a wound on a leaf and then spreads from there.

Project findings:

This project is part of a long-term, multi-site study led by Aida Kebede. Research findings will be made available by Aida Kebede and team.

Materials & Methods:

Experimental Design	100 row observation nursery
Entries	100
Seeding	May 10, 2021
Termination	October 22, 2021
Data collected	**Date collected**
% Emergence	May 31
Tasseling Date	Jul 05 – Aug 02
Silking Date	Jul 12 – Aug 20
Ear Formation	Aug 02 – Aug 27
Heights	Aug 05

The nursery was terminated on October 22 after collecting data for Goss's Wilt observations.

Agronomic info:

Standard recommended agronomic protocols were adopted for each crop. Fertilizers were applied with respect to soil test results. Herbicide were applied, when required.

Manitoba Oilseed Sunflower Variety Performance Testing (VPT)

Project duration May 2021 – September 2021

Objectives Evaluate candidate sunflower hybrids for regional variety adaptation and performance.
Collect sound, unbiased, replicated data on hybrids that will be or currently are available in the marketplace.

Collaborators Daryl Rex – Manitoba Crop Alliance

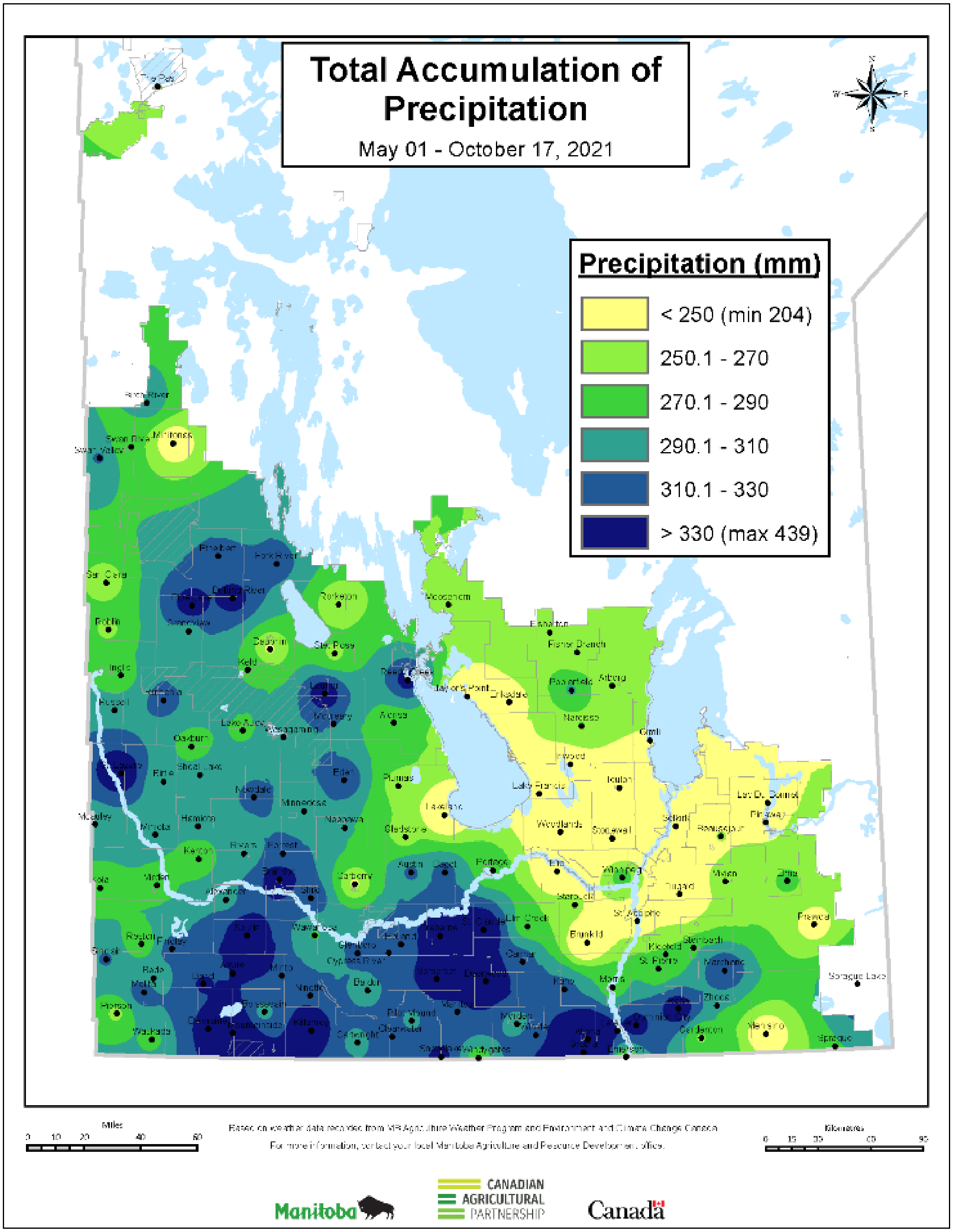
Background:

The Manitoba Sunflower Variety Performance Trials (VPT) were organized and conducted by the Manitoba Crop Alliance (MCA) in co-ordination with Manitoba Agriculture. 2021 was the 15th year that these trials have been coordinated and serve to continue as an important tool for sunflower growers for generating 3rd party, impartial hybrid performance data within Manitoba. The trials included hybrids that are either commercially available and registered within Canada or new hybrids that are being considered for registration. In 2021, the MCA coordinated the VPTs at 4 locations within the province: Carberry, Elm Creek, Melita and Rossendale.

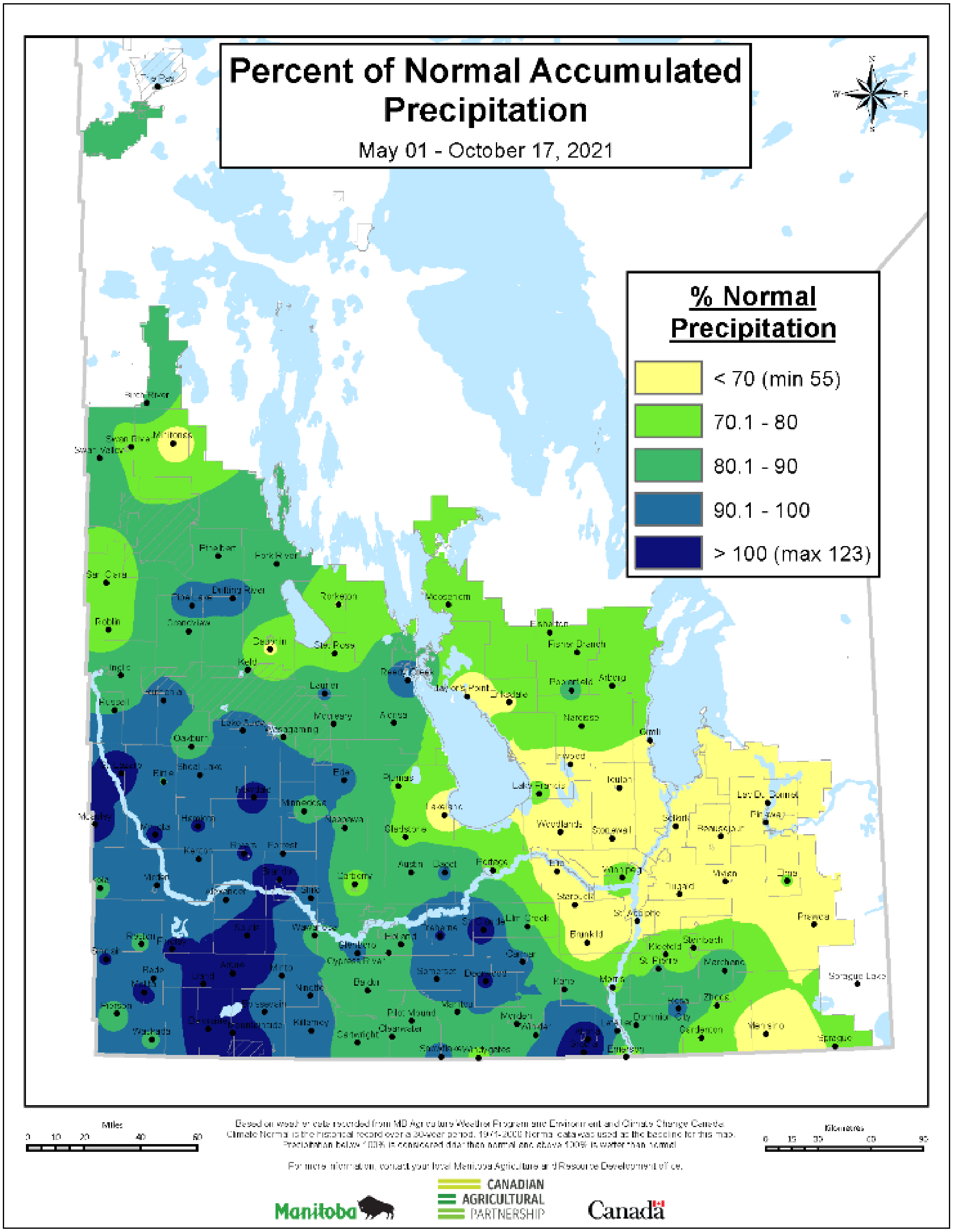
The 2021 growing season was dry for the majority of the growing season. The trials were all initially planted the first part of May, but due to herbicide damage at the Elm Creek location the trials were replanted on June 4. The smaller seeded oilseed hybrids seemed to germinate and emerge more evenly than the larger seeded confection hybrids, creating more plant population variability in the confection trial. Variability was noted throughout the season due to the previous crop residue and soil moisture availability. Birds did not seem to be much of an issue in the trials this year. Both the Melita and Carberry locations desiccated the trials prior to harvesting.

All the trials were harvested, but due to a high CV the confection trial data at Carberry was not published. A big “Thank-you” to all the producers, seed companies and site contractors that provided the land for the trials, seed of the hybrids being tested, and the hard work conducting the trials and generating the trial results.

Precipitation (mm)



Percent Normal Precipitation (mm)



Results:

These varieties were tested and data donated by the Manitoba Crop Alliance. Oil Sunflower markets - include birdfood, oil crush and de-hull. Variety selection become more important when trying to capture de-hull markets. Choose varieties with better de-hull ratio, larger size and higher test weight. Environment will contribute greatly to final product.

SUNFLOWERS - OIL TYPE

Comments:

These varieties were tested and data donated by the Manitoba Crop Alliance (MCA).
Oil Sunflower markets - include birdfood, oil crush and de-hull. Variety selection becomes more important when trying to capture de-hull markets. Choose varieties with better de-hull ratio, larger size and higher test weight. Environment will contribute greatly to final product.
Plant population and environment will contribute greatly to the final product.
Percent (%) oil content was unavailable at press time, visit www.mbcropalliance.ca for more detail.

Variety Descriptions

Company	Variety	Herbicide/Disease Tolerance [1]	Site Years	Yield (% check)	Maturity[2] (+/- check)	Height (inches)	% Oil	Oil Type[3]	Test Weight[4]
Pioneer Hi-Bred	P63HE60	ExSun / DM	15	101	3	-4	45.5	HO	31.7
Pioneer Hi-Bred	P63ME80	ExSun / DM	18	100	0	0	48.4	NS	30.9
NuSeed	N4H302 E	ExSun	9	94	-4	2	44.0	HO	28.6
NuSeed	N4HM354	CL / DM	15	112	-2	-7	47.7	NS	33.0
NuSeed	Talon	ExSun	18	102	-3	-3	44.1	NS	28.2
Experimental lines tested/proposed for registration in Canada									
Pioneer Hi-Bred	P63HE501	ExSun	5	106	-1	2	42.9	HO	28.1
CHS Sunflower	8D310CL	CL	5	113	3	5	39.5	CO	24.8
NuSeed	N4H161 CL	CL	3	98	-5	-7	44.0	HO	28.0
NuSeed	NLKP74437	CL	3	120	-1	7	44.6	NS	27.7
WinField United | CROPLAN	CP432E	ExSun	5	114	-2	0	43.4	NS	28.1
WinField United | CROPLAN	CP455E	ExSun	5	126	2	2	45.2	HO	27.8
	CHECK CHARACTERISTICS								
	P63ME80		18	3012	126	65			
			site years	lb/ac	days	inches			

1 Genetic traits include CL = Clearfield herbicide tolerance; ExSun = Express SG herbicide tolerance; DM = Downy Mildew Resistance.
2 Physiological maturity for sunflowers is R9, where the bracts on the head are almost completely brown.
3 Oil Type designations are NS=NuSun; HO=High Oleic; CO = ConOil
4 Test weights reported in lbs per Avery (Canadian) bushel.

Site Comparisons

	Carberry					Elm Creek				
Hybrid	Yield (lb/ac)	Moisture (%)	Maturity[1] (days to R9)	Test Wt[2] (lb/bu)	Oil (%)	Yield (lb/ac)	Moisture (%)	Maturity[1] (days to R9)	Test Wt[2] (lb/bu)	Oil (%)
N4H302 E	2265	15.1	139	26.4	47.7	1612	12.9	110	29.7	45.3
N4HM354	2573	12.8	139	27.5	50.6	1799	13.9	106	32.6	48.3
Talon	2713	14.9	142	26.4	46.3	1647	15.0	104	29.0	44.6
P63HE60	2546	12.7	140	26.9	47.4	1212	13.3	113	29.7	42.1
P63ME80	2714	12.5	142	29.3	48.9	1251	13.6	114	28.8	41.9
Experimental lines being tested/proposed for registration in Canada										
8D310CL	3104	15.5	145	27.1	42.7	1858	13.8	115	28.2	36.7
P63HE501	2270	12.1	139	28.4	45.0	1679	13.0	105	32.6	42.2
N4H161 CL	2266	14.8	144	27.3	46.2	1094	11.2	92	33.6	45.1
NLKP74437	2881	20.3	139	26.5	45.8	1659	15.1	114	28.0	40.4
CP432E	2826	12.5	142	28.4	46.4	1316	12.6	105	30.9	39.4
CP455E	3379	16.4	142	27.4	46.2	1649	14.1	114	31.5	41.7
Site Average	2685	14.5	141	27.4	46.7	1525	13.5	108	30.4	42.5
CV%	7.4					10.2				
Sign Diff	Yes					Yes				
LSD (0.05)	444					265				
Planting Date	12-May					04-Jun				
Desiccation Date	29-Sep					--				
Harvest Date	12-Oct					22-Oct				

	Melita					Rossendale				
Hybrid	Yield (lb/ac)	Moisture (%)	Maturity[1] (days to R9)	Test Wt[2] (lb/bu)	Oil (%)	Yield (lb/ac)	Moisture (%)	Maturity[1] (days to R9)	Test Wt[2] (lb/bu)	Oil (%)
N4H302 E	2769	8.0	--	30.5	48.1	1180	9.6	115	21.5	39.8
N4HM354	2871	7.7	--	32.9	50.0	1405	9.1	114	29.1	46.1
Talon	2794	7.9	--	28.6	47.1	1336	9.5	113	20.6	37.6
P63HE60	2374	8.4	--	30.1	44.4	1548	9.2	114	27.7	40.3
P63ME80	2381	8.5	--	30.3	47.2	1270	8.9	119	25.8	44.7
Experimental lines being tested/proposed for registration in Canada										
8D310CL	2769	9.0	--	27.8	40.5	1556	8.9	120	19.3	35.2
P63HE501	2946	7.8	--	32.0	42.9	1495	9.1	117	25.8	39.2
N4H161 CL	2610	8.5	--	31.1	46.6	1334	8.7	108	25.7	39.1
NLKP74437	3242	9.7	--	31.0	46.3	1537	9.1	121	27.7	41.8
CP432E	3065	8.1	--	31.1	44.4	1678	10.0	115	26.2	40.1
CP455E	3412	9.0	--	31.3	48.0	1837	9.0	119	26.3	43.9
Site Average	2839	8.4		30.6	46.0	1471	9.2	116	24.9	40.7
CV%	8.4					14.5				
Sign Diff	Yes					Yes				
LSD (0.05)	405					365				
Planting Date	12-May					12-May				
Desiccation Date	21-Sep					28-Sep				
Harvest Date	06-Oct					11-Oct				

1 Physiological maturity for sunflowers is R9, where the bracts on the head are almost completely brown.
2 Test weights are reported in lbs per Avery (Canadian) bushel.
Refer to the MCA website at www.mbcropalliance.ca for more details.

Confectionary Sunflower Variety Performance Testing

Project duration	May 2021 – September 2021
Objectives	Evaluate candidate sunflower hybrids for regional variety adaptation and performance. Collect sound, unbiased, replicated data on hybrids that will be or currently are available in the marketplace.
Collaborators	Daryl Rex – Manitoba Crop Alliance

Background:

The Manitoba Sunflower Variety Performance Trials (VPT) were organized and conducted by the Manitoba Crop Alliance (MCA) in co-ordination with Manitoba Agriculture. 2021 was the 15th year that these trials have been coordinated and serve to continue as an important tool for sunflower growers for generating 3rd party, impartial hybrid performance data within Manitoba. The trials included hybrids that are either commercially available and registered within Canada or new hybrids that are being considered for registration. In 2021, the MCA coordinated the VPTs at 4 locations within the province: Carberry, Elm Creek, Melita and Rossendale.

The 2021 growing season was dry for the majority of the growing season. The trials were all initially planted the first part of May, but due to herbicide damage at the Elm Creek location the trials were replanted on June 4. The smaller seeded oilseed hybrids seemed to germinate and emerge more evenly than the larger seeded confection hybrids, creating more plant population variability in the confection trial. Variability was noted throughout the season due to the previous crop residue and soil moisture availability. Birds did not seem to be much of an issue in the trials this year. Both the Melita and Carberry locations desiccated the trials prior to harvesting.

All the trials were harvested, but due to a high CV the confection trial data at Carberry was not published. A big "Thank-you" to all the producers, seed companies and site contractors that provided the land for the trials, seed of the hybrids being tested, and the hard work conducting the trials and generating the trial results.

Results:

These varieties were tested and data donated by the Manitoba Crop Alliance. All sunflowers varieties listed are susceptible to sclerotinia and sunflower rust strains present in Manitoba. Genetic resistance to verticillium wilt is rated as moderately susceptible to moderately resistant for all sunflower varieties presented.

SUNFLOWERS - CONFECTIONARY TYPE

Comments:

These varieties were tested and data donated by the Manitoba Crop Alliance (MCA).
All sunflowers varieties listed are susceptible to sclerotinia and sunflower rust strains present in Manitoba.
Genetic resistance to verticillium wilt is rated as moderately susceptible to moderately resistant for all sunflower varieties presented.
Plant population and environment will contribute greatly to the final product.

Variety Descriptions

Company	Hybrid	Genetic Traits [1]	Site Years	Yield % Check	Maturity [2] (+/- check)	Height (inches)	Seed Sizing (%) [3] >22/64	>20/64	<20/64
NuSeed	6946 DMR	DM	31	100	0	0	35	30	33
NuSeed	Panther DMR	DM	39	100	0	-2	53	26	17
Experimental lines tested/proposed for registration in Canada									
CHS Sunflower	20-EXP3	ExSun	3	90	6	-1	51	24	25
CHS Sunflower	21-EXP1	ExSun	3	94	6	4	26	35	38
MCA	EX 35957	ExSun	6	110	-3	2	53	21	26
NuSeed	N6L377 CL	CL	3	97	1	-1	47	25	29
	CHECK CHARACTERISTICS								
	6946 DMR		31	3022	121	65			
			site years	lb/ac	days	inches			

1 Genetic traits include CL = Clearfield tolerance; ExSun = Express tolerance; DM = Downy Mildew Resistance.
2 Physiological maturity for sunflowers is R9, where the bracts on the head are almost completely brown.
3 Totals may not add to 100% due to rounding; information based off three sites at Elm Creek, Melita, and Rossendale.
Refer to the MCA website at www.mbcropalliance.ca for more details.

Site Comparisons

	Elm Creek						Melita						Rossendale					
	Yield	Maturity[1]	2021 Seed Sizing (%)[2]			Test Wt	Yield	Maturity[1]	2021 Seed Sizing (%)[2]			Test Wt	Yield	Maturity*	2021 Seed Sizing (%)[2]			Test Wt
Hybrid	(lb/ac)	(days to R9)	>22/64	>20/64	<20/64	(lb/bu A)	(lb/ac)	(days to R9)	>22/64	>20/64	<20/64	(lb/bu A)	(lb/ac)	(days to R9)	>22/64	>20/64	<20/64	(lb/bu A)
6946 DMR	1934	106	1	4	95	25.0	2670	--	45	29	26	26.1	1896	113	19	46	34	17.8
Panther DMR	1672	101	8	28	65	22.7	2968	--	62	23	15	25.7	1925	114	35	42	23	16.5
Experimental lines being tested/proposed for registration in Canada																		
20-EXP3	1339	114	10	33	57	17.4	2762	--	75	17	8	23.4	1723	116	67	21	11	16.3
21-EXP1	1278	113	18	30	51	13.4	3166	--	33	40	27	23.8	1697	118	28	36	35	16.5
EX 35957	1749	103	1	16	84	27.3	2771	--	62	20	19	26.5	1674	113	57	31	12	17.8
N6L377 CL	1566	106	8	27	66	21.6	2811	--	66	22	12	22.8	1935	114	66	27	8	14.6
Site Average	1637					21.7	2858					24.7	1808	115				16.6
CV%	11.8						12.1						11.0					
Sign Diff	Yes						No						No					
LSD (0.05)	344						--						--					
Planting Date	04-Jun						12-May						12-May					
Desiccation Date	--						--						28-Sep					
Harvest Date	22-Oct						06-Oct						11-Oct					

1 Physiological maturity for sunflowers is R9, where the bracts on the head are almost completely brown.
2 Totals may not add to 100% due to rounding
Refer to the MCA website at www.mbcropalliance.ca for more details.

Manitoba Corn Hybrid Performance Trials

Project duration	May 2021 – October 2021
Collaborators	Daryl Rex – Manitoba Crop Alliance, Manitoba Corn Committee.
Objectives	Evaluate candidate corn hybrids for regional variety adaptation and performance. Collect sound, unbiased, replicated data on hybrids that will be or currently are available in the marketplace.

Background:

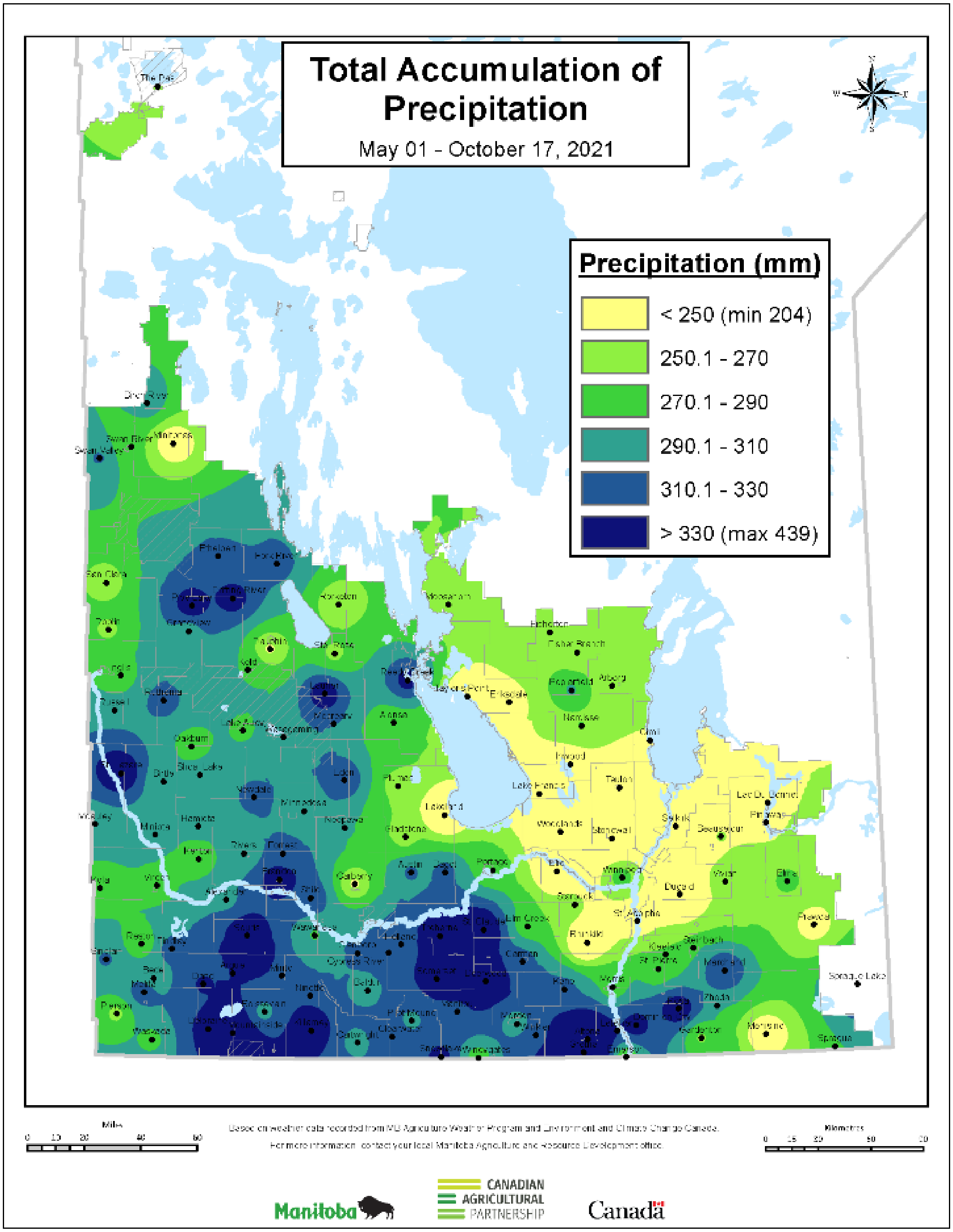
The 2021 growing season was once again a dry one. Some would say it was drier than 2020. Seedling emergence and growth was highly variable within a commercial field as well as within the corn trials. This is why replication is used in the small plot trials. Variability resulted from differences in previous crop residue as well as soil moisture availability. At the end of the season, 2 out of the 10 corn trials were lost due to a high CV and variability within the hybrids in the trials.

There were 7 grain corn trial locations planted with 5 trials producing harvest data. The 7 locations were located near: Carman, Rosebank, Horndean, MacGregor, St. Pierre, Carberry and Melita. Both the Carberry and Melita trials were lost due to high trial CVs.

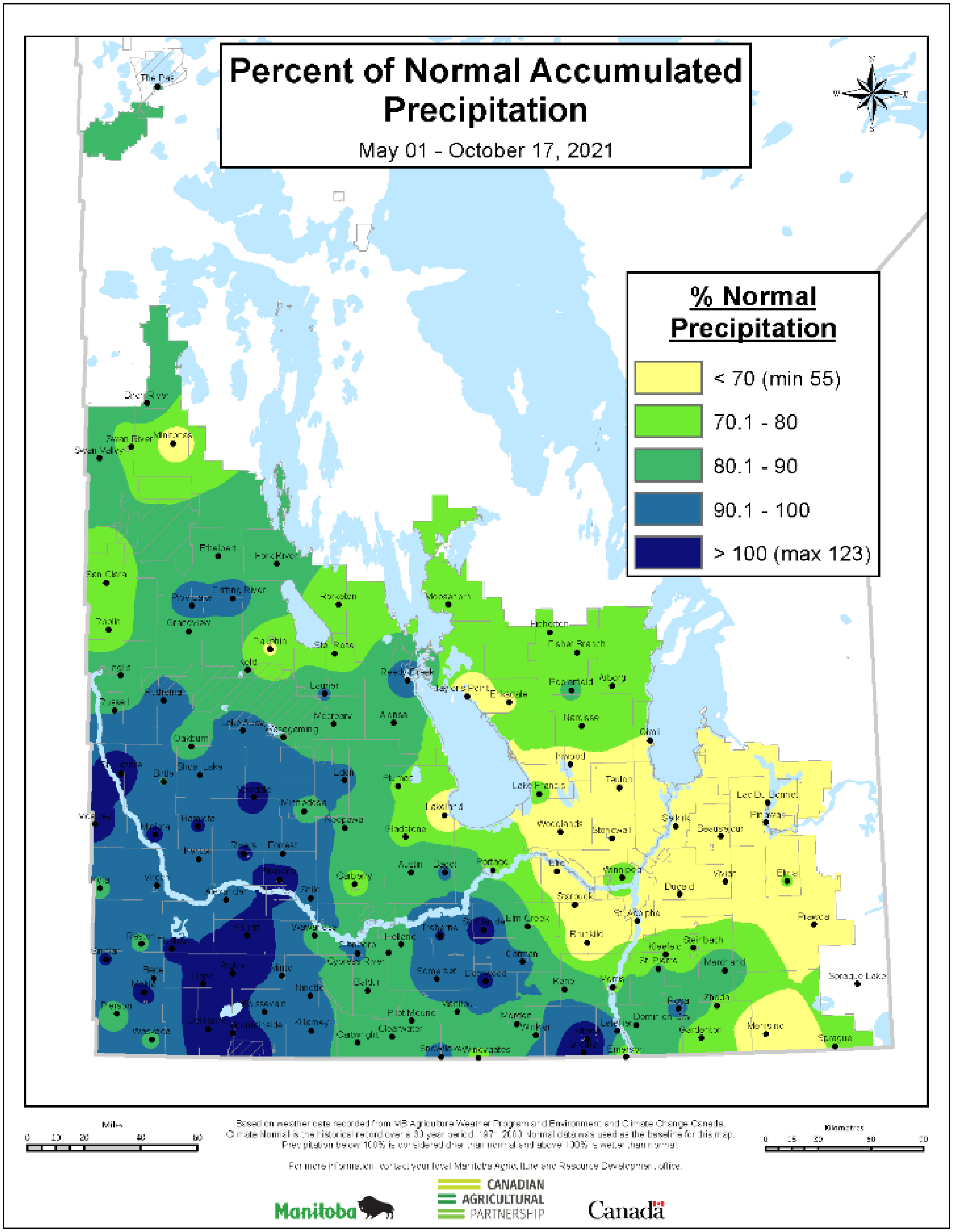
There was great participation in the grain corn trials. The long season test had 69 hybrids being tested; the mid-season trials had 60 hybrids; and the short season trials had 29 hybrids.

Three Silage trial locations were planted in 2021. These were located near Elm Creek, St. Pierre and Arborg. There were 64 hybrids being tested at both the Elm Creek and St. Pierre locations and 30 hybrids at Arborg. All 3 trials were taken to yield. Quality samples from each trial were collected and submitted to Central Testing Labs (Winnipeg) for moisture determination and feed quality analysis. The Milk2006 worksheet was used to evaluate corn silage hybrid feed quality performance.

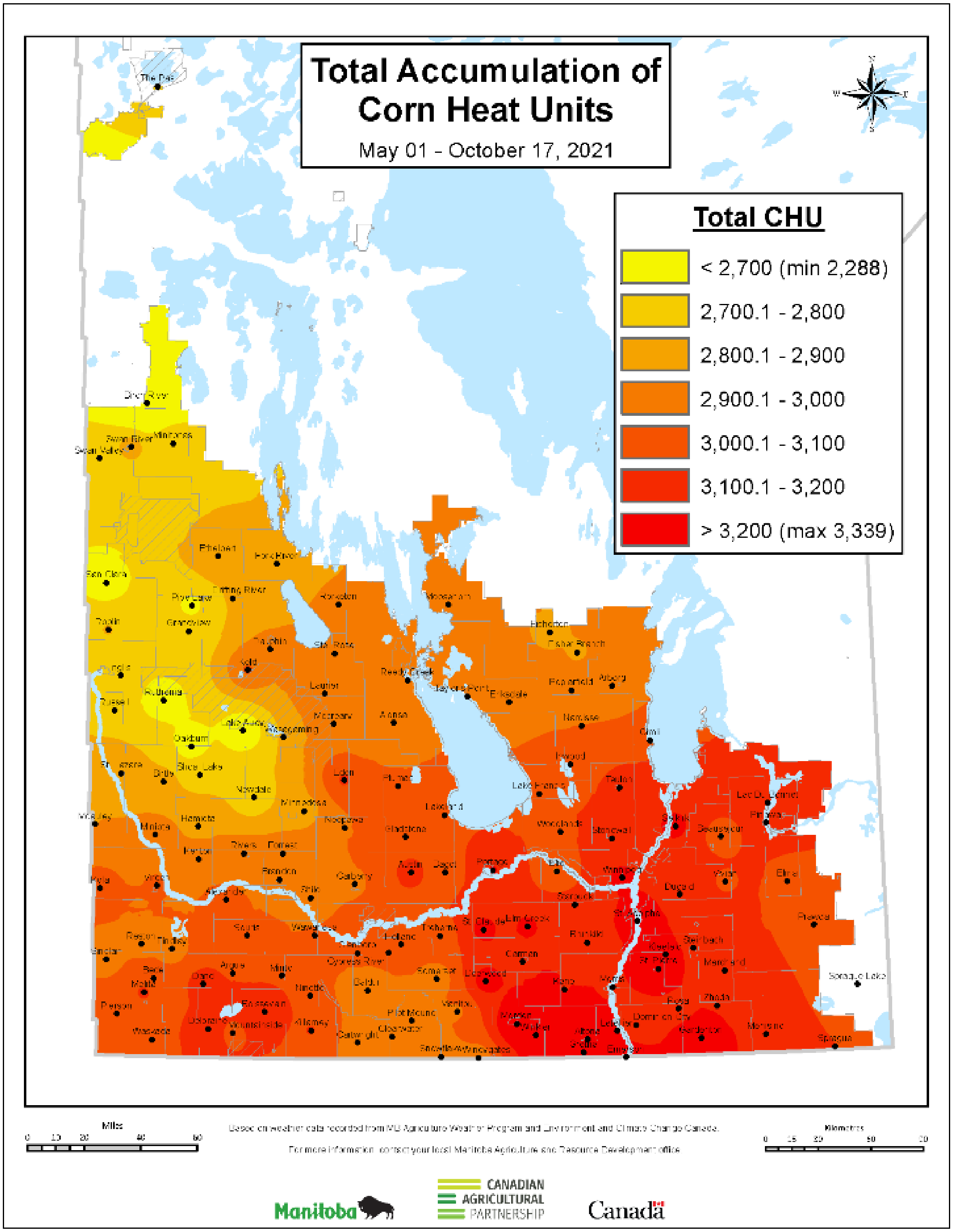
Total Accumulation of Precipitation (mm)



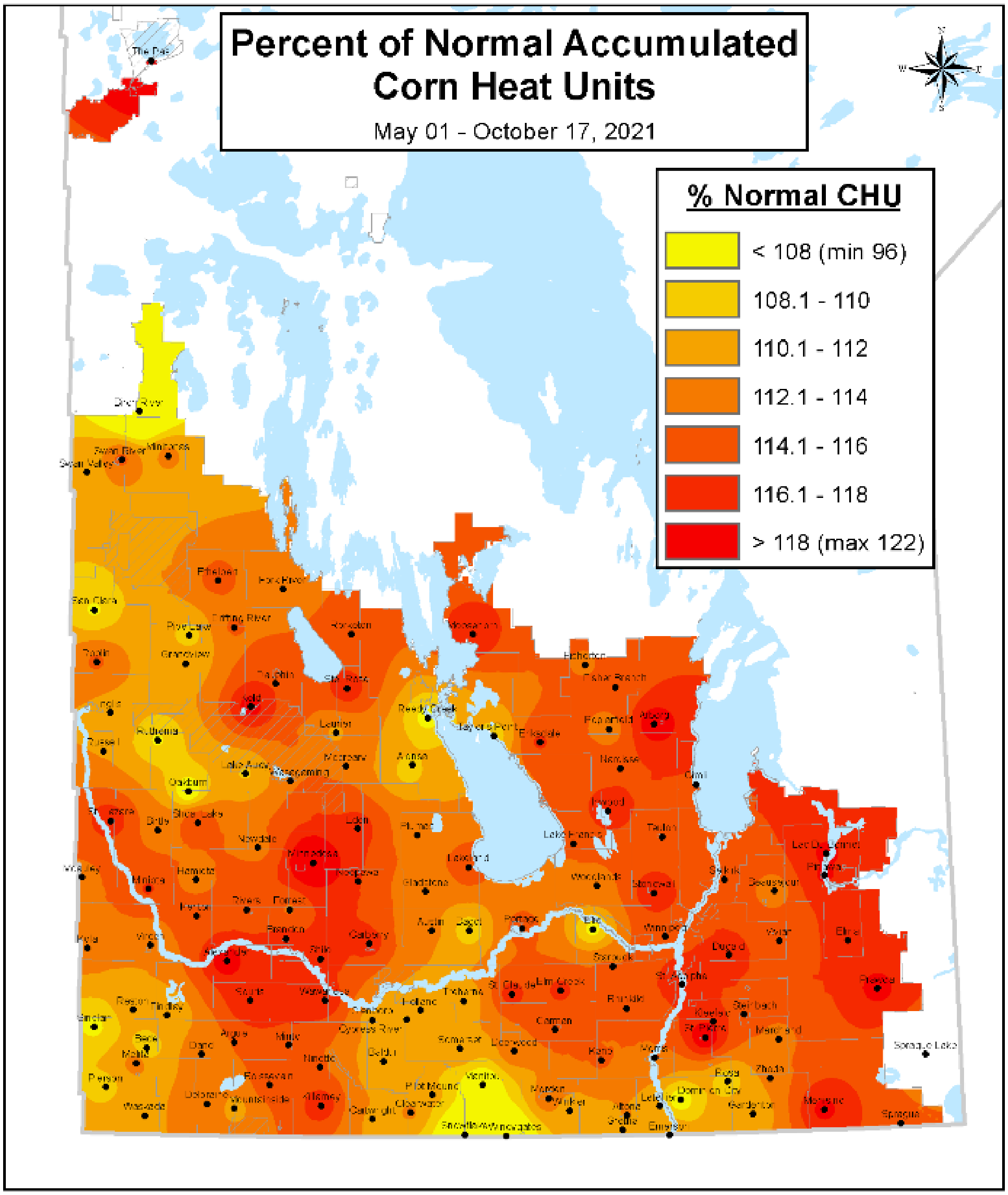
Total Accumulation of Precipitation (mm)



Corn Heat Unit Data for 2021



Corn Heat Unit Data for 2021



Based on weather data recorded from MB Agriculture Weather Program and Environment and Climate Change Canada. Climate Normal is the historical record over a 30 year period. 1971 - 2000 Normal data was used as the baseline for this map. Heat accumulation below 100% is considered cooler than normal and above 100% is warmer than normal.

For more information, contact your local Manitoba Agriculture and Resource Development office.

Quinoa Variety Adaptation Evaluation

Project duration: May 2021 to September 2021

Objectives: Evaluate quinoa lines/varieties for adaptation and yield performance in the Central Plains region of Manitoba.

Collaborators: Phillex Inc.

Results:

Days required to reach maturity were significantly different and ranged from 129 to 135 among varieties. Late maturity entries which required 134 days to reach maturity also yielded significantly more grain (P=0.001) compared to the other varieties. Grain yield ranged from 1658 to 2768 lb/A. PHX21-06 had the highest lodging rating of 3 which could have likely caused grain losses resulting in low yield of 1432 lb/A. The highest coefficient of variation of grain yield was caused by PHX21-07 entry. All treatments showed high vigor especially considering that the rating ranged from 6 to 8 and this was a sign of healthy plants. The variety trial had a few challenges with stem borer larvae that required chemical control more than 3 times during the season. The caterpillar penetrates and feed inside the stem causing severe lodging and eventually reduces grain yield and quality. However, there was better timing of scouting and application of alternating insecticides for better control of the stem borer compared to 2020 growing season.

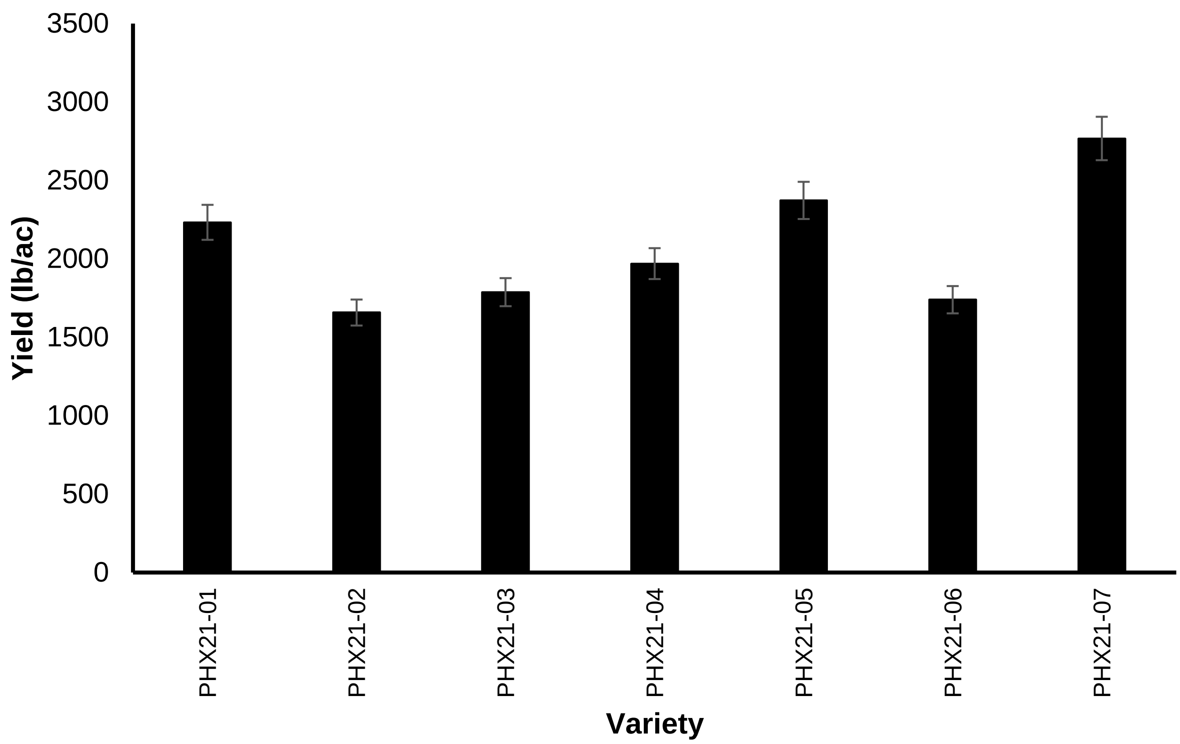


Figure 1: Quinoa lines and yield performance at Carberry in 2021.

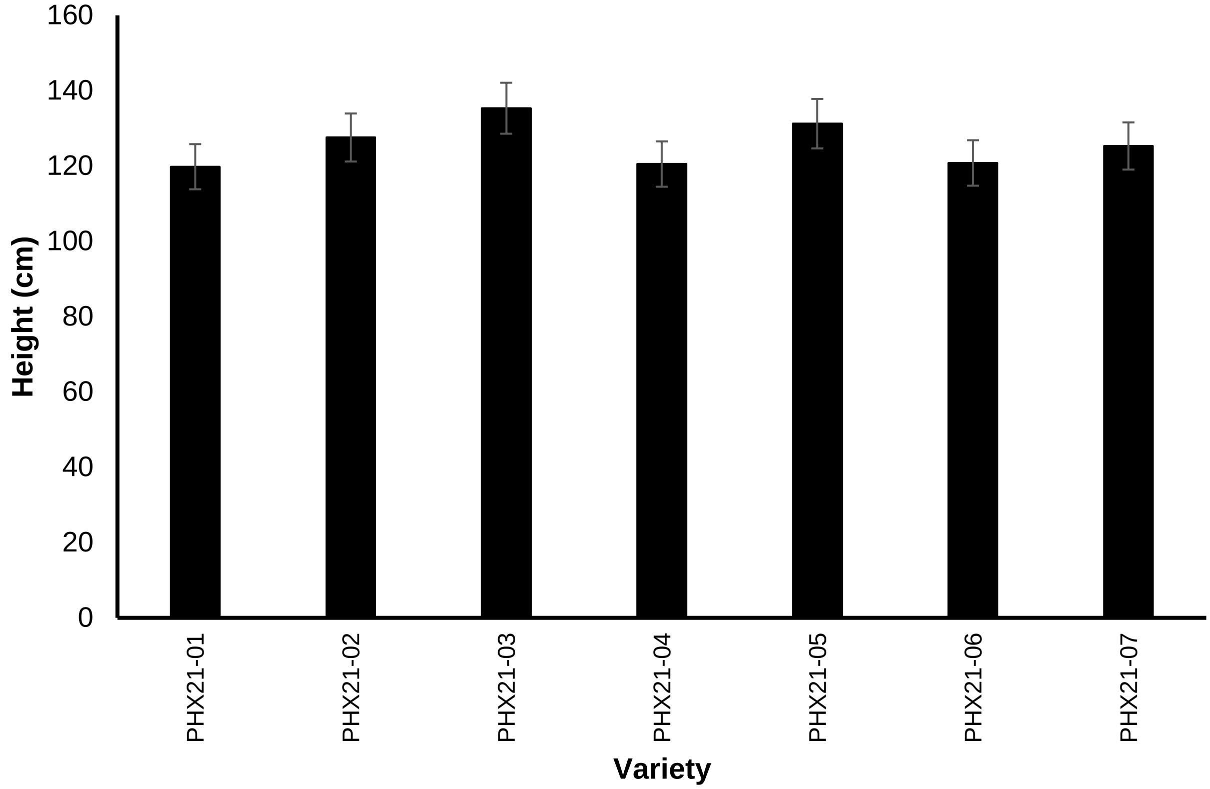


Figure 2: Height of quinoa lines at Carberry in 2021

Background:

Quinoa is a broadleaf annual plant that producers small, round seeds with excellent nutritional qualities. The crop can be grown in all agricultural regions of Manitoba. Phillex Ltd, based in Portage la Prairie, participated with Canada-Manitoba Crop Diversification Centre to conduct the quinoa variety trial.

Quinoa is one of the few crops that can help maintain productivity on rather poor soils and under conditions of erratic rainfall and high salinity. As a result, it becomes an alternative crop that could play a significant role in sustainable agriculture. Apart from its usefulness in marginal agricultural lands, the crop is an exceptionally nutritious food source that has high protein content with all essential amino acids, high content of calcium, magnesium, iron and health promoting compounds such as flavonoids. Other positive values of quinoa are the saponins present in the seed hull and lack of gluten.

Materials & Methods:

Experimental Design:	Randomized complete block design with 3 replicates
Seeding:	May 07
Harvest:	Sep 27

Fertility:	120lb/ac actual N (46-0-0); 26lb/ac actual Phos (11-52-0); 4lb/ac actual Sulfur (20-0-024)

Data collected	**Date collected**
Emergence Population	June 4
Heights	Sep 24
Yield	Sep 27
Moisture	Sep 27

Agronomic info:

Standard recommended agronomic protocols were adopted for each crop. Fertilizers were applied with respect to soil test results. Herbicide were applied, when required.

Evaluation of Hemp-Cereal Intercrop Mixes for Silage Production

Project duration: May 2020 – August 2022

Objectives: To evaluate intercrop mixes with hemp for silage production

Collaborators: PCDF, CMCDC

Background:

Silage plays an important part in the Manitoba livestock industry. Corn silage provides high yields, relative to barley silage (14 t/ac, over 7.5 t/ac, 2021 Silage Cost of Production, Manitoba Agriculture). In the Parkland area, the yield for corn silage is variable and many producers opt to produce a cereal silage, such as barley or oat. PCDF and CMCDC have worked together to explore intercropping options for cereals silage.

Hemp provides an interesting opportunity for silage production, due to its high production potential and good nutritional qualities. However, Canadian regulations currently prohibit the use of hemp products as a livestock feed ingredients in Canada. As such, this research is purely exploratory, and is not intended to provide recommendations to producers. The Manitoba Diversification Centres are working with the Canadian Hemp Trade Alliance to develop data in support of changes to regulations around the use of hemp in livestock feed.

Results:

Figure 1. Clockwise from top-left: (1) hemp-only; (2) barley-hemp; (3) oat-hemp; (4) oat-only; (5) hemp-oat silage, chopped; (6) long fibres from over-ripe hemp plants.

The silage yields at PCDF (t/ac) for treatments is shown in Figure 2. Hay yields (1500-lb bales/ac, 15% moisture) are shown in Figure 3.

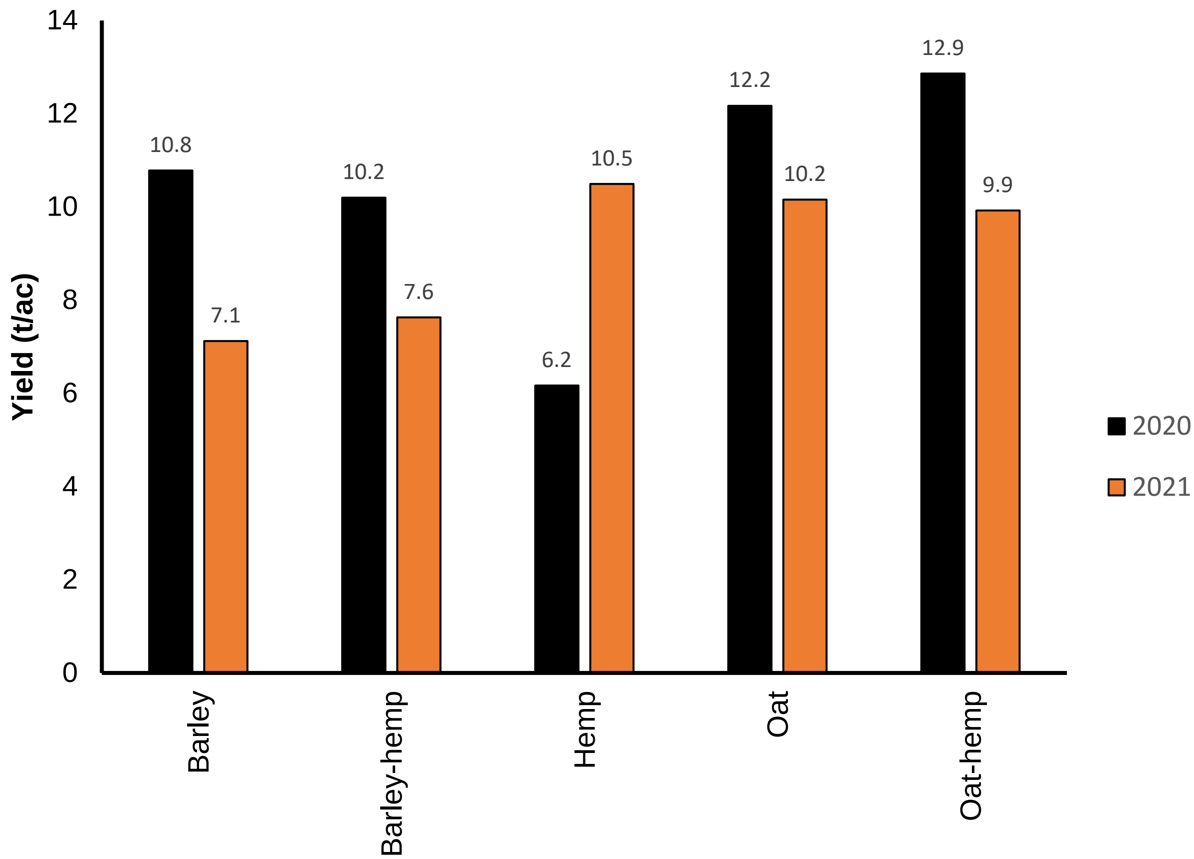


Figure 2: PCDF wet silage yield (t/ac) by treatment; all yields adjusted to 65% moisture.

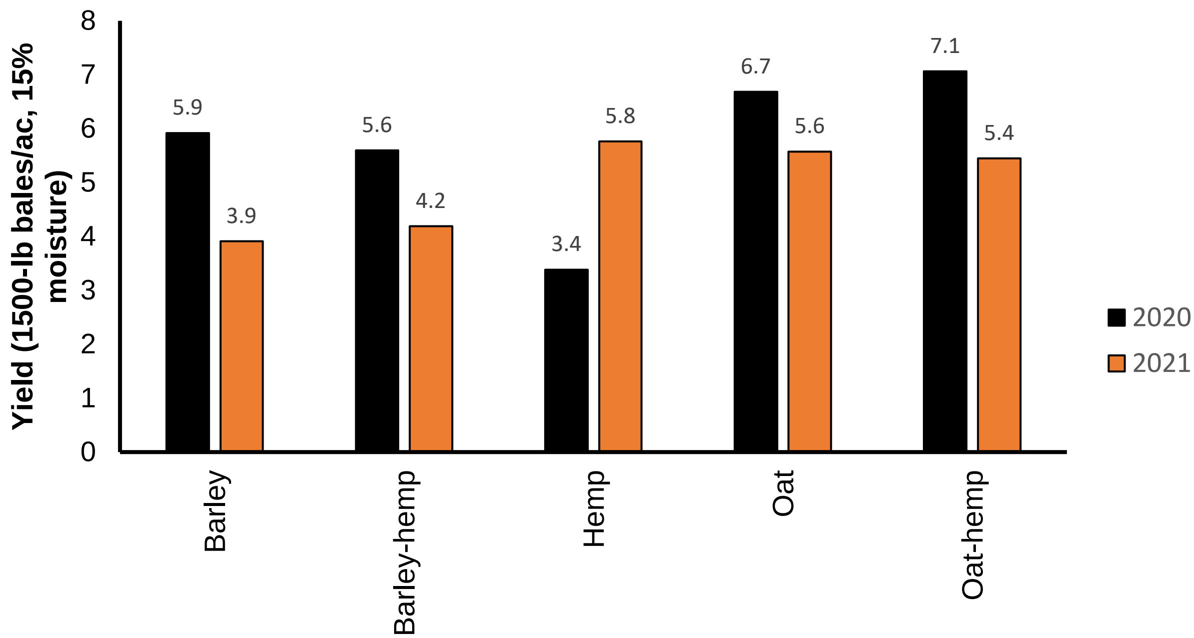


Figure 3: PCDF hay yield (1500-lb bales/ac, 15% moisture) by treatment.

The silage yields at MHPEC (t/ac) for treatments is shown in Figure 4. Hay yields (1500-lb bales/ac, 15% moisture) are shown in Figure 5.

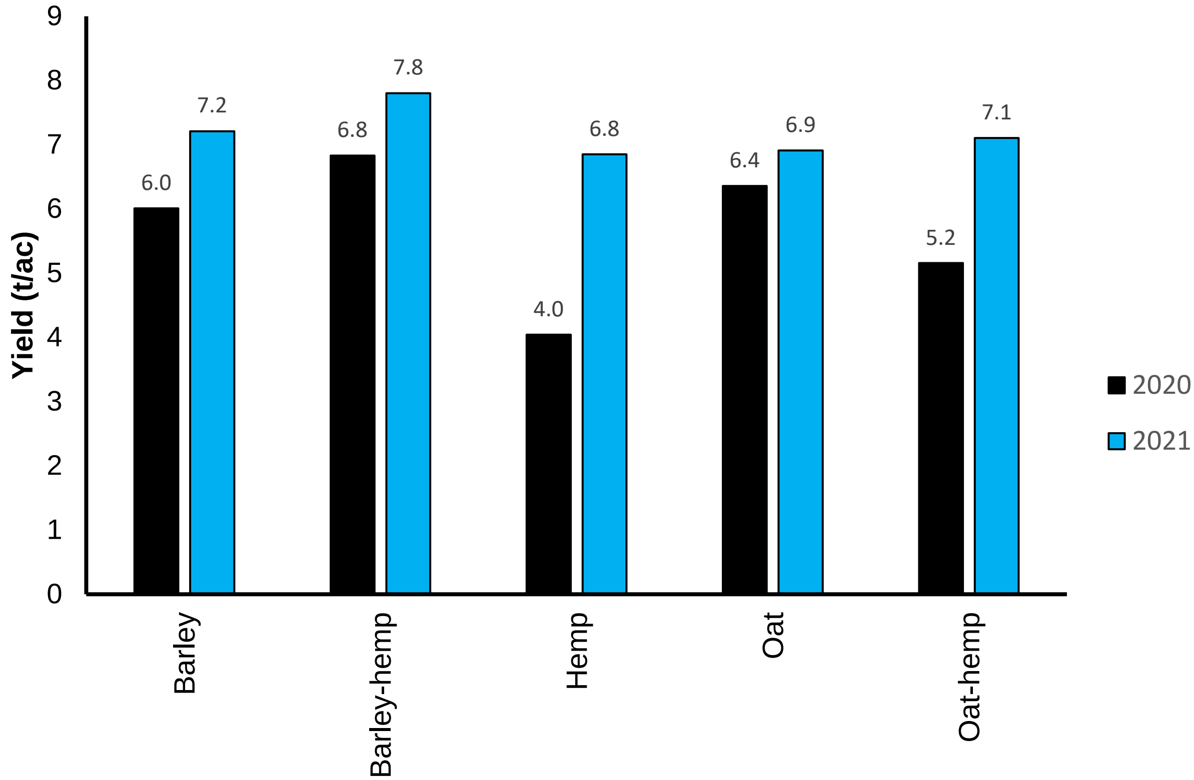


Figure 4: MHPEC wet silage yield (t/ac) by treatment; all yields adjusted to 65% moisture.

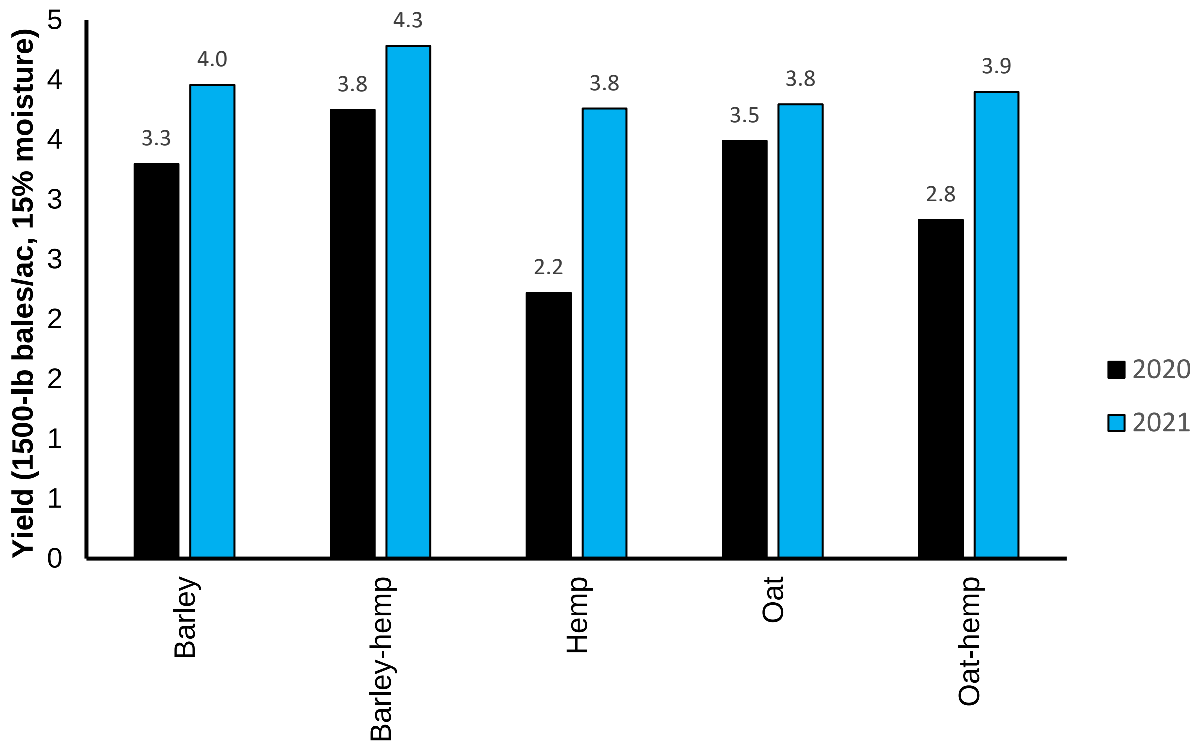


Figure 5: MHPEC hay yield (1500-lb bales/ac, 15% moisture) by treatment.

<u>Summary of statistical information and feed values</u>

The results for silage yield differ statistically by treatment (Table 1). The hemp-only treatment provided significantly lower silage yields than treatments including barley and oat. Further, the inclusion of hemp in the silage mixture did not significantly increase yield over barley-only or oat-only. In 2021 at PCDF, the yield for the barley-only treatment was significantly greater than for other treatments. Note that the reliability of these results is low due to a high percent CV for silage yield.

Table 1: PCDF summary of statistical information for silage yield

Entry	**Silage yield (t/ac) wet yield**		**Statistical significance***			
	2020	**2021**	**2020**		**2021**	
Barley	12.9	10.5	A		A	
Barley-hemp	12.2	10.2	A		A	B
Oat	10.8	9.9	A		A	B
Oat-hemp	10.2	7.6	A		A	B
Hemp	6.2	7.1		B		B

LSD (0.05)	**3.4**	**3.2**	
% CV	**27.8**	**22.9**	

* Treatments not marked with the same letter are statistically different from other treatments.

<u>MHPEC summary of statistical information and feed values</u>

[See PCDF for comparative discussion: simple interpretation of yield differences.]

Table 2: MHPEC summary of statistical information for silage yield

Entry	**Silage yield (t/ac) wet yield**		**Statistical significance***			
	2020	**2021**	**2020**		**2021**	
Barley	6.0	7.2			A	
Barley-hemp	6.8	7.8			A	
Oat	5.4	6.9			A	
Oat-hemp	5.2	7.1			A	
Hemp	4.0	6.8				B
LSD (0.05)		**3.4**				
% CV		**27.8**				

* Treatments not marked with the same letter are statistically different from other treatments.

The feed values and mineral content for each treatment for PCDF and MHPEC are shown in Tables 3 and 4.

Table 3: PCDF and MHPEC feed values for silage by treatment compared to animal feed requirements*

Entry	% Crude Protein			% TDN		
	2020	2021	Average	2020	2021	Average
PCDF values						
Barley	10.1	10.6	10.4	58.3	69.4	63.8
Oat	10.8	11.4	11.1	59.8	65.8	62.8
Hemp	12.6	10.2	11.4	43.7	50.5	47.1
Barley-hemp	12.2	12.0	12.1	58.7	56.1	57.4
Oat-hemp	12.2	11.4	11.8	58.9	67.2	63.1
MHPEC values						
Barley	10.8	10.3	10.6	71.9	68.2	70.0
Oat	8.4	9.8	9.1	55.5	63.4	59.4
Hemp	11.9	11.4	11.6	43.3	53.5	48.4
Barley-hemp	10.2	10.8	10.5	62.4	75.1	68.8
Oat-hemp	9.6	11.7	10.7	63.2	65.1	64.2
Animal feed requirements						
Mature cows						
Mid gestation	7			50-53		
Late gestation	9			58		
Lactating	11-12			60-65		
Replacement heifers	8-10			60-65		
Breeding bulls	7-8			48-50		
Yearling bulls	7-8			55-60		

* Animal feed requirements developed by Elisabeth Nernberg (ARD).

Table 4: PCDF and MHPEC mineral content for silage by treatment

Treatment		Ca	P	Mg	Na	K	Mo	Cu	Zn	Mn	Fe
		Mineral									
PCDF values											
Barley	2020	0.35	0.19	0.12	0.39	1.25	1.29	4.23	17.3	30.24	112.85
	2021	0.30	0.22	0.16	0.13	1.73	1.05	2.96	17.23	17.36	68.24
	Average	**0.33**	**0.21**	**0.14**	**0.26**	**1.49**	**1.17**	**3.60**	**17.27**	**23.80**	**90.55**
Oat	2020	0.28	0.2	0.13	0.49	1.42	2.54	3.54	17.88	52.04	153.07
	2021	0.40	0.21	0.21	0.36	1.97	1.10	2.90	11.46	38.59	99.71
	Average	**0.34**	**0.21**	**0.17**	**0.43**	**1.70**	**1.82**	**3.22**	**14.67**	**45.32**	**126.39**
Hemp	2020	1.55	0.27	0.36	0.12	1.46	1.33	7.51	23.54	64.06	151.36
	2021	1.65	0.19	0.31	0.01	1.68	0.72	5.85	16.23	48.48	190.25
	Average	**1.60**	**0.23**	**0.34**	**0.07**	**1.57**	**1.03**	**6.68**	**19.89**	**56.27**	**170.81**
Barley-hemp	2020	0.64	0.24	0.18	0.3	1.29	1.13	5.35	21.34	36.88	145.81
	2021	1.20	0.22	0.31	0.09	1.88	1.20	4.86	19.30	44.60	239.80
	Average	**0.92**	**0.23**	**0.25**	**0.20**	**1.59**	**1.17**	**5.11**	**20.32**	**40.74**	**192.81**
Oat-hemp	2020	0.38	0.21	0.15	0.47	1.56	2.07	3.68	19.39	54.02	184.17
	2021	0.37	0.24	0.18	0.19	1.65	1.47	3.04	15.11	42.12	151.66
	Average	**0.38**	**0.23**	**0.17**	**0.33**	**1.61**	**1.77**	**3.36**	**17.25**	**48.07**	**167.92**
MHPEC Values											
Barley	2020	0.26	0.31	0.16	0.03	1.33	0.34	4.13	21.69	31.75	125.09
	2021	0.36	0.13	0.20	0.06	1.44	0.18	3.79	25.01	51.03	124.86
	Average	**0.31**	**0.22**	**0.18**	**0.05**	**1.39**	**0.26**	**3.96**	**23.35**	**41.39**	**124.98**
Oat	2020	0.25	0.18	0.16	0.14	2.31	0.52	2.75	14.79	82.19	143.81
	2021	0.26	0.14	0.17	0.16	1.65	0.81	3.18	21.41	97.59	151.66
	Average	**0.26**	**0.16**	**0.17**	**0.15**	**1.98**	**0.67**	**2.97**	**18.10**	**89.89**	**147.74**
Hemp	2020	1.46	0.26	0.51	0.04	1.64	0.44	7.98	24.24	79.26	217.14
	2021	2.20	0.13	0.77	0.02	1.24	0.29	8.54	22.70	121.52	244.91
	Average	**1.83**	**0.20**	**0.64**	**0.03**	**1.44**	**0.37**	**8.26**	**23.47**	**100.39**	**231.03**

Barley-hemp	2020	0.44	0.25	0.23	0.09	1.76	0.41	4.82	19.56	41.27	134.41
	2021	0.25	0.18	0.19	0.06	1.43	0.21	4.22	31.12	42.00	111.41
	Average	**0.35**	**0.22**	**0.21**	**0.08**	**1.60**	**0.31**	**4.52**	**25.34**	**41.64**	**122.91**
Oat-hemp	2020	0.25	0.22	0.17	0.19	1.96	0.84	3.42	16.66	76.83	164.26
	2021	0.53	0.17	0.24	0.19	1.42	1.00	3.95	24.85	99.40	188.61
	Average	**0.39**	**0.20**	**0.21**	**0.19**	**1.69**	**0.92**	**3.69**	**20.76**	**88.12**	**176.44**

Observations

The silage was prepared by running the harvested material from each plot through a plant shredder (see Figure 1.5). Hemp is a plant with long fibres that become tougher towards maturity. If the crop becomes too mature, these fibres have the potential to tangle in the chopping equipment. Further, the higher fiber content makes for lower digestibility by livestock. This is reflected in the lower percent-TDN figure for the hemp-only treatment (Table 3). Nevertheless, even a reduced rate of hemp appeared to positively increase percent-protein content for the oat-hemp and barley-hemp treatments.

Materials and methods

The experimental is a random complete block design with five entries and three reps. Seed costs for both PCDF and MHPEC are provided in Table 4. Agronomic data is summarized in Tables 5 and 6.

Table 5: Treatments, seeding rates and costs

Treatments	Percent of each monocrop seeding rate	Seeding Rate (lb/ac)	Cost per acre
Barley (Maverick)	100	90	$14.91
Oat (Haymaker)	100	90	$19.72
Hemp (Katani)	100	25	$50.00
Barley-hemp (Maverick-Katani)	75-33	68-8	$27.26
Oat-hemp (Haymaker-Katani)	75-33	68-8	$30.90

Table 6: Agronomic data

	PCDF		MHPEC	
	2020	2021	2020	2021
Seeding date	May 25	May 20	May 25	May 24
Harvest date	Aug 12	Aug 11	Aug 19	Aug 16
Previous crop	Barley silage	Oat silage	Soybean	Canola
Soil type	Erickson Loam Clay		Clay Loam	
Seedbed prep	Heavy harrow	Vertical tillage	No-till	No-till

Table 7: Fertility information

	PCDF		MHPEC	
	Available	Added	Available	Added
N				
2020	79 lb/ac	47 lb/ac	19 lb/ac	124 lb/ac
2021	151 lb/ac	10 lb/ac	24 lb/ac	113 lb/ac

P				
2020	22 ppm	10 lb/ac	14 ppm	11 lb/ac
2021	47 ppm	15 lb/ac	11 ppm	16 lb/ac
K				
2020	257 ppm	none	-	-
2021	143 ppm	none	-	-

There are some herbicides registered for use with hemp, and there are no herbicides registered for both hemp and barley or oats, making silage intercropping for hemp and cereals a challenge. Good weed control prior to seeding is crucial. The trials were hand-weeded.

Evaluation of Hemp-Cereal Intercrop Mixes for Silage Production

Project duration: May 2019 – August 2022

Objectives: To evaluate pea-cereal intercrop mixes for silage production

Collaborators: PCDF, CMCDC

Background:

Silage plays an important part in the Manitoba livestock industry. Corn silage provides high yields, relative to barley silage (14 t/ac, over 7.5 t/ac, 2021 Silage Cost of Production, MARD). In the Parkland area, the yield for corn silage is variable and many producers opt to produce a cereal silage, such as barley or oat. Some producers have explored pea-cereals mixtures as a means to increase silage protein content. PCDF is eager to explore options for cereals silage production.

Results:

The silage was harvested at soft-dough stage (approximately 65% moisture). The PCDF 2019-2021 wet silage yields (t/ac) are shown in Figure 1, and dry yields (lb/ac at 15% moisture) are shown in Figure 2. The MHPEC 2020-2021 silage yields (t/ac) for treatments is shown in Figure 4, and dry yields (1500-lb bales/ac, 15% moisture) are shown in Figure 5.

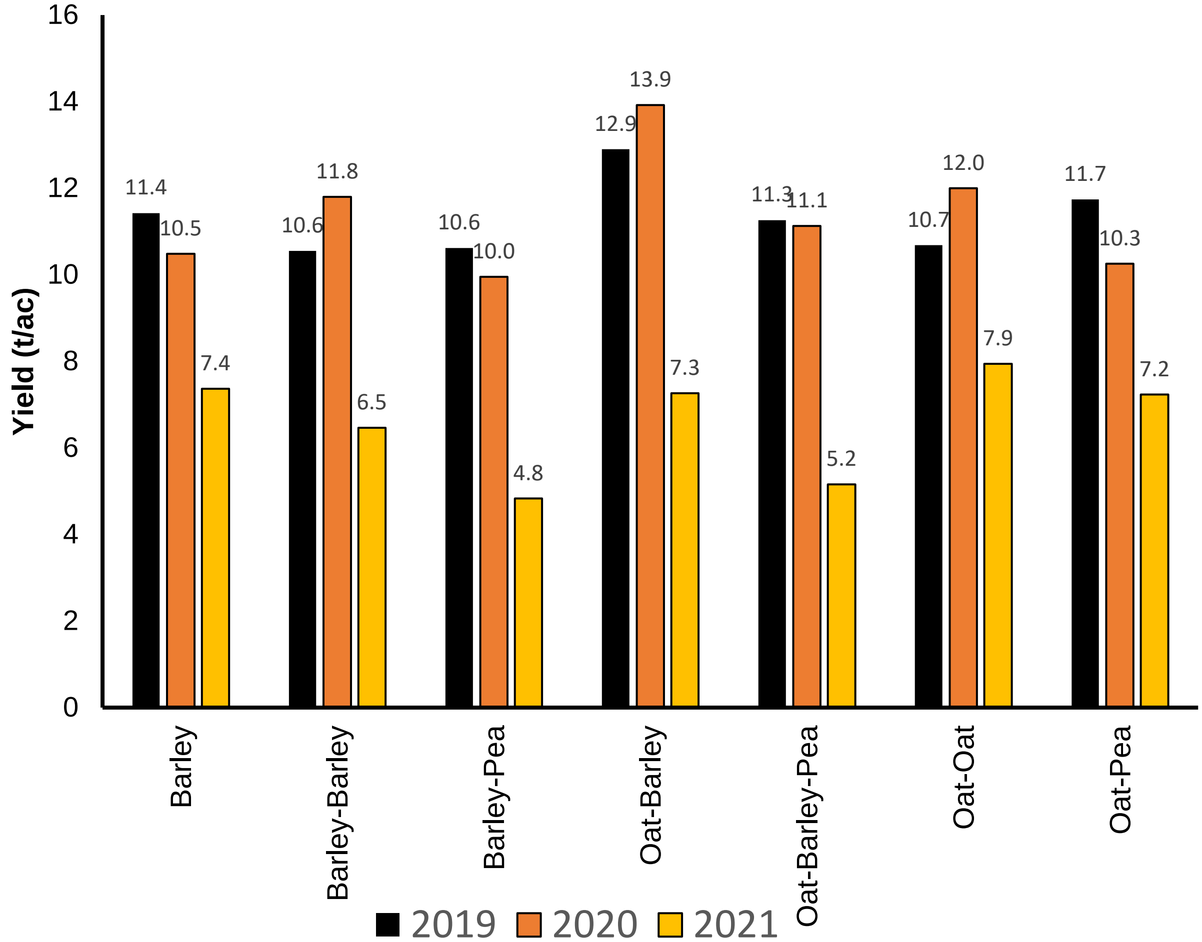


Figure 1: PCDF wet silage yield (t/ac, 65% moisture) by treatment.

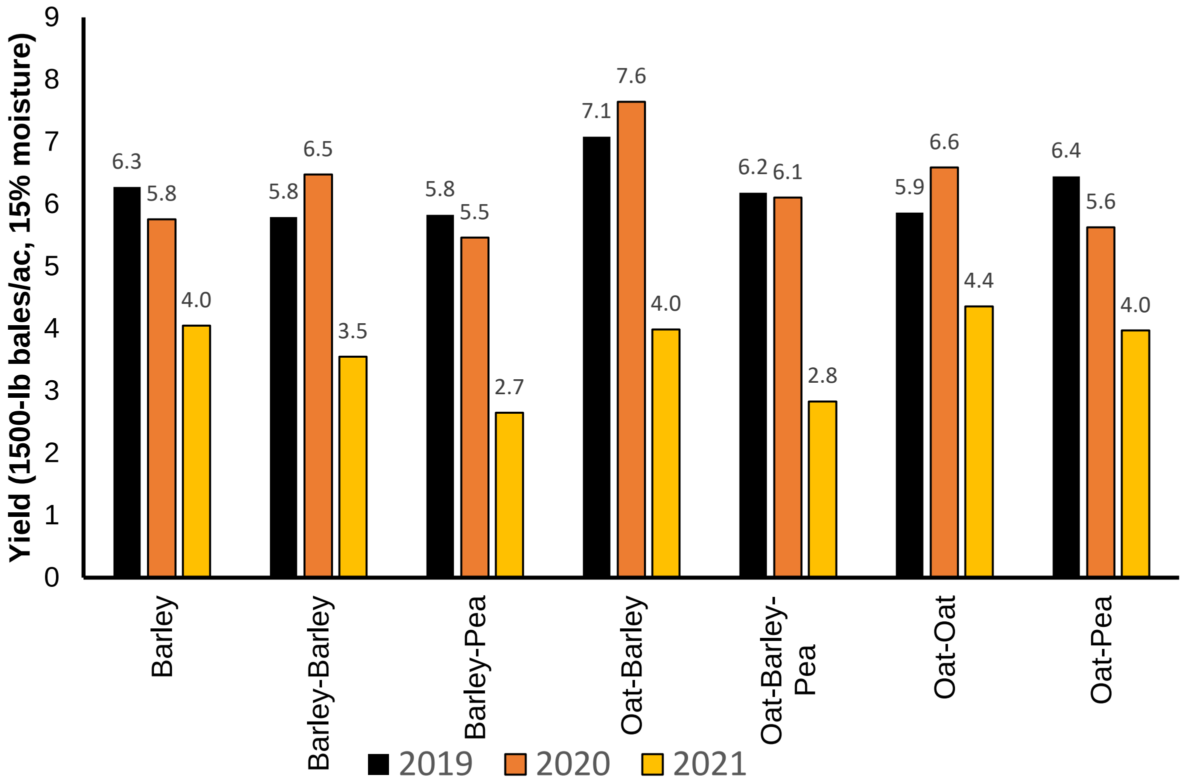


Figure 2: PCDF hay yield (1500-lb bales/ac, 15% moisture) by treatment.

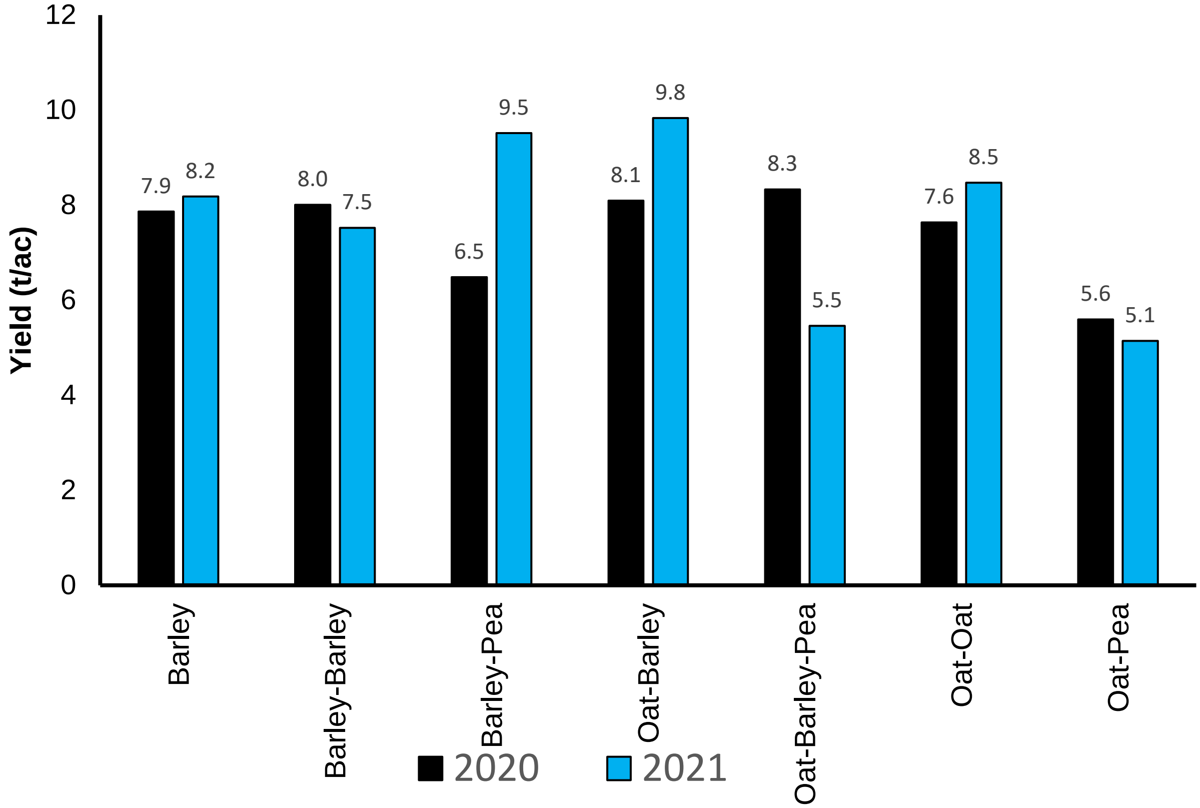


Figure 3: CMCDC wet silage yield (t/ac, 65% moisture) by treatment.

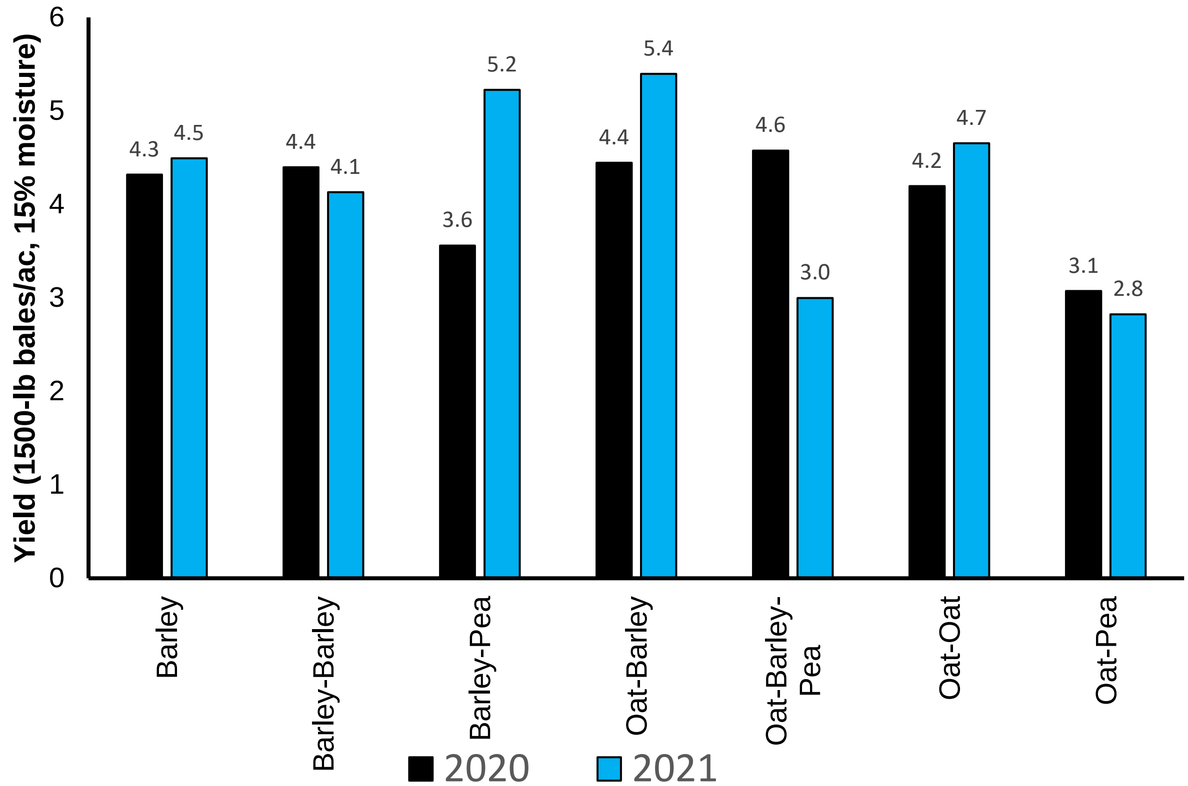


Figure 4: CMCDC hay yield (1500-lb bales/ac, 15% moisture) by treatment.

Table 1: PCDF summary of statistical information for silage yield

Entry	**Silage yield (t/ac) wet yield**			**Statistical significance***				
	2019	**2020**	**2021**	**2019**	**2020**			**2021**
Barley	11.4	10.5	7.4		A	B		A
Barley-Barley	10.5	11.8	6.5		A			A
Barley-Pea	10.6	10.0	4.8			B		A
Oat-Barley	12.9	13.9	7.3				C	A
Oat-Barley-Pea	11.3	11.1	5.2		A	B		A
Oat-Oat	10.7	12.0	7.9		A			A
Oat-Pea	11.7	10.3	7.2		A	B		A
LSD (0.05)		**1.8**	**4.1**					
% CV		**13.8**	**34.1**					

* Treatments not marked with the same letter are statistically different from other treatments.

Table 2: MHPEC summary of statistical information for silage yield

Entry	Silage yield (t/ac) wet yield		Statistical significance*			
	2020	2021	2020	2021		
Barley	7.9	8.2			B	C
Barley-Barley	8.0	7.5			B	
Barley-Pea	6.5	9.5				C
Oat-Barley	8.1	9.8		A		
Oat-Barley-Pea	8.3	5.5			B	C
Oat-Oat	7.6	8.5			B	
Oat-Pea	5.6	5.1			B	C
LSD (0.05)		**1.8**				
% CV		**13.8**				

* Treatments not marked with the same letter are statistically different from other treatments.

The feed values and mineral content for each treatment for PCDF and MHPEC are shown in Table 3.

Table 3: PCDF and MHPEC feed values for silage by treatment compared to animal feed requirements*

Entry	% Crude Protein				% TDN			
	2019	2020	2021	Average	2019	2020	2021	Average
PCDF values								
Barley	10.2	8.2	10.7	9.7	67.6	58.9	70.3	65.6
Barley-Barley	11.0	8.2	11.0	10.1	68.6	60.5	71.2	66.8
Barley-Pea	10.6	10.9	11.4	11.0	72.9	60.7	70.0	67.9
Oat-Barley	12.1	7.1	11.2	10.1	71.3	63.2	70.1	68.2
Oat-Barley-Pea	12.2	8.8	11.7	10.9	69.0	60.4	62.9	64.1
Oat-Oat	10.8	7.8	10.9	9.8	69.8	61.5	65.8	65.7
Oat-Pea	13.4	9.1	12.8	11.8	66.0	59.3	60.0	61.8
MHPEC values								
Barley	-	10.4	10.1	10.3	-	66.7	73.3	70.0
Barley-Barley	-	10.7	10.7	10.7	-	73.1	77.5	75.3
Barley-Pea	-	12.0	12.2	12.1	-	54.9	72.7	63.8
Oat-Barley	-	9.4	11.0	10.2	-	61.1	72.1	66.6
Oat-Barley-Pea	-	12.8	11.3	12.1	-	60.3	65.6	63.0
Oat-Oat	-	9.0	10.2	9.6	-	58.2	67.5	62.9
Oat-Pea	-	12.5	13.8	13.2	-	61.1	69.9	65.5
Animal feed requirements								
Mature cows								
Mid gestation	7				50-53			
Late gestation	9				58			
Lactating	11-12				60-65			
Replacement heifers	8-10				60-65			
Breeding bulls	7-8				48-50			
Yearling bulls	7-8				55-60			

* Animal feed requirements developed by Elisabeth Nernberg (ARD).

Summary of statistical information and feed values

- At PCDF, yield for all silage mixtures fell in 2021, due to dry growing conditions (Table 4). However, yield at MHPEC did not drop substantially, or even increased, during the 2021 season.
- In 2021, the yields at PCDF did not differ significantly by treatment. At MHPEC, oat-barley silage provided significantly higher yields than other treatments.
- The trend across all years and sites is for crude protein to increase in mixtures containing pea. However, total digestible nutrients (TDN) tends to be less for these mixtures.

Table 4: Seasonal precipitation

Site	PCDF			MHPEC	
Year	2019	2020	2021	2020	2021
Precipitation*	156 (73%)	219 (100%)	160 (73%)	224 (102%)	148 (68%)

* mm (% normal), May 1 – August 15

Observations

The silage was prepared with a plant shredder. The oat-barley treatment appears to be a promising option, both for higher yields relative to other treatments (Tables 1 and 2) and high TDN values (Table 3). Oat-barley silage allows for good weed control, but there are no herbicides registered for barley-oat-pea silage intercrops. Good weed control prior to seeding is crucial. The trial was hand-weeded.

Materials and methods

The experimental is a random complete block design with seven entries and three reps. Seed costs for both PCDF and MHPEC are provided in Table 4. Agronomic data is summarized in Tables 5 and 6. Barley-barley and oat-oat treatments combine a forage- and grain-type variety to maximize biomass and energy production.

Table 4: Treatments, seeding rates and seeding costs

Treatments	Percent of Monocrop Seeding Rate	Seeding Rate (lb/ac)	Cost per acre
Barley (Maverick)	100	90	$14.91
Barley-barley (Maverick-Austenson)	75-75	68-68	$22.53
Barley-pea (Maverick-Lacombe)	25-100	22-150	$34.89
Oats-oats (Haymaker-Summit)	75-75	68-68	$28.40
Oats-barley (Haymaker-Maverick)	75-75	22-150	$26.16
Oat-pea (Haymaker-Lacombe)	25-100	22-150	$36.07
Oats-barley-pea (Haymaker-Maverick-Lacombe)	12.5-12.5-100	11-11-150	$35.48

Table 5: Agronomic data

	PCDF			MHPEC	
	2019	2020	2021	2020	2021
Seeding date	May 16	May 25	May 20	May 25	May 24
Harvest date	Aug 9	Aug 12	Aug 11	Aug 19	Aug 16
Previous crop	Barley Silage	Barley silage	Oat silage	Soybean	Canola
Soil type	Erickson Loam Clay			Clay Loam	
Seedbed prep	Heavy harrow	Heavy harrow	Vertical tillage	No-till	No-till

Table 6: Fertility information

	PCDF		MHPEC	
	Available	Added	Available	Added
N				
2019	156 lb/ac	-		
2020	79 lb/ac	47 lb/ac	19 lb/ac	124 lb/ac
2021	151 lb/ac	10 lb/ac	24 lb/ac	113 lb.ac
P				
2019	9 ppm	20 lb/ac		
2020	22 ppm	10 lb/ac	14 ppm	11 lb/ac
2021	47 ppm	15 lb/ac	11 ppm	16 lb/ac
K				
2019	170	none		
2020	257 ppm	none	-	-
2021	143 ppm	none	-	-

Evaluation of Hops Varieties in Manitoba

Project duration: May 2021 – September 2021

Objectives: Evaluation and Demonstrate the adaptability of hops in the Carberry region of Central Plains, Manitoba.

Collaborators: CMCDC

Background:

Hops are used as a flavoring and preserving ingredient in beer as well as for aroma. For large commercial brewers the majority of production has been centralized in Washington USA; however, the explosion of the craft brewing industry south of the border, and more recently in Canada has somewhat re-vitalized the hop industry on more of a regional scale.

Many of the resources citing characteristics used to describe hops come from work in the Pacific Northwestern USA, and therefore traits may not be expressed the same in our more northern/non-costal environment. Traits most important to Manitoba growers include: maturity firstly, followed by disease/pest resistance and of course yield. Specific characteristics related to bitterness (% alpha acid), aroma (% beta acid and volatile fatty acids), and storability (Harvest Storage Index) are also important considerations but can be dependent on marketing plans. The most important thing when acquiring rhizomes, crowns or cuttings for yard establishment is to ensure they are disease free and from a reputable source.

Hops favor well drained medium textured soil with ideal pH within the 6.2-6.5 range. On lighter textured soil drip irrigation may be required to experience full yield potential. Fertility is important, with Nitrogen and Potassium being of greatest importance followed by Phosphorus. Once established nitrogen demands during the season for biomass production can reach 150+lbs per acre, with approximately half converted by the plant into cone production. Potassium requirements at these Nitrogen levels are approximately 100lbs/acre and 25lbs/ac for Phosphorus.

As with most crops there are numerous pests that can potentially reduce yield/quality and/or significantly impact the general long-term health of the hop yard. Dominant insect pests include aphids, spider mites, and various leaf eating caterpillars such as Bertha Armyworm. Main diseases of concern are Powdery Mildew, Downy Mildew and Verticillium. Pruning of the leaves off the bottom 0.5-1m of bine to promote air-flow is one effective means of reducing the incidence of disease (Mildews). Integrated pest management techniques are encouraged regardless if the yard is organic or conventional; especially considering the long-term investment of a hop yard.

Varieties established at Carberry are listed in Table 1 with detailed descriptions in Appendix A.

Table 1: Hop varieties demonstrated at CMCDC Carberry.

Plot	Name
1	**Cascade:** A well-established American aroma hop developed by Oregon State University's breeding program in 1956 from Fuggle and Serebrianker (a Russian variety), but not released for cultivation until 1972. It has a flowery and spicy, citrus-like quality with a slight grapefruit characteristic.
2	**Golding:** A popular English aroma hops grown prior to 1790 but also widely cultivated in the USA. They tend to have a smooth, sweet flavour.
3	**Wild Miami:** A wild selection taken from Miami Manitoba in 2009 – not an official registered variety.
4	**Garden:** Used as an ornamental vine and does not produce cones.
6	**Mt Hood:** A soft American variety frequently used in styles that require only a subtle hop aroma (German/American lagers). Named for Mount Hood in Oregon.
8	**Golden:** Typically used as an ornamental vine, it is popular as a foliage accent in the garden, particularly in cool-summer regions. Golden Hops has attractive yellow foliage which emerges gold in spring. The fuzzy lobed leaves are ornamentally significant but do not develop any appreciable fall colour. The flowers are not ornamentally significant. It produces abundant clusters of yellow hop-like fruit from midsummer to mid fall.
9	**Brewers Gold:** British bittering hop developed in 1919. Both Brewer's Gold and Bullion are seedlings of BB1 (found wild in Manitoba). Many modern high alpha hops were developed from Brewer's Gold. Has a resiny, spicy aroma/flavor with hints of black currant.
10	**Fuggle:** This variety was noticed growing "wild" in the hop garden of George Stace's house at Horsmonden in Kent, England in 1861. In 1875 it was introduced by Richard Fuggle who lived in the village of Brenchley and hence it was called Fuggle. The aroma is earthier and less sweet than Goldings.

Plant Growth, Maturity and Yield Observations

Relative growth habits, vigor and cone yields were consistent. For the third straight year Brewer’s Gold was the greatest producer while Fuggle produced the least suggesting that relative yield differences within maturity groups listed from other geographies most likely hold true in Manitoba as well.

Multiple harvest samples were taken though September and into October and submitted for quality testing to help identify ideal harvest timing. For each date samples of random cones were picked from each variety and dried immediately in an oven at 50 ^{o}C for three days or until dry. Once dry, samples were vacuum sealed and frozen at -20 C until shipped for analysis. Quality analysis was conducted by Alpha Analytics Inc, in Yakima, Washington USA.

Spider mites were the dominant pest.

Figure 1: Spider mite damage observed on hops at CMCDC.

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