CMCDC Annual Report

2020

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

Canada-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.

Message from Site Manager

Thank you for taking the time to read and review our 2020 report and looking forward the 2021 year. I have only been employed by Manitoba Horticultural Productivity Enhancement Center (MHPEC) since early November 2020 and find it both exciting and challenging. Since March due to Covid-19 restrictions, our offices have been closed to the public and access can be granted by appointment only. With the limited access to our site, all of our outdoor activities including Crops-A-Palooza, field days, and tours had to be cancelled. As we look forward to 2021, it is shaping up to be similar to last year all tours and field days are on hold at this point.

Here at the MHPEC site we are fortunate to have the support of our three industry partners Keystone Potato Producers, Simplot Canada 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.

We have two research specialists on site. Zack Frederick is our Potato Research Specialist and his research is directed towards disease control and plant nutrition and irrigation for the potato industry. Zack's report on his trials can be found within this publication.

We also have Haider Abbas at the Carberry site. Haider is the Applied Research Specialist with Manitoba Agriculture. Haider's research interests include a wide array of forages, legumes, grains, and specialty crops. Haider's potato trial research and a summary of his work with other crops can also be found within this publication.

In closing I would like to thank you for taking the time to read and review this publication. We welcome any and all researchers and interested parties to bring forward your research projects for discussion. We always open to the possibility of new research and trials at our site.

Garth Christison
Site Manager for MHPEC Inc
CMCDC Carberry Manitoba

Potato Program

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 Program

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 Canadian Agricultural Partnership (CAP), a federal-provincial-territorial government initiative.

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Evaluation of the Potential for Mustard Cultivar 'Caliente Rojo' to Manage Verticillium Wilt of Potato in Manitoba

Deliverables

1. Implement and validate the applicability of a real-time Verticillium dahliae quantification tool for soil testing
2. List approximate number of acres planted, and practices used to grow the crop
3. Individual grower will have comparison of numbers of Verticillium propagules at three timings: 1) before mustard biofumigation 2) one-month post-biofumigation and 3) post-potato production.
4. Verticillium wilt symptoms ratings will occur in the potato rotation to document visual reduction of disease, possibly as response to Verticillium wilt
5. Calculate cost of biofumigant use for the reduction in Verticillium CFU/g or Verticillium wilt (e.g. cost-benefit analysis)

Conclusions

1. Deliverables

i. Implement and validate the applicability of a real-time Verticillium dahliae quantification tool for soil testing
   a. Completed in 2019. PSI is running qPCR markers developed by Guillaume et al. (2011) for V. dahlia every year of study.

ii. List approximate number of acres planted, and practices used to grow the crop
   a. Completed every year. Since 2019, 100 - 300 acres of biofumigant mustard are planted across the province and new recommendations are developed annually (see supplementary file on recommendations for current best practices)

iii. Individual grower will have comparison of numbers of Verticillium propagules at three timings: 1) before mustard biofumigation 2) one-month post-biofumigation and 3) post-potato production.
   a. Ongoing – more fields are needed for completed analysis

iv. Disease ratings will occur in the potato rotation to document visual reduction of disease, possibly as response to Verticillium wilt
   1. Severity of Verticillium wilt symptoms
   2. Severity of black dot symptoms
   3. Severity of Rhizoctonia symptoms
   a. Ongoing – this process is a year behind point iii, meaning more fields are needed to complete the analysis

v. Calculate cost of use for reduction in Verticillium CFU/g or Verticillium wilt
   a. Will be calculated once a large biomass crop has been successfully demonstrated to reduce V. dahliae microsclerotia in soil and/or Verticillium wilt in the subsequent potato crop.

Although only two fields survived to biofumigate in 2019, useful observations were still gathered to add to the collection of information that the project leads have amassed so far. Superficially, it appears as if biofumigation did work to reduce V. dahliae microsclerotia in one field in 2019. More fields and years of study are necessary to assert if the biofumgiation process can achieve the objective to control Verticillium wilt of potato in Manitoba.

Additional anecdotal observations were also recorded in 2019. Chaff spreading is necessary on rye and wheat fields before seeding mustard because a thick mulch reduces soil to seed contact and reduces germination and growth, leading to mustard that is at the cotyledon stage after a month and a few inches tall after two months of growth. Flea beetle damage was severe in 2019, but markedly less so in fields that were not in Carberry or had stubble to protect mustard seedlings. Even a rigorous insecticide program did not afford the same protection as the presence of stubble. It was also surprising to see that a dryland field was so effective in 2019 to raise a mustard crop using only precipitation and two flea beetle insecticide treatments, granted a crop of rye was lost to plant the mustard in May. Growers and consultants have also expressed interest in whether mustard biofumigation has any control of powdery scab, can build organic matter, or can reduce wind erosion.

All fields survived to biofumigate in 2020, however the amount of biomass and levels of V. dahliae CFU differed dramatically between fields. Superficially, it appears as if biofumigation did work to reduce V. dahliae microsclerotia, but the analysis must include more fields from a variety of soil types and varying pressures of Verticillium wilt. The data set is too narrow at present to definitively state that mustard biofumigation works as intended to reduce Verticillium wilt in Manitoba, especially given the amount of sampling error showing up in the standard error of each figure.

Additional anecdotal observations from 2020 suggest the fields with the most mustard biomass generally had seed drilled at higher rates of 10 lbs per acre and were planted in early June and biofumigated in mid-July. These fields required fairly frequent irrigation in the first two weeks after planting and needed a total of 6-9 inches of water depending on the sand content of the soil. The sandiest soils in Shilo seem to need 3 extra inches of water and 130 lbs more nitrogen to achieve the same biomass result as in the Carberry area. Shilo may even need an increase of nitrogen to 180 lbs N, with most being applied through frequent (weekly) fertigation events that put down approximately 30 units of N because of the sandy soil’s propensity to leach. These changes to our guidelines should allow more growers to hit the biomass targets and are very timely and helpful as the project progresses into identifying whether biofumigation reduces Verticillium wilt by giving us more fields where success was likely to occur.

Methods

The field-scale experiment had two components in two separate field years: the mustard biofumigant crop and the potato crop that followed.

Mustard biofumigant crop:

The grower provided the mustard cv "Caliente Rojo" seed, fertilizer, and water for seedlings. The grower seeded, watered, and raised the crop. The principal investigator will retrieve all relevant planting info from grower (date, depth, irrigation, fertility, conditions, stubble, texture, costs of inputs).

Fields were generally selected based on previous experience with Verticillium wilt for a field variability study from 2015-2019, although a few fields were selected because of grower willingness to test mustard biofumigation. The experiment was set up only in one quarter section of field to reduce soil variability between plots. A single field was the unit of replication. A quadrant of the field was selected for experimentation to reduce variability in soil conditions, and the exact area selected depended on the known distribution of *Verticillium* CFU from a previous field variability project (data can be retrieved from mbpotatoresarch.ca from the project by the same name). Each plot was 10m wide x 12m long, and four plots of biofumigated and four plots of non-biofumigated crop area were left bare per field (expecting to lose at least one because we may not know Verticillium distribution ahead of time).

Plots were geolocated for return to the plot after biofumigation, and the equipment recorded an average of 20 cm deviation at the time of sampling. A large plot size was selected to avoid the criticism that non-fumigated plots were in close enough proximity to be bio fumigated anyway. Strips of the field were to be bare for non-biofumigated strips. Some growers offered to not plant certain sections to create non-biofumigated strips, while other fields had bare spots created by hand after germination. Each plot (biofumigated and non) had two sampling points. The attempt was made to sample medium to high Verticillium areas and collect from center of the plot, with a few meters between sampling points. Each sampling point consists of two 0-10 cm composite samples. With eight strips per field and two sampling points a strip, there will be 16 sampling points per field. With four fields per year, that is 64 samples. There will be two collection dates (before biofumigation, three weeks after biofumigation) or 128 samples each year. For two years there will be a total of 256 samples. Verticillium counts were determined from 0-10 cm soil samples before biofumigation, just after the grower plants the mustard in late July. Biomass was recorded by harvesting all above-ground plant matter within one square meter from three random locations within a plot and immediately recording the weight in kilograms. Post-biofumigation sampling was done by returning to the same geolocated sampling points and sampling 0-10 cm one month after biofumigation, when biofumigant activity has ceased.

The soil samples were ground to fine powder to prepare them for DNA extraction and eventual *V. dahliae* quantification. Two sub-samples of 0.25g 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 Guillaume et al. (2011) 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. The both parties of PSI 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*. The first assessment of the effectiveness of biofumigation will be through the comparison of microsclerotia pre and post biofumigation, using the biomass measurement as an approximate measurement for “dose”.

Potato crop:

The final assessment for the effectiveness of biofumigation will be the reduction of Verticillium wilt in potato and/or the continued reduction of *V. dahliae* microsclerotia during the potato rotation that follows mustard. There will be one more verticillium testing date the following year after biofumigation on the potato rotation. There are 64 samples (eight strips x two points/strip X four fields) for three years, or 192 samples, making a total of 448 samples in total for both the potato and mustard component of the field study. This sample from the potato rotation will be from the same geolocated plots as the mustard crop year and will be from 0-10 cm in depth. The *V. dahliae* from these soils will also be quantified using the same method as before. These samples will be collected in mid August, and a 10m row of potato plants over each sampling point will be rated for percentage wilt severity from 0-100%. If applicable, ratings for black dot, rhizoctonia, or other disease symptoms and signs will be rated for severity (0-100%).

Results

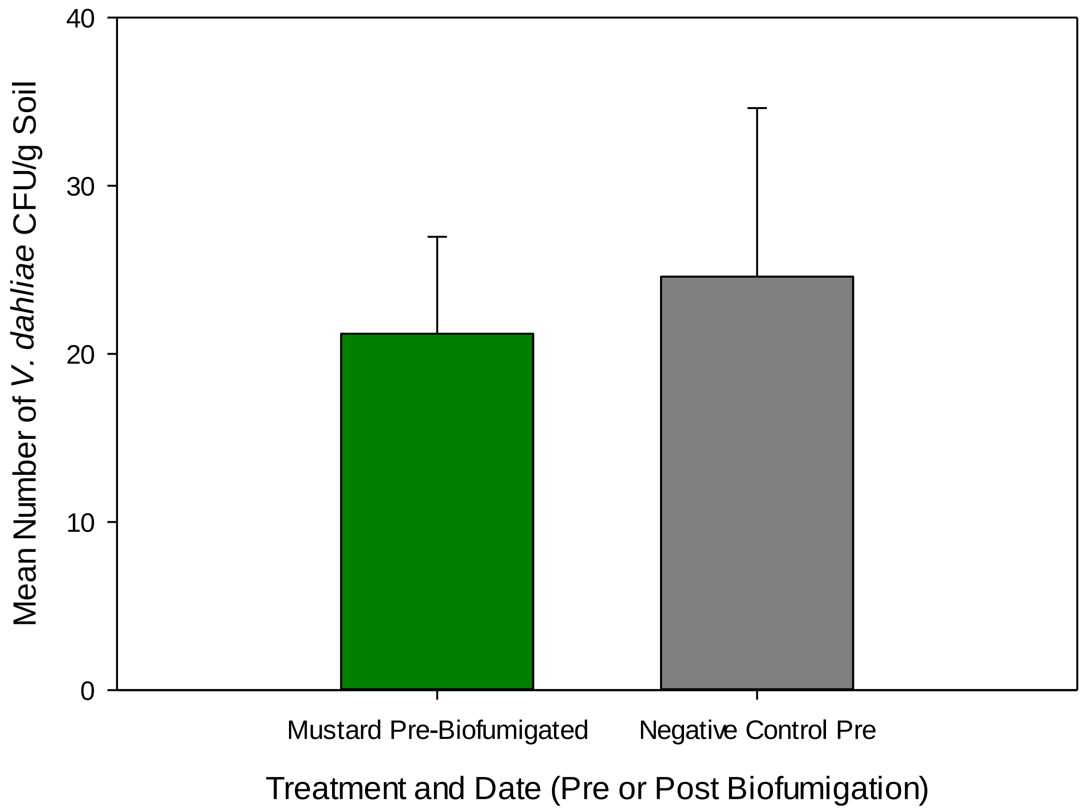
Six field sites were established in 2020 with generally one field site per grower cooperator (Table 1, below). ‘Caliente Rojo’ seed was treated with 16 cwt/acre of Gaucho in 2020, which when coupled with generally lower flea beetle pressure in 2020 than 2019, led to all mustard fields surviving until the desired biofumigation date. The absence of heavy snow or rain at the desired dates of biofumigation also allowed all fields to progress as originally planned. Three irrigated fields in 2020 excelled in biomass production and produced mustard crops that were over 5 feet tall (MB-7, MB-8, MB-10), which was a first for the project. These fields generally had seed drilled at higher rates of 10 lbs per acre and were planted in early June and biofumigated in mid-July. These fields required fairly frequent irrigation in the first two weeks after planting and needed a total of 6-9 inches of water depending on the sand content of the soil. The sandiest soils in Shilo seem to need 3 extra inches of water and 130 lbs more nitrogen to achieve the same biomass result as in the Carberry area. Shilo may even need an increase of nitrogen to 180 lbs N, with most being applied through frequent (weekly) fertigation events that put down approximately 30 units of N because of the sandy soil’s propensity to leach.

Four field sites were established in 2019 for study with one field site per grower cooperator. Two sites did not survive to biofumigate (MB-1 and MB-4) due to three feet of snow in mid September and extreme flea beetle pressure, respectively. MB-3 did not have sufficient growth to successfully biofumigate (average of 3-5 inches plant height). MB-2 was the only site with several feet of biomass with about 3-4 feet of mustard in wetter, high organic matter areas and 1-2 feet in the sand ridges (data not shown). An additional 6 fields were added in 2020, all of which survived until biofumigation.

Year	Designation	Planting Date	Biofumigation Date	Irrigation Status	Flea Beetle Damage	Cold Damage
2019	MB-1	July 20	N/A	Irrigated	Moderate to destroyed	Did not survive
2019	MB-2	May 29	July 23	Dryland	Minor	N/A
2019	MB-3	August 1	October 28	Irrigated	Minor to moderate	Minor to moderate
2019	MB-4	July 26	N/A	Irrigated	Did not survive	N/A
2020	MB-5		October 14	Irrigated	Minor	N/A
2020	MB-6		October 14	Irrigated	Minor	N/A
2020	MB-7	June 3	July 14	Irrigated	Minor	N/A
2020	MB-8	June 3	July 15	Irrigated	Minor	N/A
2020	MB-9	June 6	July 23	Dryland	Minor	N/A
2020	MB-10			Irrigated	Minor	N/A

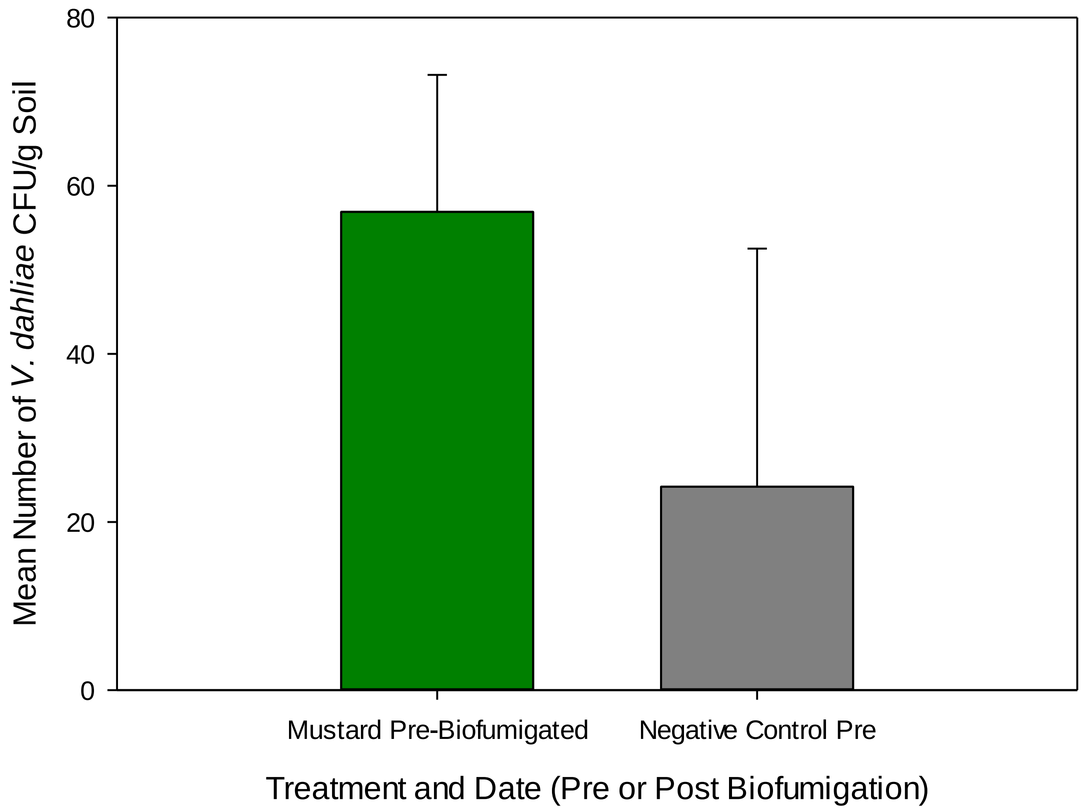
Table 1 – All relevant planting, biofumigation, irrigation status, flea beetle damage, and cold damage information relevant to raising the mustard crops in each field that participated in the study

Field MB-5



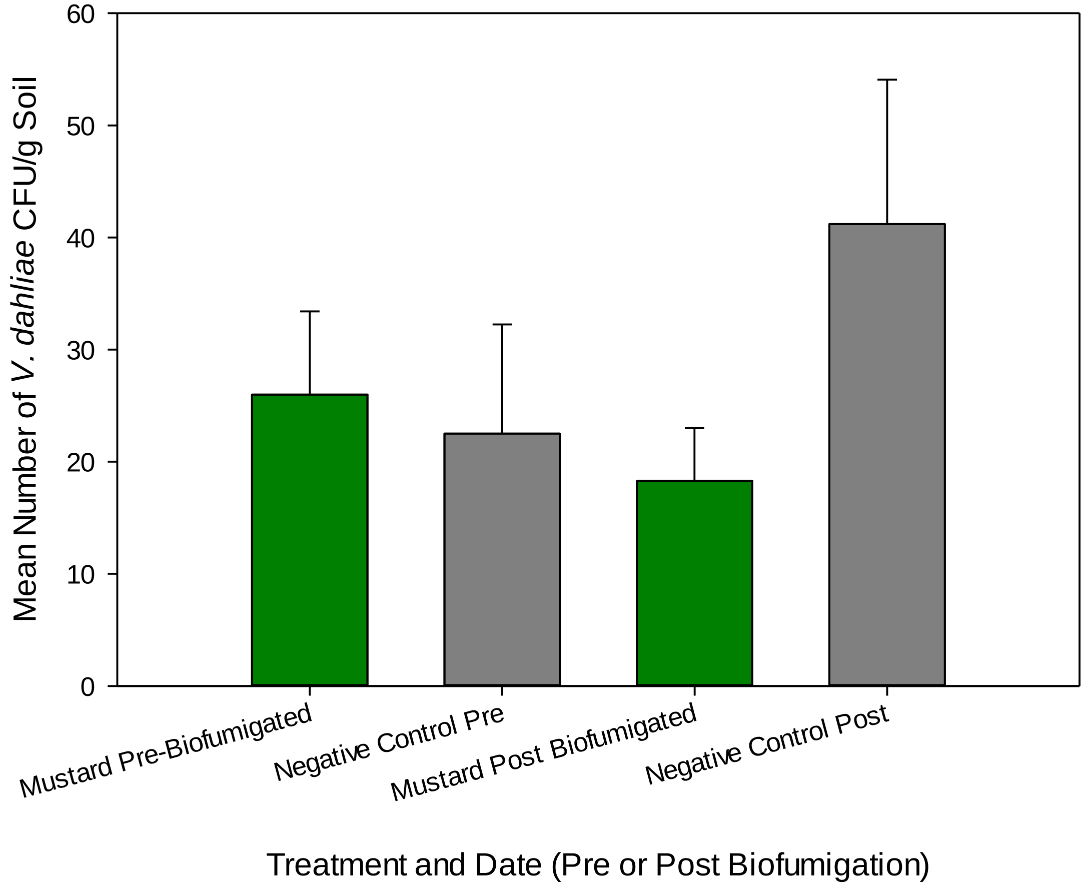
This field did not have sufficient biomass (at least 5 feet) for biofumigation at a rate that is expected to kill *V. dahliae* microsclerotia, meaning no post biofumigation testing was completed. However, this information from the pre-biofumigation does confirm that *V. dahliae* levels are over the 10 CFU threshold needed for disease in both plots, and both plots have very similar loads of *V. dahliae* in the soil. From the grower perspective, the levels of *V. dahliae* are not extreme with no sample exceeding 40 CFU, and in severe fields upwards of 600 CFU can be found in Manitoba.

Field MB-6



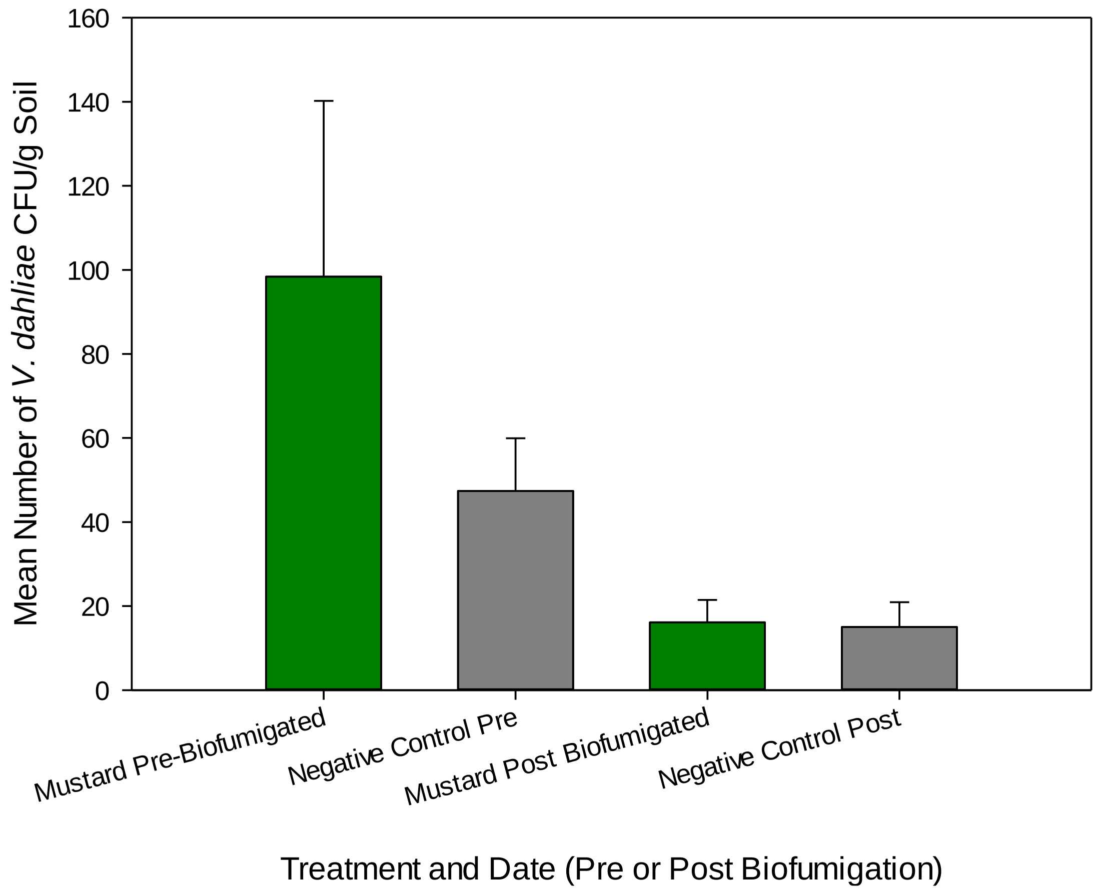
This field did not have sufficient biomass (at least 5 feet) for biofumigation at a rate that is expected to kill *V. dahliae* microsclerotia, meaning no post biofumigation testing was completed. However, this information from the pre-biofumigation does confirm that *V. dahliae* levels are over the 10 CFU threshold needed for disease in both plots, and both plots have very similar loads of *V. dahliae* in the soil. From the grower perspective, the levels of *V. dahliae* are not extreme with no sample exceeding 80 CFU, and in severe fields upwards of 600 CFU can be found in Manitoba. However, 80 CFU is eight times the minimum threshold, meaning that some kind of treatment could be considered very soon for this field.

Field MB-7



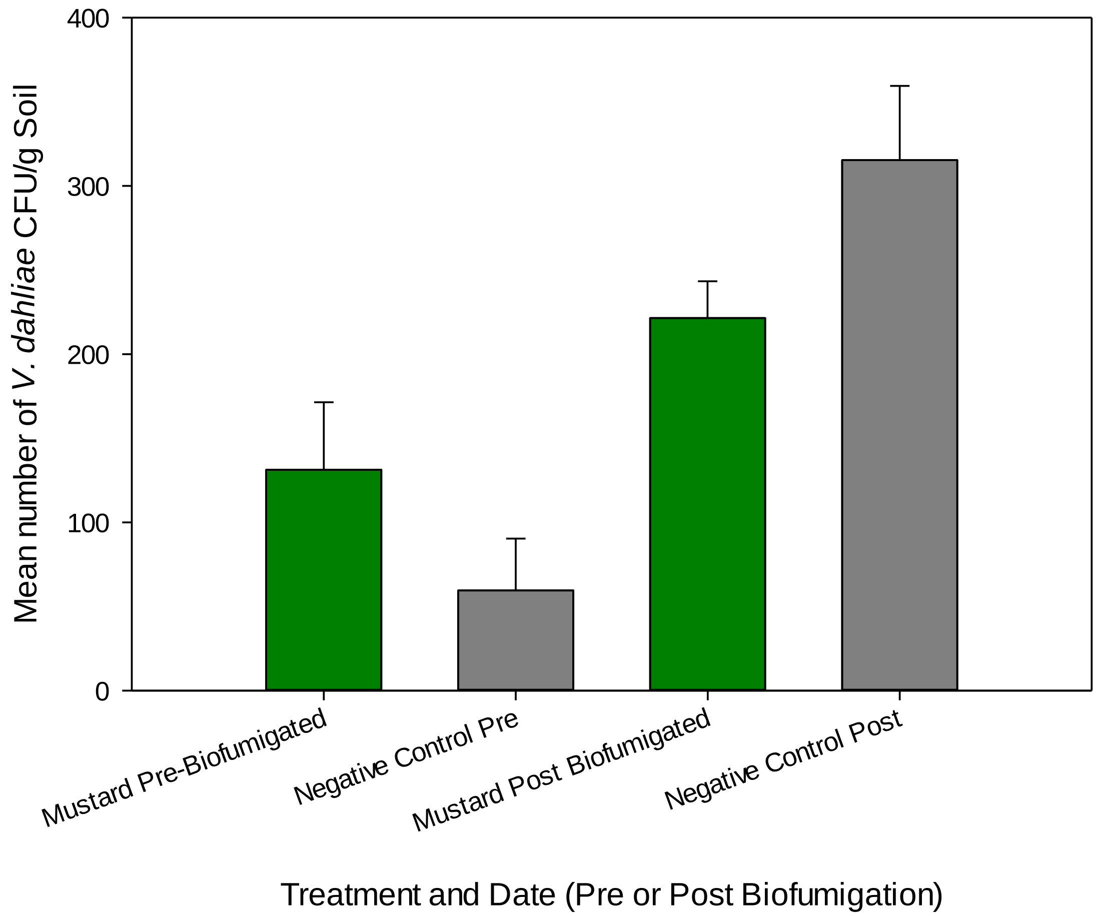
This field did have sufficient biomass (at least 5 feet) of mustard in order to biofumigate and possibly kill *V. dahliae* CFU in the soil. The pre-biofumigation plots had nearly identical amounts of *V.* dahliae CFU in the soil, as indicated by similar means and overlapping error bars, which is a positive attribute as the experiment started in the same place and the main difference in the post-biofumigation experimental means between treatments suggests that mustard biofumigation reduced *V. dahliae* CFU in the soil compared to the negative control.

Field MB-8



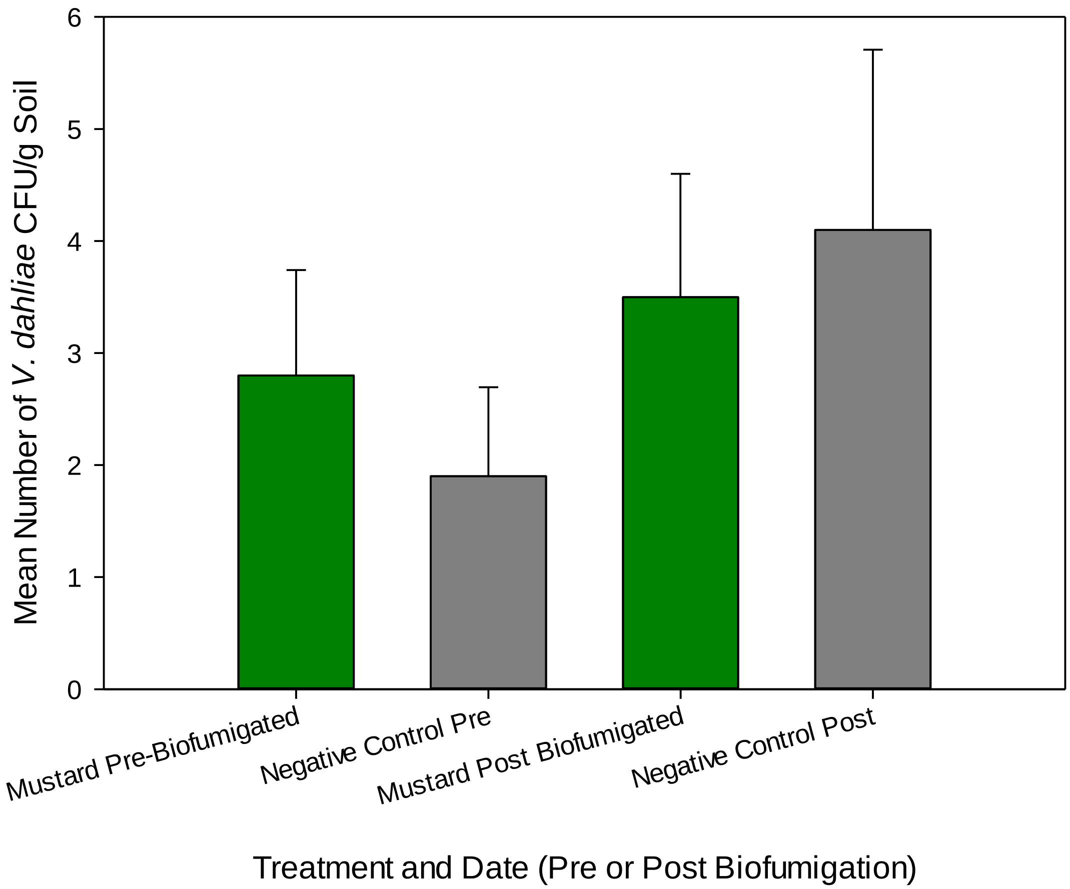
This field did have sufficient biomass (at least 5 feet) of mustard in order to biofumigate and possibly kill *V. dahliae* CFU in the soil. The pre-biofumigation plots did have similar amounts of *V.* dahliae CFU in the soil, as indicated by dissimilar means <u>but overlapping error bars</u>, which is a positive attribute as the experiment started in nearly the same place. The fact that pre and post biofumigation mustard plots had different levels of *V. dahliae* CFU suggests that mustard biofumigation reduced *V. dahliae* CFU. However, the negative control also went down over time, indicating that the negative controls were either contaminated with mustard or the sample sites had different levels of *V. dahliae*. Whatever happened in the negative control plots, it was very consistent across all 16 sample sites because the error bar is very small, indicating the load of Verticillium was virtually the same.

Field MB-9



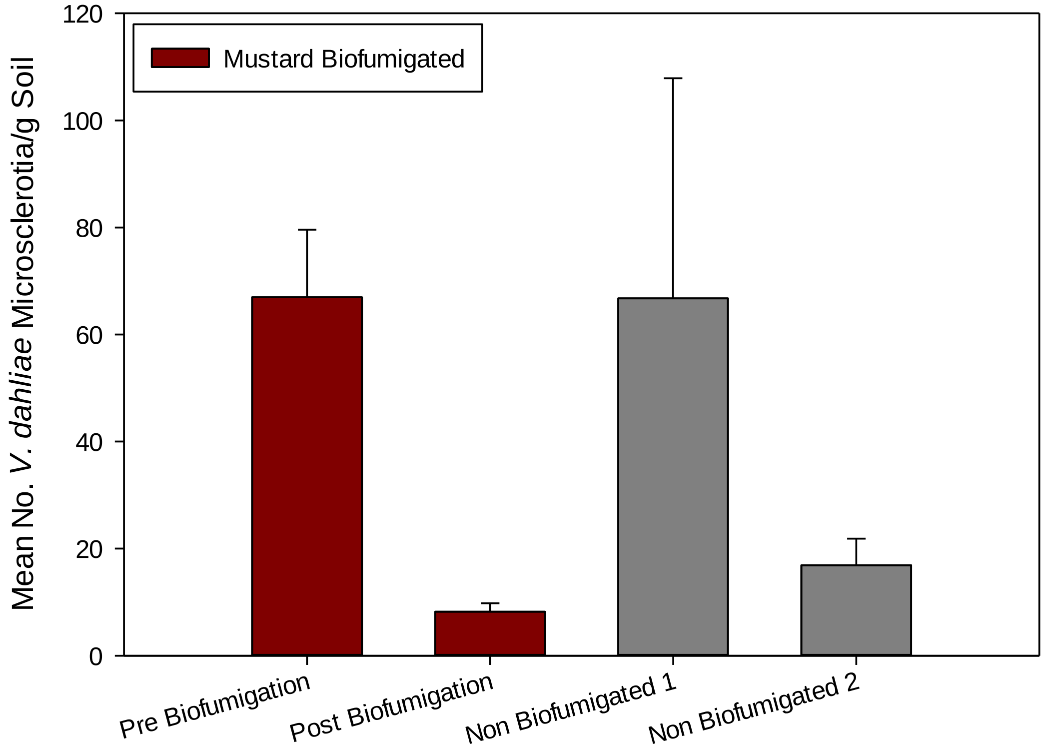
This field did not have sufficient biomass (at least 5 feet) for biofumigation at a rate that is expected to kill *V. dahliae* microsclerotia. Post biofumigation samples were completed because the load of *V. dahliae* CFU in the soil was so high (10 times minimum threshold of 10 CFU on average). The pre-biofumigation plots did have similar amounts of V. dahliae CFU in the soil, as indicated by dissimilar means but overlapping error bars, which is a positive attribute as the experiment started in nearly the same place. The fact htat the error between the 16 sample sites in this field exceeds the total *V. dahliae* CFU found in some Manitoba fields means that the levels of Verticillium in this field, while high, also vary by large gradients in the field in an area that is only 2 inches apart. In this field, the mustard biofumigation could have reduced *V. dahliae* CFU, as the negative control generally has more CFU in it than the biofumigation plot after biofumigation.

Field MB-10



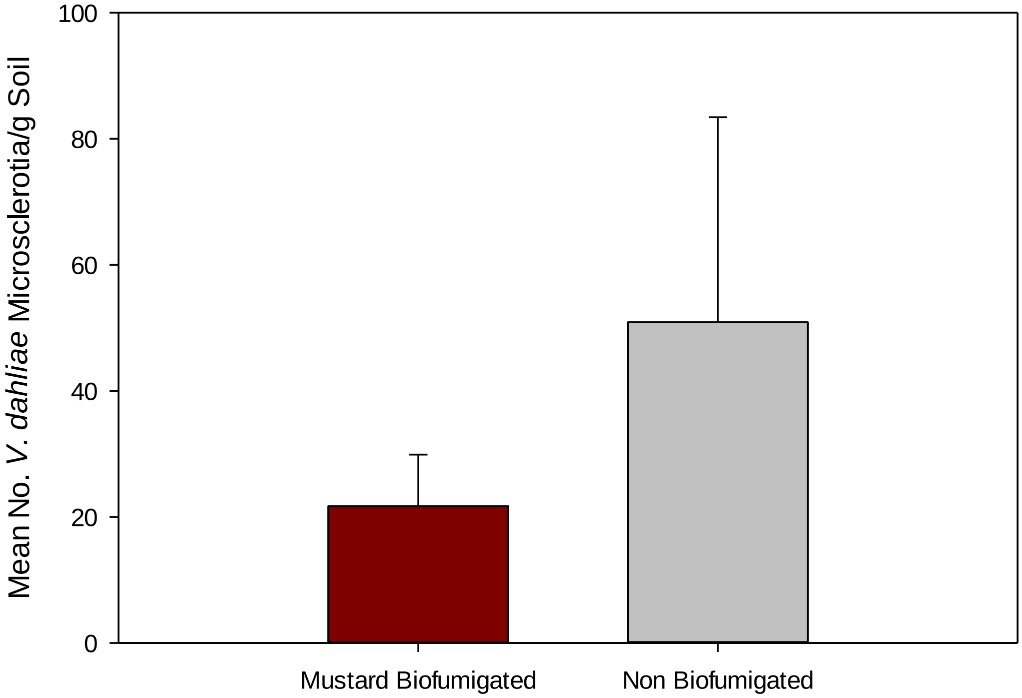
This field did have sufficient biomass (at least 5 feet) of mustard in order to biofumigate and possibly kill *V. dahliae* CFU in the soil. Any differences you can see between the treatments isn't biologically meaningful. If you look on left axis, the highest number of *V. dahliae* CFU ever observed in this field was 6, and the minimum needed for potato infection is 10. Biofumigation wasn't really successful in this field because no plot had enough *V. dahliae* to cause disease.

Field MB-2 Mustard Year 1 (2019) Results averaged amongst all four plots – year of mustard biofumigation



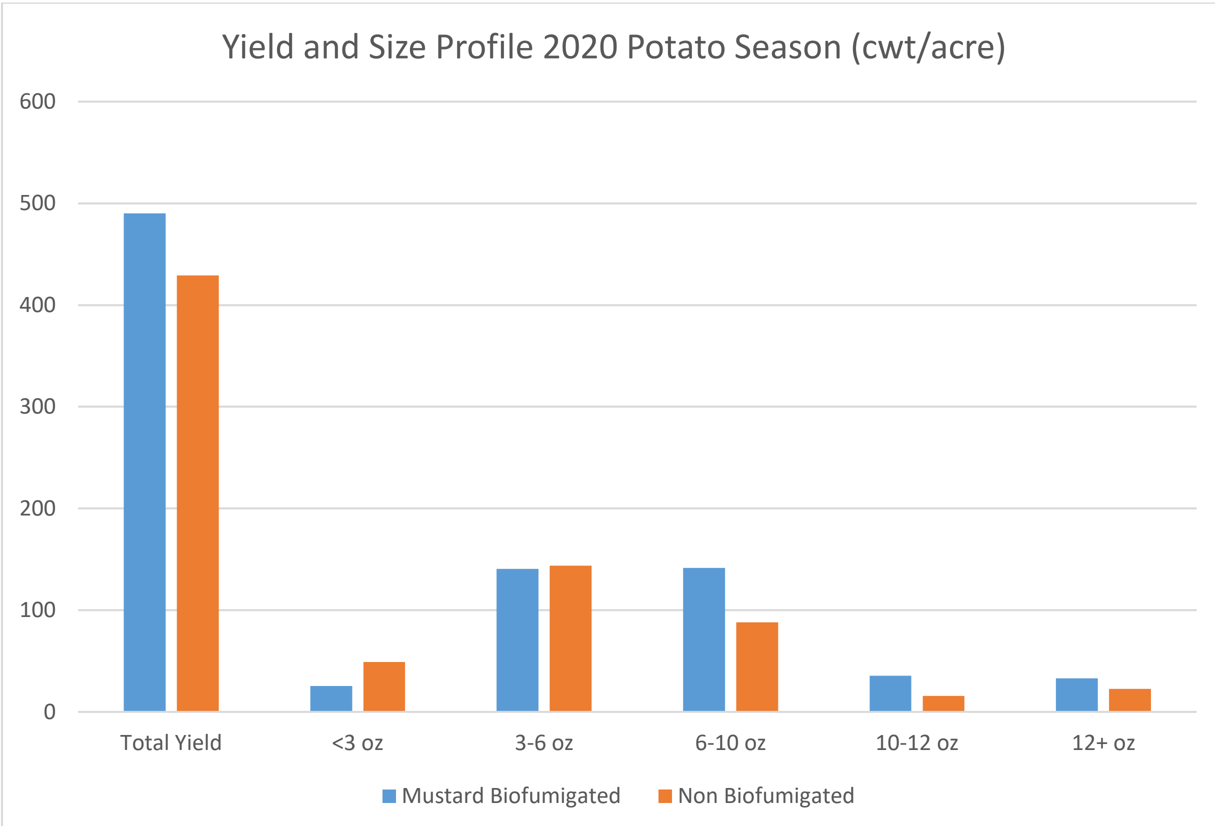
MB-2 was selected for more detailed analysis in 2019 and 2020 because the field survived in 2019 (Table 1), even though the relative amount of mustard was not at the maximum thought possible for Manitoba because the field was grown dryland instead of irrigated. The initial results are promising despite the limitations of the dryland method. The red columns appear to show that less *Verticillium* was found after biofumigating than before. However, the second set of samples after biofumigating had less *Verticillium* on average because the nonbiofumigated areas were also lower on the second sampling date. It is hard to say whether the *Verticillium* reduction was caused by sampling differences or by mustard biofumigation. The mustard crop was 3 feet tall at the most, meaning the biofumigant dose wasn't at full strength. More study is needed for definitive answer on whether mustard is working or not.

Field MB-2 First year after mustard (2020) Results averaged amongst all four plots – potato year



The initial results still appear promising but are not definitive. The error lines above the bars extend both up and down, and when they overlap as they do here then there is no statistical difference. That being said, the overall numbers in all plots decreased between 2018 and 2020 by hundreds of microsclerotia and many plots are just at the threshold where Verticillium wilt can occur (30 CFU/g) rather than 10 times over threshold as they were in 2018 (300+ CFU/g). The are three probable reasons why complete success remains elusive: mustard biofumigation is known to take several attempts to bring a *Verticillium* epidemic of this scale under control, the mustard biofumigation that was done in 2019 was with a crop that did not pack as much biomass as possible, and the nightshade problem remains at large every year. The jump in *Verticillium* counts from 2017-2018 was attributed to nightshade presence, and it is possible that continued nightshade growth will muddy the water because Verticillium counts will increase annually as long as there is this much nightshade around.

Field MB-2 Yield Data from potato year (2020, averaged between four plots in each treatment, harvest date Sept 3)



The largest impact on total yield came from a difference in 6-10 oz tubers between the plots subjected to biofumigation and those that were not. Offhand it appears that mustard biofumigation increased the number of 6-10 oz tubers and decreased the number of tubers under 3 ozs. These results need to be viewed with some caution as Verticillium wilt wasn't the only problem observed in the field. Nightshade weed density was still extremely high in the northeast part of the field, although the plants were only half as tall as 2017. Black dot was also present on the dead potato vines in addition to Verticillium wilt. Water erosion also washed away the hills in most plots. Regardless, a 60-cwt increase in yield in mustard plots over plots without biofumigation is a promising early lead. It is possible that further improvements to the 10-12 oz and 12+ oz categories can be made if other issues can be addressed so that potato vines are not dead by Sep 3. Many of these plots would not have experienced any additional bulking in the month of September in 2020.

Characterization of Agronomic Practices for Mustard Cultivars 'AC Volcan', 'Caliente Rojo', and 'Cutlass' Necessary to Achieve Maximum Biomass to Theoretically Maximize Glucosinolate production

Objectives and Deliverables

a. Practices to target: planting date (Mid July, Late July, Aug 1, Mid Aug), 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)

Conclusions

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.

CMCDC will test the biomass production from treated mustard varieties planted at four seeding dates (June 1, June 15, July 02, and July 15) during the 2021 planting year again. For this purpose, cereal crops of fall rye, and winter wheat were seeded as a stubble crop in the fall of 2020.

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 2018, and 2019, 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 two different dates with an interval of two weeks. In the 2019 growing season, July 26, and August 09 were first and second seeding dates for mustard, respectively. However, mustard was seeded on July 24, and August 07 in the 2020 growing season. The mustard seed was treated with a seed treatment product called 'Gaucho 600' in the 2020 growing season ensuring protection of the mustard plant against pests from the time of sowing well into the growing period. However, no seed treatment was applied in the 2019 growing season. 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 in both years. An area of 1 m^2 was harvested to analyze biomass production in each variety. In addition to CMCDC, 2 more local sites were selected to collect data points from off-site for observation purpose.

1). CMCDC On-site:

2019-Growing Season:

Fall Rye: Biomass production from all varieties was significantly different from each other. No sufficient biomass was generated in the Date 2 of Caliente Rojo, and Cutlass varieties due to the high infestation rate of flee beetles.

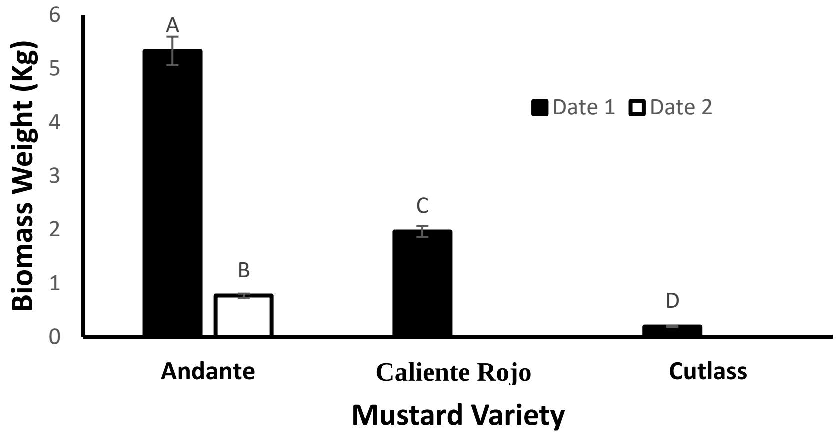


Fig. 1 Mustard varieties seeded on Fall Rye (Variety: Bono) Stubbles

Winter Wheat: Biomass production of seeding Date 1 & 2 of Andante variety was significantly different from each other. No sufficient biomass was generated in the Date 1 & 2 of Caliente Rojo, and Cutlass varieties due to the high infestation rate of flee beetles.

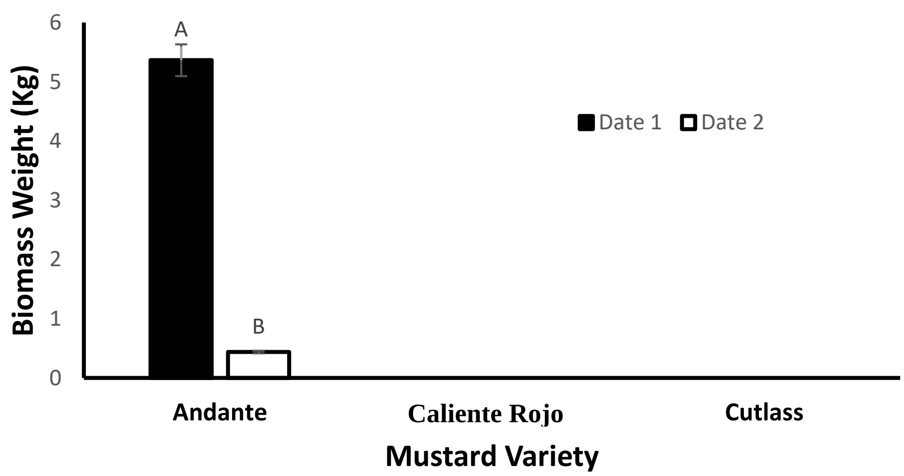


Fig. 2 Mustard varieties seeded on Winter Wheat (Variety: Wildfire) Stubbles

2). Field MB-3

Data was collected at 4 different sites (Locations 1-4) with same treatment but different land features.

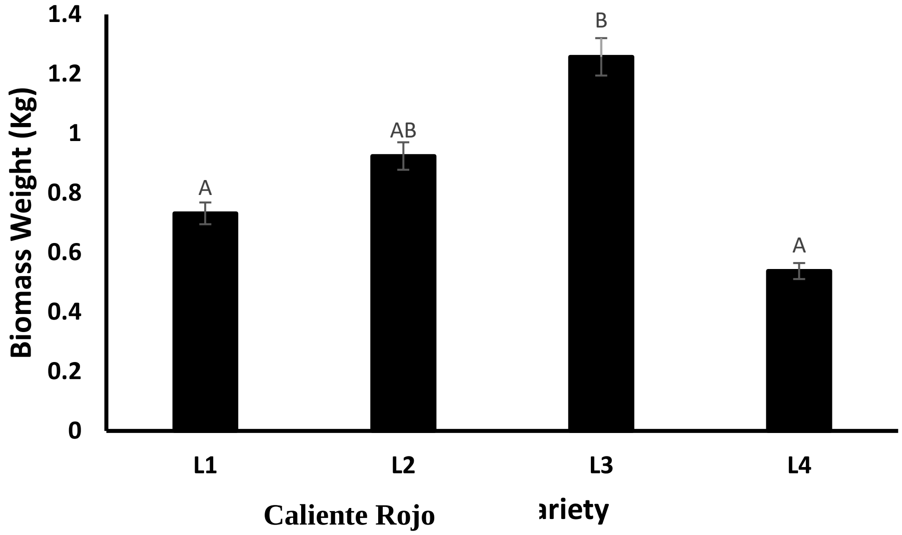


Fig. 3 Biomass data collected in producer's field – single seeding date

3). Field MB-1

Mustard was seeded at 3 different dates. No significant difference in biomass production was observed in Date 1 and Date 3. However, Date 2 was significantly different from Date 1, and Date 3.

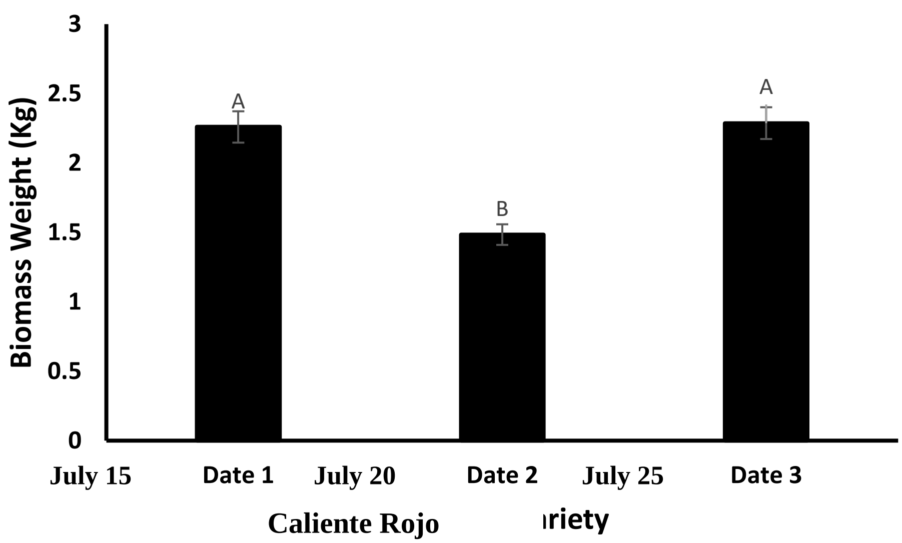


Fig. 3 Biomass data collected in producer's field – multiple seeding dates

2020-Growing Season

Treatments

<u>Primary Treatments</u>

- Seeding on Cereal Stubbles (Fall Rye, and Winter Wheat)
- Seeding on Non-stubble land

<u>Secondary Treatments</u>

- Seeding dates (2 dates)
- Seed Treatment (Treated vs non-treated)

Results

Fall Rye Stubbles

Date 1 vs Date 2:

A relatively higher proportion of biomass, plant counts, and plant height was observed in the seeding date 1 compared to the seeding date 2 for all mustard varieties within the 1 m^2 harvested area (Fig. 1, 2, & 3).

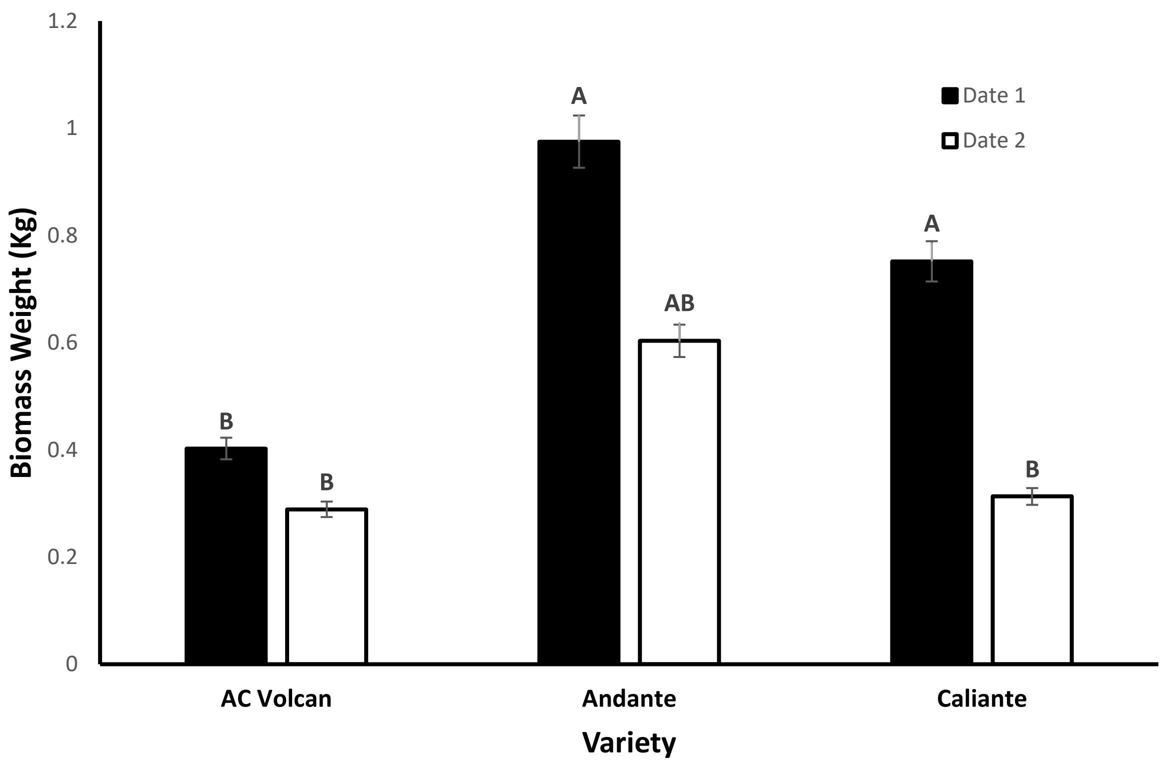


Fig. 1 Biomass of mustard varieties seeded on Fall Rye Stubbles – Seeding dates comparison

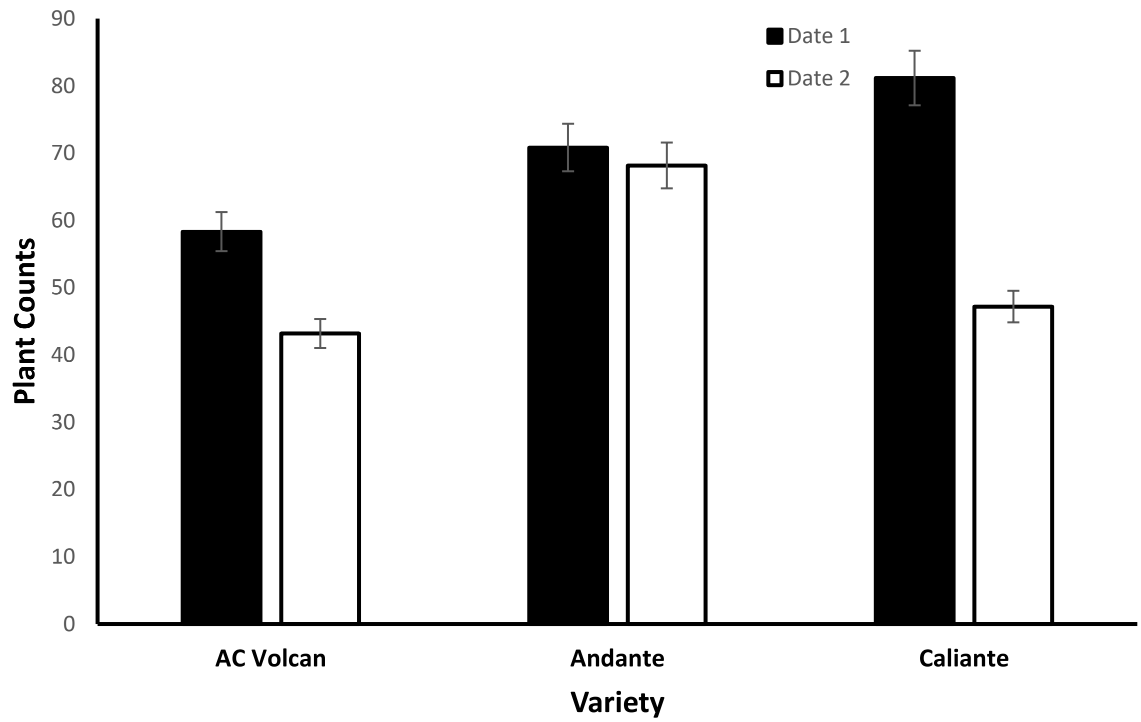


Fig. 2 Plant Counts of mustard varieties seeded on Fall Rye Stubbles – Seeding dates comparison

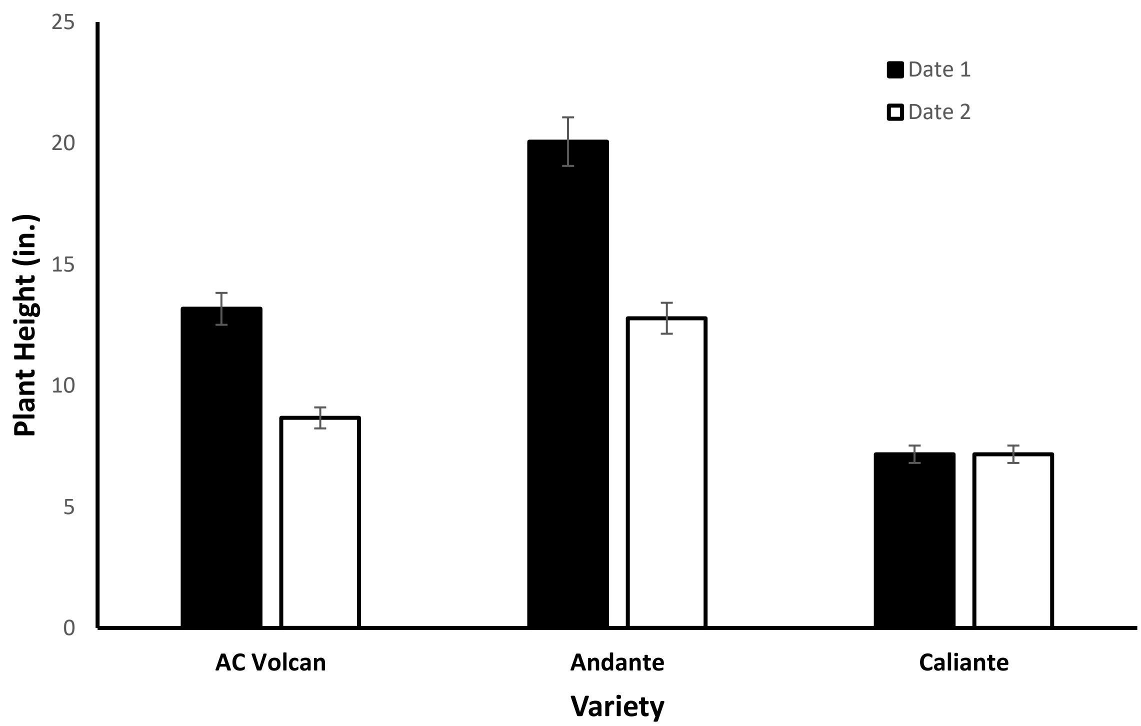


Fig. 3 Plant Heights of mustard varieties seeded on Fall Rye Stubbles – Seeding dates comparison

Treated Seed vs Non-treated Seed:

A relatively higher proportion of biomass, plant counts, and plant height was observed in the treated seed treatment compared to the non-treated seed treatment for all mustard varieties within the 1 m^2 harvested area (Fig. 4, 5, & 6).

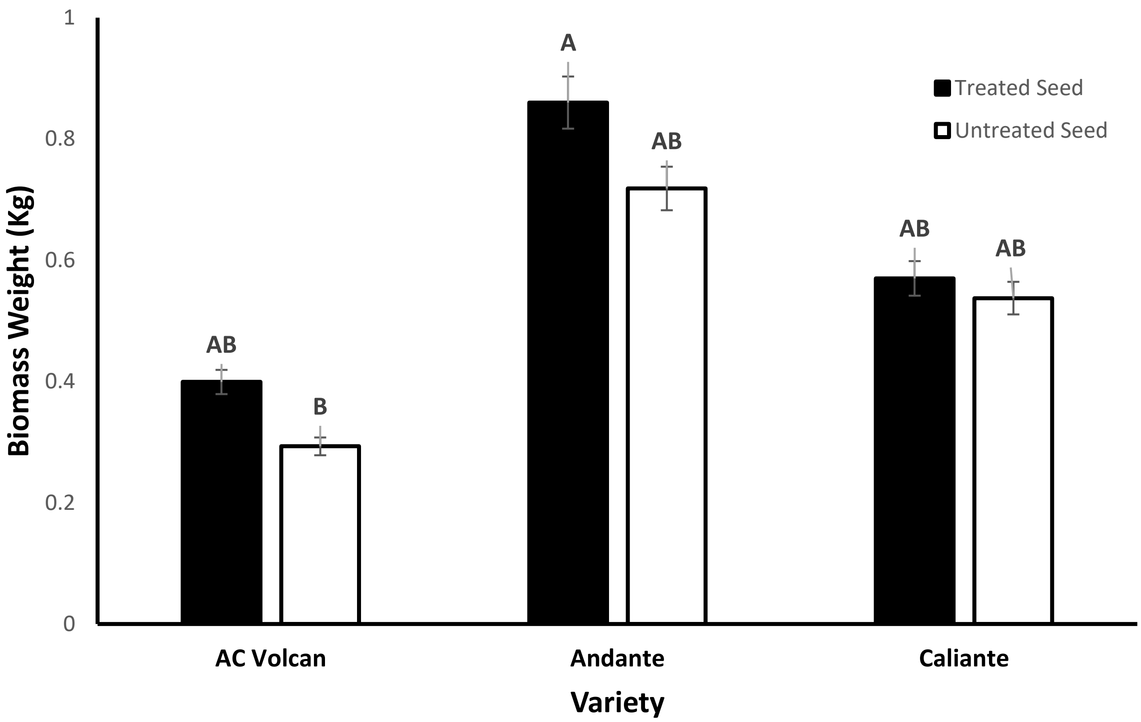


Fig. 4 Biomass of mustard varieties seeded on Fall Rye Stubbles – Seed treatment comparison

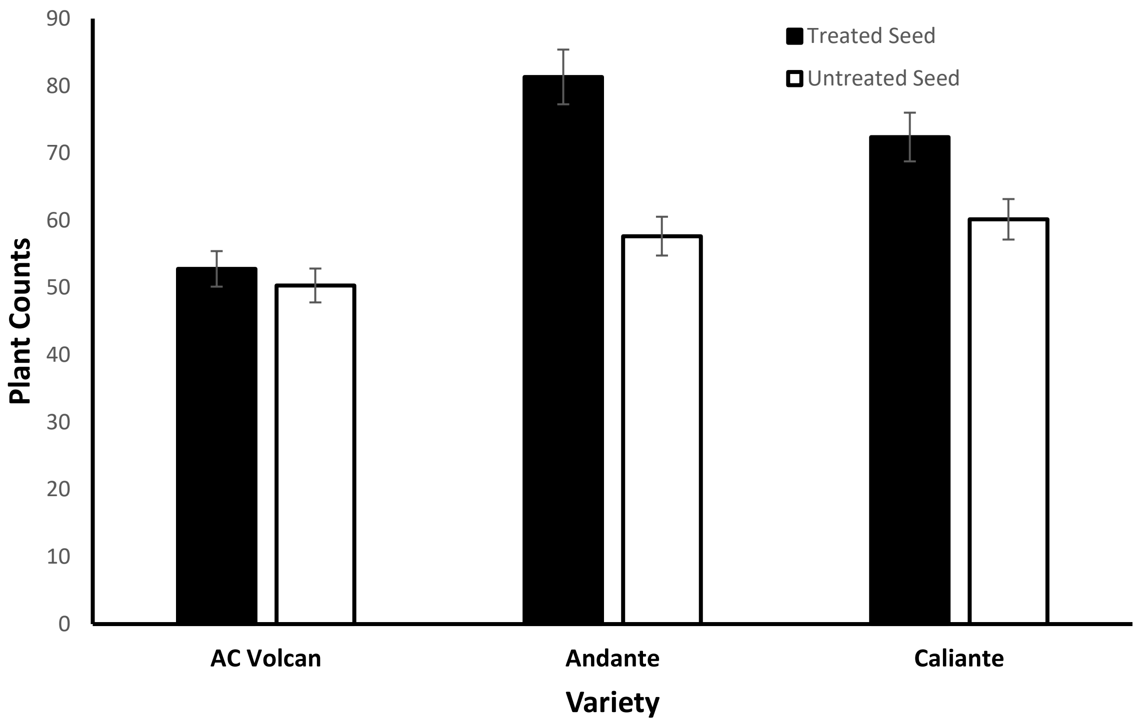


Fig. 5 Plant Counts of mustard varieties seeded on Fall Rye Stubbles – Seed treatment comparison

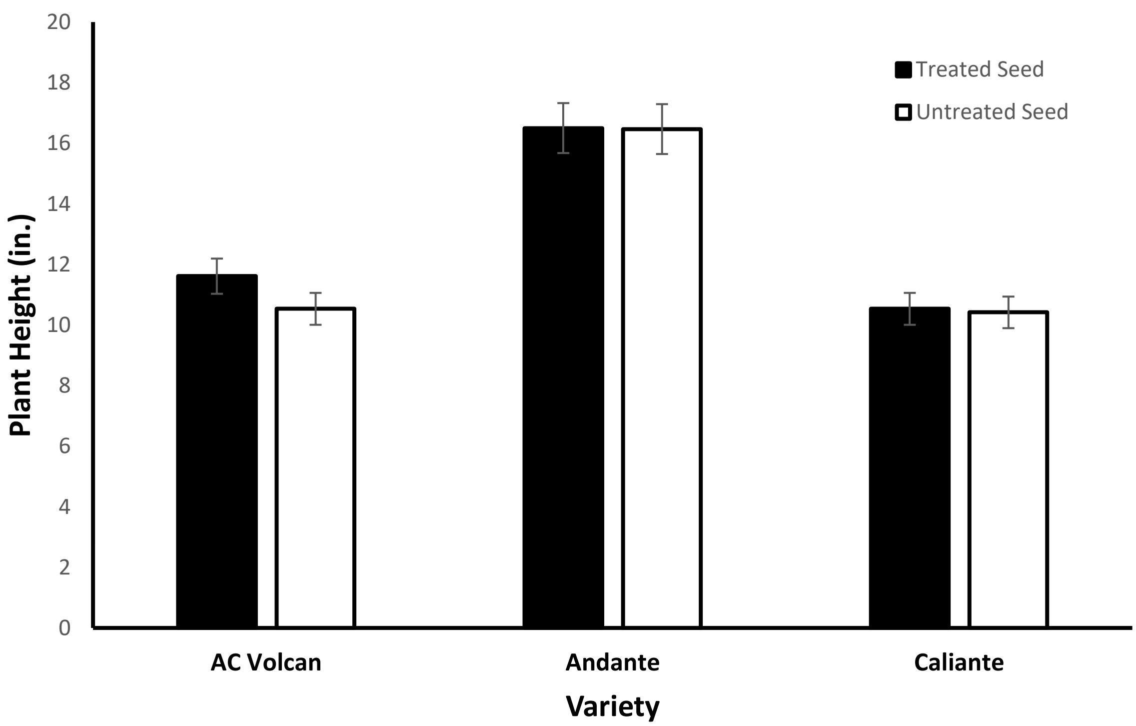


Fig. 6 Plant Heights of mustard varieties seeded on Fall Rye Stubbles – Seed treatment comparison

Winter Wheat Stubbles

Date 1 vs Date 2:

A relatively higher proportion of biomass, plant counts, and plant height was observed in the seeding date 1 compared to the seeding date 2 for all mustard varieties within the 1 m^2 harvested area (Fig. 7, 8, & 9).

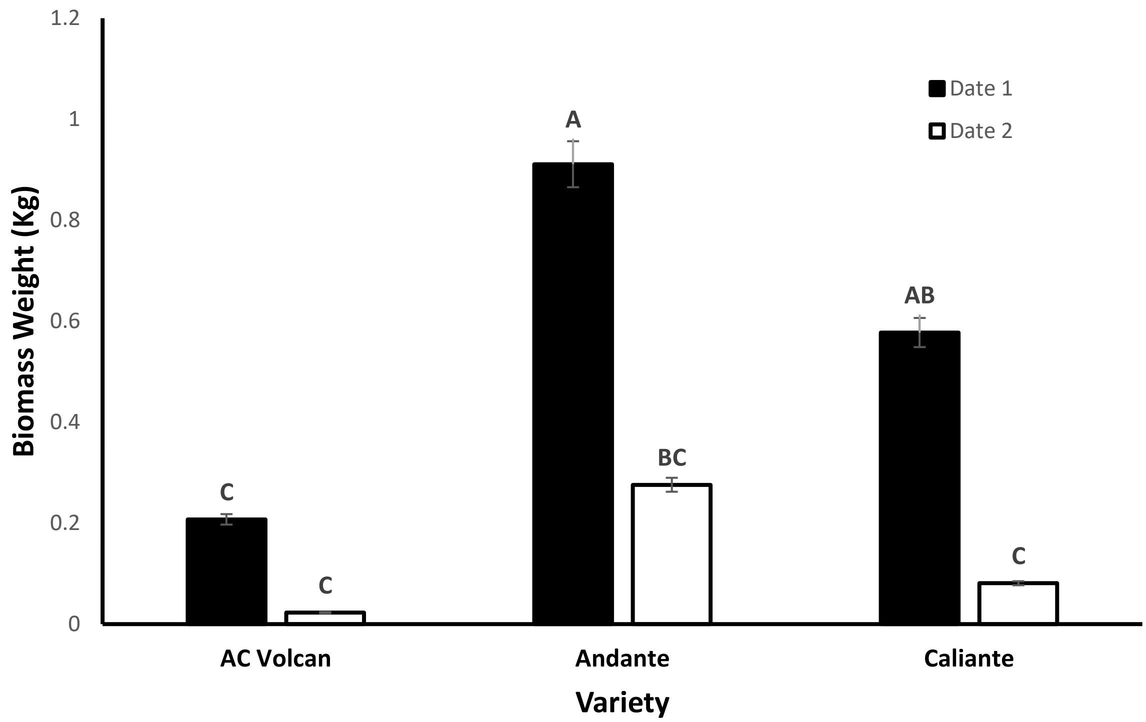


Fig. 7 Biomass of mustard varieties seeded on Winter Wheat Stubbles – Seeding dates comparison

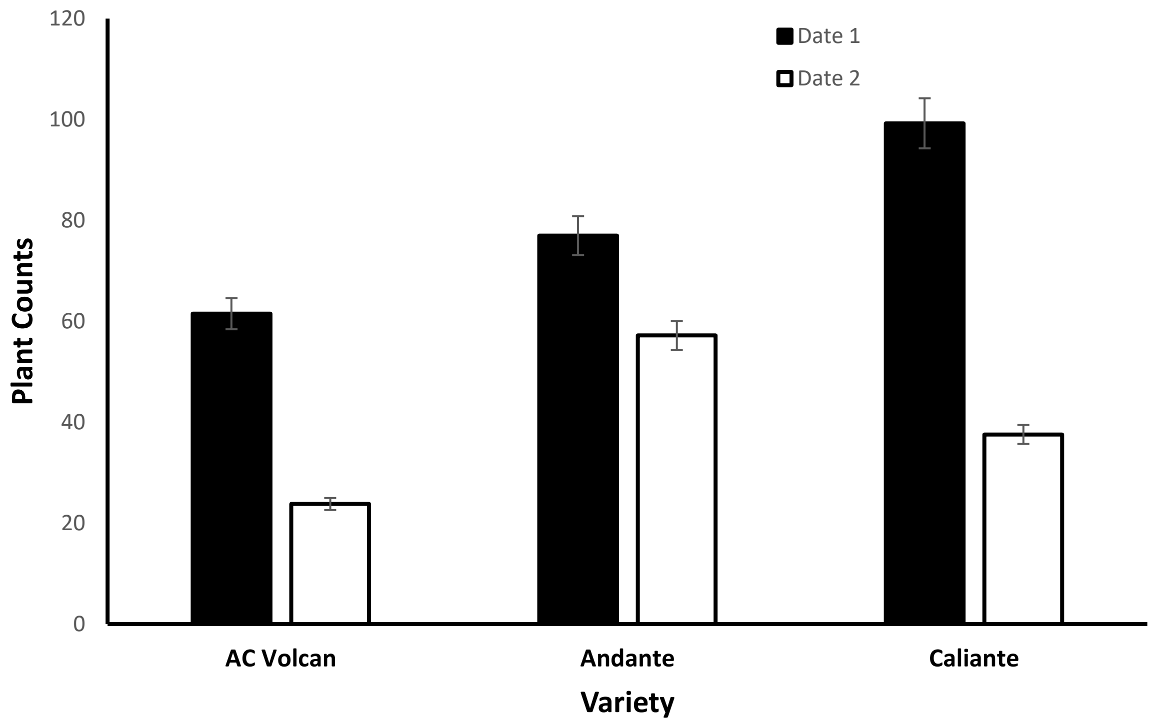


Fig. 8 Plant Counts of mustard varieties seeded on Winter Wheat Stubbles – Seeding dates comparison

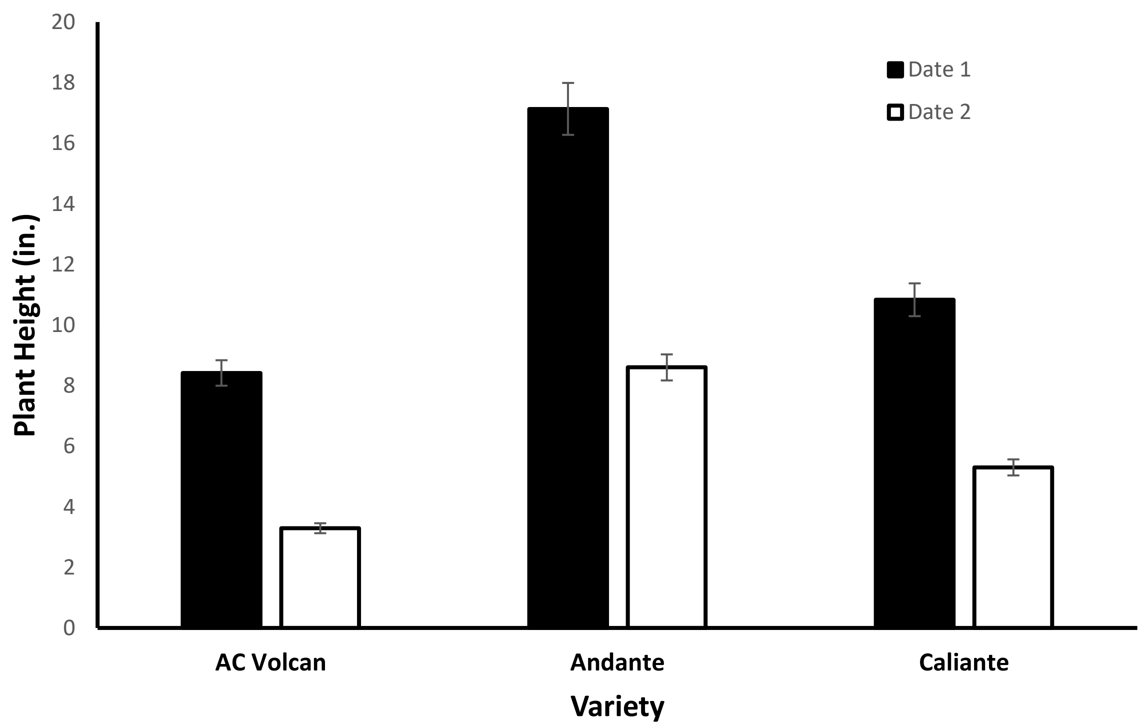


Fig. 9 Plant Heights of mustard varieties seeded on Winter Wheat Stubbles – Seeding dates comparison

Treated Seed vs Non-treated Seed:

A relatively higher proportion of biomass, plant counts, and plant height was observed in the treated seed treatment compared to the non-treated seed treatment for all mustard varieties within the 1 m^2 harvested area (Fig. 10, 11, & 12).

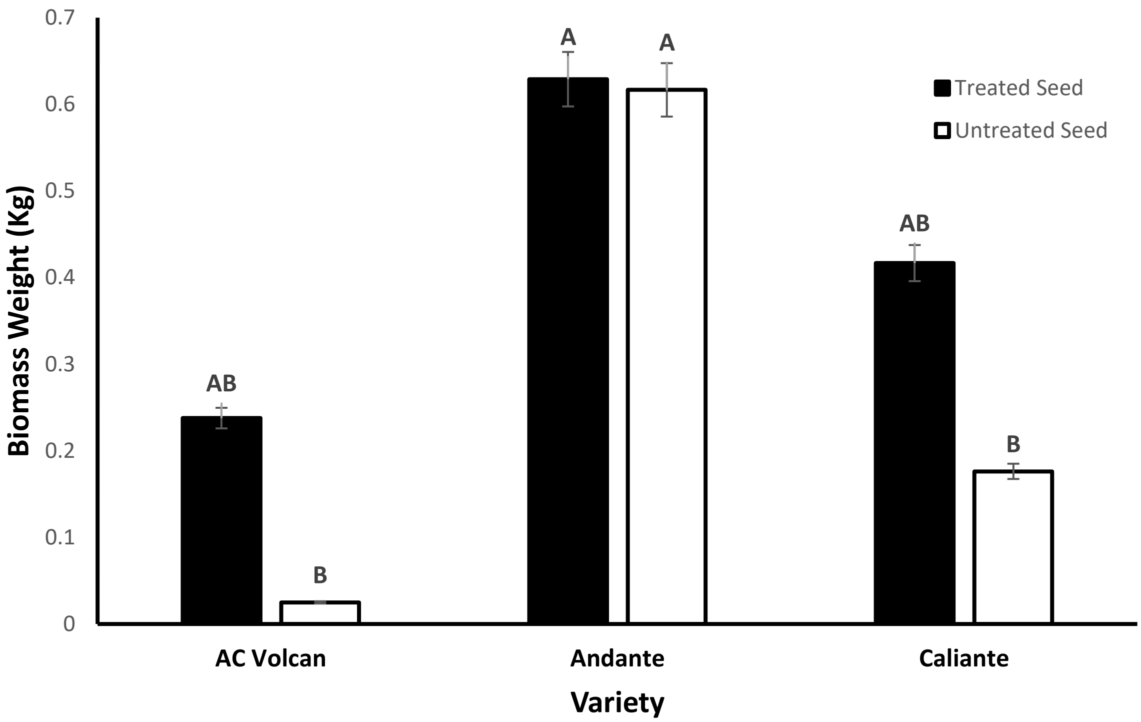


Fig. 10 Biomass of mustard varieties seeded on Winter Wheat Stubbles – Seed treatment comparison

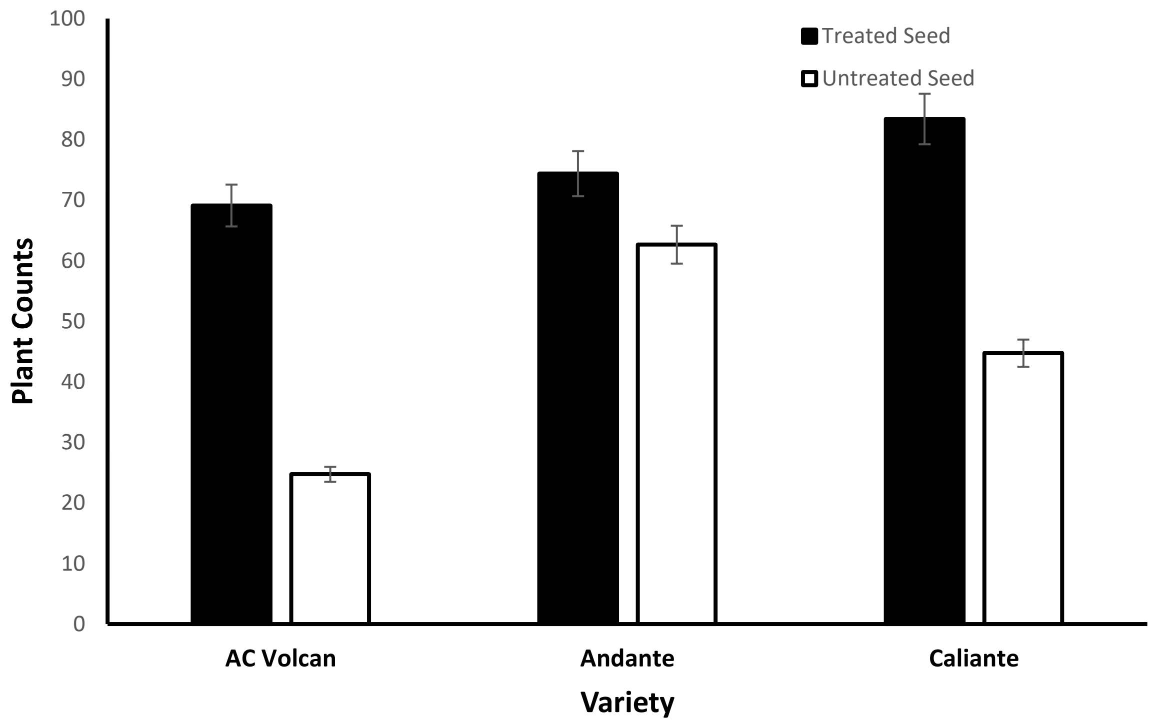


Fig. 11 Plant Counts of mustard varieties seeded on Winter Wheat Stubbles – Seed treatment comparison

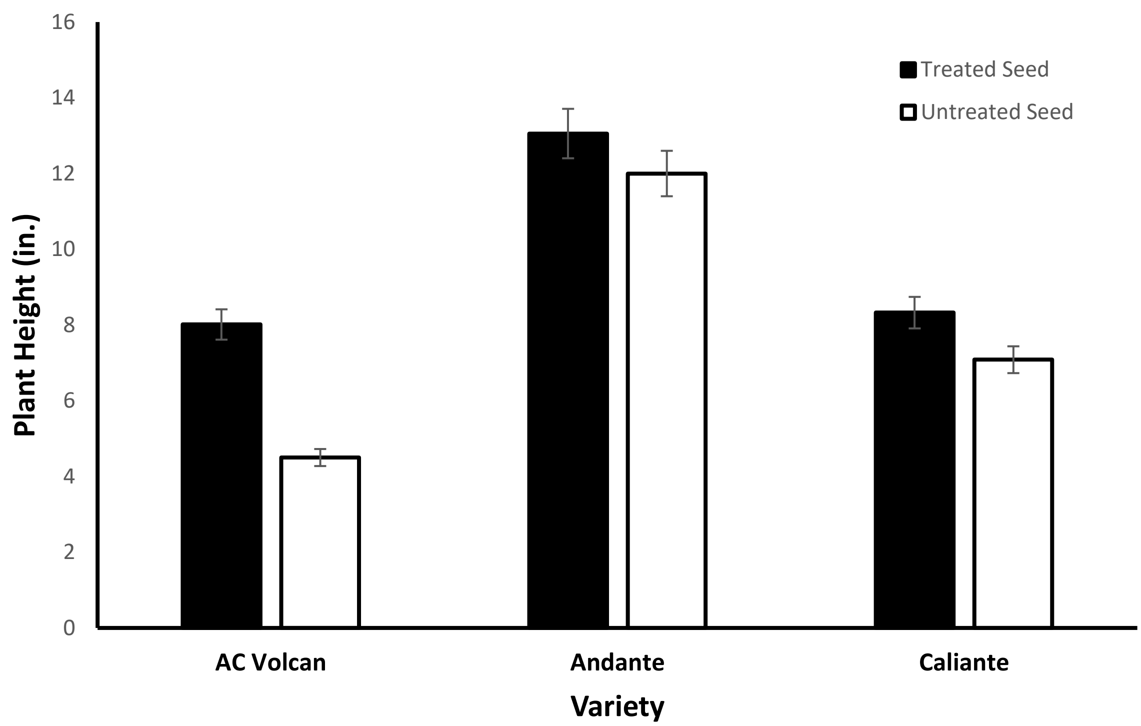


Fig. 12 Plant Heights of mustard varieties seeded on Winter Wheat Stubbles – Seed treatment comparison

Non-stubble Land

Date 1 vs Date 2:

A relatively higher proportion of biomass, plant counts, and plant height was observed in the seeding date 1 compared to the seeding date 2 for all mustard varieties within the 1 m^2 harvested area (Fig. 13, 14, & 15).

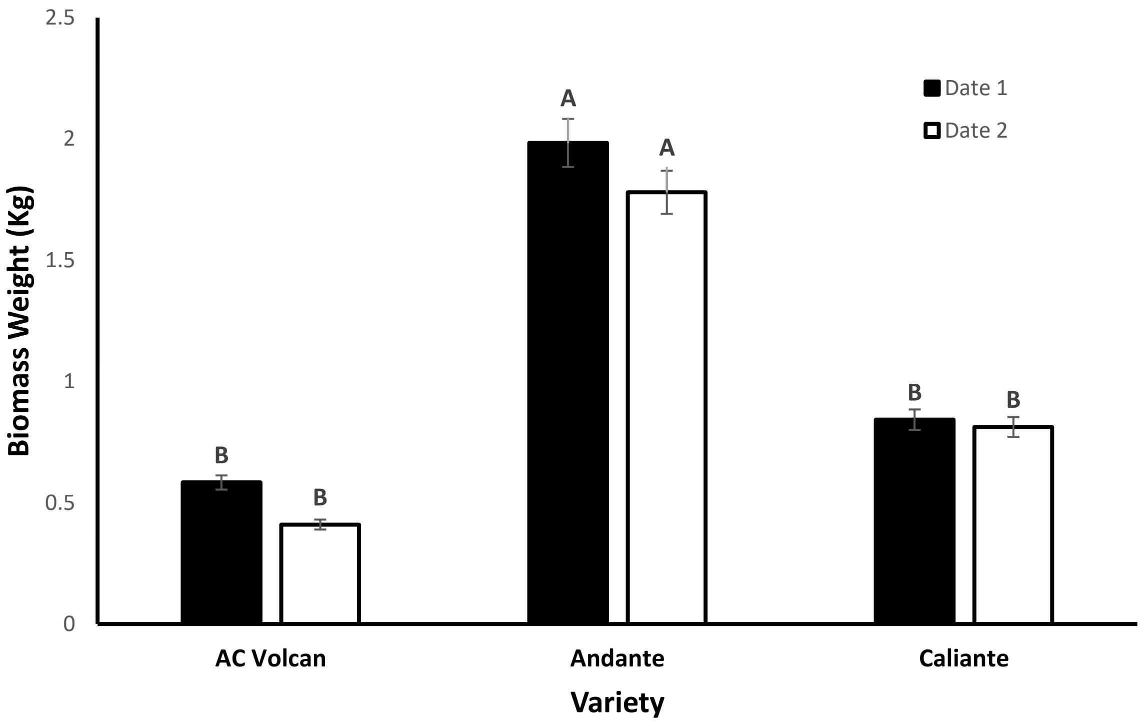


Fig. 13 Biomass of mustard varieties seeded on Non-stubble land – Seeding dates comparison

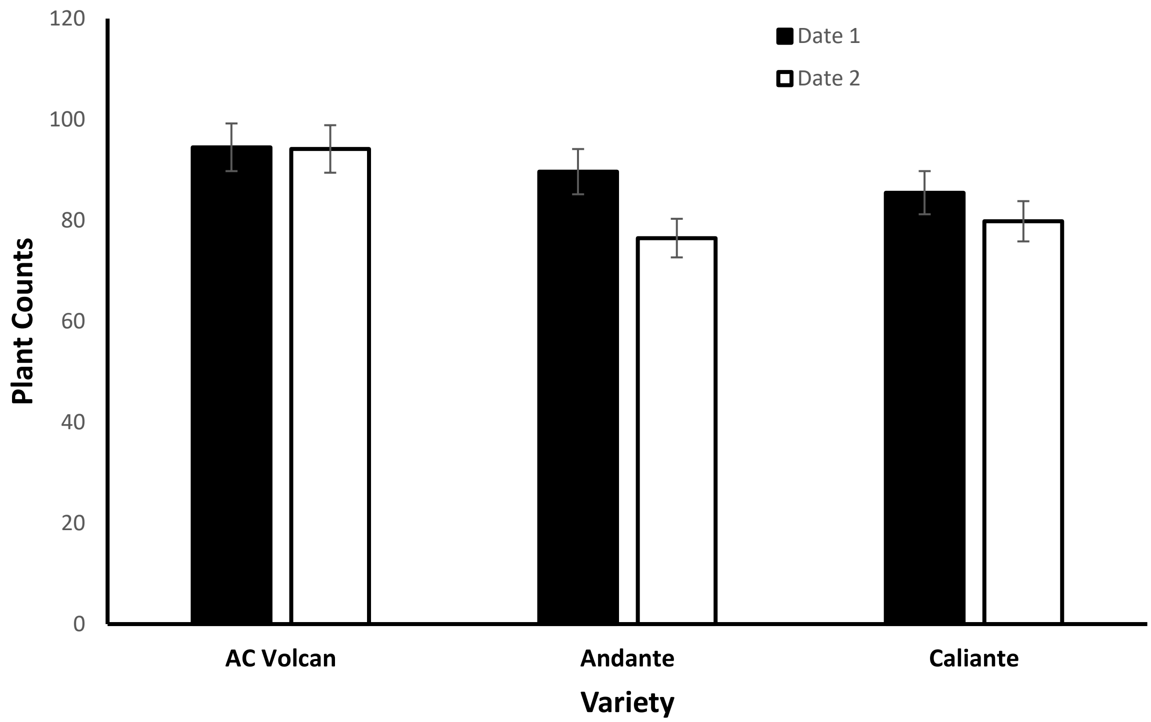


Fig. 14 Plant Counts of mustard varieties seeded on Non-stubble land – Seeding dates comparison

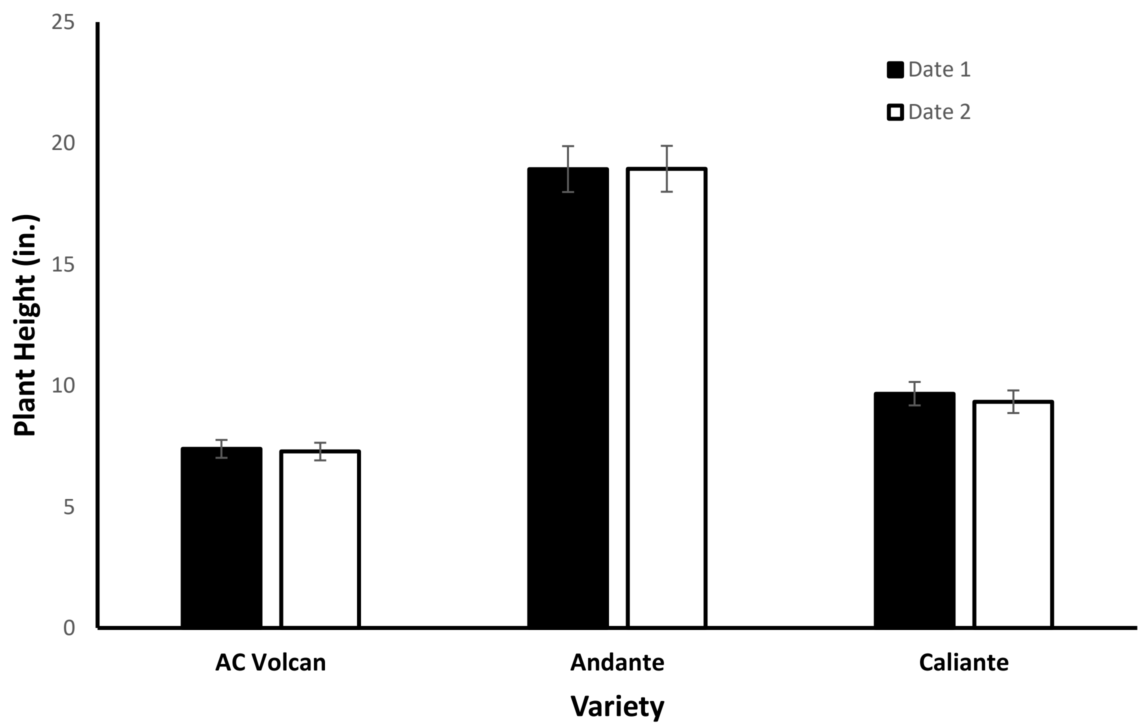


Fig. 15 Plant Heights of mustard varieties seeded on Non-stubble land – Seeding dates comparison

Treated Seed vs Non-treated Seed:

A relatively higher proportion of biomass, plant counts, and plant height was observed in the treated seed treatment compared to the non-treated seed treatment for all mustard varieties within the 1 m^2 harvested area (Fig. 16, 17, & 18).

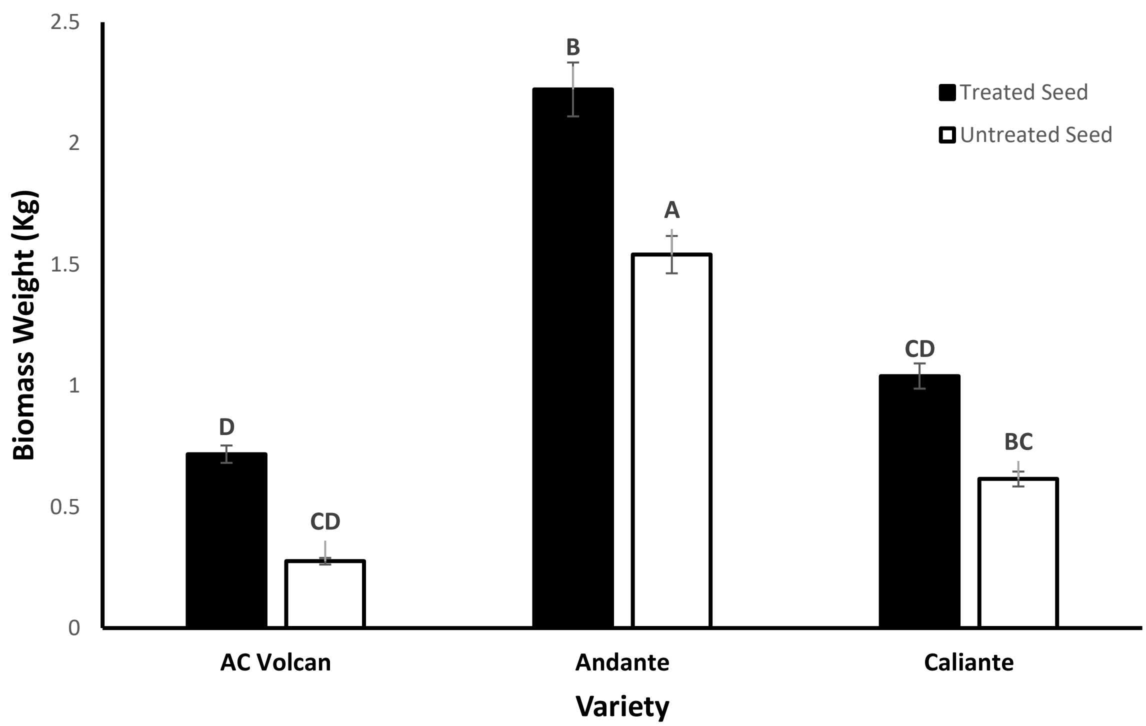


Fig. 16 Biomass of mustard varieties seeded on Non-stubbles land – Seed treatment comparison

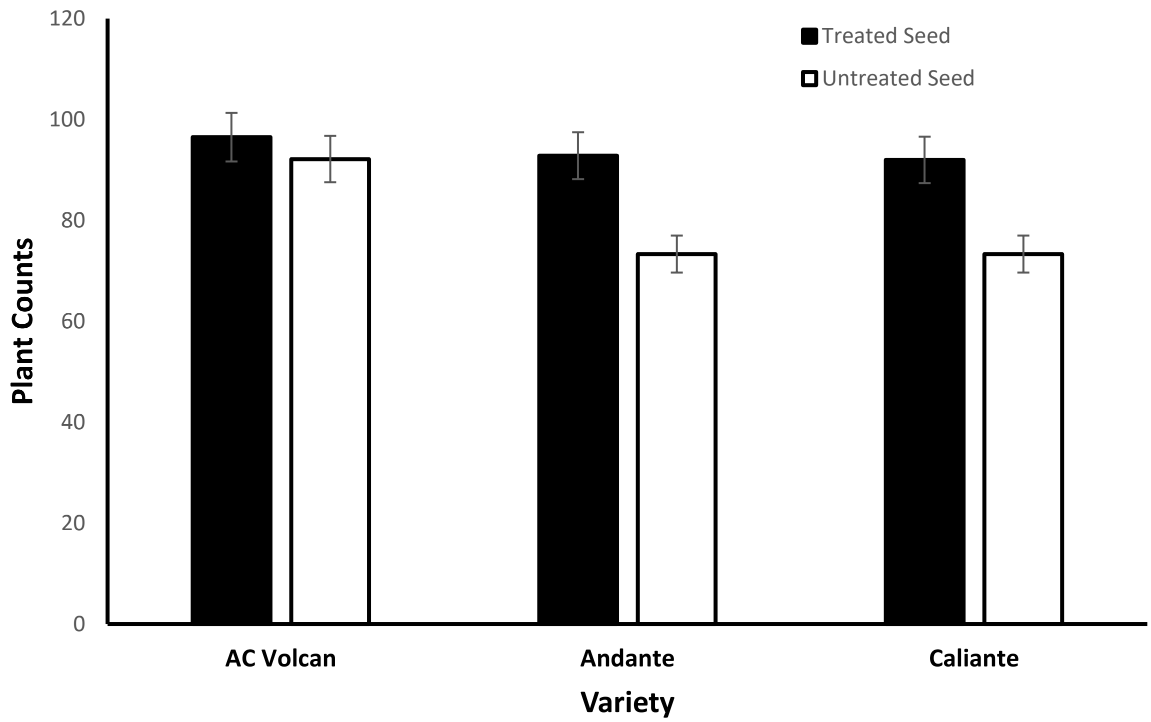


Fig. 17 Plant Counts of mustard varieties seeded on Non-stubbles land – Seed treatment comparison

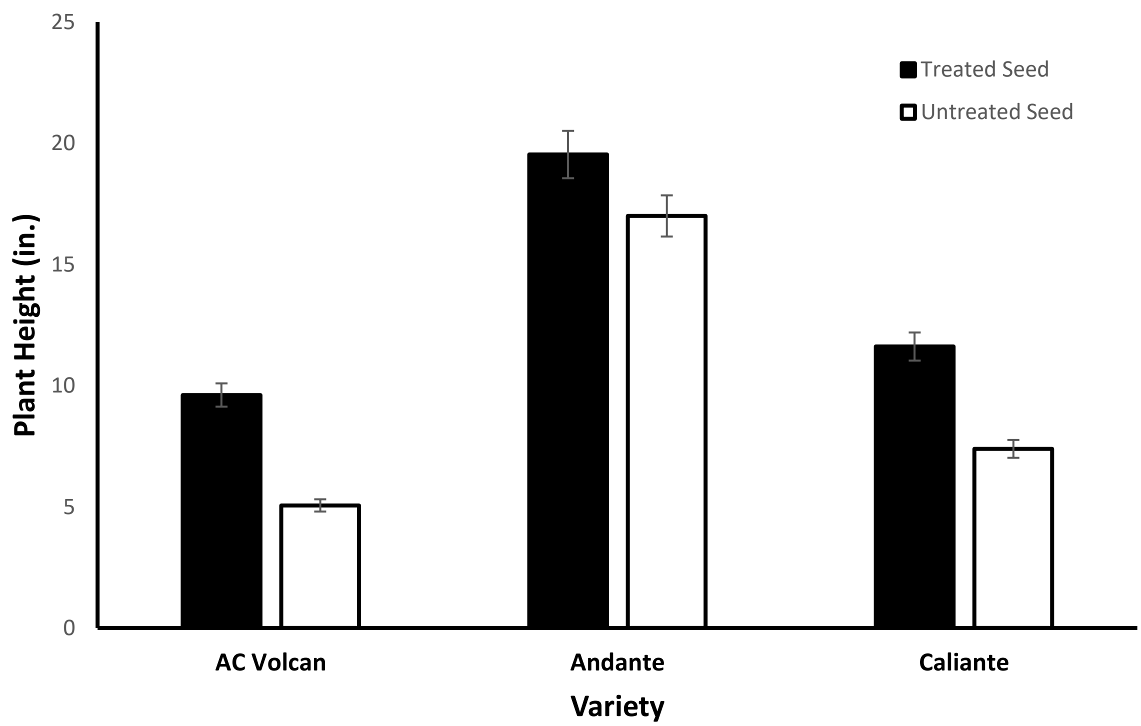


Fig. 18 Plant Heights of mustard varieties seeded on Non-stubbles land – Seed treatment comparison

General Comparison

Date 1 vs Date 2:

A relatively higher proportion of biomass, plant counts, and plant height was observed in the seeding date 1 compared to the seeding date 2 for all mustard varieties within the 1 m^2 harvested area (Fig. 19, 20, & 21).

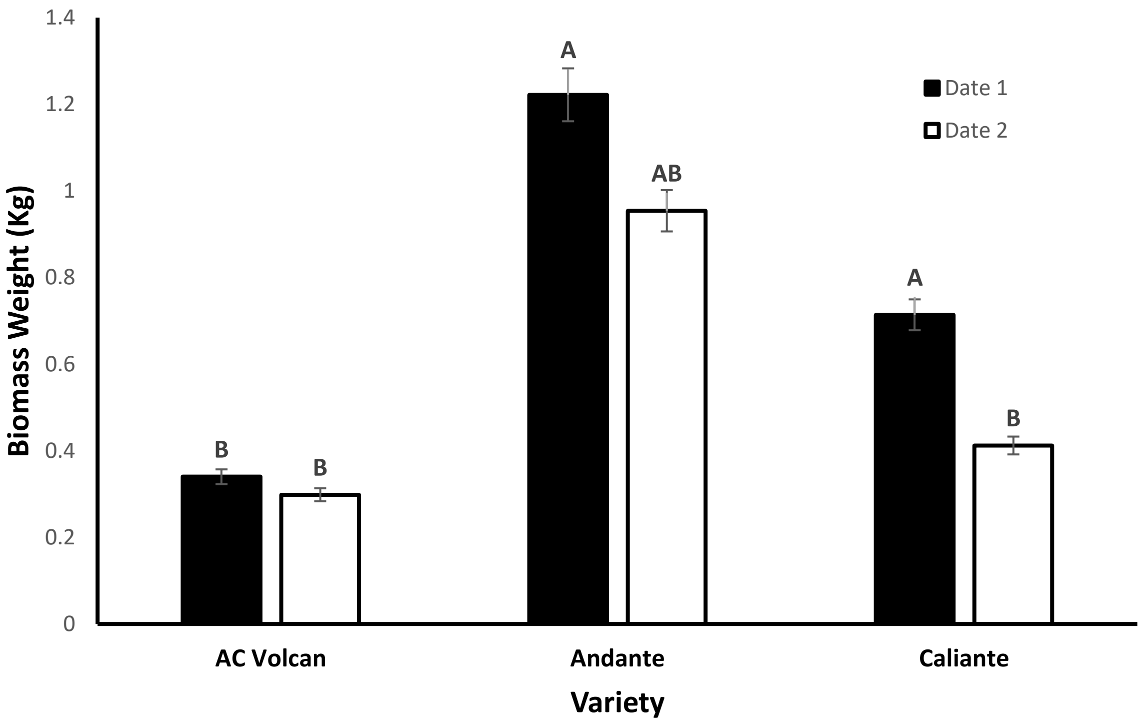


Fig. 19 Biomass of mustard varieties – Seeding dates comparison

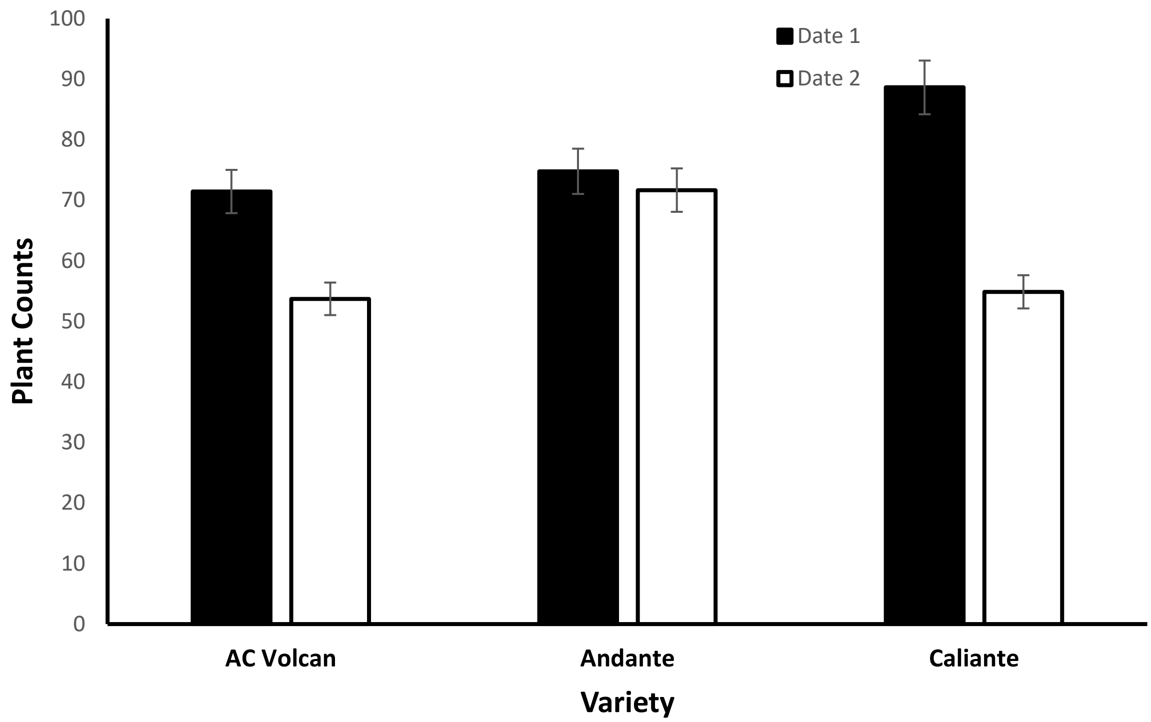


Fig. 20 Plant Counts of mustard varieties – Seeding dates comparison

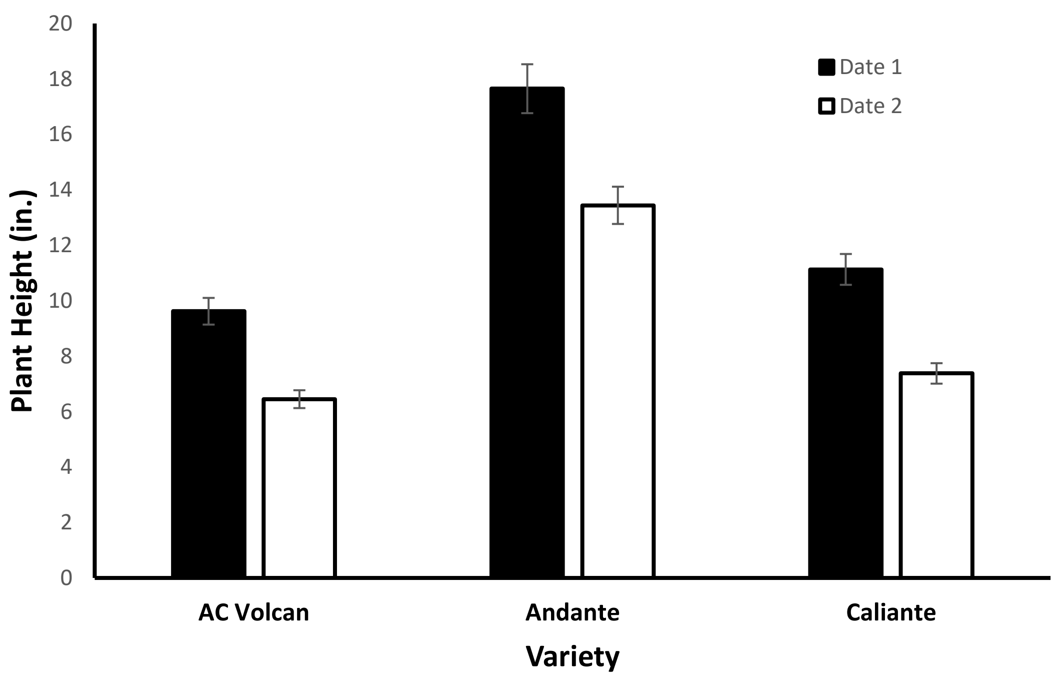


Fig. 21 Plant Heights of mustard varieties – Seeding dates comparison

Treated Seed vs Non-treated Seed:

A relatively higher proportion of biomass, plant counts, and plant height was observed in the treated seed treatment compared to the non-treated seed treatment for all mustard varieties within the 1 m^2 harvested area (Fig. 22, 23, & 24).

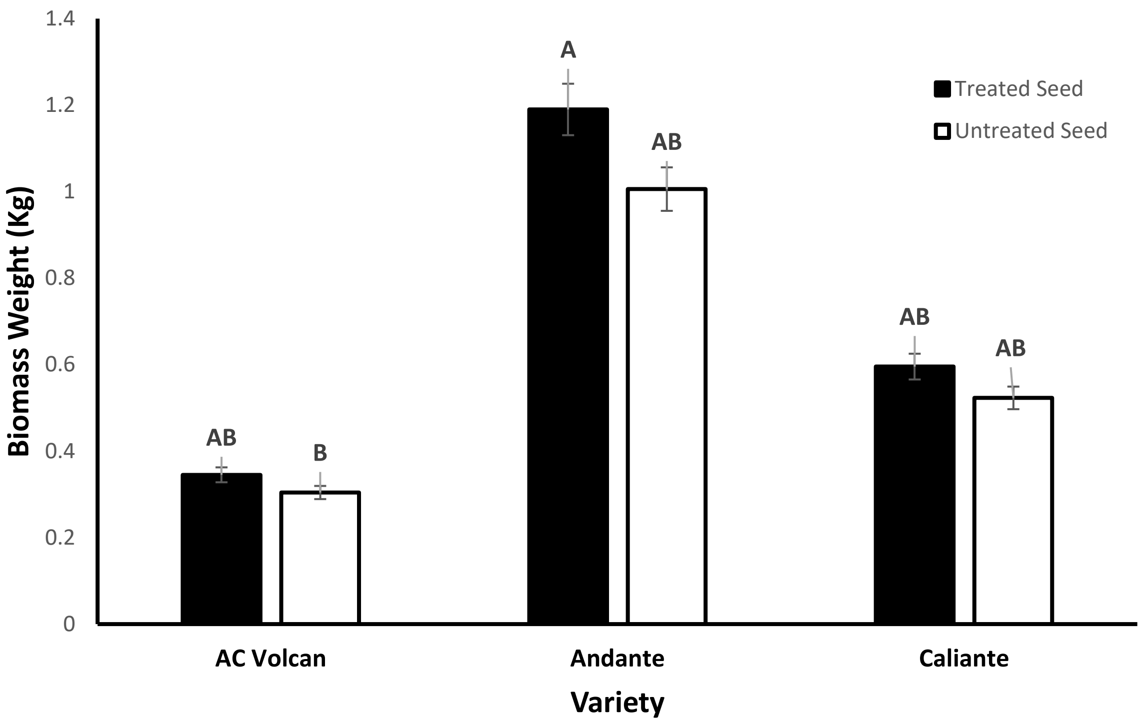


Fig. 22 Biomass of mustard varieties – Seed treatment comparison

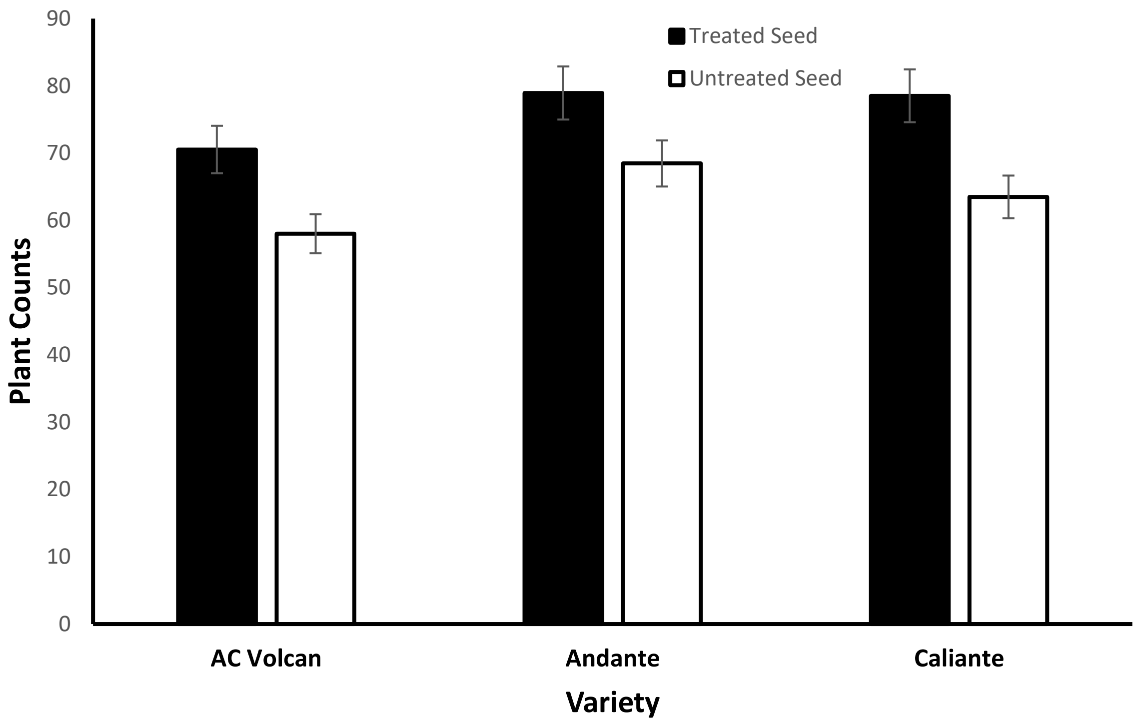


Fig. 23 Plant Counts of mustard varieties – Seed treatment comparison

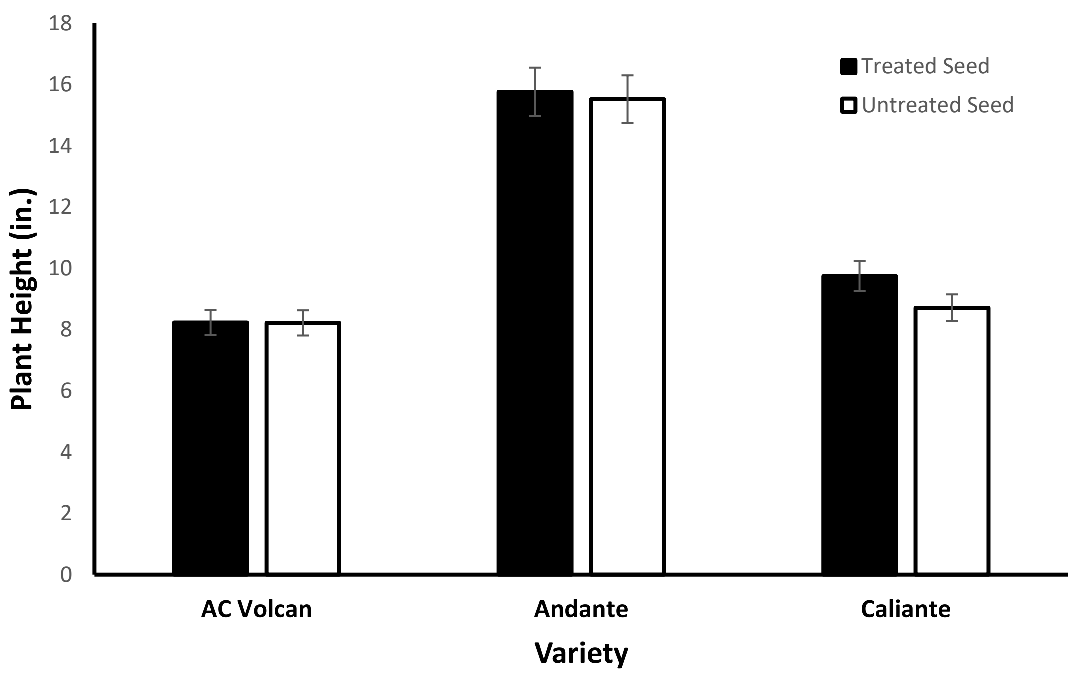


Fig. 24 Plant Heights of mustard varieties – Seed treatment comparison

Data collected from Producers' Field:

Field Name: MB-8

Data was collected at 4 different sites (Locations 1-4) with same treatment but different land features. Variability in biomass density, plant counts, and plant heights is shown in Fig. 25, 26, & 27. The producer seeded the treated Caliente variety of mustard and an area of 1 m^2 for observations and analysis.

Average Biomass: 2.78 Kg

Average Plant Counts: 142

Average Plant Height: 35 in.

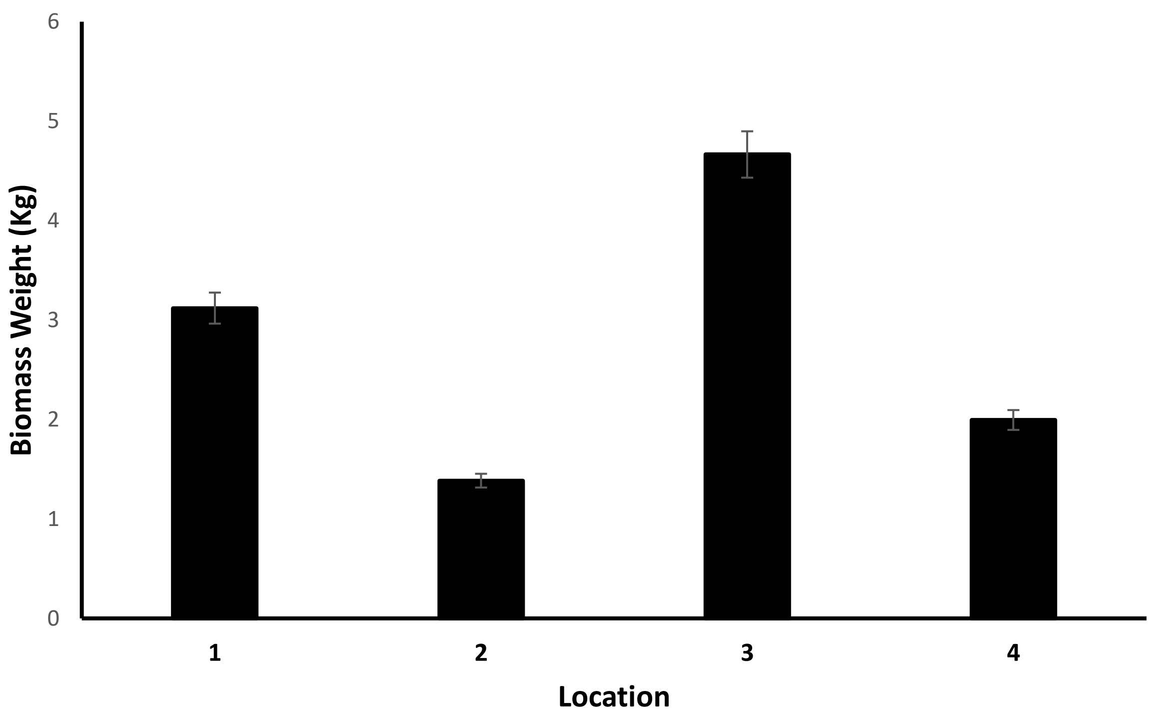


Fig. 25 Biomass weight at MB-8

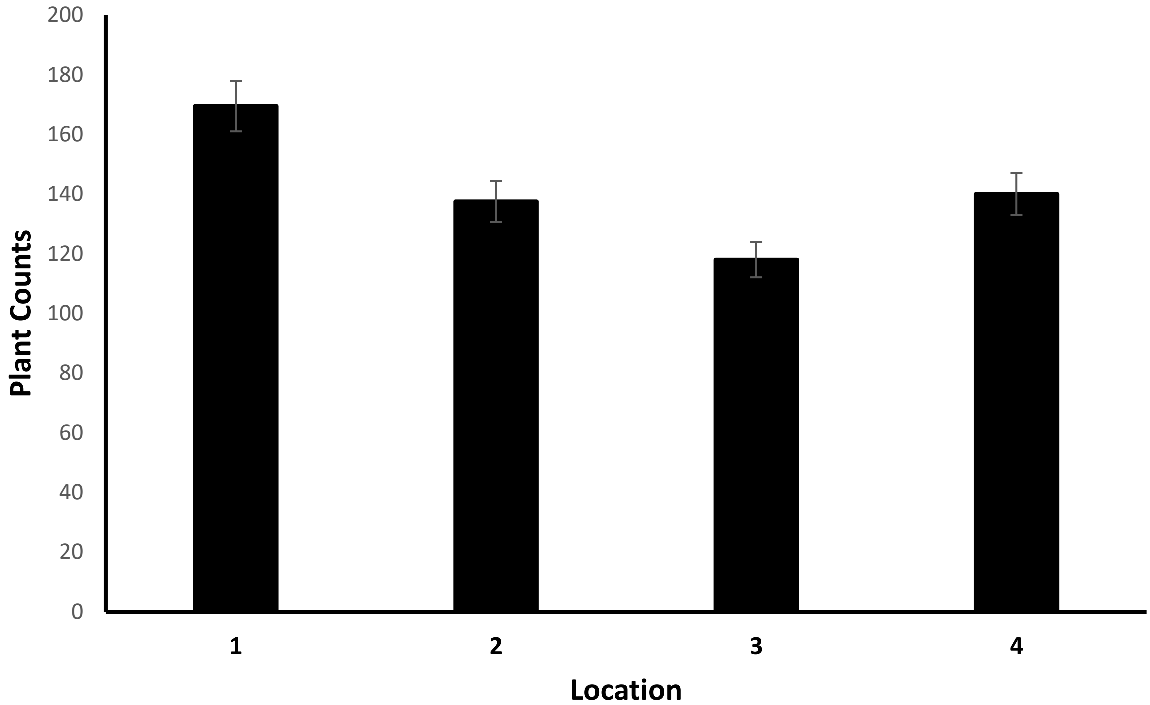


Fig. 26 Plant Counts at MB-8

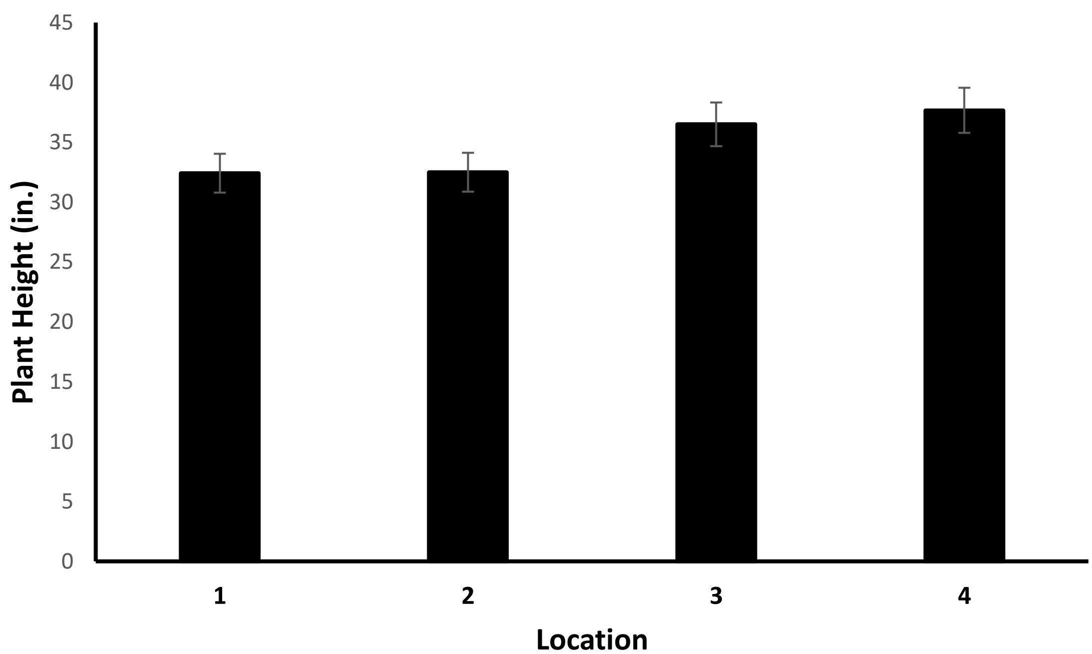


Fig. 27 Plant Heights at MB-8

Field Name: MB-7

Data was collected at 4 different sites (Locations 1-4) with same treatment but different land features. Variability in biomass density, plant counts, and plant heights is shown in Fig. 28, 29, & 30. The producer seeded the treated Caliente variety of mustard and an area of 1 m^2 for observations and analysis.

Average Biomass: 1.5 Kg

Average Plant Counts: 88

Average Plant Height: 14 in.

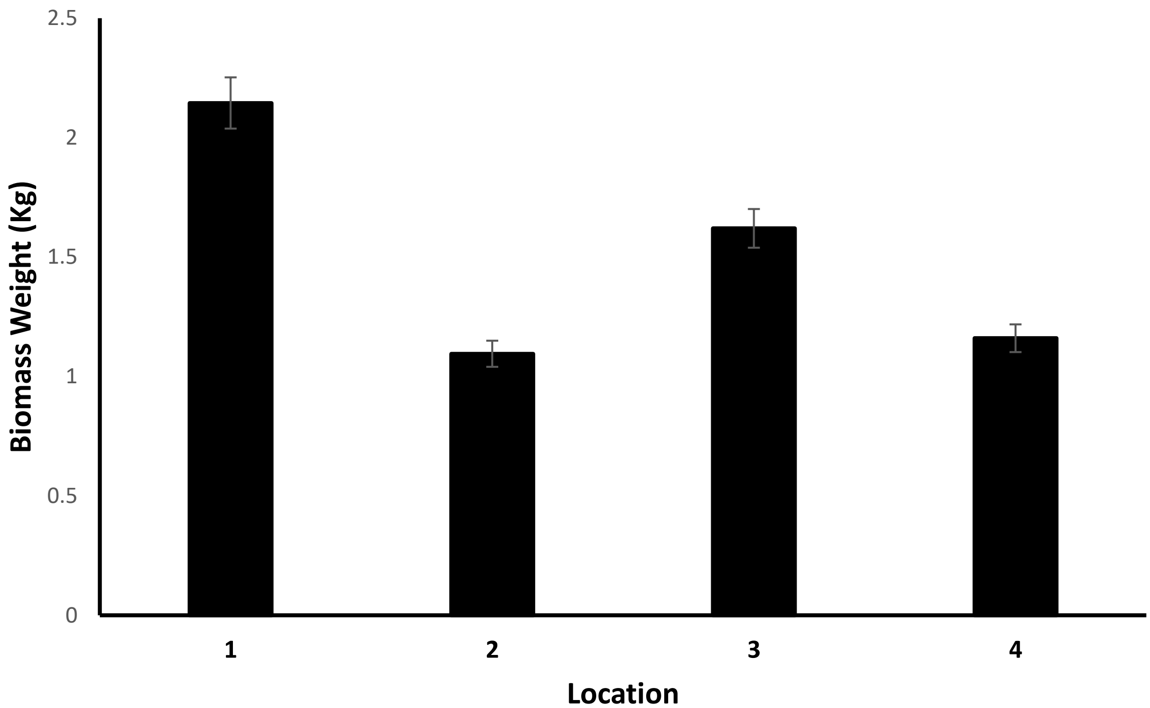


Fig. 28 Biomass weight at MB-7

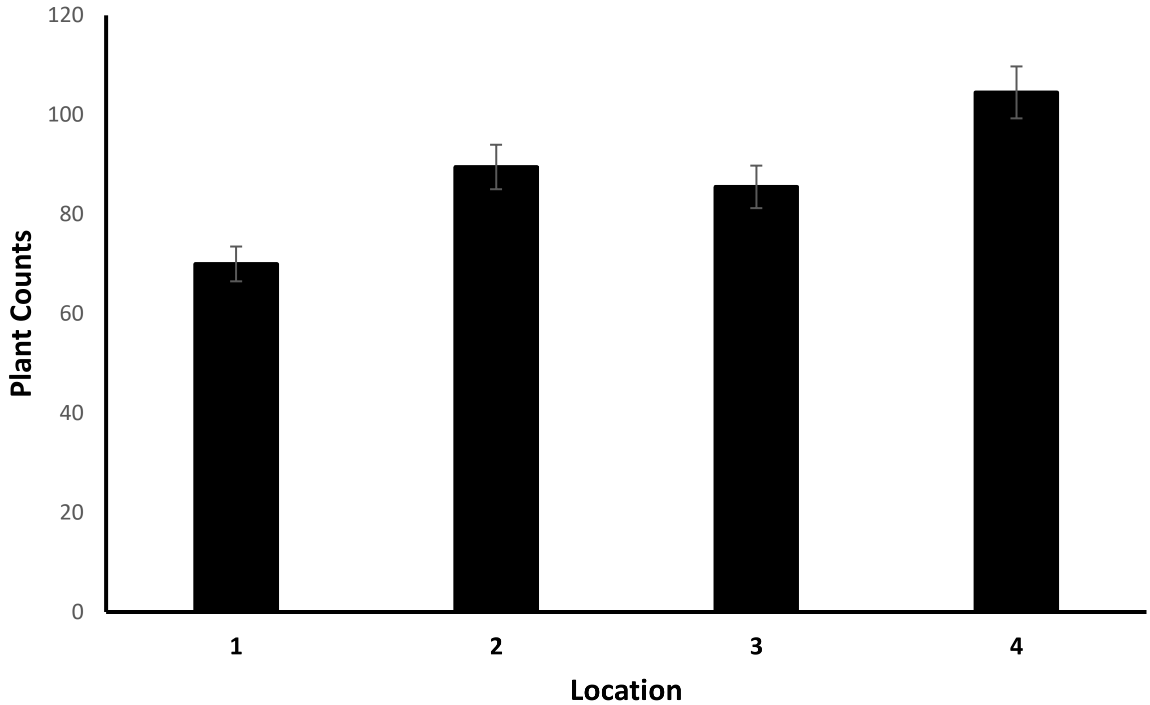


Fig. 29 Plant Counts at MB-7

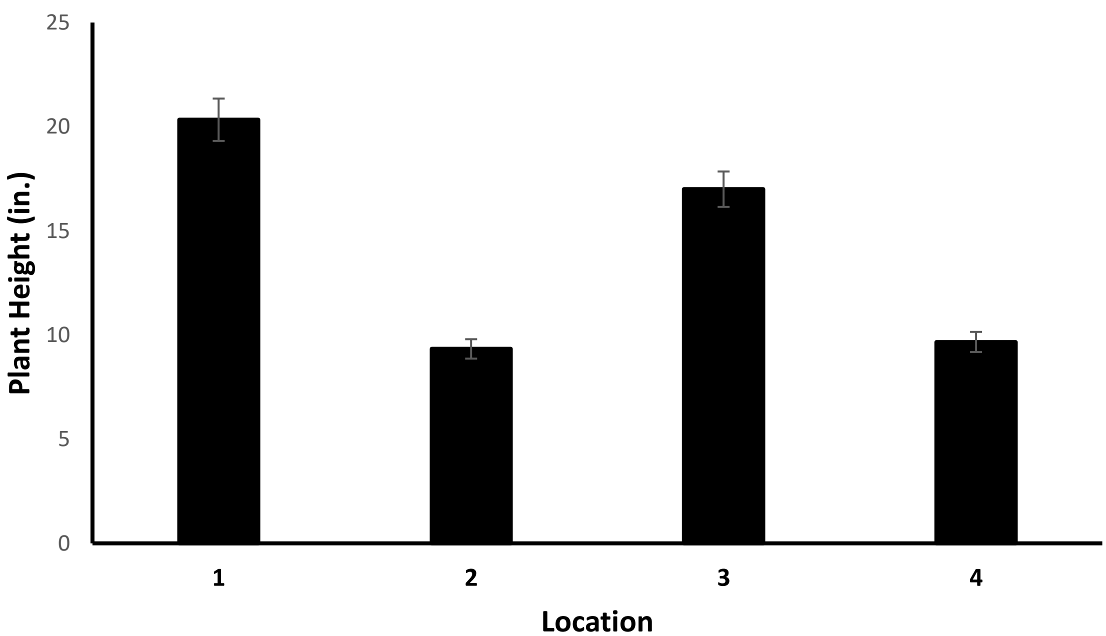


Fig. 30 Plant Heights at MB-7

Field Name: MB-10

Data was collected at 4 different sites (Locations 1-4) with same treatment but different land features. Variability in biomass density, plant counts, and plant heights is shown in Fig. 31, 32, & 33. The producer seeded the treated Caliente variety of mustard and an area of 1 m^2 for observations and analysis.

Average Biomass: 1.84 Kg

Average Plant Counts: 217

Average Plant Height: 23 in.

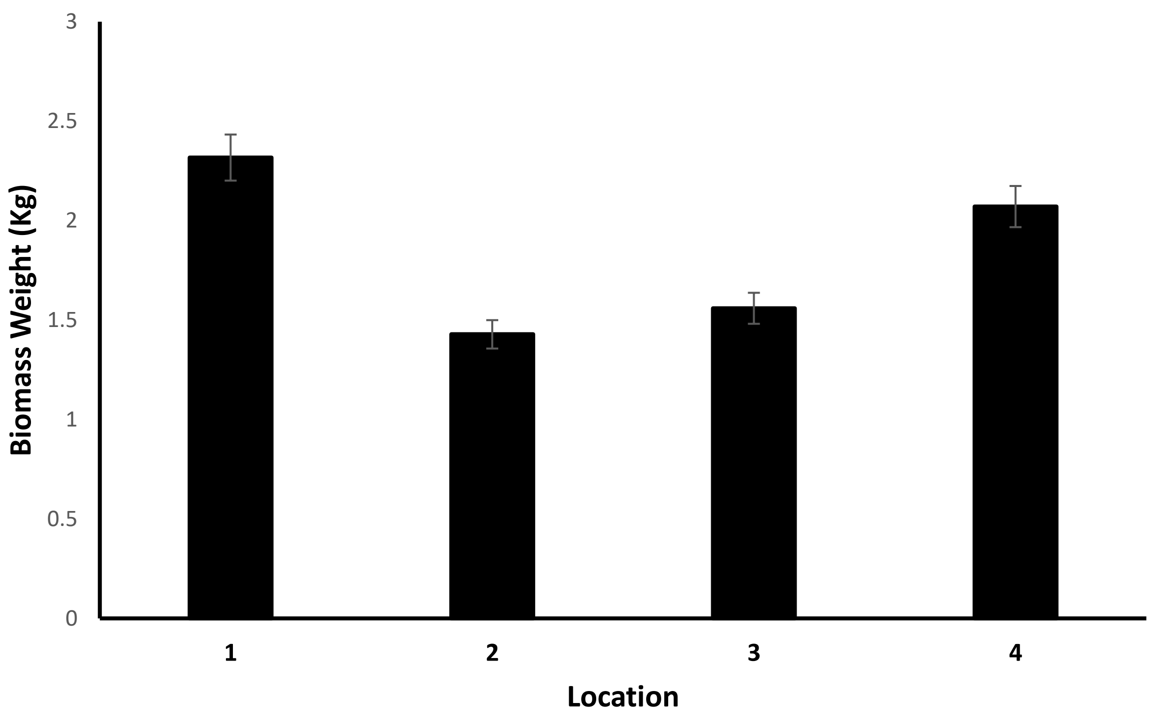


Fig. 30 Biomass weight at MB-10

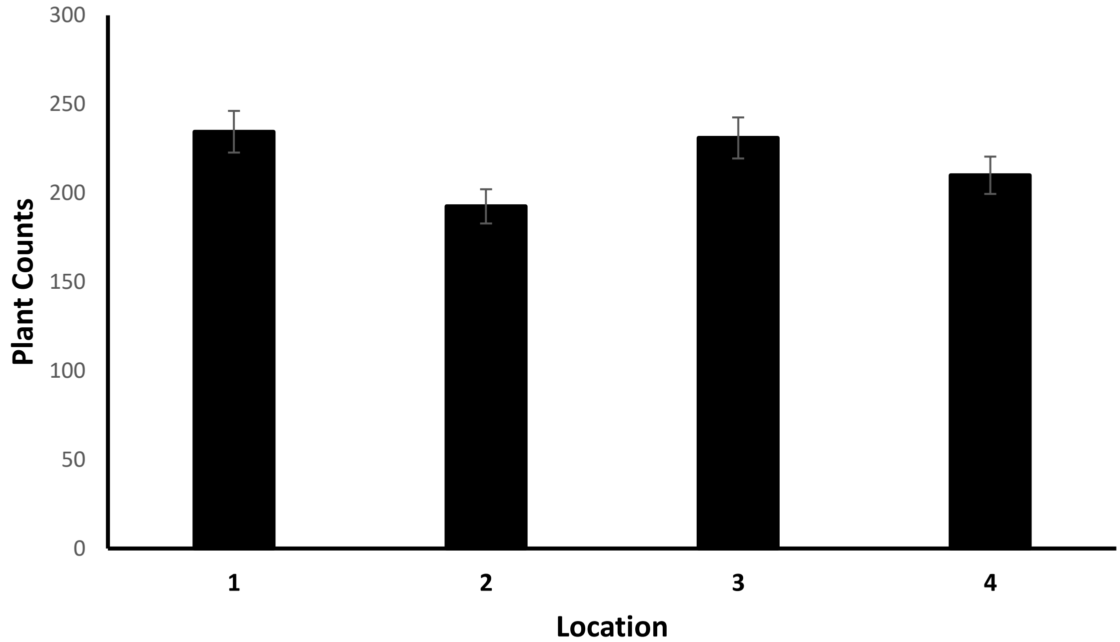


Fig. 31 Plant Counts at MB-10

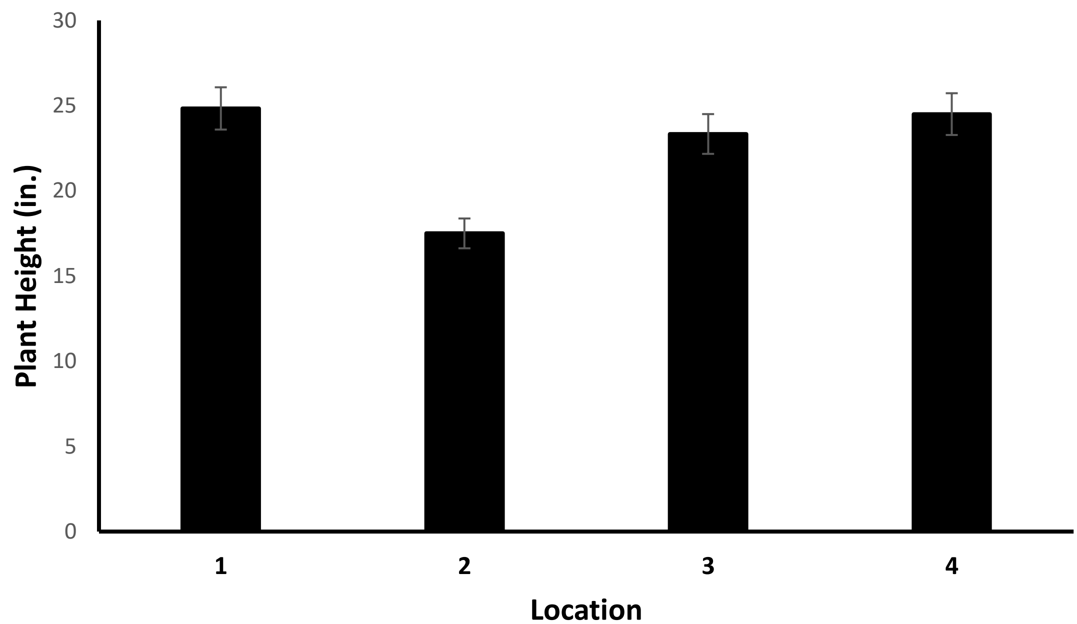


Fig. 31 Plant Heights at MB-10

Discussion:

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). Moreover, mustard seed treated with Gaucho seed treatment produced more biomass and had higher percent cover in terms of plant counts and plant height in all mustard varieties. 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.

Suggested Changes to Mustard Growing Recommendations

- Grower for MB-10 put on more fertilizer more frequently than recommended with most of it being fertigated on Jun 11, 23, Jul 28. He thought he still ran out of nitrogen and could have gotten more biomass. He strongly suggests moving the recommendation up to 180 lbs N and that fertilizer needs to be spaced out and fertigated on.
- I also learned today that grower for MB-5 and MB-6, who had knee-high mustard this year, put most of his fertilizer on as urea preplant (220 lbs), and I bet it leached and part of the problem we saw was lack of nitrogen because the soil has a very high propensity to leach. He did fertigate once.
- Grower for MB-10 put on 9 inches of water on his mustard for the June-July crop and 10 inches of water on the Aug-Oct crop. Both hit the biomass targets very well, but 9 inches of water isn't going to get us many growers.
- Grower for MB-10 is backing off of the 2 year idea because of common scab problems. I take this as a good thing. The grower is thinking of growing mustard in problem spots during the canola rotation, which will preserve the 3-year rotation in Shilo AND is irrigated with enough water to get the 9 inches.
- Grower for MB-10 suggests a new Bayer seed treatment called Buteo that is new this year. It's supposed to be good against both crucifer and striped flea beetles and could outperform senator. Senator did well in grower fields this year but poor Haider still had a lot of flea beetle pressure at CMCDC in Carberry.
- Grower for MB-7 and MB-8 but down 6 and 5 inches of irrigation, respectively, with most going down in the first two weeks. Drilled seed at 10 lbs per acre. Put down 70 units of N and 15 units of S in less sandy soil and fertigated until 130 units N put down and 25 units of S.

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

Objective

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 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 4-320 lbs from 0-30 cm in depth. In a cursory examination of the data set, 130-180 lbs of nitrogen appeared to be the beneficial amount of available soil nitrogen, 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 lbs 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 lbs 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.

MHPEC's 2020 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 lbs 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 130-180 lbs of nitrogen are found in 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.

Conclusion

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 lbs were expected by row closure ended up having far more soil nitrogen than anticipated. Treatments of ESN and urea where 180 lbs 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 or more lbs. 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 lbs treatment, which had more >12 oz percentage of tubers than urea treatments with more or less nitrogen (280 and 40 lbs, respectively). More study 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 consultant. Answering the original research question requires going back to the community 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 can overcome the deficiencies outlined in the first two years of this study.

Methods

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 8-26 lbs of soil nitrogen available at the start of each season.

The entire experiment was 57869.28 ft2 (1.33 Acres). Each plot was 3.6m wide and 24 m long, or 86.4 m2 (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 lbs 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 lbs by row closure (lbs/acre)	Lbs/acre fertilizer rate applied pre-plant	Fertigation Fertilizer and Formulation	Fertigation rate (lbs)
46-0-0	Urea	40	180	UAN-28	60 lbs
46-0-0	Urea	130	325	UAN-28	60 lbs
46-0-0	Urea	180	400	UAN-28	60 lbs
46-0-0	Urea	280	500	UAN-28	60 lbs
44-0-0	ESN	40	180	UAN-28	60 lbs
44-0-0	ESN	130	325	UAN-28	60 lbs
44-0-0	ESN	180	400	UAN-28	60 lbs
44-0-0	ESN	280	500	UAN-28	60 lbs
No Pre-plant Nitrogen			0	UAN-28	60 lbs

Table 1. Nitrogen fertilizer products employed in the study are listed to display the amount of each product necessary to achieve the goal lbs 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 lbs N/acre (6.67 gals UAN 28/acre). Two fertigation events were required in 2020, as determined by petiole testing from Agvise Inc. All plots received 115 lbs/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 lbs/ acre.

Only the cultivar Russet Burbank was used for the study. Experimental plots were prepared by cultivating on April 22nd 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 lbs/acre to 584 lbs/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 (2-3 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 6-7 inches deep (from top of hill). Seed was treated with Titan Emesto (Bayer, Leverkusen, Germany) at a rate of 20.8 mL per 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 lbs 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 2-4 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 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.

Harvest occurred on September 14th and was completed using 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 lbs harvested, as well as the lbs of each tuber size category (less than 3 oz, 3-5.9 oz, 6-9.9 oz, 10-11.9 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).

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.

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 6-10 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.

Results

The 2020 nitrogen study indicated that the amount of available soil nitrogen, in lbs, 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 lbs of nitrogen found in the soil prior to nitrogen fertilizer application at the start of the season ($P = 0.9615$, data not shown) with 10-18 lbs of residual nitrogen in October of 2019. In general, the treatments of ESN and urea where 40 or 130 lbs were expected by row closure ended up having far more soil nitrogen than anticipated. Treatments of ESN and urea where 180 lbs 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 or more lbs. Neither fertilizer treatment could achieve targets of 280 lbs of nitrogen in a soil test by row closure.

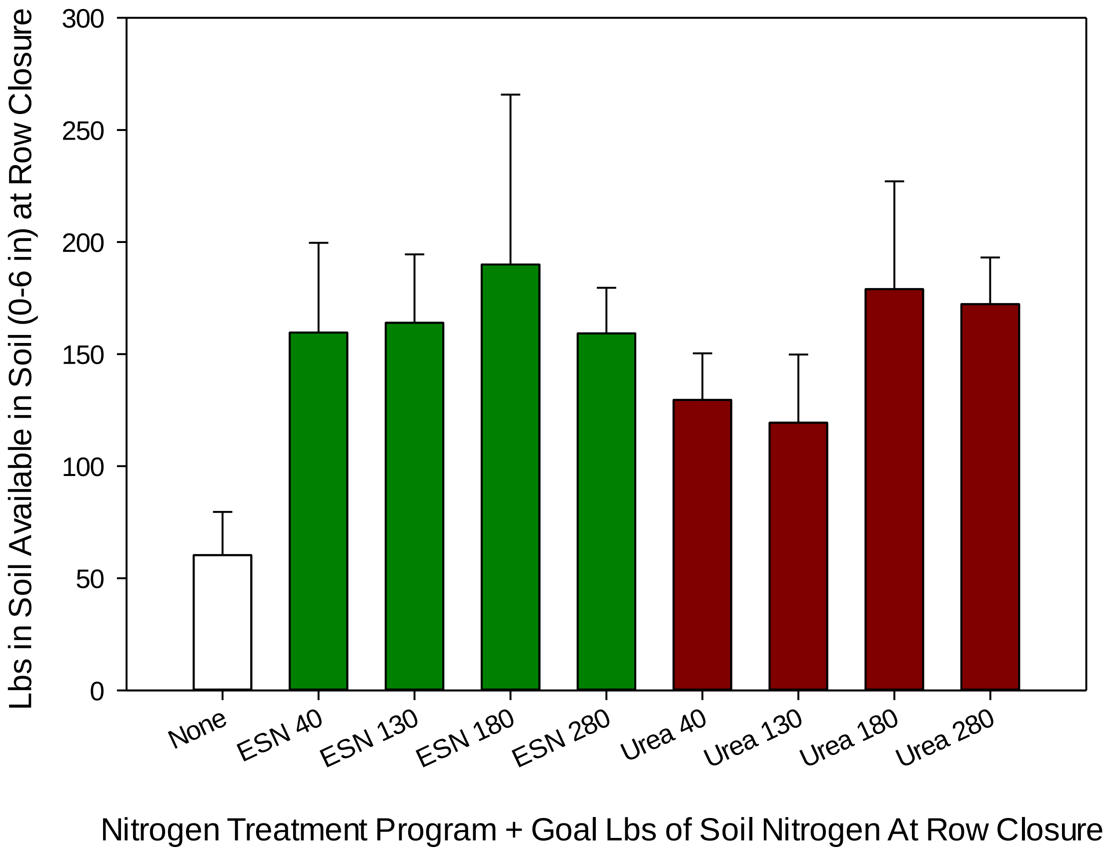


Fig. 2

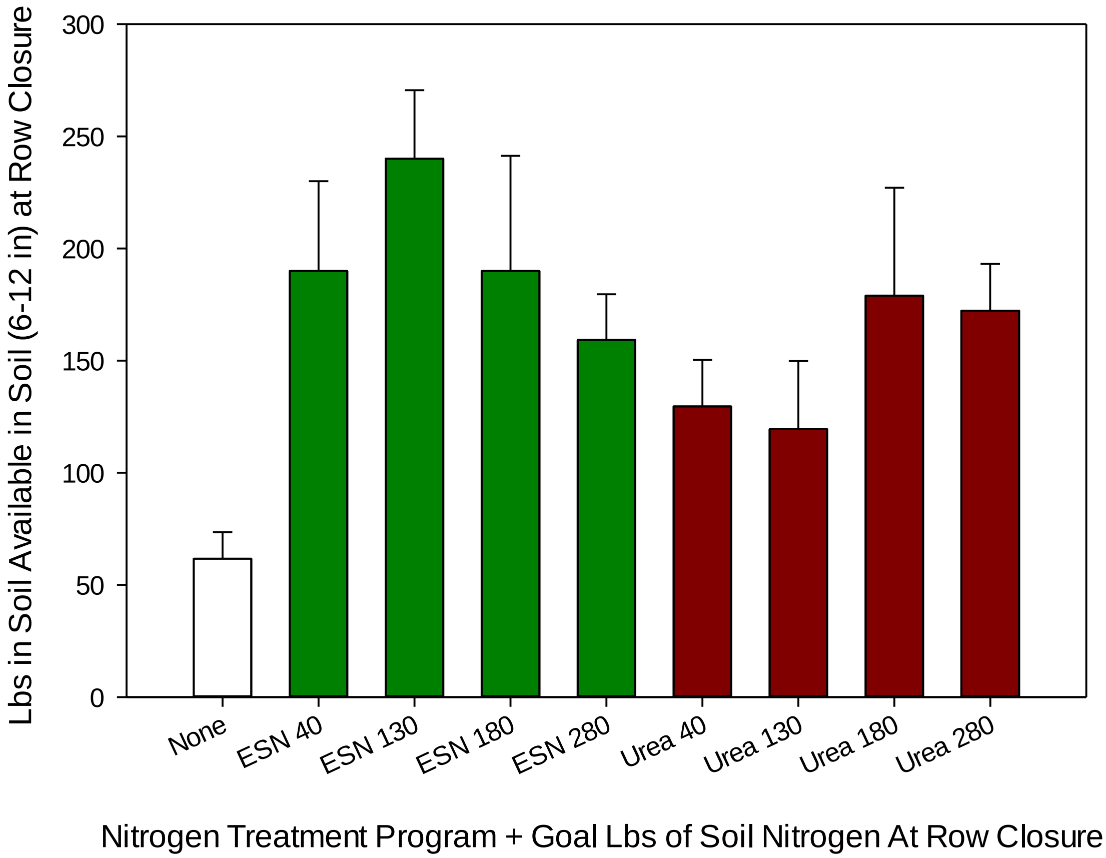
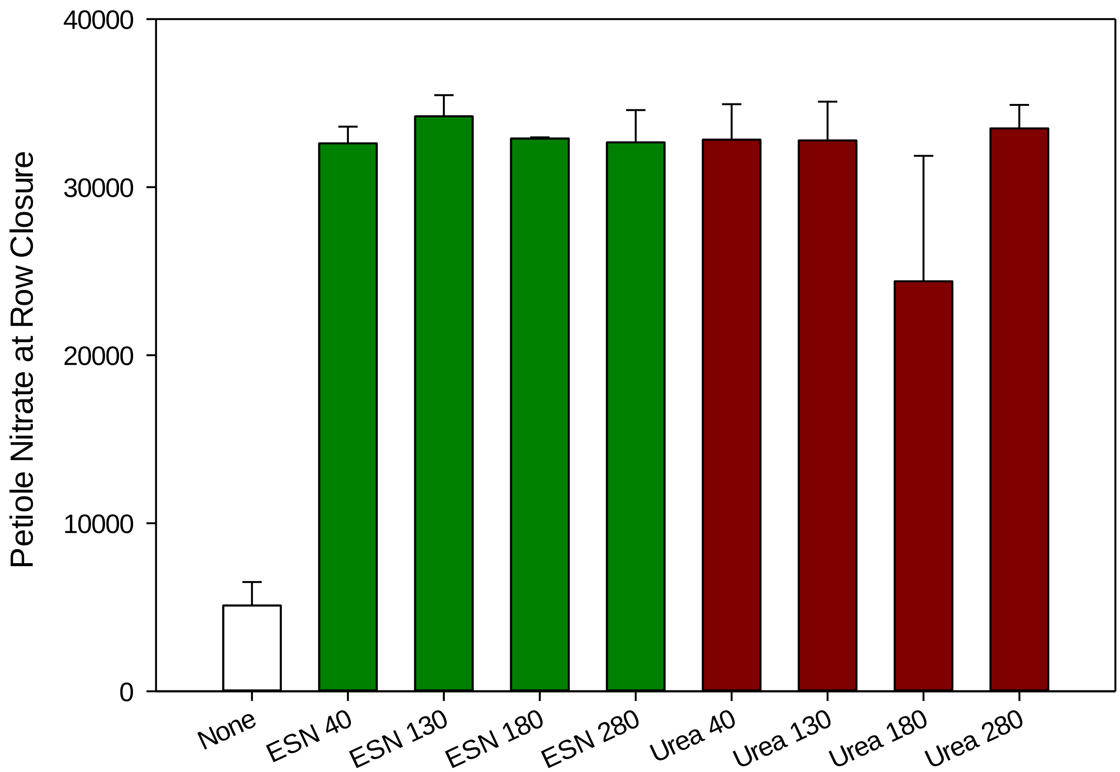


Fig. 3

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.



Nitrogen Treatment Program + Goal Lbs of Soil Nitrogen At Row Closure
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). An curious observation is that the extreme ESN treatment (ESN 280, where 500 lbs of ESN were applied preplant with the intent of having 280 lbs residual by row closure) has a numerical decrease in total yield when compared to the ESN 40 treatment or the treatment with no additional nitrogen.

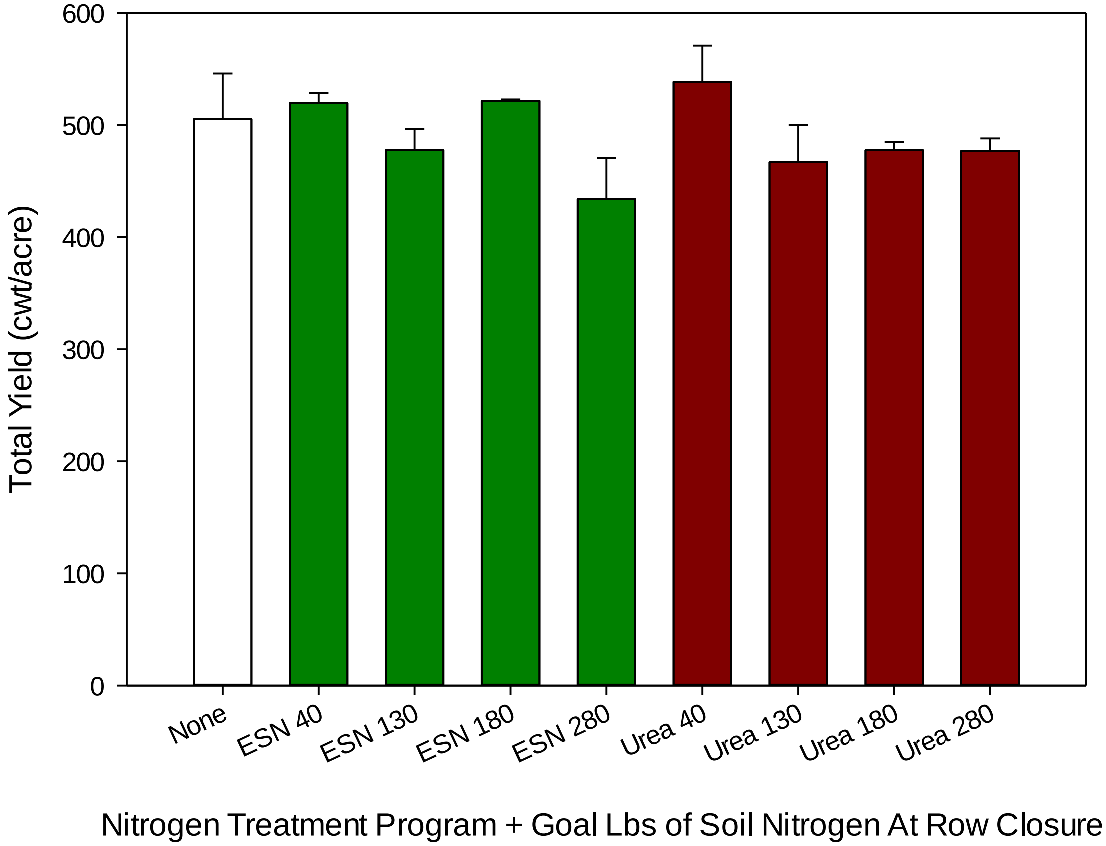


Fig. 5

There was a nearly 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 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 lbs were applied preplant with the intent to have 280 lbs by row closure, dropped the specific gravity compared to lower rates of each fertilizer or the plots that received no supplemental nitrogen preplant.

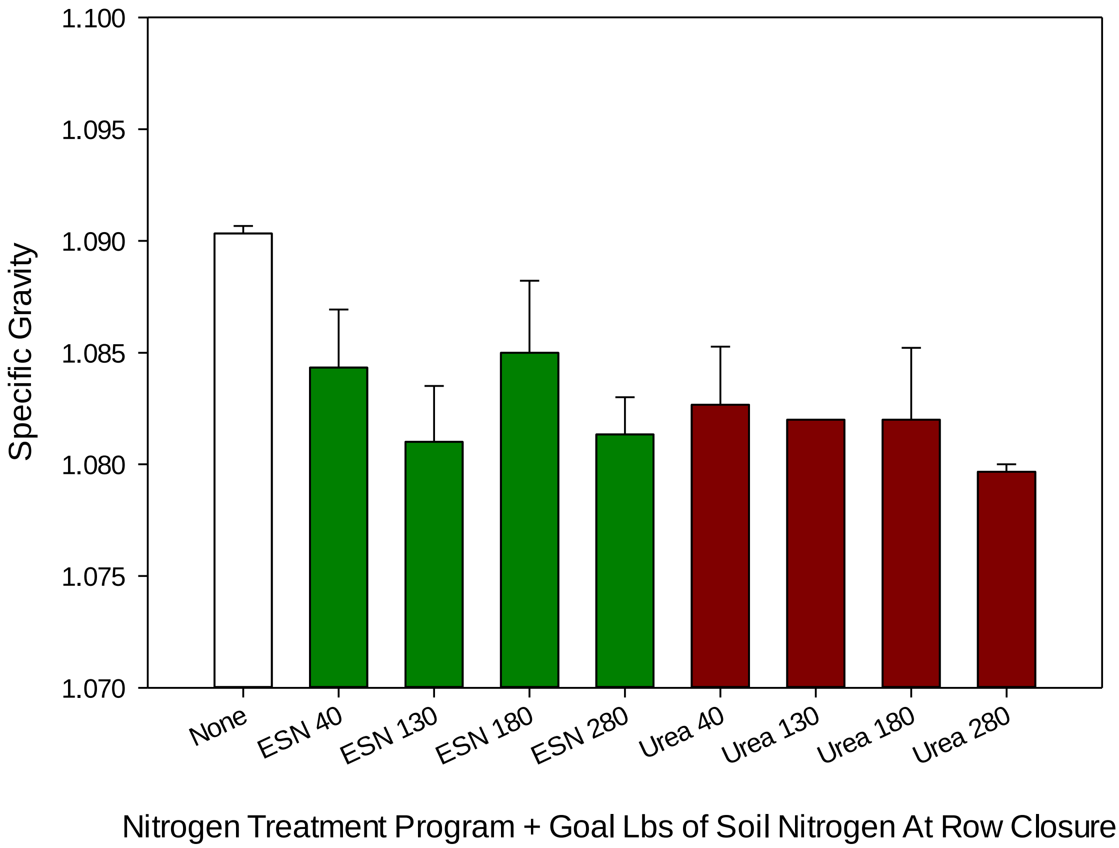


Fig. 6

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

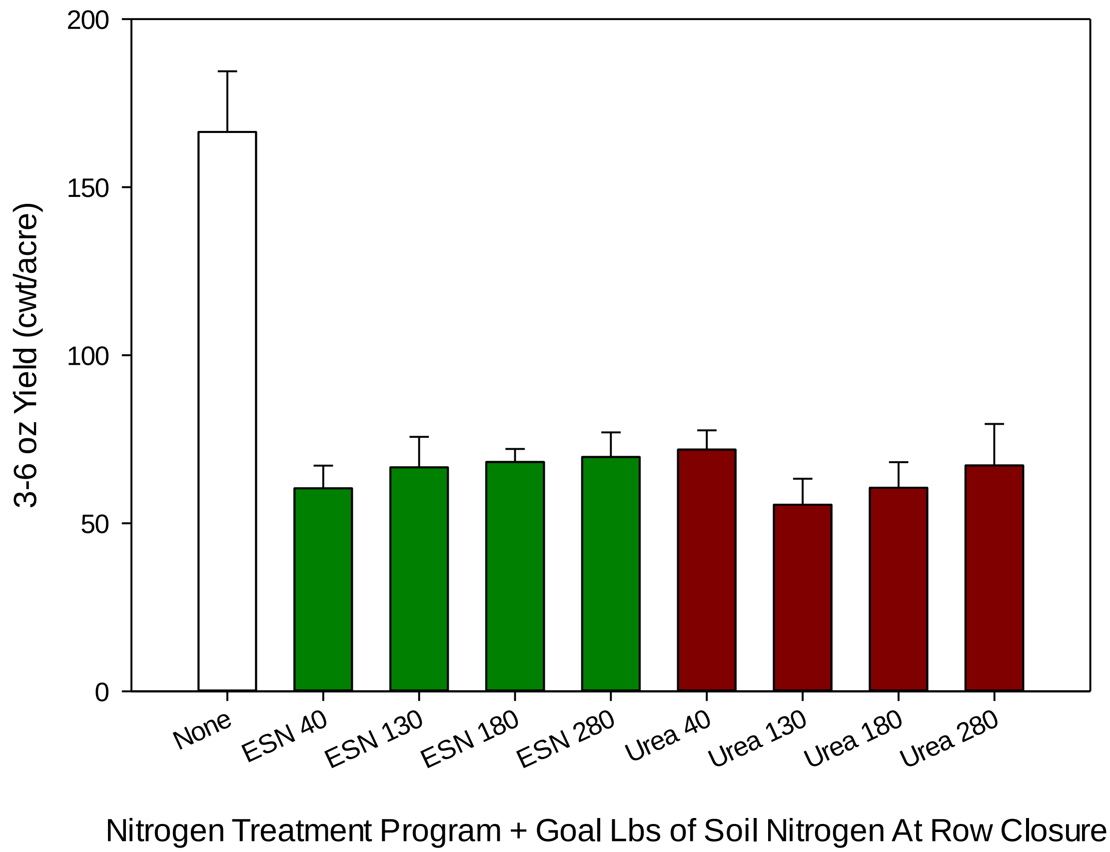
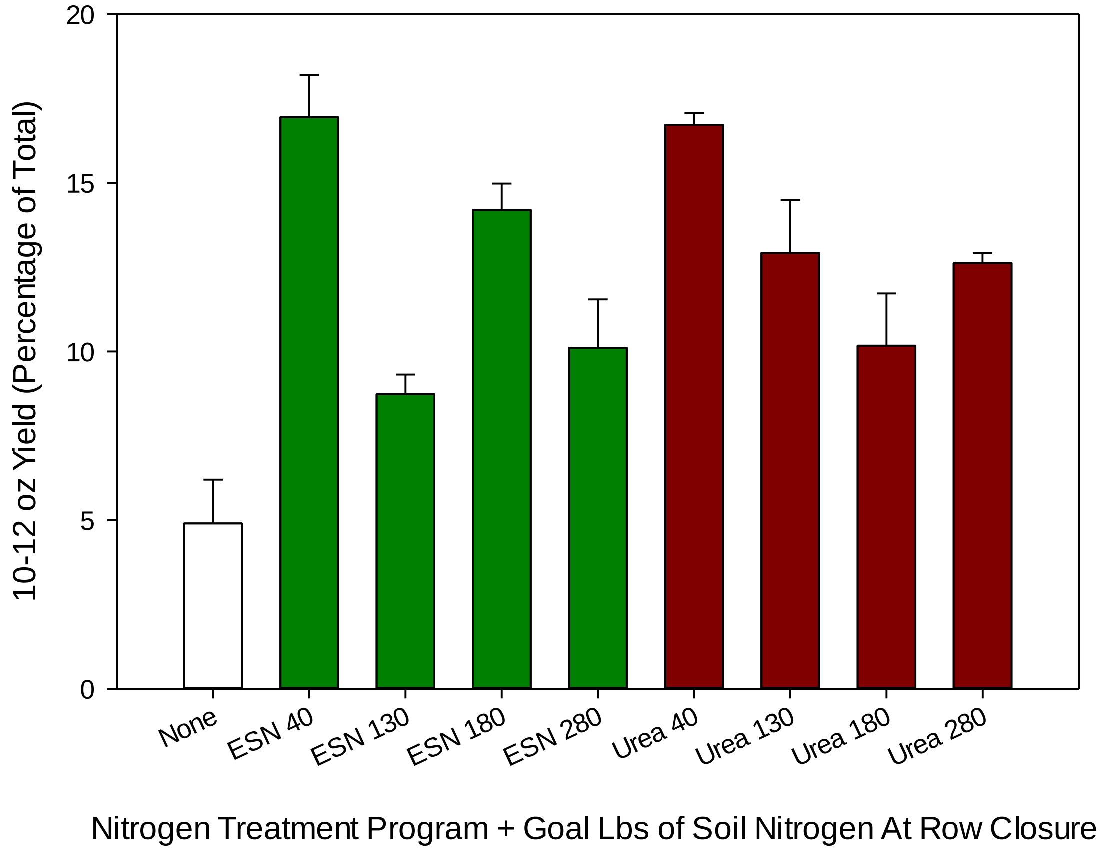


Fig. 7

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 3-6 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 10-12 oz tubers harvested from the experiment (Fig. 8). The treatments where 40 lbs of nitrogen were targeted by row closure had the greatest percentage of 10-12 oz tubers when compared to the negative controls or higher rates of fertilizer, such as 280 lbs of nitrogen by row closure.



10-12 oz Yield (Percentage of Total)
20
15
10
5
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. 8

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 10-12 percentage of yield first, the lesser treatment second, and the *P*-value third. All other pairwise comparisons that are listed are nonsignificant ($P > 0.05$).

There was a significant impact ($P = 0.0007$) of nitrogen treatment and rate on the percentage of 10-12 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).

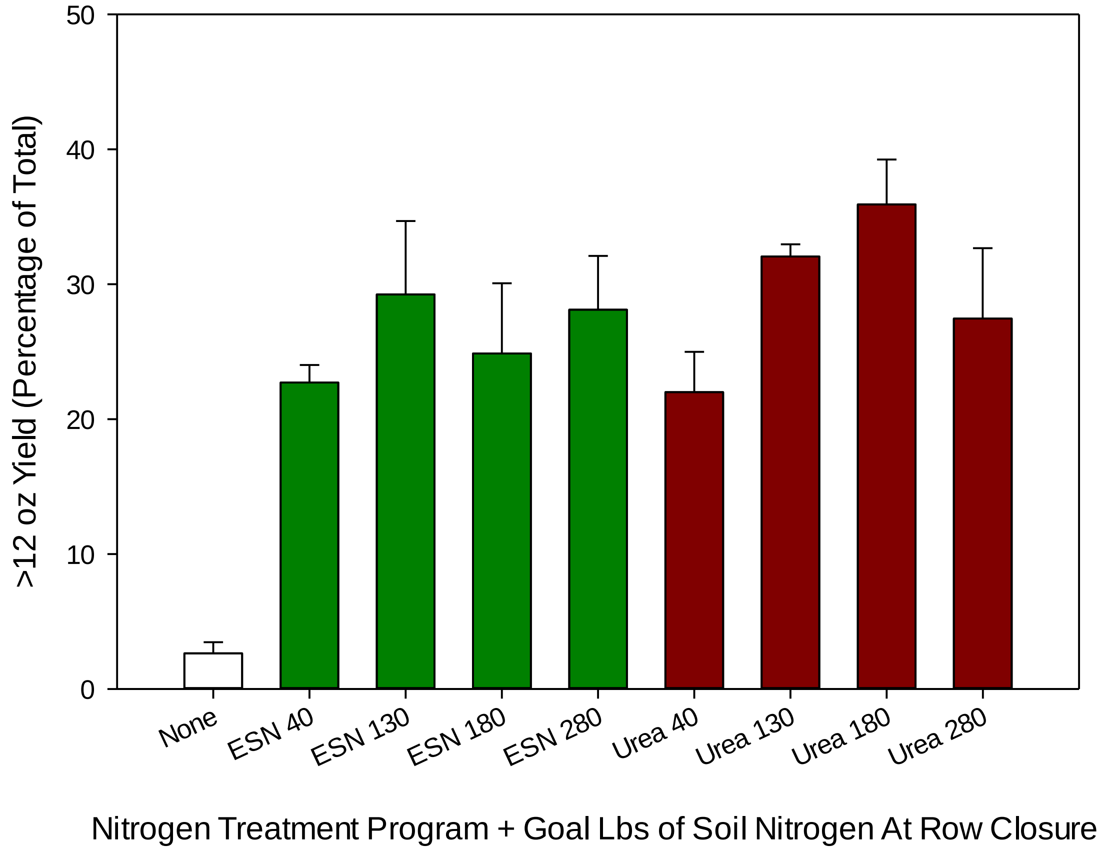

>12 oz Yield (Percentage of Total)
50
40
30
20
10
0
None
ESN 40
ESN 130
ESN 180
ESN 280
Urea 40
Urea 130
Urea 180
Urea 280
Nitrogen Treatment Program + Goal Lbs of Soil Nitrogen At Row Closure

Fig. 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 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 25-50 % 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.

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 2020 growing season is shown in figure 10-17. 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.

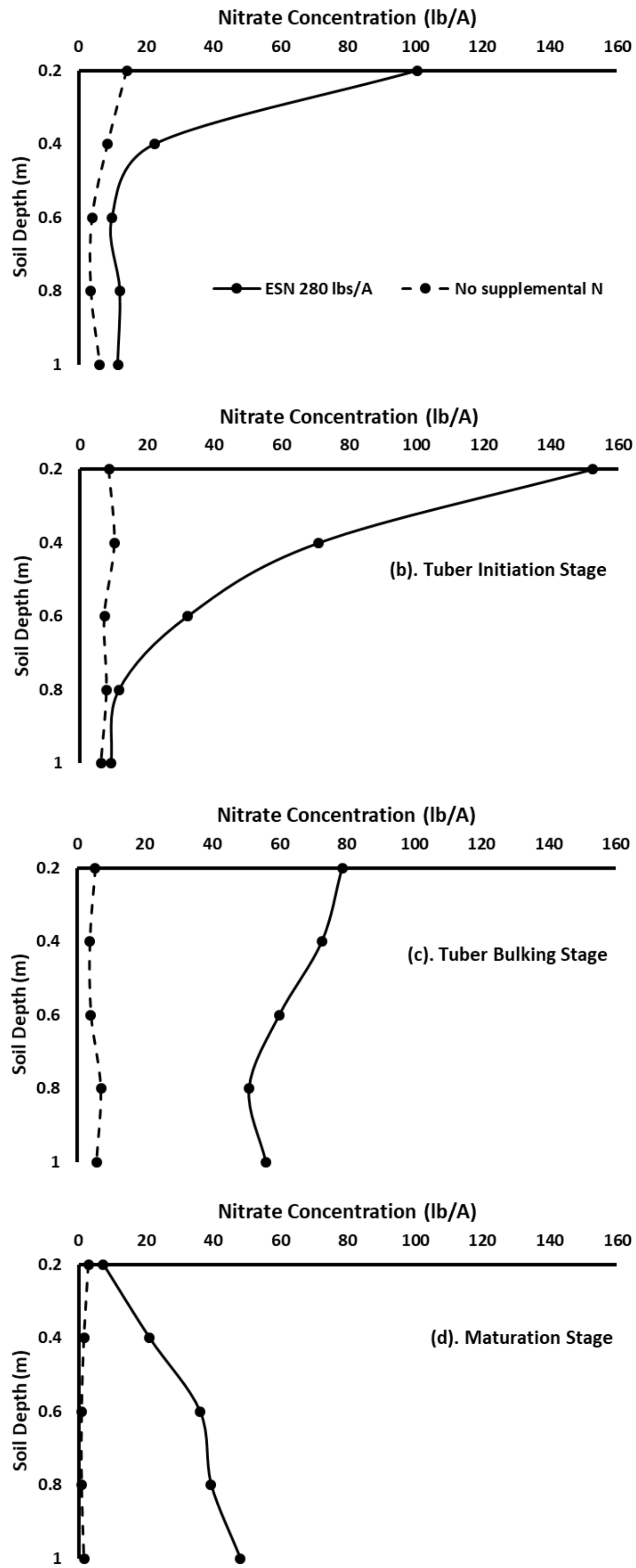


Fig. 10 Comparison of N application rate of ESN = 280 lb/A and no-supplemental N

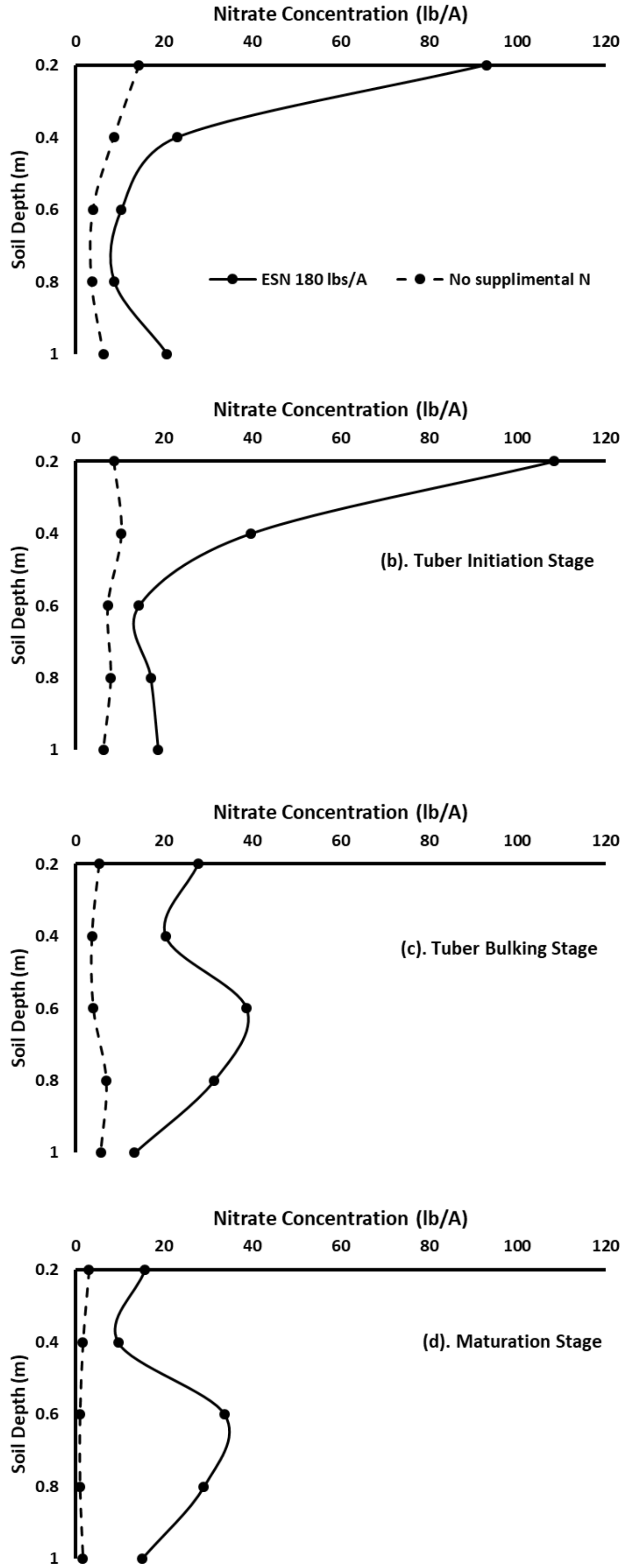


Fig. 11 Comparison of N application rate of ESN = 180 lb/A and no-supplemental N

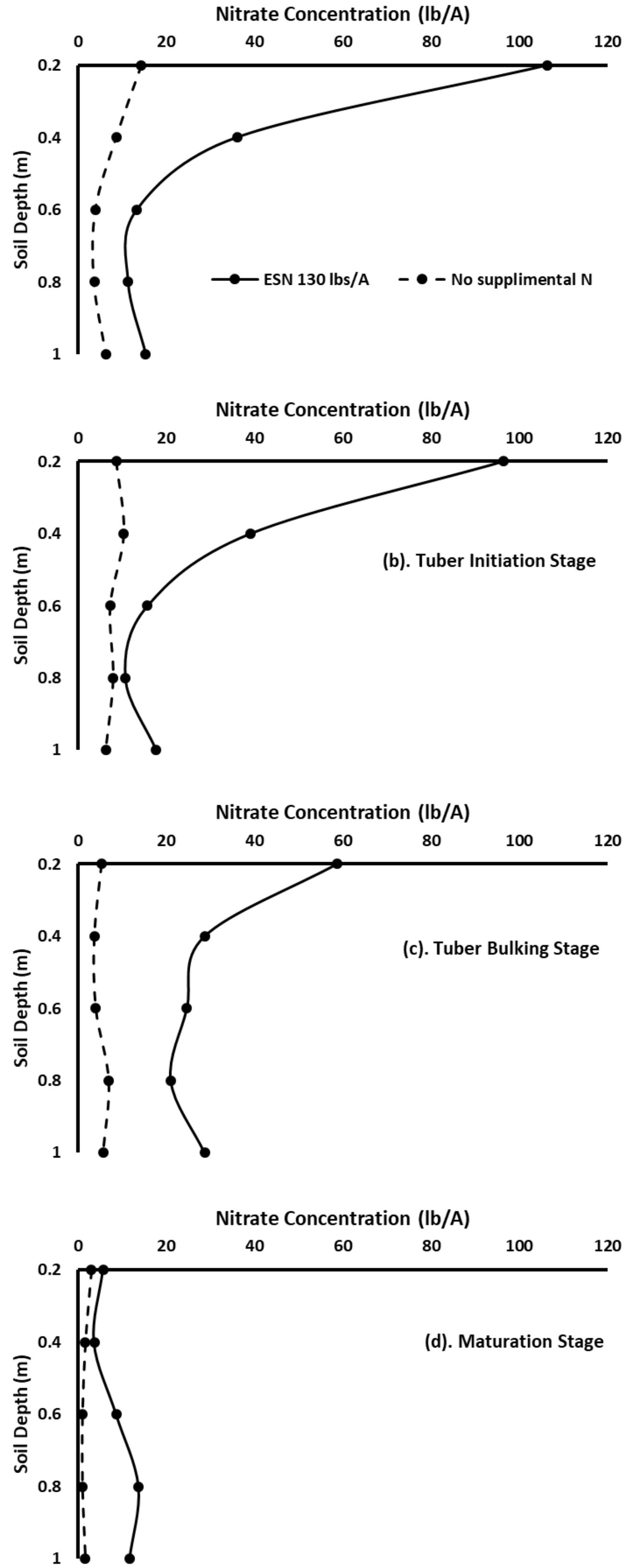


Fig. 12 Comparison of N application rate of ESN = 130 lb/A and no-supplemental N

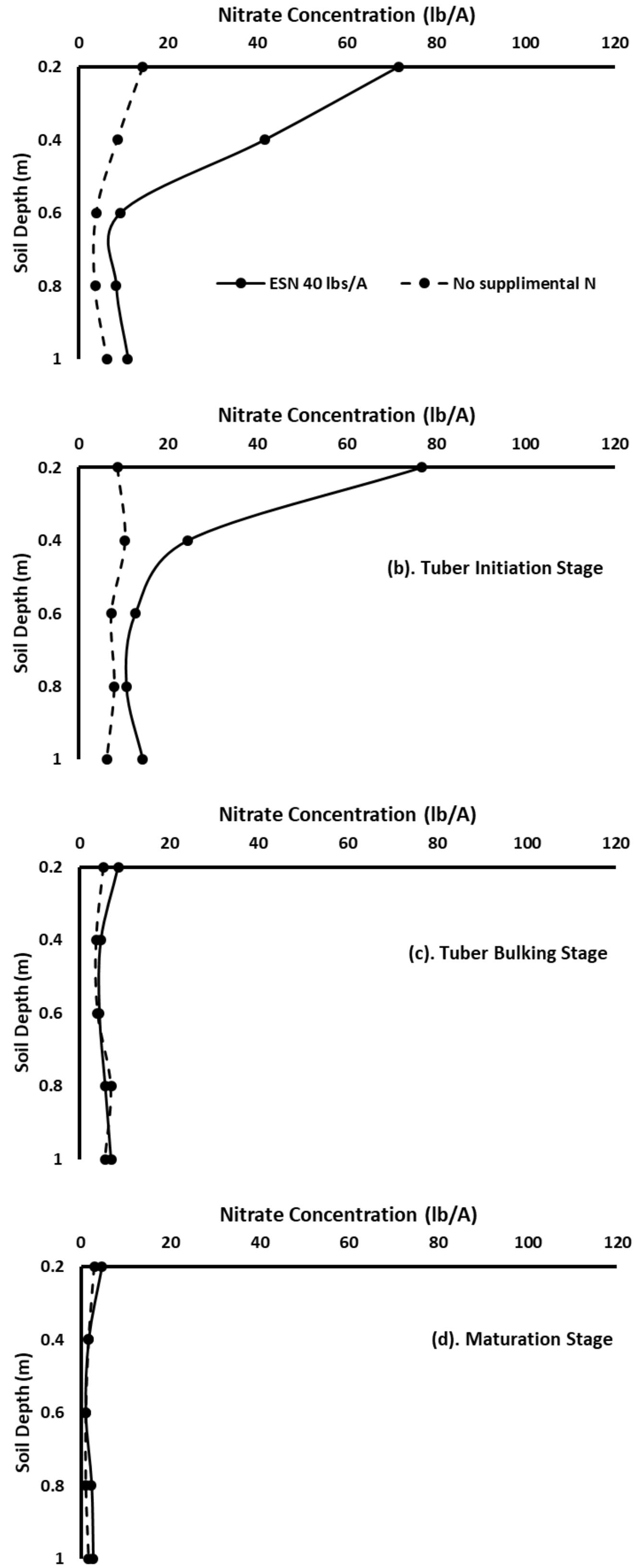


Fig. 13 Comparison of N application rate of ESN = 40 lb/A and no-supplemental N

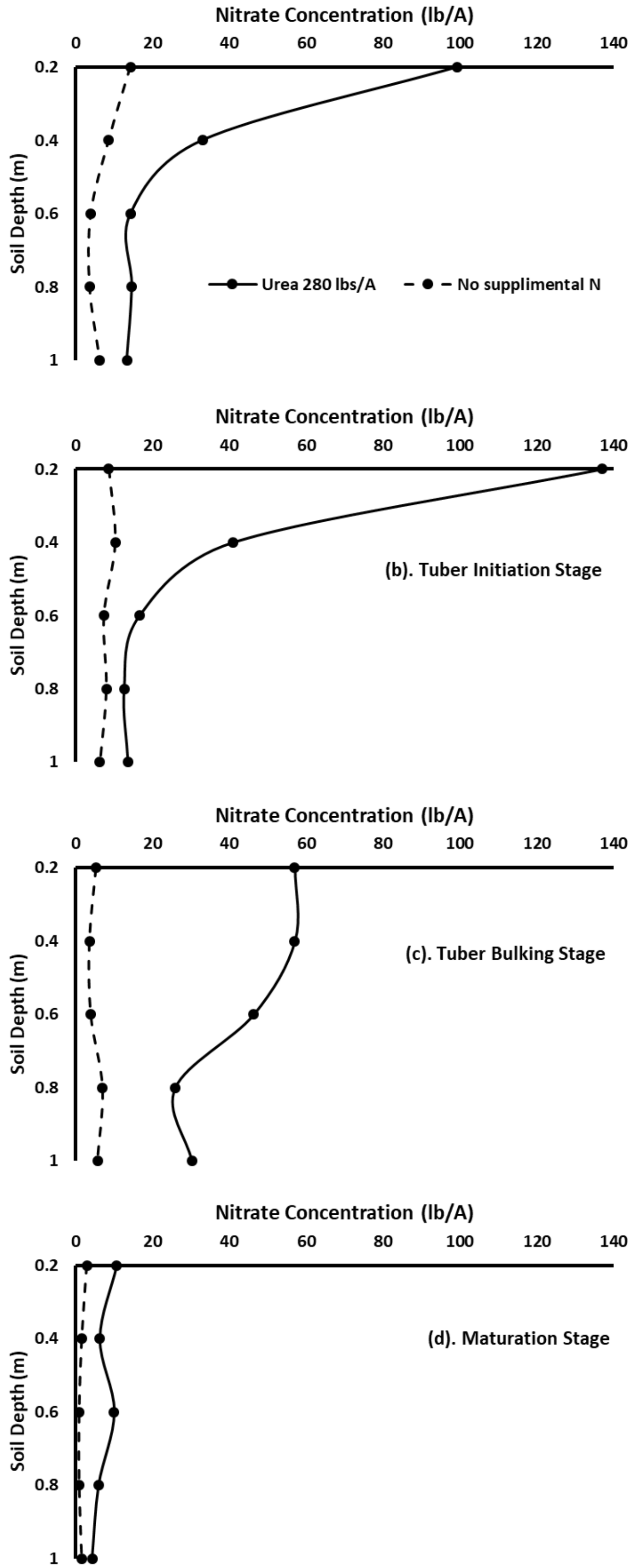


Fig. 14 Comparison of N application rate of Urea = 280 lb/A and no-supplemental N

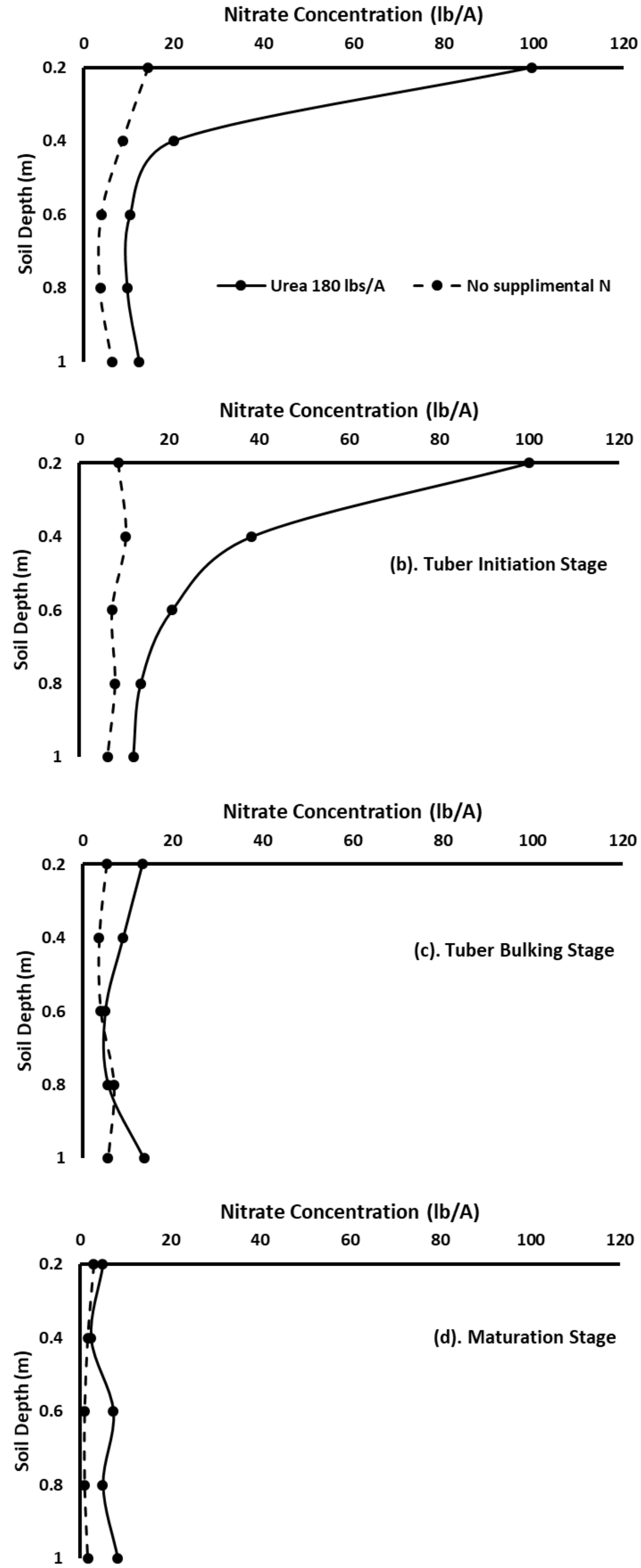


Fig. 15 Comparison of N application rate of Urea = 180 lb/A and no-supplemental N

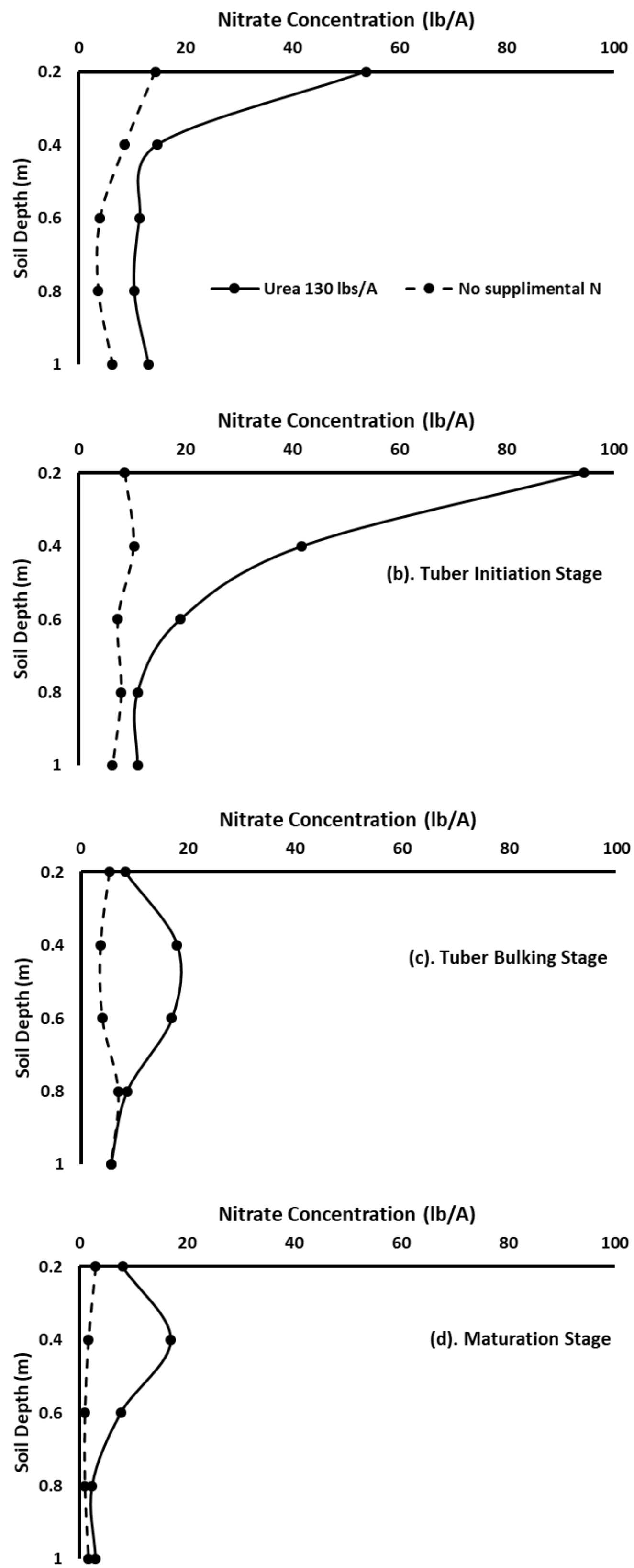


Fig. 16 Comparison of N application rate of Urea = 130 lb/A and no-supplemental N

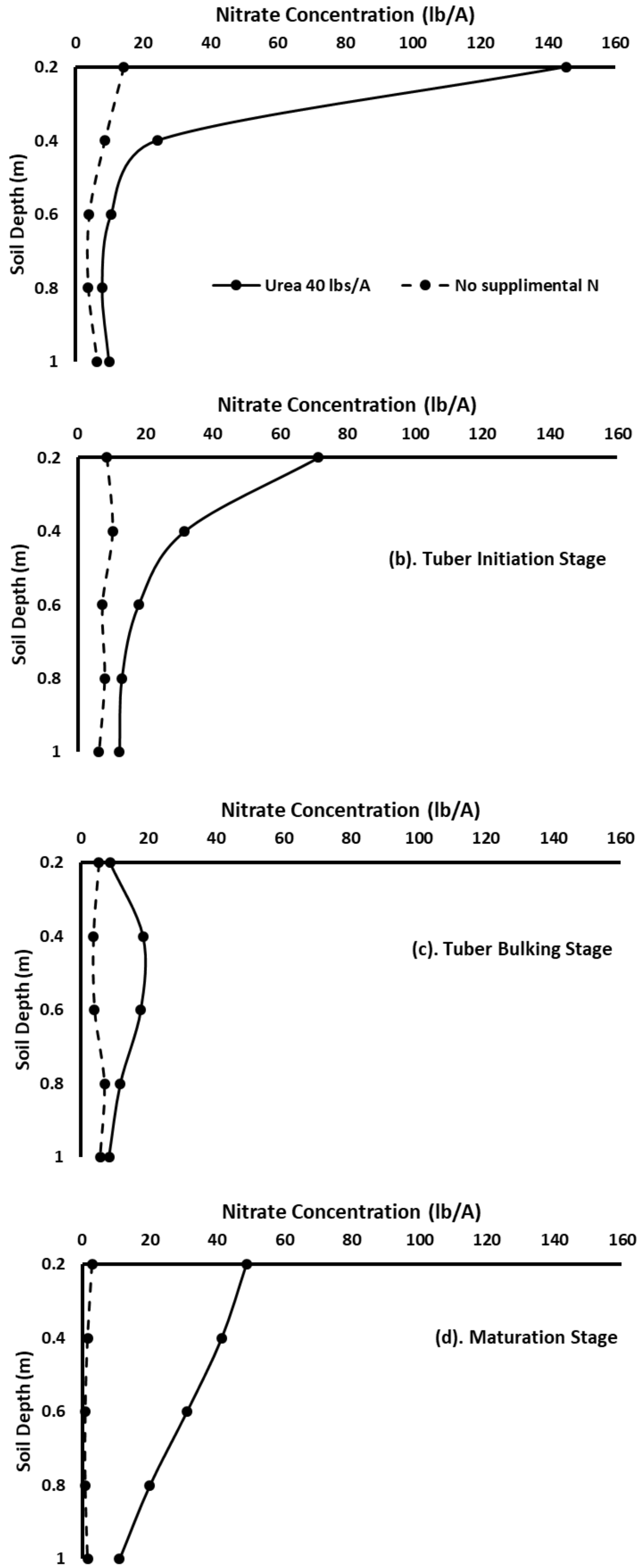


Fig. 17 Comparison of N application rate of Urea = 40 lb/A and no-supplemental N

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 (Fig. 18). 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.

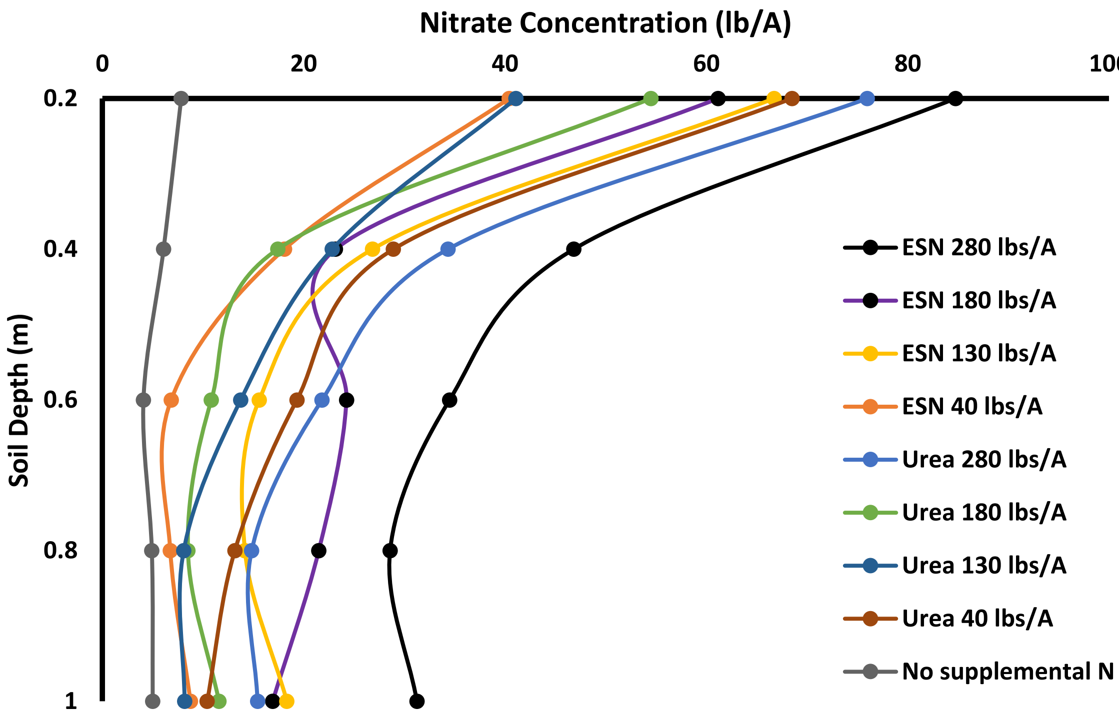


Fig. 18 Nitrogen dynamics within the potato root-zone throughout the growing season

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. 19 shows 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 2020, 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.

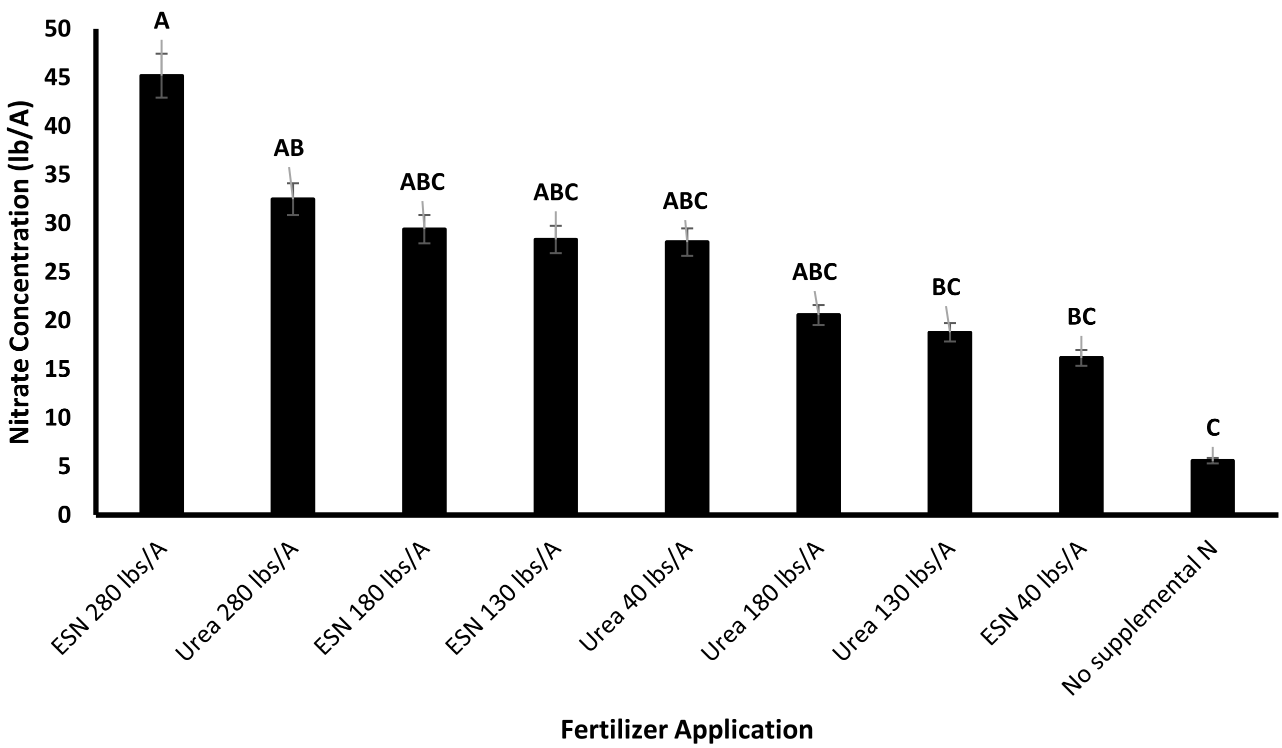


Fig. 19 Nitrogen availability within the potato root-zone throughout the growing season

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.

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

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 6-10, 10-12, and 12+ oz yields. The assumed ideal soil sulphur test is 40 lbs 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 0-120 lbs, regardless of sampling date. In a cursory examination of the data set, 40-60 lbs 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 (6+ ozs). 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. 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 4-14 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 and April 30th 2020. 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 (2-3 oz, average 2.5 oz (data not shown)) was planted on May 6th 2019 and May 5th 2020 with no gaps between plots, 36 inches between rows, 13 inches between seed pieces within row, and 6 inches deep (from top of hill). Seed was treated with Titan Emesto (Bayer, Leverkusen, Germany) at a rate of 20.8 mL per 100 kg of seed. The 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 and June 2nd 2020 using a power hiller attached to a tractor. Row closure was observed on July 15th 2019 and June 30th 2020, 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 and August 18th 2020. The lbs of sulphur available in soils and the percentage of sulphur in petioles were determined by Agvise Inc (Northwood, North Dakota).

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 and July 23rd 2020. 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 2-4 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 3.6m 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, Irricana, Alberta), Tiger Combo (Tiger-Sul Inc, Irricana, Alberta), 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 ($(NH_4)_2S_2O_3$ ATS) through fertigation (Redfern Farm Services, Brandon, Manitoba). Each fertilizer treatment, except the negative control, was applied at the equivalent of 20, 60, and 100 lbs 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, with exact application rates displayed in Table 1 below:

Formulation (NPKS)	Fertilizer	Goal lbs by row closure	Lbs/A of product required to achieve goal	Lbs product applied preplant per replicate (4 plots)	Fertigation Fertilizer and Formulation	Sulphur Fertigation rate (lbs)
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 lbs of sulphur available at row closure, as determined at a soil test conducted by Agvise, Inc. (Northwood, North Dakota). The fertigation rate assumes three lbs 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 lbs/acre (A) of mono-ammonium phosphate (MAP, 11-52-0-0), 42.24 lbs/A of Kmag blend (0-0-60-0), and 466.6 lbs/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 and September 14th 2020 and was completed using 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 lbs harvested, as well as the lbs of each tuber size category (less than 3 oz, 3-5.9 oz, 6-9.9 oz, 10-11.9 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 (lbs/acre) by row closure to a yield parameter (for example: the fertilizer Tiger XP at 60 lbs by row closure impact on the 6-10 oz yield category). This analysis was completed for each yield parameter separately (e.g. 6-10 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. In 2020, when year became a significant interaction term, the slice statement was used to study simple effects in the dataset that combined both years of study.

Results

The growing seasons in 2019 and 2020 were so different that the data could not be combined across years for analysis. The mixed procedure identified the year variable as highly significant ($P < 0.0001$) for each yield category, indicating that combining any yield data from the same treatment across years would incur such extreme variability that no statistical test could identify any differences between treatments. The following results will be presented with each year analyzed separately.

Yield Results for 2020:

There was no significant sulphur treatment effect on total yield ($P = 0.1164$), value ($P = 0.1303$), specific gravity ($P = 0.1499$) or any size profile in 2020 (Fig. 2). More specifically, observed differences in the 3-6 oz yield ($P = 0.6253$), 6-10 oz yield ($P = 0.5394$), 10-12 oz yield ($P = 0.1163$), and greater than 12 oz yield ($P = 0.5133$). There was also no significant sulphur treatment effect on the percentage of any tuber size profile in 2020. More specifically, observed differences in the 3-6 oz percent yield ($P = 1$), 6-10 oz percent yield ($P = 0.8817$), 10-12 oz percent yield ($P = 0.2545$), and greater than 12 oz percent yield ($P = 0.2520$).

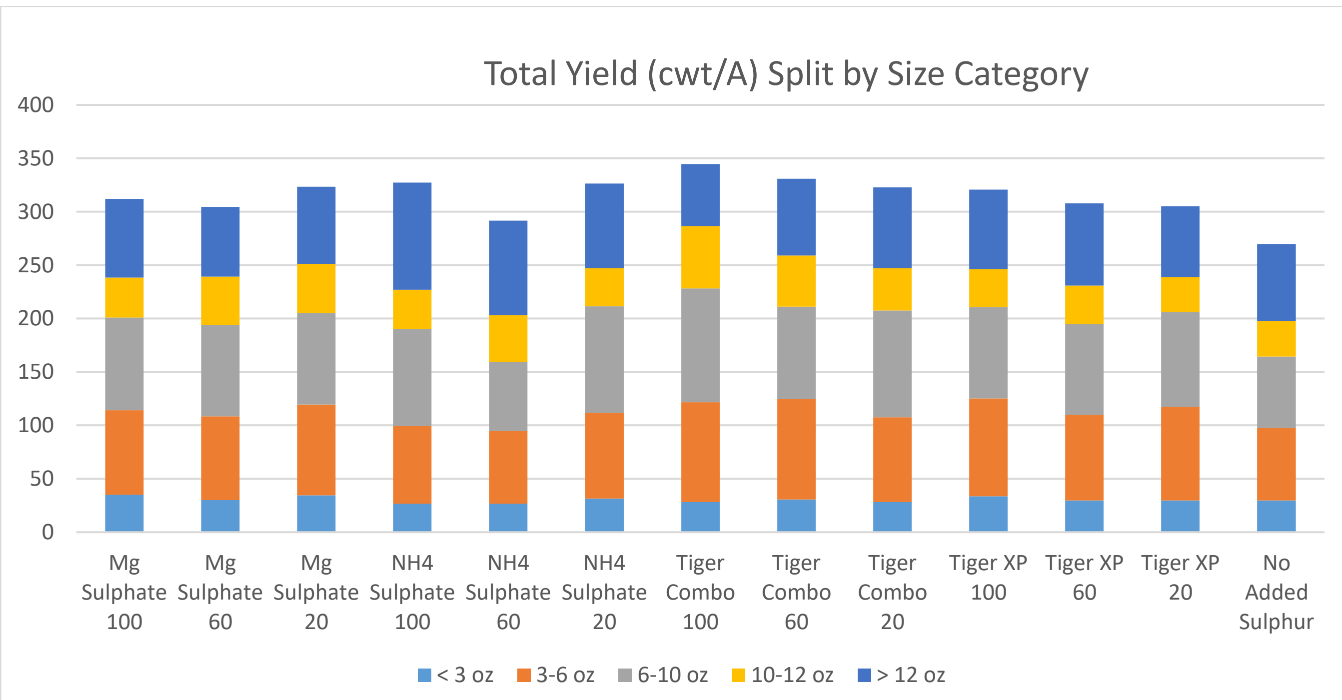


Fig. 2 The total yield consisting of the average of the four replicates of each fertilizer treatment with each column separated by the tuber size profile in 2020. The tuber size profile also consists of the average of the four replicates within a given treatment. There was no significant sulphur treatment effect on total yield or any size category.

There was a significant effect ($P = 0.0164$) of fertilizer product use on total yield when the rates of each fertilizer were combined in the 2020 analysis. All fertilizers improved total yield when compared to the negative control. There were no significant total yield differences between the fertilizer products. Tiger Combo trended towards significance vs Magnesium Sulphate (Mg

Sulphate in Fig. 3, P = 0.0989) and Tiger XP trended towards significance vs Magnesium Sulphate (Mg Sulphate in Fig. 3, P = 0.9089), with Tiger Combo treatments having the numerically greatest yield.

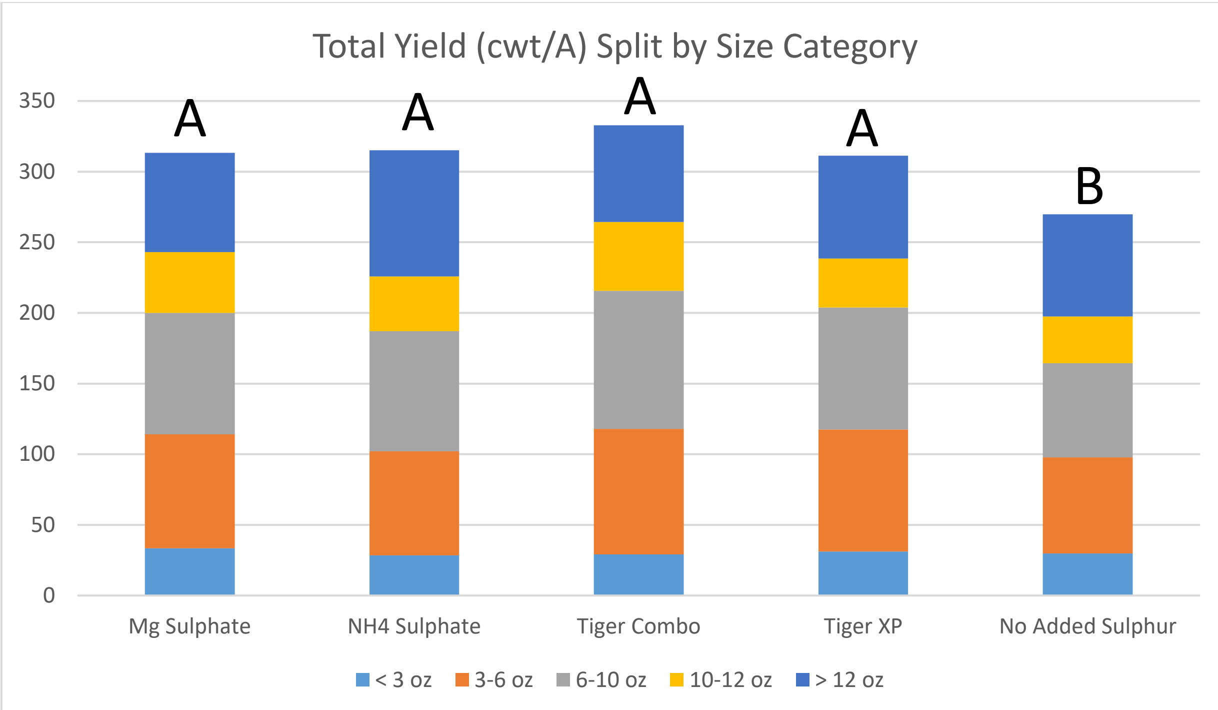


Fig. 3 The total yield by each fertilizer product consisted of the average of the twelve replicates of each fertilizer product (treatment rates combined) with each column separated by the tuber size profile. Letters denote statistical differences as determined by the mixed procedure with Tukey post-hoc tests with significance determined at $P \leq 0.05$. There was a significant effect (P = 0.0164) of fertilizer product use on total yield when the rates of each fertilizer were combined in the 2020 analysis. All fertilizers improved total yield when compared to the negative control. There were no significant total yield differences between the fertilizer products.

There was also a significant effect (P = 0.0211) of fertilizer use on the dollars per cwt when the rates of each fertilizer were combined in the 2020 analysis. All fertilizers improved total yield when compared to the negative control, which received no sulphur fertilizer. There were no significant dollar value differences between the fertilizer products. Tiger Combo trended towards significance vs Magnesium Sulphate (Mg Sulphate in Fig. 4, P = 0.1006).

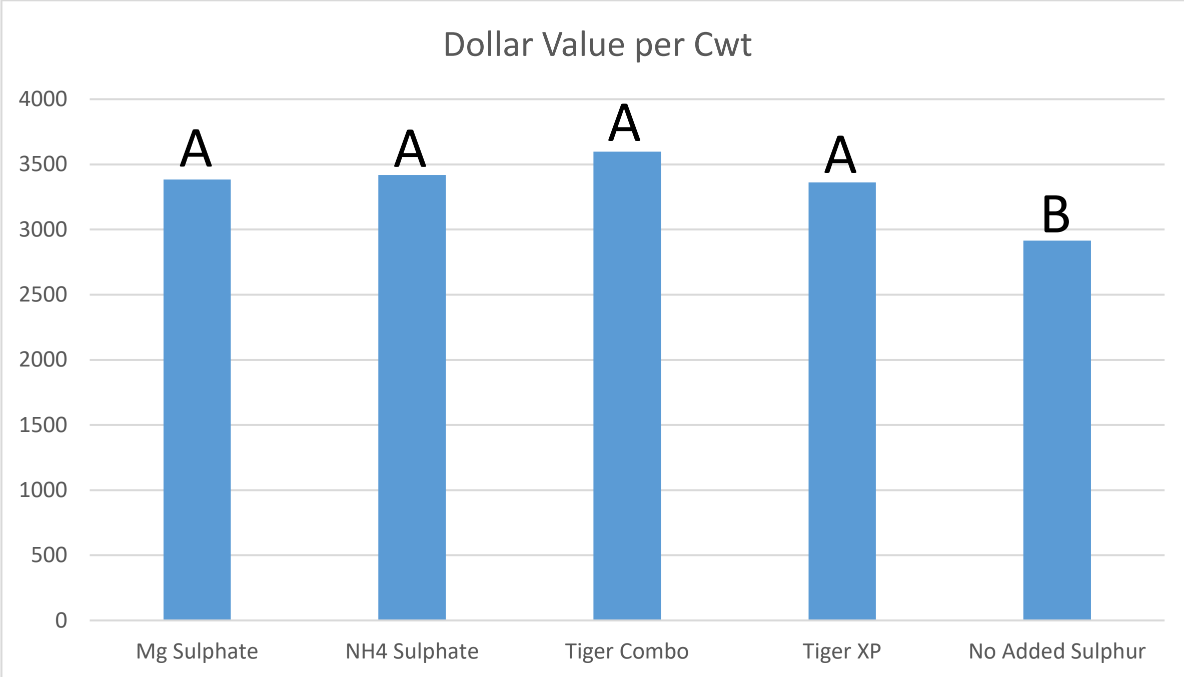


Fig. 4 The dollar values per cwt for each fertilizer product that consisted of the average of the twelve replicates of each fertilizer product (treatment rates combined). Letters denote statistical differences as determined by the mixed procedure with Tukey post-hoc tests with significance determined at $P \leq 0.05$. There was a significant effect ($P = 0.0164$) of fertilizer product use on total yield when the rates of each fertilizer were combined in the 2020 analysis. All fertilizers improved the value when compared to the negative control. There were no significant total yield differences between the fertilizer products.

There was also one final significant effect ($P = 0.0094$) of fertilizer use on the 10-12 oz yield when the rates of each fertilizer were combined in the 2020 analysis. All fertilizers improved total yield when compared to the negative control except the Tiger XP ($P = 0.8950$) and Ammonium Sulphate treatments ($P = 0.9750$). There were no significant total yield differences between the fertilizer products. Tiger Combo trended towards significance vs Tiger XP (Fig. 5, $P = 0.1070$), and Tiger Combo was the treatment with numerically greater 10-12 oz yield.

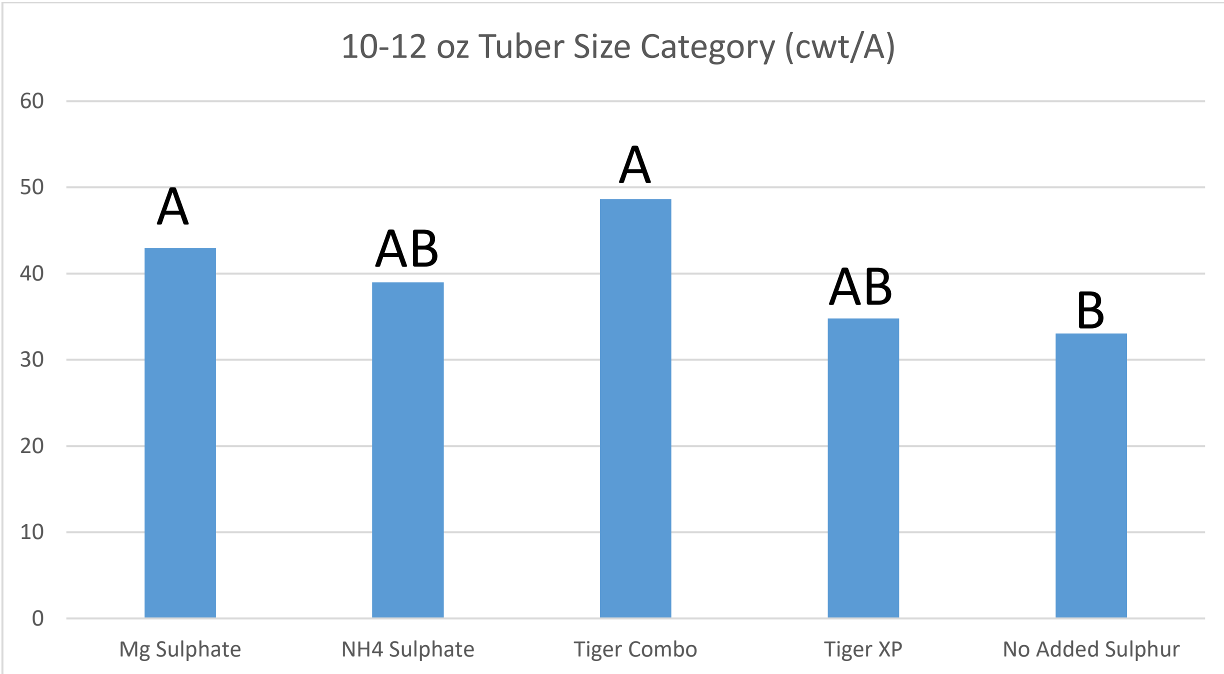


Fig. 5 The 10-12 oz yield for each fertilizer product that consisted of the average of the twelve replicates of each fertilizer product (treatment rates combined). Letters denote statistical differences as determined by the mixed procedure with Tukey post-hoc tests with significance determined at $P \leq 0.05$. All fertilizers improved total yield when compared to the negative control except the Tiger XP ($P = 0.8950$) and Ammonium Sulphate treatments ($P = 0.9750$).

Because of the significant interaction of year, any combined analysis and interpretation of main effects with fertilizer use on yield for 2020 and 2019 data would be null and void. However, it is legitimate to test the simple effects of fertilizer rate on total yield (Table 2), dollars per cwt (Table 3) and 10-12 oz yield (Table 4). Particular fertilizer rates that had a significant impact on the dependent variable (total yield, dollar value, or 10-12 oz yield) are highlighted in green, and the test does not indicate whether the trend is positive or negative (i.e. a significant result in the none, or no additional sulphur fertilizer added, doesn't necessarily mean that the experiment failed. It could mean that the "none" treatment had lower yield than other treatment, but that can not be verified until a main effects test can be done without an interaction.)

Tests of Effect Slices for Total Yield				
Effect	**Fertilizer**	**Rate**	**F Value**	**Pr > F**
Year*Fertilizer*Rate	**NH4 Sulphate**	**20**	4.36	0.0527
Year*Fertilizer*Rate	**NH4 Sulphate**	**60**	10.27	0.0053
Year*Fertilizer*Rate	**NH4 Sulphate**	**100**	0.29	0.5990
Year*Fertilizer*Rate	**Tiger Combo**	**20**	39.38	<.0001
Year*Fertilizer*Rate	**Tiger Combo**	**60**	14.46	0.0015
Year*Fertilizer*Rate	**Tiger Combo**	**100**	13.55	0.0019
Year*Fertilizer*Rate	**Mg Sulphate**	**20**	6.12	0.0236
Year*Fertilizer*Rate	**Mg Sulphate**	**60**	9.24	0.0071
Year*Fertilizer*Rate	**Mg Sulphate**	**100**	7.99	0.0112
Year*Fertilizer*Rate	**None**	**0**	74.47	0.0002
Year*Fertilizer*Rate	**Tiger XP**	**20**	4.26	0.0538
Year*Fertilizer*Rate	**Tiger XP**	**60**	4.70	0.0437
Year*Fertilizer*Rate	**Tiger XP**	**100**	0.46	0.5056

Table 2 Test of simple effects of fertilizer and rate on total yield using the slice feature in proc mixed. Particular fertilizer rates that had a significant impact on the dependent variable (total yield, dollar value, or 10-12 oz yield) are highlighted in green ($P \leq 0.05$)

Tests of Effect Slices Dollars/cwt				
Effect	**Fertilizer**	**Rate**	**F Value**	**Pr > F**
Year*Fertilizer*Rate	**NH4 Sulphate**	**20**	4.25	0.0555
Year*Fertilizer*Rate	**NH4 Sulphate**	**60**	9.08	0.0081
Year*Fertilizer*Rate	**NH4 Sulphate**	**100**	0.20	0.6617
Year*Fertilizer*Rate	**Tiger Combo**	**20**	36.87	<.0001
Year*Fertilizer*Rate	**Tiger Combo**	**60**	10.93	0.0042
Year*Fertilizer*Rate	**Tiger Combo**	**100**	10.36	0.0052
Year*Fertilizer*Rate	**Mg Sulphate**	**20**	5.16	0.0358
Year*Fertilizer*Rate	**Mg Sulphate**	**60**	7.41	0.0140
Year*Fertilizer*Rate	**Mg Sulphate**	**100**	7.42	0.0140
Year*Fertilizer*Rate	**None**	**0**	60.68	0.0004
Year*Fertilizer*Rate	**Tiger XP**	**20**	3.76	0.0683
Year*Fertilizer*Rate	**Tiger XP**	**60**	3.88	0.0644
Year*Fertilizer*Rate	**Tiger XP**	**100**	0.27	0.6127

Table 3 Test of simple effects of fertilizer and rate on dollars per cwt using the slice feature in proc mixed. Particular fertilizer rates that had a significant impact on the dependent variable (total yield, dollar value, or 10-12 oz yield) are highlighted in green ($P \leq 0.05$)

Tests of Effect Slices 10-12 oz yield (cwt/acre)				
Effect	**Fertilizer**	**Rate**	**F Value**	**Pr > F**
Year*Fertilizer*Rate	**NH4 Sulphate**	**20**	0.67	0.4255
Year*Fertilizer*Rate	**NH4 Sulphate**	**60**	10.40	0.0051
Year*Fertilizer*Rate	**NH4 Sulphate**	**100**	3.00	0.1020
Year*Fertilizer*Rate	**Tiger Combo**	**20**	3.44	0.0822
Year*Fertilizer*Rate	**Tiger Combo**	**60**	9.10	0.0082
Year*Fertilizer*Rate	**Tiger Combo**	**100**	18.45	0.0006
Year*Fertilizer*Rate	**Mg Sulphate**	**20**	12.70	0.0023
Year*Fertilizer*Rate	**Mg Sulphate**	**60**	7.17	0.0155
Year*Fertilizer*Rate	**Mg Sulphate**	**100**	9.30	0.0070
Year*Fertilizer*Rate	**None**	**0**	0.94	0.3750
Year*Fertilizer*Rate	**Tiger XP**	**20**	1.78	0.2013
Year*Fertilizer*Rate	**Tiger XP**	**60**	9.86	0.0064
Year*Fertilizer*Rate	**Tiger XP**	**100**	6.84	0.0188

Table 4 Test of simple effects of fertilizer and rate on dollars per cwt using the slice feature in proc mixed. Particular fertilizer rates that had a significant impact on the dependent variable (total yield, dollar value, or 10-12 oz yield) are highlighted in green ($P \leq 0.05$)

Yield Results for 2019:

There was no significant sulphur treatment effect on total yield (P = 0.2184), value (P = 0.3564), or any size profile in 2019. More specifically, observed differences in the 3-6 oz yield (P = 0.4908), 6-10 oz yield (P = 0.7179), 10-12 oz yield (P = 0.3162), and greater than 12 oz yield (P = 0.8958) were all not significant (Fig 6). The effect of sulphur treatment on specific gravity trended towards significance (P = 0.1060, Fig. 6), which is a notable outcome for a single year of study.

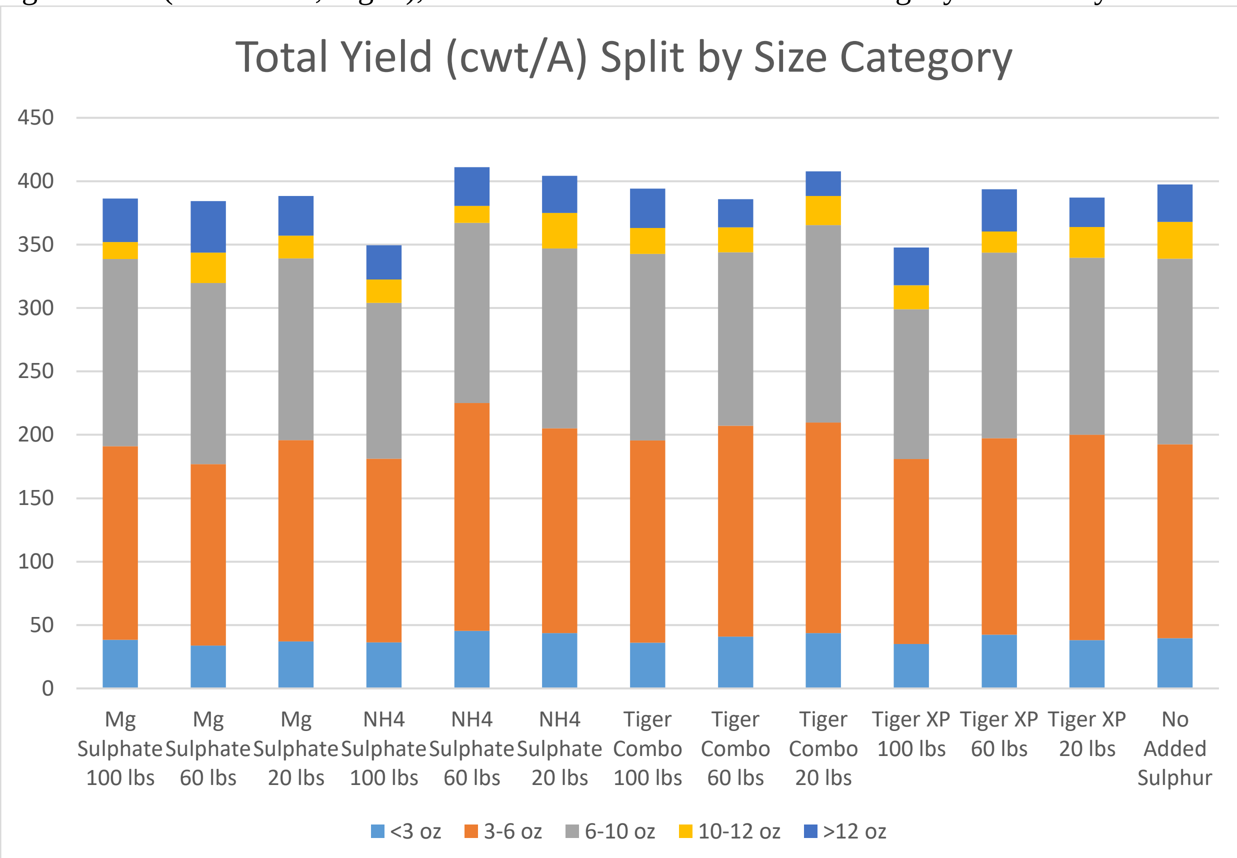


Fig 7. The total yield consisting of the average of the four replicates of each fertilizer treatment with each column separated by the tuber size profile. The tuber size profile also consists of the average of the four replicates within a given treatment. There was no significant sulphur treatment effect on total yield or any size category.

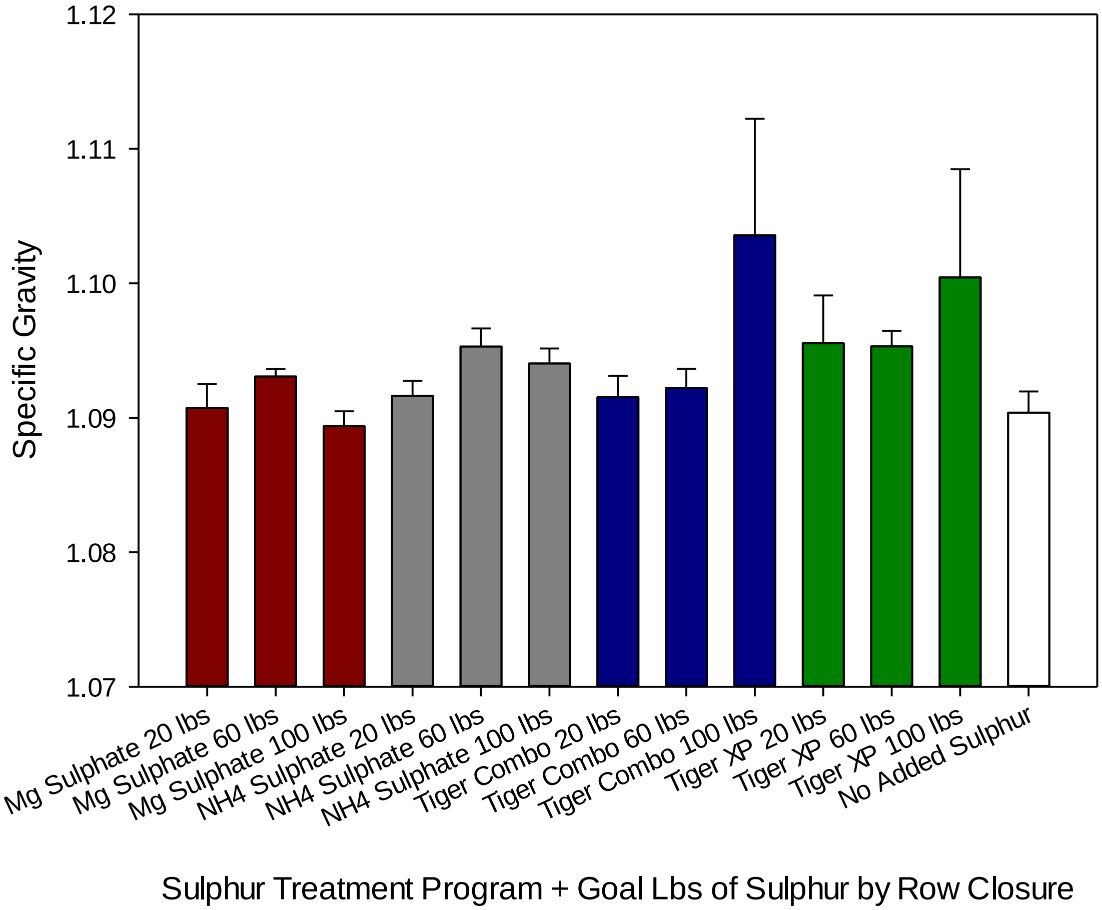


Fig. 7. The effect of sulphur treatment program on potato specific gravity. There was a nearly significant effect (*P* = 0.1060) of sulphur treatment program on specific gravity.

2020 Soil and Petiole Sulphur results:

The pounds of soil sulphur at row closure from 0-6 inches in depth did not differ between treatments (*P* = 0.1868, data not shown), nor did the soil sulphur levels at the same depth at late bulking (*P* = 0.3776, data not shown). The amount of petiole sulphur did not differ between treatments at row closure (*P* = 0.7639, data not shown). The observed pounds of soil sulphur at row closure from 6-12 inches were significantly different between treatments (*P* <.0001).

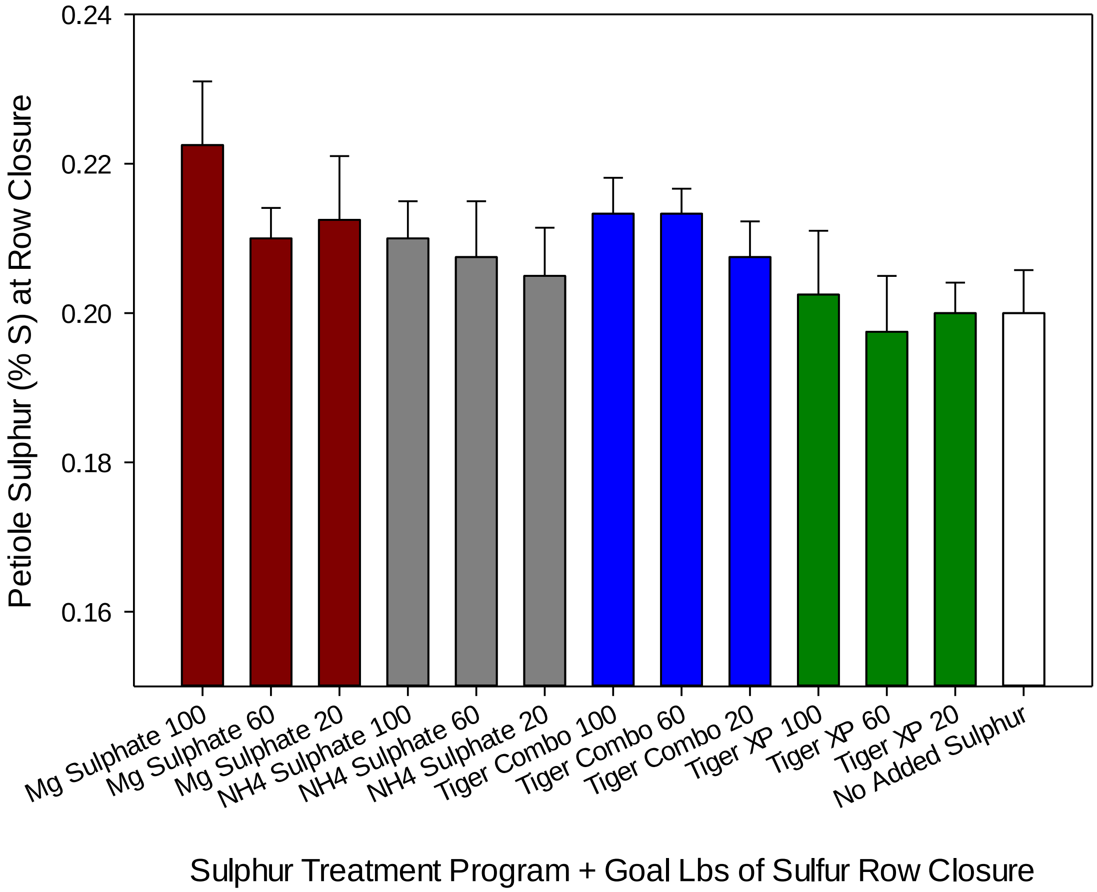


Fig. 8 The effect of sulphur treatment program (x-axis) on the availability of soil sulphur (y-axis) at row closure. Bars indicate mean lbs of sulphur and the standard error is above each bar. Mg sulphate signifies magnesium sulphate, while NH4 sulphate stand for ammonium sulphate. All fertilizer rates for each treatment can be found in Table 1.

Specific pairwise comparisons of sulphur treatments on available petiole sulphur is as follows in Table 5. The greater column refers to the treatment with the greatest lbs of sulphur in soil, whereas the lesser has the smaller amount of petiole sulphur. Combinations of fertilizers that are not present were not significant ($P \geq 0.05$). This list does include comparisons that trended towards significance ($P = 0.05 \leq 0.1$).

Greater Fertilizer Treatment	Lesser Fertilizer Treatment	*P*-value
NH4 Sulphate 100	No Added Sulphur	<.0001
NH4 Sulphate 100	Tiger XP 20	<.0001
Tiger Combo 100	Tiger Combo 20	<.0001
Tiger Combo 100	Tiger Combo 60	<.0001
Tiger Combo 60	No Added Sulphur	<.0001
Tiger Combo 60	Tiger XP 20	<.0001
Tiger Combo 100	No Added Sulphur	<.0001
Tiger Combo 100	Tiger XP 20	<.0001
Tiger Combo 100	Tiger XP 60	<.0001
Tiger Combo 100	Tiger XP 100	<.0001
Mg Sulphate 100	No Added Sulphur	<.0001
Mg Sulphate 100	Tiger XP 20	<.0001
NH4 Sulphate 100	Tiger Combo 20	0.0002
NH4 Sulphate 100	Tiger XP 60	0.0002
Tiger Combo 100	NH4 Sulphate 20	0.0003
NH4 Sulphate 100	Tiger XP 100	0.0003
Mg Sulphate 100	Tiger Combo 20	0.0004
Mg Sulphate 100	Tiger XP 60	0.0004
Mg Sulphate 100	Tiger XP 100	0.0007
Tiger Combo 100	Mg Sulphate 20	0.001
Tiger Combo 60	Tiger XP 60	0.001
Tiger Combo 60	Tiger Combo 20	0.002
Tiger Combo 60	Tiger XP 100	0.005
Tiger Combo 100	Mg Sulphate 60	0.006
NH4 Sulphate 60	No Added Sulphur	0.011
NH4 Sulphate 60	Tiger XP 20	0.015
Tiger Combo 100	NH4 Sulphate 60	0.026
NH4 Sulphate 100	Mg Sulphate 20	0.051
NH4 Sulphate 100	NH4 Sulphate 20	0.055
Mg Sulphate 100	Mg Sulphate 20	0.062
NH4 Sulphate 20	Mg Sulphate 100	0.071
NH4 Sulphate 60	Tiger Combo 20	0.082
NH4 Sulphate 60	Tiger XP 60	0.087

In general, all fertilizers met or exceeded their target amount of soil sulphur on average with the exception of Tiger XP (Fig. 8). All of the fertilizer treatments that targeted 100 lbs of soil sulphur by row closure were observed with significantly more soil sulphur than the treatment with no added sulphur, with the exception of Tiger XP 100 lbs. Considerable variability was observed for all fertilizers with the 60 lbs soil sulphur target, and the only fertilizer treatment with this target that varied from the treatment that received no additional soil sulphur was the ammonium sulphate 60 lbs treatment (Table 5). Tiger Combo 100 lbs was observed with significantly more soil sulphur than Tiger Combo 60 and 20 lbs treatments. Ammonium sulphate (NH4 sulphate, Tables 1, 5) at 100 lbs was observed with significantly more soil nitrogen than the Ammonium sulphate 20 treatment, but not when compared with the Ammonium sulphate 60 treatment. Magnesium sulphate (Mg sulphate, Tables 1, 5) at 100 lbs was observed with significantly more soil nitrogen than the magnesium sulphate 20 treatment, but not when compared with the magnesium sulphate 60 treatment. Tiger XP treatments did not differ from one-another in terms of available soil sulphur at row closure, and most fertilizer treatments had significantly more soil sulphur than any of the Tiger XP treatments (table 5).

2019 Soil and Petiole Sulphur results

The first year of study in 2019 indicated that sulphur treatments had a significant effect on the amount of available soil sulphur, in lbs, at row closure ($P = 0.0277$) and late bulking ($P = 0.0079$).

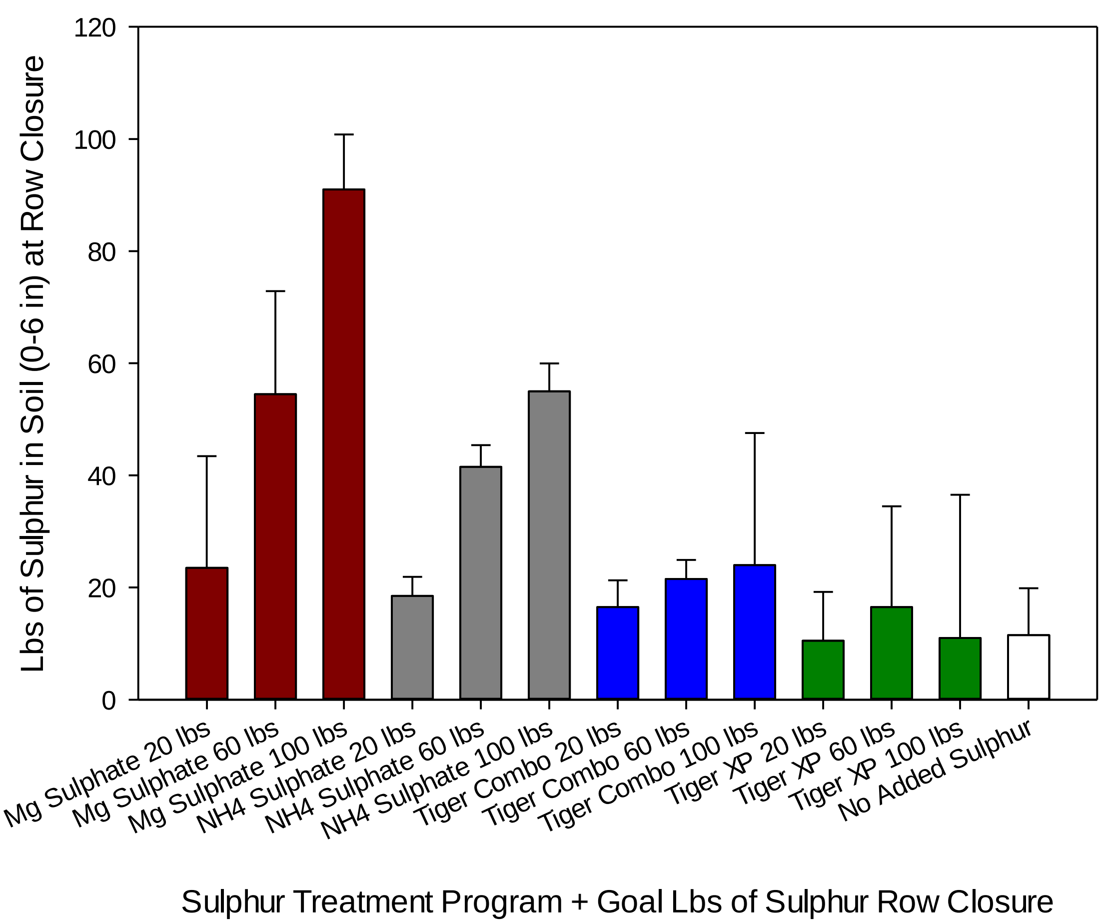


Fig 9. The effect of sulphur treatment program (x-axis) on the availability of soil sulphur (y-axis) at row closure. Bars indicate mean lbs of sulphur and the standard error is above each bar. Mg

sulphate signifies magnesium sulphate, while NH4 sulphate stand for ammonium sulphate. All fertilizer rates for each treatment can be found in Table 1.

The goal of each treatment, whether 20, 60, or 100 lbs, was to have a standardized amount of sulphur available by row closure in order to evaluate the impact on final yield parameters and compare between fertilizer products. Treatments where 20 lbs of sulphur was intended to be available in the soil were generally very close to the target because the means in Fig 9 are generally close to 20 lbs. However, 60 and 100 lbs of soil sulphur were harder to achieve with the same precision. The 60 and 100 lb targets for ammonium (NH4) sulphate, Tiger combo, and Tiger XP were less than expected by approximately 20-60 lbs of sulphur at row closure. The exception was observed with the magnesium (Mg) sulphate treatment, where the amount of available sulphur was within 10 lbs of the target by row closure (Fig 9).

Specific pairwise comparisons of sulphur treatments on available soil sulphur at row closure is as follows in Table 6. The greater column refers to the treatment with the largest amount of soil sulphur, whereas the lesser has the smaller amount of soil sulphur. Combinations of fertilizers that are not present were not significant ($P \leq 0.05$). This list does not include comparisons that trended towards significance ($P \leq 0.1$).

Greater Fertilizer Treatment	Lesser Fertilizer Treatment	*P*-value
Ammonium sulphate 100 lbs	Tiger combo 20 lbs	$P = 0.0478$
Ammonium sulphate 100 lbs	None	$P = 0.0189$
Ammonium sulphate 100 lbs	Tiger combo 60 lbs	$P = 0.0269$
Magnesium sulphate 100 lbs	Ammonium sulphate 20 lbs	$P = 0.0381$
Magnesium sulphate 100 lbs	Tiger combo 100 lbs	$P = 0.0418$
Magnesium sulphate 100 lbs	Tiger combo 20 lbs	$P = 0.0376$
Magnesium sulphate 100 lbs	Tiger combo 60 lbs	$P = 0.0287$
Magnesium sulphate 100 lbs	Magnesium sulphate 20 lbs	$P = 0.0417$
Magnesium sulphate 100 lbs	None	$P = 0.0293$
Magnesium sulphate 100 lbs	Tiger Xp 100 lbs	$P = 0.0363$
Magnesium sulphate 100 lbs	Tiger Xp 20 lbs	$P = 0.0338$
Magnesium sulphate 100 lbs	Tiger Xp 60 lbs	$P = 0.0326$
Magnesium sulphate 60 lbs	Ammonium sulphate 20 lbs	$P = 0.0410$
Magnesium sulphate 60 lbs	Tiger combo 100 lbs	$P = 0.0493$
Magnesium sulphate 60 lbs	Tiger combo 20 lbs	$P = 0.0403$
Magnesium sulphate 60 lbs	Tiger combo 60 lbs	$P = 0.0385$
Magnesium sulphate 60 lbs	None	$P = 0.0295$
Magnesium sulphate 60 lbs	Tiger Xp 100 lbs	$P = 0.0387$
Magnesium sulphate 60 lbs	Tiger Xp 20 lbs	$P = 0.0353$
Magnesium sulphate 60 lbs	Tiger Xp 60 lbs	$P = 0.0338$
Tiger combo 20 lbs	None	$P = 0.0287$

In general, all magnesium sulphate and the 100-lb treatment of ammonium sulphate increased soil sulphur at row closure compared to the negative control; no sulphur was supplied in any negative control plot. Ammonium sulphate and magnesium sulphate generally provided more soil sulphur than comparable rates of Tiger Xp. Magnesium sulphate was the only sulphur fertilizer where the comparison between 100 and 20 lbs treatments produced statistically distinguishable soil sulphur tests.

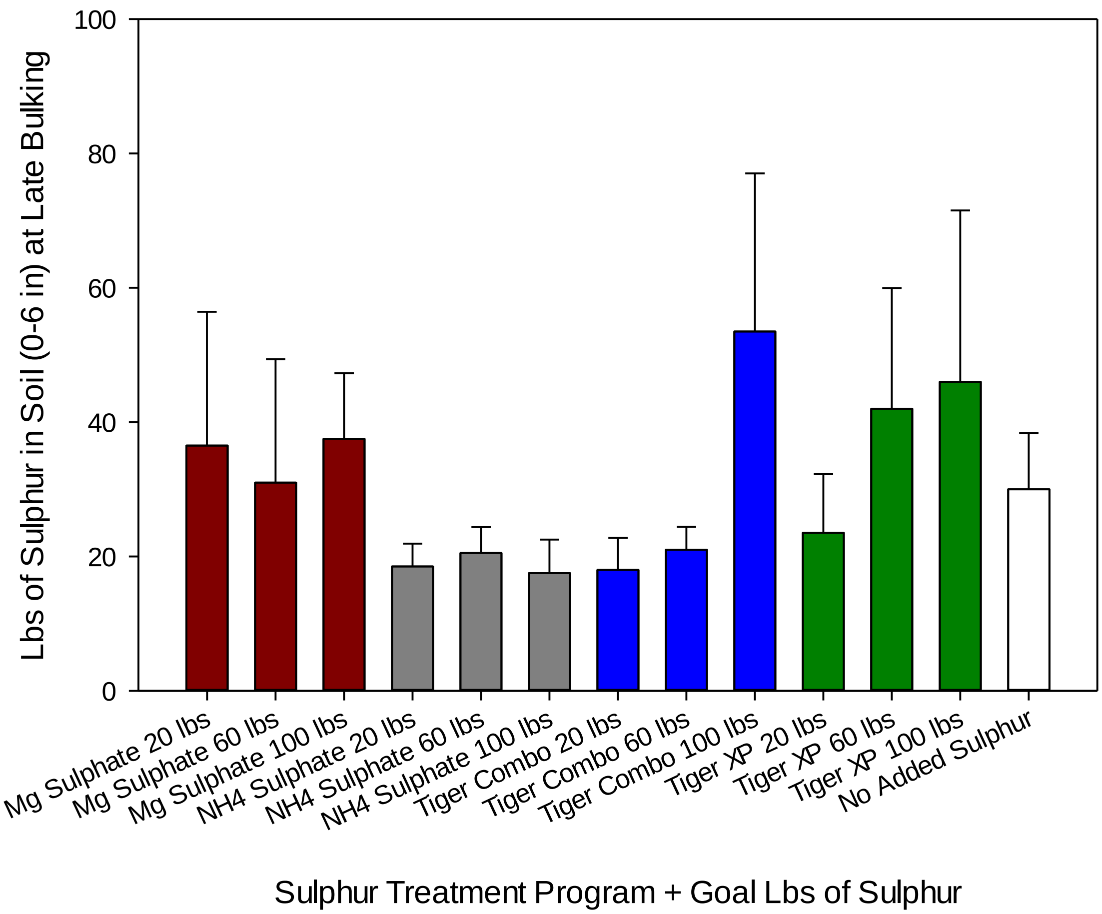


Fig 10. The effect of sulphur treatment program (x-axis) on the availability of soil sulphur (y-axis) at late bulking. Bars indicate mean lbs of sulphur and the standard error is above each bar. Mg sulphate signifies magnesium sulphate, while NH4 Sulphate stand for ammonium sulphate. All fertilizer rates for each treatment can be found in Table 1.

Specific pairwise comparisons of sulphur treatments on available soil sulphur at late bulking is as follows in Table 7. The greater column refers to the treatment with the largest amount of soil sulphur, whereas the lesser has the smaller amount of soil sulphur. Combinations of fertilizers that are not present were not significant ($P \leq 0.05$). This list does not include comparisons that trended towards significance ($P \leq 0.1$).

Greater Fertilizer Treatment	Lesser Fertilizer Treatment	*P*-value
None	Ammonium sulphate 60 lbs	$P = 0.0293$
Tiger Xp 20 lbs	Ammonium sulphate 60 lbs	$P = 0.0261$
Tiger Xp 60 lbs	None	$P = 0.0279$
Tiger Xp 60 lbs	Tiger Xp 20 lbs	$P = 0.0145$
Tiger Xp 100 lbs	Ammonium sulphate 60 lbs	$P = 0.0453$

Fewer comparisons between rates within or between treatment programs were statistically significant at late bulking (Table 3) than at row closure (Table 2). A likely explanation for these observations exists in two general observations when contrasting Figs 2 and 3: first, the standard errors generally appear to be larger at late bulking than at row closure (indicating greater variability of soil sulphur in the late season). Second, the general availability of soil sulphur was less in the later season than the early season for treatments with magnesium sulphate, but the opposite was true for Tiger Xp. An additional noteworthy observation was that lower rates of Tiger Xp had more available soil sulphur than the ammonium sulphate treatment. Finally, Tiger Xp was the only treatment again to have statistically significant differences between the lowest rate (20 lbs) and the moderate rate (60 lbs).

The availability of petiole sulphur at row closure, expressed in the percentage of dry plant matter composed of sulphur, was also significantly impacted by sulphur treatment ($P = 0.0002$).

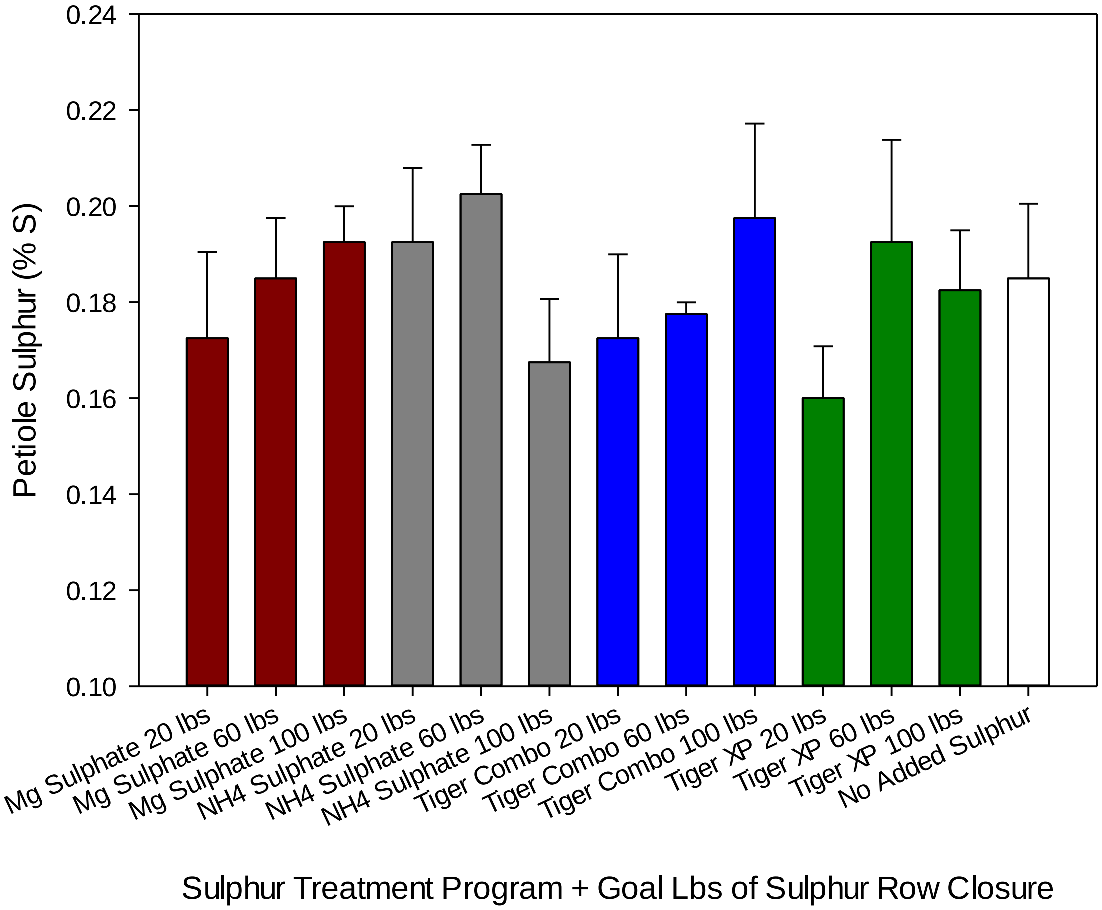


Fig 11. The effect of sulphur treatment program (x-axis) on the availability of petiole sulphur (y-axis) at row closure. Bars indicate mean lbs of sulphur and the standard error is above each bar. Mg sulphate signifies magnesium sulphate, while NH4 Sulphate stand for ammonium sulphate. All fertilizer rates for each treatment can be found in Table 1.

Specific pairwise comparisons of sulphur treatments on available petiole sulphur is as follows in Table 8. The greater column refers to the treatment with the largest amount of petiole sulphur, whereas the lesser has the smaller amount of petiole sulphur. Combinations of fertilizers that are not present were not significant ($P \leq 0.05$). This list does not include comparisons that trended towards significance ($P \leq 0.1$).

Greater Fertilizer Treatment	Lesser Fertilizer Treatment	*P*-value
Ammonium sulphate 100 lbs	None	*P* = 0.0035
Ammonium sulphate 100 lbs	Tiger Xp 20 lbs	*P* = 0.0038
Ammonium sulphate 100 lbs	Tiger Xp 100 lbs	*P* = 0.0077
Ammonium sulphate 60 lbs	Tiger Xp 20 lbs	*P* = 0.0012
Ammonium sulphate 60 lbs	Tiger Xp 100 lbs	*P* = 0.0032
Ammonium sulphate 60 lbs	None	*P* = 0.0014
Magnesium sulphate 100 lbs	Tiger combo 60 lbs	*P* = 0.0379
Magnesium sulphate 100 lbs	Tiger Xp 20 lbs	*P* = 0.0263
Magnesium sulphate 100 lbs	None	*P* = 0.0004
Magnesium sulphate 100 lbs	Tiger Xp 100 lbs	*P* = 0.0008
Magnesium sulphate 100 lbs	Tiger Xp 20 lbs	*P* = 0.0002
Magnesium sulphate 60 lbs	None	*P* = 0.0020
Magnesium sulphate 60 lbs	Tiger Xp 20 lbs	*P* = 0.0018
Tiger combo 60 lbs	None	*P* = 0.0121
Tiger combo 60 lbs	Tiger Xp 100 lbs	*P* = 0.0379
Tiger combo 60 lbs	Tiger Xp 20 lbs	*P* = 0.0149
Tiger Xp 100 lbs	Tiger Xp 60 lbs	*P* = 0.0294
Tiger Xp 100 lbs	Tiger Xp 60 lbs	*P* = 0.0037
Tiger Xp 60 lbs	None	*P* = 0.0013
Tiger Xp 60 lbs	Tiger Xp 20 lbs	*P* = 0.0006

In general, all sulphur amendments increased soil sulphur at row closure compared to the negative control, where no sulphur was supplied. Ammonium sulphate and magnesium sulphate generally provided more soil sulphur than comparable rates of Tiger Xp. Tiger Xp was the only sulphur fertilizer where the 100, 60, and 20 lbs rates actually produced statistically distinguishable soil sulphur tests.

Discussion

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 lbs 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.

The results contained in this report are from two years of study that were analyzed separately, indicating all results and trends are still preliminary at best. At least two combined years of study are required for conclusive results. In addition, these results are from small plot studies. Field scale studies with grower partners are required to identify if trends carry over into larger scales and are economically feasible for processing growers to enact on their farms.

Because of the significant interaction of year, any combined analysis and interpretation of main effects with fertilizer use on yield for 2020 and 2019 data would be null and void. For example, this would mean that one cannot analyze the combined data set to determine if sulphur fertilizer and rate had greater impact than another on total yield. There are a few possible explanations for why lower yields were observed in plots receiving the same treatment in 2020 compared to 2019. Dan Sawatzky told Spud Smart Magazine in their fall 2020 issue (page 54) that the 2020 growing season was “less than ideal with a later planting date and drier, hotter weather following which resulted in some heat stress expression through heat runners, especially in the Russet Burbank crop.” Infrequent and heavy rain events (up to 4 inches at a time, data not shown) over the course of July and August also contributed to that heat stress by decreasing the water available for evaporative cooling during the bulking season.

The significant interaction of year makes it reasonable to compare simple effects such as asking the question: in both 2019 and 2020, did a particular sulphur fertilizer rate have an impact on total yield? The simple effects in the results from tables 2, 3 and 4 indicate all three rates of Tiger Combo and magnesium sulphate have significant impacts on total yield, dollar value per cwt, and 10-12 oz yield. There is a problem in that these simple effects do not translate well into comparisons that Tiger Combo or magnesium sulfate at 100 lbs by row closure significantly improved total yield.

The procedure employed to analyze the simple effects was the slice procedure in proc mixed. The slice procedure is generally not used unless a study have significant interactions. Even if there wasn’t a significant interaction, the use of the slice procedure comes with a power (and likely accuracy) advantage over the separate standard t-tests, because t-tests use only half of the observations to compute the error term and significance is only based on half the degrees of freedom. Using simple effects tests (like planned contrasts) will use the within-cell variation for all the cases in the data set and generally will result in a smaller and more reliable error term, thus leading to higher power. The reason why the statistical theory is important here is that even though there were no significant comparisons of fertilizer and rate on yield or size profile (Fig. 2), which would normally constitute experimental failure, the significant simple effects slices with higher power show that there are significant trends underlying in the dataset. It is entirely possible that the results that trended towards significance, total yield ($P = 0.1164$), value ($P = 0.1303$), specific gravity ($P = 0.1499$), 10-12 oz yield ($P = 0.1163$), are actually important variables impacted by sulfur fertilizer but we lack the statistical power to identify them. It is possible that magnesium sulfate and Tiger Combo fertilizers have the most meaningful impact of the four fertilizers tested. The remedy for the lack of statistical power is another year of study with a balanced design and a year that allows the data from 2021 to be combined with 2020 or 2019 data.

The results from 2020 support that using virtually any of the four sulfur fertilizers, regardless of rate, provides improvements to total yield, dollar value, and 10-12 oz yield when compared to the treatment that received no additional sulfur (Figs. 2, 3, 4). Of the four fertilizers, magnesium sulfate and Tiger Combo were the most consistent in producing significantly greater total yield, dollar value, and 10-12 oz yield when compared to the treatment that received no additional sulfur (Figs. 2, 3, 4). It could be possible that the use of any small amount of sulfur fertilizer on sandier soils, such as the one the present experiment was planted on, can provide basic improvements to yield and dollar value, specifically in the 10-12 oz tuber size category and the bonuses that come with having more tubers that are larger.

The present study was set up with the assumption that the ideal soil sulphur test is 40 lbs 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). At least one additional year of study is needed to ensure that a target of 60 lbs of soil sulfur by row closure ensures that at least 40 lbs remains in sandy soils approximately two months after fertilization (row closure) and that this target provides the desired improvements to yield and value. 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 sulfur deficiency in the most cost-effective manner possible.

Manitoba Crop Variety Evaluation (MCVET) Trials

MCVET Winter Wheat Variety Evaluation

MCVET Fall Rye Variety Evaluation

MCVET Flax Variety Evaluation

MCVET Pea Variety Evaluation

CMCDC is one of the many contractors that are part of the 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 2020 planting year, CMCDC conducted MCVET trials on winter wheat, fall rye, flax, and peas 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 Resource Development 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

Crop type	# of plots	Site
Winter Wheat	24	Carberry
Fall Rye	15	Carberry
Flax	27	Carberry
Field Peas	78	Carberry
Total plots	144	

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

Management Practices for High Yielding Spring Wheat

Project duration: May 2018 – September 2020

Objectives: To quantify the yield benefit of intensive management practices in spring wheat, and to determine if these management practices provide the same benefit to a variety of cultivars.

Collaborators: Anne Kirk, Rejean Picard, and Earl Bargen, Manitoba Agriculture and Resource Development

Background

Canadian Western Red Spring (CWRS) wheat cultivars are increasingly high yielding, and may require specific management practices to achieve their yield potential. A study looking at rates of yield gain in CWRS cultivars found that yields rose 0.67% per year between the early 1990's and 2013 (Thomas and Graf 2014). Higher yielding CWRS cultivars may require specific management practices in order to achieve their yield potential. While there are a variety of management practices promoted as increasing yields, this project will focus on nitrogen (N) rates, plant growth regulators (PGR's), and fungicides.

Targeting higher yields often means increasing N rates, which brings with it the increased risk of lodging. PGR's may be a good fit for management systems with higher N rates as they have been shown to reduce plant height in spring wheat (Clark and Fedak 1977), and can be used as a risk management tool to reduce lodging and maintain yield (Strydhorst et al., 2017). The PGR Manipulator (chlormequat chloride) is registered for use in Canada but more information about this PGR is needed as response depends on crop type and cultivar, application timing, and weather conditions.

Fungicides to control FHB and leaf diseases are commonly used on spring wheat in Manitoba. Ransom and McMullen (2008) reported yield increases of 6-44% with foliar fungicide use, with the greatest increases occurring when susceptible cultivars were grown under high disease pressure.

Objective

Materials and Methods

Field trials were established at Arborg, Carberry, Melita and Roblin in the 2018 and 2020 growing seasons. Treatments were laid out in a randomized complete block design with three replicate blocks in a two-factor split plot. There were four cultivars and five management practices, for 20 treatments in total (Table 1).

Table 1. Treatments

Cultivar (Main plot)	Management (Sub Plot)
AAC Brandon	Standard (100 lb N/ac, no PGR, no fungicide)
AAC Cameron VB	Additional N (150 lb N/ac, no PGR, no fungicide)
AAC Viewfield	PGR (100 lb N/ac, PGR Manipulator applied at BBCH 31-32, no fungicide)
Cardale	Fungicides (100 lb N/ac, no PGR, fungicides at flag leaf and anthesis)
	Advanced (150 lb N/ac, PGR, fungicides at flag leaf and anthesis)

Herbicides were applied pre-seed and during the growing season as necessary. Plots were seeded at a rate of 280 plants/m^2. Fungicides were applied at flag leaf and anthesis in treatments requiring fungicides, with products differing between locations. Fungicides applied at flag leaf included Acapella, Headline, Prosaro, and Twinline. Prosaro was applied at anthesis for fusarium head blight (FHB) management. The plant growth regulator Maniplator 620 (chlormequat chloride) was applied at 1.8 L/ha as a single dose between Zadoka GS31 to 32. Data collection included plant height, lodging, yield, protein.

Table 2. Agronomic information

	Arborg		Carberry		Melita		Roblin	
	2018	2020	2018	2020	2018	2020	2018	2020
Soil Series	Peguis Clay		Wellwood Loam		Waskada Loam	Newstead Loam	Erickson Loamy Clay	
Previous Crop	Canola	Canola	Canola	Canola	Soybean	Spring wheat	Oat	Barley
Seed Date	11-May	19-May	15-May	04-May	07-May	07-May	15-May	11-May
Plot Size	8.2 m^2	8.2 m^2	7.5 m^2	8.4 m^2	13 m^2	13 m^2	8.4 m^2	12 m^2
Harvest Date	20-Aug	20-Aug	30-Aug	24-Aug	13-Aug	18-Aug	23-Aug	01-Sep

Table 3. Growing season summary (May 1 - September 30). Data from Manitoba Agriculture Growing Season Report: web43.gov.mb.ca/climate/SeasonalReport.aspx

	Arborg		Carberry		Melita		Roblin	
	2018	2020	2018	2020	2018	2020	2018	2020
Precipitation (mm)	249	212	300	249	242	187	418	235
Normal precipitation[1]	320	320	307	307	338	338	300	300

Growing degree days (GDD)	1668	1604	1747	1634	1780	1712	1461	1424
Normal GDD[1]	1554	1554	1524	1524	1637	1637	1396	1396

[1]Based on 30-year averages

Results and Discussion

Plant Height
The four cultivars included in this study varied in plant height, with AAC Cameron VB being the tallest at all sites and AAC Viewfield being the shortest (data not shown).

There were no significant height differences between management practices at the Roblin site in both years of the study. At the locations where there were height differences between management practices, the PGR reduced height relative to the standard and additional N treatments (Figure 1 and 2). Compared to standard management, the addition of a PGR reduced plant height by 6, 5, and 2 cm at Arborg, Carberry, and Melita, respectively in 2018 (Figure 1). In 2020, the additional of a PGR reduced plant height by 7, 4, and 8 cm compared to the standard treatment at Arborg, Carberry, and Melita, respectively.

There was a significant interaction between management and cultivar at Arborg in 2018, but not in any other site years. This significant interaction indicates that not all cultivars had the same height response to management. Response to the PGR varied for the four cultivars, with no significant difference between standard management and the addition of the PGR for AAC Brandon. The height difference between the standard management treatment and the PGR treatment for AAC Cameron and AAC Viewfield were 4 and 6 cm, respectively. AAC Viewfield, the shortest variety, had a 13 cm height difference between the standard and PGR treatments (Figure 3).

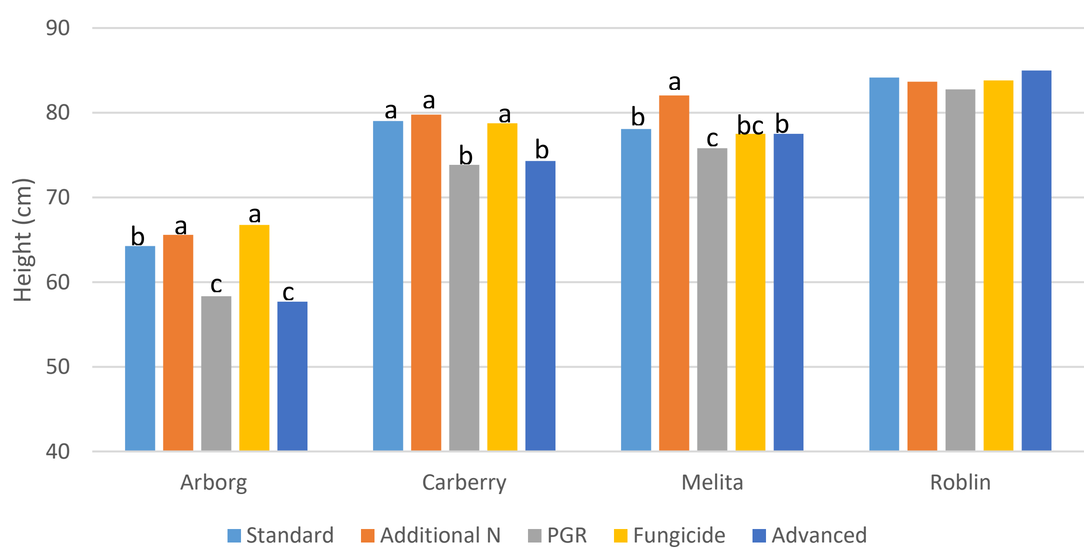


Figure 1. Height (cm) of the five treatments averaged across cultivars at Arborg, Carberry, Melita, and Roblin in 2018. Letters above the bars show statistically significant differences. Treatments within the same site with the same letter are not significantly different (P<0.05).

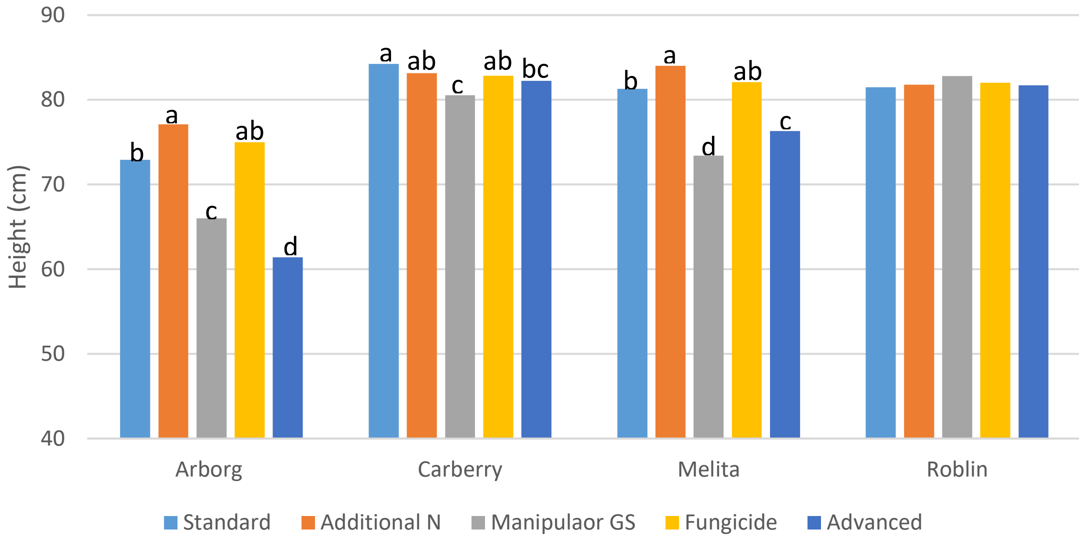


Figure 2. Height (cm) of the five treatments averaged across cultivars at Arborg, Carberry, Melita, and Roblin in 2020. Letters above the bars show statistically significant differences. Treatments within the same site with the same letter are not significantly different (P<0.05).

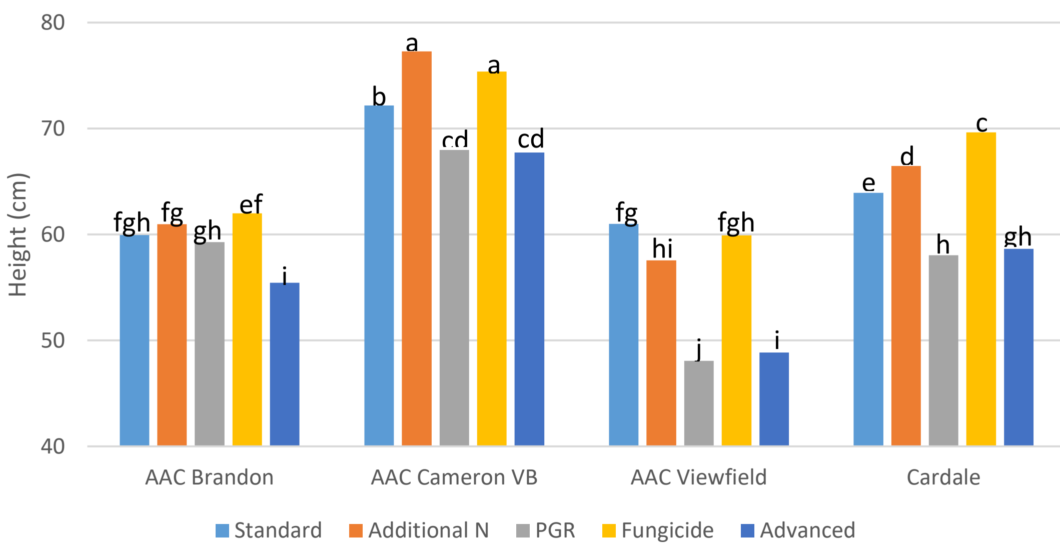


Figure 3. Height (cm) of the five treatments for each cultivar at Arborg 2018. Letters above the bars show statistically significant differences. Bars with the same letter are not significantly different (P<0.05).

Lodging
There was no lodging at any of the sites in 2018 and 2020.

Yield
There was no significant yield difference between cultivars at any of the sites in 2018 and 2020. Yield differences between management treatments were significant at Arborg and Melita in 2018 (Figure 4) and Arborg, Carberry and Melita in 2020 (Figure 5). Yield was not reported at Roblin in 2020. There was no significant interaction between cultivar and management in either year, indicating that the cultivars had similar yield responses to the management treatments (data not shown).

At Arborg and Melita 2018, the additional N and advanced management treatments yielded significantly more than the other three treatments, indicating that the additional 50 lb/acre of N resulted in a yield advantage (Figure 4). In 2020, the results were less clear. Compared to the standard treatment, additional N resulted in a significant yield increase at Arborg. Both additional N and fungicides resulted in a significant yield increase compared to standard at Melita, but the advanced treatment was highest yielding overall (Figure 5). Overall, additional N resulted in a yield increase in four of seven site years, and fungicides resulted in a yield increase in one of seven site years.

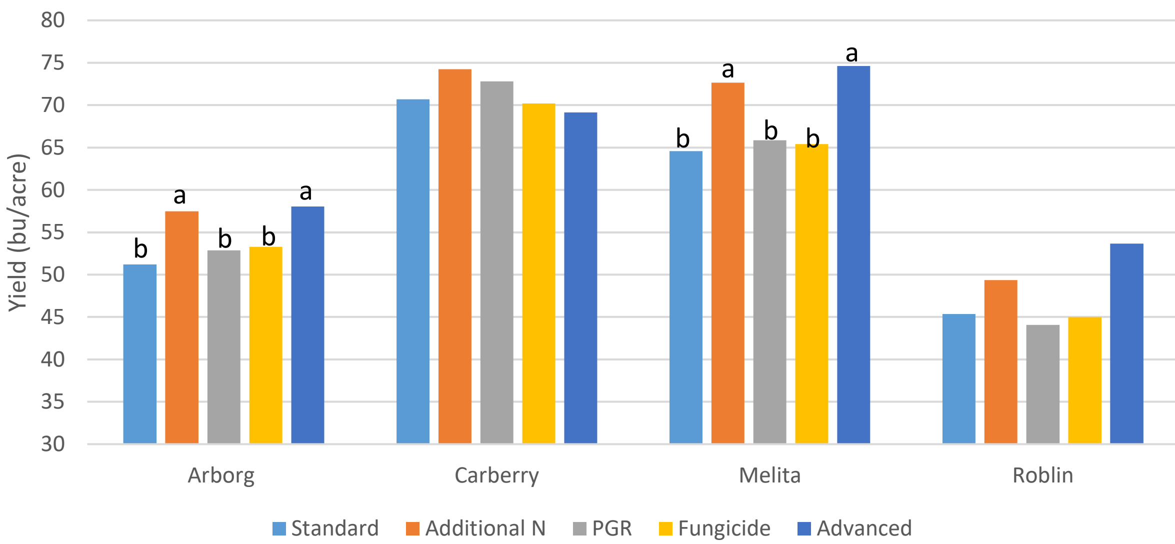


Figure 4. Yield (bu/ac) of the five treatments averaged across varieties at Arborg, Carberry, Melita, and Roblin 2018. Letters above the bars show statistically significant differences. Treatments within the same site with the same letter are not significantly different (P<0.05).

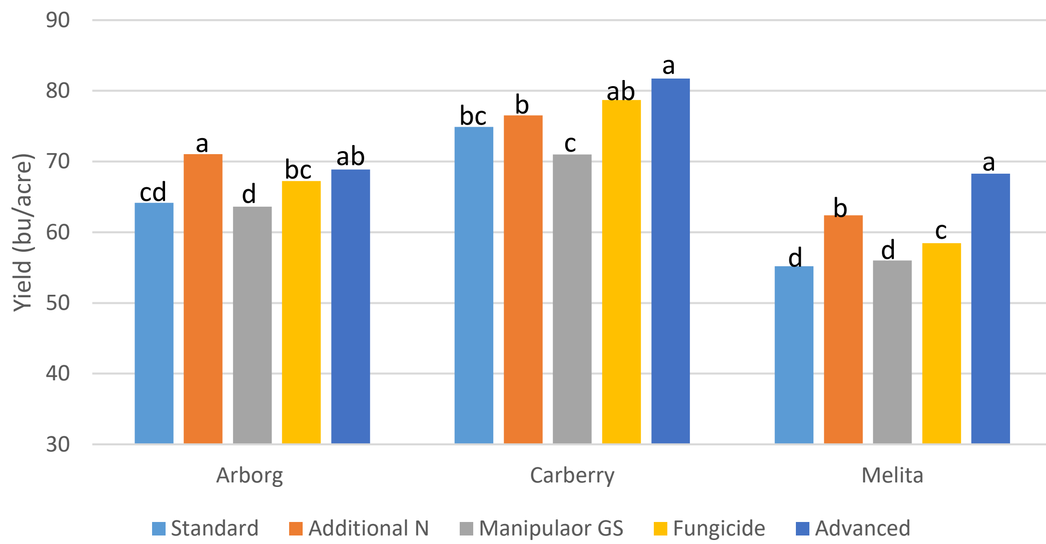


Figure 5. Yield (bu/ac) of the five treatments averaged across varieties at Arborg, Carberry, and Melita 2020. Letters above the bars show statistically significant differences. Treatments within the same site with the same letter are not significantly different (P<0.05).

Protein

Protein was measured on composite samples; therefore, results were not statistically analyzed. Of the management practices studied, treatments with higher N rates had the highest protein concentrations at most locations. Protein concentrations were similar between management treatments at Melita 2020 and Roblin 2018 (Table 4).

Table 4. Protein concentration (%).

	Arborg		Carberry		Melita		Roblin
	2018	2020	2018	2020	2018	2020	2018
	--------------------------- Protein (%) ---------------------------						
Variety							
AAC Brandon	14.3	12.2	15.9	15.1	12.0	12.3	11.6
AAC Cameron VB	13.9	12.0	16.2	14.6	12.1	11.3	11.0
AAC Viewfield	13.5	11.4	15.0	15.7	11.8	11.8	10.4
Cardale	14.1	12.4	17.1	16.1	12.3	12.7	11.5
Management							
Standard	13.2	11.5	15.7	15.3	11.7	11.9	11.3
Manipuator	13.2	11.3	15.7	15.2	11.4	11.7	11.0
Fungicide	13.0	12.0	15.9	15.4	11.5	11.7	11.0
Additional N	15.3	12.4	16.4	15.4	12.9	12.7	11.3
Advanced	15.1	12.8	16.6	15.6	12.9	12.3	11.1

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

Project duration: September 2019 – August 2020

Objectives: To increase understanding of resulting Fusarium Head Blight (FHB) infection for spring and winter wheat, barley and durum based on the current model.

Collaborators: Manasah Mkhabela PhD., Research Associate University of Manitoba Soil Science

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 Fig. 1. The quality ratings for the crops are not included here.

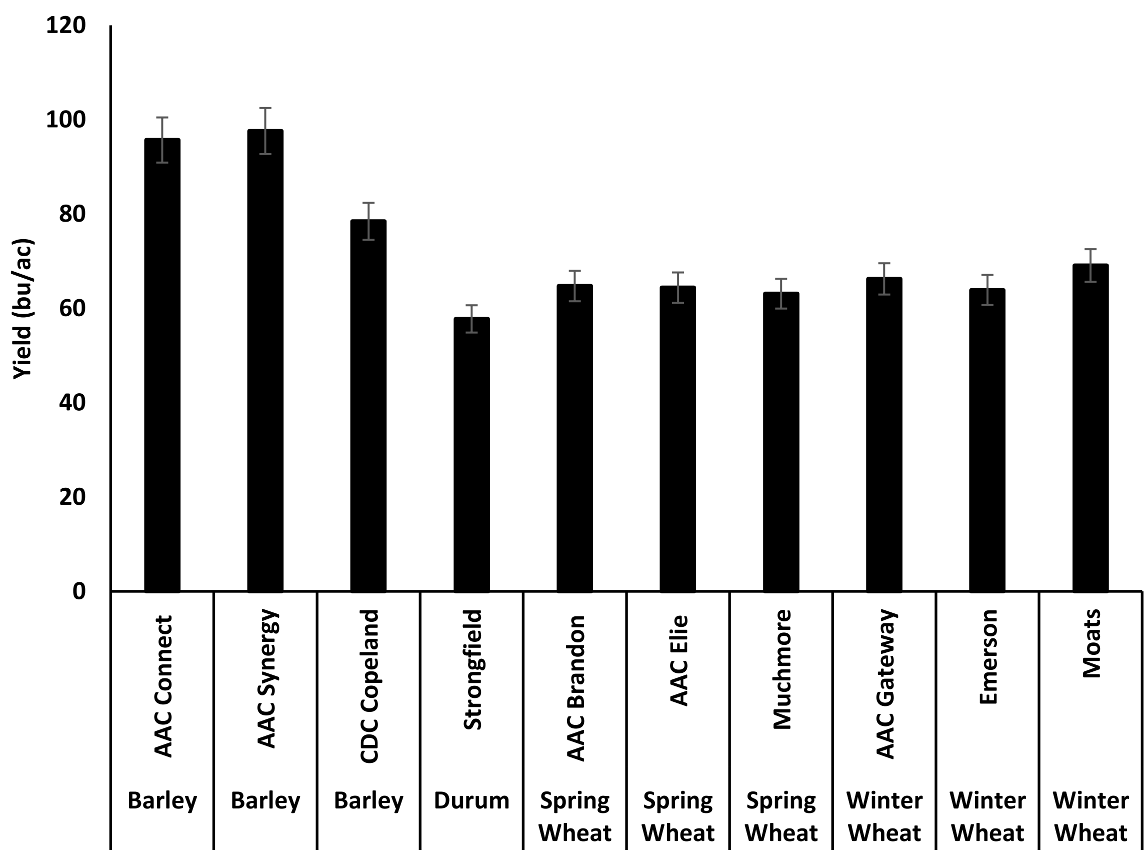


Fig. 1 Average yields for cereals tested

Background:

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.

Materials & Methods:

Entries:	3 varieties for each winter wheat, spring wheat and barley; 1 variety for durum
Seeding:	Winter Wheat seeded Sept 19 2019; Barley, Spring Wheat and Durum seeded May 04, 2020
Harvest:	Winter Wheat harvested Aug 17 2020; Spring Wheat and Durum harvested Aug 24, 2020 Barley harvested Aug 25, 2020
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 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 with respect to soil test results. Herbicide were applied, when required.

Evaluating Yield Potential of New Winter Wheat Varieties

Project duration: September 2019 – August 2020

Objectives: Establishing a fertility program to achieve high yield winter wheat

Collaborators: Elmer Kaskiw, Ducks Unlimited Canada

Results:

Grain samples were sent for protein analysis, but no report for these results has yet been generated. CMCDC will post a link when this report is available.

Background:

In Western Canada, winter wheat is a high-yielding, profitable crop, and it is good practice to match your fertility rates with your yield goals. Managing the health of winter wheat is important for its success, and fertility is a key player in crop health. Nitrogen (N) fertility is an important consideration in winter wheat production, and can be one of the most challenging factors for producers planning winter wheat. Selecting the right source will help ensure your soil has a balanced supply of essential plant nutrients.

Performing annual soil tests and applying nutrients to meet crop requirements will assist in deciding on the right rate. Applying nutrients at the right time will ensure nutrient uptake when the demand is high. Lastly, the right place helps minimize the risk of loss while increasing the availability of nutrients to the crop. Ducks Unlimited Canada wanted to evaluate two practices: the “producer practice” with regards to fertility and a balanced “high yield practice”.

Materials & Methods:

Experimental Design:	Random Complete Block Design - Factorial
Entries:	6
Seeding:	September 16, 2019
Harvest:	August 11, 2020
Varieties:	Winter Wheat: Gateway, Elevate, Wildfire

Table 1: Treatments

Treatment	Fertility	Variety
Producer Practice	100% added in Spring	Elevate
Producer Practice	100% added in Spring	Gateway
Producer Practice	100% added in Spring	Wildfire
Balanced Practice	50%N added as ESN in Spring	Elevate
Balanced Practice	50%N added as ESN in Spring	Gateway
Balanced Practice	50%N added as ESN in Spring	Wildfire

Data collected	**Date collected**
Heading Date:	Jun 10 – Jun 14
Heights:	At heading
Lodging:	August 11
Yield:	August 11
Moisture:	August 11

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.

Winter Wheat Fertility Program to Maximize Yield Potential of New Winter Wheat Varieties

Project duration: 2019-2020

Collaborators: Ducks Unlimited Canada, Western Ag Lab and Professional Agronomy

Objectives: To compare historical/standard "Producer Practice {100% spring}" fertility program to a balanced "High Yield Practice {Balanced}" as determined by Western Ag Soil analysis and recommendations.

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 the integral part of the overall management package aimed at achieving higher yields in winter wheat (Halvorson et al. 1987). Recommended fertilizer management, particularly nitrogen, differs widely in winter wheat production but the crop's nitrogen demand is correlated to yield potential and availability of moisture in dryland productions 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 escalating cost of production per unit area, which is the main goal that producers aim to achieve. There is still a knowledge gap on the rates as well as timing of application of nitrogen fertilizer, particularly in Western Canada, that would result in improved yield without compromising the quality of grain 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.

Materials and Methods

This study was established at four locations; Melita, Arborg, Carberry and Roblin in Manitoba in the fall of 2019 (Table 2b). In Melita, wheat was seeded onto wheat stubble to a depth of 0.5" on September 16 using a 6-row dual knife seed hawk air seeder. The soil was characterized as Ryerson5Loam/Regent5Loam. Preemergence weed control was necessary to ensure a clean seedbed and this was done using Roundup tank mixed with Aim at 0.75 L ac^{-1} and 0.015 L ac^{-1}, respectively. Post emergence weed control was done in spring by application of Achieve and Mextrol herbicides tank mixed at 0.2 L ac^{-1} and 0.5 L ac^{-1}, respectively, with 1% of Turbocharge added as an adjuvant. As a preventative measure for fungal diseases such as fusarium head blight (FHB) and stem rust, a spray application was done with Prosaro at 0.325 L ac^{-1} at 75% heading. The treatment structure consisted of a factorial arrangement of two fertilizer management practices and three winter wheat varieties in a randomized complete block design. The three winter wheat varieties utilized were; Gateway, Elevate and Wildfire. Fertilizer treatments included:

- producer practice at 100 lbs of nitrogen (urea plus agrotain) per acre applied in spring and 30 lbs phosphorus banded at seeding in fall and,
- balanced fertility practice as per Western Ag recommendations split applied with 50% banded at seeding and the other 50% urea plus Agrotain broadcasted in spring.

A summary of fall soil tests conducted at Melita, Roblin, Carberry and Arborg, and fertilizer treatments for 2019/2020 are presented in table 2a.

Table 2a: Fall Soil test results by site and fertilizer treatments for winter wheat in 2019/2020 season

Fall Soil Test - All Values (lbs/ac)				
	Location			
Nutrient	**Melita**	**Roblin**	**Carberry**	**Arborg**
N	31	39	38	53
P	11	76	32	4
K	84	132	179	19
S	205	22	16	523
Zn	1.0	0.64	0.52	0.08
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	155	135	145	125
P	55	15	40	55
K	85	30	20	50
S	0	10	10	0
Zn	0	0	0	2

Table 2b: Site description and agronomics for winter wheat trial in 2019/2020 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)	LLcanola-s.wheat	Canola (2019), Soybean (2018)	Barley silage (2019 &2020)	spring wheat canola
Soil Series	Ryerson Loam	Ramada Clay Loam	Erickson clay loam	Fyala heavy clay
Soil Test Done? (Y/N)	Yes	Yes	Yes	
Field Prep	no till	no till	harrowed	no till
Stubble	spring wheat	Canola	Barley	Canola
Burnoff (Date/Rate per ac/Products)	Roundup 0.75L + Aim 15 ml	Roundup 0.67 L + Heat 29 g + Water 40 L; sprayed before seeding (September 17, 2019)	Sep 12 Glyphosate 0.67 L	No burnoff
Soil Moisture at Seeding	Excellent	Good	Good	
Seed Date	Sep/16	Sep/16	Sep/19	Sep/17
Seed depth (Inches)	0.5	1.5	0.625	1
Seeder (drill/planter?)	Knife drill	Knife drill	Disc drill	Disc drill
Errors at seeding	none	N/A	None	
Topdressing	May/04	May/07	May/12	May/12
Herbicides (Date, Rate/ ac, Name)	Achieve 0.2 L Mextrol 0.5 L + turbocharge 1%	June 12 Fitness 90 ml	May 26 Axial 0.5 L Prestige XC 0.18 L	None
Fungicides (Prosaro)	23-Jun	26-Jun	09-Jun	19-Jun
Harvest Date	Aug/03	Aug/11	Aug/24	Aug/10
Total Precipitation (mm) (Seeding > Harvest)	332	415	319	345

Results

Winter wheat yield was not significantly influenced by variety, fertilizer management practice or interaction of the two factors at Melita but there was a significant (P=0.004) variety influence on protein content. Gateway had 13.5% protein compared to Elevate and Wildfire that had 12.2% and this could only due to genetic differences between the varieties. Although there were relatively low grain yields at Roblin compared to other sites, there was a significant influence of variety (P<0.001), variety x fertilizer management practice (P=0.012) and no significant effect of fertilizer management practice on winter wheat yield. Wildfire yielded significantly more grain (4145 kg ha^{-1}) compared to Elevate (3234 kg ha^{-1}) and Gateway (2875 kg ha^{-1}). An interaction of Wildfire variety x balanced fertilizer management practice significantly contributed to more grain yield (4692 kg ha^{-1}) compared to other interactions while Wildfire variety x 100% spring applied fertilizer management practice yielded significantly more grain (3598kg ha^{-1}) than balanced fertilizer application on Gateway variety (2732 kg ha^{-1}). As observed at Melita, protein content was significantly (P=0.001) high for Gateway variety (15.6%) compared to Elevate (14.6) and Wildfire (14.2%). Fertilizer management practice also significantly (P=0.022) influenced protein content at Roblin with balanced fertilizer having 15.1% compared to 100% spring applied on 14.5%.

At Carberry, there was a significant influence of variety (P<0.001) and fertility management practice (P=0.001) on winter wheat grain yield. Wildfire, Elevate and Gateway yielded 6864 kg ha^{-1}, 6336 kg ha^{-1} and 5822 kg ha^{-1}, respectively. Balanced fertilizer management practice resulted in approximately 8.33% more grain yield compared to 100% spring applied practice. There was no significant influence by any of the treatments on protein content. At Arborg, variety significantly influenced winter wheat grain yield (P=0.024) and protein content (P=0.007) while fertility management practice had a significant influence on yield (P=0.014) alone. On variety influence, Wildfire had the highest yield (6082 kg ha^{-1}) while Gateway and Elevate had 5233 kg ha^{-1} and 5110 kg ha^{-1}, respectively. Gateway variety continued to show similar trends as other sites with significantly higher protein content (13.3%) compared to Elevate (12.2%) and Wildfire (12.3%). Combining data from all sites resulted in significant influence by variety (P<0.001) on yield and protein content while fertility management practice significantly (P<0.001) influenced yield only. Four-site year analysis showed Wildfire leading in yield at 5473 kg ha^{-1} followed by Elevate with 4891 kg ha^{-1} and Gateway at 4588 kg ha^{-1}. On the other hand, Gateway had the highest combined protein content of 14.3% compared to 13.3% for Elevate and Wildfire. Balanced fertility management significantly influenced winter wheat grain yield resulting in attainment of 5199 kg ha^{-1} compared to 100% spring applied fertility management practiced that attained 4769 kg ha^{-1} (Table 2c).

Table 2c: Analysis of variance for winter wheat yield (kg ha^{-1}) and protein content (%) at Melita, Roblin, Carberry, Arborg and combined for all sites in 2019/2020 season

			Location									
			Melita		Roblin		Carberry		Arborg		All Sites	
	Treatment		Yield	Protein	Yield	Protein	Yield	Protein	Yield	Protein	Yield	Protein
	Elevate	**1**	4884	12.2**b**	3234**b**	14.6**b**	6336**b**	14.4	5110**b**	12.2**b**	4891**b**	13.3**b**
	Gateway	**2**	4420	13.5**a**	2875**b**	15.6**a**	5822**c**	14.8	5233**b**	13.3**a**	4588**c**	14.3**a**
Variety	**Wildfire**	**3**	4803	12.2**b**	4145**a**	14.2**b**	6864**a**	14.6	6082**a**	12.3**b**	5473**a**	13.3**b**
	100%Spring	**1**	**4628**	**12.6**	**3292**	**14.5b**	**6065b**	**14.8**	**5089b**	**12.6**	**4769b**	**13.6**
Fertility	**Balanced**	**2**	**4776**	**12.7**	**3545**	**15.1a**	**6616a**	**14.4**	**5861a**	**12.5**	**5199a**	**13.7**
Var x Fert	**1,1**		4706	12.4	3258**bc**	14.5	6157	14.6	4538	12.3	4665	13.4
	1,2		5062	12	3210**bc**	14.6	6515	14.2	5681	12.1	5117	13.2
	2,1		4312	13.2	3019**bc**	15	5489	14.9	4692	13.6	4378	14.2
	2,2		4528	13.8	2732**c**	16	6154	14.6	5774	12.9	4797	14.4
	3,1		4866	12.1	3598**b**	14	6549	14.8	6038	12.1	5263	13.2
	3,2		4739	12.3	4692**a**	14.5	7180	14.4	6126	12.4	5684	13.4
	P values	**Variety**	**0.21**	**0.004**	**<0.001**	**0.001**	**<0.001**	**0.371**	**0.024**	**0.007**	**<0.001**	**<0.001**
		Fertilizer	**0.5**	**0.675**	**0.143**	**0.022**	**0.001**	**0.055**	**0.014**	**0.548**	**<0.001**	**0.738**
		Var x Fert	**0.644**	**0.361**	**0.012**	**0.226**	**0.49**	**0.968**	**0.225**	**0.282**	**0.988**	**0.351**
		CV%	**10**	**5**	**10**	**3**	**4**	**3**	**10**	**4**	**8**	**4**

Results from this study indicate that balanced fertilizer management approach could be a better option than the farmer practice of applying all nitrogen in spring. This is largely due to the fact that winter wheat requires adequate starter nitrogen during early days of establishment in fall and when it resumes development in spring. Continued field study would be necessary to effectively develop fertilizer management recommendations that winter wheat producers can use for their areas of production.

Effect of Residue Management on Growth, Yield and Quality of Soybean

Project duration: May 2019 – September 2020

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

Collaborators: Ramona Mohr and Aaron Glenn (AAFC-Brandon)

Results:

Manitoba's soybean industry has grown rapidly over the past decade. The introduction of short-season cultivars 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 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 on early-season temperature and moisture conditions and, in turn, on soybean establishment, growth, yield and quality. In 2019, early seeding increased yield at 2 of 3 sites, suggesting the potential benefit of early planting in a year like 2019 where spring frosts were not an issue, but where an early and cold fall delayed crop maturity and harvest. These results contrast with 2018 where planting date had no effect on yield. Residue management affected soybean yield only at Indian Head in 2019, with tall stubble enhancing yield in some cases, similar to the results at this site in 2018. These are preliminary results only from ongoing field trials.

Study 1: Effect of residue management and planting date on soybean (A. Glenn, C. Holzapfel, H. Abbas, R. Mohr)

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 to subplots. Residue treatments were imposed on wheat (Brandon, Carberry) or canaryseed (Indian Head) stubble in fall 2017 and 2018, and these plots were planted to soybean in 2018 and 2019, respectively. This will be repeated in 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. In 2019, soybean (R2, 00.3, 2375 CHU) was planted into residue treatments in early or late May (May 9, 10, 14 and May 29, 23, 30 at Brandon, Carberry and Indian Head, respectively). Preliminary analysis of the 2019 data indicated no date x residue management interactions for the data presented, therefore main effects of data and residue management are reported herein.

Dry early season conditions and a wet, cool fall with early snowfall contributed to challenging growing season conditions for soybean in 2019. While soil temperature at planting was significantly lower for the early than late planting date at all sites, soil temperatures for the early planting date were near or above the recommended 10 C (Fig. 1a). Residue management influenced soil temperature only at Brandon, with higher temperatures measured in short stubble (-straw) and tall stubble (+/- straw) than in short stubble (+straw) treatments (Fig. 1a). Soil moisture at planting varied among sites and planting dates (Fig. 1b). Soil moisture was higher for the early than late planting date at Indian Head with the opposite evident at Brandon. Residue management had no effect on soil moisture at planting at Brandon or Indian Head; however, soil moisture was lower in the tilled than all other treatments at Carberry.

In 2019, seeding date had a marked effect on days to emergence (DTE). Early seeding increased DTE by an average of 5 to 13 days depending on site whereas, in cases where differences in DTE due to residue management were observed, differences among treatments often averaged only about 1 day (data not presented). While planting date and residue management influenced plant stand at both Carberry and Indian Head, average plant stands met or exceeded the provincial recommendation of 40 plants/m2 regardless of treatment (Fig. 1c).

In 2019, early planting increased soybean yield at Brandon and Indian Head (Fig. 1d). These findings demonstrate the potential benefit of early planting in a year like 2019 in which spring frosts were not an issue, but where an early and cold fall delayed crop maturity and harvest. These results contrast with 2018 where planting date had no effect on yield. Residue management affected soybean yield only at the Indian Head site in 2019 (Fig. 1d). Tall stubble resulted in a higher yield than either short stubble (+straw) or tilled treatments, with tall stubble (-straw) also producing higher yields than either the burn or short stubble (-straw) treatments. Tall stubble also out-yielded burn and short stubble (-straw) treatments at this site in 2018. It is interesting to note that, although residue management did not have a statistically significant effect on yield at Brandon (P=0.08) or Carberry (P=0.12) in 2019, contrast analysis identified higher yields in stubble treatments where straw was removed. This appeared to be associated with differences in plant stand at Carberry but not at Brandon.

Treatment had no effect on seed quality (protein, oil, seed weight, test weight) at Brandon or Carberry, except for test weight at Brandon which was higher for early than late seeding. At Indian Head, however, test weight, seed weight and %oil were higher with early planting, and were also influenced by residue management (data not presented).

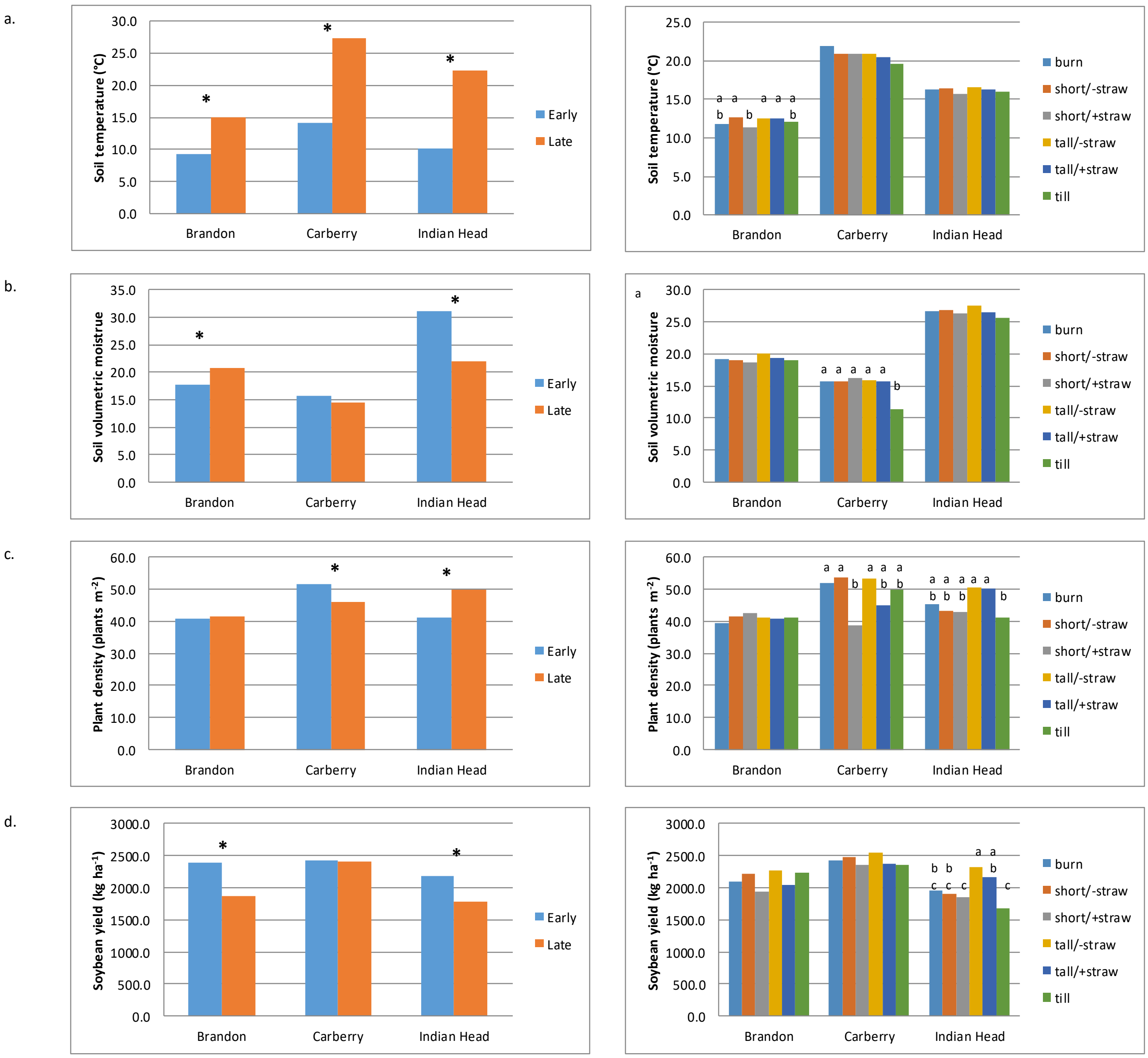


Figure 1. Effect of planting date (early vs late May) and preceding residue management (fall burn, short stubble with and without straw, tall stubble with and without straw, fall tillage) on soil temperature and moisture at soybean planting, and on soybean plant stand and yield, at Brandon, Carberry, and Indian Head. Reported values for planting date are averaged across residue management practices, and for residue management practices are averaged across planting dates. (*indicates that planting dates are significantly different within a given site. Residue management practices within a site that are denoted by the same letter are not significantly different from one another)

Fig 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 (D. Tomasiewicz, R. Mohr)

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. Beginning in January 2018, a series of controlled environment studies have been conducted annually for several months each year to assess the effect of temperature and seed characteristics on soybean germination and emergence. In each case, a completely randomized design with three or four replicates are employed, and a range of temperature treatments are assessed. The effect of various factors including soybean size, seedlot, and conditions under which soybeans were produced is being investigated, with studies underway currently.

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 (NDSU Extension Service 2010), 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.

Materials & Methods:

Experimental Design:	Split plot design with four replications
Entries:	12
Seeding:	May 11 (Date 1), May 25 (Date 2)
Harvest:	October 08

Treatments

Main plots: two planting dates of soybean (May 11; May 25)

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 with respect to soil test results. Herbicide were applied, when required.

Corn Variety Evaluation

Project duration: May 2020 – October 2020
Objectives: To develop and release early maturing cold tolerant corn inbreds.

Collaborators: Lana Reid Ph.D – AAFC Research Scientist Ottawa Research and Development Centre
Manitoba Corn Growers Association

Results:

This project is part of a long-term, multi-site study led by Lana Reid. Research findings will be made available by Lana Reid 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
Seeding	May 15, 2020
Harvest	October 07, 2020

Data collected	**Date collected**
% Emergence	Jun 01
Tasseling Date	Jul 06 – Aug 03
Silking Date	Jul 10 – Aug 21
Ear Formation	Jul 31 – Aug 28
Heights	Aug 03
Lodging	October 07, 2020
Yield	October 07, 2020
Moisture	October 07, 2020

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.

Corn Parent Evaluation Nurseries

Project duration	May 2020 – October 2020
Objectives	To develop and release early maturing cold tolerant corn inbreds.
Collaborators	Lana Reid Ph.D – AAFC Research Scientist Ottawa Research and Development Centre

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 Lana Reid. Research findings will be made available by Lana Reid and team.

Materials & Methods

Experimental Design	500 row observation nursery
Entries	500
Seeding	May 15, 2020
Harvest	October 07, 2020

Data collected	**Date collected**
% Emergence	Jun 01
Tasseling Date	Jul 06 – Aug 03
Silking Date	Jul 10 – Aug 21
Ear Formation	Jul 31 – Aug 28
Heights	Aug 03
Lodging	October 07, 2020
Yield	October 07, 2020
Moisture	October 07, 2020

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.

Corn Goss's Wilt Nurseries Evaluation

Project duration May 2020 – October 2020

Objectives Establishment of a Goss's Wilt nursery in MB.

Collaborators Lana Reid Ph.D – AAFC Research Scientist Ottawa Research and Development Centre

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," Holly Derksen, field crop pathologist with Manitoba Agriculture, Food and Rural Development (MARD), says.

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," Wilt Billing, DuPont Pioneer's area agronomist for central and eastern Manitoba, explains. "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. However, Billing and Derksen have not seen the systemic form in commercial corn fields in Manitoba. 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.

Billing notes, "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," Billing says. 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 in 2014 didn't favour the disease. Billing says, "In 2014, we found the disease in many fields in mid to late July. However, we had a dry spell during late July to early August, so the disease was really limited in its impact."

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, Billing advises, "When you're walking through your corn field, look for greyish brown lesions with water-soaked margins. 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'll see that black freckling. If conditions are damp, like a heavy dew in the early morning, you'll sometimes see a glossy sheen on the lesion."

Derksen notes fungicides are not effective for controlling Goss's wilt because it is a bacterial disease. She has two main recommendations for managing the disease: "One is to lengthen your crop rotation. However, that may not always be enough to prevent the disease if neighbouring fields have Goss's wilt. 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 Lana Reid. Research findings will be made available by Lana Reid and team.

Materials & Methods

Experimental Design	100 row observation nursery
Entries	100
Seeding	May 15, 2020
Harvest	October 07, 2020

Data collected	**Date collected**
% Emergence	Jun 01
Tasseling Date	Jul 06 – Aug 03
Silking Date	Jul 10 – Aug 21
Ear Formation	Jul 31 – Aug 28
Heights	Aug 03

The nursery was terminated on October 16 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.

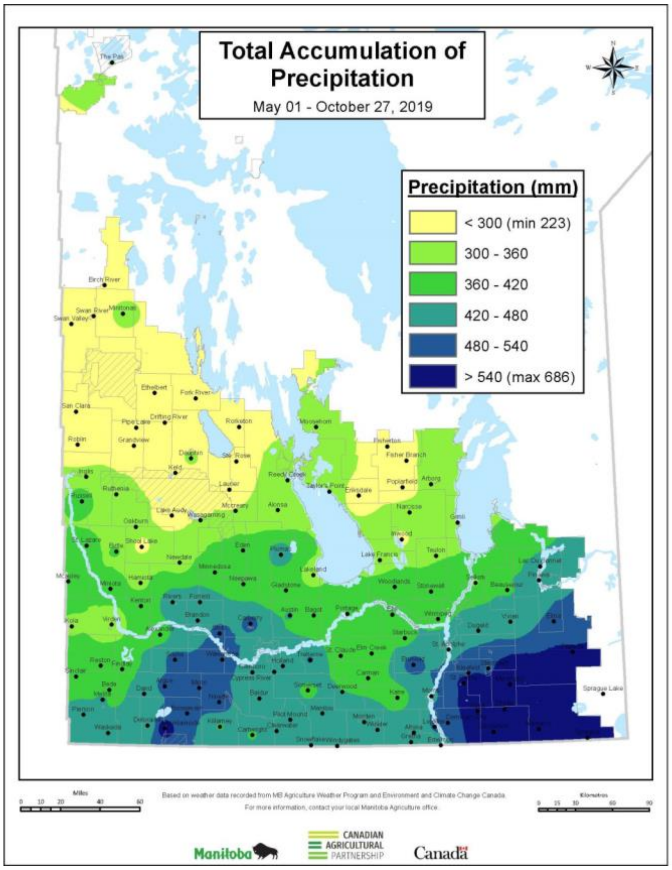
Sunflower Variety Performance Testing

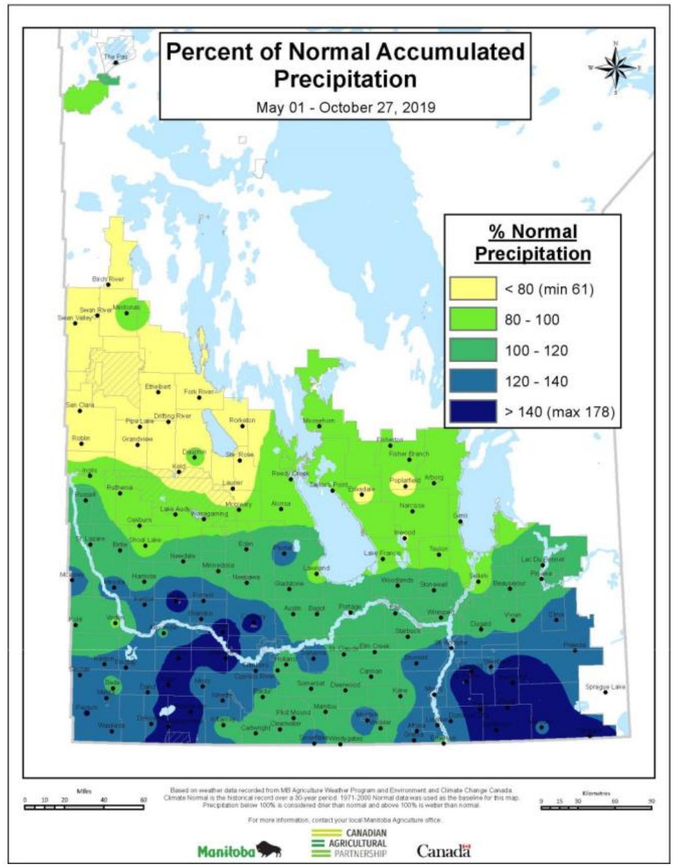
The Manitoba Sunflower Variety Performance Trials (VPT) were organized and conducted by the Manitoba Crop Alliance (MCA) in co-ordination with Manitoba Agriculture and Resource Development (MARD). 2020 was the 14th year that these trials have been coordinated and serve to continue as an important tool 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 2020, the MCC coordinated the VPTs at 4 locations within the province: Carberry, Elm Creek, Melita and Rossendale.

The 2020 growing season started off still dealing with the effects of a very wet fall in late 2019. Combined with cool spring weather, there was a slow melt. This resulted in crops being planted later than normal by about 1 week. Cool and dry conditions would continue through spring. At all the test sites the trials were sprayed with an insecticide for the presence of cutworms. The Carberry trials were lost due to heavy cutworm damage resulting in poor plant establishment. Dry conditions continued throughout the growing season for most of the testing sites. The presence of disease was low due to the drier conditions resulting in generally good seed quality after harvest. An early September frost in the southwestern part of the province may have affected the hybrids. There were generally good conditions for harvesting operations. Sunflower yields across the province were good to excellent in 2020.

The VPT trials and results are made possible with your continued support through the sunflower check-off levy. A 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 results.

Precipitation Data (mm)





Confectionary Sunflower Variety Performance Testing

Comments:

These varieties were tested and data donated by the National Sunflower Association of Canada Inc. (NSAC) 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.

Summary Table

		Genetic	Site	Yield	Maturity	Height	2019 Seed Sizing (%) [2]		
Company	Hybrid	Traits [1]	Years	% Check	(days to R9)	(inches)	>22/64	>20/64	<20/64
NuSeed America	6946 DMR	DM	25	100	0	0	41	30	26
NuSeed America	Panther DMR	DM	33	100	1	-3	55	26	14
Experimental lines being tested/proposed for registration in Canada									
NSAC	EX 43400	ExSun	2	82	-1	3	47	32	22
NSAC	EX 88647	ExSun	2	91	-3	3	70	23	7
	CHECK CHARACTERISTICS								
	6946 DMR		25	3195	121	68			
			site years	lb/ac	days	inches			

Site Comparisons:

	Carberry						
	Yield	Maturity*	2019 Seed Sizing (%) ²			Test Wt	
Hybrid	(lb/ac)	(days to R9)	>22/64	>20/64	<20/64	(lb/bu A)
6946 DMR	3289	129	39	40	21	25.4
Panther DMR	3875	131	49	40	11	26.8
Experimental lines being tested/proposed for registration in Canada						
EX 43400	2714	127	25	40	36	25.4
EX 88647	3407	125	54	35	11	24.1
Site Average (lb/ac)	3321	128				25.4
CV%	6.96					
Sign Diff	No					
LSD (0.05)	--					
Planting Date	14-May					
Desiccation Date	--					
Harvest Date	22-Oct					

	Dakota Plains					
	Yield	Maturity*	2019 Seed Sizing (%) [2]			Test Wt
Hybrid	(lb/ac)	(days to R9)	>22/64	>20/64	<20/64	(lb/bu A)
6946 DMR	3519	128	67	23	10	24.0
Panther DMR	3167	129	71	20	9	23.4
Experimental lines being tested/proposed for registration in Canada						
EX 43400	2898	128	69	23	7	24.0
EX 88647	2821	126	87	11	3	23.7
Site Average (lb/ac)	3101	128				23.8
CV%	9.46					
Sign Diff	No					
LSD (0.05)	--					
Planting Date	28-May					
Desiccation Date	--					
Harvest Date	19-Oct					

Oilseed Sunflower Variety Performance Testing

Comments:

These varieties were tested and data donated by the National Sunflower Association of Canada Inc.

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.

Summary Table

Company	Variety	Herbicide/ Disease Tolerance	Site Years	YIELD % check	Maturity (days to R9)	Height (inches)	% Oil	Oil Type	Test Weight
NuSeed Americas	N4HM354 DMR	CL/DM	12	104	-1	-2	47.9	NS	34.3
NuSeed Americas	Talon	ExSun	15	97	-2	-4	45.2	NS	29.7
DuPont Pioneer	P63HE60	ExSun / DM	12	96	-2	0	46.9	HO	33.2
DuPont Pioneer	P63ME70	ExSun / DM	17	100	0	0	47.8	NS	31.0
DuPont Pioneer	P63ME80	ExSun / DM	15	94	1	0	49.8	NS	32.4
Experimental lines being tested/proposed for registration in Canada									
NuSeed Americas	N4HE302	ExSun	6	88	-2	3	44.5	HO	30.7
NuSeed Americas	N5LM307	CL	2	103	0	-8	39.4	CO	30.7
	CHECK CHARACTERISTICS								
	P63ME70		17	3313	124	69			
			site years	lb/ac	days	inches			

1 Genetic traits include CL = Clearfield tolerance; ExSun = Express tolerance; DM = Downy Mildew Resistance.

Site Comparisons

	Carberry			
Hybrid	Yield (lb/ac)	Maturity* (days to R9)	Test Wt (lb/bu A)	Oil (%)
N4HM354 DMR	2203	128	34.9	41.9
Talon	2426	122	32.3	41.1
P63HE60	2148	125	33.2	40.0
P63ME70	2115	129	31.5	42.7
Experimental lines being tested/proposed for registration in Canada				
N4HE302	2212	133	32.3	41.4
N5LM307	2110	129	32.4	37.0
Site Average (lb/ac)	2202	128	32.8	40.7
CV%	8.9			
Sign Diff	No			
LSD (0.05)	--			
Planting Date	14-May			
Desiccation Date	--			
Harvest Date	22-Oct			

	Dakota Plains			
	Yield	Maturity*	Test Wt	Oil
Hybrid	(lb/ac)	(days to R9)	(lb/bu A)	(%)
N4HM354 DMR	3179	127	34.8	47.2
Talon	3302	128	29.8	44.8
P63HE60	3588	128	34.6	46.9
P63ME70	3374	128	31.3	48.2
Experimental lines being tested/proposed for registration in Canada				
N4HE302	3406	130	31.5	46.5
N5LM307	3549	128	29.1	40.7
Site Average (lb/ac)	3400	128	31.9	45.7
CV%	5.7			
Sign Diff	No			
LSD (0.05)	--			
Planting Date	28-May			
Desiccation Date	--			
Harvest Date	19-Oct			

*Physiological maturity for sunflowers is R9, where the bracts on the head are almost completely brown.

At Carberry, heads were clipped and dried artificially for stationary combining.

Efficacy of Herbicides in Flax

Project duration: 2020

Collaborators: Saskatchewan Crop Development Centre, Helen Booker

Objectives

- To compare efficacy of standard (Authority) treatments to experimental (Armezon) treatments on flax and weeds.
- To observe any safety concerns with herbicide combinations

Background

Flax (*Linum usitatissimum*) is an important crop known for its value in food and fibre industrial markets around the world. However, flax has a low competitive ability with weeds compared to other crops is recommended to be grown on relatively weed free fields. Various weed management strategies that include; competitive varieties, early seeding, increased seeding rates and the use of pre and post emergence herbicides can help to effectively control weeds and reduce yield loss than employing one control factor alone (Kurtenbach et al., 2019). Preemergence weed control is crucial in flax to reduce yield loss since flax is a weak competitor with weeds (Berglund and Zollinger, 2007). Post emergence weed control, if done soon after weed emergence to small weeds and flax seedlings, usually results in better control and allow more time for flax recovery from possible herbicide injury than when herbicides are applied to larger weeds and flax later on in the growing season. There is currently a challenge in herbicide options for flax as a result of herbicide resistance. Furthermore, concerns for herbicide injury on flax with the use of different herbicide combinations need to be examined. There is need to investigate possible alternative options, combinations and timing of application for control of both broad leaf weeds and grasses. Armezon® herbicide, which is classified as Group 27, is an effective tank-mix option that is currently registered as a post emergence herbicide for control tough broad leaf weeds and grasses in corn and has potential for use in flax for control of Group 1 resistant grasses due to its suppression effect on grasses (Table 7.0a). Currently, the herbicide is not registered for use in flax but extensive field trials can provide for a pathway to registration and this will benefit flax producers. Therefore, this study seeks to evaluate several herbicides including Authority, Mextrol, Koril, Select and experimental Armezon used alone or tank mixed with compatible herbicides in flax in order to effectively control resistant weeds and reduce yield losses as a result. The study also seeks to evaluate any safety concerns with the use of different herbicide mixes in flax.

Table 7.0a List of Weeds controlled by Armezon, Authority, Mextrol, Koril and Select

Weeds Controlled	Herbicide Name				
	Armezon	Authority	Mextrol	Koril	Select
	Herbicide Group				
	27	14	4 + 6	6	1
Barnyard Grass	S				C
Foxtail Green	S				C
Foxtail Yellow	S				C
Quackgrass					C
Volunteer Cereals					C
Wild Oats					C
Wild Buckwheat		C	C	C	
Night-flowering Catchfly			C		
Chickweed	S				
Cleavers		S			
Cocklebur			C	C	
Dandelion					
Flixweed			C		
Hemp-nettle					
Kochia	C	C	C	C	
Lambsquarters	S	C	C	C	
Round leaved Mallow					
Wild Mustard	C		C	C	
Red Root Pigweed	C	C	S	C	
Russian Thistle	S		C	C	
Shepherds Purse			C		
Annual Smartweed	S		C	C	
P. Sow thistle			TG		
Stinkweed			C	C	
Canada Thistle			TG		
Vol. Canola	C		C	C	

C – Control

S – Suppress

TG – Top growth

Adapted from 2019 Manitoba Crop Protection Guide

Materials and Methods

The trial was conducted at Melita, Roblin and Arborg in Manitoba, as randomized complete block design with 9 herbicide treatments replicated 3 times. Herbicide treatments included; UTC (no weeding), UTC (hand weeded), 0.1 L ac^{-1} Authority applied before seeding, 0.015 L ac^{-1} Armezon post emergence + Merge adjuvant, Authority before seeding and Armezon post emergence, Authority before seeding and 0.5 L ac^{-1} Mextrol 450 + 0.1 L ac^{-1} Select + Amigo adjuvant at 2-4 inches crop height, Authority before seeding and 0.49 L ac^{-1} Bromoxynil + Select at 2-4 inches crop height, Armezon + Mextrol + Select + Amigo adjuvant post emergence, and Armezon + Bromoxynil + Select post emergence. Herbicide treatments were applied using a calibrated CO_2 backpack sprayer. Herbicide formulation and treatment description is summarized in Table 7.0b. At Melita, all plots were seeded using a 6 row dual knife Seed hawk air seeder with rows spaced at 0.24 m at a depth of

0.5” on the 8th of May 2020. All fertilizer requirements were achieved during seeding by side banding with the same implement at 108-35-20-8-2 (N-P-K-S-Zn) actual lb ac^{-1}. A burnoff application with 0.5 L ac^{-1} Roundup and 0.015 L ac^{-1} Aim was done over all plots after seeding and other herbicide treatments were applied as per protocol. Reglone was applied to all plots as a desiccant and control late weeds one week prior to harvesting. Ratings for phytotoxicity on flax were taken at 2 and 4 weeks after treatment while herbicide injury on weeds was only assessed at 2 weeks after treatment. Additional data were collected for flax height at 2 weeks after treatment, flax count at 4 weeks after treatment, top weed species names, weed density at flowering, seed yield and moisture content.

Table 7.0b Herbicide formulation and treatment description for flax herbicide trial in 2020

Trade name	Chemical	App. Rate g a.i./L	Field Rate ml/ac	Water Vol. Rate gal/ac	Treatment
Armezon	Topramezone	336	15	10	4,5,8,9
Merge	Adjuvant		0.25L/100L	10	3,4
Authority	Sulfentrazone	480	100	10	3,5,6,7
Mextrol	MCPA + Bromoxynil	225 + 225	500	10	6,8
Koril	Bromoxynil	235	490	10	7,9
Select	Clethodim	252	100	10	6,7,9,9
Amigo	Surfactant		0.5L/100L	10	6,8

Treatments

1. UTC (no weeding)
2. UTC (Hand weeded check)
3. Authority (pre-seed) 100 ml/ac
4. Armezon (in crop) 15 ml/ac + Merge @ 0.25L/100L 10 gpa
5. Authority (pre-seed) + Armezon (in crop)
6. Authority (pre-seed) + (Mextrol 450 0.5L/ac + Select 100 ml/ac + Amigo in crop) 2-4” stage
7. Authority (pre-seed) + (Bromoxynil 0.49L/ac [Koril] + Select) 2-4” stage
8. Armezon + (Mextrol 450 + Select + Amigo) 9. Armezon + (Bromoxynil + Select)

General plot management differed from site to site in 2020. Summary of site description, agronomy information, spray information and assessment dates are presented in Tables 7.0c and d.

Table 7.0c: Characterization and Agronomy information for Arborg, Melita and Roblin in 2020

Description	Site		
	Arborg	Melita	Roblin
Research Group	**PESAI**	**WADO**	**PCDF**
Legal Land Location	NW 16-22-2 E1	SE 26-3-27 W1	NE 20-25-28 W1
Soil Series	Fyala heavy clay	Newstead Loam	Erickson clay loam
Stubble	wheat	spring wheat	silage barley
Field Prep	no till	harrowed, no till	harrowed, no till
Soil Test N-P-K (lbs/ac)	112-22-380	35-18-900	66-92-1224
Fertilizer App N-P-K-S-Zn (lbs/ac)	50(B)-20 (SB)-0	108-35-20-8-2 Zn (SB)	54-10-0 (SB)
Seeder Type	disc drill	Knife drill	disc drill
Rows and Spacing (inches)	8 (7.5)	6 (9.5)	5 (9.5)
Seed Date	21-May	08-May	27-May
Seed Depth	0.75"	0.5"	0.5"
Fungicide/Insecticides	NA	NA	NA
Desiccation Product	Reglone	Reglone	Reglone
Harvest Date	08-Sep	24-Aug	04-Sep
Growing Season Meteorology information (Seed Date - Harvest Date)			
GGDs actual Base 5*C	1403	1380	1157
GGDs normal	1242	1313	1141
Precipitation actual	195	168	225
Precipitation normal	252	272	215

GDD – growing degree days, B – broadcast, SB – side banded, NA – not applicable

Table 7.0d Spraying information for Arborg, Melita and Roblin site in 2020

Spraying Information	Site		
	Arborg	Melita	Roblin
Spray Tip	TeeJet AI80015	TeeJet AI8002	BFS Orange AI 01
Water Volume (imp. Gal/ac)	10	10	10
Burnoff	NA	08-May	29-May
Burnoff Product (Rate)	NA	Roundup (0.5 L/ac) + Aim (15 ml/ac)	Roundup (0.64L/ac)
Pre-Emerg app Date	22-May	08-May	29-May
In-crop app Date	13-Jun	04-Jun	25-Jun
Assessments:			
Crop Injury 2WAA	26-Jun	18-Jun	08-Jul
4WAA	13-Jul	02-Jul	22-Jul
Weed Injury Date 2WAA	26-Jun	26-Jun	08-Jul
Weed Count Date at flower	13-Jul	02-Jul	27-Jul
Crop Height Date 2WAA	13-Jul	20-Jul	22-Jul

Results and discussion

Weed injury percentage was significantly (P=0.001) different among treatments at 2 weeks after application of weed control alternatives at Roblin (Table 7.0e). Application of Authority as a pre-seed injured 73% of the sampled weeds compared to 43% observed for a tank mix of Armezon + Bromoxynil + Select applied in-crop. High efficacy of Authority applied prior to seeding could have been as a result of activation by rainfall following herbicide application. All other herbicide options, including Armezon applied in-crop alone were not effective, with only 5 to 8% weed injury at 2 WAA and were not significantly different. At 2 WAA of treatments, flax injury (47%) was significantly ($P<0.001$) high when Armezon + Mextrol + Select (treatment 8) were applied post emergence in a single tank mix. All other options resulted in between 0 and 3% flax injury and could be considered to be safe options for the crop in this regard. Further observations made at 4 WAA of the treatment materials found significant ($P=0.014$) recovery of flax from 47% to 22% for treatment 8 while other alternatives ranged between 0 and 1%. Crop height measurements at 2 WAA of treatments, again, showed that a combination of Armezon + Mextrol + Select applied to flax resulted in significantly ($P<0.001$) lower height (16 cm) compared to other herbicide options. Although weed injury was only 5% and comparable to 7 other herbicide treatment at 2 WAA, application of Armezon + Mextrol + Select reduced crop height at the same observation period. This might give an indication of negative impact that this combination might have, such as influencing flax development and ultimate yield in the long term. On the other hand, a tank mix of Armezon + Bromoxynil + Select resulted in crop height that was not significantly different from treatments 1, 3, 4 and 5 and is acceptable compared to treatment 8 (Table 7.0e). Therefore, Armezon + Bromoxynil + Select applied in-crop and Authority applied pre-seed could be better options when considering herbicide injury percentages and crop height impact. There were no significant yield differences observed regardless of herbicide treatment applied but numerically, in-crop application with Armezon achieved the highest seed yield of 4041 kg ha^{-1}.

Overall high coefficient of variation for weed injury was as a result of treatment 9 (Armezon + Bromoxynil + Select) and 3 (Authority pre-seed), which had lots of variation. Flax emergence lower than expected due to excessively dry conditions at crop establishment. The site was seeded on the 27th of May but only received about 5.1 mm of rainfall between the 26th of May and the 5th of June (web43.gov.mb.ca/Climate/DailyReport.aspx).

Table 7.0e GLM Analysis of variance for weed injury, weed density, flax emergence, crop injury, crop height and crop yield at Roblin in 2020

Treatment	Weed Injury (%) 2WAA	Weed Density ppms at flower	Flax Emergence ppms	Crop Injury (%)		Crop Height (cm) 2WAA	Crop Yield (kg/ha)
				2WAA	4WAA		
1. UTC (no weeding)	*	51	155	*	*	39abc	3097
2. UTC (Hand weeded check)	*	*	149	*	*	44a	1939
3. Authority (pre-seed)	73a	53	134	0b	0b	40ab	2976
4. Armezon (in crop)	8c	72	136	0b	0b	35bcd	4041
5. Authority + Armezon	5c	52	158	3b	0b	37abcd	3141
6. Authority + [Mextrol + Select (in crop)]	5c	60	150	3b	0b	31cd	3110
7. Authority + [Bromoxynil + Select (in crop)]	5c	41	157	2b	0b	30d	3013
8. Armezon + Mextrol + Select	5c	68	146	47a	22a	16e	2418
9. Armezon + Bromoxynil + Select	43b	62	180	3b	1b	33bcd	2864
P value (treatment)	**0.001**	0.573	0.794	**<0.001**	**0.014**	**<0.001**	0.320
Coefficient of Variation	33	10	21	85.8	196.2	14	29
MSE	2.351	0.03	1001.7	0.0056	0.005	24.002	759257
GM	4.671	1.77	150	0	0.034	34	2954

At Melita, there were significantly (P=0.005) more weed injury percentages with herbicide combinations than single herbicide treatments (Table 7.0f). A combination of Armezon + Bromoxynil + Select caused higher weed injury percentages compared to other herbicide treatments. Higher weed injury percentages for combination treatments involving Authority were probably as a result of adequate rainfall for herbicide activation following application of treatments. Herbicide combinations also caused significant (P=0.004) reduction in weed densities compared to Armezon or Authority applied alone. Overall, weed density was lower at Melita compared to Arborg and Roblin, which could be due to site specific differences. It is also important to note that although Armezon (in-crop) application alone caused little injury on weeds and flax than when applied in combination with other herbicides at 2WAA, it did not have a negative impact on flax height compared to combination herbicides. Crop injury recovery was observed at 4 WAA of combination herbicides involving Armezon, which explains the ability of flax to recover in the short term after herbicide treatment. Flax emergence was not significantly different at Melita but the plant stand was more than 300% better than Roblin across all herbicide treatments. This was probably due to differences in soil moisture at crop establishment between the two sites. There were no significant differences in flax seed yield across all treatments and the yields were lower than at Roblin site overall.

Table 7.0f GLM Analysis of variance for weed injury, weed density, flax emergence, crop injury, crop height and crop yield at Melita in 2020

Treatment	Weed Injury (%) 2WAA	Weed Density ppms at flower	Flax Emergence ppms	Crop Injury (%)		Crop Height (cm) 2WAA	Crop Yield (kg/ha)
				2WAA	4WAA		
1. UTC (no weeding)	*	23a	541			37ab	2473
2. UTC (Hand weeded check)	*	*	537			36ab	2508
3. Authority (pre-seed)	27bc	13ab	520	0d	0b	37ab	2512
4. Armezon (in crop)	7c	21a	567	0d	0b	37ab	2376
5. Authority + Armezon	45bc	6bc	473	10cd	0b	34ab	2762
6. Authority + [Mextrol + Select (in crop)]	78ab	4c	500	20bc	0b	31bc	2490
7. Authority + [Bromoxynil + Select (in crop)]	92a	4c	537	10cd	2b	32abc	2603
8. Armezon + Mextrol + Select	72ab	4c	506	43a	8a	26cd	2596
9. Armezon + Bromoxynil + Select	93a	5c	524	37ab	10a	24d	2526
P value (treatment)	**0.005**	**0.003**	0.627	**0.001**	**0.008**	**0.002**	0.699
Coefficient of Variation	28	26	10	68.4	140.7	11	9
MSE	4.257	0.07	2881	0.0102	0.001	14.2	50518
GM	7.467	1	522	0.15	0.02	33	2540

Weed injury percentage was significantly (P<0.001) high among all combination treatments including Armezon applied in-crop and ranged from 60% to 87% compared with Authority (pre-seed) that only caused 10% injury (Table 7.0g). Treatments 6, 8 and 9 had best weed control with 80, 87 and 85% weed injury at 2 WAA, respectively. It is possible that efficacy of Authority was low as a result of low rainfall within 2 of application of the herbicide. Authority applications require a moderate rainfall of between 10 to 20 mm or equivalent irrigation within 10 to 14 days for proper activation. During the 2-week period from application of Authority, Arborg site only received 3.8 mm rainfall (https://web43.gov.mb.ca/Climate), which was not adequate for activation of the herbicide and could explain the reason why there was only 10% weed injury. Weed density measured at flowering was significantly (P=0.037) different at Arborg. The ideal herbicide option was considered to be the one with the lowest weed density after herbicide treatment relative to other options under consideration. In this regard, weed density was significantly lower in Authority + {Mextrol + Select (in-crop)} (11 ppms) and Armezon + Mextrol + Select (15 ppms). Similar pattern in crop injury recovery as with Melita and Roblin was observed at Arborg with initially high injury percentages at 2 WAA followed by significant (P=0.007) recovery at 4 WAA. Crop height was also significantly (P<0.001) reduced in combination herbicide options especially treatment 8 and 9 that included Armezon + Mextrol + Select and Armezon + Bromoxynil + Select, respectively. Flax plants in these treatments were more than 50% shorter in height compared to the non-weeded check at 2 WAA. Perhaps Bromoxynil and Mextrol components influenced the reduction in flax height. Flax seed yield was significantly ($P<0.001$) high in combination herbicides that had Armezon in the mixture and was comparable to the hand weeded check. Overall, flax yield ranged from 1889 kg ha^{-1} to 3553 kg ha^{-1}, with the lowest being the non-weeded check as expected. Although it caused significantly high percentage in weed injury during the first 2 WAA, the MCPA component in Mextrol with Armezon + Mextrol +Select appeared to have reduced flax seed yield. Probably application rates of the Mextrol component might need to be revised so as to reduce the impact on yield but not compromising on weed control.

Table 7.0g GLM Analysis of variance for weed injury, weed density, flax emergence, crop injury, crop height and crop yield at Arborg in 2020

Treatment	Weed Injury (%) 2WAA	Weed Density ppms at flower	Flax Emergence ppms	Crop Injury (%)		Crop Height (cm) 2WAA	Crop Yield (kg/ha)
				2WAA	4WAA		
1. UTC (no weeding)	*	96a	264	*	*	42ab	1889e
2. UTC (Hand weeded check)	*	*	313	*	*	47a	3553a
3. Authority (pre-seed)	10b	93ab	293	8	12ab	35bc	2217de
4. Armezon (in crop)	60a	109a	304	13	13ab	20d	2574cd
5. Authority + Armezon	67a	104ab	317	13	7c	32c	3198ab
6. Authority + [Mextrol + Select (in crop)]	80a	11c	279	12	6c	46a	3007bc
7. Authority + [Bromoxynil + Select (in crop)]	78a	68abc	315	17	8bc	22d	3052b
8. Armezon + Mextrol + Select	87a	15bc	315	28	15a	17d	2944bc
9. Armezon + Bromoxynil + Select	85a	70a	277	23	13ab	19d	3116ab
P value (treatment)	**<0.001**	**0.037**	0.29	0.242	**0.007**	**<0.001**	**<0.001**
Coefficient of Variation	12	17	10	15.2	25.7	13	10
MSE (mean square error) for CV calculations	0.946	0.104	876.200	0.010	0.001	18.620	75721.000
GM	8.061	1.839	300.306	0.645	0.100	32.360	2813.144

A combined site analysis conducted to determine performance of herbicide treatments across different environments found no significant differences in efficacy on weed injury, weed density at flowering stage and flax emergence. However, based on numerical figures available, Armezon + Bromoxynil + Select option caused the highest percentage in weed injury (74%) while other options ranged from 25 to 58% (Table 7.0h). Crop injury at 2 WAA varied significantly (P=0.003) and application of Armezon (pre-seed) + Mextrol + Select (in-crop) caused the highest flax injury (39%) while other herbicide options ranged from 3 to 21%. At 4 WAA there were significant (P=0.023) differences in flax injury as observed at individual site analysis and there were also significant recoveries from herbicide injury within the 2-week period from the initial observation. The impact of treatments 8 and 9 were not significantly different on crop injury at 4 WAA. Height of flax was significantly (P=0.004) different due to different herbicide options applied. Treatments 7, 8 and 9 resulted in significantly shortened flax plants at 2 WAA and the heights were 28, 20 and 25 cm, respectively, compared with hand weeded check that had 42 cm at the same observation period. There were also significant treatment x site interactions in flax plant height (P=0.007), weed density (P=0.015) at 2 WAA and crop yield (P=0.048). Differences in site characterization may have influenced results of these responses to different herbicide options available in this study. Selection of herbicide options to use will likely be based on their performance in a specific geographical area.

Table 7.0h GLM Combined (Melita, Arborg and Roblin) Analysis of variance for weed injury, weed density, flax emergence, crop injury, crop height and crop yield in 2020

Treatment	Weed Injury (%) 2WAA	Weed Density ppm at flower	Flax Emergence ppms	Crop Injury (%)		Crop Height (cm) 2WAA	Crop Yield kg/ha
				2WAA	4WAA		
1. UTC (no weeding)	*	57	320	*	*	39ab	2486
2. UTC (Hand weeded check)	*	*	333	*	*	42a	2667
3. Authority (pre-seed)	37	53	315	3c	4b	37abc	2568
4. Armezon (in crop)	25	67	336	4c	4b	31bcd	2997
5. Authority + Armezon	39	54	316	9bc	2b	34abcd	3034
6. Authority + Mextrol + Select (in crop)	54	25	309	12bc	2b	36abc	2869
7. Authority (pre-seed) + Bromoxynil + Select (in crop)	58	38	336	9bc	3b	28cde	2889
8. Armezon (pre-seed) + Mextrol + Select (in crop)	54	29	322	39a	15a	20e	2653
9. Armezon + Bromoxynil + Select (in crop)	74	46	327	21b	8ab	25de	2835
P value (treatment)	0.647	0.058	0.821	**0.003**	**0.023**	**0.004**	0.876
P value (Site)	0.22	0.202	0.159	0.291	0.208	<0.001	0.392
P value (Site x Treatment)	**0.015**	0.075	0.481	0.056	0.082	0.007	**0.048**

Weed species composition differed across the 3 sites under study in 2020 (Table 7.0i). Arborg had predominantly red root pig weed in treatments 1, 2, 4 and 8 while lambsquarters was only present in treatment 1 and 2. At Melita, biennial wormwood was predominant in treatments 1, 3, 4 and 6 while volunteer wheat appeared in more than 50% of the treatments. At Roblin, volunteer canola was predominant in all treatments followed by green foxtail.

Table 7.0i Summary of four major weeds (ranked as most to least) by site after herbicide treatment at flower stage in 2020

Treatment	Site		
	Arborg	Melita	Roblin
1	RRP> C> D> LQ	BW> D> VW> CT	C> GF> LQ> SP
2	RRP> D> C> LQ	D>W	C> GF> LQ> D
3	WB> D	BW> VW> WB> K	C> GF
4	RRP> C> WB> D	BW> D> WB> VW	C> GF
5	D> WB> RRP	WB> CT> VC> BW	C> GF> D
6	C> D> RRP> WB	BW> VW> WO> VW	C> GF> D
7	D	D> VW> RRP> BW	C> GF> SP
8	RRP> C> D	WB> BW	C> GF> LQ

Key

RRP – Red root pig weed, C – volunteer canola, D – Dandelion, WB – Wild Buckwheat, LQ – Lambsquarters, BW – Biennial Wormwood, WO – Wild Oat, K – Kochia, VW – Volunteer Wheat, CT – Canadian Thistle, GF – Green foxtail, SP – Shepherd's purse

Conclusions

Interestingly there were no flax injuries with Authority + Mextrol option but Armezon in combination with Mextrol caused injuries. Based on these preliminary findings, this combination should be avoided in real farm situations unless if further studies with reduced applications rates of Mextrol can prove otherwise. Armezon on its own did not seem to show crop injury, but it stunted the height of flax, which could reduce seed yield. Arborg was the only site that showed yield loss based on herbicide use in general. At this site, Armezon showed yield loss both in sole use, and in combination with Mextrol. The study will be conducted again in 2021 before recommendations can be made available for registration of Armezon in flax. There might be need to consider reducing Mextrol application rates when used in combination with Armezon in order to address crop injury concerns.

Multi-Crop Intercrop trial (Pea-Oats-Canola-Wheat-Flax-Mustard)

Project duration: 2019-2021

Collaborators: Manitoba Pulse & Soybean Growers Association - Daryl Domitruk, PCDF-Roblin, WADO-Melita

Objectives

- Evaluate agronomic performance of peas in a monocrop or when intercropped with oats, canola, spring wheat, flax or mustard

Background

Choice of an intercropping system depends on many factors including: weather, machinery available for seeding, harvesting and separation of seed, economics and compatibility of the crops involved. Many organic agriculture farmers have resorted to various intercropping systems with the aim of addressing weed and disease pressure, which often inhibits organic systems under monoculture situations (Pridham and Entz, 2007). Scientists have been advocating for ways to counteract effects of climate change. Intercropping systems can be one of the ways that can help address climate change in some ways such as biological control of insect pests, weeds and diseases. Biological control allows for less use of synthetic chemicals hence addressing the chemical resistance issues. Another benefit of intercropping is improving soil health at low cost considering residual nitrogen if a legume is included. In other studies, pea-wheat intercropping systems have been shown to be efficient in the use of nitrogen due to their spatial self-regulating dynamics, which allows pea to improve its interspecific competitive ability in fields with lower soil nitrogen and vice versa for wheat (Andersen et al., 2004 and Ghaley et al., 2005). This enables future options to reduce synthetic nitrogen inputs and negative environmental impacts of crop production. Compared to pea sole crop, pea-oats intercrop results in reduced pea lodging because of the support provided by oats to the pea crop, this also helps reduce harvesting difficulties and increase economic returns (Kontturi et al., 2010). This study evaluated various intercrop combinations that can be utilized by producers in different areas of production.

Materials and Methods

The trials were established at Reston, Melita and Roblin in 2020. Soil tests were conducted to determine nutrient status before seeding at all sites (Table 24(I)). A randomized complete block design with 11 treatments and 4 replicates was used at each site. Reston site was seeded on May 15th then reseeded on the 29th due to severe damage by flea beetles while Melita site was seeded on May 8th at a depth of 0.75”. Fertilizer was applied together with the inoculant during seeding at 10-35-20-8-2 (N-P-K-S-Zn) lb ac^{-1} at Reston and 9-35-20-8-2 (N-P-K-S-Zn) lb ac^{-1} at Melita. Differences in N application rates was due to differences in soil test results at both sites. Reston and Melita received 0.5 L ac^{-1} Roundup + 0.015 L ac^{-1} Aim, 0.08 L ac^{-1} Authority + 0.65 L ac^{-1} Rival in flax, pea and mustard, and 0.65 L ac^{-1} Rival in canola plots soon after seeding to burnoff weeds. Additional herbicide application was done as post emergence control with 17.3 g ac^{-1} Odyssey in pea-canola and peas, 0.1 L ac^{-1} Arrow in pea-flax-mustard, 0.91 L ac^{-1} Basagran in wheat and flax-pea, and 0.1 L ac^{-}

[1] Select in all treatments except cereals at Melita. At Reston, post emergence herbicides applied were 0.91 L ac^{-1} Basagran tank mixed with 0.1 L ac^{-1} Arrow in flax or flax-pea, 17.3g Odyssey + 0.1L ac^{-1} Arrow in pea or pea-canola, 0.5 L ac^{-1} Axial + 0.283 L ac^{-1} in wheat or wheat-pea and 8 g ac^{-1} Muster + 0.2 L ac^{-1} Assure II + 0.5% Prosurf in canola. Flea beetles were controlled initially at V1 stage using 0.063 L ac^{-1} Pounce followed up by a second application at Melita while Reston required three applications of the same product to effectively control the insect pests. Desiccant products applied at Reston before harvest were 0.65 L ac^{-1} Reglone + 0.5 L ac^{-1} + 0.5% v/v LI700 surfactant + 0.5 L ac^{-1} Roundup ensuring spray volume of 20 gal ac^{-1} while 0.5 L ac^{-1} Roundup + 0.042 L ac^{-1} Heat LQ was applied at Melita. Summary of site description and agronomy as well as weather information are presented in Table 24(II). Various data were collected and these included plant counts at emergence and flowering, weed counts at flowering, flowering date, grain yield, percentage of pea splits, percentage of pod shatter, test weight and protein content. Disease severity data collected was for mycospharella, powdery mildew, rust, sclerotinia and fusarium wilt. Data were analyzed using Minitab 18 and means were separated using Fisher's LSD at the 5% significance level.

Table 24(I): Soil test results and nutrients applied by site in 2020

Soil Test:

Nutrient Location	N kg ha^{-1}	P ppm	K ppm	S kg ha^{-1}	Zn ppm	Organic Matter (%)	pH
Melita	38	7	327	81	0.71	2.8	7.9
Reston	77	18	224	404	1.23	4.8	7.3
Roblin	82	65	649	168	N/A	4.6	7.8

Applied:

Nutrient	N	P	K	S	Zn
Location	kg ha^{-1}				
Melita	10	39	22	9	2
Reston	10	39	22	9	2
Roblin	3	22	0	0	0

Table 24(II) Site characterization and agronomic description in 2020

Location	Reston, MB	Melita, MB	Roblin, MB
Legal Land Location	SE 11-7-27 W1	SE 26-3-27 W1	NE 20-25-28 W1
Soil Series	Ryerson Loam	Newstead Loam	Erickson Clay Loam
Previous Crop	RR Canola	Spring wheat	Silage Barley
Field Preparation	Harrowed, No-till	Harrowed, No-till	Harrowed, No-till
Pre-Emergent Herbicides	Glyphosate all, Authority + Rival on Flax Pea Mustard; Rival in Canola plots after seeding	Glyphosate all, Authority + Rival on Flax Pea Mustard; Rival in Canola plots after seeding	Glyphosate
Soil Moisture at Seeding	Good	Excellent	Excellent
Seed Date	May/29	May/08	May/19
Seed Depth (inch)	0.75	0.75	0.75
Herbicides	Basagran, Arrow, Odyssey, Axial, Muster + Assure ll	Odyssey, Arrow, Basagran	None used
Insecticides	Pounce x 3 - flea beetles	Pounce x 2 -flea beetles	None
Desiccation	Reglone-August 25	Roundup- August 10	Reglone
Harvest Date	Aug/31	Aug/19	Sep/24
Combine Settings			
Rotor	800	800	800
cleaning fan	930	930	930
rotor-concave space	10 mm (3 mm flax)	10 mm (3 mm flax)	10 mm
Growing Season Report (May 1 - Aug 31, 2020)			
Precipitation (mm)	211	166	239
Normal (mm)	259	262	265
Growing Degree Days	1270	1303	1349
Normal GDDs	1248	1249	1302

Results and Discussion

Peas intercropped with canola yielded significantly (P<0.001) more grain resulting also in significantly higher partial pea LER (P<0.001) at 1.19 and higher TLER (P<0.0001) at 2.01 compared to other intercrop options at Reston. Similar trends were observed in 2019. Peas intercropped with flax resulted in significantly low grain yield of 101 kg ha^{-1} and low partial and TLER at the same site (Table 24a). In 2020, Reston yields were markedly low owing to low seasonal rainfall compared to normal, presence of diseases as discussed in the Pea-Mustard-Canola study (Section 25.0) and reseeding on the 29th of May as a result of severe crop damage by flea beetles. Contrasting results were obtained from Melita, with the highest partial pea yield of 3072 kg ha^{-1} obtained from a flax intercrop but this was not significantly different from pea yield obtained from mustard (3027 kg ha^{-1}) or canola (2745 kg ha^{-1}) intercrops. Pea yield from oat intercrop was the lowest at 1501 kg ha^{-1}, more than 100% lower than pea-mustard intercrop option (Table 24b). Partial pea land equivalence ratio followed the same pattern as yield with pea-flax, pea-canola and pea-mustard having 0.62, 0.55 and 0.61, respectively. Just like in 2019, TLER for pea-mustard (1.30) intercrop was not significantly different from other treatments except pea-flax and pea-wheat intercrops which had 1.07 (P=0.001)

(Table 24b). Results from Roblin in Table 24c, show significant (P=0.001) differences in partial pea intercrop yield. There appeared to be significant pea yield benefits for intercrops involving canola or mustard compared to oats, which recorded pea yield reduction of 1567 kg ha^{-1} compared to pea yield in the canola option. This was a significant shift from 2019, where no significant differences where observed among different intercrop combinations. Partial pea LER was significantly higher (P=0.001) in pea-canola (0.79), pea-flax (0.54) and pea-mustard (0.58) compared to pea-flax intercrop which had 0.31. Overall, TLER for intercrops at Roblin was lower than Melita and Reston in 2020 (Table 24 a, b and c). In 2020, there were no significant differences observed in final crop emergence or weed biomass at all locations (Table 24 d, e, f).

There were no significant differences in split peas obtained from different intercrop options at all locations based on a 500g pea sample. Throughout all intercropping options, split peas were estimated at 1 to 2.5% for each sample selected in 2020. Protein content of peas was not significantly different at either Melita or Reston and ranged from 23.6 to 24.5% at both locations. However, there were significant (P=0.035) differences in pea protein content in pea sole crop (23.8%) compared to pea-oat intercrop (22.7%) at Roblin during the 2020 season (Table 24g). All other intercrop options were not significantly different from pea sole crop.

Significant differences were observed in net revenue realized from different pea intercrop options at all locations. Notable at Reston was the negative net revenue of -$282 for pea sole crop while significantly (P<0.001) higher revenues were obtained from pea-mustard ($713) and pea-oat ($633). This suggests same benefits in revenue when a producer decides to include either mustard or oats in their intercropping system compared to pea alone which generates a net loss. Inclusion of flax, wheat or canola generates significantly less net revenue compared to mustard or oat but would be a better option than pea alone due to positive revenues of $142, $334 and $391, respectively at Reston in 2020 (Table 24h). At Melita, there was no significant benefit of including oat or mustard in a pea intercropping system compared to pea sole crop because of similar net revenues of $213, $199 and $231 for pea sole, pea-oat and pea-mustard, respectively. On the other hand, pea-wheat and pea-flax had significantly (P<0.001) low net revenue of $72 and $122, respectively. Therefore, based on Melita results for 2020 alone, inclusion of flax or wheat may not be a best option for the producer considering other alternatives like oat or mustard (Table 24i). At Roblin, pea-oat intercrop had a net revenue of $214, which was the highest but was not significantly different from revenue obtained from pea-wheat, pea-canola and pea-mustard (Table 24k). However, pea-flax and pea sole had significantly (P=0.001) low net revenue of -$80 and $39, respectively, compared to other intercrop options. This implies that, selection of pea-flax intercrop results in significant losses by the producer under Roblin conditions in 2020.

Table 24a. Analysis of variance for yield, partial LER and TLER at Reston MultiCrop in 2020

Trt	Crop	Yield (kg/ha)			LER		
		Sole	Crop-IC	Pea-IC	Partial Sole	Partial Pea	TLER
1	Pea	206	-	-	1.00	-	1.00**c**
2,7	Flax	2680	2252	101**c**	0.87	0.50**c**	1.37**bc**
3,8	Oat	8830	8951	162**b**	1.06	0.80b**c**	1.86**a**
4,9	Wheat	8051	6305	171**b**	0.79	0.86**b**	1.64**ab**
5,10	Canola	4385	3604	236**a**	0.82	1.19**a**	2.01**a**
6,11	Mustard	3886	3042	182**ab**	0.79	0.90**ab**	1.69**ab**
	P value			**<0.001**		**<0.001**	**<0.001**
	CV			**14**		**16**	**13**

Table 24b. Analysis of variance for yield, partial LER and TLER for Melita MultiCrop in 2020

Trt	Crop	Yield (kg/ha)			LER		
		Sole	Crop-IC	Pea-IC	Partial Sole	Partial Pea	TLER
1	Pea	4970	-	-	1.00	-	1.00**b**
2,7	Flax	1406	630	3072**a**	0.45	0.62**a**	1.07**b**
3,8	Oat	4240	3463	1501**c**	0.83	0.30**c**	1.14**ab**
4,9	Wheat	2416	1449	2330**b**	0.61	0.47**b**	1.07**b**
5,10	Canola	1847	1099	2745**ab**	0.59	0.55**ab**	1.14**ab**
6,11	Mustard	1080	744	3027**a**	0.69	0.61**a**	1.30**a**
	P value			**<0.001**		**<0.001**	**0.001**
	CV			**11**		**11**	**7**

Table 24c. Analysis of variance for yield, partial LER and TLER for Roblin MultiCrop in 2020

Trt	Crop	Yield (kg/ha)			LER		
		Sole	Crop-IC	Pea-IC	Partial Sole	Partial Pea	TLER
1	Pea	3298	-	-	1.00	-	1.00a
2,7	Flax	2592	306	1763abc	0.12	0.54abc	0.66b
3,8	Oat	5515	4090	1011c	0.74	0.31c	1.05a
4,9	Wheat	4485	2404	1378bc	0.54	0.42bc	0.96a
5,10	Canola	3292	1020	2578a	0.32	0.79a	1.11a
6,11	Mustard	2255	668	1908ab	0.28	0.58ab	0.86ab
	P value			**0.001**		**0.001**	**0.002**
	CV			**21**		**21**	**13**

Table 24d. Analysis of variance for final crop emergence counts and weed biomass at Reston in 2020

Trt	Crop	Final Emergence ppms			Weeds (g/m2)	
		Sole	Crop-IC	Pea-IC	Sole	Pea-IC
1	Pea	91	-	45 (adj)	486.0	-
2,7	Flax	381	205	37	548.0	387.0
3,8	Oat	190	112	32	726.0	661.0
4,9	Wheat	192	110	34	90.80	255.8
5,10	Canola	54	32	39	168.3	98.00
6,11	Mustard	51	22	34	809.0	308.8
	P value			**0.112**		**0.177**
	CV			**17.9**		**29**

Table 24e. Analysis of variance for final crop emergence counts and weed biomass at Melita in 2020

Trt	Crop	Final Emergence ppms			Weeds (g/m2)	
		Sole	Crop-IC	Pea-IC	Sole	Pea-IC
1	Pea	49	-	25 (adj.)	41	-
2,7	Flax	240	101	36	136	45
3,8	Oat	177	110	28	40	76
4,9	Wheat	165	71	28	8	25
5,10	Canola	54	38	32	67	127
6,11	Mustard	54	36	21	47	41
	P value			**0.164**		**0.982**
	CV			**26.5**		**43**

Table 24f. Analysis of variance for final crop emergence counts and weed biomass at Roblin in 2020

Trt	Crop	Final Emergence ppms			Weeds (g/m2)	
		Sole	Crop-IC	Pea-IC	Sole	Pea-IC
1	Pea	58	-	29 (adj.)	71.4	-
2,7	Flax	227	86	38	92.3	265
3,8	Oat	119	92	30	51.1	107
4,9	Wheat	170	91	36	70	67
5,10	Canola	50	20	48	14.7	81.5
6,11	Mustard	28	16	29	85.3	52.4
	P value			**0.215**		**0.41**
	CV			**32.9**		**30**

Table 24g. Analysis of variance for pea splits and protein content at Melita, Reston and Roblin in 2020

		Reston		Melita		Roblin	
Trt	Crop	Pea splits g/500 seeds	Pea protein % DM basis	Pea splits g/500 seeds	Pea protein % DM basis	Pea splits g/500 seeds	Pea protein % DM basis
1	Pea	14a	24.2	6.6	23.6	11.2	23.8a
2,7	Flax	3c	23.6	6.5	23.8	10.1	23.1ab
3,8	Oat	7bc	24.2	4.6	24.5	9.0	22.7b
4,9	Wheat	9ab	23.6	10.0	24.4	12.2	23.6ab
5,10	Canola	12a	23.8	6.8	23.5	12.0	22.9ab
6,11	Mustard	11ab	23.8	9.8	24.4	12.1	23.3ab
	P value	**<0.001**	**0.766**	**0.081**	**0.012**	**0.202**	**0.035**
	CV	**22**	**3.4**	**36**	**1.8**	**18**	**2**

Table 24h. Economic analysis for Reston MultiCrop in 2020

		Economics					
Trt	Crop	Sole-COP	IC – COP	Gross Revenue		Net Revenue	
				Sole	IC	Sole	IC
1	Pea	303	-	21	-	(282)	(282)d
2,7	Flax	289	325	544	467	254	142c
3,8	Oat	292	318	922	951	630	633a
4,9	Wheat	308	316	807	650	498	334bc
5,10	Canola	328	339	859	731	532	391b
6,11	Mustard	317	336	1315	1049	998	713a
	P value						**<0.001**
	CV						**28**

Table 24i. Economic analysis for Melita MultiCrop in 2020

		Economics					
Trt	Crop	Sole-COP	IC - COP	Gross Revenue		Net Revenue	
				Sole	IC	Sole	IC
1	Pea	303	-	519	-	213	213ab
2,7	Flax	289	325	285	447	(4)	122cd
3,8	Oat	292	318	443	517	151	199ab
4,9	Wheat	308	316	242	387	(66)	72d
5,10	Canola	328	339	362	501	34	161bc
6,11	Mustard	317	336	366	566	49	231a
	P value						**<0.001**
	CV						**18**

Table 24j. Economic analysis for Roblin MultiCrop in 2020

		Economics					
Trt	Crop	Sole-COP	IC - COP	Gross Revenue		Net Revenue	
				Sole	IC	Sole	IC
1	Pea	303	-	343	-	39	39bc
2,7	Flax	289	325	526	245	236	(80)c
3,8	Oat	292	318	576	532	284	214a
4,9	Wheat	308	316	449	384	141	68abc
5,10	Canola	328	339	645	468	317	128ab
6,11	Mustard	317	336	763	424	446	89ab
	P value						**0.001**
	CV						**94**

Evaluation of pea-cereal intercrop for silage production

Project duration: May 2020 – August 2020

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

Collaborators: PCDF, CMCDC

Results

The silage was harvested at soft-dough stage (65% moisture). The wet silage yields (t/ac) for treatments are shown in Figure 1, and dry yields (lb/ac at 15% moisture) are shown in Figure 2. The results are for 2019 and 2020.

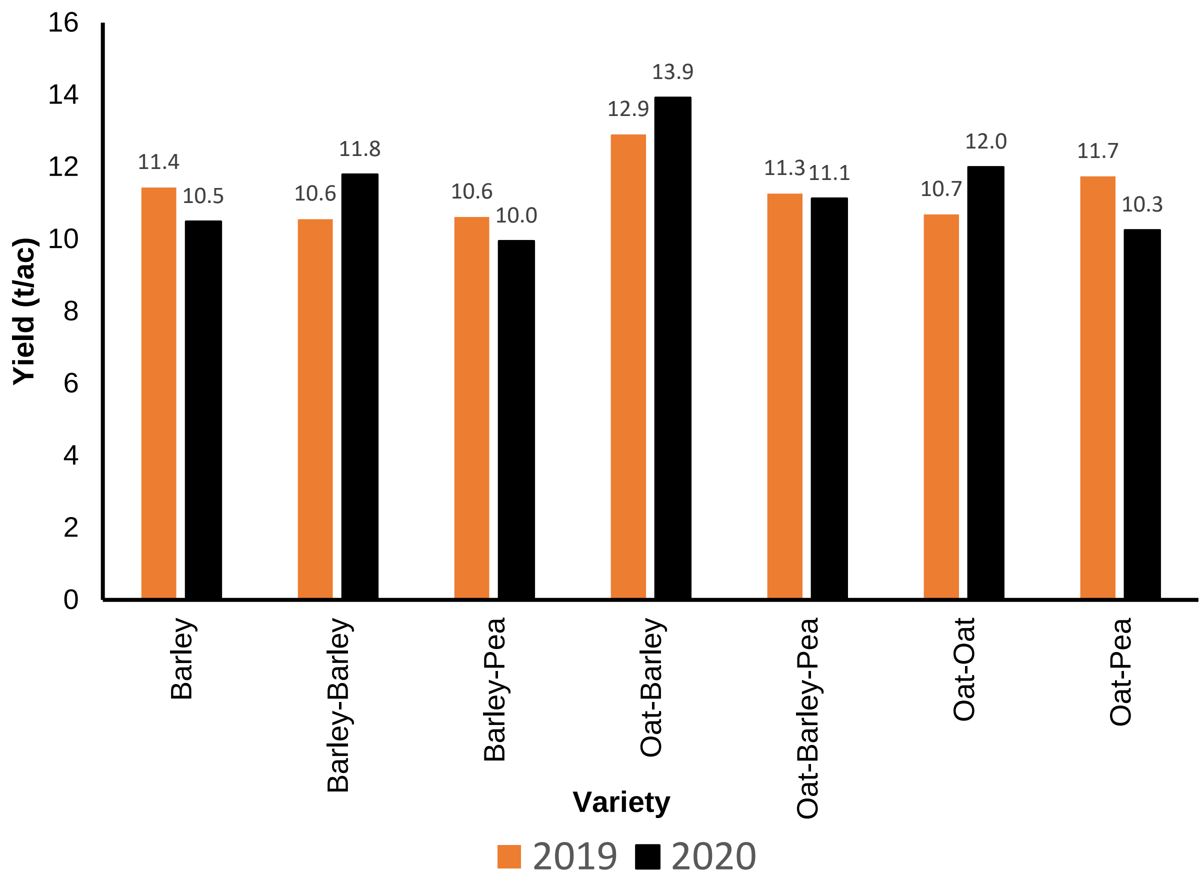


Figure 1: Wet silage yield (t/ac) by treatment, adjusted to 65% moisture.

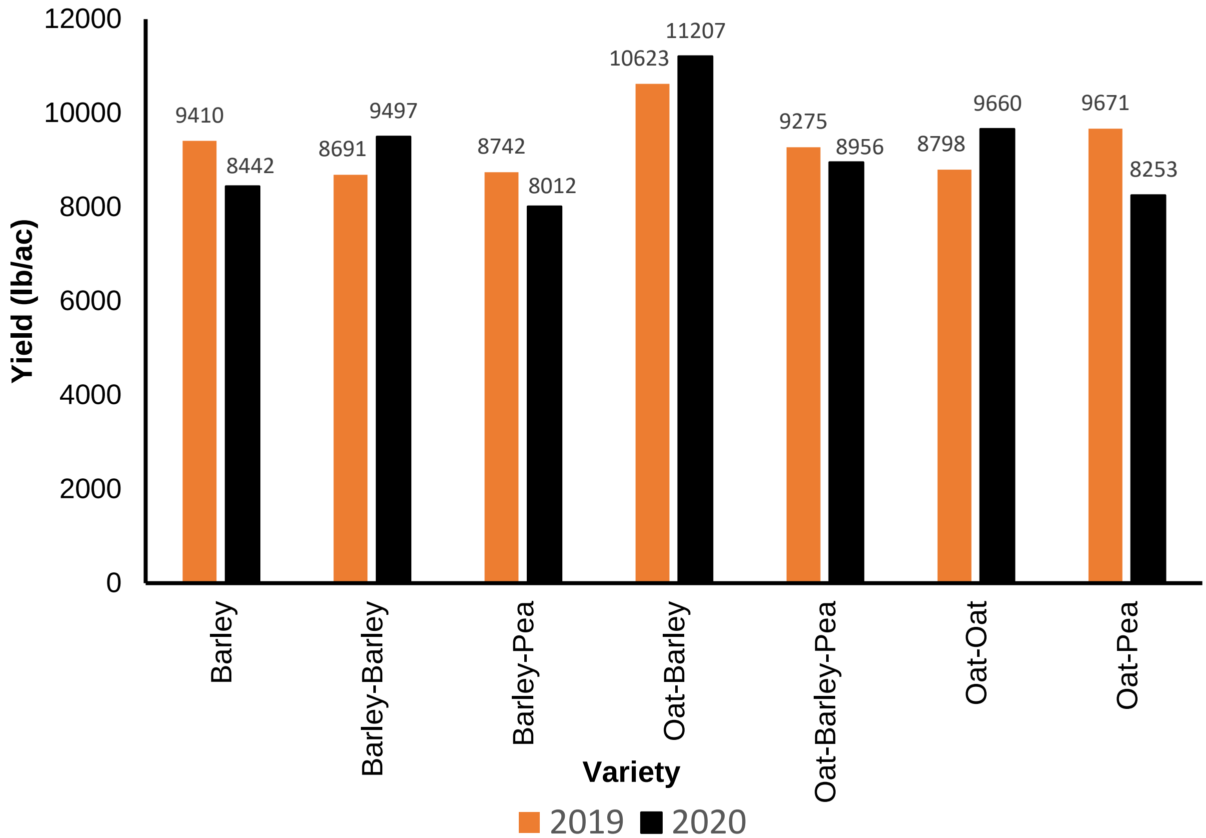


Figure 2: Yield (lb/ac) by treatment, adjusted to 15% (hay) moisture.

The results for silage yield differ statistically by treatment (Table 1). Oat-barley yields were significantly higher than other treatments (A). Yields for treatments including pea were not statistically different from the barley-only treatment (C).

Table 1: Summary of statistical information for 2020 silage yield

Entry	**Statistical significance: wet and dry***		
Barley-only		B	C
Barley-Barley		B	
Barley-Pea			C
Oat-Barley	A		
Oat-Barley-Pea		B	C
Oat-Oat		B	
Oat-Pea		B	C
CV (%)	13.8		
LSD (0.05)	1.8		

* Wet = 65% moisture; dry = 15% moisture. Treatments not marked with the same letter are statistically different from other treatments.

The feed values for each treatment, as well as recommendations, are shown in Table 2.

Table 2: Feed values for silage by treatment compared to animal feed requirements

Entry	% Crude Protein	% TDN
Barley	8.21	58.86
Oat-oat	7.78	61.46
Barley-barley	8.24	60.51
Oat-barley	7.14	63.19
Barley-pea	10.91	60.65
Oat-pea	9.12	59.26
Oat-barley-pea	8.84	60.43
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

Observations

The silage was prepared by running the harvested material from each plot through a plant shredder. The oat-barley treatment appears to be a promising option, both for higher yields relative to other treatments (Table 1) and higher TDN values (Table 2). However, this treatment will not provide enough protein to meet all animal feed requirements.

Materials & Methods

Experimental Design:	Random Complete Block Design
Entries:	7
Replications:	3
Seeding:	May 25
Harvest:	Aug 12

Barley-oat 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.

Table 3: 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

Data collected	**Date Collected**
Pea Emergence:	Jun 2-4
Cereal Emergence:	Jul 5-7
% Emergence:	Jul 11-18
Plot Wet Weight:	Aug 12
Plot Dry Weight:	Sep 12

Agronomic info

Previous year's crop:	Barley Silage
Soil Type:	Erickson Loam Clay
Landscape:	Rolling with trees to the east
Seedbed preparation:	Heavy harrowed

Table 3: Fertility Information

	Available	Added	Type
N	72 lb/ac	none	N/A
P	22 ppm	10 lb/ac	11-52-0-0
K	257 ppm		
Inoculant added			

Evaluation of intercrop mixes with hemp for silage production

Project duration: May 2020 – August 2020
Objectives: To evaluate intercrop mixes with hemp for silage production
Collaborators: CMCDC, PCDF

Results

The silage yields (t/ac) for treatments is shown in Figure 2. The results are for one year of data only.

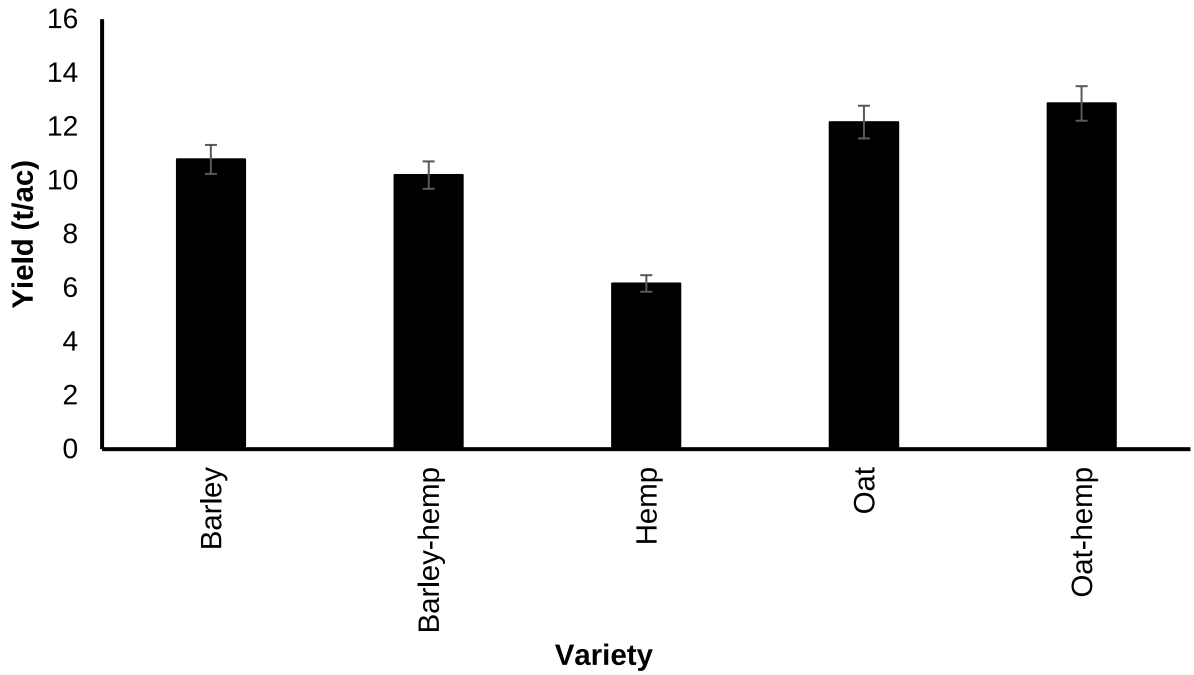


Figure 2: Wet silage yield (t/ac) by treatment; all yields adjusted to 65% moisture.

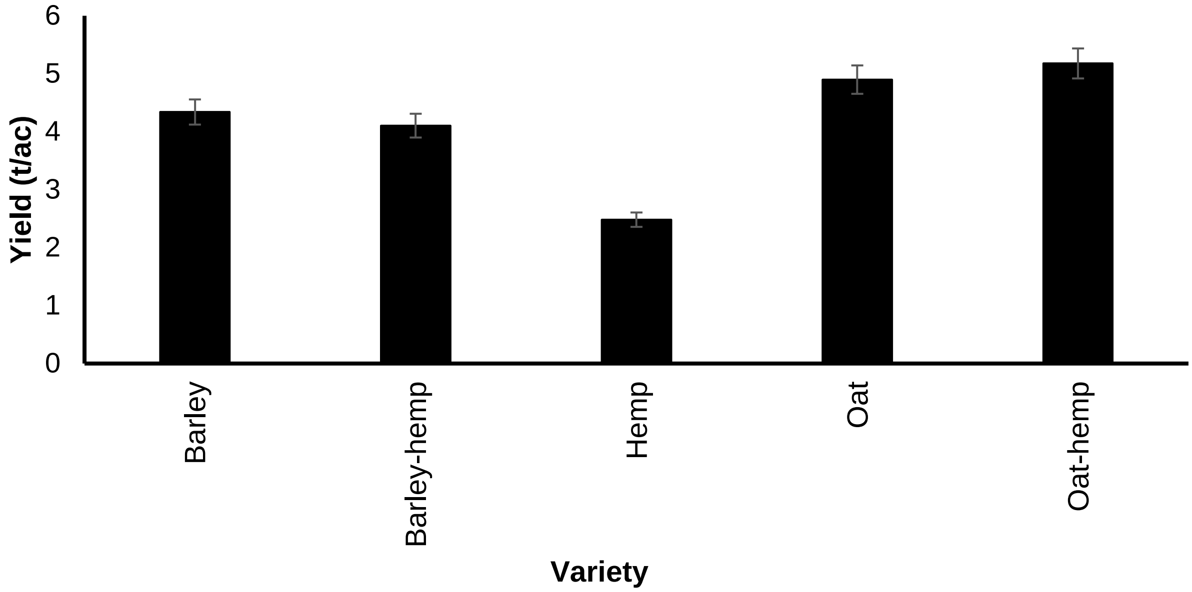


Figure 3: Dry silage yield (t/ac) by treatment; all yield adjusted to 15% (hay) moisture.

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. Note that the reliability of these results is low due to a high percent CV for silage yield. The feed values and mineral content for each treatment are shown in Tables 2 and 3.

Table 1: Summary of statistical information for silage yield

Entry	**Silage yield (t/ac) wet yield**	**Silage yield (t/ac) dry yield**	**Statistical significance: wet and dry***	
Barley	10.8	8.7	A	
Barley-hemp	10.2	8.2	A	
Oat	12.2	9.8	A	
Oat-hemp	12.9	10.4	A	
Hemp	6.2	5.0		B
CV (%)	27.8			
LSD (0.05)	3.4	2.8		

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

Table 2: Feed values for silage by treatment compared to animal feed requirements

Entry	% Crude Protein	% TDN
Barley	10.14	58.27
Oat	10.80	59.79
Hemp	12.58	43.70
Barley-hemp	12.18	58.69
Oat-hemp	12.22	58.94
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

Table 3: Mineral content for silage by treatment

Mineral	Barley	Oat	Hemp	Barley-hemp	Oat-hemp
Ca	0.35	0.28	1.55	0.64	0.38
P	0.19	0.20	0.27	0.24	0.21
Mg	0.12	0.13	0.36	0.18	0.15
Na	0.39	0.49	0.12	0.30	0.47
K	1.25	1.42	1.46	1.29	1.56
Mo	1.29	2.54	1.33	1.13	2.07
Cu	4.23	3.54	7.51	5.35	3.68
Zn	17.30	17.88	23.54	21.34	19.39
Mn	30.24	52.04	64.06	36.88	54.02
Fe	112.85	153.07	151.36	145.81	184.17

Materials & Methods

Experimental Design:	Random Complete Block Design
Entries:	5 (3 replications)
Seeding:	May 25
Harvest:	Aug 12

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 trial was hand-weeded.

Table 4: 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

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 2). Nevertheless, even a reduced rate of hemp appeared to positively increase percent-protein content for the oat-hemp and barley-hemp treatments.

Data collected	**Date Collected**
Hemp Emergence:	May 28 – Jun 7
Cereal Emergence:	May 25 – Jun 6
% Overall Emergence:	Jul 11-18
Plot Wet Weight:	Aug 12
Plot Dry Weight:	Sep 12

Agronomic info

Previous year's crop:	Barley Silage
Soil Type:	Erickson Loam Clay
Landscape:	Rolling with trees to the east
Seedbed preparation:	Heavy harrowed

Table 5: Fertility Information

	Available	Added	Type
N	79 lb/ac	47 lb/ac	46-0-0
P	22 ppm	10 lb/ac	11-52-0-0
K	257 ppm		

National Industrial Hemp Fibre and Grain Variety Evaluation

Project duration: May 2020 – October 2020
Objectives: To evaluate industrial hemp varieties for grain, fibre and cannabinoid content for the National Industrial Hemp Variety Evaluation Trial
Collaborators: Canadian Hemp Trade Alliance

Background

The industrial hemp industry has developed around grain and fibre use. With changes to Canadian legislation around industrial hemp, the CHTA trials enhanced their protocols around cannabinoid testing.

There were a number of new developments in Canadian legislation which very directly affected Canadian hemp growers. The CHTA website outlines these new developments, specifically the changes in Cannabis legislation as well as Health Canada's revision of Section 56 of the Controlled Drugs and Substances Act (CDSA). These changes now allow hemp farmers to immediately collect and store industrial hemp flower, bud and leaf material, a vital piece that was previously prohibited. However, ongoing debate continues to discuss how to classify hemp cannabinoids in relation to the better known recreational cannabis and whether to classify and regulate it as a medical drug. CHTA and Canadian Health Food Association continue to call on the Canadian government to improve the legislation in to allow Hemp cannabinoids to legally fill the gap that illegal sources are currently filling.

Materials & Methods

Experimental Design: Random Complete Block Design
Entries: 7 Grain entries and 7 Dual Purpose entries with 4 replications
Seeding: June 10
Harvest: Oct 2

Table 1: Hemp Varieties

Grain only	Dual Purpose (grain and fibre)
CFX-2	Anka
X59	Altair
Katani	CRS-1
Grandi	Petera
CRS-1 (check)	Rigel
Earlina	Santhica 27
Judy	Santhica 70

Data collected	**Date collected**
Emergence:	Jun 19-22
Mortality plant counts:	With emergence
Stem Elongation plant counts:	July 15
Flowering:	Jul 25 – Aug 6
Height:	Aug 22
Lodging:	Sep 2
Yield:	Sep 7
Moisture:	Sep 7

Agronomic info

Previous year's crop:	Barley
Soil Type:	Erickson Loam Clay
Landscape:	Rolling with trees to the east
Seedbed preparation:	Heavy harrowed twice

Table 2: Spring 2019 Soil Test

	Available	Needed
N	79 lb/ac	120 lb/ac
P	13 ppm	40 lb/ac
K	222 ppm	10 lb/ac
S	42 lb/ac	5 lb/ac

Table 3: Added N and P Fertilizer

Blend	Blend (actual lbs/ac)	Actual lbs N	Actual lbs P
46-0-0	70.7	32.5	0
11-52-0-0	76.9	8.5	40
Total	-	41.0	40

N side-banded; P Banded with seed

Table 4: Herbicide Application

Crop stage	Date	Product	Rate
Pre-emerge	May 19	Heat	28.4 g/ac
		Round-up	0.67 L/ac
In-crop	Jun 20	Brotex 240	0.5 L/ac
		Centurion	0.15 L/ac

Results

Results for the 2020 will be made available through the CHTA website and shared on the Diversification Centres website when available.

Evaluation of Hops Varieties in Manitoba

Project duration: May 2020 – September 2020
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. The price of hops can be erratic and harvest very labor intensive without expensive mechanization. Typically, brewers prefer peletized hops but fresh hops for seasonal brews is also possible.

There is little information on variety adaptability to Manitoba Growing conditions, especially varieties originating in Europe. This is despite the use of selections native to Manitoba in some of the early variety development (Manitoba Wild selection used as parent for variety Brewers Gold). 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.

Quality Observations

Cone samples were taken for the longest maturing varieties. Sampling continued based on availability and maturity.

Table 2: Average quality parameters of hops

Row Labels	Samples Collected	Average % Alpha	Average % Beta	Average HSI
Brewers Gold	17	5.91	3.04	0.30
Casscade	9	5.83	4.11	0.25
Fuggle	5	3.34	2.22	0.26
Goldings	5	4.06	2.20	0.24
Mount Hood	5	4.82	6.02	0.28

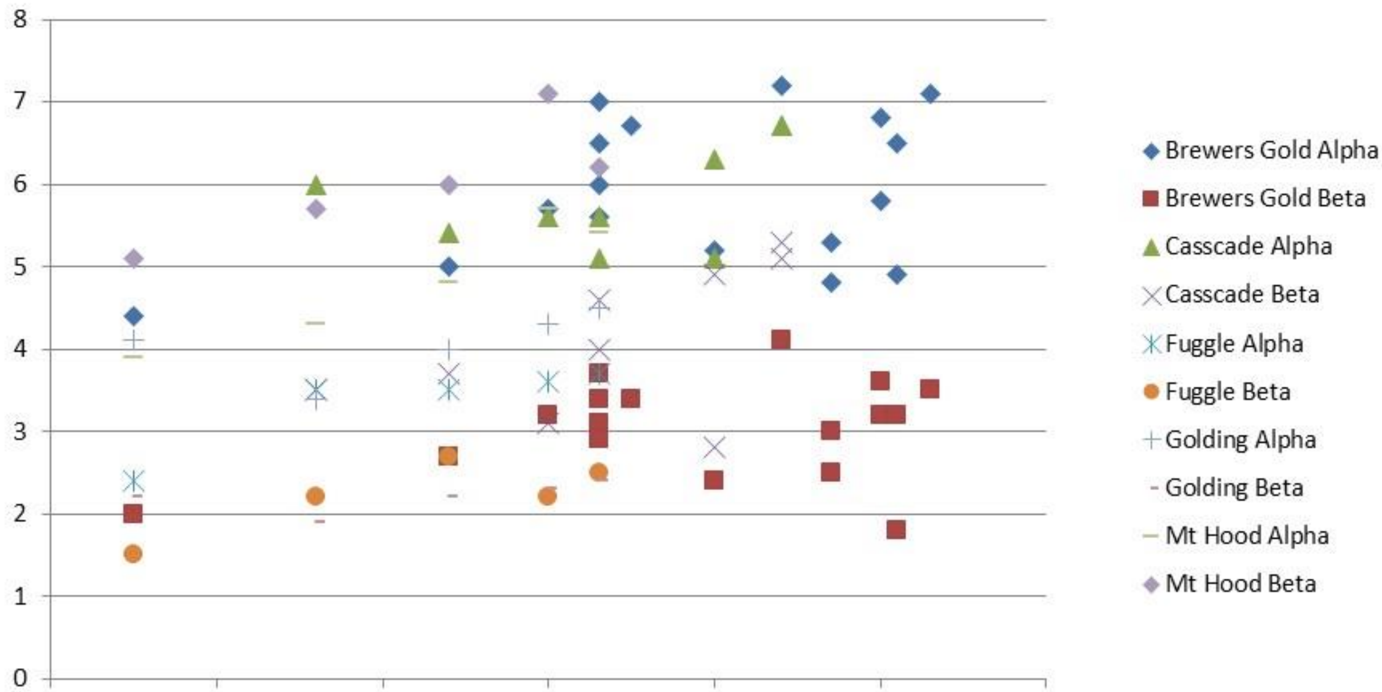


Figure 2: Alpha acid % and Beta acid % of Brewers Gold, Cascade, Fuggle, Golding, and Mt Hood

The two main quality criteria are alpha and beta acid content. Ideally the best time to harvest hops is when both Alpha and Beta acid levels are at their maximum. Harvest Storage Index (HSI) is used to indicate the potential storability of hops harvested and indicates an estimated depletion rate of alpha acid potential within the first 6 months of storage at 20°C. When hops have dropped to below 50% of their original alpha acid content they start to "go bad" in the sense that they often take on a skunky odor.

Quality parameters for both Cascade and Brewers Gold peaked around October 11th with the peak for Brewer's Gold being at the low end of historical ranges for both parameters; 7.1% and 4.1% for Alpha and Beta, respectively. Cascade on the other hand was within historical range at the first sampling on September 13th for Alpha levels but Beta levels did not reach historical levels until September 30th. Fuggle met historical ranges by September 13th and Golding stayed relatively static for the entire sampling period. Mt Hood increased steadily for both Alpha and Beta through the month of September, reaching historical means on the final sampling dates. For the varieties listed above, Hop Storage Index values averaged 0.27, or a projected decrease in Alpha content by 27% over 6mo if stored at 20C. There was not any significant trending with HIS and harvest date.

APPENDIX A

Name	Usage	Maturity	Storage Stability	VW	DM	PM	Alpha Acid (10yr range)	Beta Acids (10yr range)	Cohumulone	Vigor
Casscade	Aroma	Medium-Late	P	MR	MR	MR	6.3 (5.1-8.5)	5.6 (4.0-6.6)	36-40	VG
Golding	Aroma		VG	*MR*	S	*S*	5.5	2.5	29	G
Wild Miami	na	Early-Medium	*P-F*	*na*	*na*	*na*	*5.0*	*4.3*	*na*	*E*
Garden	Ornamental					*na*				
Mount Hood	Aroma	Medium	P-F	*S*	S	MS	6	6.75	23	G-VG
Golden	Ornamental					*na*				
Brewers Gold	Bittering	Late	P	MR	MR	S	9.2 (7.1-11.3)	4.8 (3.3-6.1)	39	E
Fuggle	Aroma	Early	VG	S	R	MS	5.1 (2.4-6.1)	2.4 (2.1-2.8)	27	P-F

VW	Verticillium Wilt Resistance	E	Excellent
DM	Downy Mildew Resistance	VG	Very Good
R	Resistant	G	Good
MR	Moderately Resistant	F	Fair
MS	Moderately Suseptible	P	Poor
S	Suseptible		

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