Minnesota Area II Potato Research and Promotion Council

and

Northland Potato Growers Association

2023 Research Reports

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Proposal Title: 2023 Support of Irrigated Potato Research for North Dakota and Minnesota

Submitted to Northland & MN Area II Potato Growers Associations

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Collaborators: Susie Thompson, Harlene Hatterman-Valenti, Andy Robinson

Executive Summary: North Dakota State University has conducted irrigated potato research for over 30 years. Over that time, growers have graciously supported this effort and, in return, had access to the wealth of information generated in the areas of cultivar development, general cultural management practices such as vine desiccation, herbicide efficacy and damage, nutrient and disease management and physiological defects including sugar ends, among others. Specifically, trials conducted at the irrigated research site near Inkster, ND, have given us a way to track resistance to QoI (FRAC 11) and SDHI (FRAC 7) fungicides in the early blight and brown spot pathogens in the region. We also have evaluated foliar and seed treatment fungicides in a program approach specific for the pathogens and environmental conditions in this region and conducted demonstration plots for the growers. These efforts have facilitated more timely and relevant grower recommendations. Without the Inkster site, the ability of the industry to react to changes in management for potato production conditions in our region would be severely impeded. If you have utilized recommendations from NDSU for managing your potato crop, you have benefitted from the work conducted at the Inkster site.

An enormous thank you goes out to Russell Benz, Dean Peterson, Hunter Bentten, Cory Ingram, Sunil Shrestha, Arslan Sarwar, and Rachel Selstedt and the entire field staff for their work on this research. We appreciate the generous cooperation from Forest River Colony for assistance with tillage, irrigation, and general support. This effort was generously funded by the MN Area II Potato Growers Association and the Northland Potato Growers Association.

Rationale: Irrigated potato production accounts for approximately 60% of the state's total production and differs substantially from non-irrigated production. The majority of the irrigated potato production is used in the production of French fries, and as a result, the spectrum of cultivars grown under irrigation differs greatly from those produced under non-irrigated conditions. In addition, the pressure from diseases, insect and weed pests, cultivar selection and use of fertilizer all differ significantly for irrigated potato production compared to potatoes produced under non-irrigated conditions. Some of the most impactful research findings from this site include the generation of a PCR assay to quantify *Verticillium dahliae* from stem tissue. This work provided us with a means to determine host resistance to the pathogen and how much pathogen is being returned to the soil, allowing us to make grower recommendations based on pathogen production, not just visual symptoms that can be variable depending on the environment and cultivar maturity. This has led directly to improved breeding for resistance to Verticillium in NDSU breeding material. Trials conducted at Inkster also have facilitated our ability to track resistance to QoI and SDHI fungicides in the early blight and brown spot pathogens in the region. Additionally, we have evaluated fungicides in a program approach specific for the pathogens and environmental conditions in this region. Again, allowing us to make timely and relevant grower recommendations. To be applicable to the many irrigated potato growers in the region, research must be conducted under irrigated conditions, mimicking as much as possible the grower experience.

The funding for the management of the Inkster irrigated research site facilitates the use of the site by potato research projects. The expenses associated with managing the research site include general maintenance for all research trials (soil tillage, cultivation, scheduling and performing irrigation, fertility management, application of herbicides, fungicides and insecticides, etc.) in addition to assisting in planting and harvest operations as needed. The potato pathology management team also monitors soil-borne pathogens to make the irrigated research site useful to everyone. For example, our research team coordinates the fumigation of the Inkster site with Hoverson Farms and has been able to secure Vapam donations from AmVac for both the NPGA and Hoverson Farms to offset all expenses associated with this fumigation, as needed. This saves approximately $7,500 annually. The Inkster plot coordinator also plants and mows all cover crops and assists in planning the annual field day.

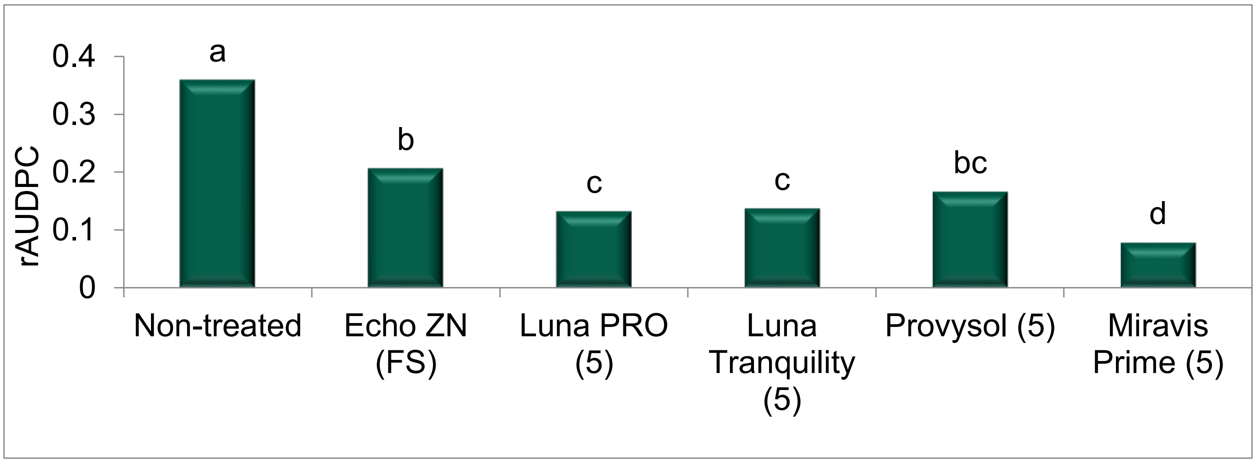
The total cost of general management of the irrigated potato research in 2023 near Inkster, ND, at the NPGA research site was nearly $80,000. Some notable increases in expenses are due to substantial increases in employee salaries and vehicle costs. We continue to make a concerted effort to re-evaluate all operations and to increase efficiencies in management of the Inkster research site. For example, in 2022 and 2023 we enlisted the use of remote soil moisture sensors to more effectively irrigate and potentially reduce travel to the site.

Procedures: The funding for the Inkster field site coordinator and additional labor facilitated the use of the irrigated potato research site. Research trials conducted include, but are not limited to, general management practices like vine desiccation, nutrient management, cultivar improvement, weed control, management of foliar diseases such as early blight and black dot, disease management of seed-borne Rhizoctonia and silver scurf blemish, seed piece decay and physiological defects like sugar ends. The Inkster coordinator performed all soil tillage, managed irrigation, made all herbicide, insecticide, and fungicide applications, as well as provided additional labor during planting and harvest operations, as needed. The Inkster plot coordinator also planted all cover crops and assisted in planning and preparing the site for the annual field day.

It was wonderful to see full trailers at the NPGA field day and the trial site looked as fabulous as usual thanks to Hunter, Russell, Dean, and the rest of the team!

Research Results: In 2023, 32 research trials were conducted on nearly 24 acres at the Inkster research site. As indicated above, these trials span the range of expertise of the potato improvement team. Among other things, data from these trials are helpful for screening registered and novel products to provide statistically unbiased evaluations for the benefit of the potato industry and growers. In many cases the trial results are confidential because products are not registered for use. The Inkster site allows us to generate data under local irrigated growing conditions over several years. Using data generated at Inkster, in part, products that are deemed successful by the cooperator are registered and marketed for use on potatoes in the region. Below we have included some results from trials conducted at Inkster. Some results are preliminary and as indicated, some results are confidential.

We saw very high disease pressure in 2023. One example of generating data over several years includes the evaluation of new foliar products / formulations for the management of early blight (Figure 2). Results reported here represent data generated at Inkster in 2023. Similar data have been generated in other years and reflect the same message. While we continue to have concerns over the development of fungicide resistance, these fungicides remain very effective against the pathogen population in our region.



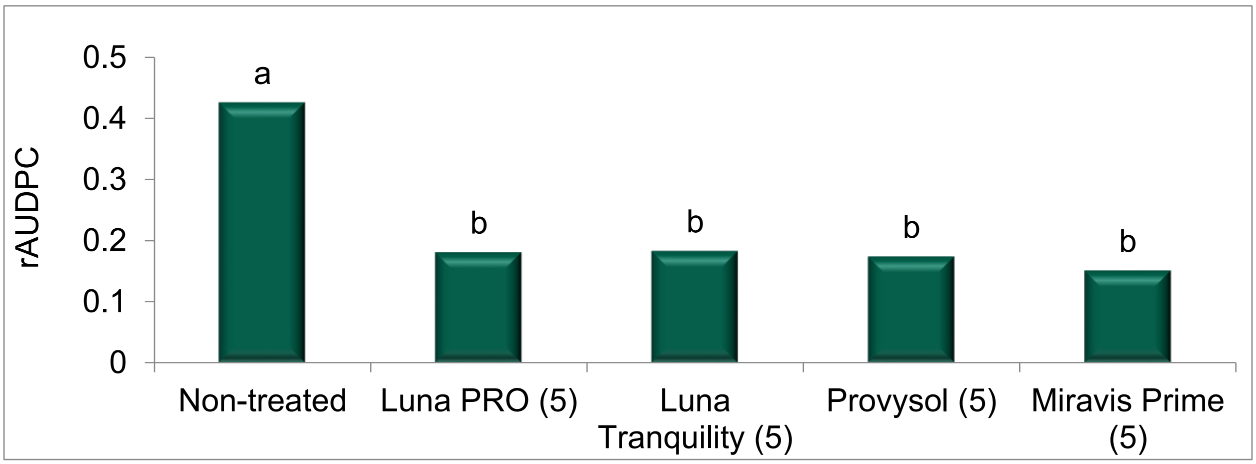


Figure 1. Trial conducted in 2023 under high disease pressure at the Inkster irrigated research site. Bars with different letters above have significantly different relative area under the disease progress curve (rAUDPC) which represent disease severity across the growing season as determined by visual disease ratings collected weekly for 10 weeks. The number in () represent the application number in a 10-application program. All treatments included A Qoi fungicide @ application 2 and Scala @ application 7. The three specialty fungicides (applications 2, 5, and 7) were rotated with chlorothalonil (applications 1, 3, 4, 6, 8-10) and tank-mixed with mancozeb.

At Inkster in 2023, the pathology project also conducted four trials to evaluate 29 treatments for managing seed-borne Rhizoctonia. Registered fungicides, experimental fungicides, and natural products were applied as seed treatments and in-furrow at planting. Most of the treatments were entered as numbered compounds and/or were confidential. Two non-treated controls were included in each trial, a non-inoculated control and a Rhizoctonia seed inoculated control. Many of the products tested did not result in significant reduction of Rhizoctonia 45 days after planting. As in past years, the best control of Rhizoctonia 45 days after planting continued to be Maxim seed treatment at 0.08 fl oz/cwt plus Quadris in-furrow at 9.0 fl oz/acre. Emesto Silver plus mancozeb plus Minuet also provided excellent reduction of

Rhizoctonia 45 days after planting. The presence of post-harvest tuber black scurf was evaluated after two months of storage, but only a small amount of scurf was found.

A field trial was conducted in 2023 at the Inkster site to evaluate efficacy of eight seed treatments and in-furrow at planting treatments to reduce blemish of harvested potatoes. Tubers cv. Agata naturally infected with silver scurf were planted at the Inkster site and grown using local agronomic practices. Tubers were harvested and incubated at 50F for four months and evaluated for total blemish, a combination of silver scurf and black dot.

Field research was conducted at the Northern Plains Potato Growers Association Irrigated Research site near Inkster, ND to evaluate Anthem Flex herbicide (not currently labelled on potato at the time of publication) for weed control and crop safety in Russet Burbank potatoes. The Inkster site was planted on June 15. Hill and herbicide application were done on June 27 (12 DAP). Plots were 4 rows by 20 feet arranged in a randomized complete block design with 4 replicates. Seed pieces (2 oz) were planted on 36-inch rows and 12-inch spacing. Extension recommendations were used for cultural practices throughout the year. The trials were harvested on October 19.

Treatment List for Inkster:		
Trt No.	**Name**	**Rate**
1	Untreated	
2	Anthem Flex	4 floz/a
	Matrix	1 oz/a
	Sencor	10.6 oz/a
3	Boundary	24 floz/a
	Lorox	1 lb/a
4	Anthem Flex	4 floz/a
	Sencor	10.6 oz/a
	Lorox	1 lb/a

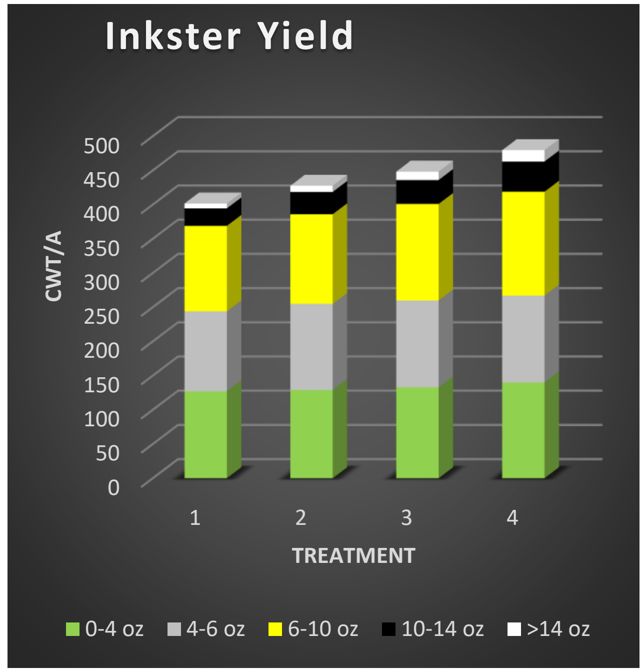
Inkster Application:	
Date:	6/27
Air Temperature (F):	76
Relative Humidity (%):	58
Wind (MPH):	8
Soil Moisture:	adequate
Cloud Cover (%):	100
Next Rain:	6/28

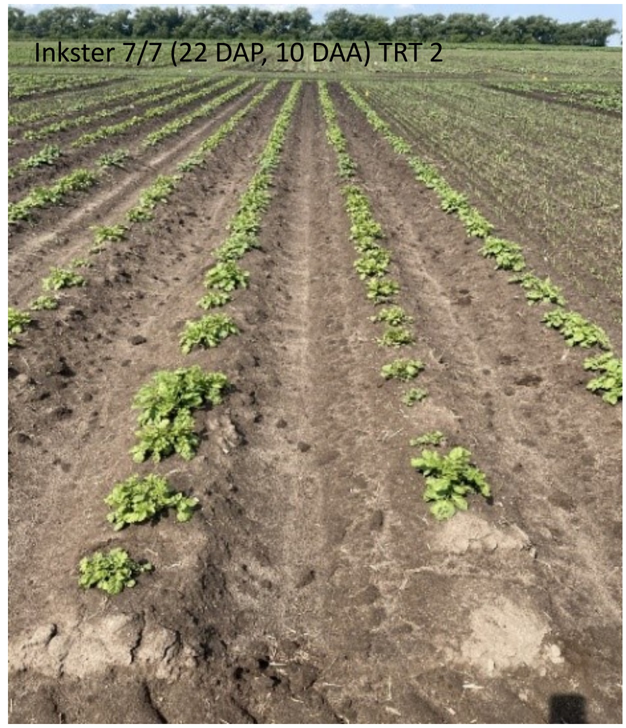
Inkster Yield (cwt/a):						
TRT No.	**Total**	**0-4 oz**	**4-6 oz**	**6-10 oz**	**10-14 oz**	**>14 oz**
1	413	127	117	123	25.5	7.1
2	439	129	126	131	32.6	9.1
3	446	133	127	141	35	12.3
4	460	140	127	152	44	16.7

Inkster Tuber Number in 20 RowFt:						
TRT No.	**Total**	**0-4 oz**	**4-6 oz**	**6-10 oz**	**10-14 oz**	**>14 oz**
1	231	129	51.8	36.9	4.62	0.75
2	233	132	55.9	38.3	6.25	1.25
3	235	132	56.2	41.0	6.80	1.65

4	244	136	56.9	44.5	8.38	2.25

Treatment 4 had the highest yields, followed by treatment 3, then treatment 2, and finally treatment 1, the nontreated. The same sequence was true for the highest yielding and greater tuber counts, in each category. Adding Lorox instead of Matrix, tank mixed with Anthem Flex and Sencor, showed the best yield in this study. Pigweed control at Inkster was excellent in treatments 2 (98% control) and 4 (95% control), significantly better than treatment 3 (85% control). The nontreated was significantly worse than all the treatments (0% control). However, as you can see in the pictures below, there was not a severe weed infestation at either location. The weed infestation is more typical of most grower fields.





We feel strongly that we are generating unbiased, reliable, robust recommendations for growers. We look forward to working with growers and researchers in the future to tackle existing and emerging challenges faced by the industry. Please contact us with any questions concerning this report or any other matters.

Northland Potato Growers Association
Minnesota Area II Potato Growers Council

Title: Impact of variety selection and harvest management on storage bruising.

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Executive Summary:

Storage Brusing: Pressure bruising may account for significant storage losses across all market types. Pressure flattening/bruising occurs after prolonged storage and the combined effect of variety selection, harvest, and storage management contribute to pressure bruising. Replicated storage trials are being conducted on seven chip varieties and 3 russet varieties sampled from three ND locations (2023 crop year).

Seed Aging Impact on Bannock Yield Components: Results from a second year of a Bannock seed aging field trial are reported. Bannock seed aging treatment increased stem number per plant but aging treatment in 2023 did not have an impact on plant emergence rates, stand count, and total yields. In the two seed lots examined in 2023, there was no clear association between tuber aging treatment and tuber size profiles, or marketable yields.

Processing Quality of Yellow Flesh and New Public Varieties: Storage quality of Fontane, a yellow flesh variety, grown under ND dryland conditions is being examined. There has also been increased seed grower interest in examining processing quality of MonDak Gold, and Elk River Russet (MN13142). Advanced potato processing clones from NDSU and other public breeding programs are also being trialed at the USDA-ARS lab in East Grand Forks. Processing quality (fry color) and sugar concentrations are compared against commercial check varieties throughout 10 months of storage at contrasting storage temperatures. Early storage processing data from the 2023 crop year is presented from select varieties.

Rational:

Storage Bruising: Pressure flattening/bruising commonly occurs following prolonged storage and poses a significant challenge to producers. Elevated water loss during early storage is often associated with increased pressure bruising. However, not all varieties behave the same, as some varieties may have different postharvest storage requirements (temperature, cooling rate/duration, and humidity) for proper wound healing that will minimize bruising. Understanding the impacts of harvest management (timing/temperature/cooling rate/duration) on tuber water relations is poorly understood, especially in newly released clones. Pressure flattening/bruising among chip and fry varieties is being examined in a controlled ventilation storage compartment.

Seed Aging Impact on Bannock Yield Components: Several concerns regarding certified Bannock seed produced in ND have been observed in recent years: including delayed emergence, decreased stem number and decreased tuber set/yield. These field observations may be attributed to delayed physiological age resulting from the shortened growing season typical in ND production. A replicated ND field trial in 2023 is the second year of the study that has examined the impact of Bannock seed age on plant emergence, and yield parameters.

Procedures:
Storage Bruising: Bruising data is being collected across seven chip varieties and 3 russet varieties sampled from three ND locations and two harvest dates in 2023. Within 48 h after harvest, tubers (8 -10 tubers/ variety treatment) were placed into mesh bags and initial sample weights recorded. Treatment bags were placed into 1000# totes (Macroplastic 32-S Pro-bin; external dimension 48''l x 44''w x 30''h). Totes were layered by replicate (4-6 replicates), and the side and top were filled with additional bulk potatoes after placement of treatment bags. A pressure plate fabricated from ½'' thick UHMW equipped with a 12 ½ ton bottle jack w/ gauge port (Norco model #76412BG) was placed on the potatoes within the tote. Bottle jack gauge pressure was adjusted to simulate pressure exerted within an 18' pile (2.1 lb/in^2). The desired gauge pressure is achieved by directing the ram into the shelving support structure; pressure is monitored and adjusted as needed (daily adjustment is required during initial storage). Samples were suberized for 2 weeks at 55°F, 95% RH. Following suberization, the temperature was lowered to 46°F at a cooling rate of (0.4°F/day). Temperature and humidity was controlled and monitored with a Techmark Inc. 755 Controller and StorTrac™ software. To test the impact of simulated pile height on bruising, 1/3 of the bottle jack pressure (0.6 lb/in^2) was applied to one treatment tote.
After 6 months storage (March 2024), totes will be removed, and sample bag weights recorded to determine water loss. Each individual tuber will be evaluated for flattened and depressed areas. The total number of flattened depressions per tuber and total impacted area will be calculated. Tuber discoloration notes will also be recorded after peeling. Chip quality will be measured following continuous processing at 365°F, 90 seconds using the USDA-ARS Pilot Scale Chip Line. Chip photos and Hunterlab scores will be collected to identify variety impact on bruising/chip defect rating.

Seed Aging Impact on Bannock Yield Components: Two ND Bannock seed lots were collected from a commercial seed farm during the 2022 harvest. For reporting purposes, lots are identified as Lot 'A' collected on 5 October 2022 and Lot 'B' was sampled on 28 September 2022. Seed tubers were transported to East Grand Forks for seed aging. Seed aging treatment was imposed through a combination of storage duration at 12 and 22°C (Table 1). Storage degree day (SDD) is the days >4°C prior to a storage holding period. Treatment 1 served as an 'un-aged' control, treatments 2 and 3 were defined as the moderate aged (500 SDD) treatments, and tubers from treatment 4 and 5 were the oldest tubers (900 SDD age treatment). After the 4°C holding period, all treatments were uniformly warmed, and tuber pieces of similar size were cut for planting. The field study was arranged as a randomized complete block with five field replicates and planting occurred on 5 June 2023 at Larimore, ND. Emergence notes were recorded through 35 days after planting (DAP) at 2 or 3-day intervals. At 35 days after planting, final stand counts and stems/plant were recorded. The trial was harvested on 28 September 2023. Tuber size profiles and yields (total and marketable) were assessed using an AgRay sorting system at the USDA-ARS East Grand Forks location, with two-point calibration.

Table. 2022-23 Storage treatments to create contrasting physiological age.

		Storage Phase						
	Tuber age[1]	Curing		Aging		Holding[2]		
Trt #	(SDD >4°C)	°C	Day	°C	Day	°C	Lot[3] B	Lot A
1	168	12	21	-	-	4	Oct-21	Oct-28
2	536	12	21	12	46	4	Dec-6	Dec-13
3	546	12	21	22	21	4	Nov-11	Nov-18
4	984	12	21	12	102	4	Jan-31	Feb-07
5	996	12	21	22	46	4	Dec-06	Dec-12

[1] storage degree day (SDD) is the days >4°C prior to storage holding period.

[2] date transferred to 4°C storage holding period.

[3] seed lot 'B' and 'A' were collected from a grower cooperator on September 30th and October 7th, 2022.

Results:

Storage Bruising: Final bruising data will be collected March 2024.

Seed Aging Impact on Bannock Yield Components: No significant differences in total emergence were detected among the seed lots and seed aging treatments in 2023 (Table 2). We were expecting to observe more rapid emergence from aged seed treatments. However, the delayed June planting date may have masked our ability to detect difference in emergence rate among the seed age treatments in 2023. The date of 50% emergence was not significantly different among seed age treatment or seed lots (data not shown). Aging treatment significantly impacted yield components and tuber yields in 2023. Yield differences were also observed between seed lots. With seed lot 'A', the oldest seed tubers of treatment 5 resulted in the highest stem/plant and tubers/plant ratios (Table 3). Similarly, aged treatment 5 in seed lot 'B' had significantly higher stems per plant. However, in seed lot 'B', both the control and aged treatment 5 had similarly high tubers/plant of 5.2 and 5.3 tubers/plant, respectively. There was no clear association between seed age treatment and tuber yields in 2023. The highest total and marketable yields from seed lot 'A' were observed from the 500 SDD (treatment 3). In contrast, the control treatment in seed lot 'B' had the highest marketable yields. With regards to tuber size profiles, increasing seed tuber age generally resulted in a larger percentage of smaller tubers with a concomitant decrease in large tubers (>10 ounce).

Table 2. % Emergence at 17, 24, and 35 days after planting (DAP) among two ND Bannock Seed Lots (2023)[1].

	% Emergence (17, 24, and 35 DAP)					
	17		24		35	
Lot	A	B	A	B	A	B
Age Trt#[2]						
Control (T1)	17	40	72	79	88	79
500 SDD (T2)	16	28	60	72	80	86
500 SDD (T3)	28	36	80	81	83	90
900 SDD (T4)	20	17	61	69	82	85
900 SDD (T5)	32	42	72	71	82	73

[1] seed pieces were cut on May 15, 2023 and stored at (10°C) prior to planting on June 5, 2023 at Larimore, ND. Emergence notes were recorded in 2-day intervals.

[2] aging treatments are defined in Table 1, where treatment (T1) is control, T2, T3 are moderately aged, and T4, T5 are the oldest aged seed. SDD storage degree day (SDD) is the days >4°C prior to seed storage holding period.

Table 3. Impact of seed age on yield parameters from two ND Bannock seed lots (2023).

Seed Lot 'A'			% Tuber Size Profile			CWT/A	
Age Trt[4]	S/P[1]	T/P[2]	<4 oz	4-10 oz	>10 oz	Total	MRKT[3]
Control (T1)	2.2c[5]	2.7c	30.8	35.9	33.3	214.0b	194.1b
500 SDD (T2)	3.0b	3.9b	36.0	38.0	25.9	241.5a	215.9b
500 SDD (T3)	2.9b	3.8b	26.0	41.8	32.2	284.7a	264.6a
900 SDD (T4)	2.4c	3.3bc	32.4	41.2	26.3	217.9b	196.6b
900 SDD (T5)	3.9a	5.0a	49.8	35.1	15.5	240.2a	193.7b
Seed Lot 'B"							
Control (T1)	2.9b	5.2a	39.0	38.3	22.7	299.8a	262.6a
500 SDD (T2)	2.7b	3.3b	32.5	33.5	34.0	249.9a	226.3b
500 SDD (T3)	2.8b	3.8b	35.6	43.7	20.7	247.6a	218.2b
900 SDD (T4)	2.3b	3.6b	35.3	38.7	26.0	248.3a	220.9b
900 SDD (T5)	3.8a	5.3a	46.6	33.9	19.5	265.3a	222.7b

[1] S/P = stems per plant

[2] T/P = tubers per plant

[3] marketable yield is reported as the total yield minus the undersized (<4 ounce) tubers.

[4] SDD storage degree day (SDD) is the days >4°C prior to seed storage holding period.

[5] means within a seed lot column that have the same letter are not statistically significant different ($P \leq 0.05$).

Processing Quality of Yellow Flesh and New Varieties: Processing quality of Fontane and select clones is reported (2023 crop). Processing quality will be evaluated through June 2024.

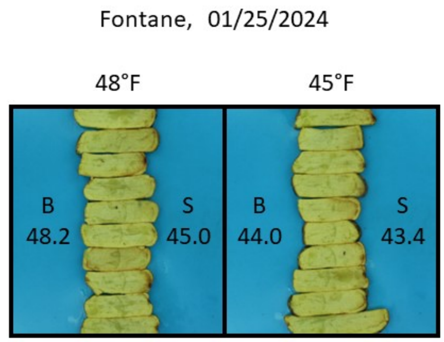

Figure 1. Fry processing of Fontane stored 48 or 45°F. Samples were fried for 3.5 minutes at 375°F and photovolt % reflectance of bud (B) and stem (S) is reported.
According to Photovolt manufacturer, % reflectance corresponds to USDA Munsell Color Chart where: USDA 1 > %44; USDA-2 = 35-44%, USDA-3 = 26-35%, and USDA 4 < 26% reflectance.

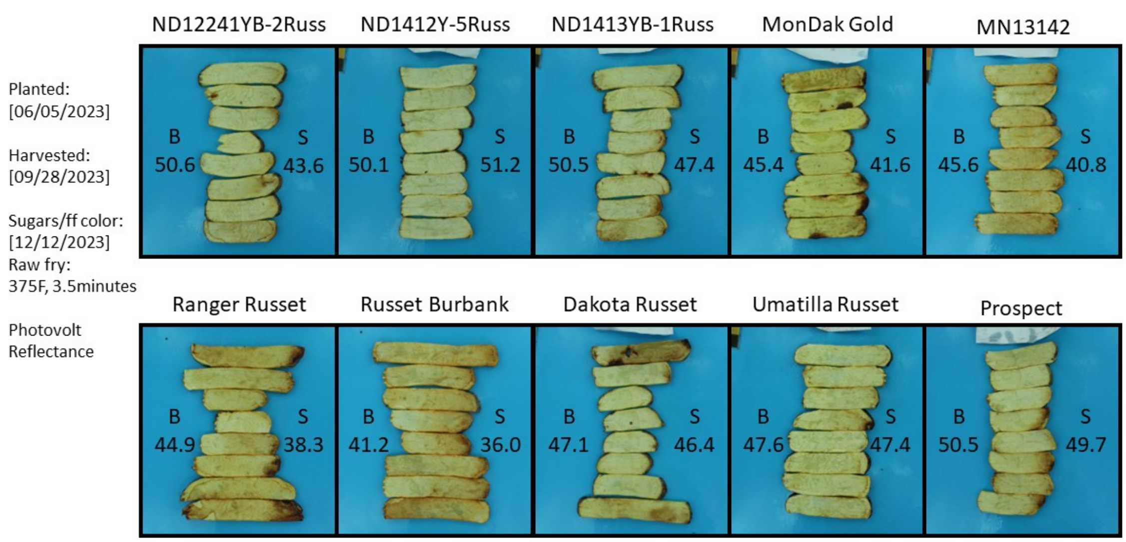

Figure 2. December fry processing of select processing clones (2023 crop). Samples were fried for 3.5 minutes at 375°F and photovolt % reflectance of bud (B) and stem (S) is reported.

According to Photovolt manufacturer, % reflectance corresponds to USDA Munsell Color Chart where: USDA 1 > %44; USDA-2 = 35-44%, USDA-3 = 26-35%, and USDA 4 < 26% reflectance.

Northland Potato Growers Association and Minnesota Area II Potato Growers Council

Research Report

Title: Evaluation of Potato Cultivars for Resistance to the Root-lesion Nematode, *Pratylenchus penetrans*

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Collaborators: Drs. Julie Pasche, Gary Secor, and Andy Robinson

Summary

In 2023, greenhouse experiments were conducted to evaluate the susceptibility of nine potato cultivars to the root-lesion nematode *Pratylenchus penetrans* and to determine the ability of seven cover crops to potentially reduce nematode reproduction. It was found that two potato cultivars (Caribou Russet and Modoc) were susceptible when compared to the control (Red Norland), five were moderately susceptible (Hamlin, Teton Russet, Columba, Musica, and Dakota Pearl), and only one was moderately resistant (Agata). The cover crop experiment determined that compared to the susceptible control (Red Norland), three crops (Vernema alfalfa, Castle Russet potato, and winter rye) were resistant to the root-lesion nematode, two cover crops (Litchi tomato and High Five alfalfa) were moderately resistant, and two mustard varieties (IdaGold and Pacific Gold) were moderately susceptible. It was also determined that IdoGold seed meal and Pacific Gold seed meal could potentially reduce the root-lesion nematode populations by 83% and 72%, respectively.

Background

Pratylenchus penetrans is the most economically damaging root-lesion nematode species affecting potato. In our previous nematode surveys, we collected 83 soil samples from five counties in ND and MN, and detected eight groups of nematodes in potato fields. Root-lesion nematodes were found in over 50% of the samples, and 30 samples (36%) were infested with *P. penetrans.* Some potato roots were found to contain up to 1,100 *P. penetrans*/g of fresh roots. *P. penetrans* is highly virulent and are usually controlled with nematicides. However, chemical nematicides are expensive and not environment-friendly. Growing resistant potato cultivars and use of poor hosts are the most-effective, economic and environmentally sound approach to control *P. penetrans*. We tested 11 potato cultivars for their responses to *P. penetrans* in previous experiments and the popultaion densities increased at least 3.5-fold and none of the cultivars showed ressitance. With last funding support from NPGA and Minnesota Area II Potato Growers Association, we tested ten cover crop species/cultivars and seed meals for the hosting and population reduction abilities to *P. penetrans* in 2022. From the one-time experiment, we found that Alfalfa cultivar Vernema reduced the nematode population and showed a poor hosting ability to *P. penetrans*, but Alfalfa (High Five) increased the nematode population showing a good hosting ability. Application of mustard Pacific Gold seed meal to *P. penetrans*-infested soil reduced the nematode population but Idagold seed meal maintained the nematode population. Litchi tomato and winter rye (Dacold) as well as mustard seeds of Pacific Gold and Idagold increased the nematode population showing good or excellent hosting abilities. These entries need to be validated by conducting more trials to confirm their responses to *P. penetrans*. The resistance level, hosting ability and population reduction ratings of these crops will be summarized and made available to growers. This information is important to help growers select resistant potatoes and better cover crops for their infested fields to control the nematode disease to increase potato tuber yield.

Root-lesion nematodes (*Pratylenchus* spp.) are the most common nematode pests of potato. Several species in this group are detrimental to potato (Mahran et al. 2010). Among the species, *P. penetrans* is the most economically damaging root-lesion nematode species (Waeyenberge et al. 2009, Neupane and Yan 2023). The yield of potatoes was reduced by 50% in an affected field in Norway. Potato plant growth was negatively correlated with densities of *P. penetrans and the damage threshold was suggested at 100 nematodes per 250 g of soil (*Holgado et al. 2009*). In USA and Canada, P. penetrans causes economic losses on potato when acting alone, but even more severe losses by interacting with Verticillium* wilt fungi, causing the Potato Early Die disease complex. This disease complex causes significant reduction in tuber size and total marketable yield and therefore is a limiting factor in potato production (Mahran et al. 2010). More than 450 plant species have been reported to be host to *P. penetrans*. *P. penetrans* are distributed globally infecting potato in Asia (Khan and Hussain 2004); Europe (Philis 1995; Esteves et al., 2015); Australia (Harding and Wicks 2007); and North America (Dickerson et al. 1964; Brown et al. 1980; Olthof et al. 1982; MacGuidwin and Rouse 1990; Baidoo et al. 2017). The broad host range observed in numerous commercially cultivated crops facilitates the rapid reproduction of *P. penetrans*, posing a significant challenge to their effective management (Townshend 1984; Davis and Ann 2000).

The use of resistant varieties and biological and chemical methods have been deployed to reduce the nematode population density in infested soil. However, many management strategies involving nematicide use has limitations, such as negative impacts on human health, the environment, and long-term soil viability. In addition to being expensive, this technique is also detrimental to other beneficial organisms (Dyrdahl-Young et al. 2020). Several fumigants have been discontinued in many countries globally. Some of the resistant potato cultivars used in the past are no longer commercially grown, and currently, there is little or no available update on resistant cultivars against *P. penetrans* (Orlando et al. 2020). Cultural practices such as crop rotation, organic amendments, cover crops, biofumigation, and eliminating weeds during harvest and the off-season can play a crucial role in controlling root-lesion nematodes in potato fields (Castillo and Vovlas 2007).

Cover cropping has potential to control plant-parasitic nematodes, and are generally not toxic to beneficial organisms and subsequent crops (McKeown and Potter 2001). Potential advantages of cover crops include improved soil health, reduced weed growth, reduced soil erosion, increased soil organic matter structure, enhanced nutrient control and cycling, promotion of beneficial soil microorganisms, and pest and pathogen control. However, some cover crops can be excellent hosts to root-lesion nematodes, while others can reduce nematode reproduction (Neupane and Yan 2023).

The objectives for this project were 1) to evaluate seven additional potato cultivars for their resistance responses to the root-lesion nematode *P. penetrans* and 2) *to validate the* hosting and population reduction abilities of ten entries of cover crops and controls to identify effective strategies for managing *P. penetrans* in potato fields.

Materials and Methods

Selection of potato cultivars and cover crops

Nine cultivars of potato used in the region were included in the greenhouse experiments under controlled conditions. These entries include Red Norland (positive control), Caribou Russet, Hamlin, Teton Russet, Modoc, Columba, Musica, Agata, Dakota Pearl, and Manistee (Table 1). Red Norland has been used in many previous experiments and has shown to facilitate good root-lesion nematode reproduction, so was included as the positive control, and unplanted infested soil was a negative control. However, Manistee potato did not germinate in any of the pots and were later removed from the analysis in the final results. Each experimental treatment (cultivar) had five replications and all results of all replications were averaged during analysis.

Cover crops and seed meals were tested for their reaction to the *P. penetrans* in the greenhouse under controlled conditions to validate our previous trial. These entries include alfalfa (cultivars Vernema and High Five), winter rye (Dacold), litchi tomato, mustard seeds and meals of *Sinapis alba* (IdaGold) and *Brassica juncea* (Pacific Gold), and potatoes (Castle Russet and Red Norland) (Table 2). Potato (Red Norland), a known susceptible cultivar, was included as a positive control. An unplanted infested soil treatment was also included as a negative control. The cover crop seeds were acquired from Allied Seed (Nampa, ID), National Small Grains Collection (Aberdeen, ID), Gilleshammer-Thiele Farms Inc. (St. Thomas, ND), Great Northern AG (Plaza, ND), and Pulse USA (Bismarck, ND). The mustard seeds and seed meals were acquired from Farm Fuel Inc. (Freedom, CA). Each experimental treatment was replicated five times and results of all replications were averaged for data analysis.

Inoculum preparation and greenhouse experiments

Cultivar experiment:

Root-lesion nematodes, *Pratylenchus penetrans*, were collected from a field in Central Minnesota and found to have an average population of 470 individual nematodes per kg of soil. Potato tubers were initially cut into 2-3 seed pieces and allowed to sprout in a brown paper bag in a climate-controlled room at 10ºC and 80% humidity for 10 days. On 8/25/23, the sprouted tuber pieces were planted in a plastic 20 cm x 15 cm black plastic pot with 1.5 kg of the naturally infested soil after thorough mixing to ensure even nematode distribution of approximately 700 root-lesion nematodes per 1.5 kg pot. Each potato seed piece was planted by placing them 1" below the soil line. Experiment was terminated on 11/14/23 and contents of each pot were placed in a plastic bag for transportation to laboratory for nematode extraction and quantification.

Cover crop experiment:

Root-lesion nematode, *Pratylenchus penetrans* collected from a potato field in Central Minnesota was increased in the greenhouse for three months using a susceptible potato cultivar Red Norland. The potato tubers were initially sprouted on moist paper towels placed in a plastic tray for ten days before planting. The sprouted tubers were cut into 2-3 pieces and a single piece of sprouted potato tuber was planted in a plastic pot (20 cm × 15 cm, 1.5 kg soil capacity) containing naturally infested soil and grown in greenhouse conditions (16 hours of daylight and an average temperature of 22ºC). After increasing the nematode population for three months, the potato plants were harvested and nematodes were extracted from soil and roots for quantification. Soil from all pots was mixed thoroughly and three soil subsamples were taken to extract nematodes using the sugar centrifugal floatation method (Jenkins 1964). Nematodes were then identified and quantified under an inverted light microscope (Zeiss Axiovert 25, Carl Zeiss Microscopy, NY, USA). The infested soil and the required amount of pasteurized soil for the experiment were thoroughly mixed for even nematode distribution. Three subsamples from the newly mixed soil were then taken to determine the initial nematode population for the experiment using the same extraction described above. The initial nematode contains a mixed population of *P. penetrans*, including all stages of juveniles and adults.

This trial was set up in October 2023 with an initial nematode population of 687 *P. penetrans* per kg of soil. All treatments have five replicates and cover crop seed was planted by directly placing them at approximately 1" below the soil. The potato cultivars (Castle russet and Red Norland) were pre-sprouted before planting. The seed meals were incorporated by evenly mixing them into 1.5 kg of infested soil per pot at 1% (weight/weight), equivalent to 15 g of seed meal per 1.5 kg of infested soil. The emerging seedlings were thinned to the appropriate number of plants per pot (Table 2) after their establishment and the healthiest or best plants were kept in the pots.

Both experiments were conducted in the Agriculture Experiment Station, NDSU greenhouse, in controlled conditions (16 hours of daylight and an average of 22ºC) for 12 weeks. The plants were watered daily and maintained during the growing period (Figure 3). During harvesting, the plant height was taken, plant tops were removed, roots were gently separated from the soil, and they were stored in a cold room at 4ºC in separate individual plastic bags until they were processed.

Processing of harvested soil samples and identification and quantification of nematodes from soil and roots

Nematodes were extracted from a 250 g soil sub-samples of each pot after harvest using the sugar centrifugal floatation method (Jenkins 1964). Root samples were also collected, weighed, and nematodes were extracted using Whitehead trey method (Whitehead and Hemming 1965). Nematodes were identified and counted using an inverted light microscope (Zeiss Axiovert 25) and the nematode population extracted from 250 g of soil was converted to the total number of *P. penetrans* in 1.5 kg of soil. The nematodes from the roots were also counted and converted to nematodes per gram of root tissue. Total nematodes from the soil and nematodes from total root tissue were added together to get total number of nematodes per pot, which was used for data analysis.

Reproductive factor and hosting abilities ratings

The reproductive factor (Rf) for each treatment (crop cultivar) was calculated by dividing the final nematode population density on the tested crop (nematodes from soil and roots) by the initial population density after the trial after termination. Resistance rating was based on the categorization relative ratio values into four classes: R = Resistant (<25% of susceptible control), MR = Moderately Resistant (26%-50%) MS = Moderately Susceptible (51%-75%), S = Susceptible (>75%) (Smiley et al. 2014).

Data analysis

The average final population densities, reproduction factors (Rf), and nematodes per gram of root (NPG) of nematodes in potato cultivars were analyzed using the SAS software (SAS 9.4, SAS Institute Inc. Cary, NC). The average final population density was determined by adding the nematode population from the soil and roots from each pot. Nematodes per gram of roots were calculated by dividing the number of nematodes from roots by the grams of roots. The general linear model (GLM) with Tukey's honestly significant difference (HSD) mean separation at a significance level of 5% was used to determine the significant difference in the values of final nematode population densities for the tested potato cultivars ($P < 0.05$).

Results and Discussion

The cultivar Red Norland, the positive control, had the greatest amount of nematode reproduction (Rf = 7.25), with Caribou Russet (7.2), Modoc (5.6), Musica (4.97), and Hamlin (4.61) not being significantly different from the positive control. Columba (4.22), Dakota Pearl (4.18), Teton Russet (3.71), and Agata (3.47) had significantly less reproduction than the positive control (Figure 1, $P < 0.05$). Three cultivars (Red Norland, Caribou Russet, Modoc) met the criteria to be classified as susceptible host with nematode reproduction being greater than 75% of the susceptible control. Five cultivars (Hamlin, Teton Russet, Columba, Musica, and Dakota Pearl were classified as moderately susceptible with nematode reproduction between 50-75% of the susceptible control. Only one cultivar (Agata) was classified as moderately resistant with nematode reproduction between 25%-50% of the susceptible control (Table 1).

While in most cases, the more total nematodes in the pots were correlated with nematodes present in the roots at the time of harvest, there are a few notable exceptions. For example, even though Teton Russet had significantly fewer nematodes overall, there was a higher concentration of them present in the roots, which could lead to greater damage potential as only nematodes actively feeding on root tissue contribute to symptoms.

The two alfalfa cultivars (Vernema and High five) tested in this trial both showed a poor hosting ability to *P. penetrans* with a reproductive factor (Rf) less than 1 (Figure 2). Alfalfa (Vernema) reduced the initial population by 68%, validating our previous trial with a 31% reduction ability. Alfalfa (High Five) showed a population reduction ability of 50% in this trial, indicating contrasting results to our previous trial, which was identified as a good host. Winter rye (Dacold) and Litchi tomato reduced the initial nematode population by 50%, showing poor hosting abilities, having an Rf of 0.46 and 0.50, respectively (Figure 2), compared to our previous trials, which had good hosting ability.

The mustards (Pacific Gold and IdaGold) and seed meals evaluated in this trial for their reaction to *P. penetrans* had a consistent result with our previous trial. The Pacific Gold and IdaGold maintained the initial population with a Rf slightly greater than one (Figure 2), and increased the initial population by 25 and 13% respectively. However, both mustard (Pacific and Idagold) seed meals showed a high reduction ability of 72% and 83%, respectively, indicating their potential to suppress the reproduction of *P. penetrans*. Several previous studies have demonstrated the hosting abilities of Pacific gold and IdaGold to *P. penetrans*. Rudolph et al. (2017) reported a multiplication of *P. penetrans* in Pacific Gold and IdaGold with Rf ranging between 1 to 3. Similarly, Belair et al., (2007) indicated an increase in *P. penetrans* in brown mustard (*Brassica juncea*), identifying it as an excellent host. Studies have also shown the efficacies of mustard seed meal in suppressing *P. penetrans*. Zasada et al., (2009) reported that glucosinolate compounds from *Brassica juncea* seed meal may be the key factor in nematode suppression. They further indicated that *Sinapis alba* seed meal influenced nematode suppression, achieving 93% suppression of *P. penetrans*. *Globodera pallida* exposed to *Brassica. juncea* seed meal extract at 4.5 t/ha exhibited a 90% reduction in egg hatch compared to a non-amended control (Dandurand et al. 2017). Similarly, *B. juncea* inhibited nematodes without phytotoxicity at 90 or 120 g seed meal/L and showed potential for controlling root-knot nematode in bermudagrass (Handiseni et al. 2017). The results of these previous studies were consistent with tested crops in our previous findings (trial) and this validation trial.

As expected, potato (Red Norland) increased the initial nematode population by almost 90%, consistently showing its potential susceptibility to *P. penetrans*. Potato (Castle Russet) showed a poor hosting ability to *P. penetrans* (Rf=0.34) and suppressed the initial nematode population by 66% (Table 3). Unplanted infested soil (fallow) reduced the initial nematode population by 78%. This study showed no significant difference between the tested mustard seed meals and the unplanted (fallow) infested soil (Table 3).

Conclusions

This research indicated that there are a large number of potential hosts for the root-lesion nematode, and only the potato cultivar Agata showed moderate resistance. Also there is great potential for cover crops such as Alfalfa, winter rye, and litchi tomato to manage root-lesion nematode infestations. Lastly, seed meals incorporated into soil could be a potential treatment to reduce root-lesion nematode population levels compared to the susceptible potato check. More research is required to validate these findings.

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Table 1. Mean final population densities of nematode on roots and soil combined, relative ratio compared to susceptible control, resistance ranking, and nematodes per gram of root (NPG) for potato cultivars and controls tested in this study for resistance reactions to the root lesion nematode, *P. penetrans,* in a greenhouse trial*

Potato Cultivar	Final population [w]	Relative Ratio[x]	Resistance Rating [y]	NPG [z]
Unplanted Control	0 c	0	-	0 c
Red Norland	5,075 a	100%	S	300.16 a
Caribou Russet	5,040 a	99.3%	S	214.31 ab
Hamlin	3,228 ab	63.6%	MS	182.03 ab
Teton Russet	2594 b	51.1%	MS	245.47 a
Modoc	3918 ab	77.2%	S	267.69 a
Columba	2,951 b	58.1%	MS	55.26 bc
Musica	3,481 ab	68.6%	MS	137.76 abc
Agata	2,426 b	47.8%	MR	56.03 bc
Dakota Pearl	2,923 b	57.6%	MS	142.40 abc
Manistee**	-	-	-	-
Pr > F	0.0001			

*The trial was initiated in August 2023 with the initial nematode population density of 700 *P. penetrans*/1.5kg of soil.

**Manistee tubers were destroyed halfway through the experiment by latent bacterial infection present on the tuber surface.

[w] Mean final population density is the mean of final population densities of nematodes from five replications of each treatment and was obtained by adding total nematode population from roots and total nematode population from soil in a single experimental unit (pot). Mean final population densities with same letters are not significantly different ($P < 0.05$).

[x] Relative ratio was calculated by dividing the final population density of *P. penetrans* in the test cultivar by the final density of *P. penetrans* in susceptible control.

[y] Resistance rating was based on the categorization of relative ratio values into four classes: R = Resistant (<25% of susceptible control), MR = Moderately Resistant (26%-50%), MS = Moderately Susceptible (51%-75%), S = Susceptible (>75%) (Smiley et al. 2014).

[z] Nematodes per gram of root is the number of nematodes recovered from root tissue divided by the grams of roots. Mean final population densities with same letters are not significantly different ($P < 0.05$). - = resistance ranking not available.

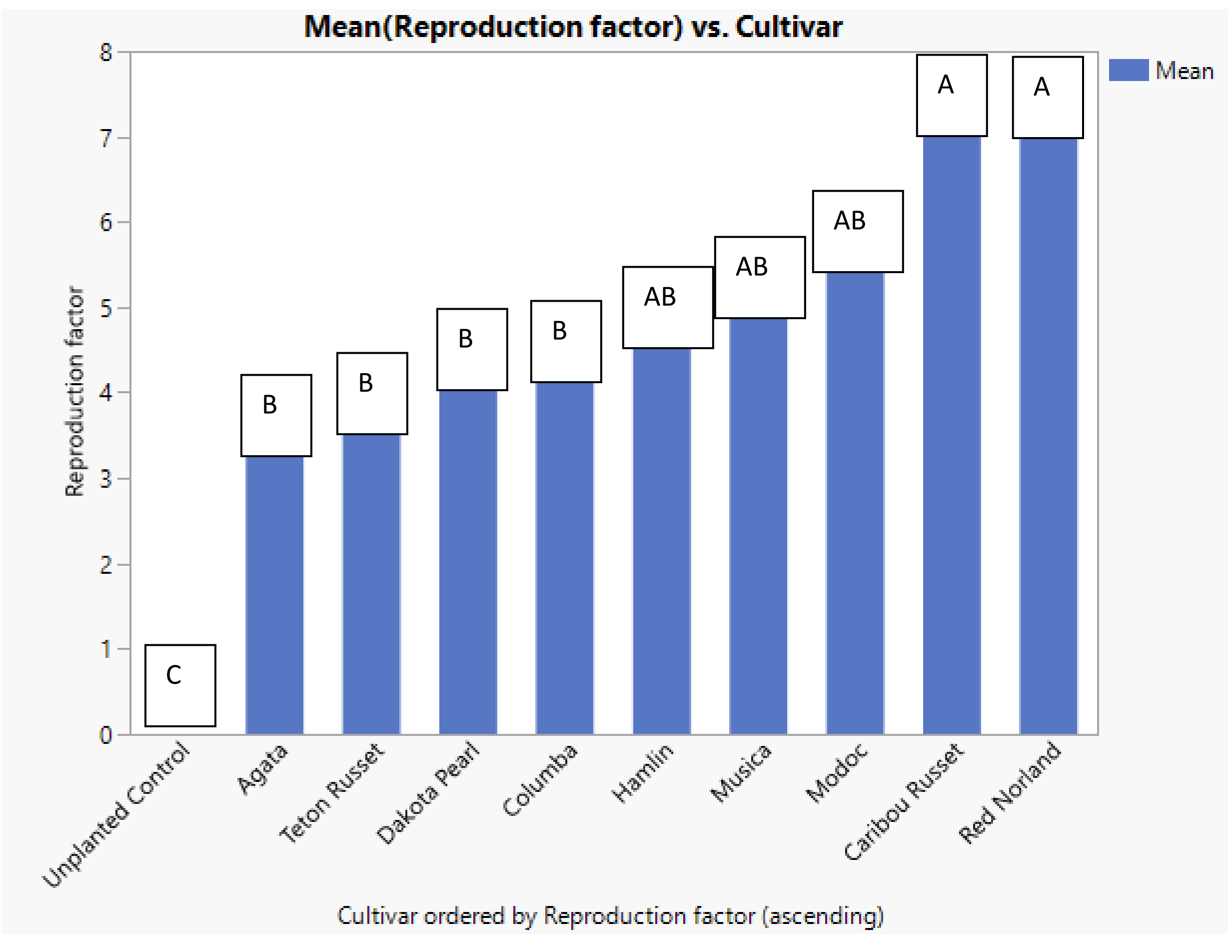

Figure 1. Reproduction factor of *Pratylenchus penetrans* on different potato cultivars. Bars not sharing common letters are significantly different from each other (P<0.05).

Table 2. List of crops tested for their host status to the root-lesion nematode, *Pratylenchus penetrans* under controlled greenhouse conditions

Crop (cultivar)/seed meal	**Scientific name**	**Family**	**No. of plants per pot**
Alfalfa (Vernema)	*Medicago sativa* L.	Fabaceae	4
Alfalfa (High Five)	*Medicago sativa* L.	Fabaceae	4
Litchi tomato	*Solanum sisymbriifolium*	Solanaceae	2
Mustard seed (Pacific Gold)	*Brassica juncea*	Brassicaceae	2
Mustard seed (Idagold)	*Sinapis alba*	Brassicaceae	2
Potato (Castle Russet)	*Solanum tuberosum*	Solanaceae	1
Potato (Red Norland)	*Solanum tuberosum*	Solanaceae	1
Winter rye (Dacold)	*Secale cereale* L.	Poaceae	2
Mustard seed (Pacific Gold)*	*Brassica juncea*	Brassicaceae	-
Mustard seed (Idagold)*	*Sinapis alba*	Brassicaceae	-

* indicates seed meals used in the experiment.

Table 3. Mean final population densities, reproductive factor (Rf), population reduction percentage (PRP), and resistance ranking of cover crops and controls tested in this study for hosting ability of the root lesion nematode, *P. penetrans*, in a greenhouse trial*

Cover crop (cultivars)/seed meal	**Final population** [w]	**Relative ratio** [x]	**Resistance rating** [y]	**PRP** [z]
IdaGold seed meal	120 c	8.9%	-	83 c
Unplanted infested soil	154 c	11.6%	-	78 c
Pacific Gold seed meal	194 c	14.7%	-	72 c
Alfalfa (Vernema)	220 c	16.8%	R	68 c
Potato (Castle Russet)	236 c	16.8%	R	66 c
Winter rye (Dacold)	316 c	24.2%	R	54 c
Litchi tomato	341 c	26.3%	MR	50 c
Alfalfa (High Five)	341 c	26.3%	MR	50 c
Mustard Seed (IdaGold)	777 b	59.5%	MS	-13 b
Mustard Seed (Pacific Gold)	857 b	65.8%	MS	-25 b
Potato (Red Norland)	1300 a	100%	S	-90 a

*The trial was initiated in October 2023 with the initial nematode population density of 687 *P. penetrans*/1.5 kg of soil.

[w] Mean final population density is the mean of final population densities of nematodes from five replications of each treatment and was obtained by adding the total nematode population from roots and the total nematode population from soil in a single experimental unit (pot). Mean final population densities with the same letters are not significantly different ($P < 0.05$).

[x] Relative ratio was calculated by dividing the final population density of *P. penetrans* in the test cultivar by the final density of *P. penetrans* in susceptible control.

[y] Resistance rating was based on the categorization of relative ratio values into four classes: R = Resistant (<25% of susceptible control), MR = Moderately Resistant (26%-50%), MS = Moderately Susceptible (51%-75%), S = Susceptible (>75%) (Smiley et al. 2014).

[z] Population reduction percentage (PRP) is the average of % reduction in nematode populations from five replications for each treatment. Nematode population reduction (%) = (initial population density on the tested crop - final population density on the tested crop)/initial population density x 100. Negative (-) PRP indicates nematode population increase in treatments.

- = Host ranking not available.

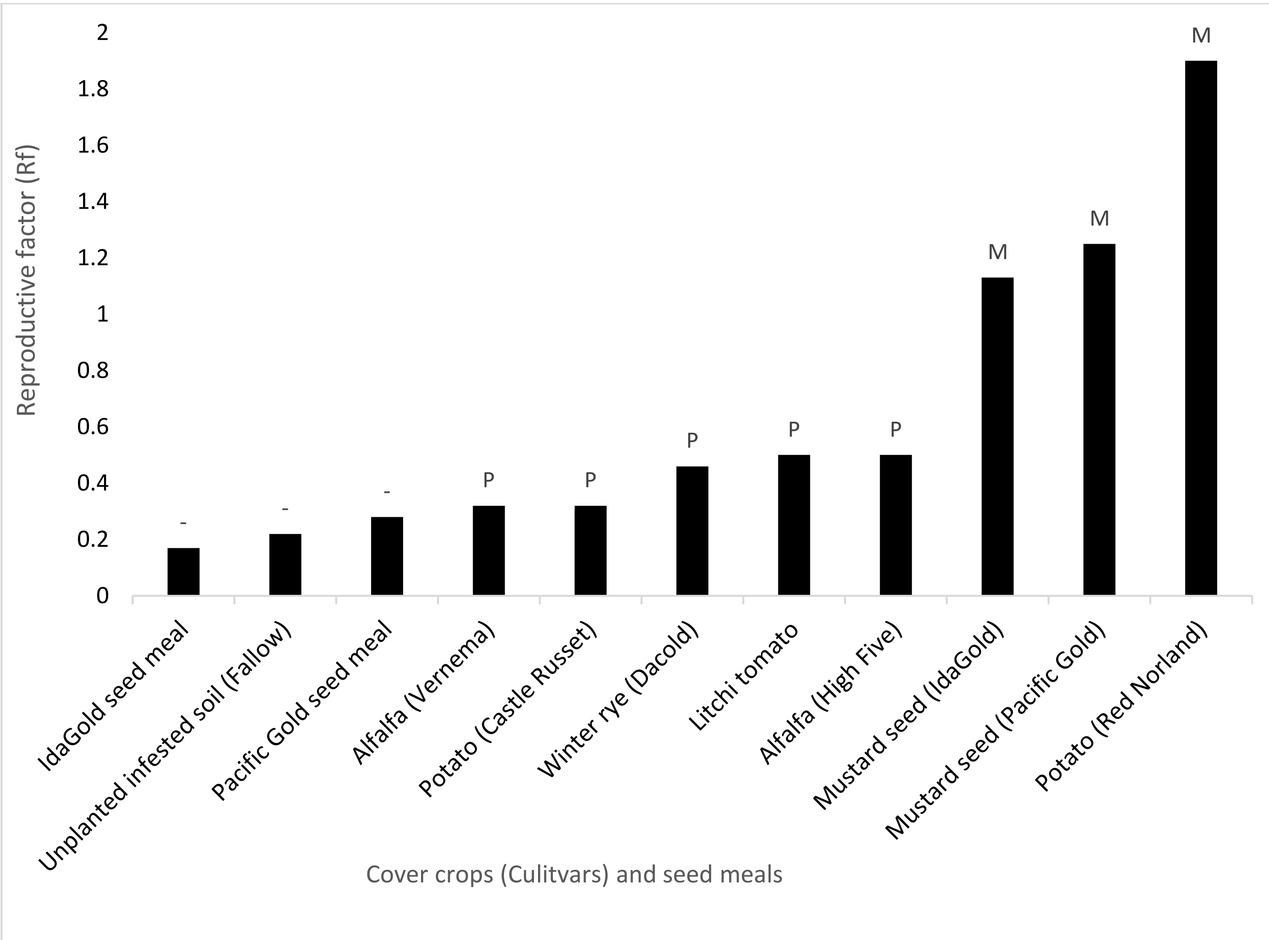

Figure 2. Host status of the cover crops included based on the average reproductive factor (Rf). Rf is the mean reproductive factor for each crop cultivar and refers to the final population density of *Pratylenchus penetrans* in the tested cultivar divided by the initial population density of the nematode. Host status was based on the categorization of Rf values into five classes: N = non-host (Rf < 0.15), P = poor host (Rf = 0.15 to 1.0), M = maintenance host (Rf = 1.0 to 2.0), G = good host (Rf = 2.0 to 4.0), and E = excellent host (Rf > 4) (Mbiro and Wesemael 2016). Seed meals with (-) = Host ranking not available.

Figure 3. Greenhouse experiment showing cover crops and seed meals before termination.

Potato Insect Management 2023

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Executive Summary – This is a project to develop and refine management tactics for 2 of the major insect pests of potato, Colorado Potato Beetles, and Aphid Vectors of virus disease in Minnesota and North Dakota. This proposal will include: 1) updating the geographic patterns of Colorado Potato Beetle resistance in Minnesota and North Dakota, 2) Assessing the ability of Colorado Potato Beetle to non-mechanically vector PVY, and 3) maintaining an aphid trapping and monitoring network for aphid vectors of virus disease in potatoes (especially PVY) and providing near real-time maps of aphid population distribution in MN and ND throughout the growing season. This information will assist in making management decisions for Colorado Potato Beetle and the timing of treatments to prevent the spread of PVY within seed potato fields..

Rationale – Colorado Potato Beetle (CPB), *Leptinotarsa decemlineata* Say, is the most damaging defoliating insect pest of potatoes in North America (Alyokhin 2009). In most years in Minnesota and North Dakota, this insect typically has a single true generation. They overwinter as adults in areas surrounding the production field, emerging in spring to enter this year's fields. They do minimal feeding while mating and laying eggs and then die. The resulting larvae are significant early season defoliators, feeding voraciously (esp the older stages) as they grow. They eventually drop to the ground and pupate. Summer adults emerge from the soil and cause a second wave of serious defoliation as they feed to prepare for overwintering. Until recently, this meant two distinct peaks of feeding in the growing season.

In the past 25 years, at-plant applications of neonicotinoid insecticides have controlled CPB populations well. Unfortunately, this tactic is becoming less effective. This insect has a pronounced ability to develop insecticide resistance (Weisz et al. 1994, Alyokhin et al. 2007, Huseth et al. 2014) (Fig 1). Lower susceptibility (the first stage of a population developing resistance) and full resistance to several insecticides has been documented in MN & ND for several years. Resistance to neonicotinoids is established in Central MN and is increasing in the Red River Valley of MN and ND (MacRae, 2019). The decreasing efficacy of at-plant applications of neonicotinoid insecticides has resulted in an increasing reliance on foliar insecticides.

Colorado Potato Beetle is often referred to as a 'SuperPest' because of its ability to develop resistance to insecticides. There are multiple mechanisms whereby insects can be insensitive to insecticides. Colorado Potato Beetle have demonstrated behavioral resistance, reduced penetration of its cuticle by insecticides, increased excretion rate of insecticides, enhanced enzymatic metabolism of toxins, and insensitivity of the active ingredient's target site. In other words, different populations have: avoided pesticides, or prevented them from entering the body, or excreted them before they could be absorbed across the gut, or broken them down with enzymes if they did get across the gut, or changed the part of the body the insecticide is designed to effect. All of these mechanisms are seldom found in the same population, but it is not unusual to find a population that has several of these mechanisms functioning. There are several reasons CPB are so prone to develop resistance to insecticides; the insect's highly adaptable genotype, ability to enzymatically degrade toxins with its active mixed-function oxidase system, its pre-adaptive ability to consume highly toxic substances (they happily feed on nightshades), and its feeding in a system that requires high agrochemical inputs. Considered together, it's obvious Colorado Potato Beetle's development of resistance to an insecticide is a when, not an if.

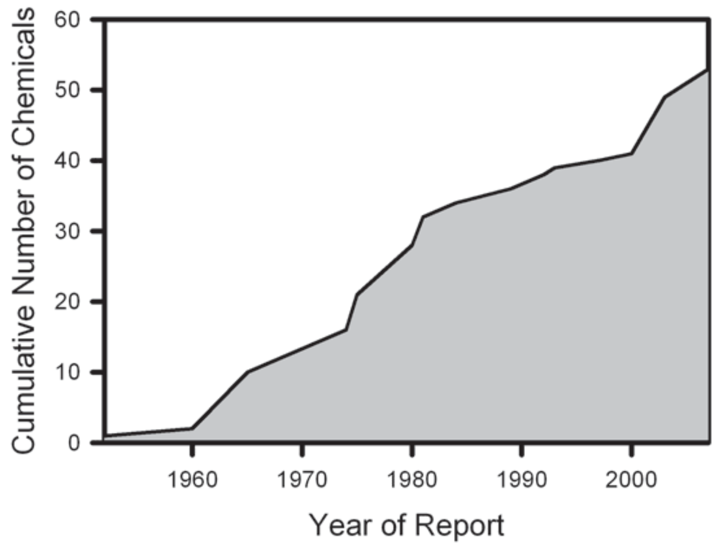


Figure 1. The cumulative number of insecticide active ingredients to which Colorado Potato Beetle has developed resistance, 1950-2006.

Data from MN and ND gathered 2017-19 indicates in some locations, not only is the efficacy of neonicotinoid insecticides decreasing, but efficacy to other modes of action is decreasing as well (MacRae 2019). This decreasing sensitivity to other insecticides is especially concerning. Populations of CPB in central MN showed tolerance to abamectin based insecticides (e.g. AgriMek) and populations from at least one site in ND showed increased tolerance of an anthranilic diamide (chlorantraniliprole, e.g. Coragen). In addition, populations from two organic production sites in MN have shown significant levels of resistance to Blackhawk (Spinosad), which is likely a result of overuse.

If foliar management programs are to remain effective against Minnesota and North Dakota CPB populations, we must manage potential resistance. It is necessary to know prior to application if resistance, or even increasing tolerance, to products has been noted. Otherwise, application may contribute to the development of further resistance.

Consequently, information on the relative efficacy of the available insecticides is necessary to develop working insecticide resistance management programs. The only way to achieve this information is to gather and test populations of CPB from different locations in MN and ND and test their susceptibility to insecticides as compared to a susceptible population. We currently maintain such a 'naïve' colony (i.e. the entire colony has historically never exposed to any insecticide) at the UMN-NWROC in Crookston.

North America seed potato production is suffering an epidemic of aphid vectored, virus causing diseases such as Potato Leaf Roll (PLRV) and Potato Virus Y (PVY). PLRV is a non-persistent (circulative) virus; that means after the insect acquires the virus from an infected plant, the virus undergoes a reproductive period inside the insect vector before it can be transmitted to another plant. This is called a *latency period*, and in PLRV it is approximately 72 hours. Consequently, PLRV is often transmitted by aphids that colonize potato; a winged female lands on the plant, decides it's a suitable food species and deposits a daughter aphid, which reproduces, resulting in a new colony of aphids. The 3-day latency means PLRV transmission can be controlled by well-timed applications of traditional insecticides (there's enough time for the insecticide to kill the aphids before it can transmit the virus).

Conversely, PVY is a non-persistent virus; there is no latency period. The virus can be acquired by an insect vector from an infected plant and transmitted to an uninfected plant in minutes (Bradley 1954). PVY can be transmitted mechanically as well as biologically. Infection is known to occur down tractor rows and on cutting tables. In fact, some biological transmission can also be considered mechanical; virus particles adhere to aphids mouthparts while they suck sap and are wiped off on the next plant upon which it feeds.

Our data from caged trials over the past two years demonstrates that feeding by CPB can also spread PVY, likely in a similar way. The virus is acquired by feeding on an infected plant, likely adheres to the beetle's jaws, and is transmitted to the next plant upon which it feeds. In most cases of mechanical transmission of PVY, the virus is usually wiped off the vector's mouthparts during feeding on the next plant. Some chewing insects, including CPB, tend to frequently regurgitate while feeding. Often, as in CPB, this is an important mechanism the insect uses to avoid exposure to harmful chemicals in the plant (Lawrence et al 2007, 2008). The material regurgitated by insects comes from the *foregut*, which is basically a gizzard where food is mechanically digested and stored before being moved to chemical digestion in the midgut. The midgut is isolated from the foregut, has a much lower pH and is the site of secretion of digestive enzymes. Conditions in the foregut are much more similar to ambient conditions outside the insect. Consequently, PVY may be able to survive and remain viable in the foregut of the beetle and be spread when it regurgitates. The beetle could feed on an infected plant, hold virus for a period of time in it's foregut, and transmit it to uninfected plants over time. Further, because summer adult CPB have strong flight abilities and often move between potato fields, CPB could potentially move PVY between commercial and seed fields.

The most efficient mechanism of testing if virus can persist in the foregut of CPB is to dissect out that section of the gut and test it for the presence of the virus. The best method to assay for PVY RNA would be the use of enzyme-linked immunoassay (ELISA) and Reverse Transcriptase polymerase chain reaction (RT-PCR). These laboratory techniques can positively confirm the presence and strain of any PVY virus present and their techniques are well established.

PVY, because it is a non-persistent virus, is often vectored by aphid species which do not colonize potato. In fact, with regards to PVY transmission, the vector you don't see on the plant is often more important than the ones you do see. A non-colonizing aphid species will fly into a potato field, probing plants to determine if they're appropriate host plants. If they are not appropriate hosts, the aphid will fly to neighboring plants to assess them as hosts (aphids have little to no agronomic knowledge and are unaware it is the same species of plant). Consequently, non-colonizing aphid species will move across a potato field, probing plants and transferring any inoculum present. This process results in non-colonizing vector species spending short periods on multiple plants in a field. This decreases the chance of finding them during normal scouting. Not only does this mean that any PVY inoculum will be readily moved from infected to non-infected plants, but non-colonizing aphids aren't in the field long enough for traditional insecticides to have sufficient time to kill the vector. Traditional insecticides, therefore, will not control the spread of PVY. Rather, the most effective insecticides have been those that quickly cause the insect's feeding behavior to stop.

There are a number of aphid species that vector virus diseases to seed potatoes, the most efficient is green peach aphid, *Myzus persicae* (Sulzer) but several others are also capable of efficiently vectoring the virus. For example, soybean aphids are only 10% as effective in vectoring PVY as is green peach aphid (Davis and Radcliffe 2008) but disperses in such high numbers (Ragsdale et al 2004) they can be an important part of seasonal epidemiology. However, potato is not a suitable host for soybean aphid so it will not colonize the crop. The importance of non-colonizing means that scouting for aphids in potatoes, while an excellent management practice, may not provide a complete picture of the amount of vectors present at a given time.

Application of Aphoil and anti-feeding insecticides can limit the transmission of PVY in colonizing in both aphids that colonize potato and those that don't (DiFonzo et al. 1997, Suranyi et al. 2004, Carroll et al. 2004, 2009, Olson et al. 2004, Hodgson et al 2005). But application timing is critical and treatments must be applied prior to aphid populations dispersing into the field from the margin (this takes about 2 weeks from initial presence of winged aphids). Consequently, accurate methods of monitoring aphid presence are essential. The regional aphid monitoring network, *Aphid Alert*, provides Minnesota and North Dakota seed potato growers near real-time information on virus vector flight activity.

Over the past several years, *Aphid Alert* has provided timely information on aphid vector presence and the seasonal patterns of vector population dynamics. This is an estimate of risk; risk is exposure to hazard. The species of aphids that we monitor have a biological ability to transmit PVY, that's hazard. The traps measure their presence, the exposure to the hazard, that's risk.

Our data has identified that the majority of vector flight occurs starting in late July and through August (Fig 2), reflecting many of the non-colonizing species moving from senescing hosts (e.g. small grains) to seek alternate food sources. This late season flight of aphid vectors confirms that the majority of PVY infection must occur late in the growing season.

The total number of vectors, however, does not tell the complete story. Not all species of aphids are equal in their ability to transmit PVY virus; some species are much more efficient vectors than others. As mentioned, the Green Peach Aphid (GPA) is the most efficient species when it comes to transmitting PVY. We've developed an index, The PVY Vector Risk Index (Fig 2), which uses the number of vector species captured in a trap and their relative efficiency at transmitting PVY to estimate the relative risk of PVY transmission at any given date.

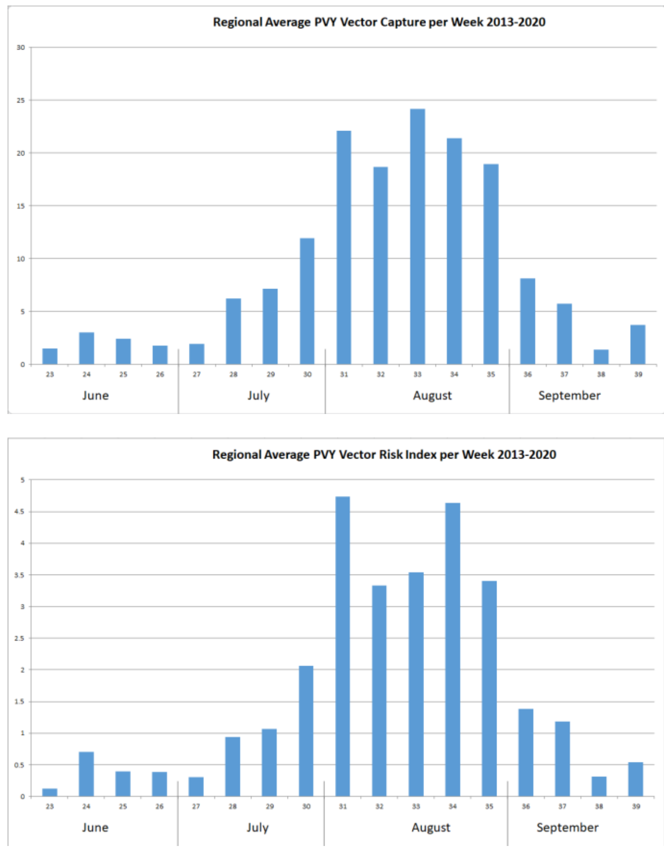


Figure 2. The capture of PVY vectoring aphids in all Aphid Alert traps by week, averaged over 2012-2020 (top graph). And the Regional PVY Risk Index/Week averaged over 2012-2020. The dates were standardized to ISO-8610 week numbers so the data could be compared across years. Note

Regional data also might not reflect what is happening at a specific location. For example, while on average, Vector numbers across Minnesota and North Dakota begin to rise in Mid-July, other sites may not follow this pattern. Some sites, such as Perham, reflect the steady growth of populations starting in mid-July and peaking in August, while other, such as Lake of the Woods, have vector Index peaks not associated with a gradual increase in population (Fig 3).

All of our cooperators have received the historical averaged data for their site. Some sites have fewer years trapping data than others but those data still provide insights into their vector activity. These local data will be used in 2021 to assist in making management decisions.

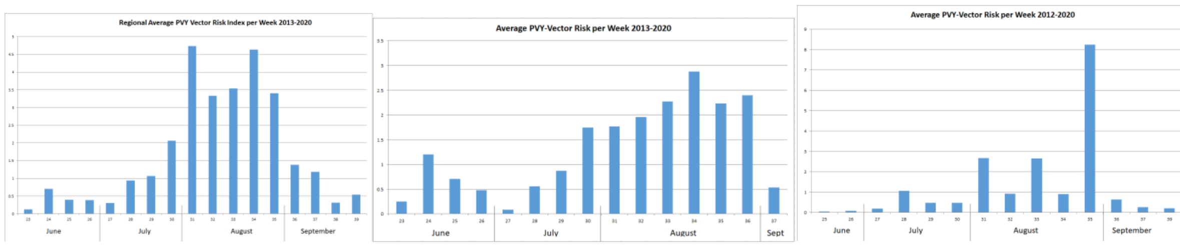


Figure 3. The seasonal PVY Vector Risk Index by week, averaged from 2012-2020 data, for MN & ND (left), Perham (middle) and Lake of the Woods (right). Note the steady ramping of the Index values at Perham vs the concentration of Index values in August at Lake of the Woods.

Over the past several years, the Aphid Alert Network has grown to provide region-wide coverage, estimating the aphid vector populations. The network relies on grower cooperators to maintain and change traps throughout the growing season and send weekly trap catches to the entomology lab at the University of Minnesota's Northwest Research & Outreach Center (NWROC). There the trap contents are sorted, aphid vector species identified and PVY Vector Risk Index values calculated. Since 2012, the *Aphid Alert* network has provided excellent regional coverage of the Minnesota and North Dakota seed producing areas.

The UMN-NWROC Entomology lab will be conducting additional research on CPB and PVY funded by Specialty Crop Block Grants from both the MN and ND Depts. of Agriculture.

In 2022, we propose to:

1. Update the distribution of resistance to insecticides in Colorado Potato Beetle populations in North Dakota and Minnesota production areas.
2. Assess the ability of Colorado Potato Beetle to vector PVY virus from it's mouthparts and foregut.
3. Continue the Aphid Alert Network, providing potato producers with information on the regional distribution and densities of aphid vectors of virus disease and weekly assessments of PVY risk transmission at each trap location.

Procedures

1) Update distribution of resistance to insecticides in Colorado Potato Beetle populations in North Dakota and Minnesota production areas.

Colorado Potato Beetle was sampled by UMN personnel from potato production areas. Samples were obtained from 6 locations in 2023. To adequately test each insecticide with adequate replication, approximately 1500 beetles per location were collected.

Similar to 2022, there were relatively few reports of insecticide failures during the 2023 growing season but several locations did have apparent applications that did not provide the expected efficacy. Adults were collected again in 2023 as laboratory testing indicated a significant handling mortality with the new protocol when it was implemented on a large scale.

Figure 4. Insecticide susceptible Colorado Potato Beetle Colony maintained at the NWROC. This population is insecticide naïve, meaning it has never been exposed to insecticides and is, therefore, considered susceptible to all modes of action. This is

Baseline mortality rates were established using the insecticide-susceptible colony (Fig 4) maintained at the UMN NWROC in Crookston. Sampled beetles will be assessed for susceptibility to registered insecticides. We produce baseline data for Neonicotinoids (e.g. Imidacloprid), Abamectins (e.g. Reaper, AgriMek), Anthranilic Diamides (e.g. Corragen), Spinosyns (e.g. Blackhawk, Delegate), and Indoxaacarbs (Avaunt). Recovered numbers prevented the testing of some other modes of action (although problems have not yet been reported with the groups we did not test).

Resistance/tolerance of CPB from each area was assessed using direct exposure tests. A gradient of concentrations of active ingredient (ai), the actual toxin in the insecticide, was used in trials to create a dose curve that indicated the amount of ai necessary to kill 50% of the population (i.e. the Lethal Dose 50% or 'LD_{50}') and the expected % mortality in the population if exposed to the high label rate of the insecticide.

Direct exposure trials were conducted by applying 10µl (microliter) drops of insecticide directly to the insect using a micro-pipette (Fig 5). Each insecticide was tested with 6 rates: amounts of inseciticide were mixed with Reverse Osmosis H_2O so that the mg/volume would be equivalent to 0x, 1X, 5X, 10X, 25X, and 50X the high label rate of the insecticide (0X were treated with RO water only). Ten beetles were placed in a Petrie plate and each rate had 4 replicate Petrie plates. So, a total of 480 beetles were treated for each insecticide (240 from the field population and 240 from the insecticide susceptible colony as a comparison). After the insecticide has dried on the insect, beetles were placed onto a potato leaf in Petri plates and left to feed for 5-7 days (120h). Beetles were initially assessed for mortality at 24h to determine handling mortality. As CPB often appear intoxicated immediately after exposure but recover after several days, mortality was again be assessed 5-7 days post application (min. of 120h), this was the reading used to assess mortality. Mortality was assessed by placing beetles on their backs and evaluating movement. Any insect not righting itself within 5 minutes is assessed as dead or moribund. The percent mortality of beetles at each rate were graphed to construct dose response curves which could then be compared to the dose response curve from that insecticide when tested on the insecticide susceptible colony.

Figure 5. Micropipette with disposable tips . Unit is capable of

Results – Resistance levels are presented here as the multiple of high label rate instead of mg/vol as it better represents useful management information. In 2023, samples were obtained only from MN locations, there were few locations in ND reporting CPB failures, and those locations were often treated prior to our being able to collect from the field. Locations sampled were Hastings, Becker, Browerville, Perham and Crookston.

There are some caveats to the resulting data that may explain some apparent anomalies with results that may have been observed in the field (Table 1). There were three products tested that are typically applied with the synergist Piperonyl Butoxide (PBO), Abamectins (e.g. Reaper, AgriMek), Indoxacarb (Avaunt), and Tolfenpyrad (Torac). Piperonyl Butoxide works by inhibiting metabolic detoxification enzymes, called Cytochrome P-450 monooxygenases, that can physiologically metabolize toxins (including insecticides). In circumstances where an active ingredient of an insecticide is subject to being physiologically degraded by Cytochrome P-450 enzymes, PBO can decrease that detoxification, resulting in higher levels of the insecticide's active ingredient reaching the toxin's target site. This will result in increasing the efficacy of the insecticide. The bioassays, however, were designed to examine the toxicity of the insecticide and the addition of PBO might skew that finding.

In summary (Table 1) :

- Becker: Abamectins were less effective than other insecticides tested (the high label rate could only be expected to provide 26.6 % mortality of the population. Other insecticides tested, including neonicotinoids surprisingly, performed reasonably well in comparison with Torac being very effective at this location.

- Browerville: only Indoxacarb was tested and its efficacy without PBO was low. (Note: this may not be reflective of field applications wherein PBO has been used as a synergist.)

- Crookston: neonicotinoids did not perform with the efficacy of other products, which performed as expected.

- Hastings: (AMD90W field) – All products tested within expected parameters but there may be some decreased efficacy in Spinosyns and diamides.

- Hastings (Schuler field): Torac performed as expected but Avaunt (in absence of PBO) showed low efficacy. (Note: this may not be reflective of field applications wherein PBO has been used as a synergist.)

- Perham: Torac performed as expected but Avaunt (in absence of PBO) showed low efficacy. (Note: this may not be reflective of field applications wherein PBO has been used as a synergist.)

Table 1. Comparative tolerances of tested insecticides from sampled locations. Data from the *Susceptible Lab Colony* can be used for comparison. This colony is insecticide naïve, it has never been exposed to insecticides. Consequently, resistant alleles within the genotype of the colony, should, therefore, remain at low level. Absence of data indicates the insecticide was not tested for that location.

Location	**Insecticide Name / Active Ingredient / Mode of Action # / Class**					
	Admire / Imidacloprid 4A Neonicotinoid	**AgriMek / Abamectin 6 Avermectin**	**BlackHawk / Spinosad 5 Spinosyns**	**Coragen / Chlorantraniliprole 28 Diamides**	**Torac / Tolfenpyrad 20-21 METI**	**Avaunt / Indoxacarb 22A Indoxacarbs**
Susceptible Lab Colony	*LD$_{50}$= 0.074X 1X= 75.6%*	*LD$_{50}$= <0.00X 1X= 97.7%*	*LD$_{50}$= 0.12X 1X= 87.0%*	*LD$_{50}$= 0.03X 1X= 89.3%*	*LD$_{50}$= 0.38X 1X= 80.5%*	*LD$_{50}$= 1.01X 1X= 49.7%*
UMN SPRF (Becker MN)	LD$_{50}$= 0.002X 1X= 78.4%	LD50= 2.6X 1X= 26.6%	LD$_{50}$= 0.42X 1X= 71.4%	LD$_{50}$= 0.002X 1X= 78.4%	LD$_{50}$= 0.002X 1X=96.3%	
Browerville (Browerville, MN)						LD$_{50}$= 30.73X 1X= 35.32%
UMN NWROC (Crookston, MN)	LD$_{50}$= 2.71X 1X= 38.7%	LD$_{50}$= 0.13X 1X= 87.1%	LD$_{50}$= 0.05X 1X= 87.8%		LD$_{50}$= 0.06X 1X= 91.8%	
AMD90W (Hastings MN)			LD$_{50}$= 0.65X 1X= 56.92%	LD$_{50}$= 0.01X 1X= 62.9%	LD$_{50}$= 0.29X 1X= 79.6%	
Schuler (Hastings MN)					LD$_{50}$= 0.328X 1X= 78.2%	LD$_{50}$= >50X 1X= 16.2%
Hwy 10 (Perham, MN)					LD$_{50}$= 0.57X 1X= 64.78%	LD$_{50}$= 33.3X 1X= 14.33%

LD$_{50}$ – the mount of insecticide (in this case expressed as X the high label rate of the insecticide) that is needed to kill 50% of the population. A lower LD$_{50}$ means less insecticide is required to kill an individual, therefore the lower the LD$_{50}$, the less resistance in the insect population to this insecticide.

1X = the percent of the insect population killed by 1X the high label rate of the insecticide. The higher this number, the less resistance to this insecticide in the insect population.

2) Assess Ability of Colorado Potato Beetle to vector PVY Over Time – This objective was not completed due to staffing issues.

*3**) Aphid Alert Trapping Network***. A network of ~20 3m-tall suction traps were established in the seed potato production areas of Minnesota and North Dakota. These traps consist of a fan, powered by solar panel and deep cell battery, drawing air down in through the trap and trapping the incoming aphids in a sample jar. Traps have a photocell, preventing the fan from running through the night and capturing night flying insects (aphids are day-fliers) reducing the amount of 'bug stew' to be sorted and saving power. The sample jars were changed weekly by grower cooperators who send them to the UMN-NWROC entomology lab. Insects in the jars were sorted and aphids removed. Aphids were then identified to species and aphid population dynamics at sample locations are determined. Maps are generated weekly showing these dynamics. This information was made available to growers on two websites (aphidalert.blogspot.com), via NPGA weekly electronic newsletter (Potato Bytes), linked to on the NDSU Potato Extension webpage (http://www.ag.ndsu.edu/potatoextension), and posted on the AgDakota list serve. Traps were established in early June and maintained until the seed field hosting the trap was vine-killed/harvested. At that point a field is no longer attractive to aphids.

The PVY Vector Risk Index was calculated weekly for each site in the network and averaged across the region as well. This index reflects the fact that aphid species have differing levels of efficiency in their ability to transmit PVY. The PVY Vector Risk Index uses relative transmission efficacies of different aphid vector species to present the relative risk of disease transmission at each location.

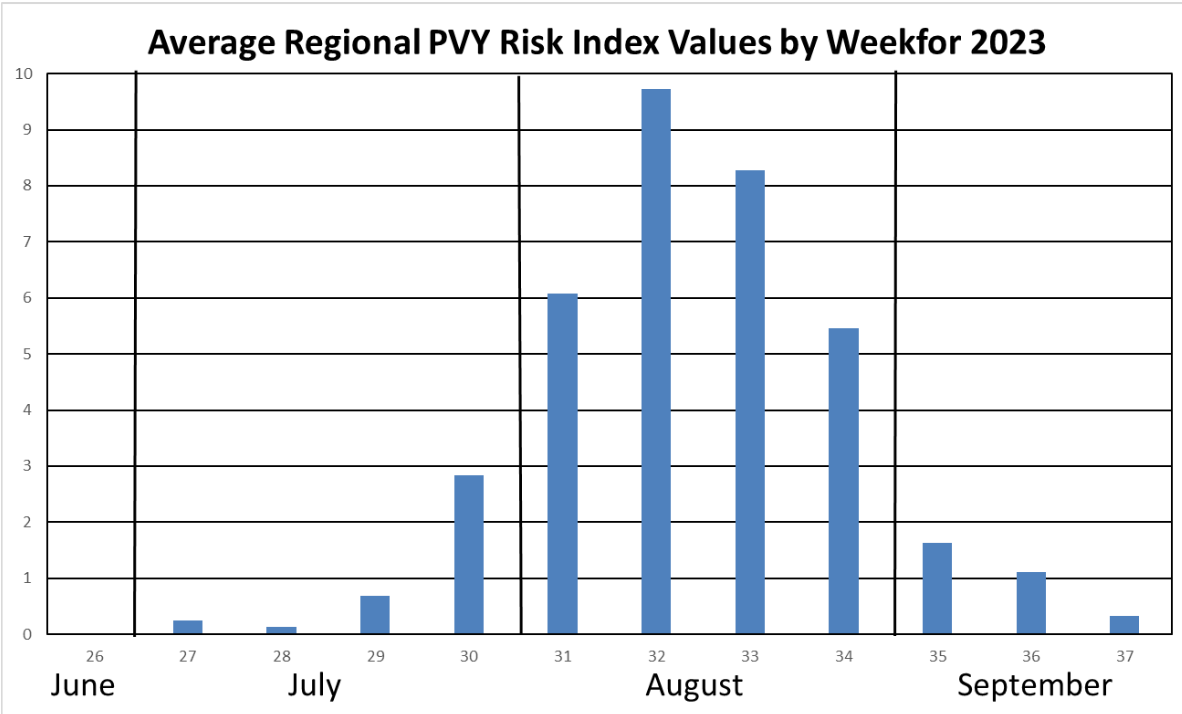
Results – The 2023 season was a *very heavy aphid vector year*. In addition, not only were capture numbers high, but several species present in high numbers were highly efficient PVY vectors (Table 2).

Table 2. Seasonal capture of vector aphid species by location in 2023. Not only were capture number high, indicating high vector populations, but the presence of many highly efficient vector species (e.g. green peach aphid, small grain aphids, potato aphids, etc) increased the likelihood of inoculum transmission within fields.

Row Labels	Sum of Green peach aphid	Sum of Soybean aphid	Sum of Bird cherry oat aphid	Sum of Corn leaf aphid	Sum of English grain aphid	Sum of Green bug	Sum of Potato aphid	Sum of Sunflower aphid	Sum of Thistle aphid	Sum of Turnip aphid	Sum of Cotton/ melon aphid	Sum of Pea aphid	Sum of Foxglove aphid	Sum of Cowpea aphid	Sum of Black bean aphid	Sum of Buckthorn aphid	Sum of Damson Hop Aphid	Sum of Cannabis Aphid	Sum of Identified non-vector	Sum of Total # captured	Sum of Total Vectors	Sum of PVY Vector Risk Index
Becker	18	45	2	12	40	0	19	0	3	0	31	0	3	0	6	2	0	0	30	210	181	34.3
Cando	3	60	3	9	206	0	32	2	39	3	32	0	0	5	12	36	2	0	55	499	444	53.03
Crookston	1	13	0	0	17	0	2	0	4	0	0	0	0	1	0	3	0	0	12	53	41	5.3
Crystal	5	144	3	15	199	0	51	1	70	3	36	1	1	0	8	64	11	0	156	768	612	87.5
Erskine	1	69	0	3	74	0	7	0	6	2	10	0	0	1	3	13	2	0	28	219	191	22.7
Gully	0	54	2	6	84	0	6	0	13	2	21	0	0	0	7	7	0	0	28	230	202	17.64
Hoople	0	63	0	5	114	0	8	2	31	0	18	1	0	0	6	28	0	0	51	327	276	31.06
Lisbon	8	174	0	11	72	0	7	4	36	2	11	0	0	0	1	20	12	1	97	455	359	50.21
LoW	1	19	0	2	17	0	3	0	5	0	5	1	0	0	1	5	0	0	8	67	59	7.77
Nebraska I	0	3	0	0	0	0	0	0	5	0	2	0	0	1	1	0	0	1	7	20	13	0.75
Nebraska II	1	2	0	2	1	0	0	1	1	0	4	0	0	0	0	1	1	0	2	16	14	2.78
Perham	2	56	0	2	8	0	2	0	2	0	8	0	0	1	1	2	1	0	26	111	85	10.65
Sabin	4	79	0	13	37	0	7	1	30	0	22	0	0	1	6	18	4	0	97	315	222	29.29
Staples I	0	30	0	0	9	0	0	0	6	2	6	0	0	1	1	1	0	0	10	66	56	5.02
Staples II	0	28	1	1	5	0	0	0	4	0	7	0	0	0	0	2	0	0	10	58	48	4.55
Stephen	25	138	1	10	224	0	40	12	41	2	25	0	6	0	1	19	8	2	90	644	554	83.24

The high numbers of vectors, and the fact that several species present were very successful vectors, means that there were highly than average chances of inoculum being spread in the field. The average PVY Vector Risk across the region was approximately twice that of the 2013-2020 average (Fig. 6) while the regional average of the number of aphids captured weekly per trap in 2023 was almost three times the 2013-2020 8-year average (Fig 7). While the population dynamics of aphid vectors was similar in pattern to the 2013-2020 average patterns (building in July, peaking in August) the numbers captured starting in July were significantly higher than the historical average. This means many vector species were present prior to vine-kill, increasing the potential for virus transmission.

Overall, the PVY Vector risk in 2023 was one of the highest seen in several years.



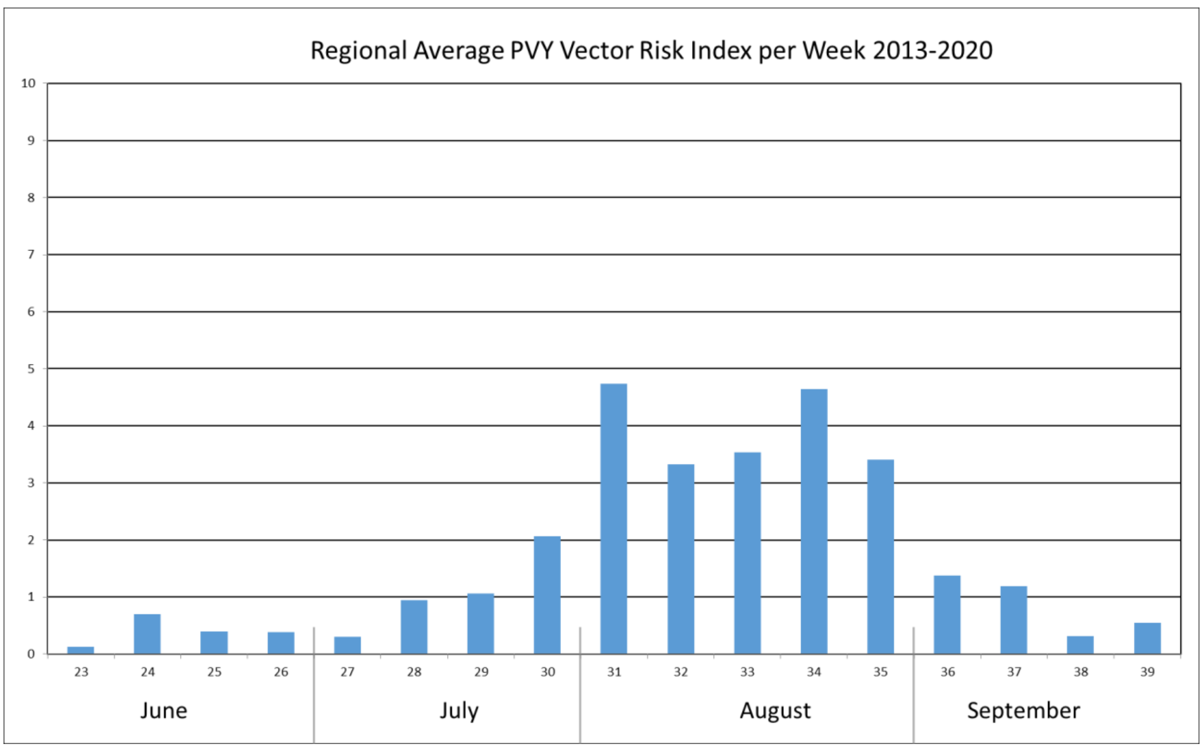
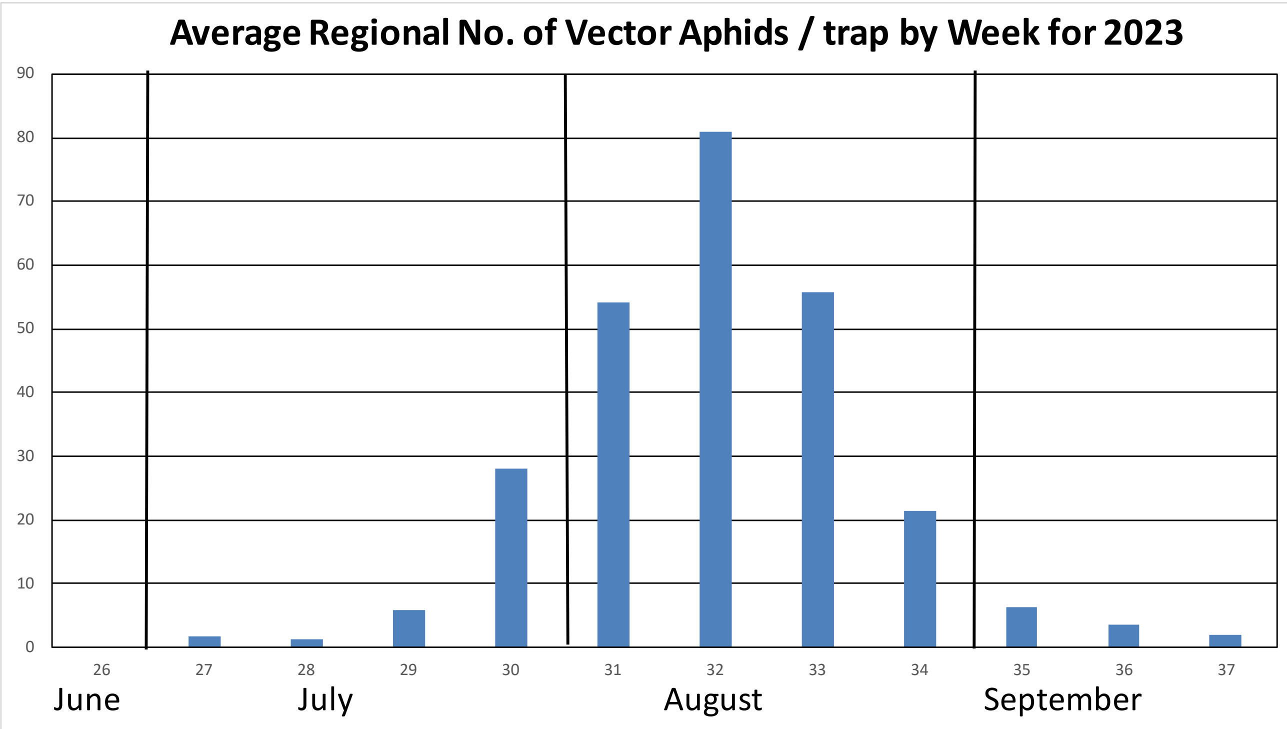


Figure 6. The average regional PVY Risk Index for 2023 (top) compared to the average regional PVY Risk Index calculated over the 2013-2020 trapping seasons. The 2023 year had approximately twice the



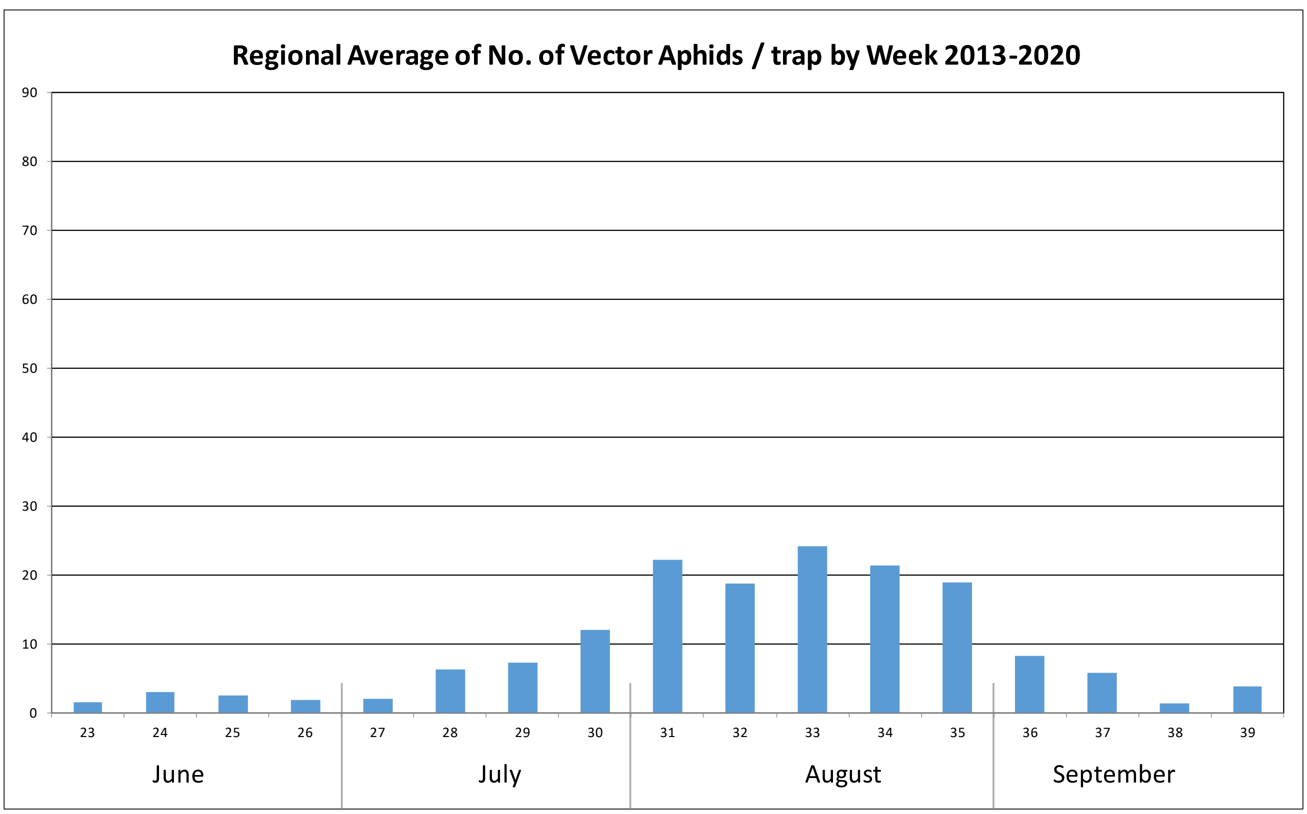


Figure 7. The regional average number of PVY vectors captured per trap by week in 2023 (top) compared to the regional 8-year average of PVY vector aphids captured / traps from 2013-2020 seasons. The number of

4) ***Within Field Distribution of Potato Virus Y. Results -*** This project was funded by a ND Specialty Crop Block Grant but is being reported on here for dissemination of information. This project was conducted with the help of North Dakota Seed Certification. Accompanying ND Seed Certification scouts early in the summer, plants infected with PVY were identified within cooperators seed potato fields during early season visual scouting for within field inoculum. Infected plants were marked with flags and precise geocoordinates obtained with Survey quality Corrected GPS. Plants at 1.5, 3, 4.5, 6, and 7.5 m on the compass rose (N, NE, E, SE, S, SW, W, & NW) from identified PVY positive plants were flagged and tested for PVY using a within-field PVY bioassay tool called an ImmunoStrip (AgDia INC., Elkhart, IN). They were found not to be infected with PVY. Later in the season, these surrounding plants were re-sampled and again tested for PVY using Immunostrips. In 2022, at the end of season, tubers were sampled from these plants and subjected to a winter growout in the greenhouse at the UMN NWROC in Crookston. It was found the growouts provided no additional data over the within field applied ImmunoStrips and was not repeated in 2023.

These data provided two interesting observations. Early planted PVY infected plants (i.e. planted inoculum) appeared to be clustered. PVY positive plants were often identified within 15m-40m of each other with large sections of the field lacking infected plants (fig 8). The entire field was not sampled for PVY infection by us so we do not know if this is an artifact of our trial protocols or a real distribution. Early season mapping of within field distribution of PVY positive plants may provide some additional insight. We also found it was as likely to find a neighboring infected with PVY at 7.5m as it was to find one at 2m. As these plants were previously negative for PVY so it was assumed this represented within-field transmission. This indicates within field spread can occur at least 7.5m from an infected plant and our scale of observation and sampling was insufficient.

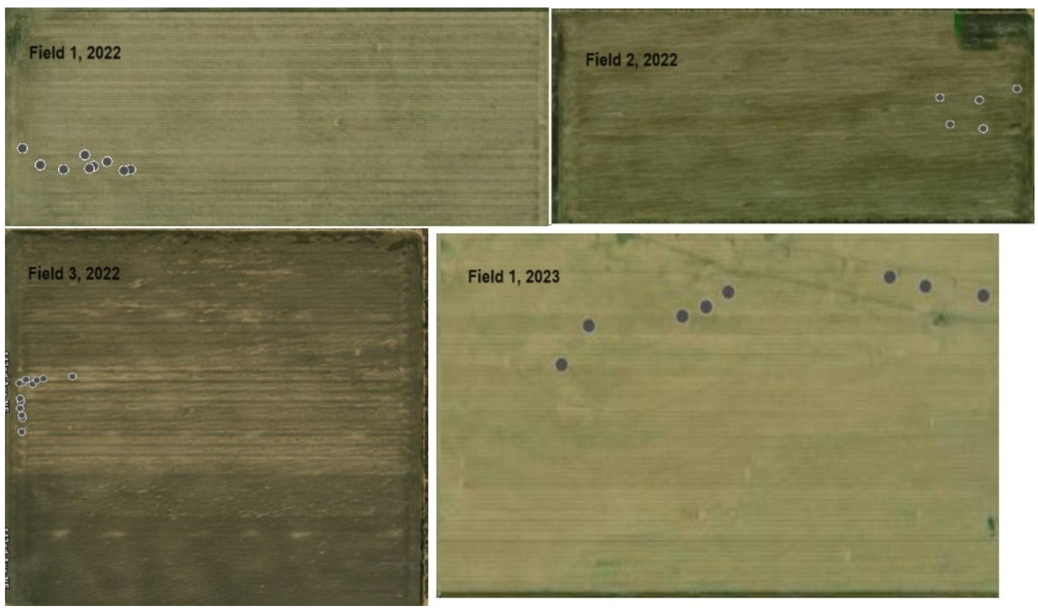


Figure 8. Sample points in the 4 fields examined to determine spatial distribution and movement of PVY inoculum within seed potato fields. Black dots denote identified PVY positive plants used as origin points for movement studies. Note that there seems to be a clustering of origin plants. These data were early season locations, consequently they most likely reflect planted inoculum. These patterns may not be reflective of the whole field distribution or they may indicate some factor that may be related to PVY

Acknowledgements – We greatly appreciate the funding provided for this research by the Northern Potato Growers Association and the Minnesota Area II Potato Growers Association.

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Report title – Screening potato lines for Verticillium wilt resistance in an irrigated potato field at Becker, MN

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Executive Summary- Verticillium wilt (caused by fungal pathogens called *Verticillium* spp.), also called potato early dying disease, is a recurring problem for Minnesota and northern plains potato growers. Potato is one of the most economically important crops impacted by Verticillium wilt. Cultural management strategies such as crop rotation with non-hosts and fumigation have had limited economic success. One of the most sustainable and economical ways to control crop diseases is to identify and generate resistant varieties of plants. For the identification of resistant varieties, it's crucial to have disease nurseries for screening potato lines. We developed a Verticillium-infested disease screening nursery in an irrigated potato field at Sand Plain Research Farm, Becker, MN, and found high Verticillium disease pressure. The breeding effort at UMN (currently led by Dr. Laura Shannon) has led to the generation of several potato lines. In the year 2023, we conducted screening of 30 potato clones/lines, including nine commercial potato cultivars for Verticillium wilt resistance screening. The study trial suggested commercial cultivars/varieties Umatilla Russet and Russet Burbank are highly tolerant. At the same time, Superior, Dark Red Norland, Goldrush, Red Norland, Russet Norkotah, and Yukon Gold are highly susceptible to Verticillium wilt. The study identified three new potato lines from UMN varieties to be highly tolerant. These potato varieties were **MN19AOR17020-009, MN18CO15083-006,** and **MN19CO17072-005** (Figure 1). MN19CO17072-005 has shown better tolerance than Umatilla Russet and Russet Burbank (Figure 1).

We also isolated Verticillium isolates from infected stems and performed their characterization. We used molecular biology and microbial techniques to characterize them (discussed more in the procedure and result section). The study identified *Verticillium dahliae* and confirmed it in the infected potato stem samples.

Rationale:

This study aims to find genetic solutions to manage the Verticillium wilt disease problem that can reduce dependency on fungicides and fumigants and secure yield loss sustainably. Our rationale for the proposed study is to use the in-home (at Sand Plain Research Farm, Becker, MN) developed Verticillium wilt disease nursery for screening potato lines for disease resistance.

Increased application of fungicides and fumigants poses environmental challenges and adds to the selection of fungicide-resistant pathogens. These strains will be an important resource for future studies, including understating their differential pathogenicity and fungicide resistance. Surveying and identifying locally adapted Verticillium pathogen isolates might provide a better understanding of its population dynamics and diversity, which might contribute to a differential degree of pathogenicity. The understanding will help inform growers about region-specific planting of potato varieties and help decide about fungicide treatments.

Therefore, to achieve these goals, we proposed the following objectives –

1). Screen UMN potato breeding lines for *Verticillium* wilt resistance in the irrigated potato field and

2). Isolate and study the diversity of *Verticillium* spp. isolated from MN potato farms.

The proposed research plan will identify new *Verticillium* wilt-resistant potato verities, ultimately leading to potato improvement for resistance against *Verticillium* wilt.

Procedures

We used the following method to achieve the above-stated objectives.

For objective 1. We conducted a screening of 30 lines bred at the UMN potato breeding, including nine commercial cultivars, Superior, Dark Red Norland, Goldrush, Red Norland, Russet Norkotah, Yukon Gold, Atlantic Russet Burbank, and Umatilla Russet (representing a range of resistance). These lines were planted with four replicates of 10 plant plots (hills) in a completely randomized block design in the *Verticillium* wilt nursery at the Sand Plain Research Farm, Becker, MN, on 15th May 2023. *Verticillium* wilt was visually assessed for disease symptoms at seven-day intervals beginning at the mid-potato vegetative growth and flowering stage (from 17th July to 10th August) by estimating the number of plants exhibiting symptoms and scoring them for disease severity. Plants were assessed for the severity of *Verticillium* wilt symptoms and stem colonization. Scoring for the severity of *Verticillium* wilt symptoms was performed by estimating the rate for the percentage of foliage exhibiting senescence using the following scale: 0 - No disease symptoms, 1 - Slight wilting and unilateral discoloration of lower leaves (1-25% wilt), 2 - Moderate wilting involving less than one-half of the plant (25-50% wilt), 3 - Severe wilting involving more than one-half of the plant (51-75%), and 4 - Plant dead or dying from wilt (75-100% wilt) (Hoyos et. al., 1991). The stem colonization was validated by *Verticillium*-specific primers (Inderbitzin et al. 2011; Inderbitzin et al. 2011) and performing PCR (Polymerase Chain Reaction) (Atallah et.al. 2007). Data analysis was conducted using standard statistical procedures.

We also included another phenotyping method for Verticillium wilt that is looking for Verticillium wilt rings (Figure 4). We randomly collected 15 tubers of each variety to score for percentage Verticillium wilt symptoms. We studied the co-relation of Verticillium wilt ring and foliar symptoms using the Pearson product-moment correlation test and Spearman's coefficient statistical tools.

For objective 2. We isolated *Verticillium* isolates from infected potato stem samples showing *Verticillium* wilt characteristics. We isolated the *verticillium* strains using a standardized lab protocol performed under sterile conditions (Figure 5A). The isolated strains were confirmed using molecular techniques, including isolating the genomic DNA and performing PCR using Verticillium-specific primers (Inderbitzin et al., 2011; Atallah et al., 2007). We will perform PCR using universal internal transcribed spacer (ITS) primers (White TJ et al., 1990: Appel DJ et al., 1995; Inderbitzin et al. 2013), followed by sequencing of the amplified product. The PCR sequence results were searched for known *Verticillium* isolate sequences and were confirmed. We also performed microbiological study of these isolates by looking for their specific characteristics (Figure 5B, C, and D).

Results

Verticillium wilt screening study was performed in a randomized complete block design in a *Verticillium dahliae*-infested field at the irrigated sand plain research station, Becker, MN. We screened ~1200 potato hills for resistance to *Verticillium* wilt. The study included thirty entries, including susceptible cultivar Superior, in four replicates. Area under disease progress curve (AUDPC) was calculated by examining disease symptom expression using the disease severity scoring as discussed above. The study identified three *Verticillium*-highly tolerant potato lines (Figure 1). Figure 2 shows the verticillium wilt disease progression in the commercial potato variety in Gold Rush Russet (susceptible) and Russet Umatilla (highly tolerant), used as check lines as observed and rated on 26th July, 2nd August, and 10th August 2023.

Figure 3 shows the verticillium wilt disease progression in the highly susceptible line (MN04844) and highly tolerant line (MN19CO17072-005) as observed and rated on 26th July, 2nd August, and 10th August 2023.

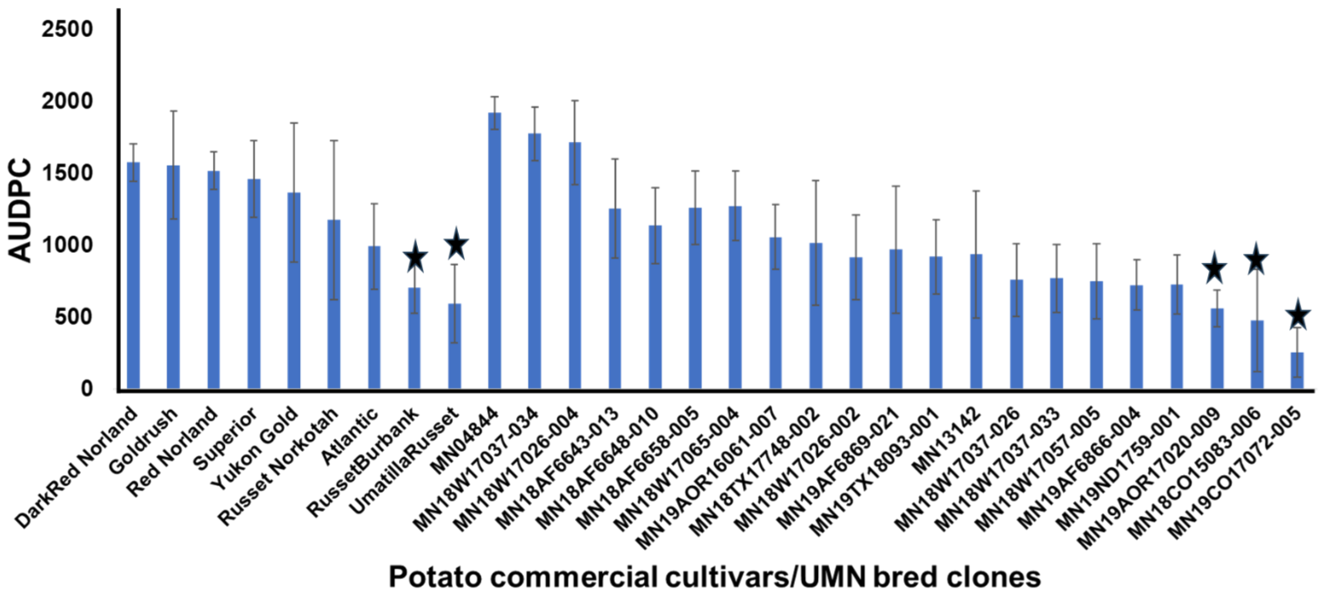

Figure 1. Area under the disease progress curve (AUDPC) of thirty varieties, including nine commercial cultivars (Superior, Dark Red Norland, Goldrush, Red Norland, Russet Norkotah, Yukon Gold, Atlantic Russet Burbank, and Umatilla Russet) using percentage disease severity foliage (DS%) from 17th July, 26th July, 2nd August, and 10th August 2023 observations. ★Indicates highly tolerant varieties. The study was performed in four replicates; each replicate has ten potato hills. Standard deviation of four replicates is shown.

Figure 2. Progression of *Verticillium* wilt disease in Gold Rush Russet (118, susceptible) and Russet Umatilla (138, tolerant) potato variety at Sand Plain Research Farm, Becker, MN. Photographed on (A, B) 26th July, (C, D) 2nd August, and (E, F) 10th August, respectively.

Figure 3. Progression of *Verticillium* wilt disease in MN04844 (9, susceptible) and MN19CO17072-005 (180, tolerant) potato variety at Sand Plain Research Farm, Becker, MN. Photographed on (A, B) 26th July, (C, D) 2nd August, and (E, F) 10th August, respectively.

We scored for Verticillium wilt ring post-harvest. Some of the tubers infected by verticillium wilt also develop light brown discoloration in the vascular tissue (Figure 4) near the tip of the tuber stem. We calculated the percentage of Verticillium wilt ring and performed a co-relation study of Verticillium wilt ring symptom and foliar symptoms using the Pearson product-moment correlation test and Spearman's coefficient statistical tools. The study suggested that Verticillium wilt rings do not relate strongly with foliar symptoms ($r = 0.1$). We can conclude from this study that foliar symptoms a better indicator of Verticillium wilt resistance.

Figure 4. Infected tubers with Verticillium wilt develop light brown discoloration in the vascular tissue (arrow pointing towards the vascular ring) of potato tubers stem end.

From this study, we can preliminarily conclude that we have identified three tolerant potato lines MN18CO15083-006, MN18CO16154-009, MN18TX17748-002, MN18W17065-004 and

MN18W17089-002 to *Verticillium* wilt. To check the consistency of the phenotype, we might have to perform another field evaluation. The filed trial suggests measurable VW resistance is apparent in U of MN potato breeding programs. We need to standardize the controlled growth chamber/greenhouse disease screening method to further screen for resistance. Continuation of our experiments for the next year will increase our sample size and give a comprehensive understanding and conclusive results. For future studies, these lines can also be used to perform genetics and omics studies to identify important potato genes involved in resistance or for breeding improved *Verticillium*-resistant potato lines.

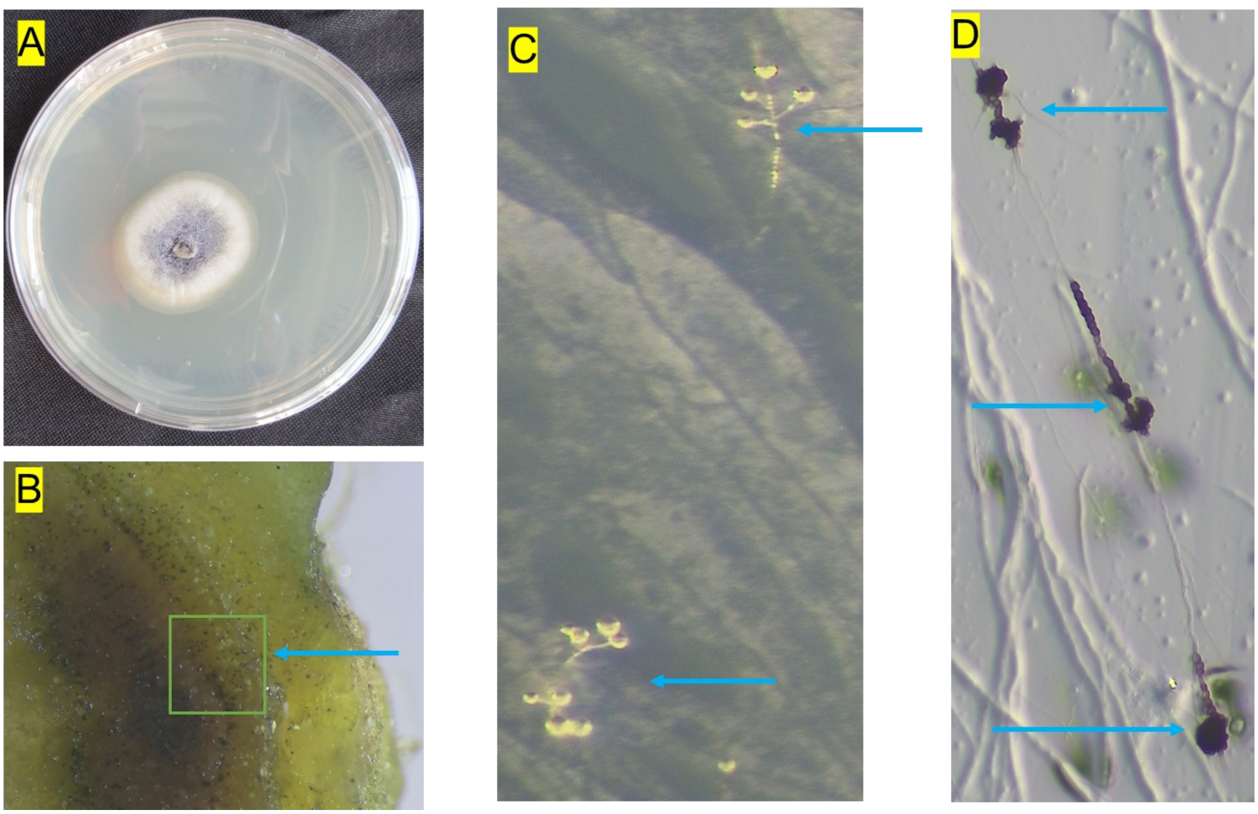

Figure 5. Morphological features of *Verticillium dahliae* strain isolated from infected potato stem. A. Colony after 14 days on PDA growing from potato stem, B. Microsclerotia forming on potato stem cross section 14 days on PDA B. Conidiophore after 15 days on WA-p (Water agar plate), C. Microsclerotia of the *V. dahliae* holotype material from stem 15 days on WA-p (Water agar plate).

We have also isolated multiple *Verticillium* isolates from a few different Minnesota sites, but we need to perform a comprehensive survey in MN to understand the diversity of *Verticillium* spp. A preliminary microbial and molecular biology study indicates the prevalence of *Verticillium dahliae* in these sites. We need to sample from more sites and counties to monitor *Verticillium* species/race in MN. Figure 5 illustrates morphological features of *Verticillium dahliae* strain isolated from infected potato stems.

Acknowledgments

We greatly acknowledge fund support from the Minnesota Area II Potato Council and the Northern Plains Potato Growers Association. The contributions of potato lines and help in planning and planting from Dr. Laura Shannon, potato breeder, and her lab group members Dr. Thomas Stefaniak, John Larsen, and Megan Harder are gratefully acknowledged. We also acknowledge help from Mark Peterson and Blake Kunkel for managing the plots for irrigation, fertilization, pest management, and harvesting at Sand Plain Research Farm station, Becker, MN. Ranjan lab members Kay Lehorl, Nick Talmo, Tatum Johson, Grace Petzold, and Dr. Kriti Tyagi are acknowledged for their assistance in the study.

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Proposal Title: Investigating the Utility of Sensors for Determining Early Die Development
Submitted to Northland & MN Area II Potato Growers Associations
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Acknowledgments

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Executive Summary: Plant pathologists from North Dakota State University will work to improve outcomes from the early die disease complex for growers. The **objectives of this research** are to quantify the accumulation of the black dot (*Colletotrichum coccodes*) and Verticillium wilt (*Verticillium dahliae*) pathogens in stem tissue and determine the utility of the use of irrigator-mounted imaging for assessing early die. Assessing pathogen colonization across the growing season will strengthen our understanding of these two important diseases. Additionally, data we obtain on pathogen populations and disease severity will be used to train the artificial intelligence crop monitoring technology to recognize the disease. While qPCR is a wonderful tool for quantifying pathogen populations, the resources in many cases are too high to justify its' use across entire commercial potato production farms. Cameras attached to irrigation systems are currently utilizing thousands of images collected while the irrigator is running to assess plant population, ground cover, insects, and weeds. Identifying diseases is one of the next steps in maximizing the value of these imaging systems for growers. With early detection of early die disease, growers can amend management practices to minimize the losses incurred by this disease complex. Additionally, precision chemical applications and planting decisions for future crops can be made on a field by field basis. Growers and other stakeholders have been involved in the development of this project. Results obtained to date indicate that significant differences in visual early die were observed. Final results generated in the coming months will be shared with growers, scientists, and other industry stakeholders at field days and grower winter meetings, and in trade journal and scientific publications.

Funding has been secured for the 2024 and 2025 growing seasons from the ND Department of Ag Specialty Crop Block Program for similar objectives as are highlighted in this request. The request outlined here is for work carried out during the 2023 growing season and post-harvest evaluations associated with the soil and stem samples collected during the 2023 growing season. We estimate that a minimum of three to five years of data will be needed to validate this system.

Procedures
A field was chosen based on the availability of the irrigator-mounted cameras and history of early die. The early die susceptible cultivar Russet Burbank was planted. The field had a split fumigation application (chloropicrin/metam sodium). On each side of the circle, 16 georeferenced sampling sites were chosen, 4 sites under each of 4 sensors (replicates), and all data and samples were taken in these areas (Figures 1 and 2). Foliar disease incidence was

visually estimated in each replicate on July 14, July 28, August 11, and 25 by evaluating 50 plants in the vicinity of each of the 32 georeferenced sites. The main stem of each of 5 plants was sampled by cutting 4-5 inches above and 2 inches below the soil line on July 13, 25, August 11, and 25 at all 32 sites (640 stem samples) (Figure 3). Soil samples were collected to 8 inches on August 3 (32 samples) and shipped to Pest Pros for early die analyses. DNA will be extracted from stem and soil samples and *C. coccodes* and *V. dahliae* will be quantified. Prior to each side of the field being harvested (September 6 and 13), the number of plants in from 10 feet of row were counted, and all tubers were hand-dug from all 32 sites. Tuber assessments include total yield, grade, market yield, and vascular discoloration. A sub-set of tubers displaying vascular discoloration will be assayed via qPCR to quantify *C. coccodes* and *V. dahliae*.

Results to Date

Plant population was significantly higher on the metam sodium side (Figure 4). Early die progressed differentially between the two field halves (Figures 5 and 6). Differences in disease were significant throughout most of the growing season, resulting in a significant difference in Area Under the Wilt Progress Curve (AUWPC) (Figure 5). Images obtained with the Prospera cameras (Figure 7) are being compared to visual ratings and will be compared to stem pathogen colonization as those data are completed. Stem samples have been dried and ground, DNA has been extracted, and qPCR for pathogen (*C. coccodes* and *V. dahliae*) quantity will be completed in the coming weeks. Yield was significantly higher in the chloropicrin treatment (Figure 8). Tuber grade differed significantly between treatments only in the largest size category (>10oz) (Figure 9). Tuber pathogen data are forthcoming.

Preliminary Conclusions (first of 3- to 5-year study)

Based on this single split field, fumigation with chloropicrin decreased disease and increased yield. Those data are very preliminary and should be interpreted with extreme caution. Data obtained from this split field will contribute substantially to our knowledge of how pathogens colonize stem tissue, and how that is affected by soil pathogen populations measured at georeferenced sites. Additionally, comparing these data with images obtained from the cameras will move us towards determining if losses due to early die can be detected earlier, allowing for growers to make appropriate crop management decisions.

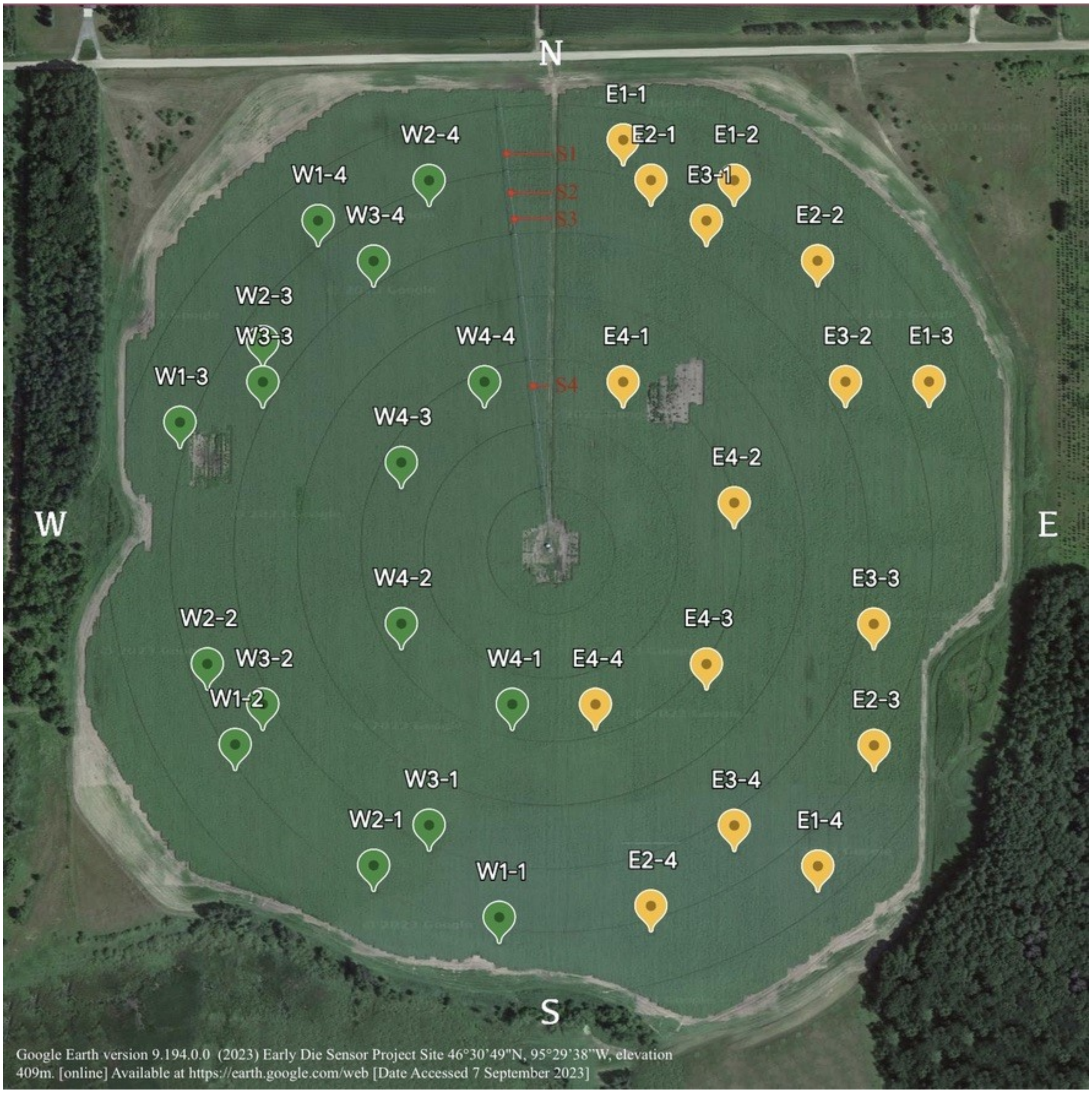

Figure 1. Georeferenced collections sites on the west (W; 4 reps × 4 sample sites/rep) and east (E; 4 reps × 4 sample sites/rep) halves of the field used for visual disease assessment, and sampling stem, soil, and tubers.

Figure 2. Left – View looking up at a camera attached to the irrigator used to visualize the crop throughout the growing season.

Right – A camera passing over a georeferenced sampling site marked by the wooden stake.

Figure 3. Stem (left) and tuber (right) sampling.

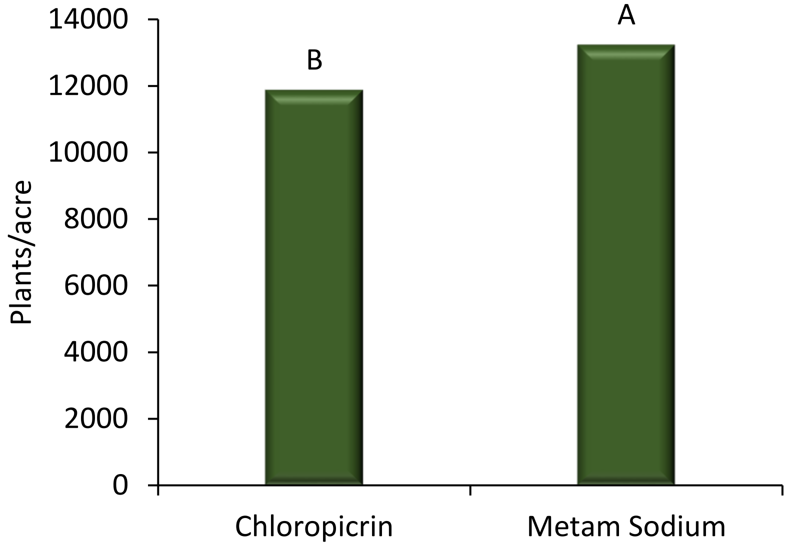

Figure 4. Plants per acre calculated from 10-foot test digs. Columns with different letters indicate significant difference.

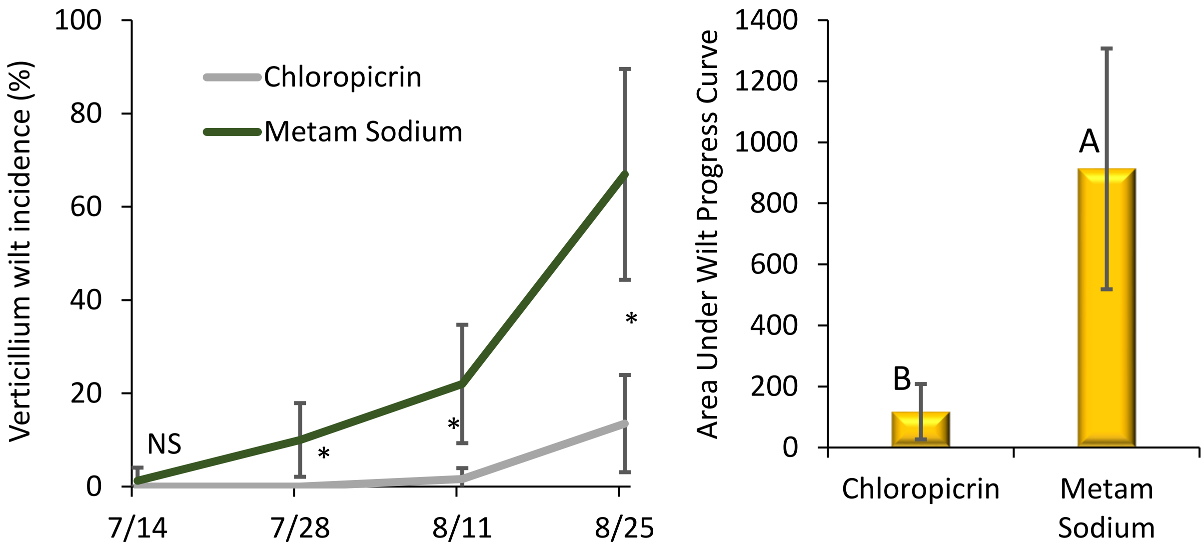

Figure 5. Left – Percent Verticillium wilt incidence based on visual assessments of disease incidence at four dates in July and August. NS; not significantly different. *; significant difference.

Right – Area under the wilt progress curve calculated over the four visual Verticillium wilt visual assessments of disease incidence data collection dates. Columns with different letters indicate significant difference.

Both graphs include bars to denote the standard deviation.

Figure 6. Chloropicrin (left) and metam sodium (right) sides of the pivot taken on August 25 (Top) and September 6 (bottom).

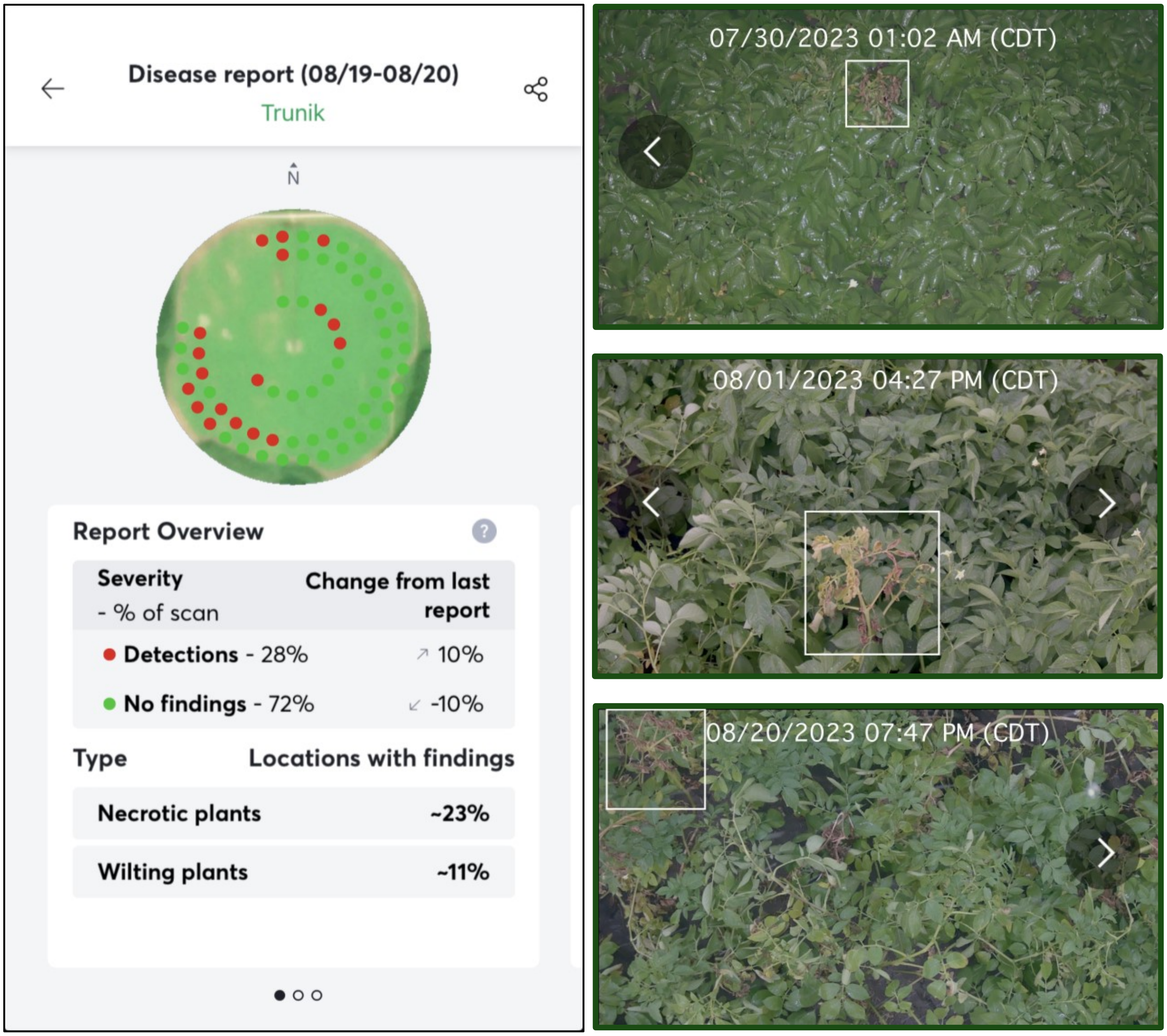

Figure 7. Left – Screenshot from Prospera app illustrating sites with necrotic or wilting plants. Right – Images from Prospera camera highlighting the detection of wilted plants.

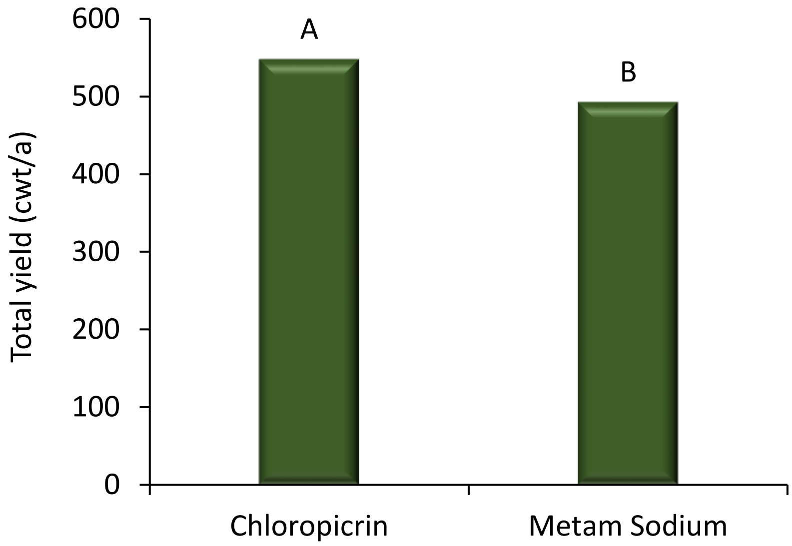

Figure 8. Total yield calculated from 10-foot test digs. Columns with different letters indicate significant difference.

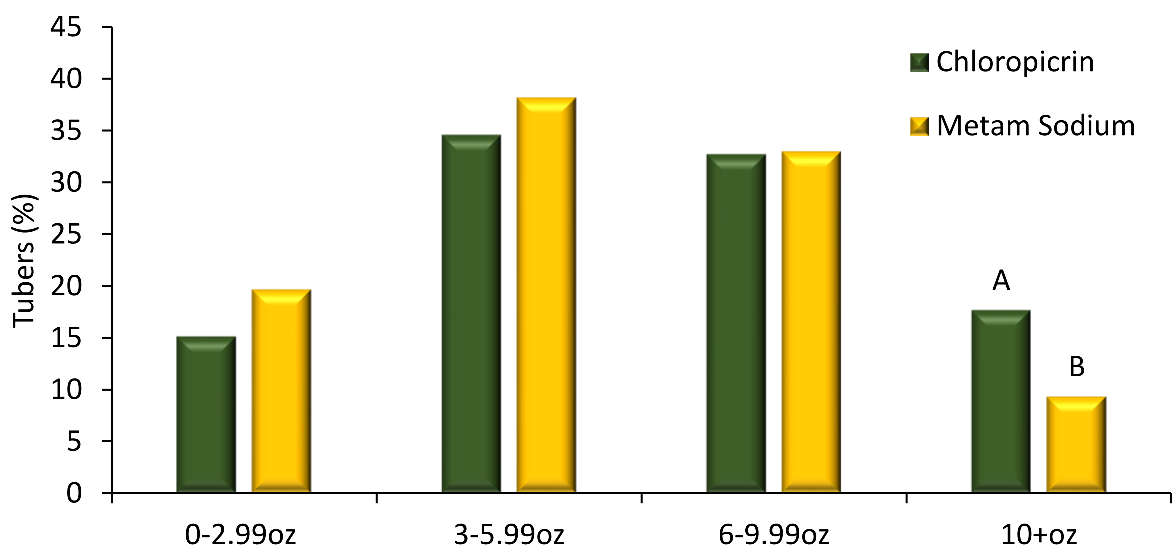

Figure 9. Tuber size profile determined from the 10-foot test digs just prior to harvest. Columns with different letters indicate significant difference.

Breeding and Development of Resilient Potato Cultivars for the Northern Plains

2023 Research Summary

Susie Thompson, Ph.D.

Department of Plant Sciences

North Dakota State University

Potato, an important horticultural crop in North Dakota and Minnesota, was produced on more than 48,562 ha in 2023 in the two states. This nutrient rich vegetable provides significant levels of potassium, vitamin C, folate and vitamin B6, amongst other health attributes. Potato is susceptible to numerous abiotic (temperature, moisture for example) and biotic (insect pests, pathogens, and nematodes to name a few) stresses, and stringent market specifications exist for each market type. Due to the tetraploid nature, potato breeding and cultivar development are long-term processes, requiring 10 or more years from hybridization to cultivar release. The primary aim of this research project was to address shortcomings of industry standard cultivars and provide potato producers, industry, and consumers with environmentally resilient and economically sustainable nutritious cultivars across market types. The potato improvement team conducts agronomic, screening, and evaluation trials across North Dakota and western Minnesota in an effort to identify early maturing selections with high yield potential, possessing pest and environmental stress resistances, diminished requirements for inputs, and that possess key market type attributes. Two research objectives were established for 2023:

1. Identify and develop genetically and environmentally resilient and economically sustainable germplasm for cultivar release adapted to North Dakota, Minnesota, and the Northern Plains.
2. Identify, evaluate, and adopt innovative tools and technologies for advancing breeding efficiencies and success.

The potato breeding program conducts potato research and production in the greenhouse, field and laboratory. During winter/spring 2023, 62 parental genotypes were used in 1,427 hybridizations, creating 175 new families; named cultivars, wild-species hybrids, and advancing selections from NDSU, USDA-ARS, Michigan State University, Texas A & M University (TAMU), and University of Maine were used as parental genotypes. Early maturity and introgression of disease, pest and stress resistance, including extreme resistance to Potato Virus Y (PVY) and *Verticillium* wilt across market types, were emphasized. Seedling tuber production in the greenhouse for planting in the single hill nursery in 2024 was conducted throughout the year. The single-hill nursery, maintenance lots, and increase lots of promising selections were grown at Baker, MN. In 2023, about 28,000 single hills were grown with more than 9,000 representing 42 NDSU families; remaining seedling tubers were received from collaborators at USDA-ARS Aberdeen (ID), U Maine, and TAMU; 484 selections were made, primarily from NDSU produced materials. More than 13,000 unselected seedling tubers were shared with collaborating breeding programs in ID, ME, MN, and TX. In maintenance lots, 743 second year selections were grown; 283 were retained. Ninety-three field year three selections were retained of 178 grown, and 258 fourth year and older selections were grown with 158 retained after evaluation. Approximately 0.4 ha of increases were produced, including promising advancing selections, and nearly 500 selections of two mapping populations focused on *Verticillium* wilt resistance and skin set (the mapping population assessments are in collaborations with Drs. Pasche and Shannon, and Drs. Dogramaci and Sarkar, respectively). Increases are used for breeding program maintenance and trials, collaborator's trials, regional and national trials, and are shared with grower/industry evaluators. As second, third, and fourth year selections were brought into storage, specific gravity was determined, light box imagery obtained, and chip/frozen processing selections sampled for chip processing evaluations from the field and from 3.3C (38F) and 5.5C (42F) following eight weeks storage and seven months storage. More than 600 clones were submitted for genotyping.

Field yield and agronomic trials were conducted at Inkster, Larimore, Oakes, ND, and Hubbard, MN, under irrigation, and at non-irrigated sites at Crystal, Hoople, and Fargo (main-station), ND, predominantly in grower cooperator fields. A disease screening trial (ND Specialty Crop Block Grant funding) was grown at the Inkster research site; this location is hosted by the Forest River Colony. The Larimore processing trial included 10 advancing selections compared to eight standard frozen processing standards (please see results in Tables 1-3 and Figure 1). ND060735-4Russ continues to provide excellent fry quality and is also very attractive making it suitable for the fresh market. A new selection, ND1791-3Russ, had excellent fry quality and we plan to put into tissue culture this winter in order to trial in the future. The PreProcessing trial included 64 dual-purpose russet selections compared to eight check cultivars, the North Central (NC) Regional trial with 86 entries from MSU, NDSU, and UMN compared to nine check cultivars, the National French Fry Processing trial (NFPT), and several agronomic trials, including a climate resiliency trial in collaboration with Drs. Dogramaci, Hatterman-Valenti, Haagenson, and Panigrahi (Purdue University). Processing selections (chip and frozen/French fry) were submitted to Dr. Darin Haagenson (USDA-ARS) for serial processing evaluations from storage. These trials were hosted by Hoverson Farms at a research pivot southeast of Larimore. Two trials were grown at the Oakes Research Extension Center, a processing trial with 8 selections compared to nine industry standards, and a fresh market trial evaluating 15 red- and yellow-skinned selections compared to five industry standards. Trials at Hubbard included a replicated *Verticillium* wilt resistance assessment trial using a mapping population compared to six industry standards with known resistance/susceptibility (ND Specialty Crop Block Grant funding), and a replicated *Verticillium* wilt trial evaluating 25 genotypes; they are in collaboration with Drs. Julie Pasche, Kim Zitnick, and Laura Shannon. Stems were collected from both for determination of colonization. The trials at Hubbard were hosted by RD Offutt Farms.

The Crystal fresh market trial compared 24 advancing selections with red, pink, purple and yellow skin/flesh to 6 popular fresh market cultivars (Tables 4-5 and Figure 2). Several selections look promising including ND1241-1Y, ND1243-1PY, and ND1859-4R. Two new yellows also showed promise with high yield of A-sized tubers, including ND1837B-3Y. The preliminary fresh market trial has evolved into a two replicate trial focused on second year genotypes; in 2023, there were 27 entries, primarily with red skin and white or yellow flesh, compared to six fresh market controls. Trials at Crystal are hosted by Dave and Andy Moquist. The focus at the Hoople trial site (in 2023 was located close to Crystal as in 2022) is chip processing, and the trial site is hosted by Lloyd, Steve and Jamie Oberg. The Hoople chip trial included 13 advancing selections compared to 6 industry standards in the four-replicate trial (please see Tables 6-8). Several performed better than the standards including ND7519-1, ND7799c-1, ND1241-1Y, and ND14247CAB-15. ND13220C-3 was not included in 2023 in order to increase seed and in favor of conducting disease screening trials. The preliminary chip processing trial evaluated 50 selections compared to five commercial chip processing standards. The National Chip Processing Trial was also grown at this location; it included nearly 200 selections compared to commercial chip standard cultivars; NDSU had two tier 2 entrants and the ND143247CAB-15 performed well as in our chip trial. An organic demonstration trial was grown on the NDSU campus in 2023 with a focus on urban agriculturalists; 15 selections with unique skin and flesh colors with enhanced nutrition and culinary opportunities, stress and pest resistance, were compared to 5 specialty cultivars. Dakota Dawn, a 2022 release from the ND Agricultural Experiment Station and NDSU, was featured in the 2023 and 2024 Row 7 Seed Catalog.

Harvest observations across sites indicated yields and overall tuber size profiles had somewhat rebounded versus 2022, despite dry conditions at the northern non-irrigated sites throughout summer 2023. Highlights for 2023 included Dakota Russet reaching the top 10 cultivars for certified seed potato production in the US following the 2023 growing season. Certified seed potatoes were produced for ND7519-1, ND7799c-1 (53 ha), ND113207-1R (6 ha), ND1241-1Y (19 ha), and ND13220C-3 (0.4) in ND and MN in 2023. Naming and release of several will be considered in 2024. ND13220C-3 will be an entry in the 2024 national SNAC trial. Please see promising selection summaries at end of this report. ND1241-1Y is a timely consideration, based on increasing importance of yellows for the fresh market in the Red River Valley. Per a recent Potato Bytes, in 2008, 3% of the fresh market production in the Red River Valley was of yellow fleshed cultivars, while in 2023 it was 40%. ND1241-1Y offers high yield of uniform, round attractive tubers suited for both the fresh market and specialty chip processing. ND1241-1Y tubers maintain their round shape under heat stress, while misshapen triangular tubers or tubers that develop heat sprouts often result when yellow cultivars developed elsewhere are grown in the northern plains. ND1241-1Y produces higher tuber numbers per hill than industry standard Yukon Gold, which due to low tuber set has a propensity for hollow heart.

Several technologies were assessed and/or adopted based upon current season and previous evaluation results (objective 2). The use of underground sensors in the field after planting that ride up the harvester in the fall has given us very useful data regarding temperature and moisture, environmental factors impacting potato yield and quality. These sensors can also be placed in storage to monitor temperature, humidity, O_2 and CO_2; in the future, we will evaluate those capabilities to track/help explain processing quality changes. Aerial imagery (drone/phone app) assessed PVY incidence in the seed field, combined with visual appraisal, and serological testing. We have adopted light box imagery for assessing tuber attributes; ideally in the future we can use imagery to assess defects. Our project migrated from AgroBase to Genovix for data management and archiving; we are also using Breedbase and Medius.Re for regional and national trial data.

The NDSU potato breeding program is supported by Kelly Peppel (research specialist), Peter

Ihry (research specialist), and undergraduate students Ena Muzafirovic, Hunter Gallagher, and Lakin Geigle (Elizabeth Krause recently completed her bachelor's degree and is now a graduate student with Dr. Harlene Hatterman-Valenti's project).

Sincere thanks are extended to the Northland Potato Growers Association, the Minnesota Area II Research and Promotion Council, JR Simplot, Cavendish Farms, Lamb Weston and RDO Frozen, to our many certified seed and commercial grower cooperators, and to many others, for research funding, hosting trials, supplying certified seed, and for all you do in support of the NDSU potato breeding and potato research efforts. Additional trial information will be submitted to the Valley Potato Grower magazine, and will be presented at potato industry meetings in 2024.

Table 1. Agronomic evaluations for advanced processing selections and cultivars grown at Larimore, ND, 2023. The processing trial was planted on June 5, and harvested October 14 and 16 (~132 DAP) using a single-row Grimme harvester. A randomized complete block design with four replicates was utilized; plots were twenty feet long, with a within-row spacing of 12 inches and 36 inches between rows.

Clone	Stand %	Stems per Plant	Vine Size[1]	Vine Maturity[2]	Tubers per plant	General Rating[3]
AND08380-1Russ	81	2.3	3.5	1.4	7.1	2.4
AND15394-2Russ	98	3.8	3.5	1.5	9.8	1.0
ND050032-4Russ	94	1.5	2.8	2.1	3.0	2.3
ND060735-4Russ	96	1.5	3.3	2.0	3.1	4.0
ND12241YB-2Russ	96	2.0	3.5	2.0	4.0	3.5
ND1412Y-5Russ	93	2.6	3.8	4.0	4.8	2.8
ND1413YB-1Russ	95	2.6	4.3	2.5	3.2	1.8
ND1791-3Russ	91	1.9	4.3	2.0	5.8	3.1
ND17103-1Russ	97	1.8	4.0	2.1	4.8	2.8
ND2015-1Russ	94	2.1	3.5	1.5	4.0	3.3
Bannock Russet	96	2.3	4.5	4.0	3.9	3.0
Dakota Russet	74	2.0	3.3	3.5	5.2	3.7
Dakota Trailblazer	94	1.7	5.0	4.3	2.9	4.0
Proprietary Russet	93	2.6	4.0	2.8	3.3	2.8
Ranger Russet	96	1.9	4.3	3.0	4.8	2.5
Russet Burbank	99	2.9	4.3	2.0	8.7	2.5
Russet Norkotah	95	2.7	2.5	1.0	4.6	4.0
Umatilla Russet	98	2.6	4.3	2.3	7.3	3.0
Mean	93	2.2	3.7	2.4	5.0	2.9
LSD ($\propto$=0.05)	10	2.0	0.7	0.9	1.5	0.8

[1] Vine size – scale 1-5, 1 = very small, 5 = very large.

[2] Vine maturity – scale 1-5, 1 = very early, 5 = very late.

[3] General rating based on yield, appearance, tuber size profile, shape, set, defects; scale of 1 to 5; 1 = very poor, 5 = excellent.

Table 2. Yield and grade for advanced processing selections and cultivars grown at Larimore, ND, 2023. The processing trial was planted on June 5, and harvested October 14 and 16 (~132 DAP) using a single-row Grimme harvester. A randomized complete block design with four replicates was utilized; plots were twenty feet long, with a within-row spacing of 12 inches and 36 inches between rows.

Clone	Total Yield Cwt./A	US No. 1 Cwt./A	US No. 1 %	0-4 oz. %	4-6 oz. %	6-10 oz. %	>10 oz. %	US 2s & Culls %
AND08380-1Russ	304	209	69	15	23	46	15	1
AND15394-2Russ	454	303	67	18	25	42	13	1
ND050032-4Russ	200	73	37	5	10	26	22	35
ND060735-4Russ	211	112	53	6	12	41	35	6
ND12241YB-2Russ	250	130	51	7	13	38	39	3
ND1412Y-5Russ	325	123	38	6	9	29	43	13
ND1413YB-1Russ	299	62	22	3	6	16	23	52
ND1791-3Russ	318	191	60	10	18	42	26	4
ND17103-1Russ	274	172	62	11	17	45	15	12
ND2015-1Russ	243	129	53	6	17	36	28	13
Bannock Russet	246	106	43	10	10	33	38	10
Dakota Russet	258	127	48	8	11	37	31	13
Dakota Trailblazer	233	80	37	3	8	28	36	23
Proprietary Russet	245	71	28	5	7	22	36	30
Ranger Russet	337	140	40	7	11	29	21	32
Russet Burbank	521	262	51	10	16	35	19	19
Russet Norkotah	280	148	53	7	14	39	34	6
Umatilla Russet	406	223	55	12	18	37	18	13
Mean	300	148	48	8	14	35	27	16
LSD (∝=0.05)	86	53	12	3	5	10	9	12

Table 3. French fry evaluations following grading for advanced processing selections and cultivars grown at Larimore, ND, 2023. The processing trial was planted on June 5, and harvested October 14 and 16 (~132 DAP) using a single-row Grimme harvester. A randomized complete block design with four replicates was utilized; plots were twenty feet long, with a within-row spacing of 12 inches and 36 inches between rows.

			Field Fry			Following 45F (7.7C) Storage		
Clone	Specific Gravity[1]	Hollow Heart[2] %	Fry Color[3]	Stem-end Color	% Sugar Ends[4]	Fry Color[3]	Stem-end Color	% Sugar Ends[4]
AND08380-1Russ	1.0756	10	1.2	2.6	75	0.8	2.8	84
AND15394-2Russ	1.0853	0	0.5	0.9	50	0.5	1.1	67
ND050032-4Russ	1.0797	0	0.5	1.4	50	0.3	1.1	50
ND060735-4Russ	1.0894	1	0.3	0.6	8	0.3	0.3	0
ND12241YB-2Russ	1.0934	0	0.3	1.2	25	0.3	1.7	42
ND1412Y-5Russ	1.0877	0	0.4	1.1	42	0.3	0.9	25
ND1413YB-1Russ	1.0840	6	1.0	2.5	59	0.5	0.9	25
ND1791-3Russ	1.0871	0	0.5	0.3	0	0.4	0.5	8
ND17103-1Russ	1.0877	1	0.9	1.1	33	0.3	0.7	50
ND2015-1Russ	1.0790	0	0.7	1.8	42	0.4	1.0	42
Bannock Russet	1.0749	14	1.5	1.6	25	0.5	1.6	75
Dakota Russet	1.0798	1	0.4	0.8	17	0.3	0.3	0
Dakota Trailblazer	1.0949	1	0.5	0.5	8	0.5	0.8	34
Proprietary Russet	1.0898	0	1.1	1.8	34	0.7	1.8	59
Ranger Russet	1.0868	0	0.9	1.4	33	1.3	1.8	42
Russet Burbank	1.0821	1	0.6	2.5	100	0.5	1.2	50
Russet Norkotah	1.0742	4	1.6	2.6	59	1.8	2.1	17
Umatilla Russet	1.0869	0	0.9	1.1	27	0.5	0.7	42

Mean	1.0843	2	0.7	1.4	38	0.6	1.2	39
LSD ($\propto$=0.05)	0.0065	8	0.8	1.1	51	0.4	0.9	41

[1] Determined using weight-in-air, weight-in-water method.

[2] Hollow heart and brown center combined.

[3] Fry color scores: 0.1 corresponds to 000, 0.3 corresponds to 00, 0.5 corresponds to 0, 1.0 equals 1.0; subsequent numbers follow French fry rating scale to 4.0. Scores of 3.0 and above are unacceptable because sufficient sugar levels cannot be leached from the tuber flesh to make an acceptable fry of good texture.

[4] Any stem-end darker than the main fry is considered a sugar end in these evaluations, thus mirroring the worst-case scenario. The processing industry defines a sugar end as a 3.0 or darker.

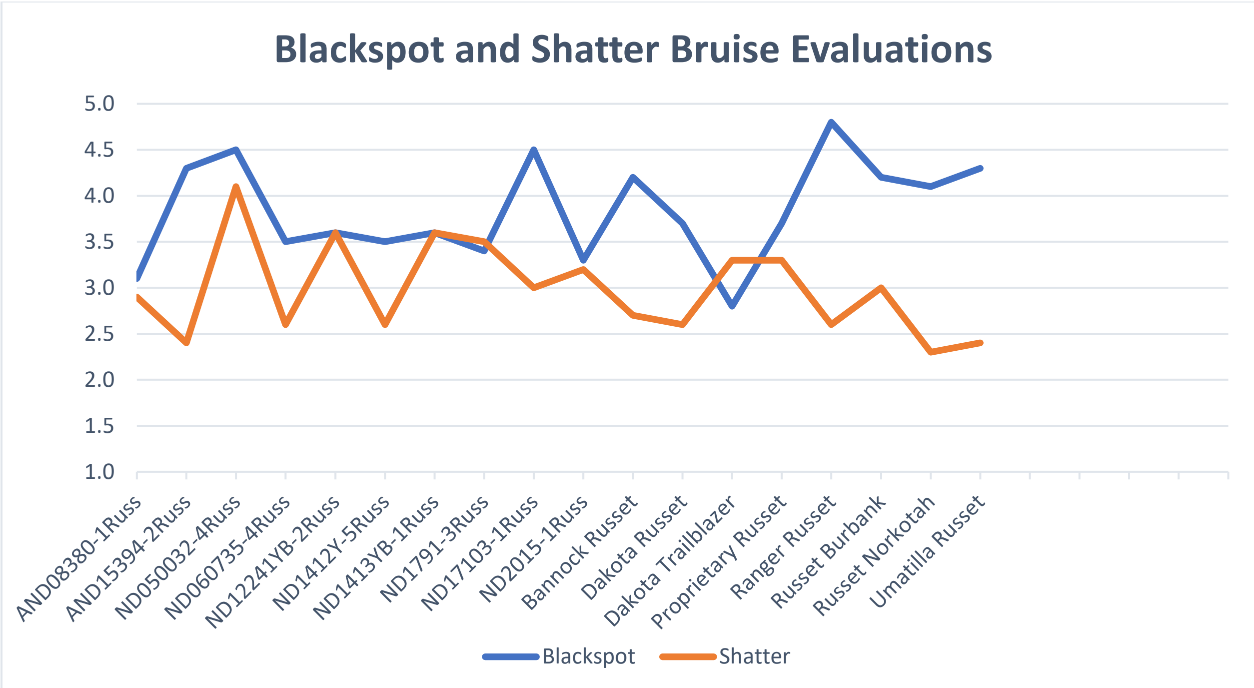

Figure 1. Blackspot and shatter bruise evaluations for advanced processing selections and cultivars grown at Larimore, ND, 2023. The processing trial was planted on June 5, and harvested October 14 and 16 (~132 DAP) using a single-row Grimme harvester. A randomized complete block design with four replicates was utilized; plots were twenty feet long, with a within-row spacing of 12 inches and 36 inches between rows. Blackspot bruise was determined by the abrasive peel method (Pavek et al. 1985), scale 1-5, 1 = none, 5 = severe. The mean for blackspot was 3.8, and the LSD = 0.6. Shatter bruise is evaluated using a bruising chamber with digger chain link baffles. Tubers are stored at 45F prior bruising. Shatter bruises are rated on a scale of 1-5, with 1 = none and 5 = many and severe. Mean shatter bruise was 3.0, and the LSD = 0.8.

Table 4. Agronomic and quality attributes (skin color, scurf, specific gravity, and general rating (breeder merit score) for advanced fresh market selections and cultivars, Crystal, ND, 2023. The trial was planted May 23, and harvested on October 9 (139 DAP) using a single-row Grimme harvester. A randomized complete block design was utilized with four replicates; plots were 20 feet long, with a 12-inch with-in row spacing, and 36 inches between rows.

Clone	Stand %	Stems per Plant	Vine Size[1]	Vine Maturity[2]	Tubers per Plant	Color[3]	Scurf[4]	Specific Gravity[5]	General Rating
AND15311-3Y	99	3.1	3.8	3.8	7.3	Y	4.1	1.0824	3.7
ND050060CB-4R	100	1.9	2.8	3.0	6.8	3.4	3.5	1.0899	3.3
ND102990B-2R	96	2.8	3.3	4.0	8.2	3.3	3.3	1.0863	3.1
ND113207-1R	199	2.8	3.0	3.5	7.5	3.5	3.3	1.0739	3.1
ND1232-2RY	99	3.0	3.5	3.0	5.6	3.6	3.5	1.0834	2.8
ND2037-2R	99	3.5	2.8	2.5	5.1	3.3	3.1	1.0697	3.1
ND1241-1Y	100	2.6	3.5	3.3	7.7	Y	4.5	1.1026	4.0
ND1243-1PY	95	2.7	4.5	4.0	7.3	P	3.0	1.0793	3.7
ND14282CB-4R	98	5.3	3.0	3.0	11.8	3.4	3.1	1.0923	3.4
ND14304-11R	94	2.5	2.3	2.1	6.1	3.4	3.0	1.0856	3.0
ND14339C-5R	98	3.7	3.0	3.6	6.9	3.4	2.9	1.0808	3.0
ND14341B-1R	98	2.3	2.0	3.1	6.3	3.3	3.4	1.0897	3.1
ND1757-10R	91	2.6	3.3	4.0	7.4	3.3	3.5	1.0835	3.3
ND17129-6P	48	2.8	1.8	3.5	5.7	P	2.3	1.0897	2.5
ND17131-1PY	100	2.2	4.3	4.1	6.1	P	2.5	1.0752	3.2
ND1837B-3Y	100	2.4	4.3	4.0	8.8	Y	4.1	1.0627	3.5
ND1842B-3p	91	2.1	3.0	2.5	5.5	3.0	3.3	1.0757	3.3
ND1842B-4R	99	2.0	2.5	2.5	5.9	2.9	2.8	1.0852	2.9
TXND20044-4R	100	4.1	3.0	2.5	10.2	3.3	3.0	1.0856	3.1
ND1858Y-4R	98	2.5	2.5	3.8	5.8	3.3	3.3	1.0781	3.3
ND1859-1R	100	3.6	2.8	3.0	9.4	3.0	3.1	1.0787	3.2

ND1859-4R	98	3.8	3.8	4.0	9.2	3.6	3.5	1.0803	3.4
ND1870-3R	96	1.8	3.5	3.0	7.2	3.0	3.0	1.0785	3.1
ND1915-2R	98	3.2	3.8	3.5	6.5	3.0	3.0	1.0865	2.0
All Blue	100	2.6	4.8	4.0	6.5	P	2.0	1.0829	2.4
Bison	98	2.7	2.0	4.0	6.4	2.5	2.3	1.0798	2.4
Dakota Jewel	84	1.3	3.0	3.5	4.8	3.8	3.4	1.0799	3.4
Red LaSoda	95	2.3	3.8	3.5	5.3	3.0	3.5	1.0753	3.0
Red Norland	100	3.9	2.5	3.0	5.8	3.0	2.0	1.0775	2.9
Yukon Gold	95	1.7	4.0	2.8	4.0	Y	4.3	1.0903	2.9
Mean	95	2.8	3.2	3.3	6.9	na	3.2	1.0821	3.1
LSD ($\propto$=0.05)	6	0.5	0.7	0.6	1.7	na	0.6	0.0117	0.6

[1] Vine size – scale 1-5, 1 = very small, 5 = very large.

[2] Vine maturity – scale 1-5, 1 = very early, 5 = very late.

[3] Color = 1-5; 1 = white/buff, 2 = pink, 3 = red, 4 = bright red, 5 = dark red, RSY = Red splashed yellow, Y = yellow, P = purple.
[4] Scurf incidence – scale 1-5, 1 = completely covered, 5 = none (not determined if silver scurf or blackdot sclerotia).

[5] Determined using weight-in-air, weight-in-water method.

[6] General Rating = 1-5; 1 = poor and unacceptable, 3 = fair, 5 = excellent.
na = not applicable.

Table 5. Yield and grade for advanced fresh market selections and cultivars, Crystal, ND, 2023. The trial was planted on May 23, and harvested on October 9 (139 DAP). A randomized complete block design was utilized with four replicates. The plots were 20 feet long, with a 12-inch with-in row spacing, and 36 inches between rows.

Clone	Total Yield Cwt./A	A Size Tubers Cwt./A	A Size %	0-4 oz. %	4-6 oz. %	6-10 oz. %	>10 oz. %	% Defects
AND15311-3Y	286	168	59	30	42	17	11	1
ND050060CB-4R	169	55	30	64	24	6	5	1
ND102990B-2R	233	110	46	50	37	9	3	1
ND113207-1R	246	121	47	43	35	12	7	3
ND1232-2RY	218	136	62	32	46	16	6	0
ND2037-2R	226	115	49	26	34	15	25	0

ND1241-1Y	277	147	53	35	38	14	13	0
ND1243-1PY	338	196	56	20	38	18	17	6
ND14282CB-4R	281	93	31	66	26	5	1	2
ND14304-11R	153	58	37	61	28	9	1	1
ND14339C-5R	252	114	46	33	32	14	15	6
ND14341B-1R	165	74	43	57	31	11	1	0
ND1757-10R	202	82	40	52	31	9	5	3
ND17129-6P	56	11	17	81	16	1	0	2
ND17131-1PY	129	27	20	79	17	3	0	1
ND1837B-3Y	365	185	54	30	39	15	12	4
ND1842B-3p	255	138	54	19	36	18	24	3
ND1842B-4R	221	121	53	35	41	13	10	1
TXND20044-4R	301	139	46	48	36	11	4	1
ND1858Y-4R	259	159	61	23	44	18	15	1
ND1859-1R	289	140	44	51	34	10	4	1
ND1859-4R	295	163	54	43	43	11	2	1
ND1870-3R	229	111	48	40	36	12	9	3
ND1915-2R	276	90	35	25	27	8	3	36
All Blue	317	156	49	17	35	14	12	22
Bison	234	98	42	29	28	13	10	19
Dakota Jewel	199	102	53	23	35	18	17	8
Red LaSoda	339	115	35	10	23	13	42	13
Red Norland	346	165	47	11	30	17	34	8
Yukon Gold	268	87	32	7	21	11	39	21
Mean	247	116	45	38	33	12	12	6
LSD ($\propto$=0.05)	80	55	16	14	12	6	11	13

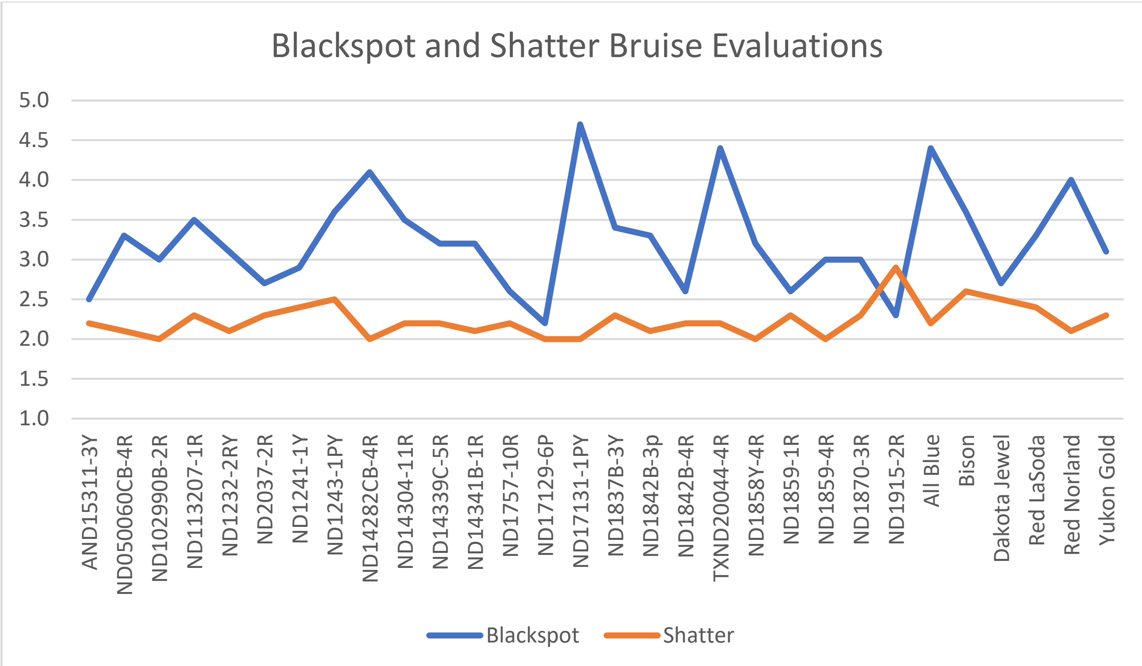

Figure 2. Blackspot and shatter bruise evaluations for advanced fresh market selections and cultivars, Crystal, ND, 2023. The trial was planted on May 23, and harvested on October 9 (139 DAP). A randomized complete block design was utilized with four replicates. The plots were 20 feet long, with a 12-inch with-in row spacing, and 36 inches between rows. Blackspot bruise determined by the abrasive peel method (Pavek et al. 1985) following storage at 45F, using a scale of 1-5, 1 = none, 5 = severe. As an example, Ranger Russet typically rates as a 4.0 or greater. The mean for blackspot was 3.2, with an LSD of 0.9. Shatter bruise is evaluated using a bruising chamber with digger chain link baffles. Tubers are stored at 45F prior bruising. Shatter bruises are rated on a scale of 1-5, with 1 = none and 5 = many and severe. Mean shatter bruise was 2.2, with an LSD equal to 1.9.

Table 6. Agronomic and merit assessments for advancing chip processing selections and cultivars, Hoople, ND, 2023. The chip processing trial was planted on June 2, and harvested October 12 (132 DAP) using a single-row Grimme harvester. The field design was a randomized complete block, with four replicates; plots were 20 feet long, with a 12-inch with-in row spacing, and 38 inches between rows.

Clone	Stand %	Stems per Plant	Vine Size[1]	Vine Matur-ity[2]	Tubers per plant	General Rating[3]
ND7519-1	95	2.1	3.3	3.5	4.2	3.6
ND7799c-1	96	1.9	2.5	2.8	4.2	3.9
ND102631AB-1	94	1.8	2.3	1.9	4.9	3.5
ND1241-1Y	100	1.7	3.0	2.8	6.4	3.8
ND12209C-2	96	2.7	2.5	2.8	6.2	3.4
ND13321CAB-2	90	1.6	2.5	3.8	4.4	3.5
ND1450CAB-3	90	2.0	2.3	2.8	6.5	3.5
ND14197CAB-1	90	1.7	2.5	3.3	5.7	3.5
ND14247CAB-15	99	3.4	2.8	2.8	8.9	3.8
ND1776-8	98	1.7	3.5	4.1	5.7	3.7
ND1776-10	96	1.8	2.8	2.9	5.2	3.5
ND1776-11	89	1.8	2.0	2.5	6.0	3.6
ND1787-6	100	2.9	3.5	3.8	5.8	3.4
Dakota Pearl	96	2.9	2.5	2.3	6.4	3.8
Lady Claire	96	2.0	4.0	3.1	7.7	3.0
Lady Liberty	98	1.7	3.8	4.0	6.8	3.9
Lamoka	86	1.1	3.5	3.8	3.4	3.8
Snowden	99	1.9	3.8	3.0	4.9	3.5
Waneta	84	1.1	2.8	4.3	5.0	3.8
Mean	94	2.0	2.9	3.1	5.7	3.6
LSD (∝=0.05)	11	0.4	0.7	0.7	1.9	0.4

[1] Vine size – scale 1-5, 1 = small, 5 = large.

[2] Vine maturity – scale 1-5, 1 = early, 5 = late.

[3] General rating based on yield, appearance, tuber size profile, shape, set, defects; scale of 1 to 5; 1 = poor, 5 = excellent.

Table 7. Yield and grade for advancing chip processing selections and cultivars, Hoople, ND, 2023. The chip processing trial was planted on June 2, and harvested October 12 (132 DAP) using a single-row Grimme harvester. The field design was a randomized complete block, with four replicates; plots were 20 feet long, with a 12-inch with-in row spacing, and 38 inches between rows.

Clone	Total Yield cwt./a	Yield A Size cwt/a	A Size %	0-4 oz. %	4-6 oz. %	6-10 oz. %	>10 oz. %	US 2s & Culls %
ND7519-1	168	110	59	36	31	27	3	3
ND7799c-1	196	116	60	21	30	31	16	2
ND102631AB-1	149	68	48	45	27	21	4	3
ND1241-1Y	201	91	44	49	21	23	6	0
ND12209C-2	205	85	42	42	22	20	15	0
ND13321CAB-2	147	83	57	31	30	27	8	5
ND1450CAB-3	177	80	43	54	26	16	3	0
ND14197CAB-1	267	163	62	16	23	39	20	2
ND14247CAB-15	246	86	35	63	25	10	1	0
ND1776-8	254	137	53	21	24	29	26	0
ND1776-10	201	104	53	31	28	25	13	3
ND1776-11	166	79	46	49	33	13	4	1
ND1787-6	249	136	54	28	27	27	16	2
Dakota Pearl	213	118	52	44	33	19	2	2
Lady Claire	267	119	44	41	23	21	11	4
Lady Liberty	326	204	63	19	23	40	17	1
Lamoka	199	103	51	7	14	36	42	0
Snowden	270	142	54	16	19	35	27	3
Waneta	210	130	60	21	25	35	19	1
Mean	216	113	52	33	26	26	13	2
LSD (∝=0.05)	78	53	14	14	10	11	10	4

Table 8. Bruising, specific gravity and chip color after grading (USDA chip chart) and following 8-weeks storage at 3.3C (38F) and 5.5C (42F) for advancing chip processing selections and cultivars, Hoople, ND, 2023. The chip processing trial was planted on June 2, and harvested October 12 (132 DAP) using a single-row Grimme harvester. The field design was a randomized complete block, with four replicates; plots were 20 feet long, with a 12-inch with-in row spacing, and 38 inches between rows.

Clone	Black-spot Rating[1]	Shatter Bruise Rating[2]	Specific Gravity[3]	Field Chip Chart[4]	38 F (3.3C) Storage Chart[4]	42F (5.5C) Storage Chart[4]
ND7519-1	4.2	3.0	1.0989	2.8	7.5	3.0
ND7799c-1	2.4	2.3	1.0849	4.0	7.5	3.5
ND102631AB-1	3.2	3.1	1.0943	2.3	7.8	4.5
ND1241-1Y	3.1	2.8	1.1018	4.0	6.3	3.0
ND12209C-2	3.2	2.2	1.0884	1.8	7.8	3.5
ND13321CAB-2	3.0	2.6	1.0885	3.3	6.8	2.6
ND1450CAB-3	3.8	3.3	1.0873	4.8	9.8	8.3
ND14197CAB-1	4.5	2.0	1.0911	4.3	8.4	7.7
ND14247CAB-15	3.5	2.5	1.0951	1.5	5.3	2.3
ND1776-8	2.9	2.7	1.0858	3.3	7.8	5.3
ND1776-10	3.2	2.5	1.0806	2.8	8.4	5.5
ND1776-11	3.1	2.6	1.0883	3.0	8.3	5.4
ND1787-6	3.3	3.6	1.0941	3.0	8.8	5.0
Dakota Pearl	2.6	2.8	1.0930	2.0	6.5	4.3
Lady Claire	3.7	2.0	1.0955	5.0	7.0	3.8
Lady Liberty	4.5	2.1	1.0941	2.3	7.5	6.0
Lamoka	3.9	2.3	1.0944	2.8	8.0	5.9
Snowden	4.6	2.3	1.0970	2.0	9.8	7.9
Waneta	2.4	2.2	1.0868	2.5	7.1	3.9
Mean	3.4	2.6	1.0916	3.0	7.7	4.8
LSD ($\propto$=0.05)	1.0	0.7	0.0057	1.8	2.1	2.4

[1] Blackspot bruise determined by the abrasive peel method (Pavek et al. 1985) following storage at 45F, using a scale of 1-5, 1 = none, 5 = severe. As an example, Ranger Russet typically rates as a 4.0 or greater.

[2] Shatter bruise is evaluated using a bruising chamber with digger chain link baffles; tubers are stored at 45F prior bruising. Shatter bruises are rated on a scale of 1-5, with 1 = none and 5 = many and severe.

[3] Determined using weight-in-air, weight-in-water method.

[4] USDA Potato Chip Color Reference Standard, Courtesy of B.L. Thomas, B.L. Thomas and Associates, Cincinnati, Ohio, Potato Chip Institute International. 1 = white, 10 = very dark; 4 and below acceptable.

ND060735-4Russ

- Dakota Russet x Dakota Trailblazer
- Dual-purpose russet
- Long and blocky
- Medium maturity
- High specific gravity (1.088 avg.)
- Excellent French fry quality
- Stores well

ND113207-1R

- T10-12 x Dakota Ruby
- Medium early maturity
- Fresh market
- Low SG (1.075 avg.)
- Some susceptibility to silver scurf
- Certified seed production in ND and MN

ND1241-1Y

NDSU NORTH DAKOTA AGRICULTURAL EXPERIMENT STATION

- AND07358-1Y x Ivory Crisp
- Dual-purpose (fresh, chip)
- Medium maturity
- High specific gravity (usually exceeds 1.100)
- Stores well
- Trace of scab noted on soils over 8.0 pH
- Certified seed acreage in ND and MN

ND13220C-3

- ND018799C-3 x ND060686C-1
- Chip processing
- Oblong
- Very high yield potential
- High specific gravity (exceeds 1.090 in ND)
- Heat and water stress tolerance
- Resistance to *Verticillium* wilt, *Phytophthora nicotianae* and *P. erythroseptica*

ND1762-19Russ

- Dakota Russet x ND12241YB-2Russ
- Blocky
- Medium early maturity
- High yield potential
- Excellent French fry quality from the field and storage
- High specific gravity (1.090+ in ND)
- Very early in evaluation process
- To TC this winter

Responses of Elk River Russet (MN13142) and Russet Burbank potatoes to N rate

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Summary

Elk River Russet (formerly MN13142) is a midseason processing or fresh-market potato recently released by the University of Minnesota. It has lower total yield than Russet Burbank, but it produces fewer undersized, oversized, or misshapen potatoes than that variety. Its tubers have a low prevalence of hollow heart, high specific gravity, and lower concentrations of glucose, resulting in lighter French fry color. It stores well, but it can be somewhat slow to emerge and benefits from pre-warming of the seed. Studies on Elk River Russet to date have been designed to address multiple questions, with the result that none has investigated the cultivar's N response in detail. To evaluate Elk River Russet's N response, we grew this variety and Russet Burbank (as a reference variety) at six N rates to evaluate N response: 40, 80, 120, 200, 280, and 360 lbs/ac N. Elk River Russet had a shorter period between planting and maturity than Russet Burbank, with canopy closure occurring later in the season and canopy senescence occurring earlier. Although Elk River Russet produced significantly lower total and marketable yields than Russet Burbank, it produced significantly higher yields of U.S. No. 1 tubers and numerically higher yields of tubers between 6 and 14 ounces. Hollow heart was less prevalent in Elk River Russet, and it had significantly higher tuber specific gravity and dry matter content. At harvest, Elk River Russet tubers had lower glucose concentrations and higher stem-end French fry reflectance than Russet Burbank. Based on marketable yield, the optimum N rate for Russet Burbank, among those applied, was 120 lbs/ac N. Elk River Russet's N response was less definite, but its optimum N rate was arguably also 120 lbs/ac N, with a substantially but not significantly lower yields at lower N rates and lower or similar yields at higher N rates These optimum N rates are lower than expected, which is probably related to the N credit from the previous crop (soybeans), low leaching from limited rainfall, and relatively high N deposition via irrigation. Accounting for these factors, treatments assigned to receiving 120 lbs/ac N received a total of approximately 180 lbs/ac N.

Background

Elk River Russet (formerly MN13142) is a mid-season processing or fresh-market potato cultivar developed at the University of Minnesota. It has a low prevalence of hollow heart and brown center, good skin set, high specific gravity, and low reducing sugar content. While it generally has lower total yield than Russet Burbank, its marketable yield often approaches that of Russet Burbank, with fewer undersized (< 4 oz.), oversized (> 14 oz.), or misshapen tubers (including U.S. No. 2 tubers) than that variety. Elk River Russet also stores well, with stem-end glucose concentrations and French fry reflectance at 6 months' storage similar to those of Umatilla Russet and Ivory Russet, and much better than Russet Burbank. Because Elk River tends not to break dormancy in storage, seed may require a period of warming before planting in order to encourage rapid emergence.

While Elk River Russet has been evaluated extensively at the University of Minnesota, previous studies have addressed many questions simultaneously, including performance relative to many other cultivars, optimum seed spacing, and response to three N rates (120, 240, and 360 lbs/ac N). The cultivar has just been named and will soon be released, and certified seed will be available in the near future. Interested growers will need more refined information on the cultivar's N response in order to optimize yield.

To evaluate how Elk River Russet responded to N rate, we grew both Elk River Russet and Russet Burbank (as a reference variety) at six N rates to evaluate N response: 40, 80, 120, 200, 280, and 360 lbs/ac N. Crop responses were measured in terms of stand, leaflet chlorophyll content, canopy cover, and tuber yield, size, grade, quality, sugar content, and French fry color at harvest.

Methods

The study was conducted at the University of Minnesota's Sand Plain Research Farm in Becker, MN, on a Hubbard loamy sand soil, in 2023 following a previous crop of soybeans. Initial soil characteristics from samples taken in April 2023 are presented in Table 1.

The study had a split-plot randomized complete block design with four replicates. Whole plots were defined by potato cultivar (Elk River Russet or Russet Burbank), and subplots within each plot were randomly assigned one of six N rates: 40, 80, 120, 200, 280, or 360 lbs/ac N. These treatments are summarized in Table 2. Each subplot was 12 feet (four rows) wide and 20 feet long. Measurements and samples were taken from the central two rows. Samples and chlorophyll readings were taken from the central 18 feet of the middle two rows, which were each demarcated by red potatoes planted at either end. The field was three plots wide and 16 plots long, with a three-foot buffer planted on all sides to reduce edge effects.

Seed potatoes were received on April 19 and stored in an unheated warehouse until planting. The whole field received 200 lbs/ac MOP (0-0-60) and 200 lbs/ac SulPoMag (0-0-22-22S-11Mg) broadcast on April 25, 2023, supplying 164 lbs/ac K_2O and 22 lbs/ac S. Furrows were opened for planting with 36" spacing on May 1. A mixture of cut "A" and uncut "B" seed of both cultivars were planted by hand with 12" spacing, and the rows were closed. "A" seed was cut shortly before planting. Belay was applied in-furrow at planting for beetle control, along with the systemic fungicide Quadris. At the same time, a planting fertilizer blend was banded in all treatments, supplying 40 lbs/ac N, 102 lbs/ac P_2O_5, 181 lbs/ac K_2O, 40 lbs/ac S, 20 lbs/ac Mg, 1 lb/ac Zn, and 0.6 lbs/ac B in the form of 173 lbs/ac DAP (18-46-0), 141 lbs/ac SulPoMag, 184 lbs/ac MOP, 2 lbs/ac $ZnSO_4$ (17.5% S, 35.5% Zn), and 3 lbs/ac Boron 15 (15% B). Weeds, diseases, and insects were controlled using standard practices. Rainfall was supplemented with sprinkler irrigation using the checkbook method of irrigation scheduling.

Just before hilling on May 22, emergence N was side dressed by hand as Environmentally Smart Nitrogen (ESN, Nutrien: 44-0-0) according to treatment. On May 31 and June 7, plant stand was assessed in the two harvest rows of each plot. On June 8, the number of stems per plant was determined for 10 plants in one of these two rows.

Foliar chlorophyll content was assessed with a SPAD-502 Chlorophyll Meter (Konica Minolta) on June 15 and 27 and July 10. Readings were taken on the terminal leaflet of the fourth mature leaf from the shoot tip for 20 shoots per plot. Canopy cover was measured using the Canopeo software application on June 12, 21, and 26, July 3, 12, 17, and 24, August 1, 8, 14, 21, and 26, and September 7 and 11.

Vines were chopped with a flail mower on September 18. Tubers were harvested on October 2 and sorted by size and grade on October 9. Weights and counts were determined for each size and grade category. Culls were not sorted by size. Total yield was calculated as the sum of yield in all categories, including culls. Marketable yield was the sum of yield in all size categories over 4 oz., excluding culls. The percentage of yield over 6 and 10 ounces were calculated as the sum of all tubers over the threshold size divided by the sum of all tubers in all size categories, excluding culls from both sums. A subsample of 25 tubers was taken from each plot's tuber sample and used to assess the prevalence of hollow heart, brown center, and common scab, as well as tuber specific gravity and dry matter content. A separate subsample was collected to determine tuber sucrose and glucose concentrations and French fry reflectance at harvest and after three and six months' storage. These measurements have been taken on the harvest subsamples.

Data were analyzed using the GLIMMIX procedure in SAS 9.4 software (SAS Institute, Inc., 2016). Each response variable was analyzed as a function of cultivar, N rate, their interaction, block, and whole plot (cultivar*block). Denominator degrees of freedom were determined by the Kenward-Roger method and the data were assumed to be normally distributed. Pairwise comparisons were evaluated where the effect of treatment was at least marginally significant ($P < 0.10$). Pairs of treatments were considered significantly different if the P value of the pairwise comparison was less than 0.10.

Results and discussion

Rainfall and irrigation

Rainfall and irrigation at the Becker site is presented in Figure 1. Overall, 2023 was a relatively dry season with 10.6 inches of rainfall, which was supplemented with 17.5 inches of irrigation water. The irrigation water and rainfall were analyzed for nitrate-N using ion chromatography techniques. The concentration in irrigation water was found to be 10mg L^{-1}, for a net deposition of ~ 40 lbs/ac N. In rainfall, the concentration of nitrate-N was 0.3 mg L^{-1}, depositing < 1 lb/ac N.

Plant stand and stems per plant

Results for plant stand and stems per plant are presented in Table 3. On 31 May, Russet Burbank had higher stand than Elk River Russet. On June 7, this relationship was reversed. In the past, Elk River Russet has shown prolonged dormancy in storage and required warming of the seed to promote high stand, and this slightly delayed emergence compared to Russet Burbank may reflect these traits.

Russet Burbank had more stems per plant than Elk River Russet. Stem count did not respond to N treatment, but there was a marginally significant effect of the interaction between N rate and cultivar. While Russet Burbank had significantly more stems per plant than Elk River Russet at most N rates, the two cultivars did not have significantly different stem numbers per plant in treatments receiving 120 or 360 lbs/ac N, and Elk River Russet had slightly more stems per plant at 360 lbs/ac N. It is unlikely that these results reflect consistent differences between the cultivars in how stem number per plant responds to N rate.

Leaflet chlorophyll content

Results for leaflet chlorophyll content are presented in Table 4. On 15 and 27 June, Elk River Russet had significantly higher chlorophyll content, averaging across N rates, than Russet Burbank. On 10 July, chlorophyll content was not significantly related to cultivar.

On 15 June, averaging across both cultivars, the treatments receiving 40 lbs/ac N total had lower leaflet chlorophyll contents than those receiving more N. On 27 June, the effect of the interaction between cultivar and N rate was marginally significant ($P = 0.0537$). Elk River Russet had lower leaflet chlorophyll content at 40 lbs/ac N total than at any other rate, and the treatment receiving 120 lbs/ac N total had lower leaflet chlorophyll content than any other treatment receiving ESN. In Russet Burbank on that date, the treatment receiving 280 lbs/ac N total had higher leaflet chlorophyll content than the other treatments which did not differ significantly from each other.. On 10 July, averaging between the two cultivars, chlorophyll content increased with N rate at lower N rates, with no significant differences between N rates at or above 200 lbs/ac N.

Canopy cover

Results for canopy cover are presented in Table 5. In both Elk River Russet and Russet Burbank, canopy cover increased between 12 June and 3 July. Russet Burbank had significantly higher canopy cover on 21 and 26 June and 3 July. On July 3, while canopy cover generally increased with N rate in Russet Burbank, it was relatively low in Elk River Russet plots receiving either the control N rate (40 lbs/ac N) or the highest N rate (360 lbs/ac N), resulting in a significant cultivar*N rate interaction effect.

On July 12, 17, and 24, canopy cover was high in all treatments and unrelated to cultivar or N rate.

Beginning on August 1, canopy cover began to decline in some treatments. The decline started earlier the less N a treatment received, and it started earlier in Elk River Russet than in Russet Burbank. The effect of the interaction between N rate and cultivar was not significant throughout this period.

Tuber yield and size

Results for tuber yield and size are presented in Table 6. Averaged across N treatments, Russet Burbank had higher total, U.S. No. 2, and marketable yields, more tubers per plant, and higher yields of 0-4-oz, 4-6-oz, and over-14-oz tubers than Elk River Russet. However, Elk River Russet had higher U.S. No. 1 yield and a larger percentage of yield in tubers over 6 ounces (but not 10 ounces) than Russet Burbank. Thus, while Russet Burbank produced more yield than Elk River Russet overall, a greater proportion of yield was found in intermediate size categories (6-14 oz.) and in the U.S. No. 1 grade category in Elk River Russet.

Averaging between the two cultivars, N rate had a significant effect on U.S. No. 1 yield. Yield increased with increasing N rate up to 120 lbs/ac N, with no directional relationship to N rate at 120 to 360 lbs/ac N. Considering each cultivar separately, this relationship was only evident in Russet Burbank, but the effect of the cultivar*N rate interaction was not significant.

In terms of total marketable yield, Elk River Russet showed little response to N rate. In contrast, Russet Burbank yield peaked at an application rate of 120 lbs/ac N total, with the treatments receiving 40, 80, or 360 lbs/ac N total having significantly lower marketable yields than this treatment. The N response of marketable yield differed enough between the two cultivars to produce a marginally significant effect of the interaction between cultivar and N rate.

The percentage of yield represented by tubers over 6 or 10 ounces increased with N rate at rates between 40 and 120 lbs/ac N in total. Tuber number per plant was not significantly related to N rate. Together, these results suggest that the rate of N applied at hilling affected yield through tuber bulking rather than tuber number.

In Russet Burbank, the optimum N rate based on marketable yield, among those evaluated, was 120 lbs/ac N. This N rate produced significantly higher yield than the next lower one (80 lbs/ac N) and numerically higher yield than any treatment receiving more N. The optimum N rate for Elk River Russet is not as obvious. The yield response between 40 and 120 lbs/ac N is closely paralleled by the response between 200 and 360 lbs/ac N. However, based on these numbers, marketable yield at 120 lbs/ac N is substantially higher than at lower rates (exceeding yields at 40 and 80 lbs/ac N by 29 cwt/ac and 22 cwt/ac, respectively), but it is not substantially lower than yield at any higher N rate (with just 4 cwt/ac higher yield at 360 lbs/ac N). It would therefore be reasonable to conclude that the optimum N rate for Elk River Russet in this field was 120 lbs/ac N, as it was for Russet Burbank.

These low optimum N rates are probably due, at least in part, to a combination of the N credit from the previous crop (soybeans: 20-30 lbs/ac N), low rainfall causing minimal leaching, and deposition from irrigation water (~ 40 lbs/ac N). A treatment assigned 120 lbs/ac N actually received roughly 180 lbs/ac N when these factors were accounted for.

Tuber quality

Results for tuber quality are presented in Table 7. Although hollow heart was not common in either cultivar, it was significantly less prevalent in Elk River Russet than Russet Burbank. Elk River Russet also had higher specific gravity and dry matter content, averaging across N rates, than Russet Burbank. The application rate of N had no significant effect on the tuber quality characteristics measured.

Tuber sugars and French fry reflectance at harvest

Results for tuber sugars and French fry reflectance are presented in Table 8. Tuber sucrose concentration was significantly higher in Elk River Russet than in Russet Burbank, while the opposite was true of glucose concentration. Corresponding to the difference in glucose concentration, French fries made from the stem end of Russet Burbank tubers had much lower reflectance (i.e., were much darker) than French fires made from the stem end of Elk River Russet tubers. There was no difference in reflectance in French fries made from the bud end.

The application rate of N had no effect on sugar concentrations or French fry reflectance when averaged between the two cultivars. However, Russet Burbank tubers receiving 80 lbs/ac N had higher glucose concentrations than those receiving 200 lbs/ac N, while Elk River Russet tubers showed no significant response to N rate and had lower glucose concentrations than Russet Burbank tubers at both rates.

Conclusions

Elk River Russet is an earlier-maturing cultivar than Russet Burbank. It achieved full stand and full canopy closure later in the year, and its canopy started dying back earlier than that of Russet Burbank.

Although Elk River Russet produced significantly lower total and marketable yields than Russet Burbank, it produced significantly higher yields of U.S. No. 1 tubers, and numerically higher yields of tubers between 6 and 14 ounces. These differences are presumably a result of Elk River Russet's shorter growing season, determinate growth form, and smaller number of tubers per plant.

Hollow heart was less prevalent in Elk River Russet than in Russet Burbank. Elk River Russet also had significantly higher tuber specific gravity and dry matter content. At harvest, Elk River Russet tubers had lower glucose concentrations and higher stem-end French fry reflectance than Russet Burbank. Taken together, these results indicate that Elk River Russet produced tubers that were not only of superior size and shape, but also of superior quality to Russet Burbank. It will be important to see how each cultivar's tubers respond to time in storage. However, Elk River Russet has maintained its advantages over Russet Burbank after 3 or 6 months in storage in previous studies.

Based on marketable yield, the optimum N rate for Russet Burbank, among those applied, was 120 lbs/ac N. Elk River Russet's N response was less definite, but its optimum N rate was arguably also 120 lbs/ac N, with a substantial but nonsignificant decrease in yield at lower rates and no substantial increase at higher rates. These low optimum N rates are probably related to the N credit from the previous crop (soybeans), low leaching from limited rainfall, and relatively high N deposition via irrigation.

Table 1. Initial soil characteristics in the study field at the Sand Plain Research Farm in Becker, MN, in 2023.

0 - 6 inches												0 - 2 feet
pH	Organic matter (%)	Bray P (mg/kg)	NH_4OAc-K (mg/kg)	NH_4OAc-Ca (mg/kg)	NH_4OAc-Mg (mg/kg)	DTPA-Mn (mg/kg)	DTPA-Fe (mg/kg)	DTPA-Zn (mg/kg)	DTPA-Cu (mg/kg)	Hot water B (mg/kg)	SO_4^{2-}-S (mg/kg)	NO_3^--N (mg/kg)
6.6	1.6	56	100	760	149	12	24	2.0	1.0	0.2	11	1.4

Table 2. N treatments applied to Elk River Russet and Russet Burbank plants at the Sand Plain Research Farm in Becker, MN, in 2023.

Treatment #	N applied to Elk River Russet and Russet Burbank (lbs/ac)		
	As MAP[1] at planting	As ESN[2] at emergence	Total
1	40	0	40
2	40	40	80
3	40	80	120
4	40	160	200
5	40	240	280
6	40	320	360

[1] Monoammonium phosphate (11-52-0)

[2] Environmentally Smart Nitrogen (44-0-0)

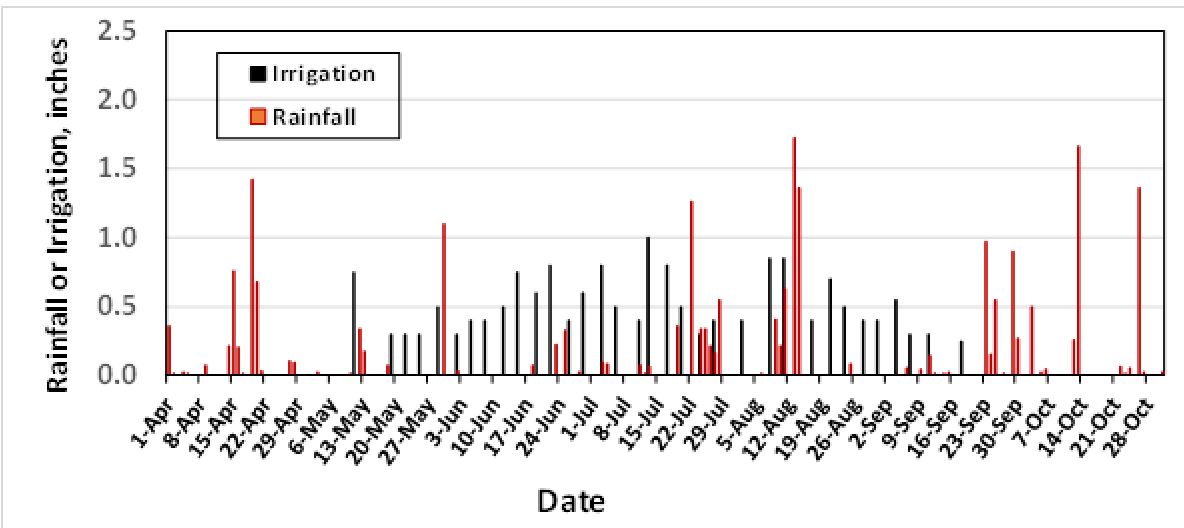

Figure 1. Rainfall and irrigation during the 2023 growing season at Becker.

Table 3. Plant stand on 31 May and 7 June and stem number per plant on 8 June 2023 in plots of Elk River Russet and Russet Burbank receiving between 40 and 360 lbs/ac N in total. Values within a column that have a letter in common are not significantly different from each other ($P > 0.10$) in post-hoc pairwise comparisons. Comparisons were only made when the effect of cultivar, N rate, or their interaction was significant at $P \leq 0.10$.

Cultivar	N treatment		Plant stand (%)		Stems / plant June 8
	Number	Total N applied (lbs/ac)	May 31	June 7	
Elk River	Averaged across N treatments		87 b	100 a	2.4 b
Burbank			94 a	94 b	3.2 a
Effect of cultivar (P-value)			**0.0007**	**<0.0001**	**<0.0001**
Average of both cultivars	1	40	93	98	2.9
	2	80	87	96	2.7
	3	120	89	95	2.9
	4	200	88	97	2.7
	5	280	95	98	2.8
	6	360	91	97	2.7
Effect of N rate (P-value)			0.1600	0.4833	0.8516
Elk River Russet	1	40	88	99	2.2 c
	2	80	84	100	2.4 c
	3	120	84	99	2.6 bc
	4	200	83	100	2.3 c
	5	280	92	99	2.2 c
	6	360	90	100	2.8 bc
Russet Burbank	1	40	97	97	3.6 a
	2	80	90	92	3.1 ab
	3	120	93	90	3.1 ab
	4	200	93	93	3.1 ab
	5	280	97	98	3.5 a
	6	360	92	94	2.6 bc
Effect of cultivar*N rate (P-value)			0.8590	0.2587	***0.0533***

Table 4. Leaflet chlorophyll content (SPAD-502 reading) on 15 and 27 June and 10 July 2023 in plots of Elk River Russet (ER) and Russet Burbank (RB) receiving between 40 and 360 lbs/ac N in total. Values within a column that have a letter in common are not significantly different from each other ($P > 0.10$) in post-hoc pairwise comparisons. Comparisons were only made when the effect of cultivar, N rate, or their interaction was significant at $P \leq 0.10$.

Cultivar	N treatment		Leaflet chlorophyll content (SPAD-502)		
	Number	Total N applied (lbs/ac)	June 15	June 27	July 10
Elk River	Averaged across N treatments		54.5 a	47.2 a	43.9
Burbank			52.7 b	46.5 b	43.5
Effect of cultivar (P-value)			**0.0009**	***0.0720***	0.3310
Average of both cultivars	1	40	51.8 b	45.1 c	40.8 c
	2	80	53.6 a	47.1 b	42.3 b
	3	120	54.0 a	46.4 b	43.4 b
	4	200	54.5 a	46.9 b	45.2 a
	5	280	53.2 a	48.4 a	45.7 a
	6	360	54.6 a	47.3 b	44.9 a
Effect of N rate (P-value)			**0.0229**	**0.0006**	**<0.0001**
Elk River Russet	1	40	52.3	44.6 d	41.0
	2	80	55.3	48.0 ab	42.8
	3	120	54.1	46.3 c	42.9
	4	200	55.9	48.2 a	45.8
	5	280	53.4	48.2 a	45.6
	6	360	56.1	48.0 ab	45.5
Russet Burbank	1	40	51.3	45.6 dc	40.6
	2	80	52.0	46.2 c	41.9
	3	120	53.9	46.5 bc	43.8
	4	200	53.1	45.7 dc	44.7
	5	280	53.1	48.6 a	45.7
	6	360	53.1	46.6 bc	44.4
Effect of cultivar*N rate (P-value)			0.2135	***0.0537***	0.6561

Table 5. Canopy cover (as measured by the Canopeo app) across the 2023 season in plots of Elk River Russet and Russet Burbank potatoes receiving between 40 and 360 lbs/ac N in total. Values within a column that have a letter in common are not significantly different from each other (P > 0.10) in post-hoc pairwise comparisons. Comparisons were only made when the effect of cultivar, N rate, or their interaction was significant at P ≤ 0.10.

Cultivar	N treatment		Canopy cover (%, Canopeo)													
	Number	Total N applied (lbs/ac)	12-Jun	21-Jun	26-Jun	3-Jul	12-Jul	17-Jul	24-Jul	1-Aug	8-Aug	14-Aug	21-Aug	26-Aug	7-Sep	11-Sep
Elk River	Averaged across N treatments		37	62 b	73 b	93 b	95	97	96	92 b	89 b	89 b	81 b	72 b	44 b	30 b
Burbank			39	69 a	85 a	95 a	96	96	92	94 a	93 a	95 a	89 a	84 a	68 a	55 a
Effect of cultivar (P-value)			0.2467	**0.0010**	**<0.0001**	**0.0116**	0.1817	0.3403	0.1358	**0.0231**	**0.0001**	**<0.0001**	**<0.0001**	**<0.0001**	**<0.0001**	**<0.0001**
Average of both cultivars	1	40	36	66	75	91 b	94	95	92	86 c	84 c	85 c	70 c	61 c	38 d	24 c
	2	80	37	65	80	95 a	96	96	94	92 b	89 b	89 b	79 b	71 b	48 c	30 c
	3	120	38	64	79	95 a	96	96	96	93 ab	94 a	94 a	89 a	82 a	61 ab	45 b
	4	200	37	68	83	96 a	97	98	97	96 a	94 a	94 a	89 a	85 a	59 b	45 b
	5	280	40	64	79	95 a	96	96	93	95 a	93 a	94 a	89 a	83 a	63 ab	54 a
	6	360	39	67	77	94 a	96	96	90	94 ab	94 a	95 a	91 a	87 a	67 a	56 a
Effect of N rate (P-value)			0.5919	0.6624	0.2936	**0.0461**	0.1666	0.1572	0.6264	**<0.0001**	**<0.0001**	**<0.0001**	**<0.0001**	**<0.0001**	**<0.0001**	**<0.0001**
Elk River Russet	1	40	37	64	72	91 cde	94	96	94	87	84	85	68	57	24	12
	2	80	37	65	75	95 abc	95	96	96	91	86	86	75	63	37	23
	3	120	39	64	76	94 bcd	96	97	95	92	91	90	85	77	55	36
	4	200	35	61	76	95 ab	97	98	97	95	92	90	86	82	45	30
	5	280	37	60	74	94 bcd	96	97	96	93	90	89	81	75	47	39
	6	360	39	60	67	89 e	95	95	95	91	91	91	87	82	58	42
Russet Burbank	1	40	36	68	77	91 de	95	94	90	86	83	86	72	66	53	37
	2	80	38	65	85	95 ab	96	96	93	92	92	93	84	78	60	37
	3	120	37	65	83	95 ab	96	96	97	95	97	97	93	87	67	54
	4	200	39	76	90	97 ab	97	97	97	97	95	97	93	88	73	61
	5	280	43	67	85	96 ab	96	96	89	97	97	98	96	92	79	70
	6	360	40	74	86	98 a	97	97	85	96	97	99	96	92	76	69
Effect of cultivar*N rate (P-value)			0.7155	0.1225	0.5048	**0.0482**	0.7546	0.5136	0.7848	0.5583	0.2183	0.3522	0.3920	0.4803	0.2368	0.2224

Table 6. Tuber yield, grade, size, and number per plant in plots of Elk River Russet and Russet Burbank receiving between 40 and 360 lbs/ac N in total. Total yield includes culls, while culls were excluded from percentages of yield in tubers over 6 and 10 ounces. Marketable yield includes all tubers over 4 ounces that were not culls. Values within a column that have a letter in common are not significantly different from each other (P > 0.10) in post-hoc pairwise comparisons. Comparisons were only made when the effect of cultivar, N rate, or their interaction was significant at P ≤ 0.10.

Cultivar	N treatment		Yield (cwt/ac)										% yield in tubers over:		Tubers / plant
	Number	Total N applied (lbs/ac)	Culled	0-4 oz.	4-6 oz.	6-10 oz.	10-14 oz.	Over 14 oz.	Total	U.S. No. 1	U.S. No. 2	Marketable	6 oz.	10 oz.	
Elk River	Averaged across N treatments		3	52 b	90 b	219	140	77 b	578 b	512 a	14 b	526 b	76 a	38	8.1 b
Burbank			6	68 a	113 a	211	135	113 a	640 a	479 b	93 a	572 a	72 b	39	9.1 a
Effect of cultivar (P-value)			0.1399	**0.0019**	**0.0024**	0.3005	0.4836	**0.0030**	**<0.0001**	**0.0200**	**<0.0001**	**<0.0001**	**0.0264**	0.7122	**0.0012**
Average of both cultivars	1	40	5	75 a	120	236	104 b	51 b	586	449 c	61	510 c	67 c	26 b	9.4
	2	80	4	58 b	105	206	140 a	90 a	599	482 bc	59	541 b	73 b	38 a	8.4
	3	120	6	50 b	88	214	159 a	116 a	627	533 a	45	577 a	78 a	44 a	8.3
	4	200	5	54 b	98	201	144 a	106 a	603	498 ab	52	549 b	75 ab	41 a	8.2
	5	280	6	61 b	100	216	137 a	105 a	620	499 ab	60	559 ab	74 ab	39 a	8.6
	6	360	2	61 ab	98	214	143 a	101 a	617	513 ab	43	556 ab	74 ab	39 a	8.7
Effect of N rate (P-value)			0.7131	***0.0937***	0.2365	0.2196	**0.0060**	**0.0284**	0.1299	**0.0269**	0.9056	**0.0038**	**0.0201**	**0.0036**	0.1433
Elk River Russet	1	40	4	60	101	250	103	59	573	504	9	513 de	72	28	8.8
	2	80	4	54	100	199	143	78	574	507	12	520 de	73	39	8.2
	3	120	5	48	80	226	159	77	590	529	13	542 cde	78	40	8.0
	4	200	3	49	87	199	134	94	564	501	14	515 de	76	40	7.6
	5	280	4	49	73	205	152	90	569	504	16	520 de	79	43	7.6
	6	360	0	50	96	235	151	63	596	527	19	546 cd	75	36	8.4
Russet Burbank	1	40	5	91	138	223	104	42	598	394	114	508 e	62	24	10.0
	2	80	3	62	110	214	136	102	624	457	105	562 bc	72	38	8.6
	3	120	8	53	96	203	159	155	665	536	77	612 a	78	47	8.6
	4	200	8	60	108	203	153	118	642	494	89	583 ab	74	42	8.7
	5	280	7	73	128	227	123	120	671	494	104	598 ab	70	36	9.7
	6	360	4	72	99	193	135	139	639	499	67	567 bc	73	43	9.0
Effect of cultivar*N rate (P-value)			0.9144	0.5965	0.3149	0.1637	0.5535	0.1492	0.2130	0.1696	0.7671	***0.0650***	0.4166	0.4438	0.4580

Table 7. Tuber quality characteristics in plots of Elk River Russet and Russet Burbank receiving between 40 and 360 lbs/ac N in total. Values within a column that have a letter in common are not significantly different from each other (P > 0.10) in post-hoc pairwise comparisons. Comparisons were only made when the effect of cultivar, N rate, or their interaction was significant at P ≤ 0.10.

Cultivar	N treatment		Prevalence (% of tubers)			Specific gravity	Dry matter content (%)
	Number	Total N applied (lbs/ac)	Hollow heart	Brown center	Common scab		
Elk River	Averaged across N treatments		1 b	1	0.2	1.0781 a	20.2 a
Burbank			3 a	1	0.3	1.0742 b	19.2 b
Effect of cultivar (P-value)			**0.0061**	0.3868	0.6579	**<0.0001**	**0.0119**
Average of both cultivars	1	40	3	1	0	1.0755	19.2
	2	80	3	2	0	1.0751	19.4
	3	120	1	1	1.5	1.0776	19.8
	4	200	1	0	0	1.0768	20.3
	5	280	2	1	0	1.0762	19.6
	6	360	2	1	0	1.0759	19.9
Effect of N rate (P-value)			0.1350	0.4886	0.1431	0.4093	0.5670
Elk River Russet	1	40	2	2	0	1.0773	19.5
	2	80	2	2	0	1.0756	19.3
	3	120	0	0	1.0	1.0814	19.7
	4	200	0	0	0	1.0783	20.9
	5	280	0	0	0	1.0783	20.5
	6	360	1	0	0	1.0778	21.2
Russet Burbank	1	40	4	0	0	1.0736	18.8
	2	80	4	2	0	1.0746	19.5
	3	120	1	1	2.0	1.0738	19.8
	4	200	1	0	0	1.0752	19.7
	5	280	4	2	0	1.0741	18.7
	6	360	3	2	0	1.0741	18.7
Effect of cultivar*N rate (P-value)			0.8243	0.3408	0.9600	0.2466	0.2336

Table 8. Tuber sucrose and glucose concentrations and French fry reflectance values at harvest for tubers from plots of Elk River Russet and Russet Burbank receiving between 40 and 360 lbs/ac N in total. Values within a column that have a letter in common are not significantly different from each other (P > 0.10) in post-hoc pairwise comparisons. Comparisons were only made when the effect of cultivar, N rate, or their interaction was significant at P ≤ 0.10.

Cultivar	N treatment		Tuber traits at harvest			
	Number	Total N applied (lbs/ac)	Sucrose (mg/g)	Glucose (mg/g)	Stem-end reflectance	Bud-end reflectance
Elk River	Averaged across N treatments		0.838 a	0.631 b	39.0 a	43.3
Burbank			0.644 b	1.100 a	27.9 b	44.0
Effect of cultivar (P-value)			**0.0020**	**0.0013**	**0.0004**	0.5881
Average of both	2	80	0.765	0.933	33.9	43.3
	4	200	0.717	0.798	33.0	44.1
Effect of N rate (P-value)			0.2475	0.1509	0.6021	0.5095
Elk River Russet	2	80	0.863	0.599 c	40.1	43.1
	4	200	0.813	0.662 c	37.9	43.6
Russet Burbank	2	80	0.667	1.267 a	27.6	43.4
	4	200	0.622	0.933 b	28.2	44.6
Effect of cultivar*N rate (P-value)			0.9574	***0.0523***	0.3913	0.7965

Potassium management effects on chloride cycling and potato yield and quality

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Summary

Potato production requires large amounts of potassium (K), without which low yield, poor bulking, and other issues may arise. Due to a recent, prolonged peak in K prices, there is strong interest in whether banded K application could reduce K fertilizer requirements in potato crops. Alternatively, K use efficiency might be improved by using split applications of K, reducing losses of K to fixation and leaching before the crop is done taking it up. There are also concerns that fertilization with KCl, which is affordable and therefore widely used, may result in reduced tuber specific gravity, and whether this effect is due to excessive Cl application. The objectives of this study were to (1) evaluate the effects of K rate on tuber yield and quality, (2) determine whether banded K application decreases potato crop K requirements, (3) evaluate the effectiveness of split K application in improving K use efficiency, (4) determine whether using K_2SO_4 in place of KCl improves tuber specific gravity, and (5) evaluate the effects of Cl application on potato crop performance and Cl leaching concentrations. Among broadcast KCl treatments, the highest total yield and specific gravity were observed at 80 lbs/ac K_2O, while the highest yields of U.S. No. 1 and total marketable potatoes were seen at 160 lbs/ac K_2O. At equivalent K_2O rates (160 or 240 lbs/ac), yields with K_2SO_4 were higher than KCl, suggesting a negative effect of chloride on yield in this study. Total and marketable yields tended to decrease as broadcast KCl rates increased above 160 lbs/ac as K_2O. Banded application of K increased the yield of U.S. No. 2 tubers but decreased tuber specific gravity. Split application of KCl produced significantly higher total, marketable, and U.S. No. 1 yields than a single broadcast application at the same total rate (240 lbs/ac K_2O). Using K_2SO_4 in place of KCl did not improve tuber specific gravity, nor did a treatment receiving $CaCl_2$ without K have lower tuber specific gravity than the check treatment, suggesting that Cl did not reduce specific gravity in this study. Banded application of KCl increased the concentration of Cl^- in soil water sampled at the 4 ft depth compared to broadcast applications of KCl or K_2SO_4 at the same K rate. It is possible that banded application would have produced better yield and less Cl^- leaching at a lower rate than 160 or 240 lbs/ac K_2O. The negative effect of high KCl rates was likely due to lack of rainfall/leaching with low Cl concentrations during the growing season coupled with high concentrations of Cl in irrigation water, which supplied over 150 lbs/ac Cl over the growing season.

Background

Potassium (K) is required in large quantities in potato agriculture. Low K in potato production results in low yield, poor tuber bulking, and black spot bruising. Deficiency symptoms include scorching of the leaves and, in severe cases, early vine dieback resembling *Verticillium* wilt. Irrigated potatoes are generally grown on sandy soils with low to medium K, so K fertilizer is usually applied to this crop, with the amount determined largely by yield goals. Current practice is to broadcast apply K to potato fields in the fall or spring before planting.

K prices increased dramatically in 2021 and remained high for over a year before decreasing in 2023. This price increase has stirred growing interest in banded K application as a possible way to decrease required K application rates in potato crops. Another approach to improving K use efficiency may be to apply K in split applications, which may provide more available K during tuber bulking and maturation, reducing the amount of K lost to fixation and leaching.

Potassium chloride (KCl, also called muriate of potash or MOP: 0-0-60) is the most economical and commonly used K fertilizer in agriculture, which means that chloride (Cl) is co-applied with K. Cl is an essential plant nutrient that has been shown to improve disease resistance in some plants. However, fertilizing with KCl can reduce tuber specific gravity, possibly because of the high application rate of Cl, and using K_2SO_4 (0-0-50) instead of KCl may therefore mitigate these symptoms.

Because Cl is highly leachable and can be environmentally detrimental in large quantities, there is also interest in understanding the fate of Cl in the soil following KCl application. Suction lysimeters at a depth of four feet were used to collect soil water samples from two weeks after planting until six weeks after harvest. These were analyzed for Cl concentration as a measure of how much Cl was leached from the soil throughout the season.

The overall objectives for the potato study were to (1) evaluate the effects of K rate on potato tuber yield and quality, (2) determine whether banded K application decreases potato crop K requirements, (3) evaluate the effectiveness of split K application in improving K use efficiency, (4) determine whether using K_2SO_4 in place of KCl improves tuber specific gravity, and (5) evaluate the effects of Cl application on potato crop performance and Cl leaching concentrations.

Methods

The study was conducted at the University of Minnesota's Sand Plain Research Farm in Becker, MN, on a Hubbard loamy sand soil, in 2023 following a previous crop of soybeans. Initial soil characteristics from samples taken in April 2023 are presented in Table 1. Rainfall and irrigation rates during the season are presented in Figure 1.

Eleven treatments were applied to Russet Burbank potatoes in a randomized complete block design with four replicates. These treatments are summarized in Table 2. Each experimental plot was four rows (12 feet) wide and 20 feet long. Eighteen feet of the central two rows were used for the end-of-season vine and tuber harvest samples, and the ends of these rows were demarcated with one red potato at each end. The field was three plots wide and 16 plots long (four plots duplicated the check treatment and were not included in the analyses). A 3-foot buffer was planted on all sides of the field to reduce edge effects.

Broadcast applications of KCl in treatments 2-5 and 8, K_2SO_4 in treatments 9 and 10, and $CaCl_2$ in treatment 11 were applied by hand according to treatment and worked in with a field cultivator on May 3. On May 4, rows were opened mechanically with 36-inch spacing and a mixture of whole "B" and cut "A" seed potatoes were planted by hand with 12-inch spacing within rows. Belay was applied in-furrow at planting for beetle control, along with the systemic fungicide Quadris. KCl was banded at planting into the rows in treatments 6 and 7 approximately 2 inches below and 3 inches to either side of the seed potatoes. At the same time, a planting fertilizer blend was banded in all treatments, supplying 40 lbs/ac N, 100 lbs/ac P_2O_5, 0.5 lbs/ac S, 1 lb/ac Zn, and 0.5 lbs/ac B in the form of 1.9 lbs/ac urea (46-0-0), 217 lbs/ac DAP (18-46-0), 2.8 lbs/ac $ZnSO_4$ (17.5% S, 35.5% Zn), and 3 lbs/ac Boron 15 (15% B). Weeds, diseases, and insects were controlled using standard practices. Rainfall was supplemented with sprinkler irrigation using the checkbook method of irrigation scheduling.

Just before hilling on May 22, the rows in treatment 8 were side dressed with KCl at 120 lbs/ac K_2O. All treatments except for treatments 9 and 10 were side dressed with ammonium sulfate (21-0-0-24S) to provide 54.4 lbs/ac S and 47.6 lbs/ac N. Treatments 9 and 10 were side dressed with 47.6 lbs/ac N as 103 lbs/ac urea (46-0-0).

Lysimeters were installed in all plots from treatments 1, 4, 7, 10, and 11 on May 16 to sample soil water at a depth of 4 feet. Soil water samples were collected on May 19, 24, and 30, June 7, 14, 22, and 26, July 3, 10, 17, and 24, August 22 and 29, September 5, 12, 19, and 26, October 16, 20, and 23, and November 15. In addition, irrigation water and rain water were periodically sampled during the season and analyzed for chloride. The chloride concentration of lysimeter water, irrigation and rainwater samples were determined using a chloride ion-selective electrode (ISE).

Plant stand in the two harvest-sample rows was assessed on May 31 and June 7. On June 8, the number of stems per plant was determined from a 10-plant sample in one of the harvest-sample rows. On June 14-15 and 27 and July 10, petiole samples and leaflet chlorophyll readings were taken in all plots. Foliar chlorophyll was measured using a SPAD-502 Chlorophyll Meter (Konica Minolta) on the terminal leaflet of the fourth mature leaf from the shoot tip for 20 shoots per plot. Petioles were then collected from the fourth mature leaf from the shoot tip for 20 shoots per plot. The petiole samples were dried at 140°F to constant weight, ground, and sent to Agvise (Benton, MN) to be analyzed for K, Cl, S, and NO_3^--N concentrations. Canopy cover was assessed in each plot using the Canopeo app on June 12, 21, and 26, July 3, 12, 17, and 24, August 1, 8, 14, 21, and 28, and September 7 and 11.

Vines were sampled from 10 feet of the two harvest rows on September 21. The full samples were weighed, then subsamples were collected, weighed, dried at 140°F to constant weight, and weighed again to determine dry matter content. Tubers were harvested on October 2 and sorted by size and grade on October 9. Weights and counts were determined for each size and grade category. Culls were not sorted by size. Total Cl was determined in subsamples of vines and tubers that were dried at 140 F and then ground using the Cl titration method.

On October 18, soil samples to a depth of 6 inches were collected from each plot. These were dried at 95°F to a constant weight and sent to the University of Minnesota's Research Analytical Laboratory (St. Paul, MN) to be analyzed for chloride content with a Lachat QuikChem 8500 Flow Injection Analyzer. In addition, samples from treatments 1, 4, and 11 were analyzed by the same laboratory for ammonium acetate extractable K.

Data were analyzed using the GLIMMIX procedure in SAS 9.4 software (SAS Institute, Inc., 2016). Each response variable was analyzed as a function of treatment and block. Denominator degrees of freedom were determined by the Kenward-Roger method and the data were assumed to be normally distributed.

Pairwise comparisons were evaluated where the effect of treatment was at least marginally significant ($P < 0.10$). Pairs of treatments were considered significantly different if the P value of the pairwise comparison was less than 0.10.

For all data except lysimeter data and the end-of-season soil K data, five contrast statements were applied to compare (1) the check treatment (treatment 1) versus the treatments receiving broadcast KCl (treatments 2-5), (2) the linear and (3) the quadratic response to KCl rate (among treatments 1-5), (4) broadcast versus banded KCl application (treatments 3 and 4 versus 6 and 7), and (5) broadcast KCl versus broadcast K_2SO_4 (treatments 3 and 4 versus 9 and 10). No contrasts were evaluated for end-of-season soil K concentration, which was only measured in 3 treatments.

Because there were numerous gaps in the lysimeter data, soil water chloride readings were analyzed as average values across four time spans: May 19 – June 14 (vegetative growth to tuber initiation), June 22 – July 24 (initiation to bulking), August 22 – September 26 (bulking to harvest), and October 16 – November 15 (post-harvest), as well as across the full season (May 19 – November 15). Because lysimeter data were collected in a subset of the treatments, a different set of contrasts were applied to compare (1) the check treatment (treatment 1) versus the treatment receiving broadcast KCl (treatment 4), (2) broadcast versus banded KCl (treatment 4 versus 7), (3) KCl versus K_2SO_4 (treatment 4 versus 10), and the check treatment versus the treatment receiving $CaCl_2$ without K (treatment 11).

Results

Tuber yield, size, and grade

Results for tuber yield, grade, and size are presented in Table 3. Total and marketable tuber yield and U.S. No. 1 tuber yield were higher in treatments receiving broadcast KCl (treatments 2-5) than in the check treatment (treatment 1). However, among the treatments receiving broadcast KCl, all three yield metrics decreased with increasing application rate, so that the overall relationship between the application rate of broadcast KCl and yield followed a negative quadratic curve. The highest total, marketable, and U.S. No. 1 yields among these treatments were achieved at 160 lbs/ac K_2O. The treatments receiving broadcast K_2SO_4 (treatments 9 and 10), as a group, had significantly higher total, marketable, and U.S. No. 1 yields than the treatments receiving broadcast KCl at the same rates (treatments 3 and 4), and the treatment with the highest marketable yield was the treatment receiving K_2SO_4 at 160 lbs/ac K_2O. The treatments receiving banded KCl (treatments 6 and 7) had lower total, U.S. No. 1, and marketable yields than those receiving broadcast KCl (treatments 3 and 4) or K_2SO_4 (treatments 9 and 10) at the same rates, but the difference was only significant for total and U.S. No. 1 yields versus broadcast K_2SO_4 at 240 lbs/ac K_2O. Under the conditions of this study the chloride seems to be reducing yields.

The yield of U.S. No. 2 tubers was higher in the treatments receiving KCl in a banded application (treatments 6 and 7) than in the treatments receiving broadcast KCl at the same rates (treatments 3 and 4). The treatments receiving broadcast K_2SO_4 (treatments 9 and 10) had marginally significantly higher U.S. No. 2 yield than the treatments receiving broadcast KCl at the same rates (treatments 3 and 4). In both contrasts, the differences were driven by the low yield of U.S. No. 2 tubers in the treatment receiving broadcast KCl at 160 lbs/ac K_2O.

The linear and quadratic contrasts of the percentage of yield represented by tubers over six ounces and ten ounces on the application rate of broadcast KCl (treatments 1-5) were significant. Both percentages increased with K rate between 0 and 160 lbs/ac K_2O, but not between 160 and 300 lbs/ac K_2O. The number of tubers per plant was not related to treatment, indicating that differences in yield among treatments were primarily due to differences in tuber bulking rather than initiation or retention.

Yields with treatments receiving banded K_2O were numerically lower than those receiving broadcast application at the same rates. These results suggest a possible negative effect of chloride on yield. In future studies a lower banded K rate should lbe included.

Tuber quality

Results for tuber quality are presented in Table 4. The prevalences of hollow heart, brown center, and common scab were low and unrelated to treatment. Tuber specific gravity was higher among the treatments receiving broadcast KCl (treatments 2-5), as a group, than in the check treatment (treatment 1). However, among the treatments receiving broadcast KCl, tuber specific gravity decreased as the application rate of KCl increased, especially between 240 and 300 lbs/ac K_2O, resulting in a significant quadratic contrast of specific gravity on KCl rate. The treatments receiving banded KCl (treatments 6 and 7), as a group, had lower tuber specific gravity than the treatments receiving broadcast KCl at the same rates (treatments 3 and 4). Although the treatment receiving 160 lbs/ac K_2O as K_2SO_4 (treatment 9) had the highest tuber specific gravity, there was no net effect of applying K_2SO_4 (treatments 9 and 10) in place of KCl (treatments 3 and 4). Tuber dry matter content was significantly related to treatment, but the effect of treatment did not correspond to KCl rate, the use of broadcast versus banded application of KCl, or the use of K_2SO_4 in place of KCl. The treatment receiving split applications of KCl (treatment 8) had significantly lower dry matter content than the treatment receiving the same rate of KCl in a single broadcast application (treatment 4). The treatment receiving $CaCl_2$ (treatment 11) did not differ significantly from the check treatment (treatment 1) in terms of tuber quality.

Plant stand and stems per plant

Results for plant stand and the number of stems per plant are presented in Table 5. Plant stand on May 31 was higher in treatments that received KCl (treatments 2-5) than it was in the check treatment (treatment 1). Based on pairwise comparisons, so long as the K_2O rate was greater than zero, it did not affect plant stand. Treatments receiving banded KCl (treatments 6 and 7), as a group, had marginally significantly lower stand on May 31 and significantly lower stand on June 7 than treatments receiving broadcast KCl at the same rates (treatments 3 and 4).

The number of stems per plant on June 8 was marginally significantly related to treatment, but it was not related to any of the contrasts, and there was no clear pattern in how differences in the number of stems per plant related to differences among treatments.

Leaflet chlorophyll content

Results for leaflet chlorophyll content as measured by a SPAD meter are presented in Table 6. On June 15, aside from a marginally significant tendency for treatments receiving banded KCl (treatments 6 and 7) to have lower leaflet chlorophyll content than treatments receiving broadcast KCl at the same rates (treatments 3 and 4), leaflet chlorophyll was unrelated to treatment. On June 27, there was a negative relationship between K_2O application rate and leaflet chlorophyll content among the treatments receiving broadcast KCl and the check treatment (treatments 1-5). On July 10, leaflet chlorophyll content was highest in the check treatment (treatment 1), as reflected in a significant linear contrast on KCl rate (among treatments 1-5) and a significant contrast between the check treatment (treatment 1) and the treatments receiving broadcast KCl (treatments 2-5). The treatment receiving $CaCl_2$ without K (treatment 11) had the highest leaflet chlorophyll content on June 27 and the second highest (behind the check treatment, treatment 1) on July 10. Overall, leaflet chlorophyll content decreased over time, and it tended to decrease more the more K_2O a treatment received. K source (KCl vs K2SO4) had no effect on SPAD readings.

Canopy cover

Results for canopy cover are presented in Table 7. On June 12, treatments receiving K_2SO_4 (treatments 9 and 10), as a group, had marginally significantly higher canopy cover than treatments receiving KCl at the same rates (treatments 3 and 4) on that date. Among the treatments receiving broadcast KCl and the check treatment (treatments 1-5), canopy cover significantly or marginally significantly increased with K_2O rate on June 12, July 12, August 8, and September 7 and 11. Among the same treatments, the treatments receiving KCl (treatments 2-5), as a group, had significantly or marginally significantly higher canopy cover than the check treatment on August 8 and 28 and September 7. These findings suggest that K_2O rate, at least as broadcast KCl, has some potential to affect a potato crop's photosynthetic capacity, although this may be tempered by the tendency for leaflet chlorophyll content per unit area to decrease with increasing KCl rate.

The treatment receiving split applications of KCl (treatment 8) had higher canopy cover than the treatments receiving single applications of KCl at the same total rate (treatments 4 and 7) on June 12. The same was true on June 26, though the difference between the split-application treatment and the treatment receiving a single broadcast application (treatment 4) was not significant on that date.

Petiole nutrient concentrations

Results for petiole nutrient concentrations are presented in Table 8. Petiole K concentration showed a consistent positive linear relationship to the application rate of broadcast KCl (among treatments 1-5). On June 14, treatments receiving broadcast K_2SO_4 (treatments 9 and 10), as a group, had marginally significantly lower petiole K concentrations than those receiving broadcast KCl at the same rates (treatments 3 and 4). On July 10, treatments receiving banded KCl (treatments 6 and 7), as a group, had higher petiole K concentrations than those receiving broadcast KCl at the same rates (treatments 3 and 4). The treatment receiving $CaCl_2$ without K (treatment 11) had a higher petiole K concentration than the check treatment on June 14, but this difference had disappeared by July 10. The treatment receiving split applications of KCl (treatment 8) had numerically lower petiole K concentrations than those receiving single applications of KCl, either broadcast (treatment 4) or banded (treatment 7), and the difference with the banded application treatment was significant on June 14 and July 10.

Like K concentration, petiole Cl concentrations consistently increased linearly with the application rate of broadcast KCl (among treatments 1-5). Treatments receiving broadcast K_2SO_4 (treatments 9 and 10), as a group, had significantly lower petiole Cl concentrations than the treatments receiving broadcast KCl at the same rates (treatments 3 and 4) on all three sampling dates. The treatments receiving banded KCl (treatments 6 and 7) had marginally lower Cl concentrations on June 27, but significantly higher Cl concentrations on July 10, than the treatments receiving broadcast KCl at the same rates (treatments 3 and 4). The treatment receiving $CaCl_2$ (treatment 11) had a consistently higher petiole Cl concentration than the check treatment (treatment 1). The treatment receiving split applications of KCl (treatment 8) had significantly lower petiole Cl concentrations than the treatment receiving banded KCl at the same total rate (treatment 7) on June 14 and July 10, while this difference was not significant on June 27. The split-application treatment had lower petiole Cl concentrations than the treatment receiving broadcast KCl at the same total rate (treatment 4) on all three dates.

Petiole S concentration decreased linearly with the application rate of KCl (among treatments 1-5) on June 14 and July 10. The treatments receiving banded KCl (treatments 6 and 7), as a group, had a lower petiole S concentration than the treatments receiving broadcast KCl at the same rates (treatments 3 and 4) on July 10.

Petiole NO_3^--N concentration showed a negative relationship to the application rate of K_2O among the treatments receiving broadcast KCl and the check treatment (treatments 1-5) on June 14 and July 10. On July 10, the treatments receiving broadcast K_2SO_4 (treatments 9 and 10) had a higher petiole NO_3^--N concentration, as a group, than the treatments receiving broadcast KCl at the same rates (treatments 3 and 4).

Vine biomass at vine kill

Results for vine biomass at vine kill are presented in Table 9. Vine fresh and dry biomass per acre was higher among treatments receiving broadcast KCl (treatments 2-5), as a group, than it was in the check treatment (treatment 1). Vine dry matter content showed a marginally significant negative relationship with the application rate of broadcast KCl (among treatments 1-5), indicating that the increase in fresh biomass with KCl rate was disproportionately due to differences in vine water content rather than vine dry biomass. Based on this result and the positive relationship between canopy cover and KCl rate in the last two canopy evaluation dates, it appears that treatments receiving more KCl tended to die back more slowly at the end of the season. This is consistent with the symptoms of K deficiency, which can resemble potato early dying from *Verticillium* wilt.

Tuber and vine elemental concentrations

Results for tuber and vine K, Cl, S, and Ca concentrations are presented in Table 10. Both tuber and vine K concentrations increased with the application rate of broadcast KCl (among treatments 1-5). Treatments receiving banded KCl (treatments 6 and 7), split-applied KCl (treatment 8), or broadcast K_2SO_4 (treatments 9 and 10) did not have significantly different tuber or vine K concentrations than those receiving broadcast KCl at the same rates (treatments 3 and 4). The lowest K concentrations were observed in the check treatment (treatment 1) and the treatment receiving broadcast $CaCl_2$ (treatment 11).

Like K, tuber and vine Cl concentrations increased with the application rate of broadcast KCl (among treatments 1-5). Additionally, tuber Cl concentrations were higher in the treatments receiving banded KCl (treatments 6 and 7) than those receiving broadcast KCl at the same rates (treatments 3 and 4). Both tuber and vine Cl concentrations were lower in the treatments receiving broadcast K_2SO_4 (treatments 9 and 10) than those receiving broadcast KCl at the same rates (treatments 3 and 4). The treatment receiving split applications of KCl (treatment 8) had a similar tuber Cl concentration, but a significantly lower vine Cl concentration, than the treatment receiving a single broadcast application of KCl at the same rate (treatment 4). The check treatment (treatment 1) had lower tuber and vine Cl concentrations than the treatment receiving broadcast $CaCl_2$ (treatment 11).

Tuber S concentration was not related to treatment. Vine S concentration decreased as the application rate of KCl increased (among treatments 1-5). Since the application rate of S among these treatments was constant, this suggests that KCl either promoted vine growth, producing a dilution effect on S concentration, or interfered with S uptake in some way. Since vine dry yield was not positively related to KCl rate (even tending to decline with increasing rate among treatments 2-5), vine S concentration cannot be declining with increasing KCl rate due to a dilution effect. It is therefore likely that KCl interfered with S uptake, although this did not affect tuber S concentration. The treatments receiving broadcast K2SO4 (treatments 9 and 10) had significantly higher vine S concentrations than those receiving KCl at the same rates (treatments 3 and 4). The lower-rate treatments in this comparison (treatments 3 and 9, which both received 160 lbs/ac K_2O) had the same total S application rates, suggesting that Cl, not K, was responsible for the lower vine S concentrations in the KCl treatments. The treatment receiving split applications of KCl (treatment 8) and the treatments receiving banded applications of KCl (treatments 6 and 7) had similar vine S concentrations to treatments receiving broadcast KCl at the same rates (treatments 3 and 4). The check treatment (treatment 1) and the treatment receiving broadcast $CaCl_2$ (treatment 11) did not have significantly different vine S concentrations.

Tuber Ca concentration showed a negative quadratic relationship to the application rate of KCl (among treatments 1-5), being higher at rates of 0 and 300 lbs/ac K_2O than at intermediate rates. Tuber Ca concentration was higher in the treatments receiving broadcast K_2SO_4 (treatments 9 and 10), as a group, than in the treatments receiving broadcast KCl at the same rates (treatments 3 and 4). The treatment receiving split applications of KCl (treatment 8) had the highest tuber Ca concentration in the study, significantly higher than the treatments receiving single broadcast (treatments 3 and 4) or banded (treatments 6 and 7) applications of KCl. The check treatment (treatment 1) and the treatment receiving broadcast $CaCl_2$ (treatment 11) did not have significantly different tuber Ca concentrations. It is not obvious why applying K_2SO_4 should result in a higher tuber Ca concentration than applying KCl, nor why split applications of KCl should produce a higher tuber Ca concentration than a single application, whether broadcast or banded. These results are not related to the application rate of Cl or total tuber yield, indicating that neither Cl toxicity nor a dilution effect are responsible. Vine Ca concentration was not related to treatment.

Soil water and irrigation water Cl^- concentrations

Results for soil water Cl^- concentrations are presented in Table 11. Concentration was unrelated to treatment in the first sampling period (May 19 – June 14), which roughly corresponded to the vegetative phase of plant growth and early tuber initiation.

In the second sampling period (June 22 – July 24), which spanned late tuber initiation and early bulking, the treatment receiving broadcast KCl (treatment 4) had marginally a significantly higher soil water Cl^- concentration than the check treatment.

In the third sampling period (August 22 – September 26), during which tubers finished bulking and matured, mean soil Cl^- concentrations increased substantially, as did the variation in concentration among treatments. However, the variation in concentration within treatments also increased, with the result that neither the treatment effect in the linear model nor any of the contrasts were statistically significant.

In the fourth, post-harvest phase (October 16 – November 15), the treatment effect was marginally significant, with the treatment receiving banded KCl (treatment 7) having higher soil water Cl^- concentrations than the check treatment (treatment 1) or the treatment receiving broadcast K_2SO_4 (treatment 10). Although the treatments receiving broadcast KCl (treatment 4) and $CaCl_2$ (treatment 11) had numerically higher soil water Cl^- concentrations than the check treatment or the treatment receiving K_2SO_4, as expected, these differences were not statistically significant.

Averaged across the season (May 19 – November 15), soil water Cl^- concentration was marginally significantly related to treatment. The treatment receiving banded KCl (treatment 7) had at least a marginally significantly higher soil water Cl^- concentration than any other treatment except for the treatment receiving broadcast $CaCl_2$ (treatment 11).

Irrigation water Cl concentrations averaged 40 ppm though out the growing season. With 17.5 inches of irrigation water supplied to supplement 10.6 inches of rainfall (figure 1), a total of 150 lbs/ac Cl was applied with irrigation. Rainwater had less than 1 ppm Cl. The lack of rainfall coupled with high Cl in irrigation may have resulted in the negative effects of high KCl rates on yield.

End-of-season soil K and Cl concentrations

Results for end-of-season soil K and Cl concentrations are presented in Table 12. Soil K concentration in the top 6 inches was measured in the check treatment (treatment 1), the treatment receiving 240 lbs/ac K_20 as broadcast KCl (treatment 4), and the treatment receiving $CaCl_2$ (treatment 11). The treatment receiving broadcast KCl had a higher soil K concentration after harvest than either of the treatments not receiving K fertilizer.

Soil Cl concentration in the top 24 inches was measured in all treatments. Among the treatments receiving broadcast KCl and the check treatment (treatments 1-5), the soil Cl concentration increased with the application rate of KCl. A similar trend was evident between the two treatments receiving banded KCl (treatments 6 and 7). These two treatments, as a group, had a higher mean soil Cl concentration than the treatments receiving broadcast KCl at the same rates (treatments 3 and 4). The difference was especially pronounced when KCl was applied at 240 lbs/ac K_2O. Applying K as K_2SO_4 instead of KCl (treatments 9 and 10 versus treatments 3 and 4) had no significant effect on end of season soil Cl concentration. Similarly, the treatment receiving $CaCl_2$ (treatment 11) did not have a higher soil Cl concentration than the check treatment (treatment 1).

Conclusions

Among treatments receiving broadcast KCl, total yield and specific gravity were highest at 80 lbs/ac K_2O, while U.S. No. 1 and total marketable yield were highest at 160 lbs/ac K_2O. Yields were higher in KCl-fertilized treatments, as a group, than in the check treatment, but they generally declined as the application rate of K increased beyond 80 or 160 lbs/ac K_2O, suggesting a negative effect due to chloride.

In terms of yield, banded application of KCl increased the yield of U.S. No. 2 tubers, but did not benefit yields of total, marketable, or U.S. No.1 tubers, nor did it improve tuber specific gravity. Banded application of KCl resulted in greater all-season Cl^- leaching than broadcast application at the same rate. It is possible that banded application would have produced better yield and less Cl^- leaching at a lower rate than 160 or 240 lbs/ac K_2O. Split application of KCl at 240 lbs/ac K_2O resulted in higher total, marketable, and U.S No. 1 yields than a single broadcast application of KCl at the same total rate.

Using K_2SO_4 in place of KCl did not improve tuber specific gravity, nor did the treatment receiving $CaCl_2$ without K have lower tuber specific gravity than the check treatment, suggesting that Cl did not reduce specific gravity in this study. However, at equivalent K_2O rates, yields tended to be higher with K_2SO_4 than KCl, suggesting a negative effect of Cl, particularly at KCl rates higher than 160 lbs/ac K_2O. The negative K_2O effect in this study may have been due to the high Cl concentrations in irrigation water coupled with low amounts of rainfall to leach out Cl during the growing season.

Table 1. Initial soil characteristics in the study field at the Sand Plain Research Farm in Becker, MN, in 2023.

0 - 6 inches												0 - 2 feet
pH	Organic matter (%)	Bray P (mg/kg)	NH_4OAc-K (mg/kg)	NH_4OAc-Ca (mg/kg)	NH_4OAc-Mg (mg/kg)	DTPA-Mn (mg/kg)	DTPA-Fe (mg/kg)	DTPA-Zn (mg/kg)	DTPA-Cu (mg/kg)	Hot water B (mg/kg)	SO_4^{2-}-S (mg/kg)	NO_3^--N (mg/kg)
6.8	1.2	56	92	652	119	6	11	1.2	0.6	0.2	9	1.4

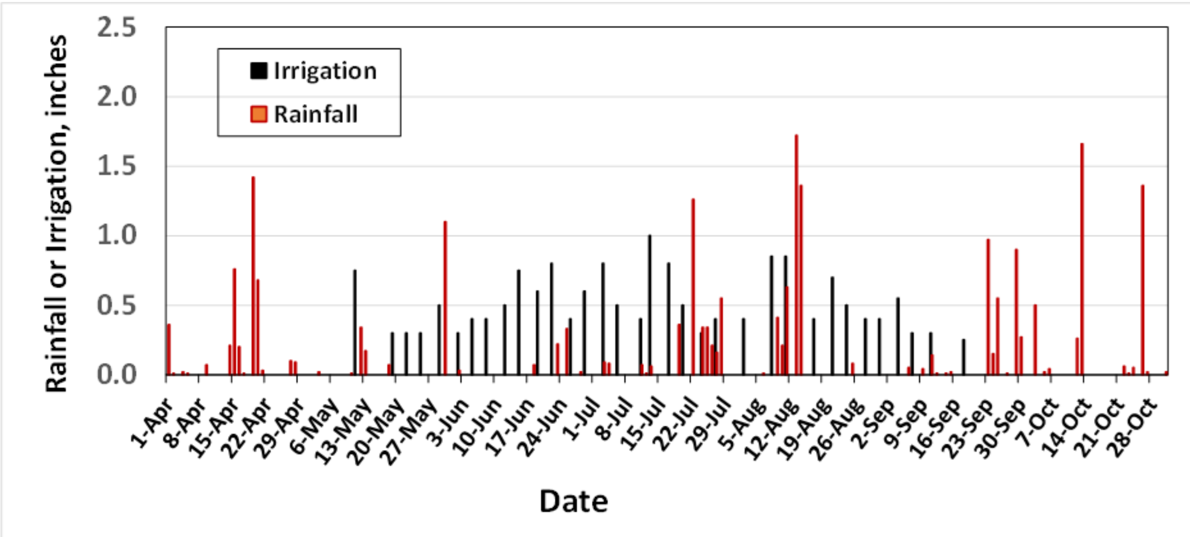

Figure 1. Rainfall and irrigation amounts on each day of the 2023 growing season.

Table 2. K treatments applied to Russet Burbank potatoes.

Treatment #	Product applied	Method of application	K_2O rate (lbs/ac)	Cl rate (lbs/ac)	S rate (lbs/ac)	S as $(NH_4)_2SO_4$ at emergence (lbs/ac)
1	None	NA	0	0	0	54
2	KCl	Broadcast preplant	80	60	0	54
3	KCl	Broadcast preplant	160	120	0	54
4	KCl	Broadcast preplant	240	180	0	54
5	KCl	Broadcast preplant	320	240	0	54
6	KCl	Banded at planting	160	120	0	54
7	KCl	Banded at planting	240	180	0	54
8	KCl	Half broadcast preplant, half sidedressed at hilling	240	180	0	54
9	K_2SO_4	Broadcast preplant	160	0	54	0
10	K_2SO_4	Broadcast preplant	240	0	82	0
11	$CaCl_2$	Broadcast preplant	0	180	0	54

Table 3. Effects of K and Cl treatment on tuber size and yield. Values within a column that are followed by the same letter are not significantly different ($P \leq 0.10$) in pairwise comparisons. Pairwise comparisons are presented only for effects where $P \leq 0.10$.

Treatment		Yield (cwt/ac)										% yield in tubers over:		Tubers / plant
Number	Nutrient rate (lbs/ac), method, source	Culled	0-4 oz.	4-6 oz.	6-10 oz.	10-14 oz.	Over 14 oz.	Total	U.S. No. 1	U.S. No. 2	Marketable	6 oz.	10 oz.	
1	No product	3	101	135	175 bcd	59	28	499 e	378 d	21	398 e	51	17	9.3
2	80 K_2O, broadcast, KCl	5	97	125	208 a	93	60	583 ab	458 ab	27	486 abc	62	26	9.9
3	160 K_2O, broadcast, KCl	6	76	115	196 abc	117	67	571 abc	486 a	8	495 abc	66	32	9.1
4	240 K_2O, broadcast, KCl	5	93	113	177 bcd	95	66	544 bcd	432 bc	18	450 cd	61	29	9.2
5	320 K_2O, broadcast, KCl	7	83	95	164 d	98	87	528 cde	419 bcd	25	445 cde	65	34	8.5
6	160 K_2O, banded, KCl	7	81	94	172 cd	118	93	559 abcd	455 ab	22	477 abc	68	36	8.8
7	240 K_2O, banded, KCl	6	74	101	171 cd	101	88	535 cde	435 bc	26	461 bcd	67	35	8.4
8	240 K_2O, broadcast+sidedress, KCl	4	82	110	202 ab	128	69	591 a	494 a	16	509 ab	67	33	9.1
9	160 K_2O, broadcast, K_2SO_4	5	79	101	215 a	114	88	597 a	496 a	22	518 a	70	34	9.1
10	240 K_2O, broadcast, K_2SO_4	4	86	110	202 ab	125	74	598 a	490 a	21	512 ab	67	32	9.6
11	180 Cl, broadcast, $CaCl_2$	2	96	110	157 d	97	62	522 de	396 cd	30	426 de	59	29	8.9
	Treatment effect (P-value)	0.4252	0.8257	0.3292	**0.0248**	0.1879	0.1767	**0.0035**	**0.0007**	0.2219	**0.0061**	0.1293	0.1914	0.7722
	Effect of KCl (1 vs. 2-5)	0.1201	0.3313	*0.0770*	0.4359	**0.0269**	**0.0183**	**0.0079**	**0.0025**	0.8733	**0.0058**	**0.0112**	**0.0124**	0.8571
	KCl rate, linear (1-5)	0.1053	0.3139	**0.0146**	0.1824	0.1246	**0.0129**	0.7479	0.3520	0.9940	0.3967	**0.0434**	**0.0149**	0.1880
Contrasts	KCl rate, quadratic (1-5)	0.6612	0.5792	0.8629	**0.0437**	*0.0827*	0.6231	**0.0034**	**0.0008**	0.1237	**0.0053**	0.1586	0.3336	0.3762
	Broadcast v banded (3&4 v 6&7)	0.5326	0.5692	0.1515	0.2447	0.8100	0.1158	0.5672	0.4640	**0.0388**	0.8738	0.3724	0.2246	0.3109
	KCl v K_2SO_4 (3&4 v 9&10)	0.3263	0.8807	0.4753	*0.0863*	0.3872	0.3409	**0.0326**	*0.0944*	*0.0987*	*0.0568*	0.2652	0.5038	0.7522

Table 4. Effects of K and Cl treatment on tuber quality. Values within a column that are followed by the same letter are not significantly different ($P \leq 0.10$) in pairwise comparisons. Pairwise comparisons are presented only for effects where $P \leq 0.10$.

Treatment		Tuber defects (% of tubers)			Specific gravity	Dry matter content (%)
Number	Nutrient rate (lbs/ac), method, source	Disqualifying hollow heart	Disqualifying brown center	Common scab		
1	No product	5	3	1	1.0798 bc	20.4 ab
2	80 K_2O, broadcast, KCl	2	2	0	1.0820 ab	20.0 ab
3	160 K_2O, broadcast, KCl	1	1	1	1.0812 abc	21.1 a
4	240 K_2O, broadcast, KCl	3	3	3	1.0806 abc	20.0 ab
5	320 K_2O, broadcast, KCl	2	2	1	1.0771 d	19.5 bc
6	160 K_2O, banded, KCl	3	2	2	1.0794 c	20.1 ab
7	240 K_2O, banded, KCl	4	3	1	1.0745 e	19.6 bc
8	240 K_2O, broadcast+sidedress, KCl	4	3	0	1.0791 dc	18.5 c
9	160 K_2O, broadcast, K_2SO_4	1	1	1	1.0823 a	20.5 ab
10	240 K_2O, broadcast, K_2SO_4	0	0	1	1.0796 c	21.1 a
11	180 Cl, broadcast, $CaCl_2$	1	1	0	1.0796 c	19.5 bc
	Treatment effect (P-value)	0.6335	0.8462	0.6422	**<0.0001**	**0.0303**
Contrasts	Effect of KCl (1 vs. 2-5)	0.1371	0.5331	0.8261	0.6966	0.6670
	KCl rate, linear (1-5)	0.3752	0.8251	0.3546	**0.0249**	0.2371
	KCl rate, quadratic (1-5)	0.2953	0.5761	0.7929	**0.0040**	0.1830
	Broadcast v banded (3&4 v 6&7)	0.3999	0.7269	0.6238	**0.0003**	0.1708
	KCl v K_2SO_4 (3&4 v 9&10)	0.3999	0.2987	0.3296	0.9130	0.5468

Table 5. Effect of K and Cl treatment on plant stand and the number of stems per plant. Values within a column that are followed by the same letter are not significantly different ($P \leq 0.10$) in pairwise comparisons. Comparisons are presented only for effects where $P \leq 0.10$.

Treatment		Plant stand (%)		Stems / plant
Number	Nutrient rate (lbs/ac), method, source	May 31	June 7	June 8
1	No product	94 c	99	3.5 abc
2	80 K_2O, broadcast, KCl	99 ab	100	3.3 bcd
3	160 K_2O, broadcast, KCl	100 a	100	4.1 a
4	240 K_2O, broadcast, KCl	100 a	100	2.9 d
5	320 K_2O, broadcast, KCl	98 ab	100	3.2 bcd
6	160 K_2O, banded, KCl	98 ab	99	3.7 ab
7	240 K_2O, banded, KCl	98 ab	96	3.2 bcd
8	240 K_2O, broadcast+sidedress, KCl	100 a	100	3.3 bcd
9	160 K_2O, broadcast, K_2SO_4	99 ab	100	3.5 abc
10	240 K_2O, broadcast, K_2SO_4	97 b	99	3.1 cd
11	180 Cl, broadcast, $CaCl_2$	98 ab	99	3.2 bcd
	Treatment effect (P-value)	**0.0378**	0.1894	*0.0874*
Contrasts	Effect of KCl (1 vs. 2-5)	**0.0004**	0.2372	0.8649
	KCl rate, linear (1-5)	**0.0341**	0.4005	0.1601
	KCl rate, quadratic (1-5)	**0.0012**	0.4766	0.3051
	Broadcast v banded (3&4 v 6&7)	*0.0651*	**0.0114**	0.9144
	KCl v K_2SO_4 (3&4 v 9&10)	0.1210	0.7384	0.3925

Table 6. Effects of K and Cl treatment on leaflet chlorophyll content (SPAD-502 readings). Values within a column that are followed by the same letter are not significantly different ($P \leq 0.10$) in pairwise comparisons. Comparisons are presented only for effects where $P \leq 0.10$.

Treatment		Leaflet cholorphyll content (SPAD-502)		
Number	Nutrient rate (lbs/ac), method, source	June 15	June 27	July 10
1	No product	56	50 ab	49.7
2	80 K_2O, broadcast, KCl	55	50 ab	47.4
3	160 K_2O, broadcast, KCl	56	50 abc	47.5
4	240 K_2O, broadcast, KCl	55	48 cd	47.1
5	320 K_2O, broadcast, KCl	56	48 cd	47.2
6	160 K_2O, banded, KCl	54	49 bcd	47.4
7	240 K_2O, banded, KCl	55	48 d	46.6
8	240 K_2O, broadcast+sidedress, KCl	56	49 bcd	47.3
9	160 K_2O, broadcast, K_2SO_4	55	48 cd	47.9
10	240 K_2O, broadcast, K_2SO_4	54	48 d	46.9
11	180 Cl, broadcast, $CaCl_2$	56	51 a	48.7
	Treatment effect (P-value)	0.5927	**0.0255**	0.3211
Contrasts	Effect of KCl (1 vs. 2-5)	0.9590	0.1088	**0.0116**
	KCl rate, linear (1-5)	0.9669	**0.0081**	**0.0429**
	KCl rate, quadratic (1-5)	0.8607	0.8146	0.1686
	Broadcast v banded (3&4 v 6&7)	*0.0866*	0.2897	0.7037
	KCl v K_2SO_4 (3&4 v 9&10)	0.1341	0.1703	0.8865

Table 7. Effects of K and Cl treatment on canopy cover, as measured by the Canopeo app. Values within a column that are followed by the same letter are not significantly different ($P \leq 0.10$) in pairwise comparisons. Comparisons are presented only for effects where $P \leq 0.10$.

Treatment		Percent canopy cover (Canopeo)													
Number	Nutrient rate (lbs/ac), method, source	12-Jun	21-Jun	26-Jun	3-Jul	12-Jul	17-Jul	24-Jul	1-Aug	8-Aug	14-Aug	21-Aug	28-Aug	7-Sep	11-Sep
1	No product	30 bc	51	79 ab	95	96	96	96	97	92	97	95	85	55	47
2	80 K_2O, broadcast, KCl	36 a	58	83 ab	97	95	96	96	97	96	98	97	90	65	53
3	160 K_2O, broadcast, KCl	31 bc	51	78 b	91	96	96	95	97	93	97	96	91	64	55
4	240 K_2O, broadcast, KCl	28 c	56	79 ab	97	97	97	97	98	96	98	97	91	69	60
5	320 K_2O, broadcast, KCl	28 c	50	82 ab	94	97	97	96	98	95	98	96	91	75	64
6	160 K_2O, banded, KCl	32 abc	51	81 ab	95	96	94	95	98	94	97	93	90	76	67
7	240 K_2O, banded, KCl	28 c	47	70 c	90	95	97	96	97	94	98	97	90	72	60
8	240 K_2O, broadcast+sidedress, KCl	35 ab	56	86 a	97	95	96	96	98	95	97	86	87	64	56
9	160 K_2O, broadcast, K_2SO_4	33 ab	56	81 ab	96	96	96	96	98	96	97	97	93	75	62
10	240 K_2O, broadcast, K_2SO_4	33 ab	61	84 ab	97	97	96	95	98	95	97	96	89	69	57
11	180 Cl, broadcast, $CaCl_2$	32 abc	48	78 b	96	96	96	97	97	95	97	95	87	65	52
	Treatment effect (P-value)	***0.0639***	0.4316	***0.0769***	0.1121	0.1834	0.4872	0.7072	0.4273	0.1099	0.9440	0.4724	0.6558	0.3144	0.7694
Contrasts	Effect of KCl (1 vs. 2-5)	0.8129	0.5967	0.6184	0.8884	0.6254	0.6550	0.8700	0.6381	**0.0151**	0.2724	0.6283	***0.0527***	**0.0441**	0.2088
	KCl rate, linear (1-5)	**0.0432**	0.7605	0.7284	0.8475	***0.0864***	0.3573	0.5021	0.1814	***0.0726***	0.3044	0.8160	0.1241	**0.0213**	***0.0915***
	KCl rate, quadratic (1-5)	0.1541	0.4173	0.7085	0.6173	0.4873	0.6489	0.4524	0.7883	0.5218	0.7681	0.7302	0.2457	0.9220	0.9760
	Broadcast v banded (3&4 v 6&7)	0.8753	0.2784	0.2899	0.6054	0.1074	0.4950	0.7427	0.3920	0.9836	0.8042	0.6584	0.6890	0.2056	0.3784
	KCl v K_2SO_4 (3&4 v 9&10)	***0.0762***	0.2724	0.1630	0.1368	0.7738	0.3838	0.5013	0.6212	0.3584	0.7820	0.9660	0.9756	0.3264	0.7076

Table 8. Effects of K and Cl treatment on petiole K, Cl, S, and NO3-N concentrations. Values within a column that are followed by the same letter are not significantly different ($P \leq 0.10$) in pairwise comparisons. Comparisons are presented only for effects where $P \leq 0.10$.

Treatment		Petiole K (ppm)			Petiole Cl (ppm)			Petiole S (ppm)			Petiole NO_3-N (ppm)		
Number	Nutrient rate (lbs/ac), method, source	14-Jun	27-Jun	10-Jul	14-Jun	27-Jun	10-Jul	14-Jun	27-Jun	10-Jul	14-Jun	27-Jun	10-Jul
1	No product	7.18 f	5.88	4.78 g	0.58 f	1.04 f	1.34 f	0.23 bc	0.22	0.24 abc	21969	20023	20710
2	80 K_2O, broadcast, KCl	8.25 e	7.55	6.03 f	1.22 e	1.71 e	1.90 e	0.25 a	0.25	0.24 a	19803	22656	20594
3	160 K_2O, broadcast, KCl	8.63 bcde	8.93	6.48 ef	1.87 cd	2.26 bcd	2.30 d	0.22 cde	0.22	0.24 ab	20257	20673	17350
4	240 K_2O, broadcast, KCl	9.23 ab	7.70	7.60 abc	2.18 bc	2.45 b	2.74 b	0.23 bcd	0.21	0.22 de	20549	19558	19884
5	320 K_2O, broadcast, KCl	9.03 abc	10.00	8.23 a	2.63 a	2.94 a	3.00 a	0.21 e	0.23	0.21 e	18838	19105	17366
6	160 K_2O, banded, KCl	8.93 abcd	7.38	7.30 bcd	1.96 bc	2.07 cd	2.62 bc	0.22 de	0.21	0.22 cde	20163	18956	19683
7	240 K_2O, banded, KCl	9.33 a	8.60	8.00 ab	2.13 bc	2.24 bcd	3.17 a	0.22 cde	0.24	0.21 e	20490	17935	20529
8	240 K_2O, broadcast+sidedress, KCl	8.63 bcde	7.40	6.98 cde	1.57 d	2.00 d	2.42 cd	0.23 bcd	0.22	0.23 abcd	20173	19667	18001
9	160 K_2O, broadcast, K_2SO_4	8.35 de	8.33	6.53 def	0.61 f	1.30 f	1.37 f	0.23 bcd	0.24	0.23 abcd	22154	23177	21127
10	240 K_2O, broadcast, K_2SO_4	8.45 cde	7.58	7.45 abc	0.65 f	1.26 f	1.42 f	0.24 ab	0.23	0.24 abc	20721	19965	21383
11	180 Cl, broadcast, $CaCl_2$	8.23 e	6.18	4.78 g	2.27 b	2.29 bc	2.50 cd	0.24 ab	0.21	0.23 bcde	19453	17070	19620
	Treatment effect (P-value)	**0.0006**	0.1075	**<0.0001**	**<0.0001**	**<0.0001**	**<0.0001**	**0.0106**	0.9688	**0.0081**	0.2221	0.8971	0.2060
Contrasts	Effect of KCl (1 vs. 2-5)	**<0.0001**	**0.0110**	**<0.0001**	**<0.0001**	**<0.0001**	**<0.0001**	0.5096	0.6989	0.3031	**0.0286**	0.7698	0.1378
	KCl rate, linear (1-5)	**<0.0001**	**0.0052**	**<0.0001**	**<0.0001**	**<0.0001**	**<0.0001**	**0.0042**	0.8107	**0.0009**	**0.0416**	0.2872	***0.0626***
	KCl rate, quadratic (1-5)	**0.0344**	0.6849	0.6398	0.1672	0.1137	0.1090	0.1489	0.8394	**0.0455**	0.8088	0.3327	0.8309
	Broadcast v banded (3&4 v 6&7)	0.4811	0.7146	***0.0693***	0.8848	***0.0927***	**0.0002**	0.2106	0.7455	**0.0399**	0.9261	0.3553	0.2279
	KCl v K_2SO_4 (3&4 v 9&10)	***0.0709***	0.6834	0.8788	**<0.0001**	**<0.0001**	**<0.0001**	0.2949	0.4834	0.5624	0.2166	0.3201	**0.0372**

Table 9. Effects of K and Cl treatment on vine fresh and dry yield per acre and dry matter content. Values within a column that are followed by the same letter are not significantly different (P ≤ 0.10) in pairwise comparisons. Comparisons are presented only for effects where P ≤ 0.10.

Treatment		Vine biomass (T/ac)		Vine dry matter content (%)
Number	Nutrient rate (lbs/ac), method, source	Fresh	Dry	
1	No product	3.79	0.93	29.2
2	80 K_2O, broadcast, KCl	6.75	1.63	26.2
3	160 K_2O, broadcast, KCl	8.08	1.59	20.6
4	240 K_2O, broadcast, KCl	6.70	1.32	20.3
5	320 K_2O, broadcast, KCl	7.65	1.38	18.8
6	160 K_2O, banded, KCl	8.89	1.59	19.7
7	240 K_2O, banded, KCl	5.92	1.55	27.7
8	240 K_2O, broadcast+sidedress, KCl	6.59	1.48	24.7
9	160 K_2O, broadcast, K_2SO_4	7.19	1.45	21.1
10	240 K_2O, broadcast, K_2SO_4	7.24	1.24	19.4
11	180 Cl, broadcast, $CaCl_2$	5.07	0.96	28.7
	Treatment effect (P-value)	0.3664	0.3509	0.5780
Contrasts	Effect of KCl (1 vs. 2-5)	**0.0241**	**0.0360**	0.1222
	KCl rate, linear (1-5)	***0.0761***	0.4066	***0.0613***
	KCl rate, quadratic (1-5)	0.1826	***0.0842***	0.6147
	Broadcast v banded (3&4 v 6&7)	0.9935	0.6222	0.4629
	KCl v K_2SO_4 (3&4 v 9&10)	0.8953	0.6342	0.9605

Table 10. Effects of K and Cl treatment on tuber and vine concentrations of K, Cl, S, and Ca at harvest. Values within a column that are followed by the same letter are not significantly different (P ≤ 0.10) in pairwise comparisons. Pairwise comparisons are presented only for effects where P ≤ 0.10.

Treatment		Tuber element concentrations (%)				Vine element concentrations (%)			
Number	Nutrient rate (lbs/ac), method, source	K	Cl	S	Ca	K	Cl	S	Ca
1	No product	1.35 c	0.14 f	0.13	0.023 ab	0.62 d	1.44 f	0.20 ab	1.85
2	80 K_2O, broadcast, KCl	1.53 abc	0.17 ef	0.14	0.015 c	1.25 cd	2.03 de	0.19 ab	1.91
3	160 K_2O, broadcast, KCl	1.43 bc	0.19 de	0.12	0.015 c	1.80 bc	2.67 bc	0.16 d	1.84
4	240 K_2O, broadcast, KCl	1.65 a	0.23 bcd	0.13	0.015 c	2.30 b	2.95 ab	0.17 cd	1.63
5	320 K_2O, broadcast, KCl	1.68 a	0.25 ab	0.12	0.020 bc	3.28 a	3.44 a	0.16 d	1.67
6	160 K_2O, banded, KCl	1.58 ab	0.24 bc	0.12	0.015 c	2.28 b	2.92 ab	0.19 abcd	1.82
7	240 K_2O, banded, KCl	1.70 a	0.28 a	0.12	0.020 bc	2.08 b	3.22 a	0.16 d	1.75
8	240 K_2O, broadcast+sidedress, KCl	1.65 a	0.22 cd	0.12	0.028 a	2.28 b	2.38 cd	0.17 bcd	1.76
9	160 K_2O, broadcast, K_2SO_4	1.55 ab	0.14 f	0.13	0.020 bc	1.95 bc	1.73 ef	0.21 a	1.98
10	240 K_2O, broadcast, K_2SO_4	1.58 ab	0.15 f	0.13	0.023 ab	2.54 ab	2.08 de	0.20 ab	1.80
11	180 Cl, broadcast, $CaCl_2$	1.35 c	0.26 ab	0.12	0.025 ab	0.84 d	2.44 bcd	0.18 bcd	1.88
	Treatment effect (P-value)	**0.0142**	**<0.0001**	0.2921	**0.0416**	**<0.0001**	**<0.0001**	**0.0369**	0.7825
Contrasts	Effect of KCl (1 vs. 2-5)	**0.0135**	**0.0002**	0.5004	***0.0657***	**0.0002**	**<0.0001**	**0.0302**	0.5610
	KCl rate, linear (1-5)	**0.0026**	**<0.0001**	0.2791	0.5929	**<0.0001**	**<0.0001**	**0.0112**	0.1284
	KCl rate, quadratic (1-5)	0.9292	1.0000	0.6447	**0.0296**	0.5942	0.4936	0.3355	0.7084
	Broadcast v banded (3&4 v 6&7)	0.1898	**0.0031**	0.2847	0.3996	0.6990	0.2468	0.3672	0.7047
	KCl v K_2SO_4 (3&4 v 9&10)	0.7397	**0.0003**	0.5183	**0.0409**	0.5522	**0.0002**	**0.0013**	0.2445

Table 11. Effects of K and Cl treatment on soil water Cl^- concentration, with values averaged across monthlong periods and the entire season (May 19 through November 15). Values within a column that are followed by the same letter are not significantly different ($P \leq 0.10$) in pairwise comparisons. Pairwise comparisons are presented only for effects where $P \leq 0.10$.

Treatment		Soil water Cl^- (ppm) by developmental phase				
Number	Nutrient rate (lbs/ac), method, source	5/19 - 6/14	6/22 - 7/24	8/22 - 9/26	10/16 - 11/15	All season
1	No product	29	7	46	80 b	34 b
4	240 K_2O, broadcast, KCl	40	24	70	107 ab	54 b
7	240 K_2O, banded, KCl	51	24	167	241 a	108 a
10	240 K_2O, broadcast, K_2SO_4	39	22	27	36 b	32 b
11	180 Cl, broadcast, $CaCl_2$	34	19	166	157 ab	65 ab
	Treatment effect (P-value)	0.3533	0.3385	0.1263	***0.0954***	***0.0908***
Contrasts	Effect of KCl (1 vs. 4)	0.3215	***0.0886***	0.6965	0.7240	0.4883
	Broadcast vs. banded (4 vs. 7)	0.3049	0.9469	0.1337	0.1026	***0.0686***
	KCl vs. K_2SO_4 (4 vs. 10)	0.8993	0.8497	0.2165	0.3587	0.4385
	Effect of $CaCl_2$ (1 vs. 11)	0.7081	0.2702	0.1562	0.3245	0.2794

Table 12. Effects of K and Cl treatment on soil K to a depth of 6 inches and Cl concentrations to a depth of 24 inches. Values within a column that are followed by the same letter are not significantly different ($P \leq 0.10$) in pairwise comparisons. Comparisons are presented only for effects where $P \leq 0.10$.

Treatment		End-of season soil:	
Number	Nutrient rate (lbs/ac), method, source	K (ppm)	Cl (ppm)
1	No product	38 b	9 cde
2	80 K_2O, broadcast, KCl	.	8 cde
3	160 K_2O, broadcast, KCl	.	5 e
4	240 K_2O, broadcast, KCl	87 a	15 bc
5	320 K_2O, broadcast, KCl	.	17 b
6	160 K_2O, banded, KCl	.	7 de
7	240 K_2O, banded, KCl	.	24 a
8	240 K_2O, broadcast+sidedress, KCl	.	10 bcde
9	160 K_2O, broadcast, K_2SO_4	.	8 cde
10	240 K_2O, broadcast, K_2SO_4	.	9 cde
11	180 Cl, broadcast, $CaCl_2$	44 b	13 bcd
	Treatment effect (P-value)	**0.0037**	**0.0067**
Contrasts	Effect of KCl (1 vs. 2-5)	.	0.4827
	KCl rate, linear (1-5)	.	**0.0264**
	KCl rate, quadratic (1-5)	.	0.1408
	Broadcast v banded (3&4 v 6&7)	.	***0.0747***
	KCl v K_2SO_4 (3&4 v 9&10)	.	0.6083

Trial of two experimental pro-microbial products on Russet Burbank yield and quality

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Summary

Grower interest in enhancing crop performance by improving soil microbiomes in production fields has increased in parallel with scientific understanding of how those microbiomes function. The purpose of this study was to evaluate two unreleased Mosaic products designed to improve agricultural microbiomes: a microbial inoculum (MOS009-A-01) and a carbon source to enhance microbial growth (MOS023-A-02). These products and a water mock treatment were applied separately in combination, either in-furrow at planting alone or at planting and in a foliar application four weeks later, to Russet Burbank potato plants. Plant responses were evaluated in terms of tuber yield and quality. In generalized linear models, only the yield of 4- to 6-oz. tubers was significantly related to treatment. Based on contrasts, the check treatment that received only water at planting had lower yield in this size class than the other treatments taken as a group, and treatments receiving only the at-planting treatment, as a group, had higher yield in this size class than matched treatments receiving treatments at planting and four weeks later. Total yield was marginally significantly greater in treatments receiving the microbial inoculum, as a group, than in matched treatments that did not receive inoculum. U.S. No. 1 yield was marginally significantly lower in the check treatment than in the other treatments taken as a group. Treatments receiving two applications, as a group, had higher tuber dry matter content than matched treatments receiving only one application of product. These results offer some evidence that the microbial inoculum MOS009-A-01 may be beneficial to tuber yield and quality.

Background

As our understanding of the effects of microbiomes on agriculture has increased, interest in applying this knowledge to improving yield has grown as well. Both established agricultural companies and small start-ups have begun to test and release new pro-microbials and microbial inoculums to meet the increasing grower demand.

The purpose of this study was to evaluate two experimental Mosaic products, a microbial inoculum (MOS009-A-01) and a carbon source to enhance microbial growth (MOS023-A-02). These products and a water mock treatment were applied to Russet Burbank potato plants, separately or in combination, either at planting alone or at planting and again four weeks later. Results were evaluated in terms of tuber yield and quality.

Methods

The study was conducted at the University of Minnesota's Sand Plain Research Farm in Becker, MN, on a Hubbard loamy sand soil, in 2023 following a previous crop of soybeans. Initial soil characteristics from samples taken in April 2023 are presented in Table 1. Rainfall and irrigation rates during the season are presented in Figure 1.

Six treatments were applied in a Latin square design. These treatments are summarized in Table 2. Each experimental plot was four rows (12 feet) wide and 20 feet long. Eighteen feet of the central two rows were used for the end-of-season vine and tuber harvest samples, and the ends of these rows were demarcated with one red potato at each end.

All plots received 200 lbs/ac MOP (0-0-60) and 200 lbs/ac SulPoMag (0-0-22-22S-11Mg) broadcast on April 25, 2023, supplying 164 lbs/ac K_2O and 22 lbs/ac S. Furrows were opened for planting with 36" spacing on May 4. A mixture of cut "A" and uncut "B" seed potatoes were planted by hand with 12" spacing, and the rows were closed. "A" seed was cut shortly before planting. Belay was applied in-furrow at planting for beetle control, along with the systemic fungicide Quadris. At-planting applications of microbial inoculum, C source, and water were applied in-furrow according to treatment. At the same time, a planting fertilizer blend was banded in all treatments, supplying 40 lbs/ac N, 102 lbs/ac P_2O_5, 181 lbs/ac K_2O, 40 lbs/ac S, 20 lbs/ac Mg, 1 lb/ac Zn, and 0.6 lbs/ac B in the form of 173 lbs/ac DAP (18-46-0), 141 lbs/ac SulPoMag, 184 lbs/ac MOP, 2 lbs/ac $ZnSO_4$ (17.5% S, 35.5% Zn), and 3 lbs/ac Boron 15 (15% B). Weeds, diseases, and insects were controlled using standard practices. Rainfall was supplemented with sprinkler irrigation using the checkbook method of irrigation scheduling. At emergence on May 22, 348 lbs/ac urea (46-0-0) were applied to all plots, supplying 160 lbs/ac N. The treatments designated to receive a foliar application 4 weeks after planting were sprayed with the microbial inoculum, C source, and/or water as prescribed by treatment. Two applications of 28% UAN, each providing 20 lbs/ac N, were made on June 29 and July 20, bringing the total amount of N applied to 240 lbs/ac.

Vines in all plots were chopped on September 15. The central two rows of each plot were harvested on October 5. On October 10, tubers were sorted by size category and grade, weighed, and counted. Culls were not sorted by size. Total yield was calculated as the sum of yield in all categories, including culls. Marketable yield was the sum of yield in all size categories over 4 oz., excluding culls. The percentage of yield over 6 and 10 ounces were calculated as the sum of all tubers over the threshold size divided by the sum of all tubers in all size categories, excluding culls from both sums. A subsample of 25 tubers was taken from each plot's tuber sample and used to assess the prevalence of hollow heart, brown center, and common scab, as well as tuber specific gravity and dry matter content.

Results

Tuber yield, size, and grade

Results for tuber yield are presented in Table 3. The effect of treatment was only significant for 4-6-oz. tubers. In this category, the check treatment (treatment 1) had a lower yield than the remaining treatments (treatments 2-6) taken as a group, and treatments receiving a single application of product (treatments 2 and 3) had higher yields than those receiving the same products at planting and four weeks later (treatments 4 and 6).

Total yield was marginally significantly higher in the treatments receiving inoculum (treatments 3 and 4), as a group, than in otherwise similar treatments that did not receive inoculum (treatments 1 and 5), as a group. U.S. No. 1 yield was marginally significantly lower in the check treatment (treatment 1) than in the remaining treatment (treatments 2-6), as a group. Similar but nonsignificant trends were evident in total and marketable yield.

Tuber quality

Results for tuber quality are presented in Table 4. Common scab was not detected in this study. Tuber dry matter content was lower among the treatments receiving inoculum only at planting (treatments 2 and 3), as a group, than among the treatments receiving inoculum both at planting and four weeks later (treatments 4 and 6). There were no other statistically significant effects of treatment on tuber quality.

Conclusions

The microbial inoculum had a marginally significant positive effect on total yield. Comparing treatments that received only the in-furrow application of inoculum at planting with matched treatments that also received a foliar application four weeks later, tuber dry matter content was higher in the treatments that received the foliar application. Taken together, these results provide some evidence that the microbial inoculum applied in this study may be beneficial to tuber yield and quality.

Table 1. Initial soil characteristics in the study field at the Sand Plain Research Farm in Becker, MN, in 2023.

0 - 6 inches												0 - 2 feet
pH	Organic matter (%)	Bray P (mg/kg)	NH_4OAc-K (mg/kg)	NH_4OAc-Ca (mg/kg)	NH_4OAc-Mg (mg/kg)	DTPA-Mn (mg/kg)	DTPA-Fe (mg/kg)	DTPA-Zn (mg/kg)	DTPA-Cu (mg/kg)	Hot water B (mg/kg)	SO_4^{2-}-S (mg/kg)	NO_3^--N (mg/kg)
6.3	2.3	51	114	1010	200	19	29	6.5	1.1	0.3	12	1.0

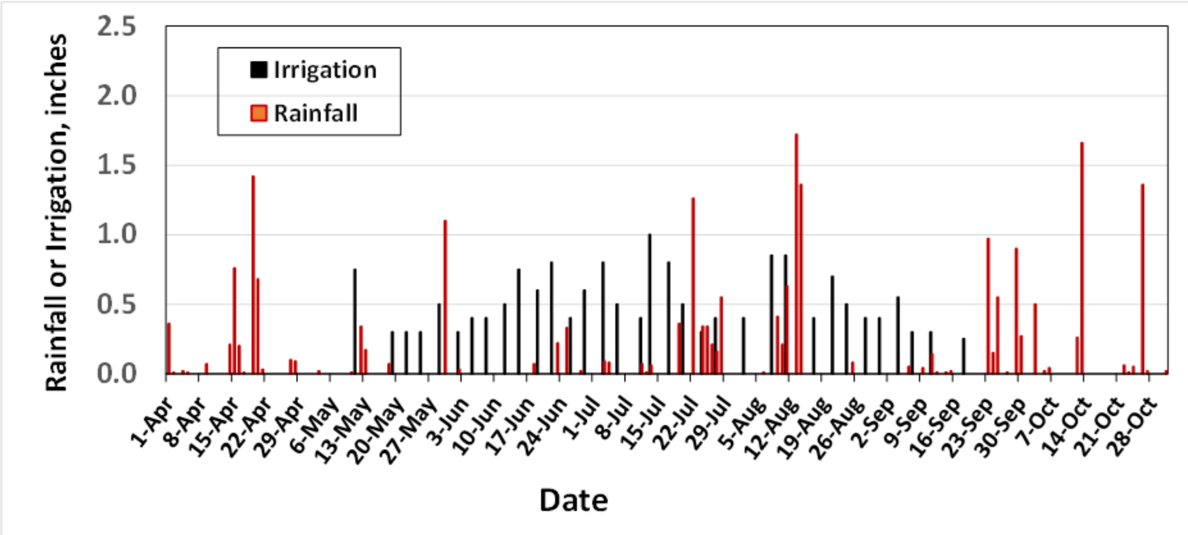

Figure 1. Rainfall and irrigation amounts on each day of the 2023 growing season.

Table 2. Combinations of a proprietary microbial inoculum (MOS009-A-01), a proprietary carbon source (MOS023-A-02), and water applied to Russet Burbank plots.

Treatment		Applied at planting (oz/ac)			Applied 4 weeks after planting (oz/ac)		
Number	Description	Water	MOS009A-01 inoculum	MOS023-A-02 fertilizer	Water	MOS009A-01 inoculum	MOS023-A-02 fertilizer
1	Check	48	0	0	48	0	0
2	Inoc + C at planting	0	16	32	48	0	0
3	Inoc at planting	32	16	0	48	0	0
4	Inoc + C at plant & 4 weeks	0	16	32	0	16	32
5	C at plant & 4 weeks	16	0	32	16	0	32
6	Inoc at plant & 4 weeks	32	16	0	32	16	0

Table 3. Effects of the microbial inoculum and carbon source treatments on Russet Burbank tuber yield, size, and grade. Values within a column followed by the same letter are not significantly different ($P \leq 0.10$) in pairwise comparisons. Pairwise comparisons are presented only for effects where $P \leq 0.10$.

Treatment		Tuber yield (cwt/ac)										% yield in tubers over:	
Number	Description	Culled	0-4 oz	4-6 oz	6-10 oz	10-14 oz	> 14 oz	Total	U.S. No. 1	U.S. No. 2	Marketable	6 oz	10 oz
1	Check	10	87	95 c	202	130	112	635	483	56	539	71	39
2	Inoc + C at planting	5	82	120 a	216	137	117	675	535	54	589	70	38
3	Inoc at planting	7	103	120 a	213	119	104	666	502	55	556	67	35
4	Inoc + C at plant & 4 weeks	8	95	98 bc	194	148	115	661	494	57	555	71	41
5	C at plant & 4 weeks	4	87	125 a	206	123	92	637	507	39	546	67	34
6	Inoc at plant & 4 weeks	8	80	114 ab	200	135	119	655	525	43	568	70	39
Effect of treatment (P value)		0.3741	0.2204	**0.0215**	0.8109	0.4433	0.7072	0.2913	0.2229	0.2682	0.2753	0.2870	0.4504
Contrasts (P values)	Check vs. others (1 v 2-6)	0.1362	0.7723	**0.0104**	0.6946	0.8320	0.8729	0.1358	***0.0961***	0.5497	0.1495	0.2355	0.5849
	Timing (2&3 v 4&6)	0.3167	0.4851	***0.0518***	0.1745	0.1996	0.6288	0.3973	0.5736	0.9681	0.5495	0.2531	0.1944
	C source (2&4 v 3&6)	0.7015	0.6819	0.2516	0.9941	0.1490	0.7329	0.5929	0.9355	0.2008	0.4696	0.2311	0.3271
	Inoculum (1&5 v 3&4)	0.7433	0.1068	0.9008	0.9369	0.5071	0.5673	***0.0715***	0.8698	0.1363	0.3600	0.8865	0.6478

Table 4. Effects of the microbial inoculum and carbon source treatments on Russet Burbank tuber quality. Values within a column followed by the same letter are not significantly different ($P \leq 0.10$) in pairwise comparisons. Pairwise comparisons are presented only for effects where $P \leq 0.10$.

Treatment		Prevalence (% of tubers)		Specific gravity	Dry matter content (%)
Number	Description	Hollow heart	Brown center		
1	Check	6.7	6.0	1.0714	17.1
2	Inoc + C at planting	6.7	6.7	1.0724	16.6
3	Inoc at planting	6.0	5.3	1.0728	17.3
4	Inoc + C at plant & 4 weeks	8.3	9.0	1.0731	17.9
5	C at plant & 4 weeks	4.7	5.3	1.0720	17.6
6	Inoc at plant & 4 weeks	7.3	7.3	1.0722	18.6
Effect of treatment (P value)		0.8797	0.8590	0.6525	0.2202
Contrasts (P values)	Check vs. others (1 v 2-6)	0.9550	0.7610	0.2124	0.4063
	Timing (2&3 v 4&6)	0.4976	0.3395	0.7062	**0.0373**
	C source (2&4 v 3&6)	0.7271	0.5181	0.5836	0.2190
	Inoculum (4 v 5)	0.2540	0.2767	0.2399	0.7934

Data Report for UMN Potato Breeding Program 2023

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Vine-kill Dates for Late State Breeding Program Clones

Aim: Since the summer of 2018 the University of Minnesota Potato Breeding program has been developing and evaluating chipping, russet, and red and yellow fresh market clones for potential release. Many of these clones have been trialed in North Dakota, Wisconsin, Michigan and/or North Carolina. Some have been part of the National Chip Processing Trial. We have accumulated data on yield and yield and components, specific gravity, skinning, tuber color and tuber shape. All advanced clones have been genotyped both for whole genome markers and for known PVY and verticillium wilt resistance genes. As we make decisions about releasing clones we need further information on their attributes and best practices for management. In Minnesota and North Dakota where summers are short and winters are long, varieties with early maturity that yield well at early vine-kill dates are ideal. Therefore, we screened those late stage clones in the breeding program to determine ideal vine-kill dates to maximize yield.

Methods: This trial included clones from field years 5 and 6 (FY5 and FY6) in the breeding program for which there was sufficient seed. The final set included 13 fresh market clones, 6 red (MN18CO15083-006, MN18W17009-001, MN18W17026-002, MN18W17026-004, MN19AF6933-006, and MN19ND1759-001) and 7 yellow (MN04844, MN18CO16154-009, MN18TX17760-002, MN18TX17760-004, MN19AF6945-003, MN19AF6945-005, MN19AF6945-008). Red Pontiac and Dark Red Norland were the fresh market checks. We had a separate trial for chips and russets which included 15 clones, 3 russets (MN13142, MN19AOR16059-002, MN19AOR16061-007) and 12 chips (MN18AF6643-013, MN18AF6648-010, MN18AF6658-005, MN18TX17748-002, MN18W17037-033, MN18W17037-026, MN18W17043-002, MN18W17057-005, MN18W17065-004, MN19AF6869-021, MN19TX18211-001, MN19TX18304-001). The checks for this experiment were Lamoka, Superior, Russet Burbank, and Russet Norkotah.

All clones were grown at the Sand Plains Research Farm (SPRF) in replicated 15 hill plots with 1ft in row spacing and 3ft between rows. Each block had a unique vine-kill date. Fresh market clones were killed 83, 90, or 97 days after planting. Chips and russets were killed 99, 106, 113, and 120 days after planting. Vines were killed using diquat with two applications a week apart. All blocks were harvested at the same time. We measured yield and size distribution for all plots using an Exeter sorter.

Results: For fresh market clones there were strong genetic effects and vine-kill date effects for yield and size distribution (Table 1). While vine-kill date did not affect total yield in a variety specific manner, it did effect number of tubers and the distribution of 0-4 oz vs 4-6 oz tubers. Almost all clones yielded best at 90 days (Figure 1) with the exception of low yielding clones for which there often was not much difference between treatments. In general, higher yield corresponded with more tubers and the highest tuber numbers were generated when vines were killed after 90 days (Figure 2). The exception to this is MN18W17026-004 where the most tubers were generated when vines were not killed until 97 days. The standout variety for tuber number was MN18CO15083-006 which produced a large number of tiny tubers (Figure 3). While at first glance, this result looks like an outlier and a result of measurement error, the high number of small tubers was consistent across both replicates. Another standout variety is MN19AF6945-003, a yellow which out yielded all the checks in our yield trial and in a fresh market trial run by Amber Walker in Wisconsin. It also showed a more favorable size distribution that was heavily weighted toward large tubers. MN19ND1759-001 was the best performing red in the trial. However, both these strong performers exhibited a yield penalty at earlier vine-kill dates.

	Clone	Vine-kill Date	Interaction
Total Yield	***	***	
Number of Tubers	***	***	**
0-4 oz	***	***	***
4-6 oz	***	**	**
6-10 oz	***	**	
10+ oz	***	**	

Table 1. ANOVA results for fresh market clones. Stars indicate level of significance in each case the model was phenotype = clone + vine-kill date + clone x vine-kill date.

Maturity was much more variable in the russet and chipping clones, where there was a significant interaction between clone and vine-kill date for total yield (Table 2). There was also a significant effect of clone for all traits and vine-kill date had a significant effect on total yield, tuber count, and the distribution of midsized tubers. There was no clone specific reaction to vine-kill date for any of the yield components.

Table 2. ANOVA results for chip and russet clones. Stars indicate level of significance in each case the model was phenotype = clone + vine-kill date + clone x vine-kill date.

	Clone	Vine-kill Date	Interaction
Total Yield	***	***	*
Number of Tubers	***	***	
0-4 oz	***		
4-6 oz	***	***	
6-10 oz	***	***	
10+ oz	***		

There were two early maturing, high yielding russets (Figure 4). MN13142, in the process of being released as Elk River Russet, peaked at vine-kill at 110 days and did not improve after that. MN19AOR16061-007 yielded best with vine-kill at 103 days and yield decreased from there. Notably, both out yielded Russet Norkotah and Elk River Russet outperformed Russet Burbank until 124 days after planting. The third russet, MN19AOR16059-002, exhibited increased yield with time but was lower yielding overall.

The earliest chips were MN18AF6658-005 and MN18W17043-002, although neither were particularly outstanding overall. For later maturing chips, MN18TX17748-002, MN18W17037-026, MN18W17037-033, MN19TX18211-001, and MN19TX18304-001 all performed well.

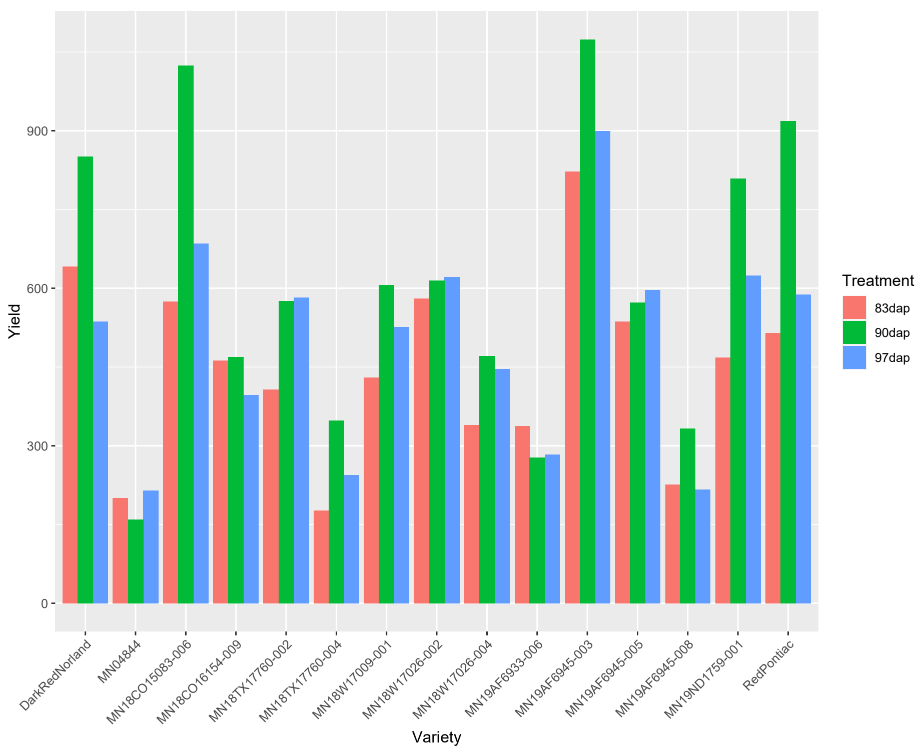

Figure 1. Total yield by variety and vine-kill date (days after planting) for fresh market clones

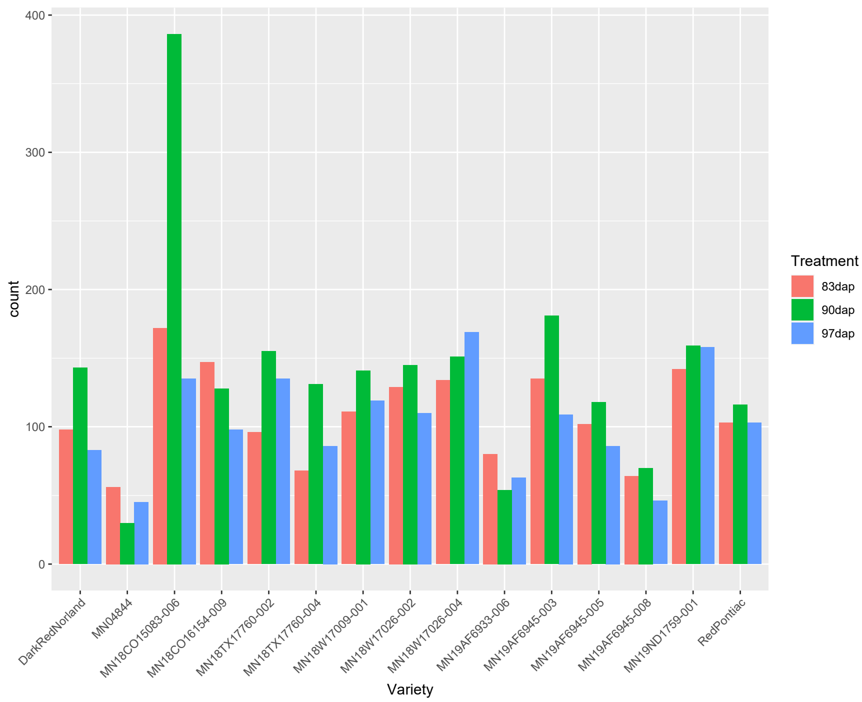

Figure 2. Tuber count by variety and vine-kill date for fresh market clones

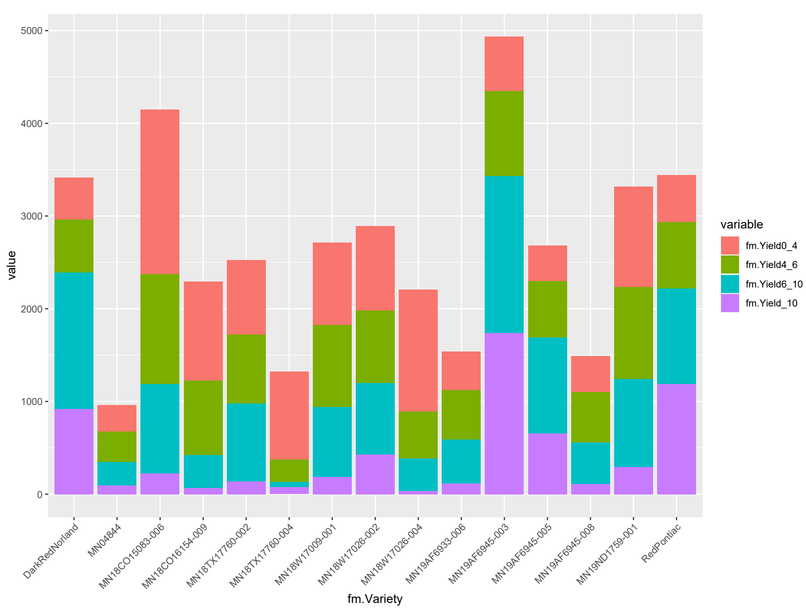

Figure 3. Size distribution by variety across vine-kill dates. The y-axis is weight. Bars are colored by size of tubers: red for 0-4 oz, green for 4-6 oz, blue for 6-10 oz, and purple for over 10 oz.

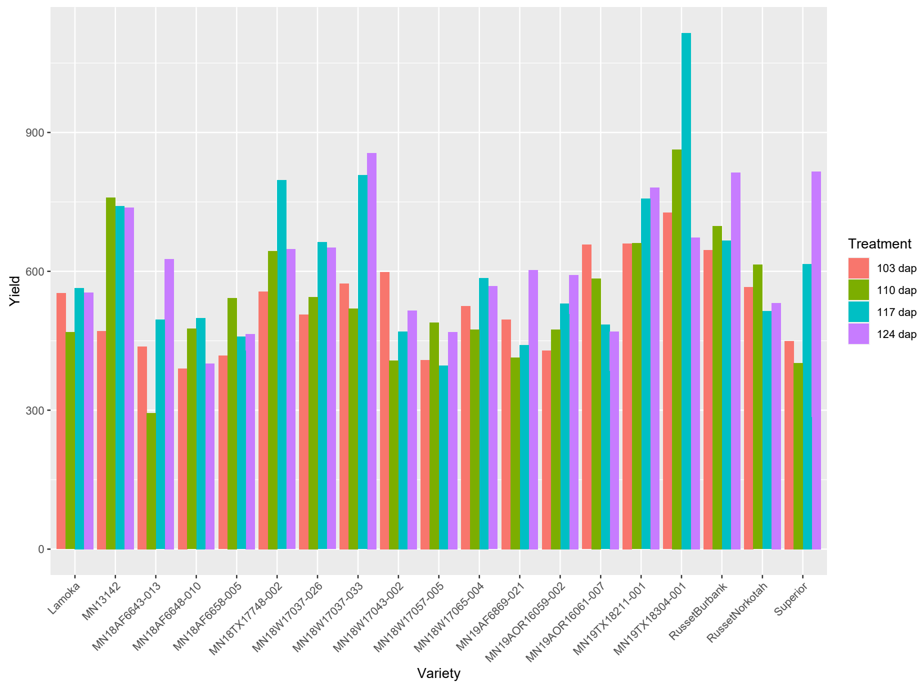

Figure 4. Yield by clone and vine-kill date for chips and russets

Conclusion: For the clones included in this trial we saw a significant clone specific response to vine-kill date for chips and russets in terms of total yield, and for fresh market clones in terms of tuber count and size distribution among the smallest tubers. For fresh market reds and yellows this suggests that if we want to push for less than 90-day clones, we would need to introduce parents from other programs and select on maturity earlier in the breeding process. We identified two early russets, including Elk River Russet, our next release, which peak around 110 days after planting. All of the chips we tested were late maturing, suggesting a need for parents from other programs. Dr. Jeffrey Endleman, at University of Wisconsin, has identified markers for *CDF1* the maturity gene in potato and put them on the latest FlexSeq genotyping platform. Going forward all material in the program will be genotyped for *CDF1*, allowing us to select for earlier material and design crosses focused on earliness.

Tissue Culture

Aim: Trials are dependent on seed. Over the past several years, we have been hindered in entering clones into multi environment trials or including them into our own agronomic trials due to lack of seed. Although we have repeatedly attempted to ramp up seed production our efforts have been limited by disease in the field and in storage and flooding at the North Central Research and Outreach Center (NCROC).

To create a more sustainable source of seed for our most promising late-stage clones, we proposed to introduce them into tissue culture and produce disease free cuttings. This would give us a backup way to produce seed in the event that our seed from NCROC was damaged or lost. For example, in 2020 we planted 80 hills of transplants of MN13142 and were able to produce sufficient seed for multilocation trials in a single season. The ability to do larger trials depends on seed and the ability to rapidly scale up disease free seed depends on anti-viral tissue culture.

Methods: Tubers from all FY5 and 6 clones were planted in the greenhouse on the St. Paul campus. Vegetative tissue was collected from each plant and leaves were removed. Cuttings with 1-3 nodes were placed into a series of solutions (70% ethanol, bleach/Tween20, DI water). Cuttings were vortexed in each solution. Finally the cleaned cuttings were placed on paper to dry and then introduced to sterile media. When plantlets increased in size, new cuttings were taken to increase the total number of plantlets for the next steps of anti-viral tissue culture.

Results: We have generated tissue culture plantlets from 16 FY6 and 10 FY5 clones and begun ramping them up for anti-viral tissue culture.

Conclusion: We have introduced our late-stage clones to tissue culture and generated multiple plantlets for each in preparation for anti-viral tissue culture and seed increase through transplanting.

Generation of Germplasm

Aim: The UMN potato breeding program works to develop new cultivars in four distinct market classes (red, yellow, chip, and russet) with increased resistance to biotic and abiotic stress. We also aim to develop cultivars which require fewer inputs (fertilizer, pesticides, irrigation, etc.) Potatoes are highly responsive to their environment, so while we test cultivars for broad adaptability, we select specifically for Minnesota and North Dakota environments, growers, and markets.

Potatoes are highly heterozygous, meaning that even a cross between two high performing cultivars can largely produces plants with little or no commercial value. Therefore, new cultivars are developed through a process of winnowing from a large number of unselected offspring from a cross, to a small number of promising clones. In the early stages of the breeding program, we focus on generating a large pool of germplasm from which to select. 2023 marked the sixth field season of the revamped Minnesota Potato Breeding Program.

Methods:

FY1

We planted 25,000 single hills. Of these, twenty families were from crosses done at UMN. The rest were kindly provided by our partnering institutions; University of Maine (26 families), North Dakota State University (30 families), Texas A&M University (100 families), the University of Colorado (35 families), and Oregon State University (39 families). All single hills were planted at the North Central Research and Outreach Center (NCROC) and selected using visual selection.

FY2

We evaluated 241 FY2 clones this year in 12-hill plots. Of these clones, 15% were chips, 58% were russet, and 26% were red. All clones were planted at the NCROC and selected using visual selection.

FY3

In FY3 we carry out preliminary yield trials. We grew 376 clones in un-replicated 15-hill plot trials at SPRF. Modoc, Chieftain, Red Norland, Dark Red Norland, Red Pontiac and Red LaSoda were used as checks for the red potatoes. Atlantic, Snowden, Cascade, Superior, and Lamoka were used as checks for the chippers. Russet Norkotah, Russet Burbank, Umatilla Russet, and Goldrush were used as checks for the russets. We used 1ft in row spacing and 3ft between rows. Vines were desiccated after 91 days for the fresh market potatoes and 108 days for processors. Tubers were harvested 3 weeks after vine desiccation.

Post-harvest we collected quantitative measures of: tuber shape, tuber color, and skin set, for each selected clone. This was accomplished by arranging a subset of 10 tubers in a 3x4 grid in a Photosimile 200 lightbox, and images were taken with a Canon Rebel T6i camera using a 24mm lens, ISO 100, 1/30 sec shutter speed and aperture f/5.6. Following the methods of Caraza-Harter and Endelman[1]. Image analysis was performed in-house using the R package TuBAR[2]. These tubers were cut in half and internal defects were counted.

All plots were graded on an Exeter grader to obtain yield and size profile data. At grading two sub samples of 10 individuals were taken. The first for photography as described, the second to test specific gravity and chip and fry color. In order to test specific gravity, we took a sample of ten tubers per clone which were weighed on a balance while suspended in the air in a mesh bag. The sample was then weighed while suspended in a sink containing about ten liters of tap water. Specific gravity was calculated as SG = weight in air /(weight in air – weight in water).

Chipping and russet potatoes were analyzed separately for chip/fry color. For the chipping potatoes, each potato in the sample was cut transversely, perpendicular to the stem-bud end axis. One cut was first made and discarded to provide a flat surface. Then that half was sliced twice to provide two slices per tuber for frying. The slices were blotted dry to remove surface moisture and then fried at 185° C for 2.0 minutes. For the frying potatoes, each potato was placed in a plank cutter longitudinally along the bud-stem end axis. An electric arm forced the potato into the cutting grid cutting the potatoes into 9.0 x 11.5 mm planks. The planks were notched at the bud end, blotted dry, then fried at 200° C for 2 minutes. Both chip and fry samples were photographed on a bench against a white background for visual evaluation.

All clones were genotyped using the FlexSeq array from Rapid Genomics. In addition to a set of whole genome markers, the array includes markers for two sources of PVY resistance (*RYsto* and *RYad*g) and Verticillium wilt resistance *(Ve2)*. These three genes were chosen as targets for selection, due to the availability of accurate markers. Additionally, 33 of the chipping clones were evaluated in 8-hillplots in North Carolina as part of the Early Generation Southern Strategy Trial.

FY4, 5 & 6

We grew FY4-6 as a replicated field trial in Becker MN with two 15-hill plots each. These were grown with both the FY3 plots and single replicate samples from North Dakota, Wisconsin, and Michigan. For each market class FY3-6, checks, and the clones from the North Central Region were grown in a partially replicated randomized design. The trial included 29 FY4 individuals: 7% fresh market, 21% russet, and 72% chip; 57 FY5 individuals: 46% fresh market, 40% chip, and 14% fresh market; and 37 FY6 individuals: 32% fresh market, 57% chip, and 11% russet. They were phenotyped as above. Thirty of these clones were also grown in North Dakota, Wisconsin, and Michigan as part of the North Central Regional trial and eleven were entered into the National Chip Processing Trial.

Results:

FY1

We selected 1% of the individuals over all to continue on in the program to year 2, resulting in 239 clones to be evaluated in 12 hills in 2024.

FY2

We selected 20% of the clones, resulting in 48 clones to be evaluated in preliminary yield trials in 2024.

FY3

We selected 11 chipping clones, 20 russets, and 18 fresh market clones which we will evaluate in replicated yield trials in 2024.

FY4, 5, 6

We selected 11 FY4 chips (Table 3), 3 FY5 chips (Table 4), and 7 FY6 chips (Table 5). All selected clones outperformed at least one check. MN18W17043-006 will be in the National Chip Processing Trial Tier 2 this year. It has both PVY and Verticillium wilt resistance and has yielded well in low nitrogen soils. MN18W17037-033 was in Tier 2 of the NCPT this year and had inconsistent specific gravity across environments however it performed very well in warm environments including Florida and that in combination with PVY resistance has earned it a place in industry trials.

Table 3. 2023 FY4 Chipping Selections (yield in % Atlantic).

Clone	Yield MN 2023	SG MN 2023	Yield NC 2023	SG NC 2023
MN20CO18192-001	104	1.081	147	1.072
MN20AF7174-001	102	1.071	135	1.067
MN20CO18127-003	101	1.114	174	1.071
Atlantic	100	1.075	100	1.075
MN20ND1810Y-297A	94	1.069	146	1.058
MN20TX417-003	90	1.071	74	1.070
Cascade	90	1.065	NA	NA

MN20AF7131-002	88	1.096	146	1.064
MN20ND184Y-120	87	1.065	106	1.065
MN20ND1833B-001	83	1.075	86	1.068
Snowden	81	1.072	129	1.074
Lamoka	68	1.077	NA	NA
MN20AF7145-002	62	1.071	74	1.074
MN20W19027-074	61	1.073	98	1.076
MN20ND1810Y-128	54	1.074	88	1.069
Superior	48	1.067	NA	NA

Table 4. 2023 FY5 Chipping Selections (NAs indicate unmeasured phenotypes, Yields are presented as % Atlantic)

Clone	Yield MN 2023	SG MN 2023	Yield MN 2022	SG MN 2022	Yield MN 2021	SG MN 2021	Yield NC 2021	SG NC 2021	PVY	Vert
MN19TX18211-001	103	1.067	102	1.070	88	1.064	200	1.054	Yes	No
Atlantic	100	1.075	100	1.073	100	1.075	100	1.064	NA	NA
Cascade	90	1.065	82	1.060	NA	NA	NA	NA	NA	NA
Snowden	81	1.072	19	1.075	92	1.071	142	1.066	NA	NA
MN19AF6892-009	76	1.073	102	1.089	80	1.074	129	1.070	No	Yes
Lamoka	68	1.077	59	1.071	77	1.068	NA	NA	NA	NA
MN19TX18032-001	63	1.059	74	1.066	85	1.067	162	1.057	Yes	No
Superior	48	1.067	27	1.064	NA	NA	NA	NA	NA	NA

Table 5. 2023 FY6 Chipping Selections (NAs indicate unmeasured phenotypes, Yields are presented as % Atlantic)

Clone	Yield MN 2023	SG MN 2023	Yield MN 2022	SG MN 2022	Yield MN 2021	SG MN 2021	Yield MN 2020	SG MN 2020	Yield WI 2021	SG WI 2021	Yield MI 2021	SG MI 2021	PVY	Vert
MN18W17043-012	102	1.083	120	1.084	153	1.081	113	1.067	NA	NA	NA	NA	No	No
Atlantic	100	1.075	100	1.073	100	1.075	100	1.064	100	1.085	100	1.088	NA	NA
MN18W17039-005	91	1.076	123	1.078	89	1.072	122	1.070	108	1.084	103	1.080	Yes	No
Cascade	90	1.065	82	1.060	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
MN18W17037-026	86	1.082	40	NA	64	1.064	94	1.063	85	1.08	77	1.079	NA	NA
MN18W17043-006	84	1.079	82	1.078	76	1.069	125	1.071	100	1.078	71	1.085	Yes	Yes
Snowden	81	1.072	19	1.075	92	1.071	NA	NA	NA	NA	NA	NA	NA	NA
Lamoka	68	1.077	59	1.071	77	1.068	NA	NA	98	1.084	87	1.081	NA	NA
MN18W17043-002	65	1.084	93	1.091	93	1.072	63	1.067	NA	NA	NA	NA	Yes	No
MN18W17043-017	63	1.094	59	1.085	95	1.069	133	1.067	102	1.085	102	1.084	No	No
MN18W17037-033	58	1.077	153	1.075	87	1.070	88	1.067	NA	NA	NA	NA	Yes	No

Superior	48	1.067	27	1.064	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

We selected 4 FY5 russets (Table 6) and 3 FY6 russets (Table 7). Of these only MN19AOR16059-001, MN19AOR17020-009, and MN18W17076-001 have processing potential. The other four have lower specific gravity and are only under consideration as fresh market russets.

Table 6. 2023 FY5 Russet Selections (NAs indicate unmeasured phenotypes, Yields are presented as % Russet Burbank)

Clone	Yield MN 2023	SG MN 2023	Yield MN 2022	SG MN 2022	Yield MI 2022	SG MI 2022	Yield WI 2022	SG WI 2022	Yield MN 2021	SG MN 2021
Russet Burbank	100	1.073	100	1.067	100	1.075	100	1.071	100	1.060
Vanguard Russet	97	1.056	NA	NA	NA	NA	NA	NA	NA	NA
MN19AOR16059-001	92	1.078	NA	NA	NA	NA	NA	NA	117	1.065
Reveille Russet	87	1.071	NA	NA	NA	NA	NA	NA	NA	NA
Russet Norkotah	83	1.060	113	1.060	54	1.061	112	1.070	54	1.055
Goldrush	81	1.062	98	1.058	NA	NA	113	1.064	98	1.054
Umatilla Russet	79	1.075	114	1.066	NA	NA	NA	NA	NA	NA
MN19AOR16061-007	75	1.069	129	1.066	67	1.066	101	1.066	63	1.056
Dakotan Russet	70	1.072	NA	NA	NA	NA	NA	NA	NA	NA
MN19CO17074-003	67	1.068	NA	NA	NA	NA	NA	NA	92	1.058
MN19AOR17020-009	53	1.073	51	1.072	NA	NA	54	1.074	63	1.066

*Table 7. 2023 FY6 Russet Selections (NAs indicate unmeasured phenotypes, Yields are presented as percent Russet Burbank except for the * Yield which is presented as percent Russet Norkotah)*

Clone	Yield MN 2023	SG MN 2023	Yield MN 2022	SG MN 2022	Yield MN 2021	SG MN 2021	Yield MN 2020*	SG MN 2020	Yield WI 2021	SG WI 2021	Yield MI 2021	SG MI 2021
MN18W17076-001	57	1.071	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
MN18W17091-005	85	1.070	128	1.045	133	1.054	206	1.057	80	1.074	79	1.072
MN18W17091-015	129	1.056	165	1.066	NA	NA	135	1.062	NA	NA	NA	NA

Dakota Russet	70	1.072	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Goldrush	81	1.062	98	1.058	98	1.054	NA	NA	89	1.071	76	1.070
Reveille Russet	87	1.071	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Russet Burbank	100	1.073	100	1.067	100	1.060	NA	NA	100	1.077	100	1.072
Russet Norkotah	83	1.060	113	1.067	54	1.055	100	1.052	92	1.069	73	1.073
Umatilla Russet	79	1.075	114	1.066	NA	NA	NA	NA	NA	NA	NA	NA
Vanguard Russet	97	1.056	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

We selected 1 red skinned white fleshed potato from FY5 and 2 from FY6 (Table 8). All of which out yielded all checks in 2023. These selections also stand out in terms of quality traits. Color in red clones is made up of two components, redness (on a red to green scale) and lightness (on a black to white scale). These components should be looked at in combination, for instance while Dark Red Norland is not very red it is very dark and the combination creates the dark red color. All three varieties are redder than all clones except Red Pontiac. MN18W17026-002 is also darker than all clones except Red Pontiac. MN19ND1759-001 and MN18W17026-004 are darker than all clones except Red Pontiac and Red Norland. MN18W17026-004 is second only to Modoc in skin retention after harvest and roundness. MN19ND1759-001 is the roundest potato of the set.

Table 8. 2023 FY5 and 6 Red Selections (NAs indicate unmeasured phenotypes. Yields are presented as percent Red Norland. Redness, roundness, lightness, and skinning were measured with TubAR digital imaging software. Redness is measured on a scale from green -100 to red 100. Roundness is measured on a scale from 0 to 1, with 1 being a perfect circle. Lightness is measured on a scale from black 0 to white 100. Skinning is measured in percent area skinned.)

Clone	Yield MN 2023	Roundness 2023	Redness 2023	Skinning 2023	Lightness 2023
MN19ND1759-001	500	0.984	19.5	0.05	50.025
MN18W17026-002	393	0.972	20.475	0.09	46.375
MN18W17026-004	318	0.982	16.4	0.02	50.075
Red Pontiac	102	0.980	21.4	0.27	44.8
Red Norland	100	0.966	15.4	0.075	49.125
Red LaSoda	95	0.967	13.8	0.03	50
Dark Red Norland	85	0.978	15.8	0.04	53.425

Modoc	70	0.984	14.4	0.0175	50.7
Chieftain	64	0.980	12.575	0.0225	52

Table 9. Historic data on 2023 FY5 and 6 Red Selections (NAs indicate unmeasured phenotypes. Yields are presented as percent Red Norland. Redness, roundness, lightness, and skinning were measured with TubAR digital imaging software. Redness is measured on a scale from green -100 to red 100. Roundness is measured on a scale from 0 to 1, with 1 being a perfect circle. Lightness is measured on a scale from black 0 to white 100. Skinning is measured in percent area skinned.)

Clone	Yield MN 2022	Yield WI 2022	Yield MI 2022	Red 2022	Light 2022	Round 2022	Yield MN 2021	Yield WI 2021	Yield MI 2021	Red 2021	Light 2021	Round 2021	Skinning 2021	Yield MN 2020
Red Norland	100	100	100	20.7	45.6	0.963	100	100	100	9.9	50.4	0.939	0	100
Red LaSoda	92	90	137	22.8	44.9	0.982	54	89	82	11.2	NA	0.967	0.345	NA
Red Pontiac	85	NA	NA	NA	NA	NA	NA	NA	NA	8.6	55.6	0.958	0.020	NA
Dark Red Norland	84	106	97	21.2	47.2	0.977	101	84	86	11.6	48.5	0.952	0	NA
MN18W17026-004	81	NA	NA	9.9	63.0	0.978	117	NA	NA	18.2	51.4	0.980	NA	42
MN18W17026-002	76	NA	NA	9.0	56.1	0.961	168	138	153	22.7	41.6	0.971	NA	99
MN19ND1759-001	70	NA	NA	23.8	50.2	0.982	95	NA	NA	15.8	53.3	0.985	0	NA
Chieftain	59	NA	NA	21.1	49.7	0.984	NA	NA	NA	12.0	52.8	0.979	0.570	NA
Modoc	39	NA	NA	NA	NA	NA	NA	NA	NA	11.9	53.2	0.965	0.220	NA

We selected 2 FY5 yellow skin and yellow flesh clones and 2 from FY6 (Table 10). All out yielded Yukon Gold and Columba. MN19AF6945-003, our highest yielding clone, also has PVY resistance and our second highest yielding clone, MN18CO16154-009 has the marker for verticillium wilt resistance.

*Table 9. 2023 FY5 and 6 Fresh market yellow selections (NAs indicate unmeasured phenotypes, Yield is percent Yukon Gold except in * trials where it is percent Red Norland)*

Clone	Yield MN 2023	Yield MN 2022	Yield MN 2021*	Yield WI 2021	Yield MI 2021*	Yield MN 2020	PVY	Vert
MN19AF6945-003	471	162	168	NA	NA	NA	Yes	No
MN18CO16154-009	203	141	93	95	441	57	No	Yes
MN18TX17760-002	202	115	52	138	154	241	No	No

MN19TX18206-002	172	NA	NA	NA	NA	NA	NA	NA
Yukon Gold	100	100	NA	100	NA	100	NA	NA
Colomba	68	NA	NA	NA	NA	NA	NA	NA

Elk River Russet

We have applied for P.V.P. on a new russet with the USDA, Elk River Russet. Elk River Russet, formerly known as MN13142, is slated to be the first russet potato released by the University of Minnesota Agricultural Experiment Station. It is an attractive potato, producing tubers under a wide variety of production systems. The skin is heavily russeted and the shape is picture perfect when tubers are baked and placed beside a steak on a dinner plate. Elk River Russet is a dual-purpose french fry/table stock potato with good fry color out of 6 months of storage at 48°F. Tuber set averages 7 per hill with over 1/3 being 10 oz. or bigger. Seed for Elk River Russet is available from Justin Dagen in Karlstad, MN.

Conclusions

We have developed multiple generations of new germplasm that segregate for a variety of traits of interest. This material will continue to be evaluated, in 2024 and beyond, in order to identify promising new clones for Minnesota and North Dakota growers. We are excited to begin to make these varieties available through release and plan to release two legacy clones: a specialty purple and a long storing dual purpose russet in 2024.

Acknowledgements

Team: Our breeding program logistics were managed by Dr. Thomas Stefaniak. Dr. Stefaniak also led the vine-kill trial. Muyideen Yusuf took the lead on phenotyping and compiled the grader data. Jessi Huege carried out all the tissue culture work. Other members of the lab who assisted in these projects include: Dr. Husain Agha, Heather Tuttle, John Larsen, Lauren Sexton, Sapphire Coronejo, Timi Sunmonu, Jonathan Boecker, Logan Rodewald, Miranda Gregory, Megan Harder, Linnea Johnston, and Sydney Berry.

The trials in WI and MI were managed by Dr. Jeffrey Endelman and Dr. David Douches. The Early Generation Southern Selection trial is managed by Dr. Craig Yencho in collaboration with Potatoes USA. Field data on verticillium wilt is from Dr. Ashish Ranjan at University of Minnesota. Keith Mann and his team took care of our fields at the NCROC while Mark Peterson took care of our field at SPRF. Pam

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Turkey Compost for Potato Nutrition 2023

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Executive summary

Turkey compost is a local source of N that has been used in potato production. Using turkey compost helps to reduce greenhouse gases and nitrogen leaching. The focus of this study was to evaluate turkey compost and Environmentally Smart Nitrogen (ESN) on Russet Burbank potato production. The overall objective of this project is to increase payable yield for potato growers in Minnesota and North Dakota. The use of 3 tons/a turkey compost with ESN or 5 tons/a turkey compost with or without ESN had similar yield and tubers above 6 oz when compared to the grower standard. Based on these results and previous work, turkey compost has proven to be a suitable option for potato fertilizer.

Rationale for conducting the research

Previous work in 2019 through 2022 evaluated turkey compost with and without additional ESN or other nitrogen fertilizers. Turkey compost has proven to be an effective source of nitrogen for potato plants. Describing the benefits of turkey compost as a source of nitrogen is important as the potato industry continues to seek more sustainable sources for plant nutrition, methods to reduce greenhouse gas emissions, prevent nitrate leaching, and improve soil health with organic matter. Building upon the previous work, we focused on different rates of turkey compost and the mixture of turkey compost with ESN. The original plans for this study were to use 50 and 100 lb N/a in the ESN form, but nitrogen applications applied were 4x the desired rate. The objective of this study was to determine the effects of high ESN nitrogen fertilization with turkey compost and compare this to the grower standard fertilizer program and no additional nitrogen.

Procedures

Field studies were established near Perham, MN in a commercial potato field in 2023. A randomized complete block with four replications was utilized. Plots were planted on 16 May 2023 with Russet

Burbank at 12 inch with-in-row spacing on 36-inch spaced rows. Prior to planting turkey compostd was spread over the plot areas. The planting equipment and hilling was used to incorporate the turkey compost. Environmentally Smart Nitrogen was applied on 8 June 2023 and hilled in the following day. Vines were removed with a vine chopper on 15 September 2023 and harvested with a single row plot harvester on 21 September 2023. Following harvest, tubers were graded and sized according to USDA standards. Data were analyzed in SAS with an analysis of variance. Differences in data were separated utilizing a Tukey pairwise comparison at p=0.05.

Results

Size profiles of tubers graded varied based on treatment (Table 1). Tubers in the 3-6 oz size range had fewer cwt when 400 lb N/a was applied with turkey compost compared to the no N treatment. While tubers >10 oz were greater for 400 lb N/a addition with turkey compost compared to the no N treatment. Tuber total yield and marketable yield were similar across any treatment receiving any nitrogen treatments (Table 2). The percent of tubers >6 oz and >10 oz were similar between all nitrogen treatments, except the 3 tons/a of turkey compost applied. Numerically, the additions of ESN to turkey compost increased the percent of tubers >6 oz and >10 oz. The fry quality of treatments at 3 months of storage at 48 °F showed that glucose levels were lower and generally stem reflectance was higher when any synthetic fertilizer was applied (Table 3). Based on these results and previous work, turkey compost has proven to be a suitable option for potato fertilizer, but variety, soil type, turkey compost all need to be taken into consideration. This work has found that turkey compost with the addition of ESN can benefit total yield and increase tuber size. An economic analysis should be conducted based on current fertilizer prices to determine what combination of turkey compost and ESN would be optimal for growing Russet Burbank.

Figure 1. Turkey compost trial near Perham, MN on July 13, 2023.

Table 1. Tuber size distribution of Russet Burbank potato grown in 2023 near Perham, MN with turkey compost treatments.

Treatment		Turkey compost	N	<3 oz	3-6 oz		6-10 oz	10-14 oz		>14 oz	
		tons/a	lb/a	cwt/a							
1	No nitrogen	0	0	29	197	a*	160	49	c	27	b
2	Grower standard	0	250	29	136	ab	186	114	abc	61	ab
3	3 tons/a TM	3	0	41	182	ab	184	55	bc	29	b
4	5 tons/a TM	5	0	25	160	ab	192	95	abc	70	ab
5	3 tons/a TM + 200 lb N/a ESN	3	200	32	139	ab	205	154	a	83	ab
6	3 tons/a TM + 400 lb N/a ESN	3	400	20	114	b	218	140	ab	113	ab
7	5 tons/a TM + 200 lb N/a ESN	5	200	21	120	ab	212	123	abc	98	ab
8	5 tons/a TM + 400 lb N/a ESN	5	400	16	103	b	215	142	ab	141	a
Average				27	144		196	109		78	
p-value				0.1062	0.0059		0.6661	0.0037		0.0100	

*Means within the same column followed by the same letter are not significantly different according to Tukey pairwise comparison (P ≤ 0.05). No letters in a column indicate no differences between treatments.

Table 2. Yield of Russet Burbank potato grown in 2023 near Perham, MN with turkey compost treatments.

Treatment		Turkey compost	N	Total		Total marketable		>6 oz		> 10 oz		Specific Gravity
		tons/a	lb/a					%				
1	No nitrogen	0	0	461	b*	432	b	51	c	16	b	1.0795
2	Grower standard	0	250	525	ab	496	ab	68	abc	33	ab	1.0787
3	3 tons/a TM	3	0	490	ab	449	ab	53	bc	16	b	1.0828
4	5 tons/a TM	5	0	542	ab	517	ab	63	abc	28	ab	1.0804
5	3 tons/a TM + 200 lb N/a ESN	3	200	613	a	581	ab	72	abc	38	ab	1.0799
6	3 tons/a TM + 400 lb N/a ESN	3	400	604	ab	584	ab	78	ab	42	a	1.0785
7	5 tons/a TM + 200 lb N/a ESN	5	200	574	ab	553	ab	75	abc	38	ab	1.0765
8	5 tons/a TM + 400 lb N/a ESN	5	400	618	a	602	a	80	a	45	a	1.0777
Average				553		527		67		32		1.0792
p-value				0.0114		0.0127		0.0069		0.0030		0.1295

*Means within the same column followed by the same letter are not significantly different according to Tukey pairwise comparison ($P \leq 0.05$). No letters in a column indicate no differences between treatments.

Table 3. Fry quality after 3 months of storage at 48 °F of Russet Burbank grown near Perham, MN

Treatment		Turkey compost	N	Specific gravity	Sucrose	Glucose	
		tons/a	lb/a		mg/g	mg/g	
1	No nitrogen	0	0	1.0786	0.67	1.67	a*
2	Grower standard	0	250	1.0765	0.56	0.85	b
3	3 tons/a TM	3	0	1.0820	0.65	1.55	a
4	5 tons/a TM	5	0	1.0795	0.66	1.35	a
5	3 tons/a TM + 200 lb N/a ESN	3	200	1.0790	0.59	0.86	b
6	3 tons/a TM + 400 lb N/a ESN	3	400	1.0797	0.60	0.72	b
7	5 tons/a TM + 200 lb N/a ESN	5	200	1.0800	0.65	0.78	b
8	5 tons/a TM + 400 lb N/a ESN	5	400	1.0771	0.56	0.79	b
Average				1.0790	0.62	1.07	
p-value				0.1612	0.2598	<.0001	

*Means within the same column followed by the same letter are not significantly different according to Tukey pairwise comparison ($P \leq 0.05$). No letters in a column indicate no differences between treatments.

Developing Variable Rate Nitrogen and Water Management Strategies for Sustainable Potato Production

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Summary

High nitrogen (N) fertilizer and irrigation water use on potatoes to achieve yield goals is often accompanied by poor N and water use efficiencies due to the shallow root system of potato plants and sandy soils. To improve N and water use efficiencies and protect the state's water resources from contamination by NO_3 leaching, innovative management practices that optimize N and water use for high tuber yield, quality, and profit and reduced nitrate leaching must be urgently developed. The objectives of this research project are to 1) evaluate the potential benefits of variable rate N and irrigation for potato production and 2) develop practical, innovative, and effective variable rate N and irrigation management strategies using sensing technologies. In 2023, a plot-scale field experiment was conducted at the Sand Plain Research Farm in Becker, MN involving three irrigation treatments based on the checkbook method (i.e. 60%, 80%, and 100%), nine N treatments (i.e. 40, 80, 160, 240, 320 lb N/ac and four precision N management treatments), and two varieties (i.e. HR; Hamlin Russet and RB; Russet Burbank). Destructive samples and proximal/remote sensing data were collected at key growth stages. The optimal N rates for HR and RB were 80 and 160 lb N/ac, respectively. HR demonstrated higher N use efficiency, while RB was higher in water use efficiency. Reducing irrigation by 20% did not negatively affect tuber yield and quality. Precision N management treatments achieved higher yield with reduced N input resulting in higher N use efficiency and economic returns. Further analyses will be conducted using lysimeter water sample data and remote/proximal sensor data as the data become available.

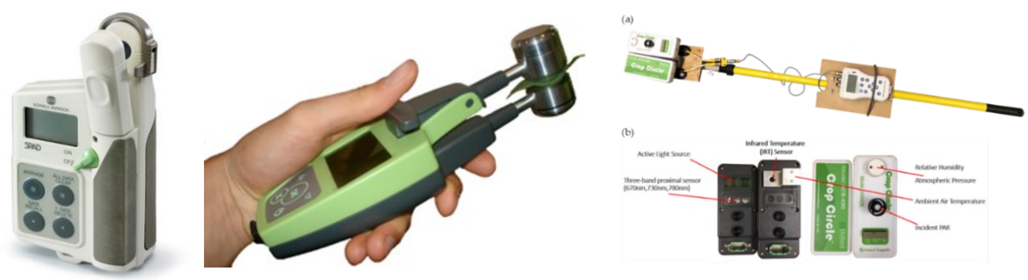
Background

The high value and unique market of potato (*Solanum tuberosum L.*) makes it one of the most important vegetable specialty crops in U.S. agriculture. Minnesota produced 19 million hundredweights of potatoes and marked $237 million in production value as the 7th largest potato producing state in 2022 (USDA & NASS, 2023). The potatoes in this region are grown on coarse-textured soils and receive high nitrogen (N) fertilizer and irrigation water application rates. Due to the shallow root system of potato plants and the low nutrient holding capacity of the coarse-textured soils, potato production is characterized by poor N recovery efficiency (Errebhi et al., 1998). The unrecovered N may leach into the ground water in the form of NO_3^- and contaminate drinking water. This environmental concern will be aggravated by the unpredictable precipitation due to the prevailing climate change. Bohman et al. (2019) showed the importance of optimizing both N and irrigation management using variable rate technologies for potato production in Minnesota to reduce nitrate leaching. In addition, the potato industry in

Minnesota has been receiving increasing pressure to reduce water use and improve water use efficiency in recent years. Further research is urgently required to develop innovative N fertilizer and irrigation management practices that maintain high tuber yield, quality, and profit while increasing N and water use efficiencies and reducing nitrate leaching losses.

Leaf chlorophyll meter SPAD-502 (SPAD; Konica Minolta, Tokyo, Japan) (Figure 1, left) and leaf fluorescence sensor Dualex Scientific+ (Dualex; METOS® by Pessl Instruments, Weiz, Austria) (Figure 1, middle) demonstrated potentials for in-season potato N status diagnosis in our preliminary research. SPAD is the most commonly used chlorophyll meter and provides relative chlorophyll readings using leaf transmittance in the red and near-infrared wavelengths. Dualex sensor is capable of measuring leaf chlorophyll, flavonoid, and anthocyanin contents using leaf transmittance and chlorophyll fluorescence screening in the green, red, Red-Edge, and near-infrared wavelengths. The ratio of chlorophyll over flavonoid readings is also displayed as N Balance Index (NBI). Crop Circle Phenom (Figure 1, right) is a new integrated multi-parameter proximal active canopy sensor capable of measuring reflectance at three wavebands (red, Red-Edge, and near-infrared) and climatic parameters such as canopy and air temperatures, relative humidity, and air pressure. The integrated capabilities of Crop Circle Phenom are promising for use in conditions where N and water stresses occur concurrently (Cummings et al., 2021). This canopy sensor is more efficient to cover a larger area than leaf sensors.

This research project aims to 1) evaluate the potential benefits of variable rate N and irrigation for potato production and 2) develop practical, innovative, and effective variable rate N and irrigation management strategies using sensing technologies to mitigate contamination of the state's water



resources while ensuring farmers' economic returns to support the sustainable potato production in Minnesota.

Figure 1. Proximal sensing technologies used in this study. From left to right; SPAD, Dualex, and Crop Circle Phenom.

Materials and Methods

Study Site

The study was conducted at the Sand Plain Research Farm (SPRF) in Becker, MN on a Hubbard (Sandy, mixed, frigid Entic Hapludolls)-Mosford (Sandy, mixed, frigid Typic Hapludolls) complex sand soil in 2023 following a previous crop of soybeans. Mean air temperature and total precipitation at this research station during this year's growing period (i.e. April 26 – October 5) were 67 °F with maximum and minimum air temperature of 84 °F and 39 °F, and 14.15 inches (Figure 2). Soil samples were collected from the top 2 feet of the soil profile for N at the beginning and end of the season and from the top 6 inches of the soil profile for other macro- and micro-nutrients at the beginning of the season. Available soil test results were summarized in Table 1.

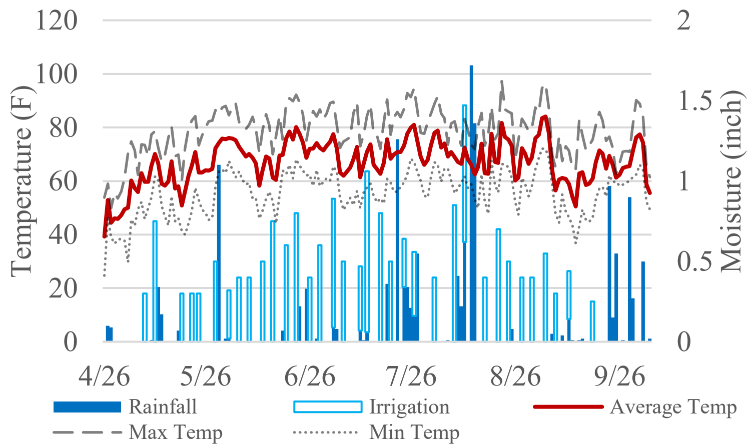


Figure 2. Weather and supplemental irrigation summary for the growing period.

Table 1. Soil test results from the beginning of the season.

Irrigation Block	-	%	Primary Nutrients				Secondary Nutrients			Micronutrients				
			mg/kg soil (ppm)											
	pH	OM	NO_3-N	NH_4-N	Bray P	K[1]	Ca[1]	Mg[1]	S[2]	Fe[3]	Mn[3]	Zn[3]	Cu[3]	B[4]
60%	7.1	1.1	2.50	4.65	55	90	626.33	115.23	7.43	10.36	5.63	6.67	0.65	0.24
80%	6.7	2.0	3.58	4.89	63	145	917.62	170.54	12.15	19.31	11.42	11.94	0.91	0.24
100%	6.8	1.2	3.20	5.52	59	95	631.24	122.00	9.68	13.69	7.83	8.28	0.83	0.23

[1] NH_4-OAc extraction, [2] Ca-phosphate extraction, [3] DTPA extraction, [4] Hot water extraction.

Study design and cultural practices

A randomized complete block design with a split plot restriction on randomization was used with three replications in this study. Variety and N treatments were the main plot and subplot effects, respectively, and were contained within each irrigation block. Three irrigation treatments included 60%, 80%, and 100% of the supplemental irrigation rates determined using the checkbook method. All of the nine N treatments received 40 lb N/ac as diammonium phosphate (DAP; 18-46-0) at planting. Treatments 1 to 5, referred to as response curve treatments, received 0, 40, 120, 200, and 280 lb N/ac as Environmentally Smart Nitrogen (ESN; Nutrien, SK, Canada; 44-0-0) at emergence, resulting in 40, 80, 160, 240, and 320 lb N/ac in total. Treatments 6 to 9, referred to as precision N management (PNM) treatments, received 40 or 120 lb N/ac at emergence as ESN depending on the varieties. Subsequently, treatment 6 received four 15 lb N/ac fixed split applications of urea ammonium phosphate (UAN; 28-0-0) about every two weeks starting at the end of June in the form of simulated fertigation. Similarly, treatments 7 to 9 received 15 lb N/ac split UAN applications up to four times after emergence depending on predicted potato N status based on different sensor-based strategies. Two varieties included Russet Burbank (RB), one of the most common processing varieties, and Hamlin Russet (HR), a new N efficient variety recently released by the Maine potato breeding program. Due to practical constraints, 60% and 80% irrigation blocks only contained N treatments 2, 3, 4, and 9. N treatment 9 was selected among the PNM treatments considering the previous experimental results.

The three irrigation blocks were sufficiently spaced considering the wetted diameter of the lateral moving irrigator. Each plot consisted of seven 20-foot rows with a 3-foot spacing except the plots on the edge of each irrigation block had 5 extra feet of buffer. Seed tubers were planted with a 12-inch spacing for RB and a 10-inch spacing for HR on April 26. The plots were hilled after emergence on May 19. Post-emergence split UAN applications were made on June 26, July 13, July 24, and August 4. Samples and sensor data were generally collected a week preceding each UAN application. Vines were harvested from the two 10-foot sections of the harvest rows on September 13 and killed subsequently. Tubers were mechanically harvested from the two harvest rows on October 5 and sorted by grade (U.S. No.1 and U.S. No.2) and size (cull, 0-4 oz., 4-6 oz., 6-10 oz., 10-14 oz., and >14 oz.) on October 11, 12 and 13. Tuber quality parameters (e.g. internal disease occurrences, specific gravity, tuber dry matter, and sugar content) were evaluated. The first and last irrigation applications were on May 8 and September 18. The plots were usually irrigated twice a week, and there were 35 irrigation events with 17.8 inches of water applied in total (Figure 2). Cultural practices, including those not listed here explicitly such as pest and disease management, were conducted by the staff at the SPRF and followed standard practices for the region.

Plant and water sampling

Petiole and whole plant samples were collected for potato N status diagnosis five and three times, respectively. Twenty petioles on the fourth leaf from the apex of the shoot were collected from a border row in each plot. Petioles were oven-dried and will be ground and analyzed for NO_3-N concentration determination. Three whole plants (i.e. vines and tubers) were sampled from the sampling row in each plot and weighed on-site for the fresh weight. Sub-samples were transported back to the campus and analyzed for percent dry matter contents in the laboratory. The sub-samples will be further analyzed for N concentration determination. A suction-cup lysimeter was installed at a 4-foot depth in the second outmost row after emergence to quantify the NO_3 movement below the root zone. Due to practical constraints, the lysimeter installation was limited to plots receiving N treatments 1, 3, 4, 6, and 9. Water samples were collected on a weekly basis and stored in the freezer for NO_3 concentration determination starting in the middle of June for future analysis. Sampling dates were summarized in Table 2.

Proximal and remote sensing

Leaf chlorophyll data were collected using SPAD and Dualex on the twenty and fifteen terminal leaflets of the fourth leaf from the apex of the shoot from the same border row as petiole sampling in each plot five times. Crop Circle Phenom data were collected from the second outmost row by holding the sensor on a pole 50 to 100 cm above the canopy from the field edge and walking at a constant pace seven times. Approximately fifteen seconds were spent walking each plot length, and fifteen readings were recorded (i.e. one reading per second by default). Crop Circle Phenom data were collected from each plot when SPAD and Dualex data were collected concurrently. Otherwise, the data were collected only from the plots with lysimeter installation. Multispectral and thermal UAV images were collected by Sentera (Sentera, Inc., St. Paul, MN, USA) using 6X Thermal Sensor five times. Access tubes were installed next to the lysimeters, and soil moisture data were collected using PR2/6 profile probe (PR2; Delta-T Devices Ltd., Cambridge, UK) at 10/20/30/40/60 and 100 cm depths in percent volumetric water content on a weekly basis. Lastly, hourly weather information including temperature, dew point, wind speed, rainfall, and total solar radiation was collected at the SPRF weather station. Sensing dates were summarized in Table 2.

Table 2. Summary of sampling and sensing dates.

Week	Samples			Sensors				
	Petiole	WP	Water[1]	Dualex	SPAD	CCP[2]	PR2	UAV
1			6/14			6/14	6/14	
2	6/22	6/20[3]	6/22	6/20[3]	6/22	6/20	6/20	6/20
3			6/26			6/27	6/27	
4	7/5		7/3	7/6	7/5	7/6	7/6	7/5
5	7/12[3]		7/11	7/13	7/12[3]	7/13	7/13	7/13
6	7/20	7/18	7/17	7/19	7/20	7/19	7/19	
7	7/27	7/26[3]	7/25	7/26	7/27	7/26	7/26	7/25
8			8/1				8/1	
9			8/9				8/9	8/8
10			8/15				8/15	
11			8/22				8/22	

[1] Water samples were collected until November, [2] Crop Circle Phenom, [3] First day of the two-day campaign noted.

Sensor-based in-season decision making for split UAN applications

As described earlier, in-season sensor-based potato N status prediction results determined whether to apply each 15 lb N/ac dose of UAN to N treatments 7, 8, and 9 after emergence. According to preliminary data analysis, N treatments 7 and 9 were based on petiole NO_3-N concentration and Nitrogen Nutrition Index (NNI) prediction using Dualex data and supplemental information on potato genetics, environment, and management in machine learning (ML) algorithms. More specifically, the data from plot-scale experiments on N use of different potato varieties conducted at the SPRF in 2018, 2019, and 2021 were used to develop a Dualex-based Random Forest (RF) regression model for petiole NO_3-N concentration prediction and Support Vector (SV) regression model for NNI prediction. Variety names, accumulated growing degree days, and as-applied N rates were incorporated into the models along with Dualex data. Figure 3 shows the validation analysis results for these two ML models. Reference NNI values were calculated using the vine-based critical N dilution curves proposed by Giletto et al. (2020). N treatment 8 was based on SPAD-based Nitrogen Sufficiency Index (NSI) using 160 lb N/ac or 240 lb N/ac as sufficient N rates for HR and RB, respectively. Different sufficiency ranges for petiole NO_3-N concentration were used at different growth stages as proposed by Rosen & Bierman (2008). For NNI and NSI, the sufficiency range of 0.95-1.05 was used. After collecting and cleaning SPAD, Dualex, and ancillary data, these three strategies were used to predict potato N status on a plot-by-plot basis during the season. If the predicted potato N status indicator was below the sufficiency range, the corresponding plot received a 15 lb N/ac UAN application.

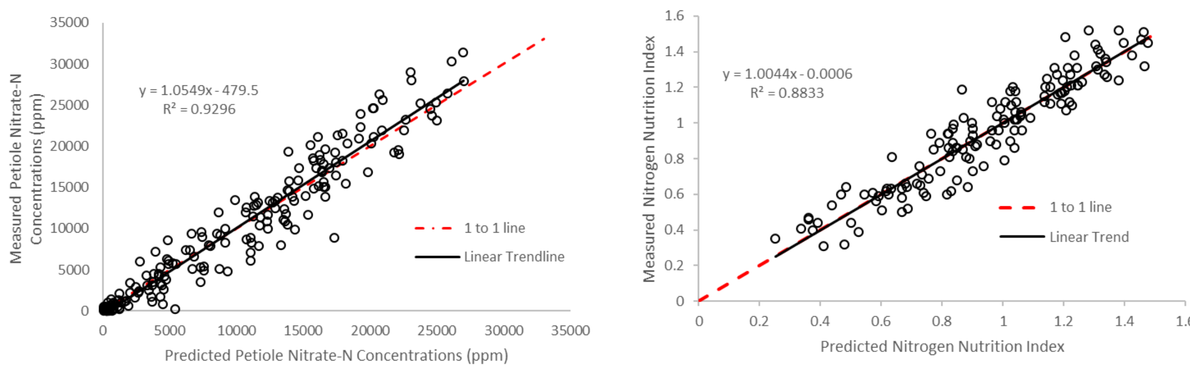


Figure 3. The correlations between the measured and predicted petiole nitrate-N concentrations (left) or Nitrogen Nutrition Index (right) based on sensor-based machine learning models.

Evapotranspiration (ET) calculation

Preliminary ET was calculated using the PR2 soil moisture content data based on the water balance method as demonstrated by Akkamis & Caliskan (2023).

$$ET = I + P - \Delta S - D - R \tag{1}$$

where I is irrigation (inch), P is precipitation (inch), ΔS is the difference in soil water contents between day i and day i-1(mm/60 cm), D is deep percolation (mm), and R is runoff (mm). The excess of the PR2 soil moisture content in comparison with the soil water content at field capacity in the top 60 cm soil profile was used as deep percolation. Field capacity for the study plot at the SPRF was obtained from USDA NRCS Web Soil Survey as follows; 0-10 cm 16.2%, 10-20 cm 16.2%, 20-30 cm 15.6%, 30-40 cm 15.6%, 40-60 cm 14.9%. Runoff was considered negligible. Assuming that the study plot was at field capacity as planting and the ET will be negligible at the late senescence stage, the ET was accumulated from the planting date until the last PR2 measurement date using the PR2 data.

Statistical analysis

All of the data cleaning, statistical, and visualization procedures were conducted in R (R Core Team, 2022). The agricolae package was used for conducting analysis of variance (ANOVA) and subsequent pairwise comparisons. The Least Significance Difference (LSD) test was used at a significance level of 0.05 with the Bonferroni correction.

Results and Discussion

Tuber yield and size responses to N rates

Under the full irrigation conditions, the RB yield increased and plateaued at 160 lb N/ac, whereas the HR yield increased to 80 lb N/ac and decreased thereafter (Figure 4). In the 60% irrigation, the RB yield increased to 160 lb N/ac and plateaued or decreased at 240 lb N/ac. In 80% irrigation, all yields except for the RB marketable yield continued to increase to 240 lb N/ac (Figure 5). It is important to note that the irrigation water had a NO_3-N concentration of 10 ppm resulting in 40, 34, and 24 lb N/ac to the 100, 80, and 60% irrigation treatment. Three-way ANOVA and LSD pairwise comparisons showed that RB produced significantly higher total yield than HR, whereas HR produced significantly higher marketable yield than RB. Similar yield trends were observed in the last few studies involving these two varieties. The effect of irrigation treatments was significant on both total and marketable yield. The 80% and 100% irrigation treatments had higher total and marketable yield than the 60% irrigation treatment. This result agrees with the findings by Bohman et al. (2019) that similar total and marketable yield can be achieved with reduced (i.e. 80%) irrigation. Over-irrigation by the checkbook method without correction using soil moisture measurements has been reported previously (Steele et al., 1997; Laboski et al., 2001). There was also a significant interaction effect between variety and irrigation on marketable yield. RB had similar

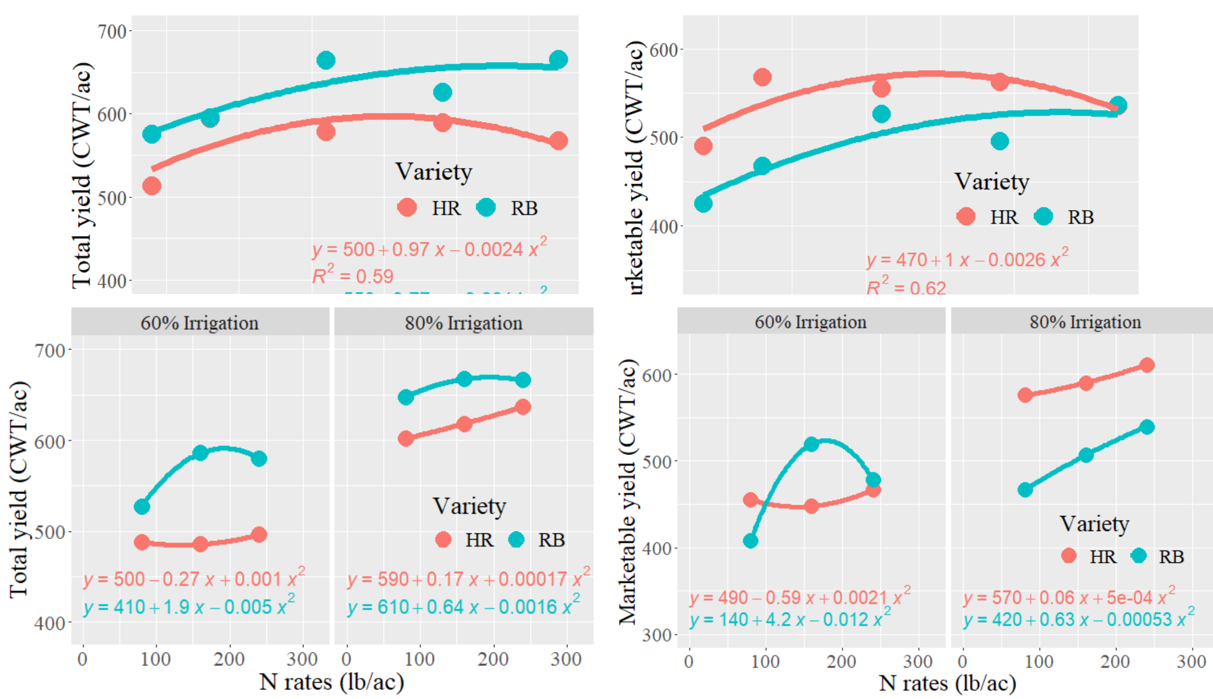


Figure 5. Total and marketable yield responses to N rates for HR and RB in the 60 and 80% irrigation treatments.

marketable yield in all irrigation treatments, but HR had a significantly lower marketable yield in the 60% irrigation. This might imply HR's lower resistance to water stress.

Figure 6 shows the total yield of each size class by each variety and irrigation treatment combination. RB produced higher yield in the smaller three size classes, whereas HR produced higher yield in the larger two size classes. Irrigation had a significant effect on the yield of the largest size class, where 60% irrigation treatments resulted in reduced yield. There was a significant interaction effect between variety and irrigation treatments on all the size classes except for the 6-10 oz. class. In the smallest two size classes, RB had significantly lower yield when receiving 60% irrigation. Hamin had lower yield receiving 60% irrigation in the upper two size classes. This finding also supports the feasibility of reduced irrigation.

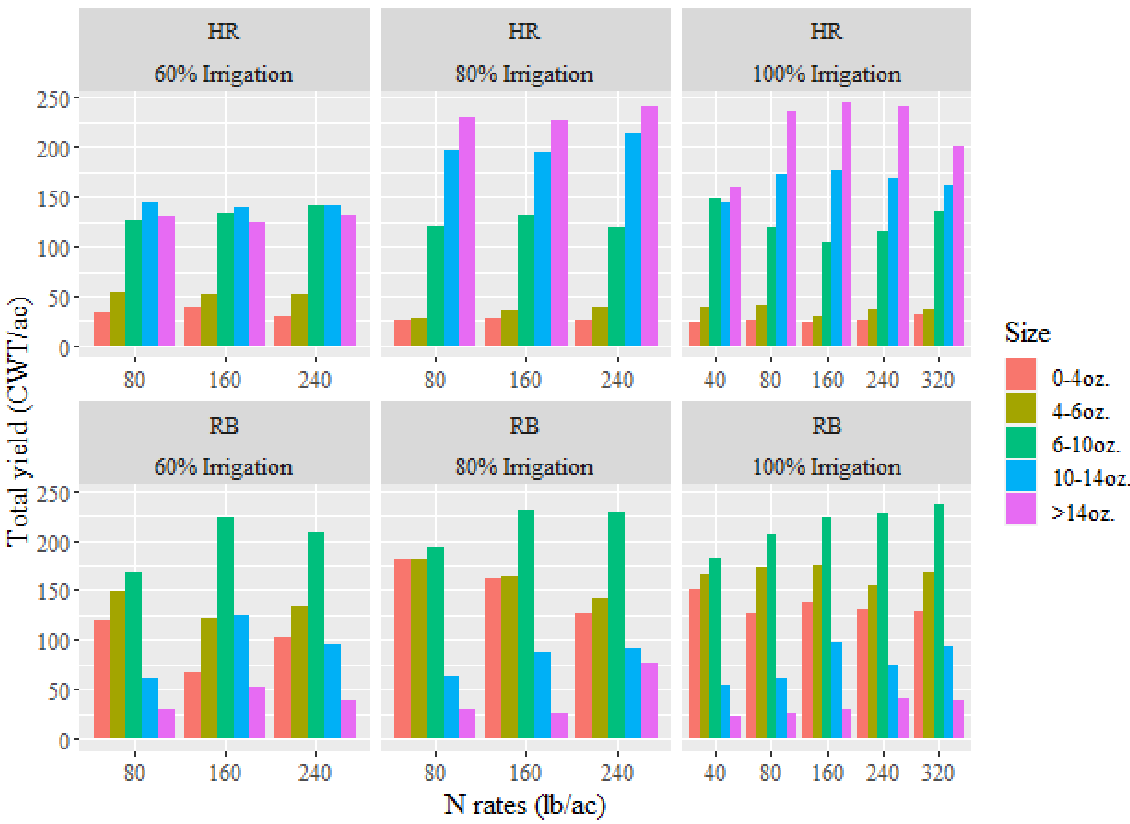


Figure 6. Total yield of HR and RB by the five size classes.

Tuber yield and size in the PNM treatments

Table 3 summarizes the timings of the split UAN applications in the PNM treatments after emergence. Total N application rates were averaged across the three replications for each variety, irrigation, and N treatment combination to make a comparison with other treatments. Figure 7 compares the total and marketable yield of HR and RB in the PNM treatments with that in the optimum N rate treatments. There was no significant difference in the total and marketable yield among all compared N treatments. Figure 8 compares the total yield of each size class for the PNM treatments with that in the optimum N rate treatments. Similarly, there was no significant difference in the total yield of each size class among all compared N treatments.

Table 3. Summary of post-hilling split UAN applications in the PNM treatments.

Plot	Treatment	Irrigation	Variety	Pre-emergence (lbs N/A)	Post-emergence (lbs N/A) 26-Jun	13-Jul	24-Jul	4-Aug	Total N (lbs N/A)	Ave N (lbs N/A)
1111	7	100	HR	80	0	15	15	15	125	
1207	7	100	HR	80	15	15	15	15	140	135
1304	7	100	HR	80	15	15	15	15	140	
1110	7	100	RB	160	0	15	0	15	190	
1212	7	100	RB	160	0	15	0	15	190	200
1317	7	100	RB	160	15	15	15	15	220	
1115	8	100	HR	80	0	15	15	15	125	
1201	8	100	HR	80	15	0	15	15	125	120
1308	8	100	HR	80	0	0	15	15	110	
1106	8	100	RB	160	0	0	0	0	160	
1206	8	100	RB	160	0	15	15	15	205	175
1311	8	100	RB	160	0	0	0	0	160	
1107	9	100	HR	80	0	0	0	15	95	
1205	9	100	HR	80	0	0	0	15	95	95
1312	9	100	HR	80	0	0	0	15	95	
2103	9	80	HR	80	0	0	0	15	95	
2201	9	80	HR	80	0	0	0	15	95	100
2308	9	80	HR	80	0	0	15	15	110	
3108	9	60	HR	80	0	0	15	15	110	
3207	9	60	HR	80	0	0	15	15	110	110
3302	9	60	HR	80	0	0	15	15	110	
1102	9	100	RB	160	0	0	0	15	175	
1204	9	100	RB	160	0	0	0	15	175	175
1315	9	100	RB	160	0	0	0	15	175	
2106	9	80	RB	160	0	0	0	15	175	
2202	9	80	RB	160	0	0	0	15	175	175
2307	9	80	RB	160	0	0	0	15	175	
3101	9	60	RB	160	0	0	0	15	175	
3208	9	60	RB	160	0	0	0	15	175	175
3303	9	60	RB	160	0	0	0	15	175	

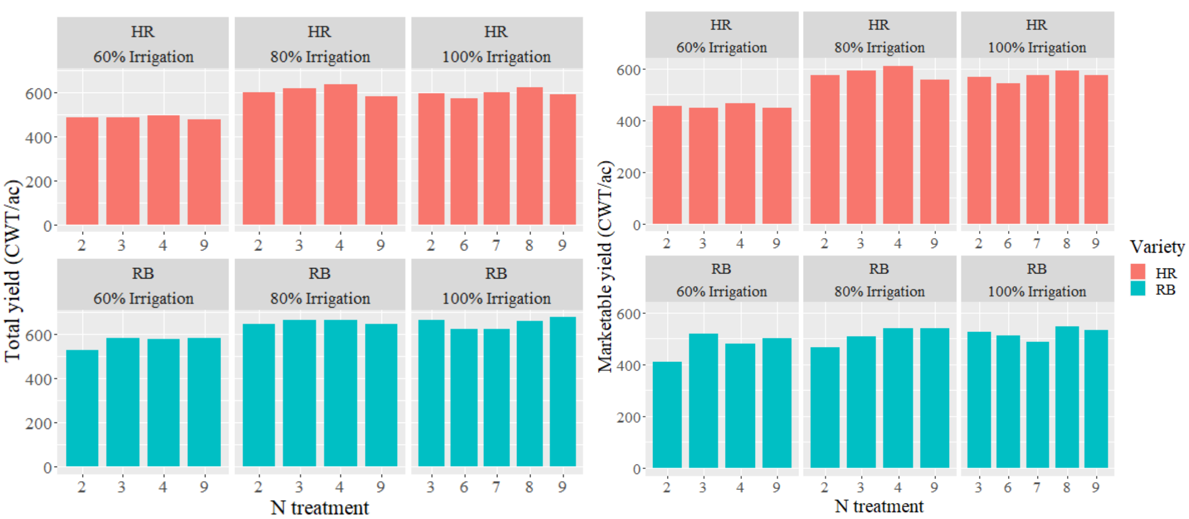


Figure 7. Total and marketable yield of HR and RB in the PNM treatments.

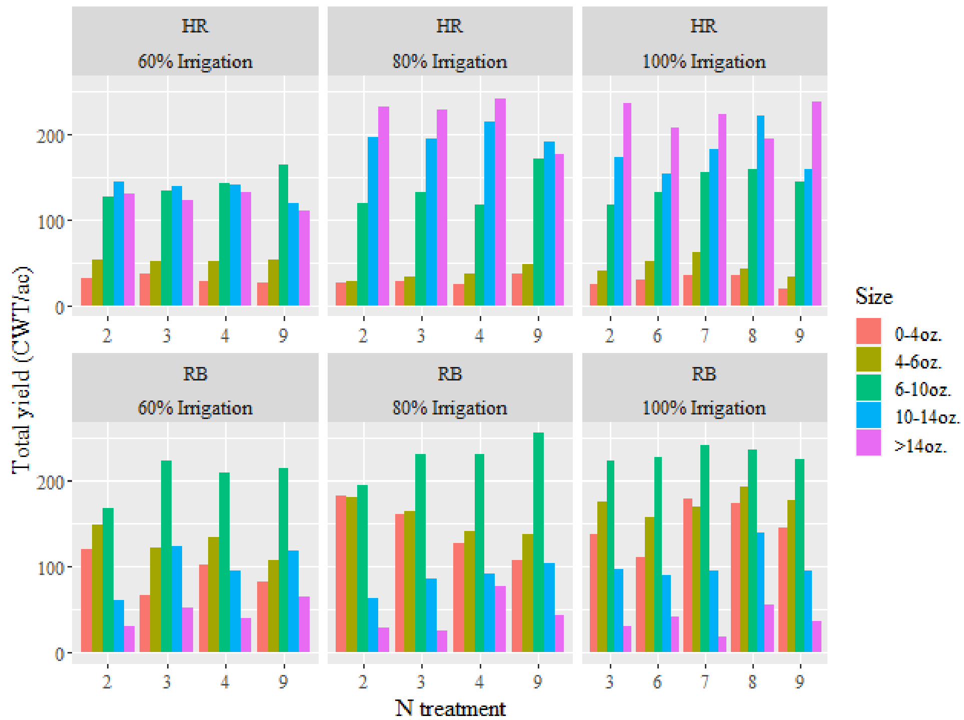


Figure 8. Total yield of HR and RB in the PNM treatments by the five size classes.

N treatments 2 to 4 are 80, 160, 240 lb N/ac; N treatments 6 to 9 are PNM treatments.

Figure 9 shows the partial factor productivity (PFP; total yield over total N rate) and economic return of the optimum N rate treatments and the PNM treatments. The following prices were used for the net return calculation according to Quinn (2023): $8 for a hundredweight of processing potatoes, $0.82/lb N for ESN, and $0.64/lb N for UAN28. The N contribution from the DAP application at planting was not taken into account in net returns calculations. Both PFP and net returns were significantly higher for HR than RB. N treatment 2 (i.e. 80 lb N/ac) for HR had significantly higher PFP than other N treatments,

Figure 9. Partial factor productivity and economic return of HR and RB in the PNM treatments.

N treatments 2 to 4 are 80, 160, 240 lb N/ac; N treatments 6 to 9 are PNM treatments.

whereas no significant difference in PFP was found among the N treatments for RB. The economic returns were significantly higher for the 80% and 100% irrigation treatments. The in-season sensor-based N status prediction models may require calibration incorporating genetic information about HR and the cumulative sum of irrigation and precipitation. HR in treatment 9, Dualex-based NNI prediction using SV regression model, showed lower PFP under the 60% irrigation conditions. Lower critical N concentrations have been reported for potatoes grown under water-limiting conditions (Bélanger et al., 2001). This could have led to over-fertilization and reduced PFP. If so, the reduction of critical N concentration may be more significant for HR than RB.

Water use efficiency and tuber quality parameters

Figure 10 shows the water use efficiency (WUE; total yield over ET) for each variety by N and irrigation treatments. RB had significantly higher WUE than HR. N treatments 3 and 9 had significantly higher WUE for RB, while all N treatments had similar WUE for HR. The 80% and 100% irrigation treatments for RB and the 80% irrigation treatment for HR had the highest and comparable WUE. Table 4 shows tuber quality parameters including specific gravity, tuber dry matter, sucrose, and glucose. Specific gravity and tuber dry matter behaved similarly due to their high correlation. These two quality parameters were significantly higher for Hamin, at N treatments 3, 4 (i.e. 160 or 240 lb N/ac), and 9 (PNM treatment), or at 60% and 80% irrigation. Sucrose concentration was significantly higher for HR or at 60% irrigation. Glucose concentration was significantly higher at N treatments 1 and 2 (i.e. 40 and 80 lb N/ac) or at 100% irrigation.

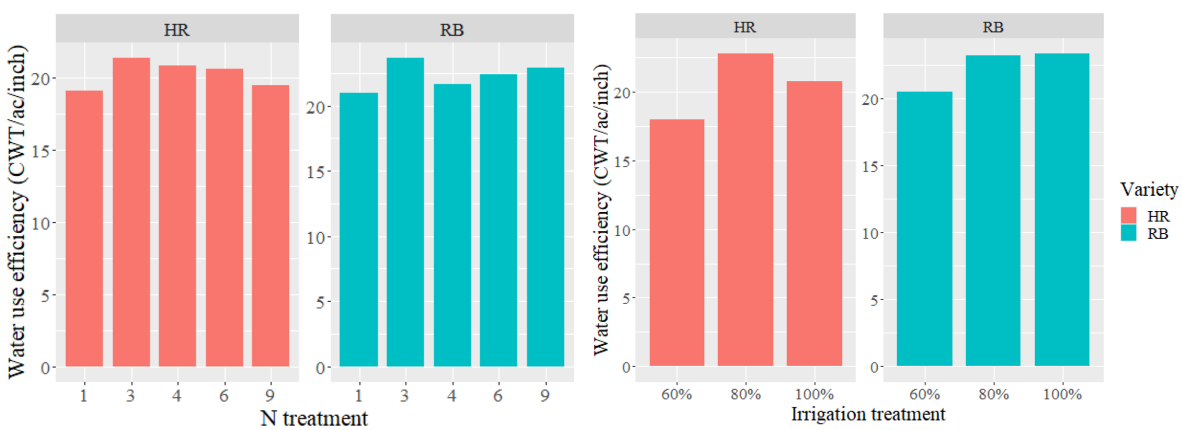


Figure 10. Water use efficiency of HR and RB by N and irrigation treatments

N treatments 1, 3, and 4 are 40, 80, 240 lb N/ac; N treatments 6 and 9 are PMN

Table 4. Tuber quality parameters of HR and RB as affected by N and irrigation. treatments.

Treatments	Specific Gravity		Tuber DM (%)		Sucrose (mg/g)		Glucose (mg/g)	
Nitrogen	RB	HR	RB	HR	RB	HR	RB	HR
40 lb N/ac	2.301	1.073	17.4	18.6	0.581	0.769	1.673	2.301
80 lb N/ac	1.538	1.076	17.9	19.2	0.677	0.853	1.649	1.538
160 lb N/ac	0.974	1.078	19.0	20.7	0.598	0.815	1.263	0.974
240 lb N/ac	0.795	1.079	19.0	21.2	0.594	0.805	1.239	0.795
320 lb N/ac	1.007	1.076	18.7	19.5	0.538	0.689	1.130	1.007
6 (PA)	0.743	1.077	17.5	19.2	0.580	0.732	0.984	0.743
7 (PA)	1.103	1.076	17.9	19.7	0.504	0.879	1.004	1.103
8 (PA)	1.464	1.075	17.6	20.2	0.475	0.887	1.384	1.464
9 (PA)	1.265	1.078	19.0	19.9	0.573	0.802	1.253	1.265
Irrigation								
60%	1.071	1.080	18.9	20.8	0.675	0.902	1.445	0.775
80%	1.071	1.078	18.8	20.6	0.604	0.810	1.207	1.210
100%	1.070	1.075	18.1	19.4	0.543	0.770	1.309	1.377
Significance								
Variety (V)	***		***		***			
Nitrogen (N)	*		***				***	
Irrigation (I)	**		**		***		**	
V x N								
V x I							***	
N x I								
V x N x I								

Proximal sensor data response to N rates and UAV image

Figures 11, 12 and 13 show the relationships between SPAD readings, Dualex NBI readings, or Crop Circle Phenom Normalized Difference Red-Edge Index (NDRE) values and N rates by variety and irrigation treatments. Some of the trendlines picked up similar patterns as the relationships between yields and N rates. Figure 14 shows the canopy and air temperature difference measured using Crop Circle Phenom. Increased canopy temperature was observed in reduced irrigation treatments, probably due to smaller cooling effects caused by reduced ET. Additionally, Figure 15 shows the percent volumetric water content measured using PR2 profile probe. Finally, Figure 16 shows NDRE and canopy temperature data obtained using an UAV image captured on July 13. Analytical approaches including machine learning and crop growth modeling will help put these proximal sensor and UAV-based data to good use.

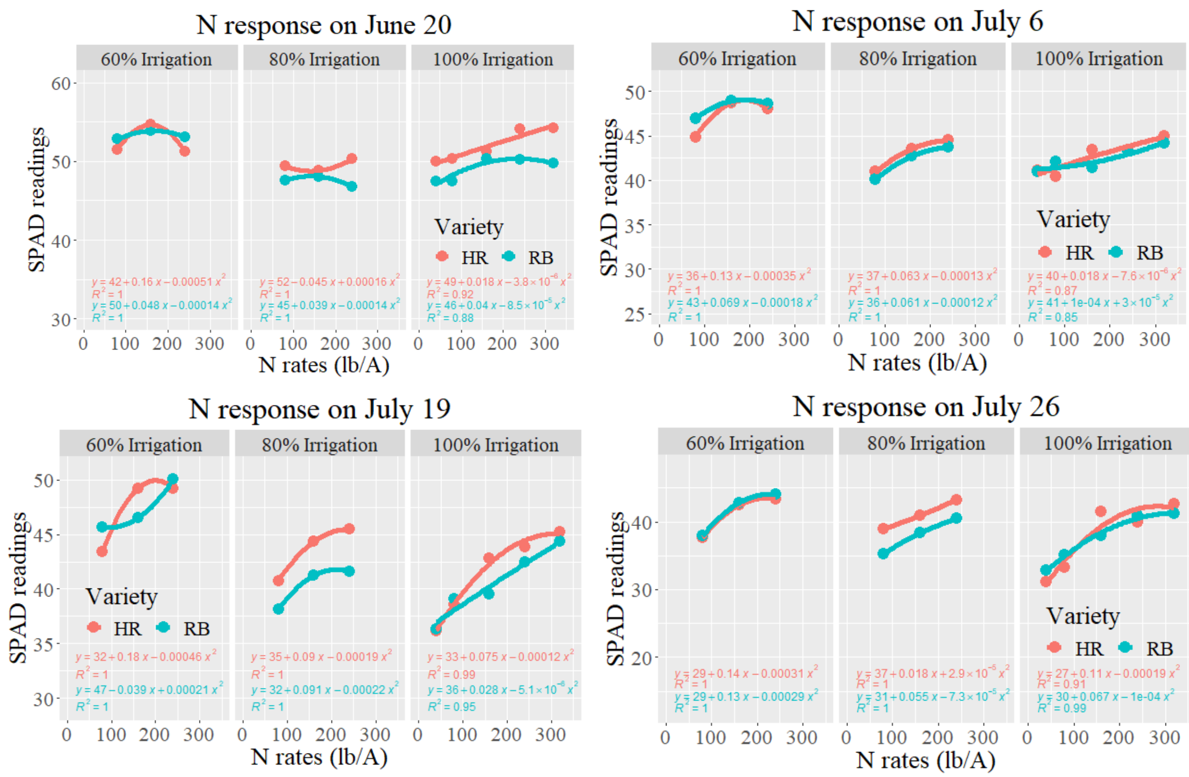


Figure 11. SPAD readings responses to N rates on four dates for HR and RB.

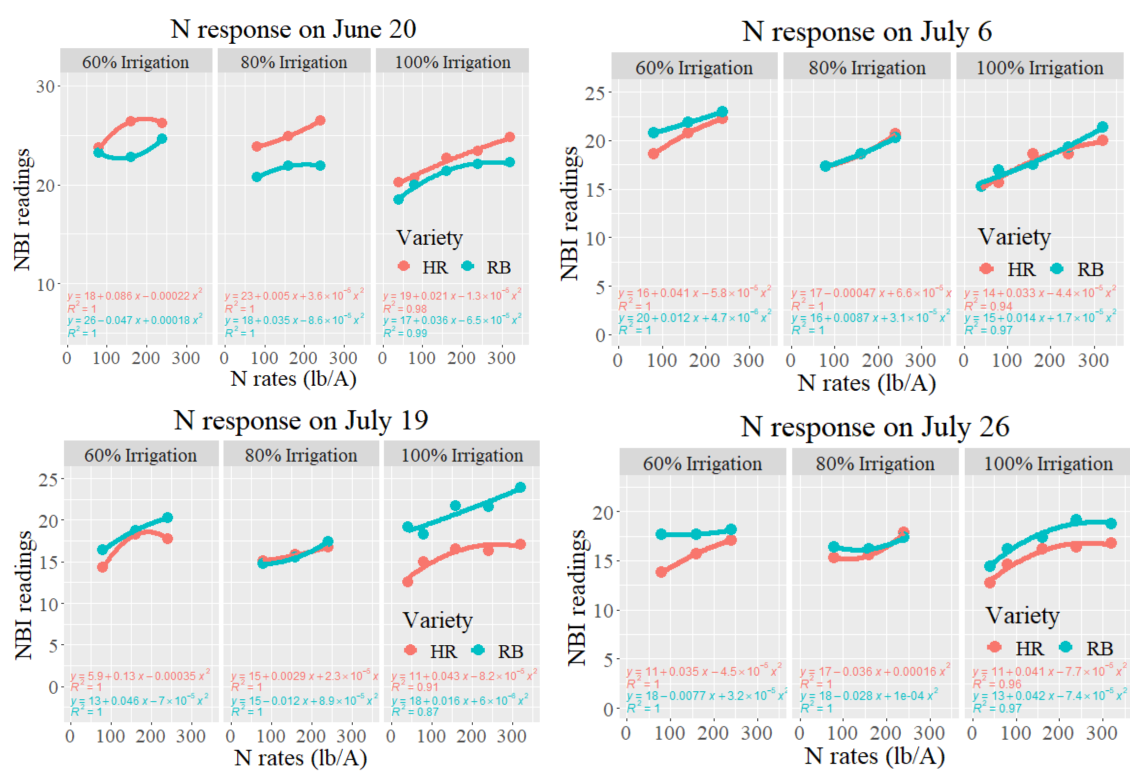


Figure 12. Dualex NBI readings responses to N rates on four dates for HR and RB.

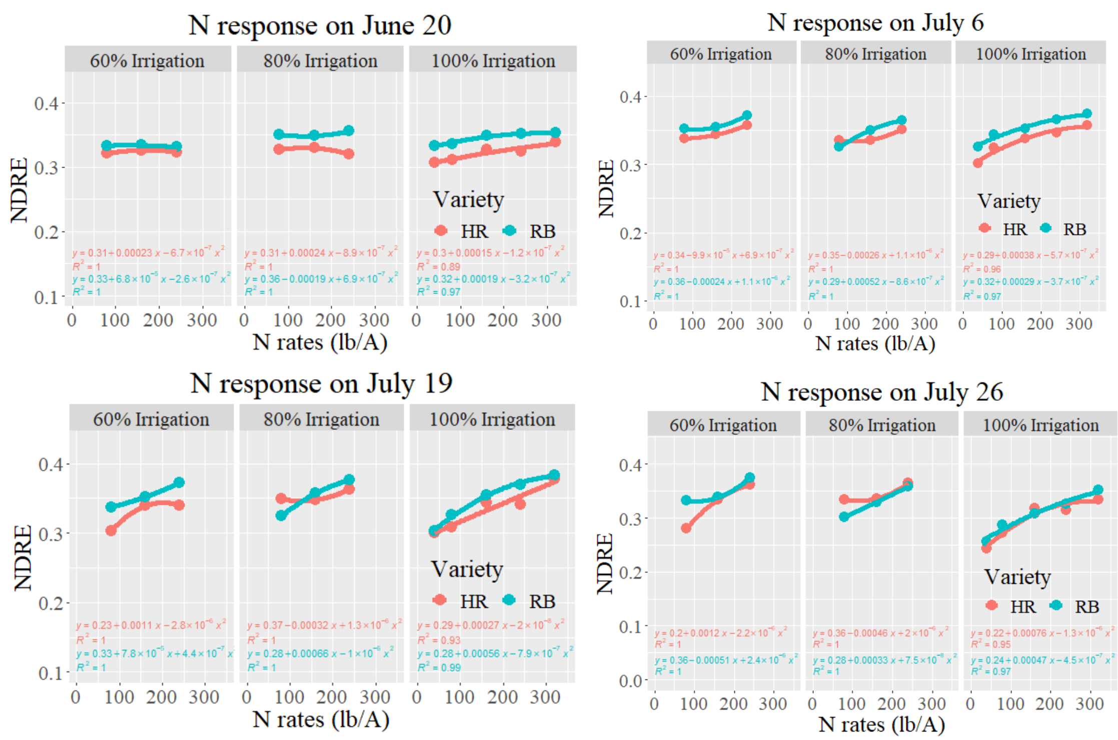


Figure 13. NDRE responses to N rates on four dates for HR and RB.

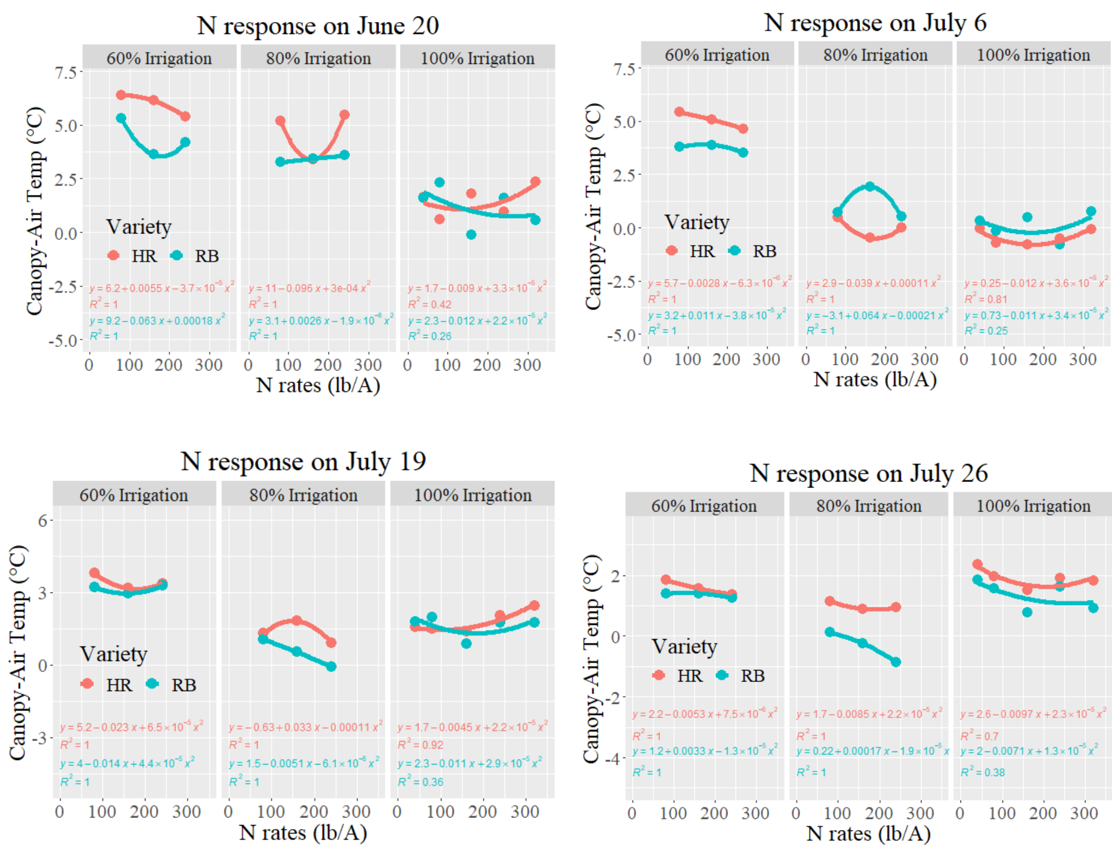


Figure 14. Canopy and air temperature difference for HR and RB.

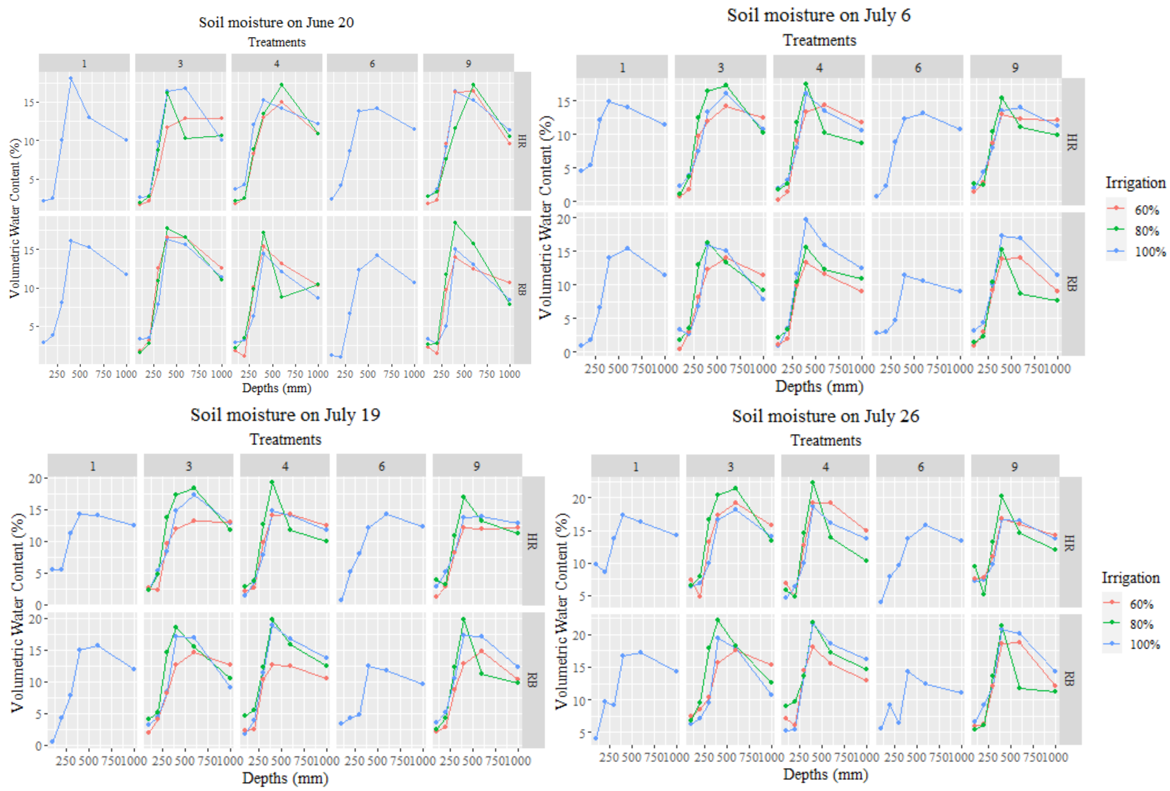


Figure 15. Soil moisture content at different depths for HR and RB.

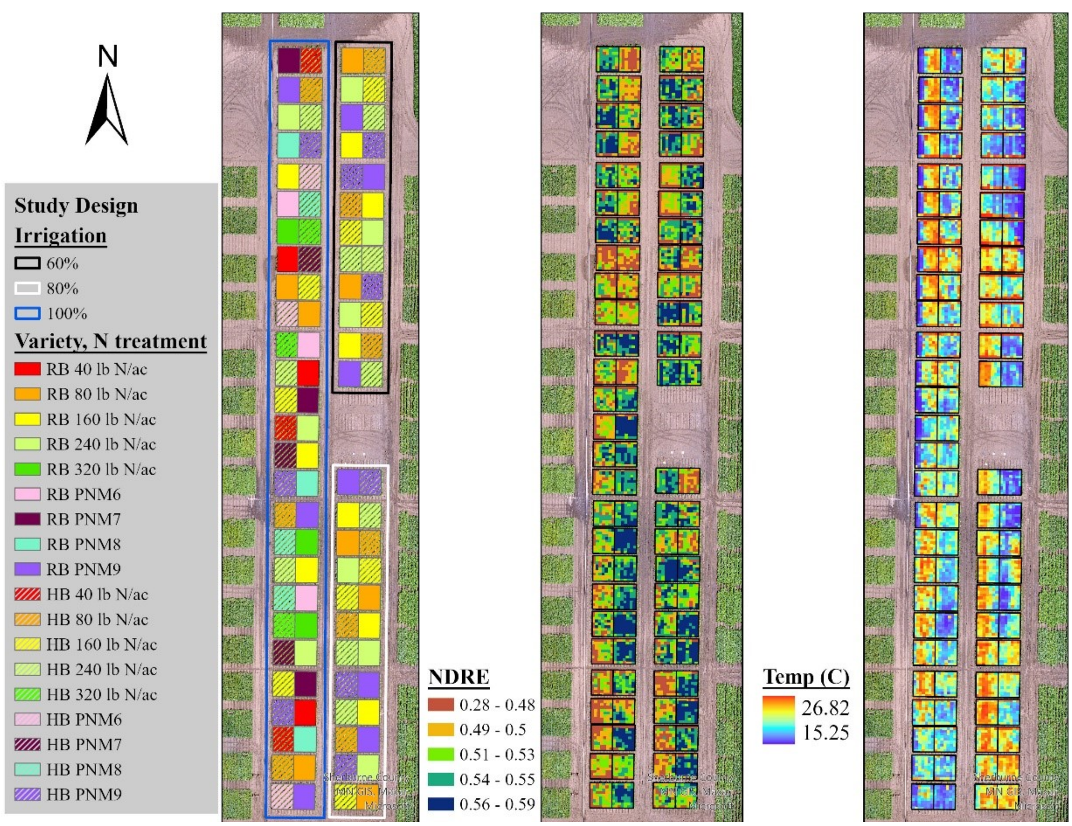


Figure 16. NDRE and canopy temperature data obtained using an UAV image from July 13.

Conclusions

The optimal N rates for HR and RB were 80 lb N/ac and 160 lb under 100% irrigation, respectively. HR demonstrated high N efficiency by producing higher marketable yield with less N fertilizer than RB. This resulted in HR's higher economic return than RB. HR's resistance to water stress and water use efficiency should be further evaluated economically. Nevertheless, the 80% irrigation treatment achieved high tuber yield and quality. The reduced irrigation will not only save irrigation costs but help reduce NO_3 leaching. The effects of different varieties, N, and irrigation treatments on the NO_3 leaching in this study will be evaluated as the data become available. Precision N management treatments achieved high yield with reduced N input resulting in higher N use efficiency and economic returns. Strategies to optimize both N fertilizer and irrigation use efficiency will be developed using proximal/remote sensing data with machine learning and crop growth models as more sample data become available.

Acknowledgements

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Title: Optimizing Potato Seed Tuber Pre-Planting Conditions to Mitigate Seed Decay

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Executive Summary: In recent years, Northland potato growers have faced profound economic losses due to seed decay after planting. To address this challenge, we initiated experiments for optimizing tuber pre-planting practices by determining the ideal conditions for tuber cutting and subsequent suberization of cut seed pieces. Two greenhouse-based experiments were conducted using: 1) seed tubers of Russet Burbank and Bannock Russet grown in crop year 2022 and stored till April-2023 (to obtain preliminary data); 2) seed tubers of Dakota Russet, Russet Burbank, and Bannock Russet grown in crop year 2023 (to execute the awarded project). In experimental procedure, one subset of seed tubers was kept in 38°F (95% RH), while second subset was warmed-up to 50°F (95% RH). Tubers were cut in 2-inch pieces and separated based on containing primary or secondary bud region, and then suberized. Seed pieces were planted in pots after 1, 2, and 4 weeks of suberization and each set was simultaneously planted with non-suberized/fresh cut seed pieces as controls. Results from the first experiment revealed that fresh cut seed pieces directly taken from cold storage (38°F) took 10-15 days longer for emergence when compared to all other subsets (seed pieces from tubers gradually warmed-up from 38°F to 50°F with or without any suberization). The earliest emergence was observed in 2-week suberized seed pieces. Among the cultivars examined better emergence and performance were observed with cv. Russet Burbank. The field-based experiment will be conducted in 2024 crop season and the impact of different durations of suberization of cut seed pieces on seed decay will be investigated. Experimental procedure and data collection for the second experiment has been ongoing and will continue in crop year 2024.

Background: During the 2022 NPGA field day, potato growers and industry stakeholders unanimously identified seed decay after planting as a major production challenge causing significant loss of tuber yield. Having superior seed tuber quality, timely sprouting, uniform crop stand, and higher resilience against biological and abiotic stresses are major contributing factors that dictate higher potato tuber productivity and subsequent profitability. The common potato tuber planting practices adopted in the Red River Valley region include collecting seed tubers from cold storage, cutting them into several pieces (with each piece containing at least one meristem/eye), followed by a fungicide treatment (e.g., CruiserMaxx), and planting them in the field immediately. Under unfavorable environments, such as extreme wet soil conditions, these cut seed pieces become susceptible to physiological as well as biological damages after planting. Therefore, improving seed preparation practices before planting to protect them from decaying or rotting in the field has significant agronomic and economic relevance. One of the best ways to minimize seed decay after planting is by enhancing the formation of the protective suberized layer in the cut surfaces of seed tubers. The protective suberized layer can preserve cut seeds under wet or extremely dry field conditions as well as provide a safeguard against bacterial and fungal infections. However, storage conditions and pre-planting practices significantly affect the curing and suberization of cut seed pieces of potato. Therefore, it is important to optimize pre-planting practices for enhancing the suberization of cut potato seed pieces for mitigating seed decay associated crop losses. The aim of this research is to optimize seed preparation conditions and to develop growers-friendly pre-planting practices for commonly grown cultivars in ND and MN, which can be adopted by potato growers and industry stakeholders under alternative climate scenarios to minimize seed decay associated crop and economic losses.

Procedure: Three agronomically relevant potato cultivars (Russet Burbank, Bannock Russet and Dakota Russet) were used, and two greenhouse-based experiments were carried out for this pre-planting optimization experiment. In the first experiment, seed tubers of cvs. Russet Burbank and Bannock Russet grown in crop year 2022 and stored till April-2023 were used (Table 1). The second experiment is still ongoing using the seed tubers of cvs. Dakota Russet, Russet Burbank, and Bannock Russet grown in crop year 2023 based on the protocol described in Figure 1. In these experiments, seed tubers were warmed up (from 38 to 50°F over 7-day), cut, and suberized; two subsets of cut seeds were incubated (at 50°F, 95% Relative Humidity or RH) to allow suberization for 1 or 2 weeks. After the suberization period, each subset was further divided in three groups. First set were planted immediately, second and third were kept under 38°F for 1 or 2 weeks prior to planting. At each planting time point, whole seed tubers, and freshly cut seed tuber pieces from 38 and 50°F storage were included with suberized seed tuber pieces for comparison. Emergence and growth of the potato plants were monitored. Formation of suberin polyphenolic (SPP) in cut open surface of the seed pieces was also determined using microscopical analysis as an indicator of suberization.

Results and Discussion: Overall, results from the first experiment (Figure 2) revealed that fresh cut seed pieces from 38°F took 10-15 days longer to emerge when compared to all other conditions (i.e., seed pieces from tubers warmed up at 50°F, cut and planted immediately; seed pieces from tubers warmed up at 50°F suberized for 2 weeks). Higher plant height, leaf area, and chlorophyll content of leaves were also observed in plants emerged from 2 weeks suberized cut seed pieces. Formation of suberin polyphenolic in the first cell layer of the cut surface of seed pieces was observed after 1-2 weeks of suberization at 50°F. Overall, cut seed tuber pieces of cv. Russet Burbank took shorter duration to emerge, when compared to seed tuber pieces of Bannock Russet. Results from initial experiment indicated that cut seed tuber pieces form protective barrier within 1-2 weeks at 50°F, which might help to minimize seed decay. Full version of the proposed project is still ongoing using the tubers grown in crop year 2023. We are continuing to collect data from the first part of the experiment where tubers were used only after ~3 months of storage. The experiment will be repeated in the spring, both under the greenhouse and field conditions, using the tubers stored till April-2024.

Table 1. Treatment details of the first experimental design with cvs. Russet Burbank and Bannock Russet.

	Group A-Fresh Cut Seed Pieces		**Group B- Suberized Cut Seed Pieces**		
	Treatment 1	**Treatment 2**	**Treatment 3**	**Treatment 4**	**Treatment 5**
Step 1	Whole seed tubers stored ~8 months in cold storage (38°F) taken for cutting	Whole seed tubers taken from 38°F, and gradually warmed-up to 50°F	Whole seed tubers taken from 38°F and gradually warmed-up to 50°F	Whole seed tubers taken from 38°F and gradually warmed-up to 50°F	Whole seed tubers taken from 38°F and gradually warmed-up to 50°F
Step 2	Tubers cut in 2-inch pieces without warming	Tubers cut in 2-inch pieces after 24 h at 50°F	Tubers cut in 2-inch pieces after 24 h at50°F	Tubers cut in 2-inch pieces after 24 h at 50°F	Tubers cut in 2-inch pieces after 24 h at 50°F
Step 3	Tubers cut in 2-inch pieces without warming	Tuber pieces planted immediately	Tuber pieces suberized for 1 week at 50°F	Tuber pieces suberized for 1 week at 50°F	Tuber pieces suberized for 1 week at 50°F
Step 4			Tuber pieces planted after 1-week suberization	Tuber pieces planted after 2-week suberization	Tuber pieces planted after 4-week suberization

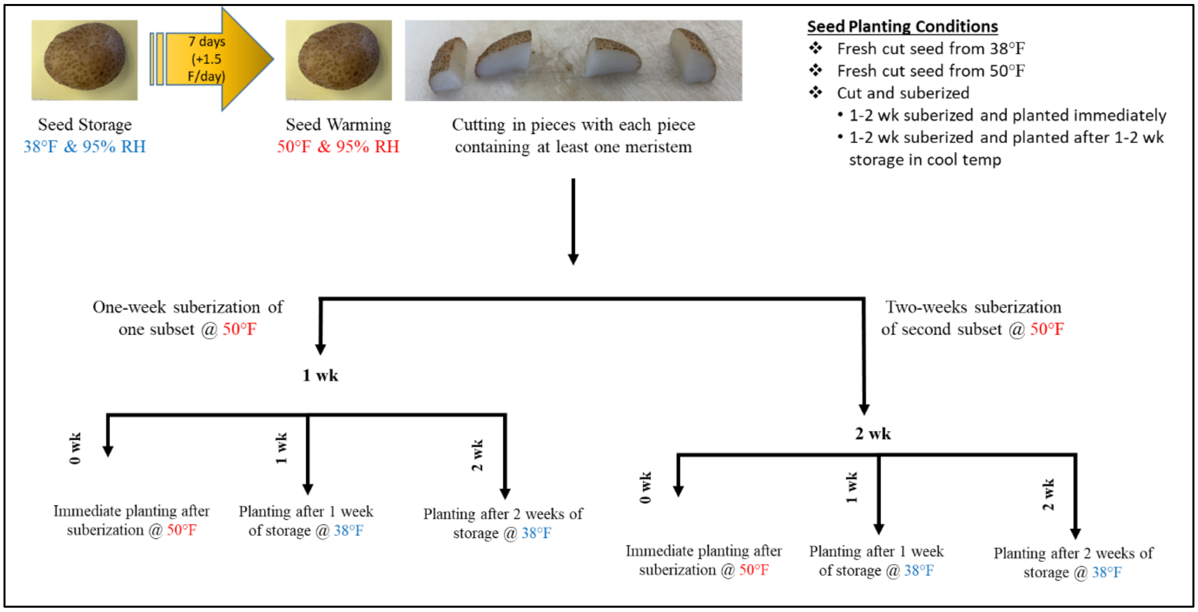

Figure 1. Treatment details of the second experimental design using cvs. Dakota Russet, Russet Burbank, and Bannock Russet.

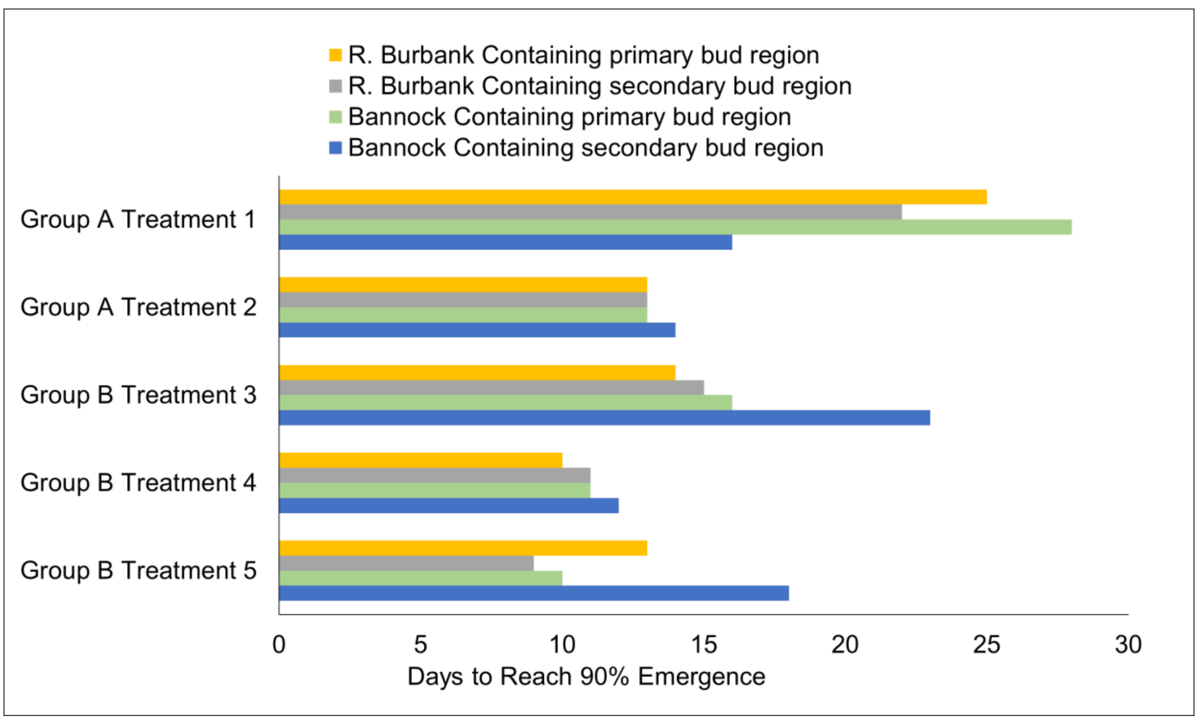

Figure 2. Emergence results from the first experiment [Number of days after planting to reach 90% emergence of fresh cut (Group A) and suberized (Group B) seed tuber pieces containing primary or secondary bud region].

Title: Investigating Wound-Healing Responses of Different Cell Layers of Potato Tubers

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Executive Summary: Wounding-induced postharvest losses of potato tubers (~30-40%) are a costly (≤$320 M/year in the United States) and widespread problem. Other than having optimum storage conditions to support wound healing, no practical postharvest strategies are currently available to address wound-induced losses of potato tubers. Therefore, investigating wound-induced changes in potato tubers and finding a safe and growers-friendly postharvest strategy to enhance wound-healing responses of potato tubers has wider economic benefits. The scientific information regarding differences in wound-healing responses across different potato cultivars, different cell layers of potato tubers, and with and without potential wound-healing treatment strategies has not been investigated extensively. The primary objective of this research was to determine the wound-healing responses/suberization processes in different cell layers of potato tubers of cvs. Russet Burbank and Dakota Russets with natural elicitor treatment. For this experiment, seed tubers grown in 2023 crop season were used. A mechanically wounding model based on cut potato discs from a cylindrical cross-section of potato tubers was used to study the wound-healing or suberization process. Wounded tuber discs were treated with one elicitor treatment (chitosan oligosaccharide + cranberry pomace residue) and compared with control treatment. Improvement in suberization with rapid deposition of protective suberin compounds was observed with natural elicitor treatment. Additionally, faster healing was observed in wounded disc tissues from the outer cell layers (near the skin or periderm) when compared to cells from inner core/cortex. Healing of the wounded tissues was also faster in cv. Russet Burbank when compared to cv. Dakota Russet. We are continuing this research and both mini and large certified seed tubers will be compared for their wound-healing characteristics.

Background: Unintended wounding during harvesting, packing, transportation, and storage and intended wounding of cut potato seeds prior to planting not only just cause direct damage to tubers, but also results in the development of various market quality defects or physiological deteriorations such as loss of texture (exposed wounds), water loss, and susceptibility to microbial spoilage. Rapid wound healing coupled with accelerated suberization of wounded potato tubers during postharvest storage is essential in supporting long-term storability and improving tuber quality. Similarly, rapid wound-healing/suberization can also help cut seed tuber pieces to tolerate biological and abiotic stresses at the pre-planting stage and even after planting in the field. Currently, growers and the potato industry do not have effective, commercially relevant, and safe postharvest treatments to minimize wound-related economic losses. Therefore, elucidating protective physiological and metabolic adjustments associated with wound-healing responses of different cell layers of potato tubers for developing and optimizing postharvest treatment strategies has practical production and market relevance. However, the pace and process of suberization might not be uniform across the different cell layers and sections of tubers and between different cultivars. Specifically, the wound healing response or suberization process might also alter based on the kind and depth of cut/wounding, which is directly related to the cell layers of the potato tubers. Therefore, it is essential to investigate the wound-healing responses or suberization processes independently for each section of the potato tubers.

Procedure: Seed tubers of cvs. Russet Burbank and Dakota Russet grown in 2023 were used for this wound-healing experiment. An established wound-healing study model based on cut potato discs from a cylindrical cross-section of potato tubers were used to study the wound-healing or suberization process. Initially, stored potato tuber (46°F & ~95% relative humidity) were acclimatized (68°F & ~95% relative humidity) for 3 days prior to the wounding treatment. For mechanical wound induction, a cylinder of tissue was excised laterally from each tuber with a vertical cork borer (Figure 1).

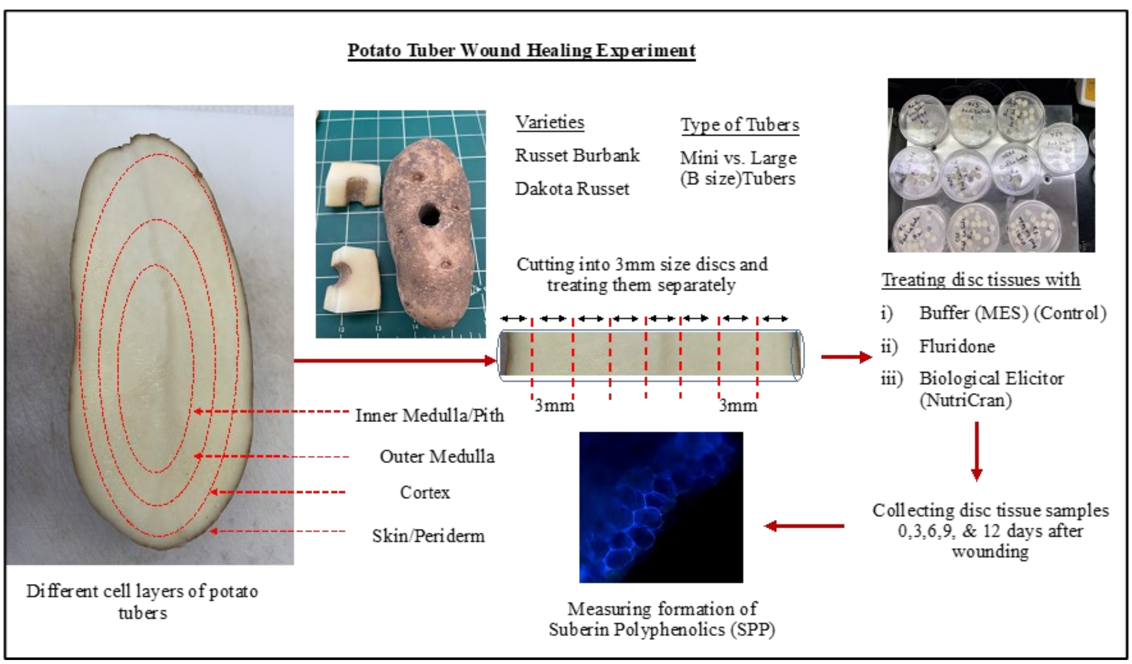


Figure 1. Experimental design to study wound healing of different cell layers of potato tuber tissues.

The cylinder of tissue was divided (in 3 mm) from the periderm to the core of the tuber and discs (11 mm diameter) were collected separately from each layer. The freshly cut and collected discs from each layer were separately treated with buffer solution (control), an abscisic acid biosynthesis inhibitor (fluridone), and a biological elicitor (chitosan oligosaccharide + cranberry pomace residue) to study the wound healing response. The treated discs were kept in a controlled environment chamber (68°F & ~95% relative humidity) for 8 days and disc tissues were collected at 0, 3, 6, and 8 days after wounding for microscopical and biochemical analysis (Figure 1). One subset of disc tissues was collected at each time point for microscopical analysis of formation of protective suberin layer. A second subset of discs were stored at a -80° freezer for biochemical analysis.

Results and Discussion: Overall, natural elicitor treatment (chitosan oligosaccharide + cranberry pomace residue) improved the formation of protective suberin barrier across all cell layers of potato tubers and in both potato cultivars. Cell layers close to the skin/periderm healed faster than the cells from the tuber core. After 3 and 6 d of wounding, faster accumulation of suberin compounds were observed in cv. Russet Burbank and with the elicitor treatment (Figure 2). However, after 9 d, cv. Dakota Russet (Figure 3) also exhibited significant formation of protective layer and suberization rating was closer to the results of the cv. Russet Burbank. This research will be repeated with both mini and large seed tubers and with different wounding models.

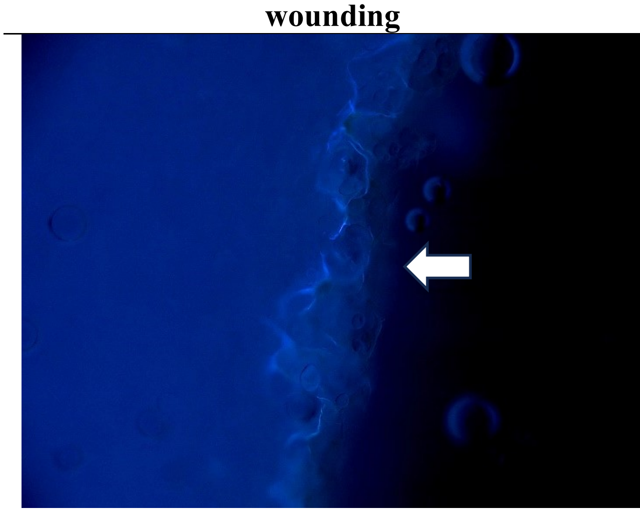
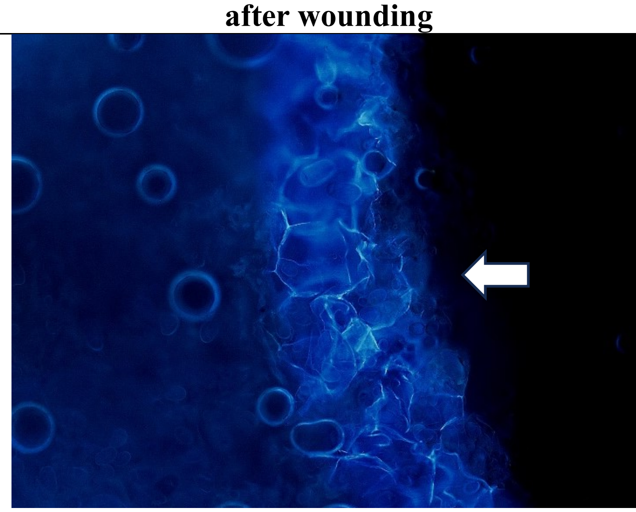
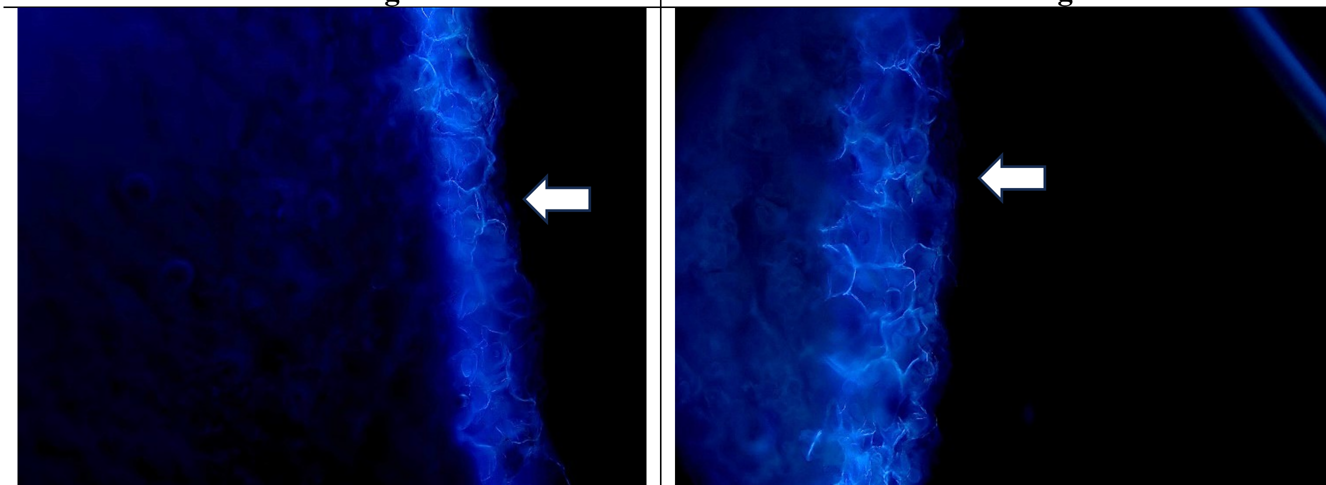
cv. Russet Burbank (Control) 6 d after wounding	**cv. Russet Burbank (Elicitor treatment) 6 d after wounding**
	
Suberization Rating (4.0)	Suberization Rating (6.6)

Figure 2. Formation of protective suberin compounds in outer cell layer of wounded tissues of cv. Russet Burbank with and without (control) elicitor treatment.

cv. Dakota Russet (Control) 9 d after wounding	cv. Dakota Russet (Elicitor treatment) 9 d after wounding



Suberization Rating (4.5)	Suberization Rating (6.0)

Figure 3. Formation of protective suberin compounds in outer cell layer of wounded tissues of cv. Dakota Russet with and without (control) elicitor treatment.