MN Area II Potato Research and Promotion Council

and

Northland Potato Growers Association

2024 Research Reports

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Potato Insect Management 2024

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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) continuing to update the geographic patterns of insecticide resistance in Minnesota and North Dakota Colorado Potato Beetle populations, and 2) 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 management of virus vectors 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 et al 2007, 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 previous year's production field, emerging in spring to enter current production fields. The overwintered adults do minimal feeding while mating and laying eggs and then die. The resulting larvae are significant early season defoliators, feeding voraciously (especially the older stages) as they grow and molt. After 4 larval stages, causing their greatest damage in the last 2, they will eventually drop to the ground, burrow into the soil, 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 and heavy defoliation in a growing season. Behavioral resistance (a genetically controlled behavior that allows the insect to avoid the insecticide) has resulted in a delayed emergence of overwintering adults (Huseth & Groves 2010). This means we see this dual peak population distribution less frequently.

In many years, growers now face adults, larvae and eggs in the same field as late as July. This has resulted in a growing requirement for foliar applied insecticides to manage CPB populations

While the beetles will feed on any variety of potato, many of the varieties produced in MN and ND seem to be well accepted. There is, however, some varietal preference in CPB; several growers have reported a fondness for particular varieties. For example, commercial growers with gardens have commented that 'purples' are the first thing CPB attack. Preference for feeding on varieties is the basis for trap cropping; planting a highly susceptible/preferred variety at the field edge to concentrate populations in an easily treated area.

Since the 1990's, at-plant applications of neonicotinoid insecticides have provided adequate control of CPB populations. 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) (Fig 1). Lower susceptibility to neonicotinoids (the first stage of a population developing resistance) and full resistance to several other insecticide modes of action have 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.

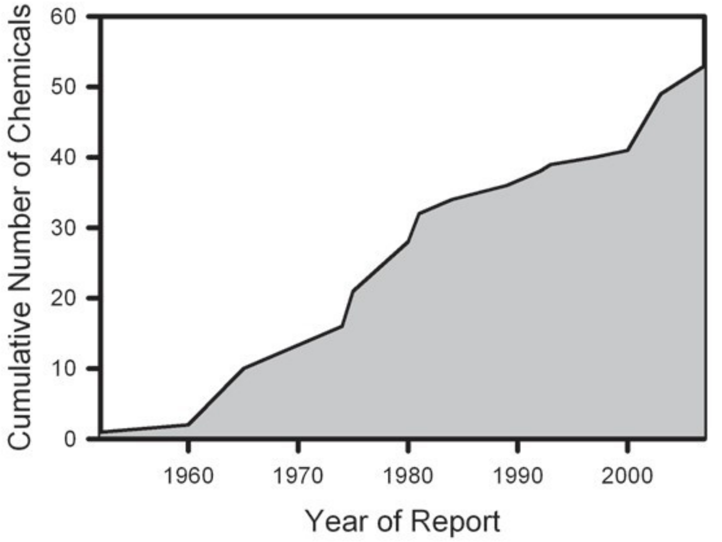

Figure 1. The cumulative number of insecticide active ingredients to which Colorado Potato Beetle has developed resistance, 1950 -2006. (Whalon 2008).

Colorado Potato Beetle is often referred to as a 'SuperPest' because of its ability to develop resistance to insecticides (fig 1). There are several mechanisms whereby insects can have insensitivity 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, or several of the above! While it is rare to find all of these mechanisms in the same population, 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 preadaptive 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.

Data from MN and ND gathered 2017-19 indicated 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. Results from 2023 testing also indicated this pattern seems well-established.

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 compare their susceptibility to insecticides to a susceptible population. We currently maintain such a 'naïve' colony (i.e. the entire colony has historically never exposed to any insecticide and therefore should be susceptible to most, if not all insecticide modes of action) at the UMN-NWROC in Crookston.

North America seed potato production is suffering an epidemic of aphid-vectored virus pathogens 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 and the virus has to undergo 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 aphid mouthparts while they suck sap and are wiped off on the next plant upon which it feeds.

Because it is a non-persistent virus, PVY 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 (they don't differentiate between plant species by sight). Consequently, noncolonizing 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 stop the insect's feeding behavior. The within-field transmission PVY resulting from this 'taste and go' behavior of vectors is obviously exacerbated by the distribution of PVY planted into a field.

There are a number of aphid species that vector virus diseases to seed potatoes, the most efficient is green peach aphid, *Myzus persicae* (Sulzer). Several other species are capable of vectoring the virus, but not as efficiently as green peach aphid. For example, soybean aphids are only 10% as effective in vectoring PVY as is green peach aphid (Davis and Radcliffe 2008) but soybean aphid 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 aphids in PVY transmission 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). 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.

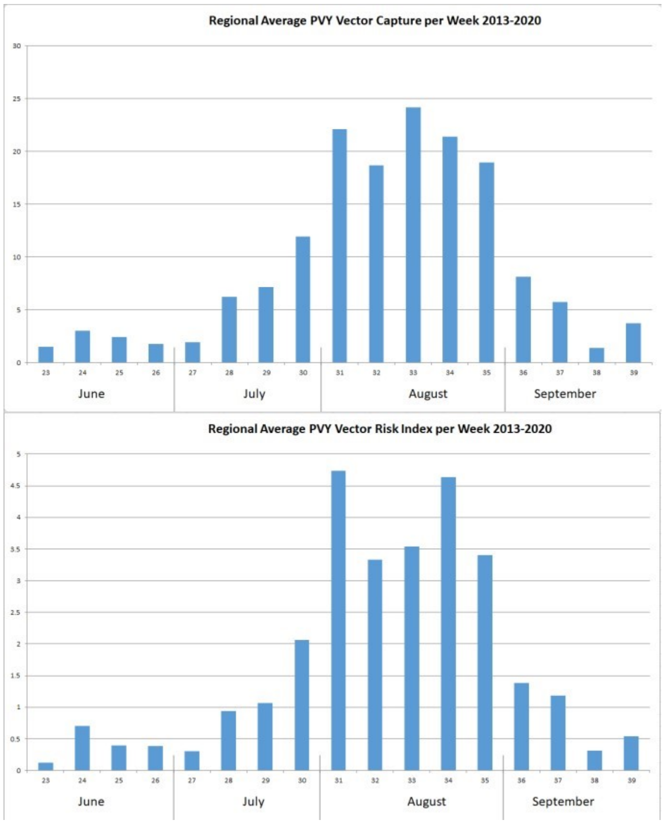

Figure 2. The capture of PVY vectoring aphids in all Aphid Alert traps by week, averaged over 2012 -2020 (top graph). And the Regional PVY Risk Index/Week averaged over 2012 -2020 . The dates were standardized to ISO -8610 week numbers so the data could be compared across years. Note that Vector Risk Index does not precisely mirror the number of Vectors capture, exmeplifying the importance of species efficiency.

Over the past several years, *Aphid Alert* has provided timely information on aphid vector presence and the seasonal patterns of vector population dynamics. It provides an estimate of risk; the amount of exposure to hazard. All of the species of aphids that we monitor have a biological ability to transmit PVY, we use the trap counts to measure the exposure to the hazard to construct the PVY Vector Risk Index.

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 the captured species' relative efficiency at transmitting PVY to estimate the relative risk of PVY transmission at any given date.

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.

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).

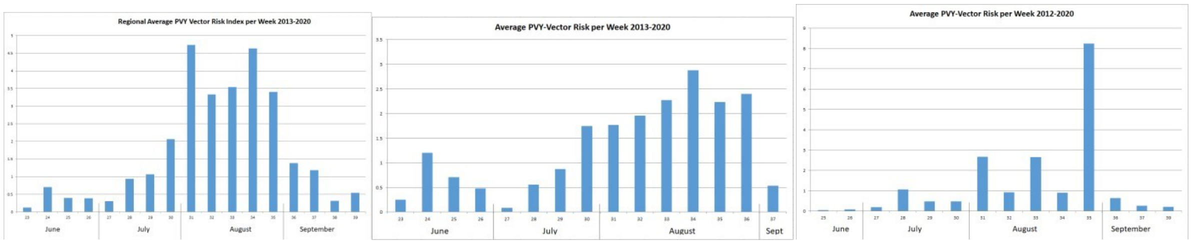

Figure 3. The seasonal PVY Vector Risk Index by week, averaged from 2012 -2020 data, for MN & ND (left), Perham (middle) and Lake of the Woods (right). Note the steady ramping of the Index values at Perham vs the concentration of Index values in August at Lake of the Woods.

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.

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.

In 2024, we:

1) Continued to update the geographic patterns of insecticide resistance in Minnesota and North Dakota Colorado Potato Beetle populations

2) Maintained the Aphid Alert trapping network, monitoring for aphid vectors of virus disease in potatoes (especially PVY) and provide near real-time maps of aphid population distribution in MN and ND throughout the growing season.

Procedures

1) Update the geographic patterns of insecticide resistance in Minnesota and North Dakota Colorado Potato Beetle populations

Colorado Potato Beetle larvae were sampled by UMN personnel from potato production areas within Minnesota and North Dakota. Samples were solicited from locations in the two states (especially from producers experiencing a failure). Approximately 1500 beetles were collected from each location.

Early season larvae were sampled from several locations in NW MN and NE ND. Summer adults were collected from 2 locations in NW MN. Established methods were used to collect and transport adults. Larvae were collected using a beat sheet; a canvas cloth on a wooden frame was held under the plant while the plant was shaken, knocking the insects onto the sheet. From the sheet, larvae were collected with forceps and placed into small plastic tubs partially filled with paper towels as a substrate on which to rest; the paper towel was also meant to insulate and protect larvae during travel.

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 one of only few such colonies in the Northern

Baseline mortality rates were established using the insecticide-susceptible colony (fig 4) maintained at the UMN NWROC in Crookston. Sampled beetles were assessed for susceptibility to registered insecticides. We will produce baseline data for Neonitotinoids (i.e. Admire), Abamectins (i.e. AgriMek), Anthranilic Diamides (i.e. Corragen), Spinosyns (i.e. Delegate), and METIs (i.e. Torac).

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, were used in trials to create a dose curve that indicates the amount of ai necessary to kill 50% of the population (i.e. the Lethal Dose 50% or ‘LD_{50}’). Direct exposure trials were conducted by applying 10µl (microliter) drops of insecticide directly to the insect using a micro-applicator or a micro-pipette. After the insecticide had dried, beetles were placed onto a potato leaf in Petri plates (fig 5) and left to feed for 5-7 days (120h). Beetles were initially assessed for mortality at 24h and then daily to determine any handling mortality and to assess food consumption. Additional leaf material was addecd if beetles had consumed what was present in the plate. As CPB often appear intoxicated immediately after exposure but recover after several days, mortality was again assessed 5-7 days post application (min. of 120h). Mortality was assessed by placing beetles on their backs and evaluating movement. Any insect not righting itself within 5 minutes was assessed as dead or moribund (basically unrecoverable).

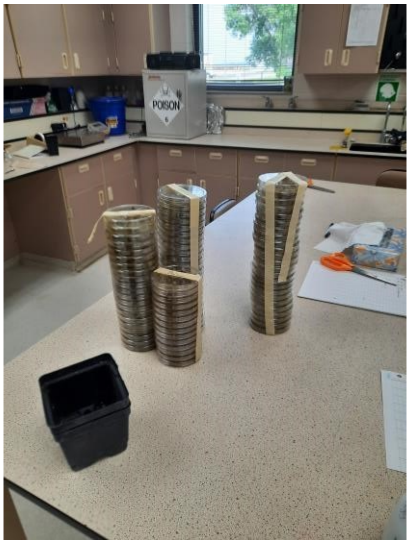

Figure 5. Petrie plates containing CPB adults for resistance testing.

2) Maintained the Aphid Alert trapping network, monitoring for aphid vectors of virus disease in potatoes (especially PVY) and provide near real-time maps of aphid population distribution in MN and ND throughout the growing season.

A network of ~20 3m-tall suction traps (fig 6) is 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, set in a large PVC pipe that, in turn, is fitted inside with a steel mesh funnel ending in a capture jar. The fan draws air down through the tube capturing nearby flying aphids (and other insects), concentrating them through the funnel and into the capture 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 then sent 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 were determined. Trap collections began in June and were maintained until the seed field hosting the trap was vine-killed/harvested. At that point a field was no longer attractive to aphids.

Figure 6. An *Aphid Alert* 3m suction trap and the weekly capture of 'bug stew' (inset).

Maps were generated weekly showing these dynamics. We used multiple digital communications techniques to disseminate this information. It was made available to growers on a website (aphidalert.blogspot.com), by X (formerly Twitter) posting (https://twitter.com/mnspudbug), via the 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.

The PVY Vector Risk Index was included into maps and all weekly reporting. 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 and Discussion

Colorado Potato Beetle populations in 2024 were highly variable at different locations. While some locations had moderate to high populations, others had very low feeding pressure from beetles. Collection sites for beetles from incoming information were not common and collections were only attempted at several locations, all in the upper Red River Valley (RRV) (several locations in Central MN being sampled in 2023). Most locations were sampled early in the season for larvae and had low populations.

Collection and transportation techniques used for larvae resulted in significant mortality, probably due mostly to handling. The collecting and testing techniques involved manipulating larvae: from leaves or the canvas sheet into plastic tubs used for collection in the field, then in the lab from the field collecting tubs into larger storage containers, which were placed into a refrigerator for storage until testing, then into the trial Petrie plates, and finally, while in the plates, onto their backs so insecticide could be placed on the ventral side of their abdomens. All handling of larvae was done using 'live' entomology forceps. These are thin, flexible stainless-steel forceps designed to hold insects without imparting sufficient crush pressure (fig 7). Unfortunately, CPB larvae are very soft and while the forceps generally do not impart significant mortality, the amount of handling (and potentially lower temperature of the refrigerator) may have caused the observed high mortality. The high rates of mortality made it difficult to find significant differences in treated and untreated control samples of larvae collected from fields, or any differences in rate of applied insecticide (basically close to 100% mortality, regardless of what had been applied). Consequently, it was not possible to determine the levels of insecticide tolerance from early season, field-collected CPB.

Figure 7. 'Live' entomology forceps.

Adult CPB tested in the central Red River Valley of Minnesota and North Dakota were relatively unchanged from 2023 with one exception, The NWROC site in Crookston, MN showed a significant decrease in efficacy of the Anthranilic Diamide tested (Coragen, ai = Chloratraniliprole) had a significant decrease in efficacy since the previous year (Table 1). The rates seen at the second location, a large multi-user garden site 10 miles to the SE, were similar to those found at Crookston. Crookston results are presented as the other location was sampled because it was a location with high feeding pressure.

Crookston, like most of the potato growing areas in NE ND and NW MN, has established resistance to the neonicotinoid insecticides Admire, ai=imidacloprid group=4, was tested). While this indicates Neonicotinoids will likely not suppress CPB populations on their own and foliar applications of alternate insecticides will be

Table 1. Relative rates of efficacy for major insecticide modes of action against Colorado Potato Beetle at Crookston, MN 2023 and 2024.

Location	**Insecticide Name / Active Ingredient / Mode of Action # / Class**				
	Admire / Imidacloprid	**AgriMek / Abamectin 6**	**Blackhawk or Delegate /**	**Coragen / Chlorantranilip**	**Torac / Tolfenpyrad 20-**
	4A Avermectin Spinosad 5 role 28 21 Neonicotinoid Spinosyns Diamides METI				
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%*
UMN	LD_{50}=	LD_{50}=	LD_{50}=		LD_{50}= 0.06X

	🟥	🟦	🟩	🟨	🟩
NWROC 2023	🟥 2.71X	🟦 0.13X	🟩 0.05X	1X= 38.7% 1X= 87.8%	🟩 1X= 91.8% 1X= 87.1%
(Crookston, MN) **UMN NWROC 2024** **(Crookston, MN)**	🟥 LD$_{50}$= 2.80X 1X label rate = 39.02% mort	🟦 LD$_{50}$= .0031X 1X label rate = 87.90% mort	🟩 LD$_{50}$= 0.0004X 1X label rate = 97.63% mort	🟨 LD$_{50}$= * 1X label rate = 61.43% mort *=not available	🟩 LD$_{50}$= 0.039X 1X label rate = 82.928% mort

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 expected percent of the insect population killed by 1X the high label rate of the insecticide based on the bioassay. The higher this number, the less resistance to this insecticide in the tested insect population.

WELL ESTABLISHED RESISTANCE **LIKELY DEVELOPING RESISTANCE**

POTENTIAL DEVELOPING RESISTANCE **NO EVIDENCE OF RESISTANCE**

necessary. This is not to say that neonicotinoids won't suppress aphids, leafhoppers and other potential susceptible insects.

The diamide tested (Coragen, ai=Chlorantraniliprole group=28) had significantly less efficacy against field tested CPB (the 1x label rate provided ~61% mortality) than it did against the naïve lab population (the 1x label rate provided ~89% mortality). While not tested in 2023, the difference in mortality between the lab population and the field population is indicative of likely developing resistance. If this is a mode of action resistance, as is most resistance based on metabolic detoxification, this could be an important loss given the current reliance on diamides as an, up to now, effective foliar against CPB.

The Abamectin tested (AgriMek, ai=abamectin, group=6) performed much as it did in 2023, providing good control of CPB in these plots. It appears the central RRV has not yet developed the level of tolerance seen in CPB populations present in Central MN.
Having said that, the levels of abamectin's efficacy against the Crookston population (a 1x label rate provided ~87% mortality) are not those seen against the lab naïve colony (a 1x label rate application provided ~98% mortality). Consequently, there may be potential resistance developing in RRV CPB populations. This is not completely unexpected. Abamectin has become a go-to first round product due to its widespread and economic availability. When using abamectin products in the RRV, growers should be aware of potential rate creep (an increase in the amount of product necessary to achieve previous levels of control) as it is an early indicator of the onset of resistance. The addition of PBO in 2020 trials (MacRae 2020) did not see a significant increase in efficacy of abamectin at the Crookston site. It may be, however, that there was little tolerance to abamectin at that time, so the addition of PBO may not have made a significant difference. It should be noted, however, that the addition of PBO to abamectin does increase it's efficacy against populations of CPB in central MN and is a regular addition to those applications.

In better news, both the tested spinosyns (Delegate, ai=spinetoram group=5) and the METI (Torac, ai=Tolfenpyrad group=21A) remain very effective and are delivering similar levels of mortality as seen against the naïve lab population. The tested RRV population of CPB showed no signs of developing resistance to either mode of action.

APHID ALERT – Regional average aphid vector trap captures in 2024 were very similar to the 2012-2023 average (fig 8). The weekly population captures were similar, as were the weekly PVY Vector Index values. The seasonal species composition across the region in 2024 varied considerably from that of the 2013-2023 average. There were considerably more soybean aphids than average and, surprisingly, fewer small grain aphids. It should be noted that there were two additional species included in the 2024 graph than in the 2013-2023 average graph; these two species were not sampled early in that period and so were not included in those data. The 2013-2023 graph is interesting in that it indicates that the majority of the most numerous aphid vector species recovered in the traps are non-colonizing species. This underscores the importance of these species in vectoring PVY and the difficulty in estimating the risk of PVY transmission based on field scouting, where such species are rarely encountered. Future reports will include calculations of the regional and annual PVY Vector Risk Index values contributed by each species captured.

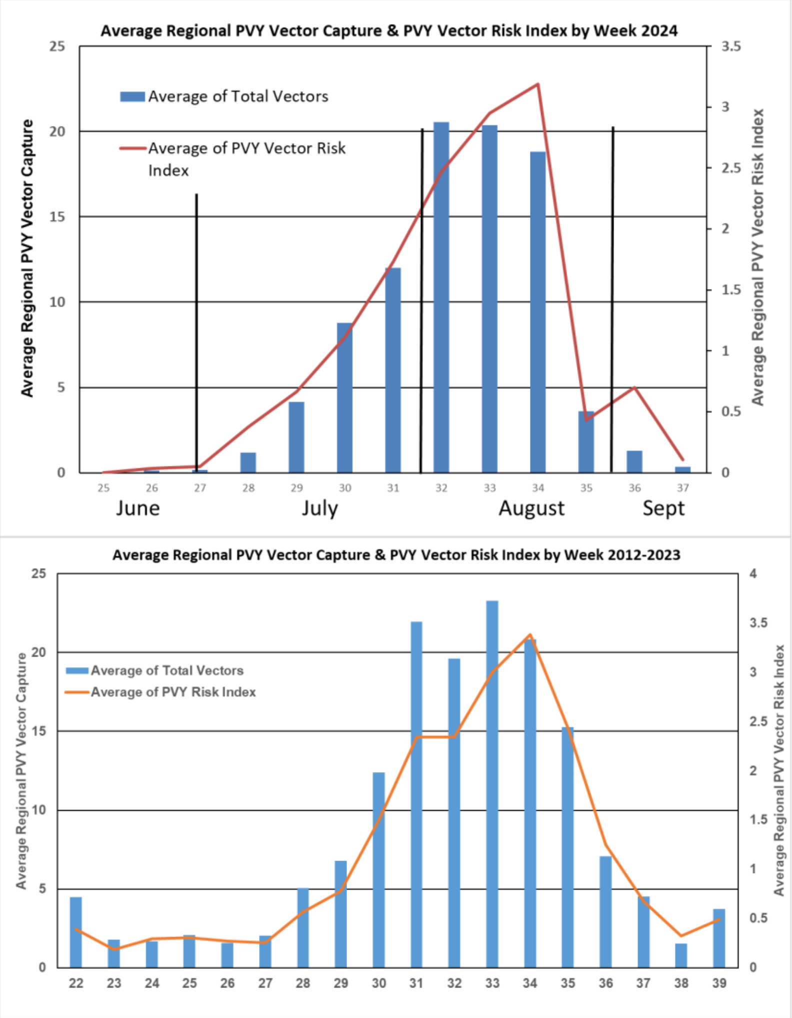

Figure 8. Average regional PVY vector captures and PVY vector risk index by week in 2024 (top graph) and the average regional vector risk index by week averaged from 2013 -2023 (bottom graph).

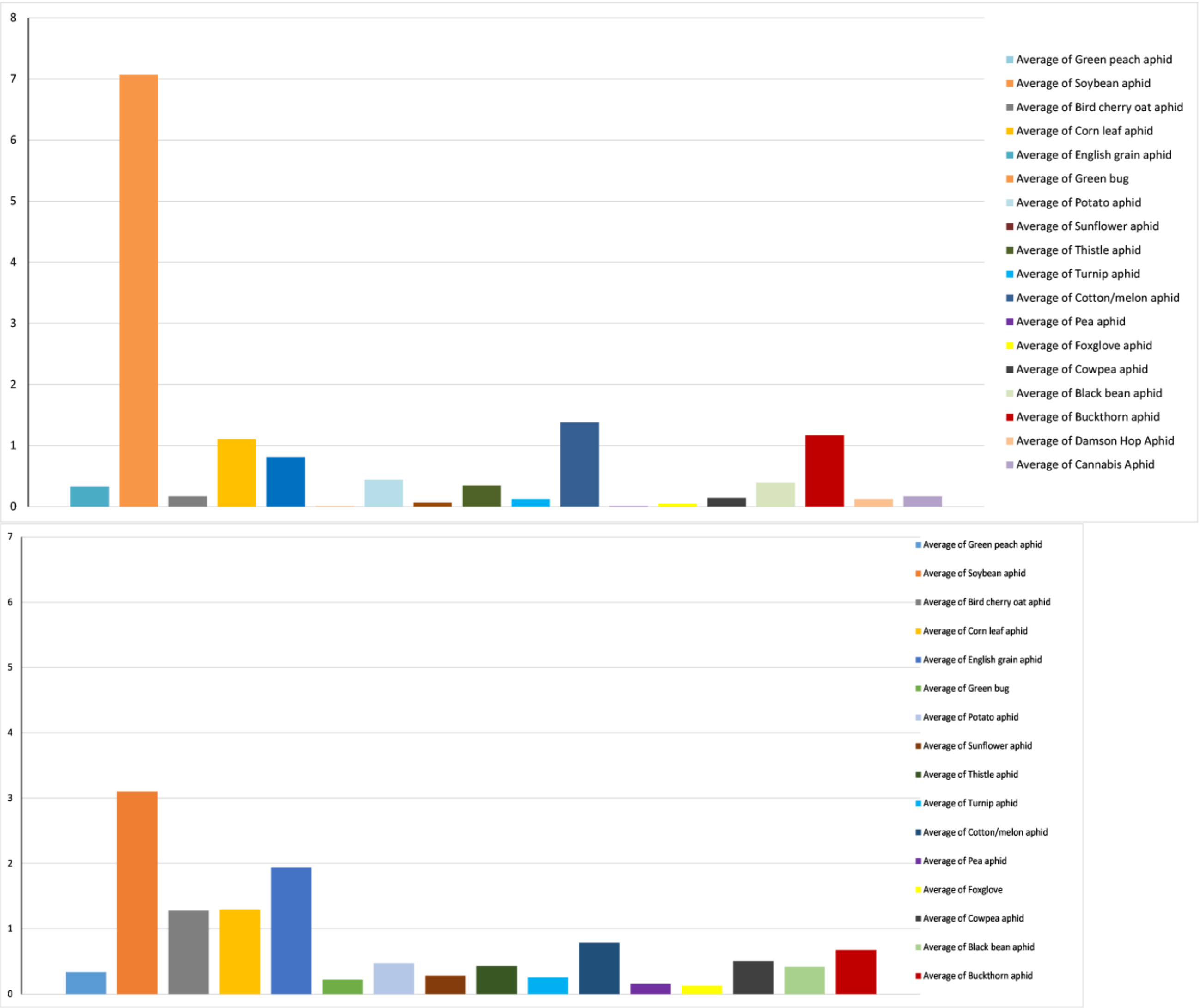

Figure 9. Average seasonal capture per trap of individual vector species in 2024 (top graph) and the seasonal capture per trap averaged across 2013 - 2023 (bottom graph).

While the regional

averages were close to the 2013 - 2023 average, this was not true for individual trap locations. Some had relatively light years, others had heavier vector pressure (fig 10). Vector pressure was higher in the RRV in 2024 than in central MN or central ND.

Individual reports are being prepared for individual trap locations and will be distributed.

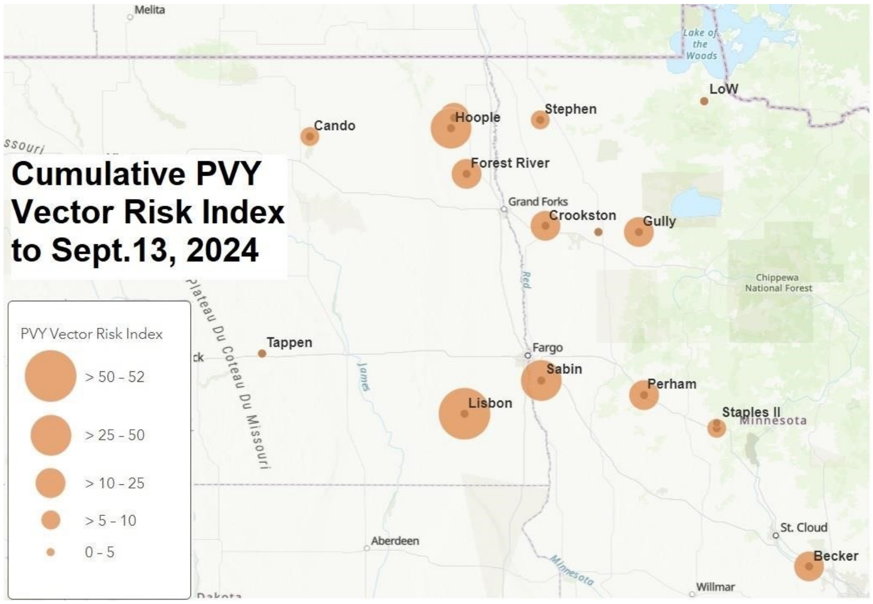

Figure 10 . Map of trap locations in North Dakota and Minnesota. The size of the shaded circle around the location point indicates the level of PVY Vector Risk Index. (aphidalert.blogspot.com)

The wide distribution of the data generated by Aphid Alert has resulted in widespread recognition of the project. At a recent meeting in Manitoba it was evident the network was well-known. Since 2012, the website (aphidalert.blogspot.com) has received ~83K visits, mostly from the U.S. but also Canada, Europe, Israel and the Middle East, Asia and South America. The data presented is apparently useful in the field as most of the audience is connecting through mobile Chrome and mobile Safari.

Although the population of vectors and vector pressure was close to a multi-year average, there were several locations where aphid populations rose to become a problem in commercial production in 2024. Several fields in Central MN had significant damage from quickly growing aphid populations late in the season. The aphids were identified as Green Peach Aphid and growers reported their establishment and population increase was rapid. This resulted was high numbers of ‘aphid holes’ in some fields (fig 11). After colonizing aphid species land in on plants, they begin to feed and then deposit a wingless daughter and then fly to a new plant. The daughters begin feeding immediately and, depending on the species and ambient temperature, can become adults and begin depositing their own daughters in as short as several days. As the population of aphids rises, they expand to neighboring plants causing roughly circular patterns as they feed on and kill host plants. Because aphids are quick to mature, are parthenogenic and lay live offspring, aphid populations tend to grow rapidly in the absence of any natural enemies or disease to limit their growth. If the population

Figure 11. Drone imagery of ‘aphid holes’ in fields. (Photo courtesy of Andrew Robinson, 2024)

reaches a point where they are crowded, they will develop another winged generation which disperses, looking for new host plants.

When first arriving in a field, aphids tend to first colonize the fields outer edge, especially along any open headland (Carroll et al. 2004, 2009). However, later in the season, aphids may fly into fields and colonize inner areas. Fast onset insecticides targeting aphids can often control populations early. Should the populations reach very large numbers, the resulting reproductive potential can potentially outpace insecticide applications. When faced with high populations and temperatures preferential for aphid population growth (generally high 60’s F to mid-80s F) selecting an insecticide specific to aphid control is a good option.

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Proposal Title: Developing Dakota Russet Irrigation and Disease Management Guidelines

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Collaborators: Jasper Tao, Graduate Student, Department of Plant Pathology, University of Minnesota, Twin Cities

Executive Summary: This project integrated soil moisture monitoring with yield and disease evaluations to assess how different irrigation regimes affect Dakota Russet water budgets, yields, and soilborne diseases. A 2024 field study at the Sand Plains Research Farm in Becker, MN tested three irrigation treatments (I1: 100%, I2: 80%, I3: 60% of conventional rates) using variable rate irrigation. Prevalence of cosmetic soilborne diseases (common scab, black dot, silver scurf, soft rots) and abiotic disorders (hollow heart and greening) were recorded from a subplot while yield was assessed through mechanical harvesting and sorting. Disease incidence evaluations revealed common scab was the most prevalent disease, particularly under low irrigation conditions, while other diseases were noted but had minimal occurrence. Hollow heart, an abiotic disorder, occurred the most under I1 and the least under I3. Irrigation treatments influenced tuber weights, with higher irrigation rates increasing healthy tuber weights and reducing diseased tuber weights. Yield analysis by size showed treatment I1 produced the most tubers below 4 oz, whereas treatments I2 and I3 had higher yields of preferred marketable tubers, with I2 slightly outperforming I3. The season's above-average rainfall (21.66 inches) likely impacted results by reducing deficit water stress. Future research under typical weather conditions is needed to validate these findings and refine irrigation strategies.

Rationale: Water is an essential component of crop growth. Water levels below crop needs may negatively impact yields and induce tuber malformations, while water logging may cause several disease problems and leach fertilizer and other applied chemicals out of the rooting zone. In most cases, high soil moisture and humidity favors disease development. Irrigation results in a reduced canopy temperature while increasing relative humidity, soil moisture, and the period of leaf wetness. Potatoes are grown on about 43,000 acres in Minnesota, most of which are irrigated. Irrigation has increased in the past few years in the context of a shifting climate. Climate projections indicate increased frequencies of heat waves and decreased summer rainfall in much of the state, flanked by wetter spring seasons and sporadic, intensive rainfall events (ccr.nelson.wisc.edu). While irrigation can buffer crop stress, irrigated systems are at an increased risk for diseases caused by some soilborne pathogens. This project aims to provide information on Dakota Russett yields and disease under irrigation.

Soilborne diseases limit potato production. Excessive soil moisture at critical points can drive foliar, stem, vine, or tuber infections and promote pathogen development, reproduction, dispersal, and survival of soilborne fungi. Soilborne fungal pathogens may also have a synergistic relationship with the soft-rot bacteria, *Pectobaterium carotovorum*. Additionally, water stressed plants in under-irrigated systems may be susceptible to disease and yields can be reduced (Boguszewska-Mankowska et al. 2022). More work is needed to understand the impact of irrigation on tuber diseases in Dakota Russett, a regional variety of interest. In this project,

soil water monitoring paired with yield and disease assessments will allow us to inform irrigated production of Dakota Russett.

Procedures:

Study site and field plan: Field experiments were conducted at the Sand Plain Research Farm (SPRF) in Becker MN. The SPRF research site has an advanced hydraulic and variable rate irrigation sprinkler system. The applied irrigation treatments were: I1) 100% of full irrigation, I2) 80% of full irrigation, and I3) 60% of full irrigation to simulate a water-stressed crop or drought conditions. The Dakota Russet variety was grown in plots that were 20 ft long and 10 ft wide, with buffer rows between the plots to allow for irrigation application without any overlap. Treatments were organized in a randomized complete block design and each treatment was replicated four times. Irrigation treatments were implemented 3 weeks after planting to allow the crop to establish.

Irrigation and Soil Moisture Monitoring: The water balance method was used to investigate the impact of irrigation rate on crop stress and water use. Yield measurements were taken at the end of the season and crop water use efficiency (CWUE) was calculated for each treatment.

Disease Incidence: To assess the impact of varied irrigation on disease development, incidence of cosmetic diseases of potatoes (common scab, silver scurf, and black scurf) and tuber rots were taken from 10’ subplots at harvest (September 19). Samples of diseased potatoes were collected for downstream diagnostics to confirm their causal agents. Diseased tubers and healthy tubers were weighed to evaluate the contribution of disease to yield losses with different irrigation rates.

Yield, Grading, and Quality assessments: Tubers were mechanically harvested on September

20, 2024 and were sorted into size classes based on their weight in ounces. The total weight of Grade A and Grade B tubers were recorded for each plot. Misshapen and overly small potatoes were weighed as “cull potatoes” from 10’ subplots at harvest to understand the impact of water and water stress on potato marketability. The number of potatoes with abiotic disorders that would prevent marketability (greening and hollow heart) were recorded. A subset of 25 potatoes per plot were dissected to scout for hollow heart. A separate subsample of 10 tubers per plot was collected to determine tuber sucrose and glucose concentrations and French fry reflectance at harvest

Data Analysis: Data analysis was conducted using R Studio software. Multiple models were tested for each parameter based on the distribution of data. The Akaike information criterion

(AIC) was calculated for each model and the model with the lowest AIC was selected as the best fit.

Results and Discussion: The 2024 field study investigated the effect of irrigation management on soil borne disease incidence, tuber quality, and marketable yields in Dakota Russet potato production, though heavy rains likely influenced treatment effects. Common scab was shown to be the most prevalent soilborne disease among all treatments, with its mean incidence highest under the lowest irrigation treatment (60%), though the incidence of common scab was not significantly different between irrigation treatments (Negative Binomial regression model, p = 0.54). Hollow heart, an abiotic disorder often associated with fluctuating water availability, varied marginally by irrigation treatment (Poisson regression model, p = 0.05). Hollow heart was observed most under I1 and the least in I3, supporting a potential relationship between overwatering and incidence of hollow heart. In Dakota Russet, hollow heart can make tubers unsuitable for processing. Other diseases and abiotic disorders, including black dot, silver scurf, soft rots, and greening, were recorded but occurred at lower incidence. Irrigation treatments did not have a significant effect on the overall weight of diseased tubers per treatment, as determined by sampling (Figure 3; ANOVA, p = 0.87). Future studies would benefit from infestation of a specific pathogen of interest in order to better understand its relationship with irrigation and water stress with uniform and intensive disease pressure.

Irrigation rates did not significantly affect healthy tuber weights (Figure 1; Gaussian distribution, linear mixed model, p = 0.72), total marketable yields (Table 1; ANOVA, p = 0.83), or tuber quality (Table 2). Considering trends, treatment I1 resulted in a higher proportion of smaller unmarketable tubers under 4 oz (Figure 2; ANOVA, p = 0.38), indicating that high moisture conditions may lead to a less preferred size. Crop water use efficiency was greatest under I3 (Table 1), indicating that in 2024, 60% irrigation had the highest yield per unit of water input.

It is likely that the season's above-average rainfall (Figure 4, 21.66 inches total) impacted the results by minimizing differences between treatments at points during the growing season (Figure 5) and reducing potential deficit water stress. Future research under typical rainfall conditions can validate findings and refine irrigation strategies.

Table 1. Mean effects of irrigation treatments on weight of diseased tubers, tuber size, and crop water use efficiency (WUE). The impact of irrigation treatments were not statistically significant on the weight of diseased tubers, tuber size over 6 oz, and total marketable yield.

Irrigation Treatment	Total Irrigation Inputs (in)	Diseased Tuber Wt (cwt/ac)[1]	Tuber Size >6 oz (%)[2]	Total Marketable Yield (cwt/ac)[3]	Water Use Efficiency (%)[4]

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[1] Tubers were harvested from a 10' subplot to scout for cosmetic diseases, then converted to a cwt/ac basis. Proportion to healthy tubers and specific incidence data can be seen in Figure 2.

[2] Plots were mechanically harvested, then sorted by size and weighed.

[3] Total marketable yield was reported as the total Grade A yield minus the undersized (<4 ounce) tubers.

I1: 100% Irrigation	9.31	95.5	45	433	16.94
I2: 80% Irrigation	7.68	88.6	46	553	17.53
I3: 60% Irrigation	6.05	95.8	48	549	21.49

[4] Crop Water Use Efficiency is a ratio that measures the marketable yield produced by a plant (cwt/ac) per inch of water that was input, including precipitation.

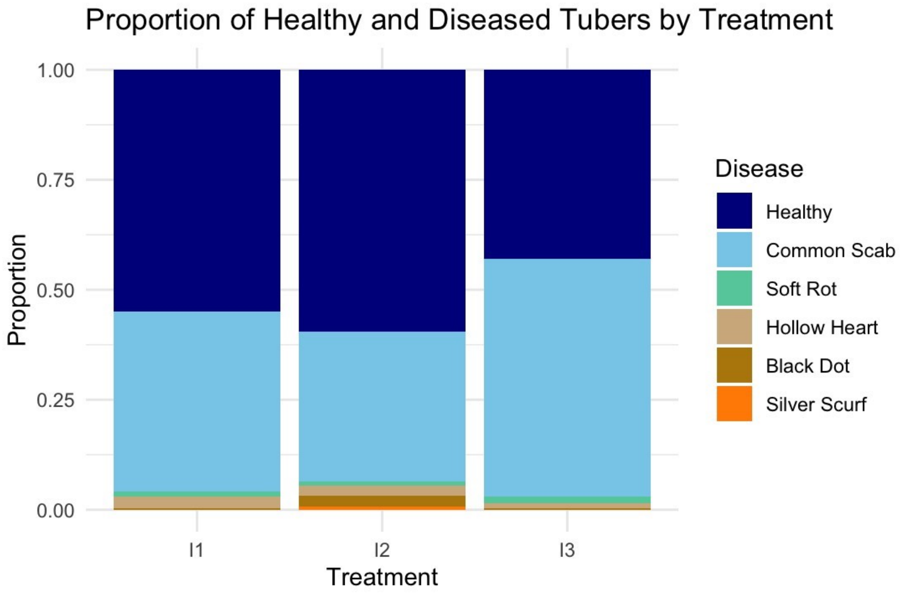

Figure 1. Disease incidence proportions by treatment. Common scab had high incidence overall and was most prevalent at low irrigation. Hollow heart was seen most in plots with high irrigation with almost no hollow heart in the lowest irrigation treatment. Low incidence was recorded for other diseases and abiotic disorders.

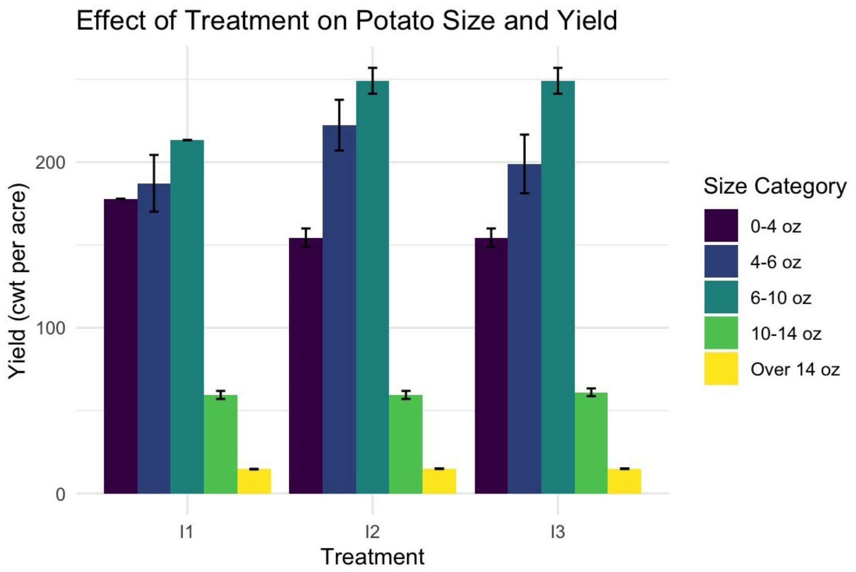

Figure 2. Potato yield by size and treatment. Treatments I2 and I3 had very similar yields, though Treatment 1 was not statistically different.

Table 2. Mean tuber sucrose/glucose concentrations and French Fry reflectance values. Fry tests were performed after harvest for a subset of ten potatoes per plot. Treatment I2 had the least difference in bud- and stem-end reflectance, suggesting a more uniform fry color. Irrigation treatments did not have a statistically significant effect on the fry test results.

Irrigation Treatment	Glucose (mg/g)	Sucrose (mg/g)	Specific Gravity	Bud-End Reflectance[1]	Stem-End Reflectance[1]
I1: 100% Irrigation	1.08665	0.5	1.087	45.115	46.48
I2: 80% Irrigation	1.08865	0.494	1.089	44.285	45.25
I3: 60% Irrigation	1.08755	0.48975	1.088	43.525	46.185

[1] A difference of 9 Photovolt units or more between bud- and stem-end reflectance constitutes non-uniform fry color.

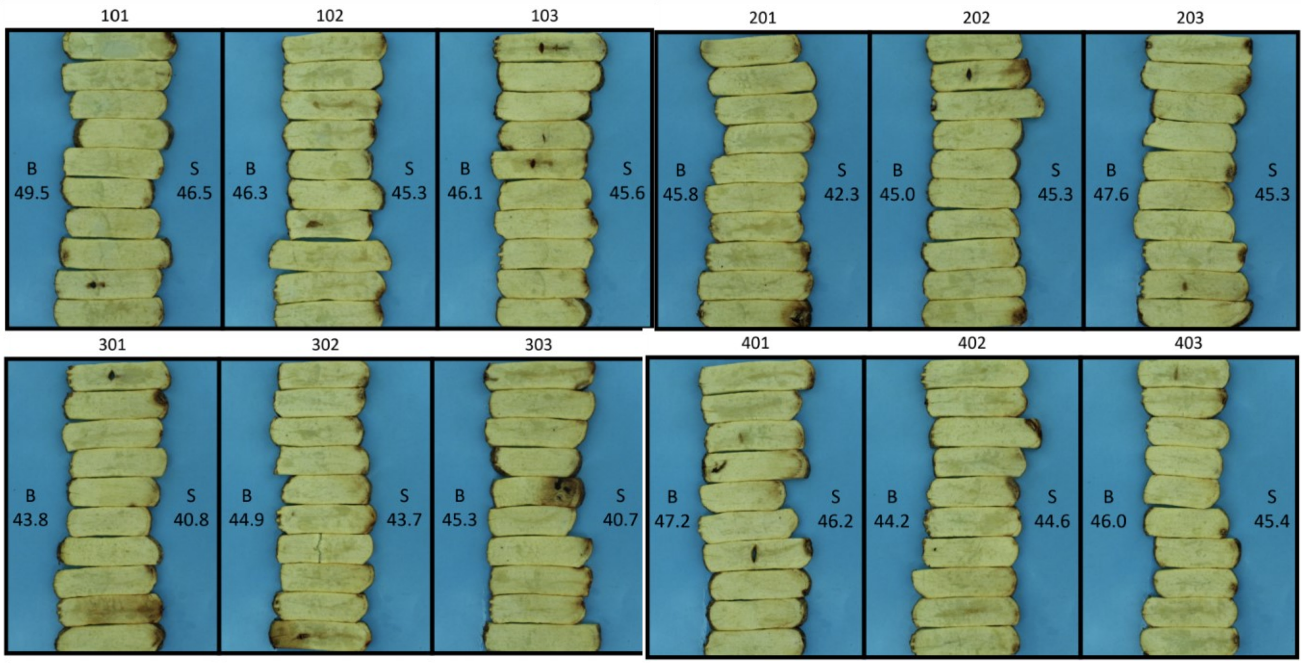

Figure 3. Fry test results after 3.5 minutes at 375° F. Photos are aligned bud to stem end (left to right).

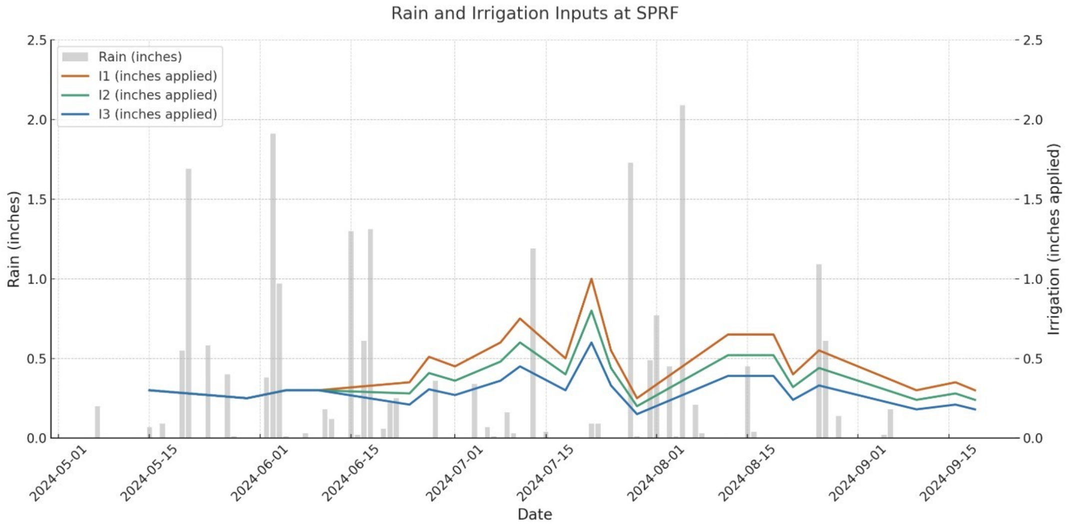

Figure 4. Water inputs from rain and irrigation throughout the growing season. Total precipitation amounted to 21.66 inches throughout the whole season, while irrigation treatments I1, I2, and I3 inputs added 9.31, 7.68, and 6.05 inches of water respectively.

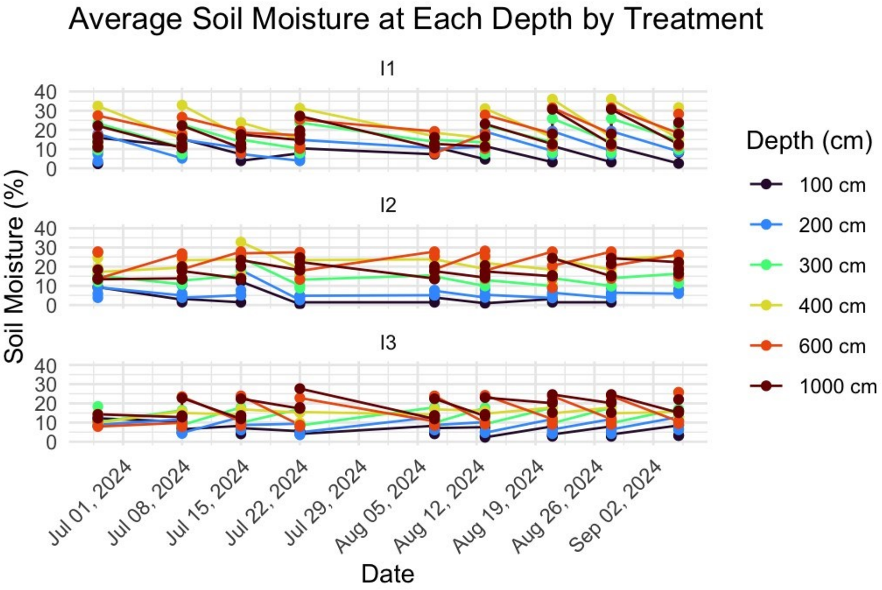

Figure 5. Average soil moisture levels per treatment at various depths. Russet potato roots typically reach around 50 cm below the soil surface and are mainly grown in sandy soil textures, leading to fast drainage.

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Title: Determining Optimum Pre-Planting Conditions for Dakota Russet Seed Tubers

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Executive Summary: Optimizing potato seed preparation practices is essential to mitigate seed decay under unfavorable environment and soil conditions. Potato growers in the Red River Valley region have expressed interest to evaluate and optimize pre-planting seed preparation conditions for agronomically relevant cultivars. In this study, we are focusing on cv. Dakota Russet as its acreage is expanding in North Dakota and Minnesota. We have conducted an experiment to determine the effects of different curing durations of cut seed tuber pieces on emergence and performance of Dakota Russet. To accomplish this, seed tubers were obtained from a commercial grower after harvest in 2024 and stored at 38°F (95% relative humidity-RH) until spring. Then, one subset of tubers was warmed-up to 50°F (95% RH) while one subset remained in 38°F. Warmed-up tubers were cut in ~2-inch pieces and suberized at 50°F for 1 and 2 weeks. Further, to mimic delayed planting scenarios, subsets from each suberization treatments were stored under 45°F for 2 or 3 weeks. Timing of the experimental treatments were coordinated to synchronize planting of all seed pieces simultaneously. Sprout emergence, plant growth (height), and yield data were collected. Results revealed early emergence from suberized and stored pieces after 15 days of planting when compared to fresh cut/non-suberized treatment. Interestingly, 30 and 60 days after planting, there was no significant difference for overall plant growth from the fresh cut and suberized seed tuber pieces examined in this study. Overall, lower emergence rate, and lower growth were observed when cut seed tuber pieces were suberized at 50°F for 1 week and then stored at 45°F for 2 weeks. The experiment will be repeated during 2025 crop year to confirm the results.

Background: Overall, having good seed tuber quality, rapid and uniform emergence after planting, and resilience against environmental and biological stresses are essential for achieving optimum crop productivity. Pre-planting curing under optimum temperature and duration can allow the formation of protective suberin layer in cut and bare surface of the seed tubers, which subsequently provides protection against environmental stresses and diseases. Such protection against non-biological and biological stresses potentially help to minimize seed decay when exposed to less than ideal conditions after planting. Current pre-planting practices do not include curing for sufficient time, which can make the seed pieces susceptible to decay under unfavorable soil conditions (both dry or wet). Another challenge is the pre-planting temperature of seed tubers, which can impact their suberization rate after cutting. While some potato cultivars have rapid wound-healing trait, others are slower to heal. Therefore, the curing temperature and duration should be optimized to promote rapid suberization of cut seed tuber pieces for agronomically significant cultivars.

Procedure: Seed tubers of cv. Dakota Russet were obtained from Nilson Farms (Hoople, North Dakota) in the fall 2023; tubers were cured for 2 weeks (~70°F and 95% RH) and temperature was ramped down to 38°F for storage. In the spring 2024, one subset of tubers was warmed up (from 38 to 50°F over 7-day), cut, and suberized. In the meantime, a subset of tubers was kept at 38°F and used as fresh cut/non-suberized treatment (as control). Subsets of cut seeds were incubated (at 50°F, 95% RH) to allow suberization for either 1 or 2 weeks. After the suberization period, each subset was further divided in three groups; one set from each suberization period was planted immediately, while second and third subsets were further stored under 45°F for 2 or 3 weeks and rewarmed to 50°F (over 3-day) prior to planting (Table 1). All seed preparation treatments were synchronized for simultaneous planting. The field experiment was conducted in Larimore, ND under commercial production practices (Hoverson Farms) with total six treatments and four replications/treatment. Emergence and growth of the potato plants were monitored weekly. After harvest, tubers were graded, and total and marketable yield along with specific gravity of the tubers were determined.

Results: Results of this experiment revealed early emergence from the suberized (1- and 2-weeks) (Treatment 2, 3, 5, 6) cut seed tuber pieces when compared to fresh cut/non-suberized treatment (Treatment 1) at 15 days after planting (DAP) (Figure 1). However, after 30 DAP, emergence rate of fresh cut tubers reached similar range as some of the suberized treatments. Overall, lower emergence rate and growth was observed for cut seed tuber pieces suberized at 50°F for 1 week + stored at 45°F for 2-weeks (Treatment 4) (Figure 1). No significant differences in plant height and growth were observed among most seed preparation treatments after 60 DAP (Figure 2). Higher total yield and marketable yield of Dakota Russet were observed for plants grown from 1-week suberized (Treatment 2) and when they are further stored at 45°F for 3 weeks (Treatment 5) (Figure 3). Follow-up experiment is needed to confirm these findings from the first year in 2025.

Table 1. Details of seed preparation treatments of Dakota Russet for the 2024 field experiment

Treatment No.	Cut seed tuber treatments
# 1	Fresh cut from tubers stored at 38°F
# 2	Suberized at 50°F for 1 week
# 3	Suberized at 50°F for 2 weeks
# 4	Suberized at 50°F for 1 week > Stored at 45°F for 2 weeks
# 5	Suberized at 50°F for 1 week > Stored at 45°F for 3 weeks
# 6	Suberized at 50°F for 2 weeks > Stored at 45°F for 2 weeks

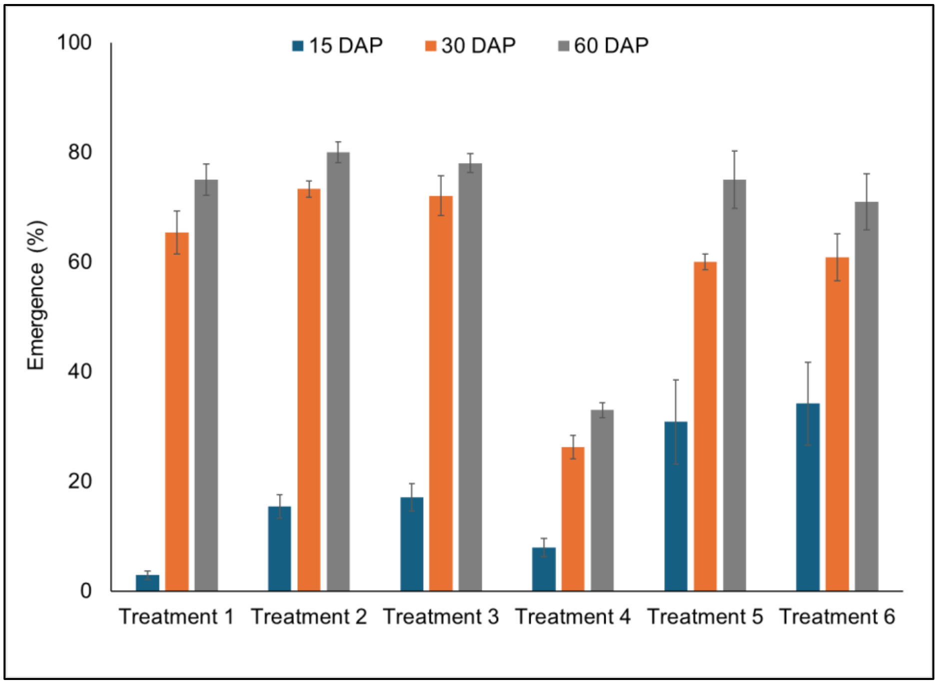

Figure 1. Emergence (%) of Dakota Russet plants from fresh cut/non-suberized (Treatment 1) and suberized (Treatment 2-6) seed tuber pieces at 15, 30, and 60 DAP.

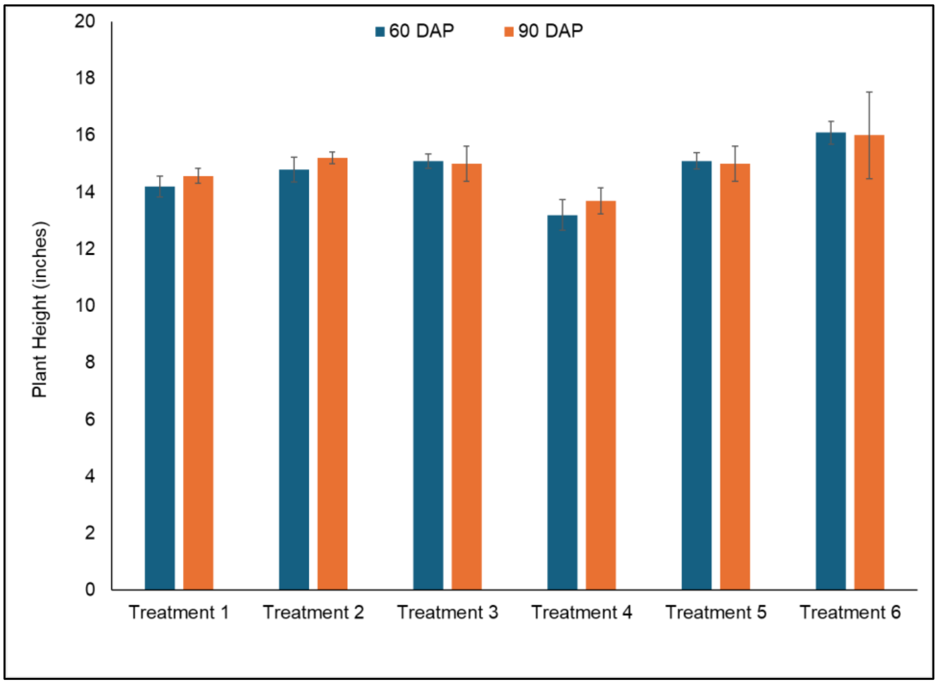

Figure 2. Height (inches) of plants grown from fresh cut/non-suberized (Treatment 1) and suberized (Treatment 2-6) seed tuber pieces at 60 and 90 DAP.

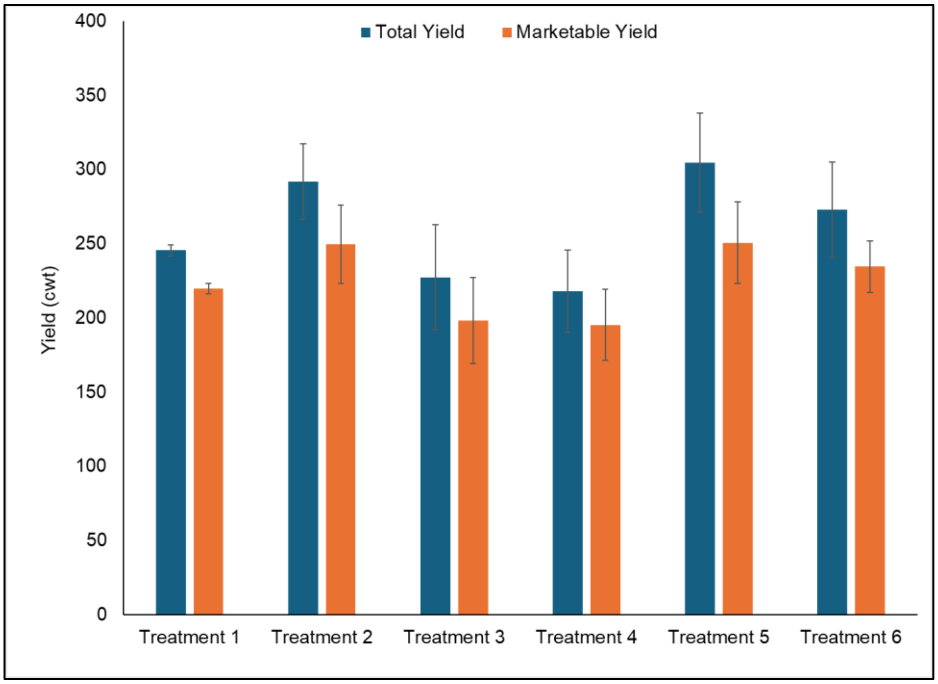

Figure 3. Total yield and marketable yield (cwt) of Dakota Russet grown from fresh cut/non-suberized (Treatment 1) and suberized (Treatment 2-6) seed tuber pieces.

Report title – Evaluating newly developed UMN potato lines for Verticillium wilt resistance

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Executive Summary- Minnesota ranked 6th potato producers nationwide in 2022, with an estimated total potato production of 1.1 M tons and an estimated value of $237M (NASS 2023). Verticillium wilt (caused by fungal pathogens called *Verticillium* spp.), is a recurring problem for Minnesota and northern plains potato growers. Potato is one of the most economically important crops impacted by Verticillium wilt. Resistant cultivars are one of the most sustainable and cost-efficient methods for controlling crop diseases. We have developed a Verticillium-infested disease screening nursery with high disease pressure in an irrigated potato field at Sand Plain Research Farm, Becker, MN. In the year 2024, we conducted Verticillium wilt disease screening of 40 potato clones/lines, including nine commercial cultivars (Superior, Dark Red Norland, Goldrush, Red Norland, Russet Norkotah, Yukon Gold, Atlantic, Russet Burbank, and Umatilla Russet). The study was designed to compare the levels of Verticillium wilt resistance in nine commercial cultivars with Thirty-one potential potato lines bred at the University of Minnesota Potato Breeding Program (led by Dr. Laura Shannon). The study trial suggested commercial cultivars/varieties Alturas Russet, Umatilla Russet and Bannock are highly tolerant to Verticillium wilt. At the same time, Superior, Dark Red Norland, Goldrush, Russet Burbank and Russet Norkotah, are highly susceptible to Verticillium wilt. The study identified five new potato lines from UMN varieties to be highly tolerant. These potato varieties were **MN19AOR17020-009, MN20CO18192-001, MN20ND1833B-001, MN18W17037-026, MN18W17037-033** and **MN18W17009-001** (Figure 3). MN19AOR17020-009 has shown better tolerance than Alturas Russet, and Bannock (Figure 3).

We also confirmed *Verticillium dahliae* infection in these potato lines using molecular biology and microbial techniques. Additionally, we sent soil samples from our disease nursery to Pest Pro (Plainfield, WI) to estimate the load of Verticillium ppg (VPPG). The VPPG range in the disease nursery was between 170 to 300 ppg of soil, suggesting a very high load of Verticillium in the soil.

Rationale:

Our rationale for the proposed study is to use the Verticillium wilt nursery (at Sand Plain Research Farm, Becker, MN) to screen potato lines for disease resistance and inform breeders about new Verticillium wilt tolerant high-yielding potato varieties. This study focuses on assessing UMN-bred potato lines to find Verticillium wilt-resistant potato lines. The study will lead to finding genetic solutions to manage the Verticillium wilt disease problem that can reduce dependency on fungicides and fumigants and secure yield loss sustainably.

Procedures

For performing screening of 40 potato lines, we used four replicate study of 10 hill plots, each in a completely randomized block design in the *Verticillium* wilt nursery at the Sand Plain Research Farm, Becker, MN. Superior, Dark Red Norland, Goldrush, and Russet Norkotah varieties were used for susceptible checks, while Alturas Russet, Umatilla Russet and Bannock were used as tolerant checks for Verticillium wilt disease. Potatoes were planted on 9th May 2024. *Verticillium* wilt was visually assessed for disease symptoms at approximately seven to ten day intervals beginning at the mid-potato vegetative growth and flowering stage (from 15th July to 25th 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. *Verticillium* wilt symptoms severity was scored as 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 Verticillium stem colonization was validated by *Verticillium*-specific primers (Inderbitzin et al. 2011; Inderbitzin et al. 2011). Data analysis was performed using standard statistical procedures.

Results

We screened ~1600 potato hills for resistance to *Verticillium* wilt in a *Verticillium dahliae*-infested field at the irrigated sand plain research station, Becker, MN. The study included forty entries, including commercial susceptible cultivars Superior, Dark Red Norland, Goldrush, and Russet Norkotah, in four replicates. Area under disease progress curve (AUDPC) was calculated by examining disease symptom expression using the disease severity scoring as discussed in method section above. Figure 1 shows the verticillium wilt disease progression in the commercial highly tolerant cultivar (Alturas Russet) and highly susceptible line cultivar (Russet Norkotah) as observed and rated on 25th July, 7th August, and 13th August 2024.

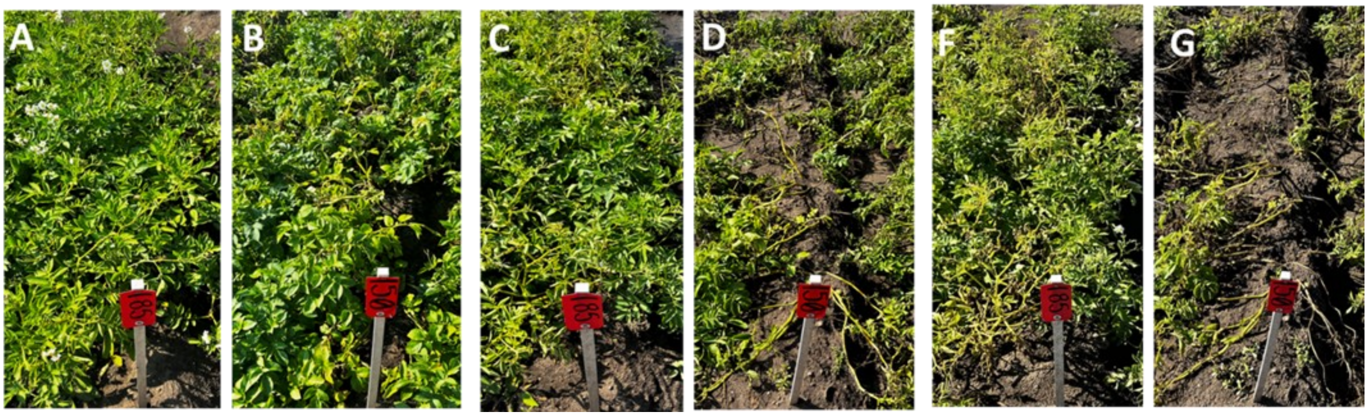

Figure 1. Progression of *Verticillium* wilt disease in AlturasRusset5 (185, tolerant) and Russet Norkotah (150, susceptible) potato variety at Sand Plain Research Farm, Becker, MN. Photographed on (A, B) 25th July, (C, D) 7th August, and (E, F) 13th August, respectively.

Figure 2 shows the verticillium wilt disease progression in the UMN potato breeding lines highly tolerant (MN19AOR17020-009) and highly susceptible breeding line (MN20TX417-003) as observed and rated on 25th July, 7th August, and 13th August 2024.

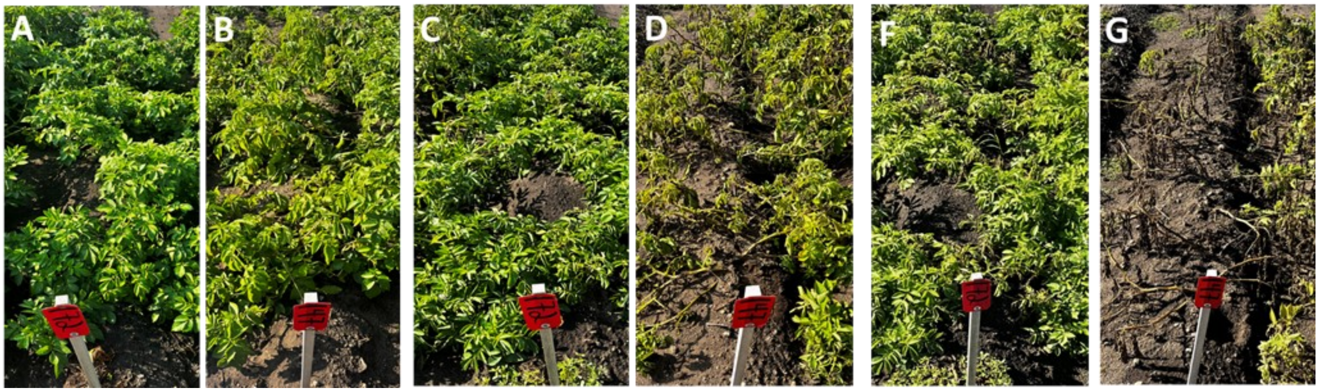

Figure 2. Progression of *Verticillium* wilt disease in MN19AOR17020-009 (172, tolerant) and MN20TX417-003 (147, susceptible) potato variety at Sand Plain Research Farm, Becker, MN. Photographed on (A, B) 25th July, (C, D) 7th August, and (E, F) 13th August, respectively.

The area under disease progress curve (AUDPC) using verticillium wilt disease severity % observation of 18th July, 25th July, 7th August, and 13th August 2024 was calculated (Figure 3). The study identified five highly resistant UMN potato bred lines and also reconfirmed commercial cultivars Alutras Russet and Bannock as highly tolerant potato cultivars. We confirmed the disease by isolating Verticillium from a few stems for each potato line using the microbial technique. We also isolated DNA from the infected stem and used Verticillium-specific primers to confirm infection.

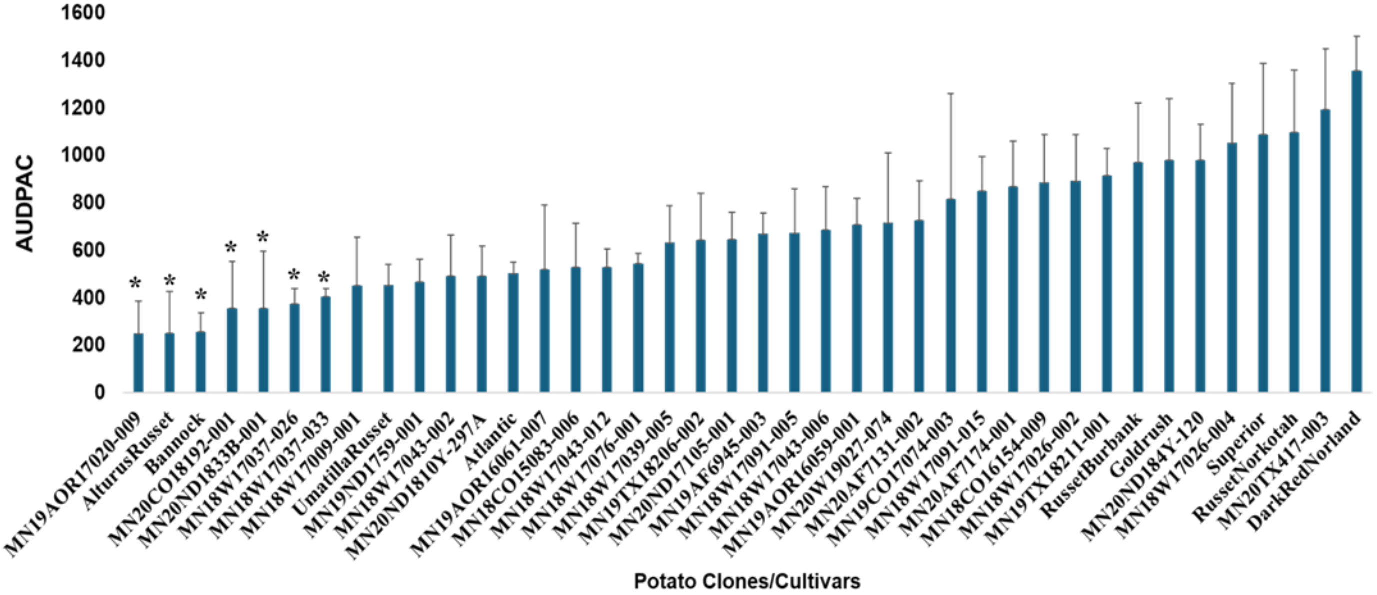

Figure 3. Area under the disease progress curve (AUDPC) of fourty varieties, including nine commercial cultivars (Superior, Dark Red Norland, Goldrush, Alturus Russet, Bannock, Russet Norkotah, Atlantic Russet Burbank, and Umatilla Russet) using percentage disease severity foliage (DS%) from 18th July, 25th July, 7th August, and 13th August 2024 observations. *Indicates highly resistant varieties. The study was performed in four replicates; each replicate has ten potato hills. Standard deviation of four replicates is shown.

From this study, we can preliminarily conclude that we have identified five tolerant potato lines from UMN bred lines **MN19AOR17020-009, MN20CO18192-001, MN20ND1833B-001, MN18W17037-026, MN18W17037-033** and **MN18W17009-001** to *Verticillium* wilt. MN19AOR17020-009 is the line that consistently performed well in our Verticillium field screening studies in 2023 and 2024, making it a useful candidate for identifying resistance genetics. 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 and aid our effort of breeding resistant cultivars for potato growers and industry needs.

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Potassium management effects on chloride cycling and potato yield and quality: year 2

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Summary

Potatoes require large amounts of potassium (K) to promote yield and tuber bulking and to minimize bruising. There is strong interest in strategies to improve K use efficiency in this crop. Banded K application is expected to improve K use efficiency by placing all applied K within the root zone of the potato crop. Splitting K application between planting and hilling may also improve K use efficiency, if much of the K applied at planting is lost to fixation in the soil before tuber bulking begins and crop K demand increases. Since K is most commonly applied as potassium chloride (KCl), there is also concern that the high chloride (Cl) content of this fertilizer may have detrimental effects on a potato crop. Using potassium sulfate (K_2SO_4) as a K source avoids this issue, but it is not clear if this advantage is worth the higher cost of K_2SO_4 compared to KCl. The objectives of this study were to (1) evaluate the effects of KCl rate on tuber yield and quality, (2) determine whether banded KCl application decreases potato crop K requirements, (3) evaluate the effectiveness of split KCl 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. The addition of K increased total and marketable tuber yield, tuber size, and the number of tubers per plant compared to the zero-K check treatment. Among treatments receiving KCl, marketable yield and tuber size increased with the application rate of K, while total yield did not. Banded KCl application decreased the yield of 6- to 10-ounce tubers compared to broadcast application. Tuber specific gravity and dry matter content decreased with the application rate of KCl, and the use of K_2SO_4 in place of KCl did not affect either variable. The yield results stand in contrast to those obtained in 2023, when tuber yield decreased with the application rate of KCl, yields were higher with K_2SO_4 than with KCl, and split application of KCl conferred an advantage over a single application in the spring. These differences between the two years may be due to a large difference in precipitation between the years. Cl excess may be a greater issue in a dry year like 2023 than in a wet year like 2024.

Background

Potatoes require potassium (K) in large quantities to promote yield and tuber bulking and to minimize bruising damage. Because irrigated potatoes are commonly grown on sandy soils with medium to low available K concentrations, K fertilizer is generally applied to irrigated potato crops. K fertilizer is typically broadcast-applied in either the spring of the year the potato crop is grown or in the fall before.

Potassium fertilizer prices in the U.S. increased dramatically from 2021 to 2022 before declining again by the middle of 2023. This spike in K prices has prompted increased interest in ways to improve K use efficiency in crops. One promising approach to improving K use efficiency in potatoes is banded K application, which places a larger percentage of the K applied within reach of the crop's roots. A second approach is to apply a portion of the K at hilling, which, compared to applying K only in the spring or fall before planting, should reduce the percentage of applied K that is lost to fixation or leaching before tuber bulking begins and crop demand increases.

The most used K fertilizer is potassium chloride (KCl, also known as muriate of potash or MOP: 0-0-60-47Cl). With this K source, chloride (Cl) is co-applied with K. Cl is an essential nutrient known to improve disease resistance in some plants. However, the use of KCl on potato crops, especially at higher rates, can reduce tuber specific gravity, and this is thought to be related to the Cl content of KCl. Applying K as K_2SO_4 (0-0-50-17S) has been found in some systems to provide the benefits of K fertilization without the cost in terms of specific gravity. While K_2SO_4 is more expensive than KCl, it may be a better choice where low specific gravity is of concern.

A second cost of applying fertilizers with a large Cl component is that Cl is highly leachable and can be environmentally harmful to freshwater ecosystems in large quantities. The effect of K management decisions on Cl leaching into ground and surface waters is therefore of some interest.

In 2024, studies that were conducted in corn and potato systems in 2023 were repeated, with the following objectives in mind for the potato study: (1) to evaluate the effects of K rate on tuber yield and quality, (2) to determine whether banded application reduces crop K requirements, (3) to determine whether split application of K reduces crop K requirements, (4) to determine whether the use of K_2SO_4 in place of KCl improves tuber specific gravity, and (5) to evaluate the effects of Cl application on potato crop performance and Cl concentrations in soil water.

Methods

The second year of the study was conducted at the University of Minnesota's Sand Plain Research Farm in Becker, MN, on a Hubbard loamy sand soil in 2024. Initial soil characteristics from samples collected in April 2024, before fertilizer application, are presented in Table 1.

Twelve treatments were applied to Russet Burbank potato plants in a randomized complete block design with four replicates. These treatments are summarized in Table 2. Each plot was 12 feet (4 rows) wide by 20 feet long. The central 18 feet of the middle two rows were used for end-of-season vine samples and tuber harvest samples. A red potato was planted at each end of each of these two rows. The field was three plots wide and 18 plots long. A 3-foot buffer was planted on all sides of the field to reduce edge effects.

KCl was broadcast applied by hand in treatments 2-5 and 8, K_2SO_4 in treatments 10 and 11, and $CaCl_2$ in treatment 12 on April 24, 2024. Planting rows were opened mechanically with 36-inch spacing between rows. A mixture of whole "B" and cut "A" seed was planted by hand with 12-inch spacing between seed pieces.

Belay was applied in-furrow at planting for beetle control, along with the systemic fungicide Quadris. At row closure, KCl was banded into the rows in treatments 6 – 8 approximately 4 inches below and to either side of the seed potatoes. At the same time, a planting fertilizer blend was banded into the rows in all treatments, providing 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. Rainfall samples were collected on 26 April, 20 May, 15 June, 28 July, and 26 August. Irrigation water samples were collected on 13 and 24 June, 22 July, and 19 August. These water samples were sent to the University of Minnesota's Research Analytical Laboratory (UM-RAL) to be analyzed for Cl and a suite of other elements and nutrients using ion chromatography. They were also analyzed for K and a suite of other elements using inductively coupled plasma mass spectrometry.

On May 15, the hills in treatment 9 were side-dressed with 200 lbs/ac KCl, supplying 120 lbs/ac K_2O. At the same time, all treatments except those that received K_2SO_4 (treatments 10 and 11) were sidedressed with 227 lbs/ac ammonium sulfate (21-0-0-24S), supplying 48 lbs/ac N and 54 lbs/ac S. The plots in treatments 10 and 11 received the same rate of N as urea (46-0-0) side-dressed at the same time. Urea was then side-dress applied to the whole study at 244 lbs/ac during hilling, supplying 146 lbs/ac N and bringing the total N rate to 240 lbs/ac.

Lysimeters were installed in all plots in treatments 1, 4, 8, 11, and 12 on May 6 to sample soil water at a depth of 4 feet. The lysimeters were flushed on May 7, and soil water samples were taken on 10 and 20 May, 20 and 27 June, 3, 11, 17, 25, and 30 July, 6, 13, 20, and 27 August, and 5, 9, and 20 September. The Cl concentration of each sample was determined using an Epock 2 Microplate Spectrophotometer (BioTek). In addition, samples collected on 29 May, 26 June, 25 July, and 18 September were sent to UM-RAL to be analyzed for K concentration using inductively coupled plasma mass spectrometry.

Plant stand was assessed among the 18 Russet Burbank plants in the middle two rows of each plot on 29 May and 6 June. The number of stems per plant was determined in a 10-plant sample in one of the middle two rows of each plot on May 31. Canopy cover was measured with the Canopeo app on 31 May; 4, 12, and 24 June; 3, 8, 22, and 29 July; and 8, 13, 20, and 27 August. The greenness of the terminal leaflet of the fourth mature leaf from the shoot tip was measured on 20 shoots per plot with a SPAD-502 Chlorophyll Meter (Konica Minolta) on 18 June and 1, 18, and 30 July. The petiole of the terminal leaflet of the fourth mature leaf from the tip was collected from 20 shoots per plot on the same dates. These petiole samples were dried at 140°F to a constant weight, ground, and sent to Agvise (Benton, MN) to be analyzed for K, Cl, S, and NO_3^--N concentrations.

On September 5, all vines were cut by hand from 10 feet in the center of the two middle rows of each plot (60 square feet in total). The fresh weight of each vine sample was determined. A subsample was taken from each sample and weighed. The vine subsamples were then dried at 140°F to a constant weight and weighed again. The fresh and dry weights of the subsamples were used to determine vine dry matter content, which was used together with the fresh weights of the 60-square-foot samples to estimate dry vine yield per acre.

Shortly after vine samples were collected on September 5, all vines were killed using a flail mower. Tubers were harvested from the central 18 feet of the middle two rows (108 square feet) on September 23. On September 24 and 26, the tubers were sorted into five size categories: 0-4 oz., 4-6 oz., 6-10 oz., 10-14 oz., and over 14 oz. Tubers over 4 oz. were sorted into U.S. No. 1 and U.S. No. 2 categories based on USDA standards for processing potatoes. Cull tubers were sorted into a single category, regardless of size. The tuber sample in each size-grade category was weighed to estimate per-acre yield.

A size-representative subsample twenty-five U.S. No. 1 tubers was collected from each plot's harvest for internal quality assessments. This subsample was used to estimate the prevalence of hollow heart, brown center, and scab, as well as tuber specific gravity and dry matter content.

On October 8 and 11, soil samples to depths of 2 feet and 6 inches, respectively, were collected from each plot. The samples were dried at 95°F to a constant weight and ground. Ground 2-foot samples were sent to UM-RAL to be analyzed for Cl concentration with a Lachat QuikChem 8500 Flow Injection Analyzer. In addition, ground 6-inch samples from treatments 1, 4, and 12 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 as a fixed effect and block as a random effect. 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 soil water K and Cl concentrations and end-of-season soil K concentrations, 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 responses to KCl rate (among treatments 1-5), (4) broadcast versus banded KCl application (treatments 2 – 4 versus 6 – 8), and (5) broadcast KCl versus broadcast K_2SO_4 (treatments 3 and 4 versus 10 and 11). No contrasts were evaluated for soil water K or Cl concentrations or end-of-season soil K concentration, which were only taken from a subset of the treatments. Soil water Cl concentrations and end-of-season K and Cl concentrations were $\log_{10}$ transformed for statistical analysis. Data presented in the graphs and tables are non-transformed means.

Results:

Rainfall and irrigation

Daily and cumulative rainfall and irrigation from April through September in the study field are presented in Figure 1. The average rainfall totals for these months in Becker, MN, are 2.83” in April, 3.78” in May, 4.37” in June, 3.91” in July, 4.15” in August, and 3.07” in September, for a total of 22.11”. In 2024, the season was much wetter than average in April (4.93”), June (7.67”), and August (6.14”), close to average in May (4.39”) and July (4.25”), and drier than average in September (0.28”). After April, rainfall was supplemented with irrigation as needed, supplying 0.55” of water in May, 1.76” in June, 4.85” in July, 2.25” in August, and 1.55” in September. In total, 27.66” in rain fell, supplemented with 10.96” of irrigation, for a total of 38.62” of water in April through September. June and August were exceptionally wet for the location, which could potentially affect nutrient availability (through leaching) and, as a result, plant growth and potato crop production.

Rainfall contained very little K (0.13 ppm, on average) or Cl (0.14 ppm), depositing approximately 0.8 lbs/ac K and 0.9 lbs/ac Cl over the course of the season. Irrigation water contained substantially higher concentrations of both K (2.28 ppm) and Cl (38.6 ppm) and deposited about 5.6 lbs/ac K and 95 lbs/ac Cl throughout the season.

Tuber yield, size, and grade

Results for tuber yield, size, and grade are presented in Table 3. Total yield was greater among treatments receiving broadcast KCl at any rate (treatments 2-5) than it was in the zero-K check treatment (treatment 1). However, none of the treatments receiving broadcast KCl had a significantly different total yield than the others. Banded application of KCl conferred no benefit to total yield in this season, producing nonsignificantly lower yields than broadcast application. Using K_2SO_4 instead of KCl also provided no benefit to total yield. Results were similar for marketable yield, except that marketable yield generally increased with K_2O rate among the treatments receiving broadcast KCl (treatments 2 – 5), with the treatment receiving 320 lbs/ac K_2O (treatment 5) having significantly higher marketable yield than the treatment receiving 80 lbs/ac K_2O (treatment 2). U.S. No. 1 yield largely paralleled total marketable yield, while U.S. No. 2 yield did not and was not related to treatment.

The percentage of yield represented by tubers over 6 ounces increased with K_2O rate among the treatments receiving broadcast KCl (treatments 2-5), and it was higher in these treatments, as a group, than in the zero-K check treatment (treatment 1). Banded application of KCl did not promote tuber bulking relative to broadcast application, producing a nonsignicantly lower percentage of total yield in tubers over 6 ounces. The percentage of total yield represented by tubers over 10 ounces was generally higher in treatments receiving 240 or 320 lbs/ac K_2O than in other treatments, with the exception of the treatment receiving 240 lbs/ac K_2O as KCl banded at planting (treatment 8).

The zero-K control treatment (treatment 1) had fewer tubers per plant than the treatments receiving broadcast KCl (treatments 2-5), as a group. The treatment receiving 240 lbs/ac K_2O as K_2SO_4 (treatment 11) also had relatively few tubers per plant, with significantly fewer tubers than the treatment receiving 160 lbs/ac K_2O from the same source (treatment 10). It is not clear why this was the case.

Application method (banded versus broadcast) and K source (KCl versus K_2SO_4) had little effect on tuber yield or size. Treatments receiving banded KCl (treatments 6 – 8) had lower yields of 6- to 10-oz. tubers than treatments receiving broadcast KCl at the same rates (treatments 2 – 4), and total yield showed a similar but nonsignificant trend, but application method had no other effects. K source had no significant effects. The addition of Cl without K in treatment 12 did not significantly alter any metric of tuber yield, grade, size, or number relative to those observed in the check treatment (treatment 1), which received neither K nor Cl.

The lack of any effect of K source on yield stands in contrast to the results obtained when the same study was conducted in 2023. In that year, broadcast K_2SO_4 supplying 160 or 240 lbs/ac K_2O (treatments 10 and 11) produced higher total yields than broadcast KCl supplying K_2O at the same rates (treatments 3 and 4), with results for U.S. No.1, U.S. No. 2, and total marketable yield approaching statistical significance. Possibly, the greater summer rainfall in 2024 leached away the excess Cl from the treatments receiving KCl, negating the advantage of K_2SO_4 in not adding large amounts of Cl to the soil. Adding Cl without K (treatment 12) had similar, nonsignificant effects on tuber yield and size in both 2023 and 2024, suggesting that, if excess Cl affected yields in 2023, when there was less leaching, it only did so when abundant K was also applied.

The wet summer in 2024 may also be responsible for the poor tuber bulking observed in this year, which was also seen in other studies at SPRF and in many growers' fields in the region. No treatment had more than 31% of its total yield in tubers over 6 ounces, or more than 8% of its yield in tubers over 10 ounces. In contrast, in 2023, a dry year, no treatment had *less* than 51% of its yield in tubers over 6 ounces, or less than 17% of its yield in tubers under 10 ounces (with the highest percentages being 70% and 36%, respectively). It is plausible that much of the N supplied as urea was leached away as nitrate instead of being taken up by the crop, providing an early pulse to promote tuber set, with little N available for bulking later in the season. In addition, tuber set was higher in 2024 compared with 2023, which also compromised tuber bulking in 2024.

Tuber quality

Results for tuber defects, specific gravity, and dry matter content are presented in Table 4. The zero-K check treatment (treatment 1) had a somewhat higher prevalence of hollow heart and brown center than the treatments receiving broadcast KCl (treatments 2 – 5). Treatment had no effect on the prevalence of scab. Tuber specific gravity and dry matter content were generally lower the higher the application rate of K. Neither banded application nor the use of K_2SO_4 as a K source significantly affected tuber quality by any metric. Application of Cl without K (treatment 12) did not significantly affect tuber quality compared to the check treatment (treatment 1). The lack of a Cl effect on specific gravity is consistent with results from 2023 and may be due to the high Cl supplied with the irrigation water. In other words, there was enough Cl supplied with irrigation water to reduce specific gravity regardless of the Cl applied with Cl-containing fertilizer treatments.

Plant stand and stems per plant

Results for plant stand and the number of stems per plant are presented in Table 5. Plant stand was consistently around 99 – 100% in each treatment. Some of the contrasts were statistically significant or approached significance on both 29 May and 6 June, but no two treatments differed significantly in percent stand on either date, and the overall treatment effects were far from significant. The number of stems per plant was also not significantly related to treatment.

Leaflet greenness (SPAD readings)

Results for leaflet greenness are presented in Table 6. The zero-K check treatment (treatment 1) had the highest SPAD readings on all four dates, resulting in a significant contrast comparing that treatment to the treatments receiving broadcast KCl (treatments 2 – 5) in each case. The application rate of K was not otherwise clearly related to leaflet greenness. The application method of K was unrelated to SPAD readings, except that treatments receiving banded applications of KCl (treatments 6 – 8), as a group, had nearly significantly higher readings on 30 July than those receiving broadcast applications at the same rates (treatments 2 – 4). Similarly, on that date, but on no other, the treatments receiving broadcast K_2SO_4 (treatments 10 and 11), as a group, had nearly significantly higher SPAD readings than treatments receiving broadcast KCl at the same rates (treatments 3 and 4). The addition of Cl without K (treatment 12 compared to treatment 1) had no significant effect on leaflet greenness.

The relatively high SPAD readings observed in the check treatment (treatment 1) may be the result of a dilution effect in the other treatments. If lack of K limited plant shoot growth in the check treatment, the more extensive shoots in the other treatments may have diluted any N that was taken up, reducing leaflet greenness readings.

Canopy cover

Results for canopy cover are presented in Table 7. Treatment effects on canopy cover were significant on June 12 through July 8. The check treatment (treatment 1) had lower canopy cover than any other treatment on these dates, though the difference was not significant compared to the treatment receiving 240 lbs/ac K_2O as K_2SO_4 (treatment 11) on 12 June, nor compared to the treatment receiving Cl without K (treatment 12) on June 12 or July 8. Canopy cover reached a plateau on June 24 through July 8 in most treatments. Beginning on July 22, canopy cover began to gradually decline in all treatments, with the decline accelerating after August 8. There were no significant effects of treatment on cover from July 22 through August 13. Treatment did have a significant effect on canopy cover on August 20 and 27, when the treatments receiving either 320 lbs/ac K_2O as broadcast KCl (treatment 5) or 160 lbs/ac K_2O as broadcast K_2SO_4 (treatment 10) retained higher canopy cover than most other treatments.

Overall, banded application of KCl (treatments 6 – 8) and broadcast application of K_2SO_4 (treatments 10 and 11) slightly decreased canopy cover relative to broadcast application of KCl (treatments 2 – 4) in June. The application of Cl in treatment 12 also improved canopy cover compared to the check treatment (treatment 1) on June 24 and July 3, possibly indicating that Cl application was beneficial to early-season canopy cover. On August 20 and 27, the treatment receiving 160 lbs/ac K_2O as K_2SO_4 (treatment 10) had the second highest canopy cover of the 12 treatments, while the treatment receiving 240 lbs/ac K_2O from the same source had the lowest or second lowest canopy cover. It is not clear why these two similar treatments produced very different results on these dates.

In 2023, a relatively dry year, treatment had little effect on canopy cover. It is possible that the significant effects observed in 2024 were related to the much greater rainfall in that year, particularly since they occurred during months (June and August) when rainfall was well above average in 2024.

Vine dry biomass yield at vine kill

Results for vine dry biomass at vine kill are presented in Table 8. Although vine dry biomass ranged from 0.51 T/ac in the check treatment (treatment 1) to 0.71 T/ac in the treatment receiving split applications of KCl (treatment 9), the effect of treatment on vine dry biomass yield did not approach statistical significance.

Soil water K and Cl concentrations

Results for soil water K concentrations at a depth of 4 feet are presented in Table 9, and results for soil water Cl concentrations are presented in Figure 2. Soil water K concentration was not related to treatment on any of the four dates evaluated. K concentrations generally increased between May 29 and June 26 and decreased substantially between July 25 and September 18. This suggests that K losses from leaching were minimal, since adding substantial quantities of fertilizer K did not increase K concentrations in the soil water.

Soil water Cl concentrations generally decreased between May 10 and May 23, then rose to a steady level by around June 20 in treatments that received 190 lbs/ac Cl as KCl or $CaCl_2$ (treatments 4, 8, and 12) or September 9 in the treatments receiving no Cl in these forms (treatments 1 and 11). There was no significant treatment effect on soil water Cl concentration on May 10, 20, or 23, though treatments receiving Cl as KCl or $CaCl_2$ had numerically higher soil water Cl concentrations than those that did not on each of these dates. On May 29, the treatment effect approached statistical significance, and it was highly significant from June 5 through November 8. On these dates, treatments that did not receive KCl or $CaCl_2$ had consistently lower soil water Cl concentrations than those that did.

Whether or not 190 lbs/ac Cl was applied to a treatment explained almost all variation among treatments in soil water Cl concentration. The treatments that received no Cl as KCl or $CaCl_2$ (treatments 1 and 11) did not differ significantly from each other in their soil water Cl concentrations on any date. Among the treatments that received 190 lbs/ac Cl (treatments 4, 8, and 12), there were significant differences in pairwise comparisons between treatments only on September 9 and November 8. On September 9, the treatment receiving banded KCl (treatment 8) had a significantly higher soil water Cl concentration than the treatment receiving broadcast KCl (treatment 4) or the treatment receiving broadcast $CaCl_2$ (treatment 12). The difference between the banded and broadcast KCl treatments (treatments 8 and 4, respectively) was observed again on November 8, but the treatment receiving $CaCl_2$ (treatment 12) did not have a significantly different soil water Cl concentration than either of these. The soil water Cl concentration may have been higher where Cl was band-applied because the lysimeters were placed in the planting hills, directly below where the bands were applied in the banded-KCl treatment (treatment 8).

End-of-season soil K and Cl concentrations

Results for end-of-season soil K and Cl concentrations in the top 6 inches of soil are presented in Table 10. The treatment receiving 240 lbs/ac K_2O as KCl (treatment 4) had a significantly higher end-of-season soil K concentration than the check treatment (treatment 1) or the treatment receiving 190 lbs/ac Cl without K (treatment 12).

The overall treatment effect on end-of-season soil Cl concentration was not significant, but differences were apparent when specific contrasts were evaluated. End-of-season soil Cl concentration increased significantly with the application rate of broadcast KCl (among treatments 1-5), and it was higher in treatments receiving KCl (treatments 3 and 4) than in treatments receiving K at the same rates as K_2SO_4 (treatments 9 and 10).

Discussion and summary

In this year of the study, the Cl component of KCl did not appear to be harmful to the potato plants. Marketable yield increased with the application rate of KCl among the treatments receiving broadcast KCl before planting. The use of K_2SO_4 as a K source conferred no yield advantage compared to KCl, although it reduced soil water Cl concentrations significantly. These results stand in contrast to those obtained in 2023, when, among treatments receiving at least 80 lbs/ac K_2O, the application rate of Cl was negatively related to total and marketable yield and treatments receiving K_2SO_4 had higher yields than those receiving KCl at equivalent rates.

The difference in yield between the two years may be due to a substantial difference in rainfall. In May through August, 10.33 inches of rain fell in 2023, as compared to 22.45 inches in 2024. The higher precipitation in 2024 may have leached Cl ions away from the potato root zone rapidly compared to the drier conditions of 2023, reducing the harm excessive Cl application could do to the plants. This also suggests that more Cl may have leached into ground or surface water in 2024 than in 2023. However, this may not have increased the Cl concentration in these waters, as the leached Cl was heavily diluted by rainwater. Soil water Cl concentrations at a depth of 4 feet were similar or lower throughout the year in 2024 compared to 2023.

Other results were more consistent between the two seasons. Tuber specific gravity was negatively related to the application rate of KCl in both years, while the percentage of total yield represented by tubers over 6 ounces increased with KCl rate. In both seasons, late season canopy cover was positively related to the application rate of KCl among the treatments receiving that K source in a broadcast application. Leaflet SPAD readings also decreased with the application rate of KCl in both years. This may be explained by a dilution effect, since canopy cover in June and July (when SPAD readings were taken) was higher in treatments receiving broadcast KCl than in the check treatment. In neither year did the use of K_2SO_4 confer a benefit in terms of increased tuber specific gravity or dry matter content, possibly because a substantial amount of Cl (95 lbs/ac) was added with irrigation water throughout the summer.

Banded application did not appear to improve the effectiveness of KCl. Compared to broadcast applications, banded applications produced significantly lower yield of 6- to 10-ounce tubers. In addition, while total yield and the percentage of yield in tubers over 6 ounces were not significantly related to application method, both variables were numerically higher with broadcast applications. With both methods, total yield showed no trend with K rate, while the yield of 6- to 10-ounce tubers and the percentage of yield in tubers over 6 ounces increased with K rate. If banded application of K at a given rate functioned similarly to broadcast application at a higher rate, then banded application at 80 or 160 lbs/ac K_2O should have performed similarly to broadcast application at a higher rate. Instead, the treatment receiving 240 lbs/ac K_2O in a banded application performed similarly to the treatment receiving 80 lbs/ac K_2O in a broadcast application. Banded application was also disadvantageous to yield in 2023. In that year, yield tended to decrease with increasing K rate among treatments receiving K, so that result was seen as consistent with increased K use efficiency. The results of the two years combined, however, indicate that banded K application may be counterproductive in this location, possibly suggesting that K fixation is not a significant problem in this soil

Split application of KCl also provided no tuber yield or size advantage over a single broadcast application at the same rate. The two treatments (split and broadcast application at 240 lbs/ac K_2O) were not significantly different from each other in terms of any of the variables measured in this study. Their yields and rates of internal defects were quite similar, and their tuber specific gravities were identical. These results contrast with those obtained in 2023, when split application significantly improved total and marketable yields. It is not clear why split application was less beneficial in 2024. Tuber size responded positively to KCl rate in 2024 but negatively in 2023, indicating that tuber bulking was K-limited in 2024 but limited by excessive Cl in 2023. Perhaps the primary advantage of split application in 2023 was not the timing of K application, but the division of Cl application between two time points. Given that end-of-season soil Cl concentrations were higher in 2023 than 2024, it is plausible that Cl excess was a more serious issue in 2023. This could have occurred both because less Cl was flushed from the soil by rainfall in 2023 and because more of the water plants received in that year was irrigation water, which was much higher in Cl than rainwater.

Table 1. Initial soil characteristics in the study field at the Sand Plain Research Farm in Becker, MN, in April 2024, before fertilizer was applied.

0 - 6 inches											
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)
5.5	1.4	28	101	561	103	47	46	1.7	0.7	0.2	9

Table 2. K and Cl 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 $(NH_4)_2SO_4$[4] at emergence (lbs/ac)
1	None	NA	0	0	0	54
2	KCl[1]	Broadcast preplant	80	63	0	54
3	KCl	Broadcast preplant	160	126	0	54
4	KCl	Broadcast preplant	240	190	0	54
5	KCl	Broadcast preplant	320	253	0	54
6	KCl	Banded at planting	80	63	0	54
7	KCl	Banded at planting	160	126	0	54
8	KCl	Banded at planting	240	190	0	54
9	KCl	Half broadcast preplant, half sidedressed at hilling	240	190	0	54
10	K_2SO_4[2]	Broadcast preplant	160	0	54	0
11	K_2SO_4	Broadcast preplant	240	0	82	0
12	$CaCl_2$[3]	Broadcast preplant	0	190	0	54

[1] KCl: 0-0-60-47Cl

[2] K_2SO_4: 0-0-50-17S

[3] CaCl2: 34% Ca, 60% Cl (94% pure)

4$(NH_4)_2SO_4$: 21-0-0-24S

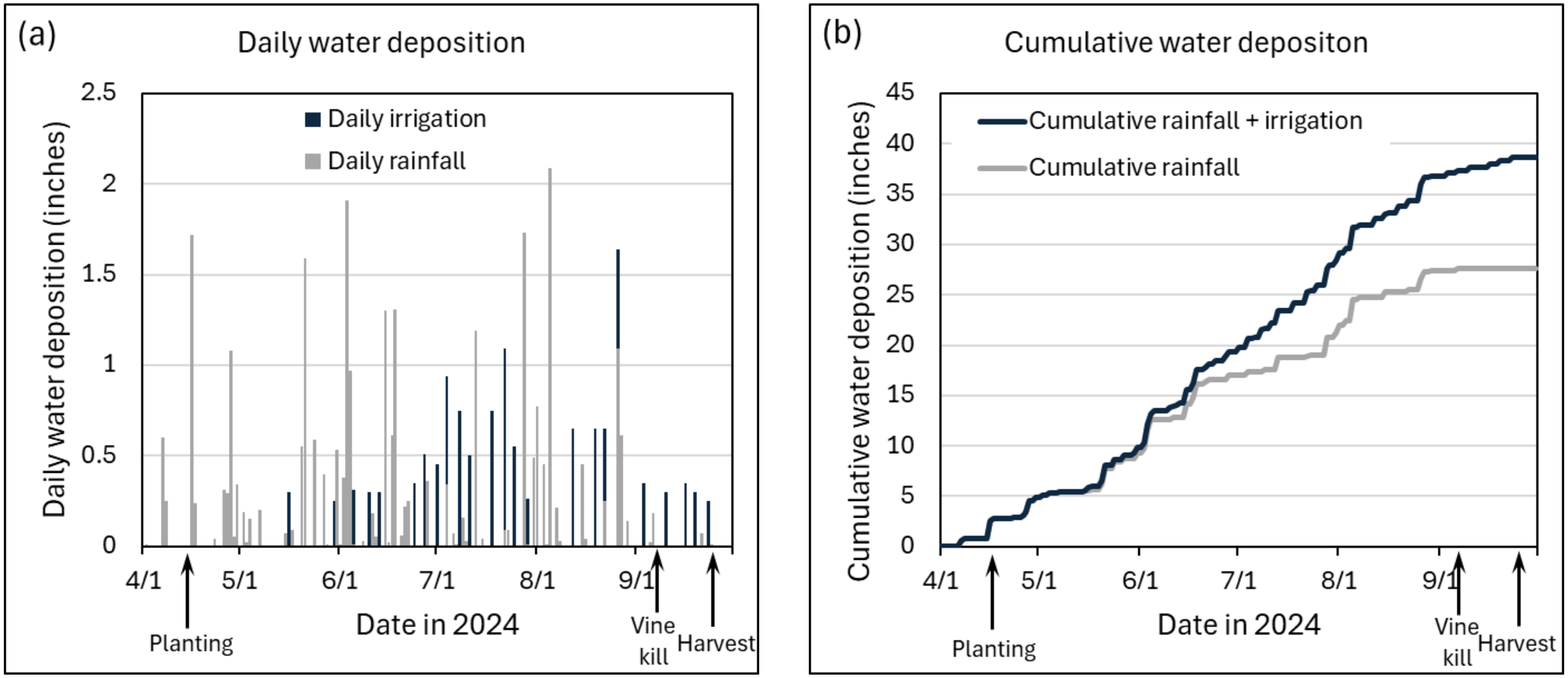

Figure 1. (a) Daily irrigation and rainfall totals and (b) cumulative rainfall and rainfall plus irrigation at the study site in 2024.

Table 3. Effects of K and Cl treatments on potato tuber size, grade, 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 where the effect of treatment has $P \leq 0.10$.

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	0.3	242 bcd	124 e	61 d	9 bc	0 b	436 d	167 e	26	193 e	16 ef	2 bc	11.6 c
2	80 K_2O, broadcast, KCl	0	290 a	153 bcd	85 bcd	8 c	2 b	538 ab	209 cde	39	248 bcde	17 cdef	2 bc	14.0 a
3	160 K_2O, broadcast, KCl	0	253 bc	171 abc	106 abc	11 bc	1 b	543 ab	274 ab	16	290 abc	22 bcde	2 bc	13.3 ab
4	240 K_2O, broadcast, KCl	0	261 abc	158 bcd	105 abc	25 ab	2 b	550 a	253 abc	37	290 abc	24 abcd	5 ab	13.3 ab
5	320 K_2O, broadcast, KCl	0	233 cd	144 cde	126 a	33 a	8 a	544 ab	280 a	32	312 a	31 a	8 a	12.2 bc
6	80 K_2O, banded, KCl	0	268 abc	165 abc	58 d	10 bc	0 b	501 bc	204 cde	29	233 cde	13 f	2 bc	13.3 ab
7	160 K_2O, banded, KCl	0	271 ab	168 abc	78 cd	11 bc	3 ab	531 ab	220 bcde	40	260 abcd	17 def	2 bc	13.8 a
8	240 K_2O, banded, KCl	0	239 bcd	176 ab	89 bcd	11 bc	0 b	516 ab	230 abcd	47	277 abcd	19 cdef	2 bc	13.3 ab
9	240 K_2O, broadcast+sidedress, KCl	0	242 bcd	169 abc	112 ab	19 abc	2 b	544 ab	258 abc	45	303 ab	25 abc	4 abc	13.7 a
10	160 K_2O, broadcast, K_2SO_4	0	265 abc	193 a	75 cd	5 c	0 b	537 ab	243 abcd	29	272 abcd	15 ef	1 c	14.0 a
11	240 K_2O, broadcast, K_2SO_4	0	208 d	162 bcd	113 ab	33 a	3 ab	519 ab	288 a	24	312 a	29 ab	7 a	11.9 c
12	190 Cl, broadcast, $CaCl_2$	0	237 bcd	133 de	71 d	11 bc	4 ab	456 cd	187 de	32	219 de	19 cdef	3 bc	12.1 bc
	Treatment effect (P-value)	0.4653	*0.0609*	**0.0169**	**0.0202**	**0.0528**	0.4115	**0.0038**	**0.0239**	0.1332	*0.0509*	**0.0061**	*0.0874*	**0.0328**
	Effect of KCl (1 vs. 2-5)	**0.0038**	0.3387	**0.0171**	**0.0077**	0.1758	0.2129	**<0.0001**	**0.0033**	0.5404	**0.0037**	**0.0370**	0.2081	**0.0132**
	KCl rate, linear (1-5)	**0.0350**	0.3224	0.2199	**0.0018**	**0.0045**	**0.0319**	**0.0011**	**0.0014**	0.6624	**0.0020**	**0.0009**	**0.0070**	0.7214
Contrasts	KCl rate, quadratic (1-5)	*0.0723*	*0.0737*	**0.0118**	0.5979	0.2647	0.2338	**0.0080**	0.2157	0.7641	0.2808	0.5101	0.2061	**0.0048**
	Broadcast v banded (2-4 v 6,7,&12)	1.0000	0.4957	0.3623	**0.0489**	0.4735	0.7435	0.1007	0.1793	0.1699	0.3746	0.1094	0.5318	0.8711
	KCl v K_2SO_4 (3&4 v 9&10)	1.0000	0.1921	0.2890	0.4128	0.9180	0.9108	0.3666	0.9384	0.9944	0.9410	0.7824	0.8228	0.5103

Table 4. Effects of K and Cl treatments on potato tuber defects, specific gravity, and dry matter content. 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 where the effect of treatment has $P \leq 0.10$.

Treatment		Tuber defects (% of tubers)					Specific gravity	Dry matter content (%)
Number	Nutrient rate (lbs/ac), method, source	Total hollow heart	Disqualifying hollow heart	Total brown center	Disqualifying brown center	Common scab		
1	No product	3	2	3	2	0	1.0822 ab	21.6
2	80 K_2O, broadcast, KCl	0	0	0	0	0	1.0826 a	21.8
3	160 K_2O, broadcast, KCl	1	0	1	0	0	1.0801 bc	21.1
4	240 K_2O, broadcast, KCl	1	1	1	0	1	1.0793 cd	20.7
5	320 K_2O, broadcast, KCl	0	0	0	0	1	1.0776 d	20.2
6	80 K_2O, banded, KCl	0	0	0	0	1	1.0821 ab	21.7
7	160 K_2O, banded, KCl	1	1	1	1	0	1.0794 cd	20.5
8	240 K_2O, banded, KCl	0	0	0	0	1	1.0773 d	20.7
9	240 K_2O, broadcast+sidedress, KCl	0	0	2	0	0	1.0794 cd	21.0
10	160 K_2O, broadcast, K_2SO_4	0	0	0	0	0	1.0806 abc	21.0
11	240 K_2O, broadcast, K_2SO_4	0	0	0	0	0	1.0794 cd	20.6
12	190 Cl, broadcast, $CaCl_2$	1	1	1	1	0	1.0802 bc	20.5
	Treatment effect (P-value)	0.2735	0.2990	0.2934	0.1645	0.7053	**0.0073**	0.2664
Contrasts	Effect of KCl (1 vs. 2-5)	**0.0081**	**0.0133**	**0.0143**	**0.0017**	0.4484	**0.0426**	0.1728
	KCl rate, linear (1-5)	***0.0545***	0.1231	***0.0771***	**0.0217**	0.1127	**0.0003**	**0.0086**
	KCl rate, quadratic (1-5)	0.3193	0.1905	0.3622	**0.0500**	0.6497	0.4679	0.5257
	Broadcast v banded (2-4 v 6,7,&12)	0.6101	1.0000	0.6413	0.4436	0.4708	0.1921	0.5106
	KCl v K_2SO_4 (3&4 v 9&10)	0.2161	0.4109	0.2573	1.0000	0.3971	0.7914	0.8313

Table 5. Effects of K and Cl treatments on potato 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. Pairwise comparisons are presented only where the effect of treatment has $P \leq 0.10$.

Treatment		Plant stand (%)		Stems / plant
Number	Nutrient rate (lbs/ac), method, source	May 29	June 6	May 31
1	No product	98.8	100	3.5
2	80 K_2O, broadcast, KCl	100	100	3.8
3	160 K_2O, broadcast, KCl	100	100	3.5
4	240 K_2O, broadcast, KCl	100	99.4	3.9
5	320 K_2O, broadcast, KCl	99.4	99.4	4.0
6	80 K_2O, banded, KCl	100	100	3.8
7	160 K_2O, banded, KCl	100	100	4.0
8	240 K_2O, banded, KCl	100	100	3.6
9	240 K_2O, broadcast+sidedress, KCl	100	100	4.2
10	160 K_2O, broadcast, K_2SO_4	100	100	4.0
11	240 K_2O, broadcast, K_2SO_4	100	100	3.4
12	190 Cl, broadcast, $CaCl_2$	100	99.4	3.5
	Treatment effect (P-value)	0.5259	0.6077	0.5783
	Effect of KCl (1 vs. 2-5)	**0.0205**	0.3728	0.3695
	KCl rate, linear (1-5)	0.3337	***0.0640***	0.2762
Contrasts	KCl rate, quadratic (1-5)	**0.0178**	0.5928	0.7826
	Broadcast v banded (2-4 v 6,7,&12)	1.0000	0.4154	0.7592
	KCl v K_2SO_4 (3&4 v 9&10)	1.0000	0.3197	0.8880

Table 6. Effects of K and Cl treatments on potato leaflet greenness (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. Pairwise comparisons are presented only where the effect of treatment has $P \leq 0.10$.

Treatment		Leaflet cholorphyll content (SPAD-502)			
Number	Nutrient rate (lbs/ac), method, source	June 18	July 1	July 18	July 30
1	No product	48.3 a	43.9	46.5 a	37.6
2	80 K_2O, broadcast, KCl	45.5 bcde	41.6	42.6 bc	34.2
3	160 K_2O, broadcast, KCl	44.1 ef	41.5	40.6 c	34.2
4	240 K_2O, broadcast, KCl	44.2 ef	39.7	40.3 c	33.5
5	320 K_2O, broadcast, KCl	44.3 def	40.3	42.4 bc	35.4
6	80 K_2O, banded, KCl	45.8 bc	41.9	42.4 bc	35.4
7	160 K_2O, banded, KCl	44.3 cdef	41.1	42.2 bc	36.4
8	240 K_2O, banded, KCl	44.1 ef	40.0	41.6 bc	35.2
9	240 K_2O, broadcast+sidedress, KCl	43.8 f	41.4	42.7 bc	36.3
10	160 K_2O, broadcast, K_2SO_4	45.7 bcd	41.1	42.4 bc	35.9
11	240 K_2O, broadcast, K_2SO_4	44.6 cdef	40.3	40.7 c	35.3
12	190 Cl, broadcast, $CaCl_2$	46.5 b	41.4	44.0 ab	36.0
	Treatment effect (P-value)	**0.0003**	0.1271	**0.0278**	0.3535
Contrasts	Effect of KCl (1 vs. 2-5)	**<0.0001**	**0.0024**	**0.0002**	**0.0078**
	KCl rate, linear (1-5)	**<0.0001**	**0.0021**	**0.0047**	0.1322
	KCl rate, quadratic (1-5)	**0.0037**	0.1873	**0.0019**	**0.0144**
	Broadcast v banded (2-4 v 6,7,&12)	0.7803	0.8881	0.3334	***0.0557***
	KCl v K_2SO_4 (3&4 v 9&10)	0.1145	0.8858	0.3329	***0.0956***

Table 7. Effects of K and Cl treatments on canopy cover (Canopeo readings). 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 where the effect of treatment has P ≤ 0.10.

Treatment		Percent canopy cover (Canopeo)											
Number	Nutrient rate (lbs/ac), method, source	31-May	4-Jun	12-Jun	24-Jun	3-Jul	8-Jul	22-Jul	29-Jul	8-Aug	13-Aug	20-Aug	27-Aug
1	No product	18	32	49 d	79 d	87 c	90 c	89	88	79	66	49 cde	21 cd
2	80 K_2O, broadcast, KCl	25	41	59 ab	95 ab	96 ab	96 ab	83	86	78	67	57 abcd	24 cd
3	160 K_2O, broadcast, KCl	22	38	60 a	97 a	96 ab	98 a	89	89	76	64	53 bcde	21 cd
4	240 K_2O, broadcast, KCl	22	39	58 ab	94 ab	96 a	97 a	85	88	81	60	57 abcd	30 c
5	320 K_2O, broadcast, KCl	23	37	60 ab	94 ab	95 ab	97 a	91	90	83	75	71 a	49 a
6	80 K_2O, banded, KCl	23	39	56 abc	91 abc	94 ab	97 a	92	87	73	60	52 bcde	24 cd
7	160 K_2O, banded, KCl	22	38	56 abc	91 abc	95 ab	98 a	86	87	76	64	55 bcde	30 c
8	240 K_2O, banded, KCl	21	37	55 bc	91 abc	96 ab	97 a	86	84	76	67	64 ab	43 ab
9	240 K_2O, broadcast+sidedress, KCl	23	40	61 a	94 ab	96 a	98 a	91	91	82	71	61 abc	31 bc
10	160 K_2O, broadcast, K_2SO_4	22	37	56 abc	90 bc	96 a	97 a	88	88	80	67	70 a	45 a
11	240 K_2O, broadcast, K_2SO_4	19	33	52 cd	92 abc	96 a	98 a	90	91	84	77	41 e	19 cd
12	190 Cl, broadcast, $CaCl_2$	22	35	52 cd	87 c	92 b	93 bc	87	86	65	62	45 de	15 d
	Treatment effect (P-value)	0.4314	0.1702	**0.0086**	**0.0059**	**0.0097**	**0.0466**	0.3965	0.6117	0.1447	0.4668	**0.0272**	**0.0008**
Contrasts	Effect of KCl (1 vs. 2-5)	**0.0166**	**0.0086**	**0.0002**	**<0.0001**	**<0.0001**	**0.0007**	0.5476	0.9088	0.8809	0.9149	0.1373	0.1076
	KCl rate, linear (1-5)	0.1920	0.2789	**0.0052**	**0.0014**	**0.0023**	**0.0049**	0.4596	0.3994	0.3840	0.5052	**0.0282**	**0.0009**
	KCl rate, quadratic (1-5)	0.1755	**0.0204**	**0.0182**	**0.0007**	**0.0023**	**0.0299**	0.2186	0.5767	0.3826	0.1872	0.3626	**0.0339**
	Broadcast v banded (2-4 v 6,7,&12)	0.5777	0.3786	***0.0507***	***0.0561***	0.4490	0.8492	0.2881	0.4444	0.3429	0.9284	0.3071	0.6967
	KCl v K_2SO_4 (3&4 v 9&10)	0.3529	***0.0879***	**0.0165**	***0.0921***	0.9635	0.8711	0.5346	0.5488	0.3373	***0.0641***	***0.0864***	**0.0241**

Table 8. Effects of K and Cl treatments on vine dry biomass at vine kill. 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 where the effect of treatment has $P \leq 0.10$.

Treatment		Vine dry biomass (T/ac)
Number	Nutrient rate (lbs/ac), method, source	
1	No product	0.51
2	80 K_2O, broadcast, KCl	0.63
3	160 K_2O, broadcast, KCl	0.64
4	240 K_2O, broadcast, KCl	0.66
5	320 K_2O, broadcast, KCl	0.69
6	80 K_2O, banded, KCl	0.54
7	160 K_2O, banded, KCl	0.67
8	240 K_2O, banded, KCl	0.62
9	240 K_2O, broadcast+sidedress, KCl	0.71
10	160 K_2O, broadcast, K_2SO_4	0.58
11	240 K_2O, broadcast, K_2SO_4	0.56
12	190 Cl, broadcast, $CaCl_2$	0.56
	Treatment effect (P-value)	0.8896
Contrasts	Effect of KCl (1 vs. 2-5)	0.1607
	KCl rate, linear (1-5)	0.1760
	KCl rate, quadratic (1-5)	0.6275
	Broadcast v banded (2-4 v 6,7,&12)	0.6242
	KCl v K_2SO_4 (3&4 v 9&10)	0.3611

Table 9. Effects of K and Cl treatments on soil water K concentration at a depth of 4 feet.

Treatment		Soil water K concentration (ppm)			
Number	Nutrient rate (lbs/ac), method, source	May 29	Jun 26	Jul 25	Sep 18
1	No product	2.2	3.1	3.7	0.6
4	240 K_2O, broadcast, KCl	2.3	4.5	4.5	0.6
8	240 K_2O, banded, KCl	1.5	2.3	2.2	0.2
11	240 K_2O, broadcast, K_2SO_4	1.6	1.7	1.9	0.4
12	190 Cl, broadcast, $CaCl_2$	2.0	2.5	2.6	0.3
	Treatment effect (P-value)	0.7987	0.1521	0.2331	0.7249

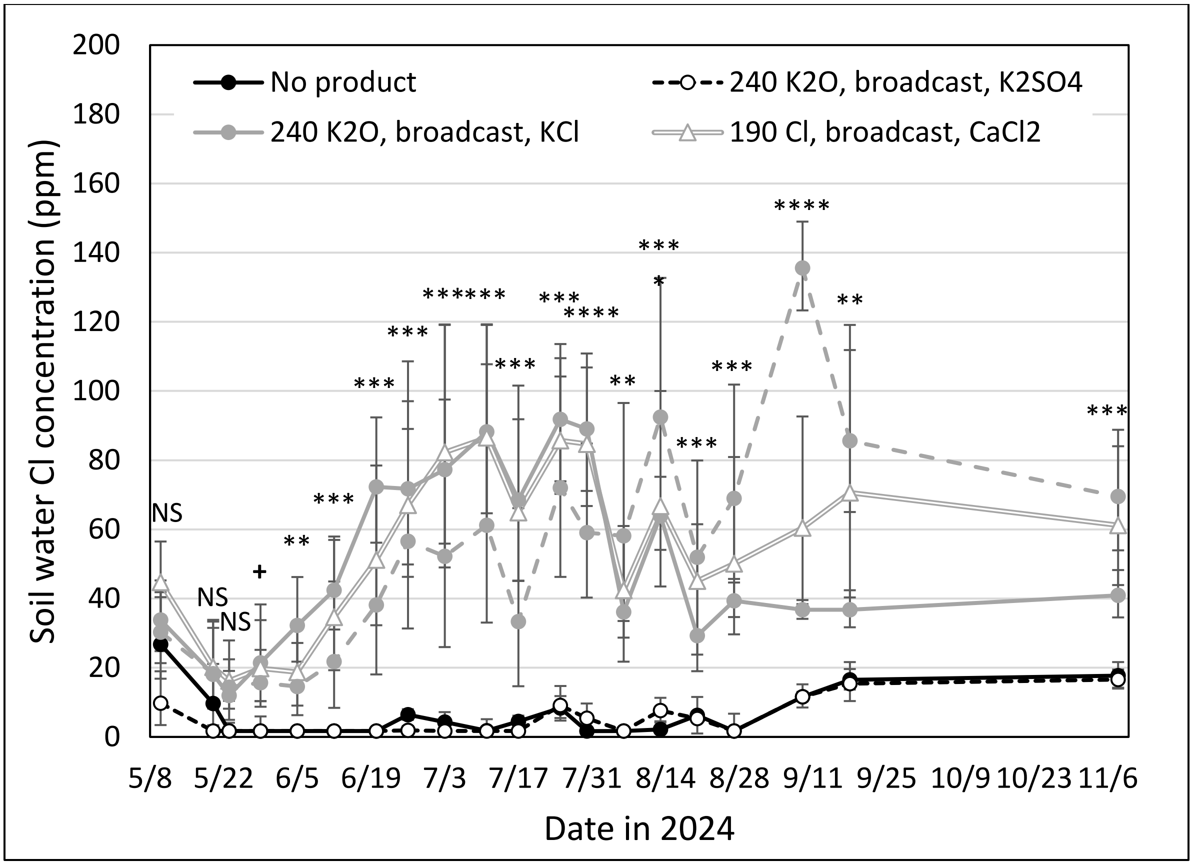

Figure 2. Effects of K and Cl treatments on soil water Cl concentration at a depth of 4 feet. Error bars indicate standard error of the mean. NS: not significant. +: P ≤ 0.10. *: P < 0.05. **: P < 0.01. ***: P < 0.001. ****: P < 0.0001.

Table 10. Effects of K and Cl treatments on end-of-season (i.e., October 11) soil K and Cl concentrations. 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 where the effect of treatment has P ≤ 0.10.

Treatment		End-of season soil	
Number	Nutrient rate (lbs/ac), method, source	K (ppm)	Cl (ppm)
1	No product	51 b	8.2
2	80 K_2O, broadcast, KCl	.	8.0
3	160 K_2O, broadcast, KCl	.	10.8
4	240 K_2O, broadcast, KCl	75 a	8.9
5	320 K_2O, broadcast, KCl	.	10.9
6	80 K_2O, banded, KCl	.	8.7
7	160 K_2O, banded, KCl	.	8.7
8	240 K_2O, banded, KCl	.	9.7
9	240 K_2O, broadcast+sidedress, KCl	.	8.8
10	160 K_2O, broadcast, K_2SO_4	.	7.1
11	240 K_2O, broadcast, K_2SO_4	.	9.1
12	190 Cl, broadcast, $CaCl_2$	52 b	9.8
	Treatment effect (P-value)	**0.0076**	0.1464
Contrasts	Effect of KCl (1 vs. 2-5)	.	0.1687
	KCl rate, linear (1-5)	.	**0.0359**
	KCl rate, quadratic (1-5)	.	0.9330
	Broadcast v banded (2-4 v 6,7,&12)	.	0.8485
	KCl v K_2SO_4 (3&4 v 9&10)	.	**0.0489**

Evaluation of agronomic performance and after-cooking tuber darkening in Elk River Russet relative to Russet Burbank

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Summary

Elk River Russet is a new fresh-market or processing potato cultivar notable for the uniform and pleasing shape of its deeply russeted, oblong tubers. While its field performance has been extensively evaluated, the clean, certified seed now available to growers has not been thoroughly tested to ensure that the results obtained from breeder seed are representative. In addition, a grower reported in 2023 that Elk River Russet tubers seemed to be prone to after-cooking darkening. In this study, we evaluated the performance of Elk River Russet and Russet Burbank, each grown with total N application rates of 80 and 200 lbs/ac, in terms of tuber yield and quality, including the prevalence of after-cooking darkening. Elk River Russet had significantly lower total yield and U.S. No. 2 yield, but significantly higher U.S. No. 1 yield and total marketable yield than Russet Burbank, as well as a larger percentage of its total yield in tubers over 6 or 10 ounces. Russet Burbank had significantly more tubers per plant than Elk River Russet, suggesting that the poor tuber bulking observed in Russet Burbank was due to each plant having more tubers than it could effectively bulk. Elk River Russet had higher tuber specific gravity and dry matter content than Russet Burbank. Tuber darkening and the occurrence of chlorogenic acid, which is implicated in after-cooking tuber darkening, were not generally related to cultivar, indicating that Elk River Russet was no more susceptible to this issue than Russet Burbank under the conditions of this study. Because after-cooking darkening has been observed in previous years, the results suggest that this disorder is affected by environmental conditions during the growing season.

Background

Elk River Russet is a mid-season fresh-market or processing potato of uncertain parentage from the University of Minnesota. It is notable for the relatively uniform and pleasing size and shape of its oblong tubers, which have deep russeting, good skin set, a low prevalence of hollow heart and brown center, and high specific gravity. While it generally has lower total yields than Russet Burbank, a greater percentage of its yield is represented by U.S. No. 1 tubers, with fewer undersized or U.S. No. 2 tubers than Russet Burbank.

The cultivar, under the breeding name MN13142, has been extensively evaluated. However, much of this evaluation has been conducted on breeder seed, not on the clean, certified seed now available to growers. In addition, reports from a grower in 2023 indicated that Elk River Russet may be prone to after-cooking darkening of the tuber flesh, which has not been the subject of previous research on this cultivar. In 2024, the performance of Elk River Russet and Russet Burbank were compared at two N rates: 80 and 200 lbs/ac total N. Crop responses to N rate are presented in terms of tuber yield, size, grade, and quality, including the prevalence of after-cooking darkening.

Methods

The study was conducted at the Sand Plain Research Farm (SPRF) at Becker, MN, in 2024, on a Hubbard loamy sand soil. The previous crop was soybeans. Initial soil characteristics from samples taken on April 12 are presented in Table 1. The study was set up as a randomized complete block design with four blocks and four treatments defined by potato cultivar (Russet Burbank or Elk River Russet) and N rate (80 or 200 lbs/ac N). These treatments are summarized in Table 2.

Each plot was 12 feet (6 rows) wide and 20 feet long. Tubers were taken from the central 18 feet of rows 4 and 5, and each of these two rows was marked by a red potato planted at each end of the row. Row 2 was used for in-season 5-plant samples. The field was 2 plots wide and 8 plots long, and the entire field was surrounded by a 3-foot buffer of potato plants to reduce edge effects. The plants in the buffer strip were of the same cultivar and received the same N treatment as the plants in the adjacent plot.

The whole field received 200 lbs/ac MOP (0-0-60) and 200 lbs/ac SulPoMag (0-0-22-22S-11Mg) on April 22. On May 2, a mixture of 3-ounce cut "A" and whole "B" seed pieces was planted by hand in each plot with 36" spacing between rows and 12" spacing within rows. 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 15, 120 lbs/ac N was side-dress applied by hand as Environmentally Smart Nitrogen (ESN, Nutrien: 44-0-0) according to treatment.

Five adjacent plants were hand-dug from row 2 of each plot on each of four sampling dates: July 31 and August 8, 19, and 28. The tubers were sorted into five size categories: 0-4 oz., 4-6 oz., 6-10 oz., 10-14 oz., and over 14 oz. Tubers over 4 oz. were sorted into U.S. No. 1 and U.S. No. 2 categories based on USDA standards for processing potatoes. Cull tubers were sorted into a single category, regardless of size. The tuber sample in each size-grade category was weighed to estimate per-acre yield.

Vines were chopped with a flail mower on September 9, and tubers were harvested on September 18. This harvest sample of tubers was sorted by the same standards used for the 5-plant samples. A size-representative subsample twenty-five U.S. No. 1 tubers was collected from each plot's harvest for internal quality assessments. This subsample was used to estimate the prevalence of hollow heart, brown center, and scab, as well as tuber specific gravity and dry matter content.

A separate subsample was set aside to evaluate the propensity of each treatment toward cooking-induced darkening. Two tubers from each treatment and harvest date were baked at 300°F for 2 hours, sliced in half lengthwise, and assessed for darkening on a subjective scale from 1 (no darkening) through 2 (minor darkening) to 3 (major darkening). A note was made when observed darkening appeared to be related to external damage (i.e., bruising), and the results were analyzed both with and without such bruise-related damage included. A third tuber was sliced and analyzed for chlorogenic acid, the primary compound implicated in after-cooking darkening, using a urea/tartaric acid/sodium nitrate staining test. Tubers were scored on a scale of 1 (no staining detected), 2 (staining around the edge or near the stem), or 3 (staining throughout the flesh). Because flesh close to the tuber surface would be removed if the tuber were peeled, darkening is of greater concern when it is deeper in the flesh.

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, and their interaction as fixed effects, with block treated as a random effect. 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

Rainfall and irrigation

Daily and cumulative rainfall and irrigation from April through September in the study field are presented in Figure 1. The average rainfall totals for these months in Becker, MN, are 2.83” in April, 3.78” in May, 4.37” in June, 3.91” in July, 4.15” in August, and 3.07” in September, for a total of 22.11”. In 2024, the season was much wetter than average in April (4.93”), June (7.67”), and August (6.14”), close to average in May (4.39”) and July (4.25”), and drier than average in September (0.28”). After April, rainfall was supplemented with irrigation as needed, supplying 0.55” of water in May, 1.76” in June, 4.35” in July, 2.25” in August, and 1.00” in September. In total, 27.66” in rain fell, supplemented with 9.91” of irrigation, for a total of 37.57” of water in April through September.

Tuber yield, size, and grade

Results for tuber yield, size, and grade at harvest are presented in Table 3. Overall, while Russet Burbank had greater total and U.S. No. 2 yield than Elk River Russet, the opposite was true of U.S. No. 1 yield and total marketable yield. The percentages of total yield represented by tubers over 6 and 10 ounces were significantly greater for Elk River Russet than for Russet Burbank. Elk River Russet had higher absolute yields of 6-10-ounce and 10-14 ounce tubers than Russet Burbank, while Russet Burbank had much higher yields of tubers under 4 ounces. These results indicate that Elk River Russet was much more successful at bulking its tubers this season. One explanation for this difference is that Russet Burbank plants had substantially more tubers (14.3 tubers per plant) to bulk, on average, than Elk River Russet plants (9.8 tubers per plant).

The application rate of N also substantially affected yield, with treatments receiving 200 lbs/ac N having higher total yield, U.S. No. 1 yield, and total marketable yield, but lower U.S. No. 2 yield, than treatments receiving 80 lbs/ac N. The higher-N treatments also had greater percentages of total yield in tubers over 6 and 10 ounces and lower yields of tubers under 4 ounces than the lower-N treatments. However, N rate had no effect on the number of tubers per plant.

The effects of cultivar and N rate on total, U.S. No. 1, and total marketable yield were additive, but the effect of the cultivar*rate interaction on U.S. No. 2 yield and the percentages of yield over 6 and 10 ounces were significant. U.S. No. 2 yield was negligible in Elk River Russet regardless of N rate, while in Russet Burbank, the lower N rate produced higher U.S. No. 2 yield. The percentages of yield in tubers over 6 and 10 ounces were more strongly affected by N rate in Elk River Russet than in Russet Burbank, but both cultivars had higher percentages at 200 lbs/ac N than 80 lbs/ac N.

Results for total tuber yield and the percentage of yield represented by tubers over 6 ounces from 5-plant samples taken on July 31 and August 8, 19, and 28, together with the results from final harvest on September 18, are presented in Figure 2. Overall, bulking increased through August 19 and then remained constant, suggesting that conditions were not conducive for late season bulking in 2024 for either cultivar. Averaging between the two N rates, Russet Burbank had greater total yield than Elk River Russet (Figure 2a) on all sampling dates. Averaging between the two cultivars, plots receiving 200 lbs/ac N had greater total yields than those receiving 80 lbs/ac N on all sample dates. The only significant cultivar*N rate interaction effect on total yield occurred on the third sampling date, August 19 (P = 0.0432). On this date, the effect of N on tuber yield was much larger in Russet Burbank than in Elk River Russet. Yield generally increased over time, especially between July 31 and August 19.

Averaging between the two N rates, Elk River Russet had significantly more of its total yield in tubers over 6 ounces on the last 4 sample dates, and the difference between the two cultivars approached statistical significance (P = 0.0543) on the first sample date. Averaging between the two cultivars, plots receiving 200 lbs/ac N had significantly more of their total yield in tubers over 6 ounces than those receiving 80 lbs/ac N on August 19 and September 18, while the difference approached statistical significance on 8 August (P = 0.0618) and August 28 (P = 0.0835). The cultivar*N rate interaction was only significant at harvest, when N rate had a stronger effect on the percentage of yield in tubers over 6 ounces in Elk River Russet than it did in Russet Burbank.

Tuber quality

Results for tuber quality are presented in Table 4. Neither cultivar nor N rate significantly affected the prevalence of hollow heart, brown center, or common scab. None of these conditions were common in any treatment. Tuber specific gravity and dry matter content were significantly higher in Elk River Russet than Russet Burbank, regardless of N rate. N rate had no significant effect on tuber specific gravity in Russet Burbank. In Elk River Russet, the treatment receiving 80 lbs/ac N had a significantly higher mean specific gravity than the treatment receiving 200 lbs/ac N.

After-cooking darkening and chlorogenic acid

Results for tuber darkening after baking and detection of chlorogenic acid (which is implicated in after-cooking darkening) are presented in Table 5. Tubers collected on July 31 August 8, 19, and 28, and September 18 (i.e., final harvest) were baked and evaluated for dark areas in the flesh. Some of these dark areas were attributable to external damage (i.e., bruising). When these areas were included in the analyses, Elk River Russet tubers collected from plots receiving 200 lbs/ac N on August 28 showed more darkening than tubers from any other treatment. Averaged across cultivars and including bruising, tubers collected at harvest from plots receiving 200 lbs/ac N had numerically more darkening than those from plots receiving 80 lbs/ac N, with the difference approaching statistical significance (P = 0.0996). When bruising damage was excluded from the analyses, neither cultivar nor N rate had a significant effect on tuber darkening on any sampling date.

The presence and spatial pattern of chlorogenic acid (i.e., whether it was detected deep within the tuber or only near the surface) was unrelated to cultivar or N rate on July 31. At harvest, tubers from plots receiving 80 lbs/ac N had more widespread chlorogenic acid than those from plots receiving 200 lbs/ac N. Given that chlorogenic acid is known to promote after-cooking darkening, this effect of N rate ran counter to the trend observed for tuber color after baking for tubers collected at harvest.

Conclusions

Consistent with previous results, Elk River Russet had lower total tuber yield than Russet Burbank, but more of that yield was represented by U.S. No. 1 tubers. In 2024, this was true to such an extent that Elk River Russet had greater U.S. No. 1 yield than Russet Burbank. This was due primarily to differences in tuber bulking between the two cultivars. Both cultivars had poor tuber bulking in this year compared to previous years, but the effect was more severe with Russet Burbank. At 200 lbs/ac N, only 57% of Russet Burbank yield was of marketable size in 2024, versus 75% of Elk River Russet yield. Typically, about 90% of yield is marketable in both cultivars. Accordingly, Elk River Russet had significantly more of its yield in tubers over 6 oz. than Russet Burbank. A secondary cause of the difference in U.S. No. 1 yield between the two cultivars is an opposite difference in U.S. No. 2 yield, with Russet Burbank having five times the U.S. No. 2 yield of Elk River Russet at 200 lbs/ac N.

Poor tuber bulking in 2024 was caused in part by greater tuber set compared to 2023. The number of tubers per plant at harvest increased from 8.1 to 9.8 for Elk River Russet and from 9.1 to 14.3 for Russet Burbank between 2023 and 2024. Apparently, Russet Burbank has greater plasticity in tuber set than Elk River Russet. In 2024, it is possible that resources for tuber production were more abundant early in the season, when tubers were set, than they were late in the season, when the plants were bulking the tubers they had set. As a result, Russet Burbank's stronger tuber set response turned out to be a disadvantage because this cultivar had effectively produced too many tubers to bulk relative to lower number of tubers per plant for Elk River Russet.

Certified grower seed for Elk River Russet was used in field evaluations at SPRF in 2023 and 2024. Because tuber bulking was unusually poor in 2024 (an issue that was widespread in the region), it is not clear whether the certified seed performs differently from the breeder seed. However, Elk River Russet's performance in 2023, in terms of tuber yield and quality, was generally not markedly different from its performance in 2020 and 2022. However, there was a substantial difference in the prevalence of hollow heart, brown center, and common scab, all of which were less common in 2023 (and 2024) than 2020 and 2022.

Based on visual examination of baked tubers and chemical tests on raw tubers, we did not find that Elk River Russet had a notably greater prevalence of after-cooking tuber darkening or deep-tissue chlorogenic acid (which causes after-cooking tuber darkening) than Russet Burbank. The prevalence of tuber darkening is known to depend in part on growing conditions, and the fresh-market grower who observed this tendency in Elk River Russet in 2023 primarily grows cultivars other than Russet Burbank. The differences in weather, soil, and reference varieties between this grower's field in 2023 and our study field in 2024 may all potentially explain the difference in Elk River Russet's apparent susceptibility to darkening between the two.

Table 1. Initial soil characteristics in the study field at SPRF in Becker, MN, in 2024.

0 - 6 inches											
pH	Organic matter (%)	Bray P (mg/kg)	NH$_4$OAc-K (mg/kg)	NH$_4$OAc-Ca (mg/kg)	NH$_4$OAc-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)
6.4	2.6	19	75	1097	200	24	31	2.3	0.8	0.3	9

Table 2. N rates applied to Elk River Russet and Russet Burbank plants at SPRF in Becker, MN, in 2024.

Cultivar	N applied (lbs/ac)		
	As DAP[1] at planting	As ESN[2] at emergence	Total
Elk River Russet	40	40	80
	40	160	200
Russet Burbank	40	40	80
	40	160	200

[1] Diammonium phosphate (18-46-0)

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

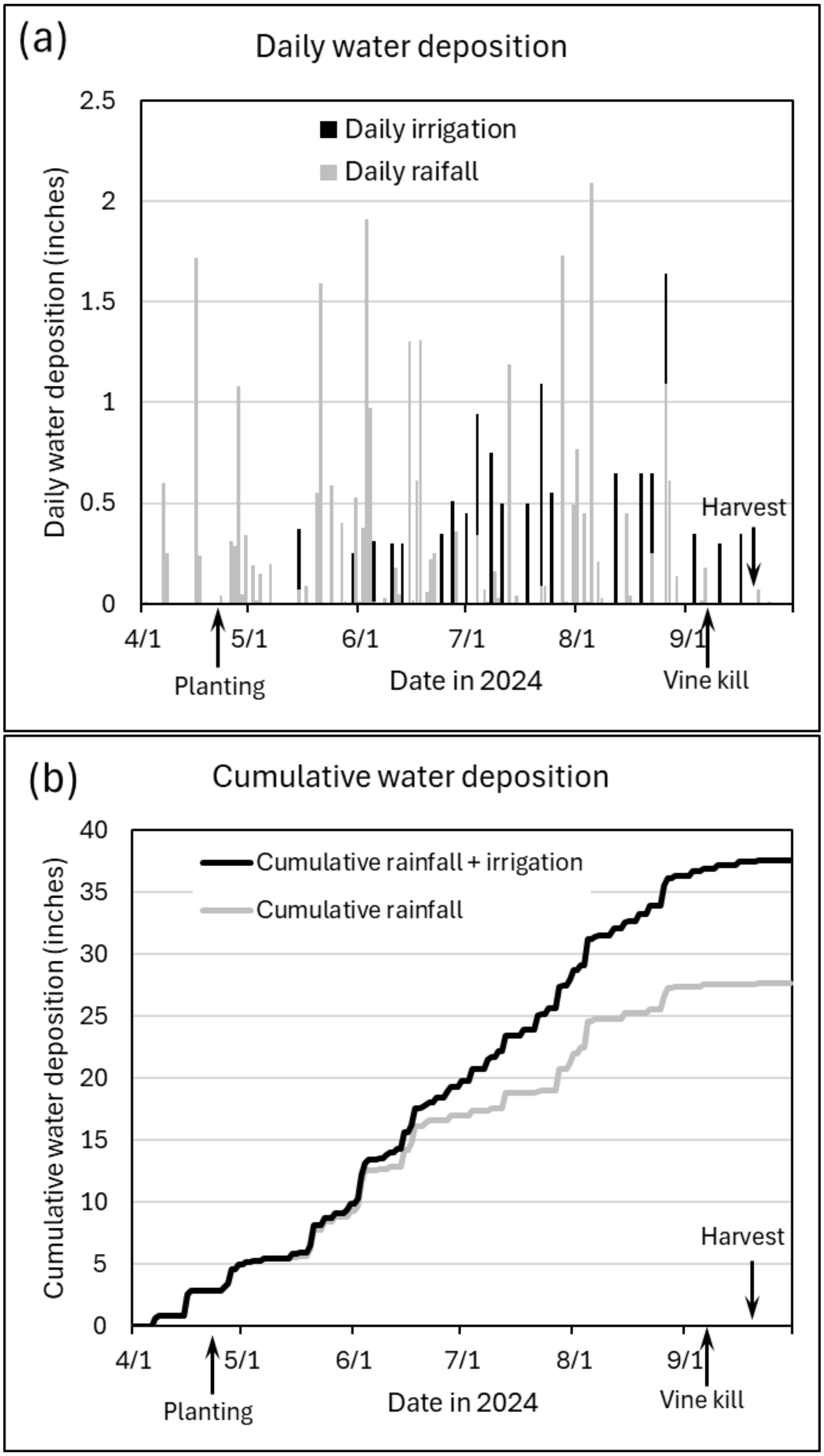

Figure 1. Daily (a) and cumulative (b) rainfall and irrigation at the study site at SPRF in 2024.

Table 3. Yield, size, and grade of Elk River Russet and Russet Burbank tubers grown with 80 or 200 lbs/ac N at SPRF in 2024.

Cultivar	Total N applied (lbs/ac)	Yield (cwt/ac)										% yield in tubers over:		Tubers / plant
		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	Average of both rates	0	134 b	162	138 a	23 a	3	460 b	324 a	2 b	326 a	35 a	5 a	9.8 b
Burbank		0	274 a	181	82 b	8 b	1	547 a	250 b	23 a	273 b	16 b	2 b	14.3 a
Effect of cultivar (P-value)		.	**<0.0001**	0.2629	**0.0002**	**0.0128**	0.3205	**0.0021**	**0.0070**	**<0.0001**	**0.0485**	**<0.0001**	**0.0105**	**<0.0001**
Average of both cultivars	80	0	218 a	164	77 b	6 b	0	466 b	231 b	16 a	247 b	18 b	1 b	12.0
	200	0	190 b	179	143 a	25 a	4	541 a	342 a	9 b	351 a	33 a	6 a	12.1
Effect of N rate (P-value)		.	**0.0253**	0.3716	**<0.0001**	**0.0023**	0.1478	**0.0050**	**0.0006**	**0.0459**	**0.0016**	**<0.0001**	**0.0053**	0.7015
Elk River Russet	80	0	142	176 ab	97	7 b	0	423	281	0 c	281	25 b	2 b	9.9
	200	0	126	147 b	179	38 a	6	496	367	3 c	371	45 a	9 a	9.8
Russet Burbank	80	0	294	151 b	56	5 b	1	508	182	31 a	214	11 c	1 b	14.1
	200	0	255	211 a	108	12 b	1	586	317	15 b	332	21 b	2 b	14.5
Effect of cultivar*N rate (P-value)		.	0.3022	**0.0237**	0.1484	**0.0282**	0.1420	0.8973	0.2930	**0.0094**	0.5562	**0.0367**	**0.0289**	0.5936

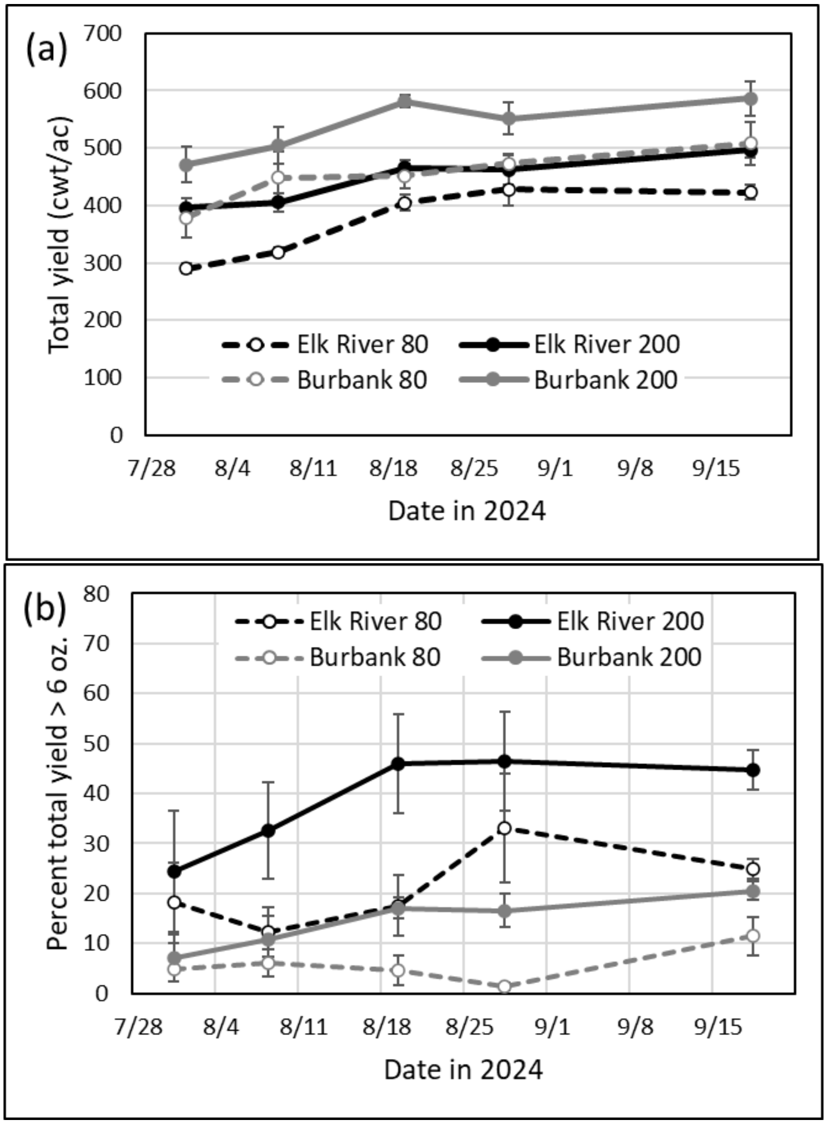

Figure 2. Total yield (a) and the percentage of total yield in tubers over 6 oz. (b) of Elk River Russet and Russet Burbank plants grown with 80 or 200 lbs/ac N at SPRF at five time points in 2024. Error bars indicate ± standard error.

Table 4. Prevalence of tuber defects as well as tuber specific gravity and dry matter for Elk River Russet and Russet Burbank tubers grown with 80 or 200 lbs/ac N at SPRF in 2024.

Cultivar	Total N applied (lbs/ac)	Prevalence (% of tubers)			Specific gravity	Dry matter content (%)
		Hollow heart	Brown center	Common scab		
Elk River	Average of both rates	2	2	1	1.0948 a	25.2 a
Burbank		4	4	0	1.0832 b	23.1 b
Effect of cultivar (P-value)		0.5674	0.5674	0.3370	**<0.0001**	**0.0002**
Average of both cultivars	80	2	2	1	1.0892	24.0
	200	4	4	0	1.0888	24.3
Effect of N rate (P-value)		0.5336	0.5336	0.3370	0.7614	0.4738
Elk River Russet	80	1	1	2	1.0968 a	25.4
	200	4	4	0	1.0929 b	25.1
Russet Burbank	80	4	4	0	1.0816 c	22.7
	200	4	4	0	1.0847 c	23.5
Effect of cultivar*N rate (P-value)		0.6578	0.6578	0.3370	**0.0319**	0.1362

Table 5. Average post-cooking tuber darkening (1= no darkening; 2 = minor darkening; 3 = major darkening) on each of five sampling dates, as well as chlorogenic acid detection scores of raw tubers (1 = none detected or specks; 2 = detected around edges of tuber or near stem; 3 = detected throughout flesh) on 31 July and at harvest, for Elk River Russet and Russet Burbank tubers grown with 80 or 200 lbs/ac N at SPRF in 2024.

Cultivar	Total N applied (lbs/ac)	Tuber darkening including bruising					Tuber darkening excluding bruising					Chlorogenic acid	
		7/31	8/8	8/19	8/28	9/18 (harvest)	7/31	8/8	8/19	8/28	9/18 (harvest)	7/31	9/18 (harvest)
Elk River	Average of both rates	1.00	1.00	1.19	1.25 a	1.25	1.00	1.00	1.00	1.19	1.13	1.83	2.08
Burbank		1.00	1.06	1.00	1.00 b	1.14	1.00	1.00	1.00	1.00	1.00	1.67	2.17
Effect of cultivar		1.0000	0.3370	0.2046	**0.0306**	0.4511	1.0000	1.0000	1.0000	0.1432	0.3774	0.5796	0.6202
Average of both cultivars	80	1.00	1.00	1.06	1.00 b	1.06 b	1.00	1.00	1.00	1.00	1.00	1.67	2.33 a
	200	1.00	1.06	1.13	1.25 a	1.33 a	1.00	1.00	1.00	1.19	1.13	1.83	1.92 b
Effect of N rate		1.0000	0.3370	0.6627	**0.0306**	***0.0996***	1.0000	1.0000	1.0000	0.1432	0.3774	0.5796	**0.0401**
Elk River Russet	80	1.00	1.00	1.13	1.00 b	1.00	1.00	1.00	1.00	1.00	1.00	1.83	2.17
	200	1.00	1.00	1.25	1.50 a	1.50	1.00	1.00	1.00	1.38	1.25	1.83	2.00
Russet Burbank	80	1.00	1.00	1.00	1.00 b	1.13	1.00	1.00	1.00	1.00	1.00	1.50	2.50
	200	1.00	1.13	1.00	1.00 b	1.15	1.00	1.00	1.00	1.00	1.00	1.83	1.83
Effect of cultivar*N rate		1.0000	0.3370	0.6627	**0.0306**	0.1321	1.0000	1.0000	1.0000	0.1432	0.3774	0.5796	0.1682

Effects of soil health management strategy and cultivar on potato yield and quality

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Summary

Managing farmland for improved soil health has been found to be economically beneficial in some corn and soybean systems. Potential benefits include reduced soil erosion, improved nutrient cycling and disruption of soil-borne disease cycles. Because the adoption of reduced tillage practices is a major part of improving soil health in such systems, it is not known whether the gains from soil health management observed in corn and soybean systems pertain to potato systems. Addressing this question is a major goal of the Potato Soil Health Project. As part of this project, the University of Minnesota established a field of experimental plots at the Sand Plain Research Farm (SPRF) in Becker, MN. In a split-plot randomized complete block design, whole plots were defined by rotation (2- or 3-year) while subplots were defined by management system and potato cultivar. In 2024, potatoes were grown for the third time in the 2-year rotation plots. Russet Burbank and Russet Norkotah were grown under three management practices: (1) a conventional potato-soybean rotation with metam sodium fumigation in the fall before each potato year and (2) pro-microbial practices in which the soybean crop and fumigant were replaced with a field pea cash crop, a mustard biofumigant crop, a rye cover crop, and an application of aged turkey manure. Russet Burbank and Bannock Russet, which is resistant to *Verticillium* wilt, were grown under (3) conventional management without fumigation. For both Russet Burbank and Russet Norkotah, the conventional management system resulted in greater total and marketable yields and a larger percentage of yield in tubers over 6 ounces than the pro-microbial system. The conventional system also had a lower prevalence of common scab in Russet Norkotah. Russet Burbank had higher total yield in the pro-microbial system than the no-fumigant system, but the two strategies produced similar marketable yields. Bannock Russet without fumigation had the highest marketable yield and percentages of yield in tubers over 6 and 10 ounces in the study, and its tubers had the highest specific gravity and dry matter content. These results suggest that the pro-microbial management approach used in this study does not provide the full benefits that soil fumigation does to tuber yield, but it produces better yield results than a conventional approach minus fumigation. In terms of crop production, based on the results with Bannock Russet, the use of disease-resistant cultivars may be a better replacement for fumigation than a mustard crop, but for Russet Burbank, pro-microbial management without chemical fumigation did confer benefits over conventional management without fumigation.

Background

Maintaining and improving soil health is essential to the long-term sustainability of a cropping system. A study released by the Soil Health Institute and Cargill in 2022 found that soil health management systems increased net income for 85% of farmers growing corn and 88% of farmers growing soybeans, with average increases of net income of $51.60 and $44.89 for corn and soy, respectively. Because these gains depend largely on the adoption of reduced or no-till practices, however, it is not clear how applicable these results are to potato cropping systems, in which significant soil disturbance occurs at planting, hilling, and harvest in potato years.

The goal of the Potato Soil Health Project is to evaluate the potential for soil-health-promoting practices to improve soil health in potato cropping systems, where low tillage is not an option. One component of this project involves small-plot studies conducted by 8 university research teams across the country. Each study evaluates 6 treatments in a 2-year rotation and 6 in a 3-year rotation.

In Minnesota, each of the two rotations has six treatments defined by cultivar and management approach. Under the first management approach, Russet Burbank and Russet Norkotah were grown in conventional rotations, including soil fumigation with metam sodium in potato years and either a potato-soybean two-year rotation or a potato-corn-soybean three-year rotation. Under the second approach, the same cultivars were grown with microbiome-promoting practices, including (1) aged turkey manure applications in potato and corn years, (2) replacement of soy in the rotations with field peas followed by mustard as a biofumigant followed by a winter rye cover crop, and (3) no chemical fumigant after the first potato year. Under the third approach, Russet Burbank and Bannock Russet were grown under a conventional regime like that used in the first approach except that no chemical fumigant was applied at any time.

Potatoes were grown in 2019 and 2022 in the 3-year rotation and in 2020, 2022, and 2024 in the 2-year rotation. Here, we present the results from research plots in Minnesota for the third potato year of the 2-year rotation (2024).

Methods

The study was conducted at the University of Minnesota's Sand Plain Research Farm (SPRF) in Becker, MN, on a Hubbard loamy sand soil in 2024. Prior to becoming part of SPRF, the field was in a three-year potato rotation for several decades. It was known to be a poor field for potato production, presenting an opportunity to evaluate the potential for soil-health-promoting practices to improve both soil health and potato production in challenging fields. The most recent pre-planting soil nutrient concentrations are presented in Table 1, while other soil characteristics are presented in Table 2.

A total of 12 treatments were applied in a split-plot randomized complete block design with whole plots defined by rotation and subplots defined by cultivar and soil health management approach. Six treatments were applied within each of the two rotations (2-year and 3-year). The results for the third potato year of the 2-year rotation are presented here.

The six treatments in this rotation were defined by soil management system (conventional, pro-microbial, or no fumigant) and cultivar (Russet Burbank, Russet Norkotah, or Bannock Russet). Russet Burbank was selected because it is widely planted and well-studied, providing a good baseline for comparison. Russet Norkotah was selected for its greater susceptibility to common scab compared to Russet Burbank, while Bannock Russet was selected for the non-fumigated treatment because it is highly resistant to potato early dying compared to Russet Burbank. Each subplot was 30 feet long and 18 feet (6 rows) wide. The entire field was surrounded by a 3-foot buffer of potato plants to reduce edge effects. The treatments are summarized in Table 3.

The conventionally managed subplots were fumigated with metam sodium applied at 50 gallons/ac on October 24, 2023. Aged turkey manure (4.3-4-4.2) was applied to the pro-microbially managed plots on April 11, 2024, at a rate of 3 T/ac, providing 135 lbs/ac total N, of which 94.5 lbs/ac N (70% of the total) was assumed to be available to plants in 2024. In addition, 37.5 lbs/ac N was assumed to be released by manure applied in 2023, for a total of 132 lbs/ac N. On 12 April, 200 lbs/ac MOP (0-0-60) and 200 lbs/ac SulPoMag (0-0-22-21S-11Mg) were broadcast over all plots, providing 164 lbs/ac K_2O equivalent, 42 lbs/ac S, and 22 lbs/ac Mg. All plots were tilled on April 12 and 18.

On April 19, all plots were planted with their assigned cultivar. Rows were spaced 36 inches apart. Cut "A" and whole "B" 3-4-oz. seed pieces were planted with 12-inch spacing. At planting, a fertilizer blend was mechanically banded in the entire field, providing 40 $lbs \cdot ac^{-1}$ N, 102 $lbs \cdot ac^{-1}$ P_2O_5, 181 $lbs \cdot ac^{-1}$ K_2O, 40 $lbs \cdot ac^{-1}$ S, 20 $lbs \cdot ac^{-1}$ Mg, 1 $lb \cdot ac^{-1}$ Zn, and 0.6 $lbs \cdot ac^{-1}$ B, supplied in the form of 173 $lbs \cdot ac^{-1}$ DAP (18-46-0), 141 $lbs \cdot ac^{-1}$ SulPoMag, 184 $lbs \cdot ac^{-1}$ MOP, 2 $lbs \cdot ac^{-1}$ $ZnSO_4$ (17.5% S, 35.5% Zn), and 3 $lbs \cdot ac^{-1}$ 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.

On May 16, 68 lbs/ac N was applied as side-dressed urea (46-0-0) in all treatments. An additional 132 lbs/ac N as urea was side dressed by hand in the conventional and no-fumigation treatments to match the N provided by manure in the pro-microbial plots so that 240 lbs/ac total available N had been applied to all treatments at this point in the season. The rows were then hilled. On 1 July, 20 lbs/ac N were applied as 28% UAN. Additional UAN applications at 20 lbs/ac N were made in plots with Russet Burbank and Bannock Russet, which has a longer growing season than Russet Norkotah, on July18 and July 31.

On August 8, vines were shredded with a flail mower in the Russet Norkotah plots. Vines were beaten in the Russet Burbank and Bannock Russet plots on September 6. All tubers were harvested on September 30 and sorted on October 4. The tubers were sorted into five size categories: 0-4 oz., 4-6 oz., 6-10 oz., 10-14 oz., and over 14 oz. Tubers over 4 oz. were sorted into U.S. No. 1 and U.S. No. 2 categories based on USDA standards for processing potatoes. Cull tubers were sorted into a single category, regardless of size. The tuber sample in each size-grade category was weighed to estimate per-acre yield.

A size-representative subsample twenty-five U.S. No. 1 tubers was collected from each plot's harvest for internal quality assessments. This subsample was used to estimate the prevalence of hollow heart, brown center, black scurf, and scab, as well as tuber specific gravity and dry matter content.

Data were analyzed using the GLIMMIX procedure in SAS 9.4 (SAS Institute, Inc., 2016). Only plots in the 2-year rotation were included in the analyses. Four plots in the 2-year rotation that were located around a flooded spot were also excluded. Each response variable was analyzed as a function of treatment as a fixed effect and block as a random effect. 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.

Two contrast statements were applied to each dependent variable to compare (1) the Russet Burbank and Russet Norkotah plots, limited to the conventional and pro-microbial management treatments, and (2) the conventional and pro-microbial management treatments across both Russet Burbank and Russet Norkotah.

Results

Rainfall and irrigation

Daily and cumulative rainfall and irrigation in the study field from April through October are presented in Figure 1. The average rainfall totals for these months in Becker, MN, are 2.83" in April, 3.78" in May, 4.37" in June, 3.91" in July, 4.15" in August, 3.07" in September, and 2.56" in October, for a total of 24.67". In 2024, the season was much wetter than average until September, with above-average rainfall in April (4.93"), June (7.67"), and August (6.14"), close to average rainfall in May (4.39") and July (4.25"), and less rainfall than average in September (0.28") and October (1.75"), for a total of 29.30" of rainfall. After April, rainfall was supplemented with irrigation as needed, supplying 1.05" of water in May, 1.46" in June, 4.85" in July, 2.25" in August, and 1.05" in September, for a total of 10.66" of irrigation between planting and harvest. During that period, 24.84” of rain fell, for a total of 35.50 inches of water between planting and harvest.

Tuber yield, size, and grade

Results for tuber yield, size, and grade are presented in Table 4. Among the treatments receiving conventional or pro-microbial management, Russet Burbank produced higher total yields than Russet Norkotah, but this different was not significant for U.S. No. 1 or total marketable yield. Russet Burbank had significantly less of its total yield in tubers over 6 or 10 ounces than Russet Norkotah did, and Russet Burbank had substantially more tubers per plant.

The conventional management plots produced significantly higher total and marketable yield and larger percentages of yield in tubers over 6 or 10 ounces than the pro-microbial plots. These two management approaches had no effect on the number of tubers per plant, indicating that the differences in yield between them were due to differences in tuber bulking. A survey of crop and weed cover in the Russet Norkotah plots just prior to vine kill found that crop cover was lower and weed cover was much higher in the pro-microbial plots than the conventional plots (data not shown). Overall canopy cover was also found to be lower in the pro-microbial plots than the conventional plots from mid-June to mid-July (data not shown). Thus, yields may have been lower in the pro-microbial plots because of greater competition from weeds, or both the lower yields and the higher weed cover may have been due to poorer potato vine growth in the pro-microbial plots.

In plots under the no-fumigant management approach, Bannock Russet had significantly higher total and marketable yields and more of its yield in tubers over 6 and 10 ounces than Russet Burbank. Russet Burbank under this regime had more tubers per plant than Bannock Russet, but fewer tubers per plant than Russet Burbank had under conventional or pro-microbial management. While Bannock Russet without fumigation had lower total yield than Russet Burbank under conventional or pro-microbial management, it had significantly higher marketable yield and higher percentages of total yield over 6 and 10 ounces than any other treatment. Russet Burbank had lower total and marketable yield under the no-fumigant management regime than the conventional regime and lower total yield than under the pro-microbial regime.

Russet Burbank showed exceptionally poor bulking in this season. The same issue was observed in other studies at SPRF, as well as multiple grower fields in central Minnesota. This may be attributable to the wet summer weather, together with the particular growth patterns of this cultivar. In studies at SPRF, Russet Burbank set between 10 and 14 tubers per plant (9.9 – 12.4 tubers in this study), as compared to 6 to 10 tubers for other cultivars (6.6 – 7.4 tubers in this study).

Possibly, heavy rainfall around hilling released abundant N from the urea applications made at that time, promoting tuber set but leaving little remaining N for tuber bulking. Cultivars like Russet Burbank that increased tuber set greatly in response to abundant early-summer N would have had fewer resources per tuber for bulking later in the summer, after mineral N had leached from the soil. Low canopy cover may also have limited tuber bulking in 2024. Based on Canopeo readings (not presented), canopy dieback also occurred early in 2024 compared to 2023, which was a dry year. This probably reduced the availability of carbohydrates for tuber bulking later in the season.

Tuber quality

Results for tuber quality are presented in Table 5. Russet Norkotah had a higher prevalence of hollow heart and brown center than the other two cultivars. The plots receiving pro-microbial management practices had a somewhat lower prevalence of brown center than those under conventional management, with the linear contrast approaching statistical significance.

As expected, Russet Norkotah had a higher prevalence of common scab than Russet Burbank. Among the Russet Norkotah treatments, the treatment under pro-microbial management had a significantly higher prevalence of common scab than the treatment under conventional management. This is a known side effect of manure application, and it is also consistent with the higher soil pH observed in the pro-microbial plots compared to the conventional plots in April 2022.

Bannock Russet tubers had the highest specific gravity of the three cultivars, followed by Russet Burbank, then Russet Norkotah. Bannock Russet also had the highest tuber dry matter content, while Russet Burbank and Russet Norkotah did not differ significantly by this metric.

Comparing the conventional treatment with the non-fumigated treatment, fumigation had no effect on the prevalence of any of the disease symptoms evaluated in this study. In the case of vascular browning as a symptom of *Verticillium* infection, it is possible that this symptom is not a reliable indicator of the disease. There are other possible causes of vascular browning, and *Verticillium* infection does not consistently cause vascular browning in the tubers. Other metrics, such as late-summer canopy cover, may be better indicators of *Verticillium* wilt.

Conclusions

One goal of the Potato Soil Health Project is to explore approaches to improving soil health in potato cropping systems for both their effectiveness in improving soil health and their economic viability. The approaches employed in the University of Minnesota's experimental plots at SPRF included the application of aged manure, the use of a more efficient N-fixing rotation crop (field peas) in place of soybeans, the use of a biofumigant crop (mustard) in place of chemical fumigation and expanded use of winter rye cover crops.

The results from 2024 indicate that the strategy for soil health improvement in this study was better in terms of potato crop production than simply removing soil fumigation from an otherwise conventional management regime. Total yield in Russet Burbank was higher under pro-microbial management than it was under conventional management minus fumigation. However, for both Russet Burbank and Norkotah Russet, the conventional management regime with fumigation outperformed the pro-microbial regime in terms of total and marketable yield and the percentage of yield over 6 ounces. Conventional management also controlled common scab in Norkotah Russet better than pro-microbial management.

In the first potato years in the study (2019 for the 3-year rotation and 2020 for the 2-year rotation), in which the conventional and pro-microbial treatments were both fumigated with metam sodium, the two treatments performed similarly. In 2022, in both rotations, the conventional treatment with fumigation performed better (though not statistically significantly so in all respects) than the pro-microbial treatment with Russet Burbank, while the opposite was true with Russet Norkotah. In 2024, the pro-microbial treatment performed worse for both cultivars. This may suggest that the pro-microbial strategy controls pathogens sufficiently to permit less frequent fumigation, but not well enough to forego fumigation entirely.

Bannock Russet under the no-fumigation management strategy had the highest marketable yield and percentages of yield in tubers over 6 and 10 ounces, by far, and its tubers had the highest specific gravity and dry matter content. This indicates that, while pro-microbial management conferred advantages over conventional management without fumigation for Russet Burbank, growing disease-resistant cultivars may be the better strategy for controlling disease issues.

Table 1. Average soil nutrient concentrations in each treatment in April 2022, the most recent pre-planting sample for which data are available.

Management	Cultivar	NO_3^--N (ppm)	NH_4^+-N (ppm)	P-Olsen (ppm)	P-Bray (ppm)	K (ppm)	Ca (ppm)	Mg (ppm)	Na (ppm)	S (ppm)	Zinc (ppm)	Iron (ppm)	Mn (ppm)	Cu (ppm)	B (ppm)
Conventional	Russet Burbank	0.9 a	7.0	41	138	165	1229	234	10	16 ab	15	1.47	1.13	0.92	0.30
	Russet Norkotah	0.9 a	8.3	45	138	201	1276	246	10	16 a	14	1.41	1.10	1.06	0.28
Promicrobial	Russet Burbank	0.5 c	6.3	44	129	177	1149	220	9	13 bcd	13	1.41	1.01	0.96	0.30
	Russet Norkotah	0.6 bc	8.4	41	143	202	1165	232	10	15 abc	15	1.37	1.04	0.87	0.30
No fumigant	Russet Burbank	0.7 ab	6.1	39	137	161	1145	214	10	12 d	12	1.35	0.94	0.62	0.25
	Bannock Russet	0.9 a	6.8	44	136	176	1310	240	10	13 cd	15	1.43	1.07	0.74	0.32
Effect of treatment (P-value)		**0.0060**	0.7960	0.6266	0.9805	0.6484	0.7488	0.8226	0.9444	**0.0074**	0.8714	0.4482	0.6947	0.3257	0.5601
Burbank v. Norkotah		0.6415	0.2709	0.9796	0.5728	0.1750	0.7553	0.5217	0.8408	0.1588	0.8467	0.2592	0.9777	0.8418	0.7171
Conventional v. Promicrobial		**0.0003**	0.8391	0.8412	0.8354	0.7497	0.3501	0.4809	0.8408	***0.0574***	0.7689	0.2453	0.3118	0.6035	0.7171

Table 2. Average soil pH, salts, CEC, and soil biology metrics in April 2022, the most recent pre-planting sample for which data are available.

Management	Cultivar	pH	Salts (mmhos/cm)	CEC (meq/100g)	Base saturation (%)					OM (%)	Total C (%)	Inorganic C (%)	Organic C (%)	POxC (ppm)	ACE protein (mg/g)	24-hour CO_2 (ppm)
					K	Ca	Mg	Na	H							
Conventional	Russet Burbank	6.5 c	0.17 a	8.8	4.8 b	70 abc	22.1	0.5	2.8	2.2	1.3	0.1	1.2	344	4.3	139
	Russet Norkotah	6.6 bc	0.16 ab	9.2	5.4 ab	69 bc	22.2	0.5	2.8	2.7	1.5	0.1	1.5	415	4.8	147
Promicrobial	Russet Burbank	6.8 ab	0.11 c	8.3	5.5 ab	69 bc	22.2	0.5	2.5	1.9	1.3	0.1	1.3	362	3.8	161
	Russet Norkotah	6.9 a	0.12 bc	8.5	6.1 a	69 c	22.9	0.5	1.9	2.0	1.2	0.1	1.2	400	4.1	157
No fumigant	Russet Burbank	6.8 ab	0.11 c	8.2	5.1 b	70 ab	21.9	0.6	2.3	1.9	1.2	0.1	1.1	321	3.8	126
	Bannock Russet	6.8 a	0.16 ab	9.2	4.9 b	71 a	21.7	0.5	2.2	2.5	1.4	0.2	1.4	407	4.3	154
Effect of treatment (P-value)		**0.0066**	**0.0128**	0.7977	**0.0459**	**0.0253**	0.2530	0.9326	0.2925	0.3527	0.7425	0.9685	0.6560	0.3165	0.4635	0.3012
Burbank v. Norkotah		***0.0880***	0.8356	0.6737	***0.0507***	0.2586	0.2878	0.9641	0.3738	0.3039	0.6353	0.6581	0.5852	0.1272	0.2839	0.8861
Conventional v. Promicrobial		**0.0007**	**0.0022**	0.3717	**0.0293**	0.3578	0.2711	0.6861	***0.0867***	0.1314	0.4217	0.9942	0.4779	0.9629	0.1729	0.1713

Table 3. Summary of treatments applied in the 2-year rotation in Minnesota's Potato Soil Health Project research field through 2024.

Management	Cultivar	2018	2019	2020	2021	2022	2023	2024
Conventional	Russet Burbank	Soybeans	Soybeans, fall Vapam	Russet Burbank, fall rye	Soybeans, fall Vapam	Russet Burbank, fall rye	Soybeans, fall Vapam	Russet Burbank, fall rye
	Russet Norkotah	Soybeans	Soybeans, fall Vapam	Russet Norkotah, fall rye	Soybeans, fall Vapam	Russet Norkotah, fall rye	Soybeans, fall Vapam	Russet Norkotah, fall rye
Pro-microbial	Russet Burbank	Soybeans	Soybeans, fall Vapam	Manure, Russet Burbank, fall rye	Field peas, then mustard cv 'Caliente 199', fall rye	Manure, Russet Burbank, fall rye	Field peas, then mustard cv 'Caliente 199', fall rye	Manure, Russet Burbank, fall rye
	Russet Norkotah	Soybeans	Soybeans, fall Vapam	Manure, Russet Norkotah, fall rye	Field peas, then mustard cv 'Caliente 199', fall rye	Manure, Russet Norkotah, fall rye	Field peas, then mustard cv 'Caliente 199', fall rye	Manure, Russet Norkotah, fall rye
No fumigant	Russet Burbank	Soybeans	Soybeans	Russet Burbank, fall rye	Soybeans	Russet Burbank, fall rye	Soybeans	Russet Burbank, fall rye
	Bannock Russet	Soybeans	Soybeans	Bannock Russet, fall rye	Soybeans	Bannock Russet, fall rye	Soybeans	Bannock Russet, fall rye

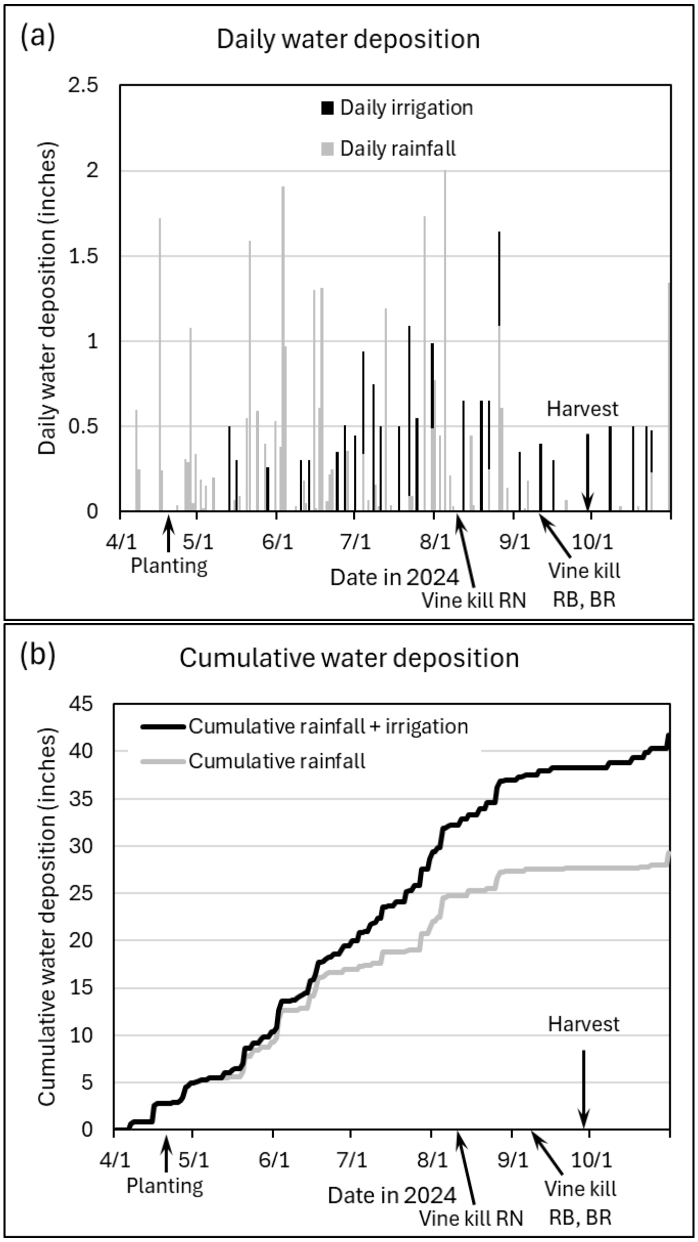

Figure 1. (a) Daily and (b) cumulative rainfall and irrigation in April through October at Minnesota's Potato Soil Health Project experimental site at SPRF in 2024.

Table 4. Effects of cultivar and soil health management practices on tuber yield, size, and grade in the 2-year rotations of the Potato Soil Health Project field at SPRF in 2024.

Management	Cultivar	Yield (CWT·ac^{-1})										% yield in tubers over:		Tubers / plant
		Culled	0 - 4 oz.	4 - 6 oz.	6 - 10 oz.	10 - 14 oz.	> 14 oz.	Total	US No. 1	US No. 2	Marketable	6 oz.	10 oz	
Conventional	Russet Burbank	0	216 b	151 a	87 b	10 bc	0 b	464 a	243 b	5 a	248 b	21 c	2 c	12.2 a
	Russet Norkotah	0.5	115 c	105 bc	93 b	16 b	3 b	332 c	216 b	1 c	217 b	33 b	6 b	7.4 c
Promicrobial	Russet Burbank	0.5	258 a	123 b	35 c	1 c	0 b	416 b	156 c	2 bc	158 c	8 d	0 c	12.4 a
	Russet Norkotah	0.1	128 c	82 d	44 c	6 bc	0 b	259 d	129 c	1 bc	131 c	19 c	2 c	6.6 c
No fumigant	Russet Burbank	0	193 b	109 bc	48 c	3 c	0 b	352 c	155 c	4 ab	160 c	14 cd	1 c	9.9 b
	Bannock Russet	1.0	76 d	94 cd	163 a	71 a	14 a	418 b	334 a	7 a	342 a	59 a	20 a	7.2 c
Effect of treatment (P-value)		0.1853	**<0.0001**	**0.0006**	**<0.0001**	**<0.0001**	**<0.0001**	**<0.0001**	**<0.0001**	**0.0095**	**<0.0001**	**<0.0001**	**<0.0001**	**<0.0001**
Burbank v. Norkotah		0.8577	**<0.0001**	**0.0001**	0.4906	0.2401	0.4371	**<0.0001**	0.1593	***0.0802***	0.1288	**0.0003**	**0.0099**	**<0.0001**
Conventional v. Promicrobial		0.7744	**0.0158**	**0.0082**	**<0.0001**	***0.0534***	0.2657	**0.0023**	**0.0001**	0.3263	**0.0001**	**<0.0001**	**0.0048**	0.4678

Table 5. Effects of cultivar and soil health management practices on tuber defects, specific gravity, and dry matter content in the 2-year rotations of the Potato Soil Health Project field at SPRF in 2024.

Management	Cultivar	% of tubers					Specific gravity	Dry matter (%)
		Hollow heart	Brown center	*Verticillium* brown ring	Black scurf	Common scab		
Conventional	Russet Burbank	6 bc	6 b	0	0	2 c	1.0695 b	18.4 c
	Russet Norkotah	29 a	29 a	2	0	10 b	1.0652 c	18.6 c
Promicrobial	Russet Burbank	0 c	0 b	0	0	1 c	1.0676 b	18.9 bc
	Russet Norkotah	18 ab	18 a	0	0	17 a	1.0656 c	20.1 b
No fumigant	Russet Burbank	4 c	4 b	0	0	2 c	1.0680 b	18.2 c
	Bannock Russet	5 c	2 b	6	5	4 bc	1.0848 a	22.7 a
Effect of treatment (P-value)		**0.0039**	**0.0017**	0.3099	0.1551	**0.0123**	**<0.0001**	**<0.0001**
Burbank v. Norkotah		**0.0007**	**0.0004**	0.7427	1.0000	**0.0011**	**0.0005**	0.2220
Conventional v. Promicrobial		0.1075	***0.0916***	0.7427	1.0000	0.3121	0.3660	***0.0964***

Data Report for UMN Potato Breeding Program 2024

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Measuring bruise in the UMN breeding program

Aim: Bruise has repeatedly been identified as a major concern of potato growers in Minnesota and North Dakota. In 1995, the estimated cost of bruise was $298 million (Thornton & Bohl, 1995). It has been estimated that a 10% reduction in bruise would increase returns to the industry by 134 million dollars (Hollingshead et al., 2020). While agronomic practices (Karlsson et al., 2006), handling (Xie et al., 2020), and storage conditions (Shetty et al. 1991, Muthukumarappan et al. 1994, Kelderman 2017) help mitigate bruise, bruise continues to be a major problem for the industry (Lathim, 2019). Bruise susceptibility differs between potato varieties (Hendricks et al., 2022), indicating potential for bruise mitigation through breeding.

The economic impact of bruise makes it a desirable breeding target and the genetic aspect of bruise susceptibility makes breeding possible. However, in order to breed for a trait we first must be able to measure it in a precise, accurate, and quantitative manner. Our previous efforts to develop methods to quantify quality traits has increased our ability to select for those traits, by improving heritability. For example, shape rated visually on an ordinal scale for fresh market clones in our breeding program had a heritability of 0.36, while a digital measure of roundness on those same clones had a heritability of 0.64 (Miller et al., 2022). Using image analysis phenotypes has also allowed us to build genomic prediction models for quality traits (Yusuf et al., 2024), for which prediction accuracy has historically been low (Sood et al., 2020).

We aimed to develop a protocol for quantitatively measuring blackspot bruise susceptibility as a first step toward breeding for bruise resistance.

Methods: With the goal of being prepared for phenotyping at harvest, we purchased red and yellow fresh market potatoes at a grocery store to experiment with over the summer. We also purchased a clothes dryer with a heatless setting to use as a tumbler. Pre-tumbling, all tubers were maintained at 40F for at least 48 hours in a cold room. Tubers were then tumbled for 5, 10 or 20 minutes and then stored at either 70 or 86F in a growth chamber for 48 hours. This resulted in a total of six different treatments accounting for all possible combinations of tumble lengths and post tumble storage temperatures. After growth chamber storage all tubers were peeled using an electric potato peeler, halved, and photographed in a Photosimile 200 lightbox, with a Canon Rebel T6i camera using a 24mm lens, ISO 100, 1/30 sec shutter speed and aperture f/5.6, and a white background (Caraza-Harter & Endelman, 2020).

Bruises were identified using ImageJ and quantified based on an index which multiplies the percent of the tuber covered in bruise by the degree of discoloration. Success of a protocol was determined based on its ability to consistently produce bruise without generating external damage, such that bruise was present but variable across individuals. With this goal in mind we reduced the tumble time and storage temperature of tubers freshly harvested from the field as they were easier to bruise.

As part of our annual yield trials, all clones from field year 3 (FY3) on were grown in 15 hill plots at the Sand Plains Research Farm (SPRF) in Becker MN. Our fresh market plot included both red skin white flesh clones and yellow skin yellow flesh clones. This set included 24 clones from our breeding program, 13 from NDSU, 13 from MSU, two from UW and eight checks (Red Norland, Dark Red Norland, Columba, Yukon Gold, Chieftain, Modoc, Red LaSoda, and Red Pontiac). Clones from FY4 on and checks were grown in two replicates, while FY3 clones and clones from other programs were grown as single replicates. Vines were killed 90 days after planting and clones were harvested 2 weeks after planting. At harvest after grading 10 tubers were selected at random from each plot and placed in mesh bags in storage. As time allowed, tubers were removed from storage and tumbled for 5 minutes, then returned to 40F storage for another 48 hours. At the end of the 48 hour period tubers were removed, peeled using an electric peeler, cut in half and photographed.

Photographs were analyzed using a custom R script, developed in our lab. This script analyzes tuber images to assess bruising severity by first loading an image and extracting its red, green, and blue (RGB) channels. A potato mask is created by defining a range of acceptable RGB values to identify the tuber while excluding the background. To prevent interference from non-tuber elements, the code applies an exclusion mask to remove regions containing a color card and a tag, using either predefined positions or user-specified factors. A bruise mask is then generated by identifying dark areas within the potato mask based on a user-defined threshold for low-intensity values in all three RGB channels. The bruise severity is quantified as the percentage of the potato area that appears bruised (1-100), while a discoloration factor (0-1) is calculated based on the average intensity of bruised areas. The bruise index, a measure of overall bruising severity, is computed as the product of bruise severity and the discoloration factor. Although chip and russet samples were also collected and tumbled, we have not optimized analysis of them yet.

Results: Using grocery store tubers, five minutes of tumbling did not produce sufficient bruise, but 20 minutes caused excessive external damage. Post tumbling storage at 86F resulted in rot. Therefore based on summer experiments we decided on ten minutes of tumbling followed by storage at 70 degrees. However, this treatment was too rough for more recently harvested tubers. Instead we tumbled them for 5 minutes and stored them at 40F for 48 hours post tumbling. This resulted in a variety of bruise phenotypes (Figure 1; Table 1).

The best performing check was Columba (bruise index = 1.96), and five breeding clones out performed it. The best performing UMN clones were also yellow: MN18TX17760-002 and MN19TX18206-002. Two red clones from NDSU and one from MSU were also stand out performers: ND2093-4R, MSFF228-2RY, and ND20102-5R. The worst performing check was Red La Soda.

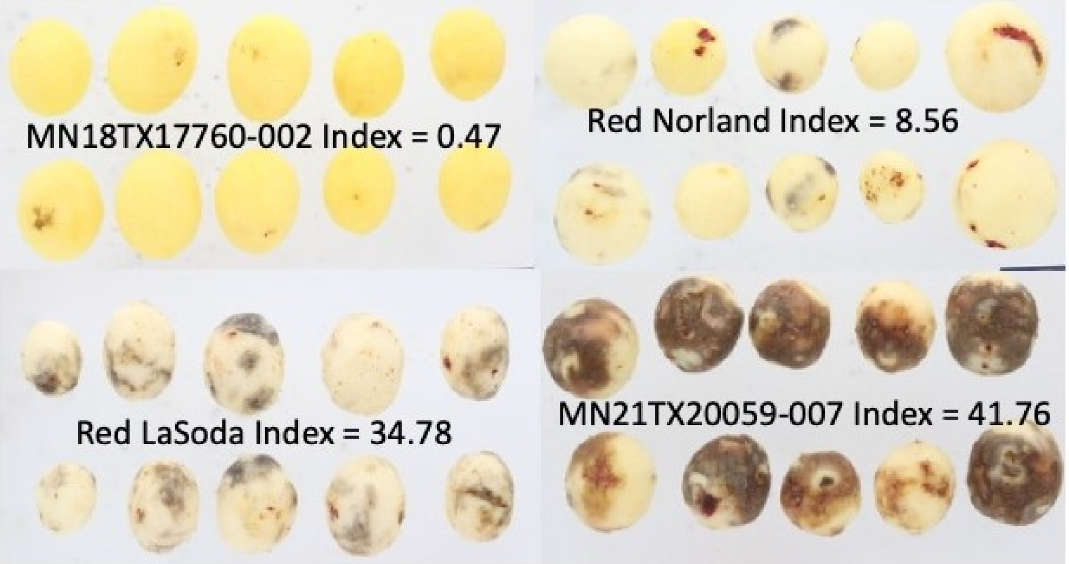

Figure 1. The range of bruising phenotypes. MN18TX17760-002 exhibited the lowest bruising with a bruising index of 0.47, while MN21TX20059-007 exhibited the most sever bruising with an index of 41.76.

Table 1. Bruise index scores for all measured fresh market clones

Clone	Bruise Index
MN18TX17760-002	0.47
ND2093-4R	0.96
MN19TX18206-002	1.32
ND20102-5R	1.54
MSFF228-2RY	1.55
Columba	1.96
MN12006WW-01R	2.33
ND2090-6R	2.59
MN21AF7330-003	2.65
ND2092-16R	3.47
MSII325-1Y	3.86
MSFF200-4PYSPL	4.07
MSII301-4	4.47
W16050-3P/Y	4.51
ND2089-1R	4.74

MN19ND1759-001	4.88
MN21TX20058-001	5.01
MN19AF6945-003	5.41
Dark Red Norland	5.55
MN18CO16154-009	5.78
MN18CO15083-006	5.80
MSII326-1	6.15
AW08112-4P/Y	6.36
MN18W17026-002	6.37
MSII353-2Y	6.47
ND20122-4pY	6.70
MN21TX20059-001	7.08
MN21ND1835B-157	7.33
MSII415-3R	7.49
ND2093-6R	7.61
Yukon Gold	7.70
MN18W17026-004	8.26
Red Norland	8.56
MSFF145-2R	9.88
MN21ND2013-002	10.60
MN20ND1824Y-001	10.89
Red Pontiac	11.23
MN18W17009-001	11.89
MN21ND2037-002	12.07
MN21AF7307-003	12.58
ND2090-2R	13.05
Modoc	13.67
Chieftain	14.05
ND2089-11R	16.04
AFND7576-1R	16.37
MN21AF7307-007	16.39
MN21TX20044-001	20.43
MN21AF7307-006	20.99
MN21AF7348-001	22.72
ND20142-3R	23.13
ND2089-17R	23.90
MSII416-2RR	28.28
MN21TX20025-002	32.22
Red LaSoda	34.78

MSII414-2PP	38.67
MN21TX20059-007	41.76

We were able to develop a protocol which allows us to observe variation in bruise susceptibility across clones. This is a necessary pre-requisite to breeding for bruise resistance. However, these measurements are only for a single year and bruise has environmental components, therefore, at least a second year of data is necessary before we can use these measurements in selection decisions.

Developing new potato varieties

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 seventh field season of the revamped Minnesota Potato Breeding Program.

Methods:

FY1

We planted 17,000 single hills. Of these, 23 families were from crosses done at UMN. The rest were kindly provided by our partnering institutions; North Dakota State University (32 families), Texas A&M University (96 families), and Colorado State University (8 families). All single hills were planted at the North Central Research and Outreach Center (NCROC) and selected using visual selection.

FY2

We evaluated 230 FY2 clones this year in 12-hill plots. Of these clones, 41% were chips, 45% were russet, and 14% 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. Dakota Russet, Elk River Russet, 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 90 days for the fresh market potatoes and 110 days for processors. Tubers were harvested 2 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 (2020). Image analysis was performed in-house using the R package TuBAR (Miller et al., 2022). 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 *RYadg*) and Verticillium wilt resistance *(Ve2)*. These three genes were chosen as targets for selection, due to the availability of accurate markers. Additionally, 29 of the chipping clones were evaluated in 8-hillplots in North Carolina as part of the Early Generation Southern Strategy Trial.

FY4-7

We grew FY4-7 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 FY3-7, checks, and the clones from the North Central Region were grown in a partially replicated randomized design. The trial included 131 FY4 individuals: 10% fresh market, 8% russet, and 82% chip; 13 FY5 individuals: 8% fresh market and 92% chip; 10 FY6 individuals: 30% fresh market, 30% chip, and 40% russet; and 16 FY7 individuals: 44% chips, 19% russets, and 37% fresh market. 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 242 clones to be evaluated in 12 hills in 2025.

FY2

We selected 21% of the clones, resulting in 49 clones to be evaluated in preliminary yield trials in 2025.

FY3

We selected 1 chipping clones and 7 russets which we will evaluate in replicated yield trials in 2025.

FY4-7

We selected 19 FY4 chipping clones all of which out performed at least one check in terms of yield in Minnesota (Table 2). All also had specific gravity of 1.077 or above in MN, higher than Cascade or Superior. Several clones were also included in the Early Generation Selection Strategy Trial in North Carolina. MN21ND1845B-030 out performed Atlantic in terms of yield in that trial suggesting some degree of heat resistance. We have one FY5 selection, MN20AF7174-001 (Table 3), which was also in the National Chip Processing Trial (NCPT) this year (Table 4). It yielded less well this year in MN than it has previously possibly because of problems with scab in our seed field. It will enter Tier 2 of the NCPT in 2025. Our single selection from FY6, MN19AF6892-009, will be part of the NCPT tier 1 in 2025 (Table 5). It stands out due to high specific gravity and verticillium wilt resistance.

We continue to move forward with 3 FY7 clones (Table 6). MN18W17037-033 is a PVY resistant clone which regularly yields well and shows strong specific gravity in MN. It shows field tolerance to verticillium wilt in Dr. Ranjan's trials and no heat necrosis. It performed particularly well in Florida in the NCPT tier 2, but was not sufficiently consistent across environments to continue on. Nevertheless, this clone may be appropriate for high stress environments.

Table 2. 2024 FY4 Chipping Selections (yield in % Atlantic).

Clone	Yield MN 2024	SG MN 2024	Yield NC 2024	SG NC 2024
Atlantic	100	1.091	100	1.085
Cascade	98	1.074	NA	NA
MN21ND1835B-073	97	1.084	81	1.084
MN21ND1835B-059	90	1.077	76	1.079
MN21ND1845B-071	90	1.082	64	1.077
MN21ND1835B-106	89	1.081	NA	NA
MN21ND1835B-001	88	1.080	NA	NA
MN21ND1845B-003	88	1.077	NA	NA
Snowden	88	1.078	113	1.085
MN21ND1835B-108	87	1.082	NA	NA
MN21ND1835B-136	86	1.082	NA	NA
MN21ND1845B-088	86	1.079	NA	NA
MN21ND1845B-029	86	1.077	86	1.086
Lamoka	83	1.080	NA	NA
MN21ND1835B-146	82	1.079	57	1.090
MN21ND1835B-143	78	1.089	NA	NA
MN21ND1835B-031	77	1.085	78	1.094
MN21ND1835B-076	77	1.081	NA	NA
MN21ND1845B-112	77	1.084	NA	NA
MN21ND1835B-129	75	1.085	NA	NA
MN21ND1835B-039	73	1.083	NA	NA
MN21ND1835B-029	71	1.087	81	1.088
MN21ND1845B-030	65	1.084	105	1.077
Superior	61	1.067	NA	NA

Table 3. 2024 FY5 Chipping Selections (yield in % Atlantic).

Clone	Yield MN 2024	SG MN 2024	Yield MN 2023	SG MN 2023	Yield NC 2023	SG NC 2023
Atlantic	100	1.091	100	1.075	100	1.075
Cascade	98	1.074	90	1.065	NA	NA

Snowden	88	1.078	81	1.072	129	1.074
Lamoka	83	1.080	68	1.077	NA	NA
MN20AF7174-001	81	1.081	102	1.071	135	1.067
Superior	61	1.067	48	1.067	NA	NA

Table 4. 2024 National Chip Processing Trial Results (yield in ct/a).

	Yield MN20AF7174-001	SG MN20AF7174-001	Yield Atlantic	SG Atlantic	Yield Snowden	SG Snowden	Yield Lamoka	SG Lamoka
FL	330.0	1.101	301.5	1.089	229.8	1.078	325.3	1.082
MD	36.0	NA	214.8	1.076	225.8	1.078	65.5	NA
MI	340.0	1.07	429.3	1.087	412.8	1.081	385.0	1.081
NC	30.5	1.072	25.3	1.089	27.7	1.083	17.7	1.076
ND	163.0	1.095	173.5	1.107	188.5	1.099	182.5	1.103
OR	465.4	1.084	449.0	1.090	778.0	1.096	622.3	1.091
WI	77.2	1.071	62.9	1.088	81.7	1.094	62.7	1.076

Table 5. 2024 FY6 Chipping Selections (NAs indicate unmeasured phenotypes, Yields are presented as % Atlantic)

Clone	Yield MN 2024	SG MN 2024	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
Atlantic	100	1.091	100	1.075	100	1.073	100	1.075	100	1.064	NA	NA
Cascade	98	1.074	90	1.065	82	1.060	NA	NA	NA	NA	NA	NA
Snowden	88	1.078	81	1.072	19	1.075	92	1.071	142	1.066	NA	NA

Lamoka	83	1.080	68	1.077	59	1.071	77	1.068	NA	NA	NA	NA
MN19AF6892-009	73	1.096	76	1.073	102	1.089	80	1.074	129	1.070	No	Yes
Superior	61	1.067	48	1.067	27	1.064	NA	NA	NA	NA	NA	NA

Table 6. 2024 FY7 Chipping Selections (NAs indicate unmeasured phenotypes, Yields are presented as % Atlantic)

Clone	Yield MN 2024	SG MN 2024	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
MN18W17037-033	114	1.083	58	1.077	153	1.075	87	1.070	88	1.067	NA	NA	NA	NA	Yes	No
Atlantic	100	1.091	100	1.075	100	1.073	100	1.075	100	1.064	100	1.085	100	1.088	NA	NA
Cascade	98	1.074	90	1.065	82	1.060	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
MN18W17043-002	97	1.090	65	1.084	93	1.091	93	1.072	63	1.067	NA	NA	NA	NA	Yes	No
MN18W17037-026	88	1.086	86	1.082	40	NA	64	1.064	94	1.063	85	1.08	77	1.079	NA	NA
Snowden	88	1.078	81	1.072	19	1.075	92	1.071	NA	NA	NA	NA	NA	NA	NA	NA
Lamoka	83	1.080	68	1.077	59	1.071	77	1.068	NA	NA	98	1.084	87	1.081	NA	NA
Superior	61	1.067	48	1.067	27	1.064	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

We selected five FY4 russet clones, two appropriate for fresh market and three which may be appropriate for either fresh market or processing (Table 7). All clones out perform at least one check in terms of yield and MN21ND2015-001 yielded more than all checks. All three potential processing clones exhibited higher specific gravity than both Russet Burbank and Umatilla Russet. MN21CO19222-002 exhibited the highest specific gravity, followed closely by Elk River Russet (MN13142) and then MN21ND2015-001. We made no selections from FY5 and one from FY6 (Table 8). MN19AOR16061-007 has potential as a fresh market russet. We have selected two high yielding FY7 russets with fresh market potential.

Table 7. 2024 FY4 russet selections (yields are presented as 5 Russet Burbank).

Clone	Yield MN 2024	SG MN 2024	PVY resistance	Potential
MN21ND2015-001	111	1.085	NA	Dual-purpose
Umatilla Russet	105	1.079	NA	NA

Russet Burbank	100	1.076	NA	NA
Goldrush	89	1.065	NA	NA
MN21ND1955-002	85	1.074	NA	Fresh Market
MN21CO19073-001	77	1.080	Yes	Dual-purpose
Dakota Russet	74	1.083	NA	NA
MN21CO19222-002	72	1.093	NA	Dual-purpose
MN21CO19187-001	71	1.074	NA	Fresh Market
Elk River Russet	70	1.090	Yes	NA
Russet Norkotah	65	1.065	NA	NA

Table 8. 2024 FY6 Russet Selections (NAs indicate unmeasured phenotypes, Yields are presented as % Russet Burbank)

Clone	Yield MN 2024	SG MN 2024	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
Umatilla Russet	105	1.079	79	1.075	114	1.066	NA	NA	NA	NA	NA	NA
Russet Burbank	100	1.076	100	1.073	100	1.067	100	1.075	100	1.071	100	1.060
Goldrush	89	1.065	81	1.062	98	1.058	NA	NA	113	1.064	98	1.054
MN19AOR16061-007	74	1.072	75	1.069	129	1.066	67	1.066	101	1.066	63	1.056
Dakota Russet	74	1.083	70	1.072	NA	NA	NA	NA	NA	NA	NA	NA
Elk River Russet	70	1.090	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Russet Norkotah	65	1.065	83	1.060	113	1.060	54	1.061	112	1.070	54	1.055

*Table 9. 2024 FY7 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 2024	SG MN 2024	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
MN18W17091-015	120	1.069	129	1.056	165	1.066	NA	NA	135	1.062	NA	NA	NA	NA
MN18W17091-005	105	1.070	85	1.070	128	1.045	133	1.054	206	1.057	80	1.074	79	1.072

Umatilla Russet	105	1.079	79	1.075	114	1.066	NA	NA	NA	NA	NA	NA	NA	NA
Russet Burbank	100	1.076	100	1.073	100	1.067	100	1.060	NA	NA	100	1.077	100	1.072
Goldrush	89	1.065	81	1.062	98	1.058	98	1.054	NA	NA	89	1.071	76	1.070
Dakota Russet	74	1.083	70	1.072	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Elk River Russet	70	1.090	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Russet Norkotah	65	1.065	83	1.060	113	1.067	54	1.055	100	1.052	92	1.069	73	1.073

We selected three field year 4 red skinned white fleshed clones, all of which out yielded at least one check (Table 10). We selected no FY5 clones and our most advanced 4 red clones from FY6 and 7 (Table 11 & 12).

Table 10. 2024 FY4 Red Selections

Clone	Yield MN 2024
Red Norland	100
MN21AF7307-007	90
Red Pontiac	89
Modoc	86
Dark Red Norland	84
MN21AF7307-006	80
Chieftain	80
MN21TX20059-001	77
Red LaSoda	69

Table 11. 2024 FY6 and 7 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 2024	Yield MN 2023	Roundness 2023	Redness 2023	Skinning 2023	Lightness 2023
MN18CO15083-006	136	NA	NA	NA	NA	NA

Red Norland	100	100	0.966	15.4	0.075	49.125
MN18W17026-002	96	393	0.972	20.475	0.09	46.375
MN18W17009-001	92	NA	NA	NA	NA	NA
Red Pontiac	89	102	0.980	21.4	0.27	44.8
MN19ND1759-001	87	500	0.984	19.5	0.05	50.025
Modoc	86	70	0.984	14.4	0.0175	50.7
Dark Red Norland	84	85	0.978	15.8	0.04	53.425
Chieftain	80	64	0.980	12.575	0.0225	52
Red LaSoda	69	95	0.967	13.8	0.03	50

Table 12. Historic data on 2024 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
MN18W17026-002	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 made four yellow skinned yellow flesh selections, all of which out yield Yukon Gold (Table 13). Additionally MN19AF6945-003 exhibits PVY resistance and MN18CO16154-009 exhibits verticillium wilt resistance.

*Table 13. 2024 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 2024	Yield MN 2023	Yield MN 2022	Yield MN 2021*	Yield WI 2021	Yield MI 2021*	Yield MN 2020	PVY	Vert
Columba	317	68	NA	NA	NA	NA	NA	NA	NA
MN21AF7330-003	125	NA	NA	NA	NA	NA	NA	NA	NA
MN18TX17760-002	124	202	115	52	138	154	241	No	No
MN18CO16154-009	123	203	141	93	95	441	57	No	Yes
MN19AF6945-003	114	471	162	168	NA	NA	NA	Yes	No
Yukon Gold	100	100	100	NA	100	NA	100	NA	NA

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Report for Proposal Title: 2024 Support of Irrigated Potato Research for North Dakota and Minnesota

Submitted to Northland & MN Area II Potato Growers Associations

Principle Investigator: Julie Pasche, Department of Plant Pathology, North Dakota

State University, Fargo, ND 58102. Julie.Pasche@NDSU.edu; 701-231-7547

Co-Principle Investigator: Gary Secor
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, management practices such as row spacing, 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 contributed to tracking fungicide resistance 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 irrigated 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, Javier Cao, Sunil Shrestha, Marcio Zaccaron, Sujata Yadav, Rachel Selstedt, Kim-Zitnick Anderson 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 Grower and the Northland Potato Grower Associations.

Rationale: Irrigated potato production accounts for approximately 60% of total production in the region and differs substantially from non-irrigated production. The majority of the irrigated potato production is used in frozen processing, 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, and fertilizer 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 quantification of the Verticillium wilt and black dot pathogens from soil and stem tissue. This work provided us with a means to determine host resistance to the pathogens 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 vary depending on the environment and cultivar maturity. 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 to the pathogens and environmental conditions in this region. Again, this allows us to make timely and relevant grower recommendations. Trials conducted at the Inkster site facilitate the screening of registered and novel products to provide statistically unbiased evaluations for the benefit of the potato industry and growers. 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. 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 the NPGA/MNAII approximately $7,500 annually. The Inkster plot coordinator also plants all cover crops and assists in planning the annual field day.

The total cost of general management (travel, labor, supplies, and repairs) of the irrigated potato research in 2025 near Inkster, ND, at the NPGA research site was over $87,000. We continue to make a concerted effort to re-evaluate all operations and to increase efficiencies in the management of the Inkster research site.

Procedures: Irrigated potato research was performed near Inkster at the NPGA irrigated research site. Research trials conducted include but are not limited to, general management practices including row spacing, 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, scheduled irrigation management, made all maintenance 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 NPGA annual field day.

Results

In 2024, 28 trials were conducted on nearly 24 acres at the Inkster research site (Figure 1). As indicated above, these trials span the range of expertise of the potato improvement team. 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. Data generated at Inkster contribute to decisions on product registration and marketing by the cooperator. Below we have included some results from trials conducted at Inkster. Some results are preliminary and as indicated, some are confidential.

We experienced high early blight disease pressure in 2024 and more notably disease severity ramped up very quickly compared to recent years (Figure 2). This is true to a lesser extent for 2023. Some growers in the region indicated they observed a similar pattern. If similar patterns continue, we may need to evaluate alternatives to our current recommendations for leaf spot management. Access to the irrigated research site will facilitate that research. One example of generating data over several years includes the evaluation of new foliar products/formulations to manage early blight (Figure 3). These data indicate that the efficacy of these products has diminished somewhat over the past decade, consistent with our lab and greenhouse results. While we continue to have concerns over the development of fungicide resistance, these fungicides remain effective against the pathogen population in our region (Figure 4).

Julie Pasche's pathology group has been evaluating products for the management of black dot for several years; however, 2024 was the first year we added tuber blemish evaluations. Tuber blemish evaluations were added to our black dot cultivar resistance screening trial. Results indicate a significant difference in the progression of black dot stem lesions across the growing season among cultivars and NDSU breeding lines evaluated (Figure 5). It is encouraging to see a couple of NDSU breeding lines with some resistance to black dot stem lesions and important for us to understand that some lines are very susceptible. Quantification of the pathogen in stem tissue via PCR and tuber blemish data for this trial is in process and will provide further valuable data about current cultivars and NDSU breeding lines. Tuber blemish has been quantified for two trials evaluating fungicides for black dot management. No products reduced tuber blemish, even where stem lesions were significantly reduced. We also evaluated the effect of harvest timing on the accumulation of black dot symptoms on tubers but saw no significant reductions with earlier harvest. These trials will be repeated in 2025. Black dot tuber blemish has been increasing in importance in recent years with a higher emphasis being placed on skin blemish in fresh market red and yellow-fleshed cultivars. With the forthcoming increase in yellow potatoes in the region, we believe that this avenue of research will continue to grow in importance.

At Inkster in 2024, Gary Secor's pathology project conducted two trials to evaluate 14 treatments for managing seed-borne Rhizoctonia. Registered fungicides, experimental fungicides, and natural products were applied as seed treatments and in-furrow at planting. Most treatments were entered as numbered compounds and/or confidential. A non-inoculated control and a Rhizoctonia seed inoculated control were included in each trial. Many of the products tested did not significantly reduce Rhizoctonia 45 days after planting. The most effective control of

Rhizoctonia 45 days after planting continues 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 and Minuet also provided an 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.

Gary Secor's group also conducted a field trial in 2024 at the Inkster site to evaluate the efficacy of 11 seed treatments and in-furrow at planting treatments to reduce silver scurf blemish of harvested potatoes. Tubers of cv. Agata naturally infected with silver scurf were planted at the Inkster site and grown using local agronomic practices. Tubers were harvested, incubated at 50F for four months, and evaluated for total blemish, a combination of silver scurf and black dot. All fungicide treatments reduced silver scurf when rated two months post-harvest.

Andy Robinson's group conducted trials at Inkster to determine the increase in stem and tuber number on Mountain Gem Russet and Dakota Russet and optimize row spacing on cvs Red Norland and Musica. Please refer to the reports for those specific trials for more details.

We believe that we continue to generate unbiased, reliable, robust recommendations for growers, based on trial results from the Inkster irrigated research site. 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.

Figure 1. Planting at the Inkster site (top) and the NPGA field day (bottom).

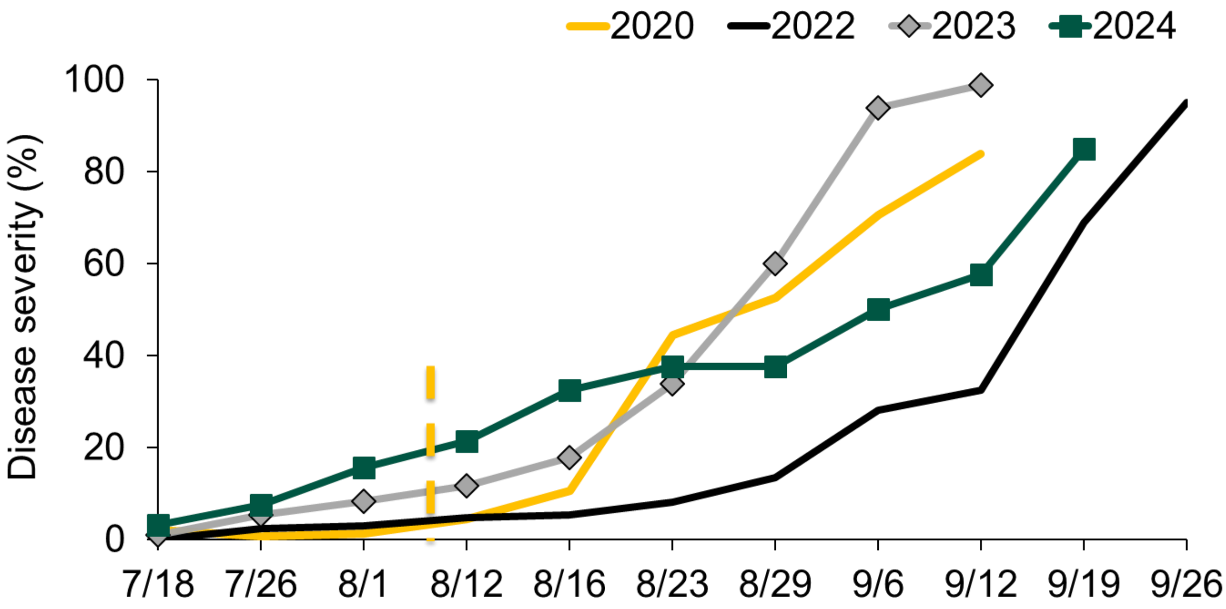

Figure 2. Early blight disease progression in non-treated control plots at Inkster from 2020 to 2024 as determined by visual disease ratings collected weekly for 9-11 weeks at the NPGA irrigated research site near Inkster. The vertical dashed line indicates the approximate timing of application #5 in a 10-application fungicide program when we typically recommend the first premium fungicide.

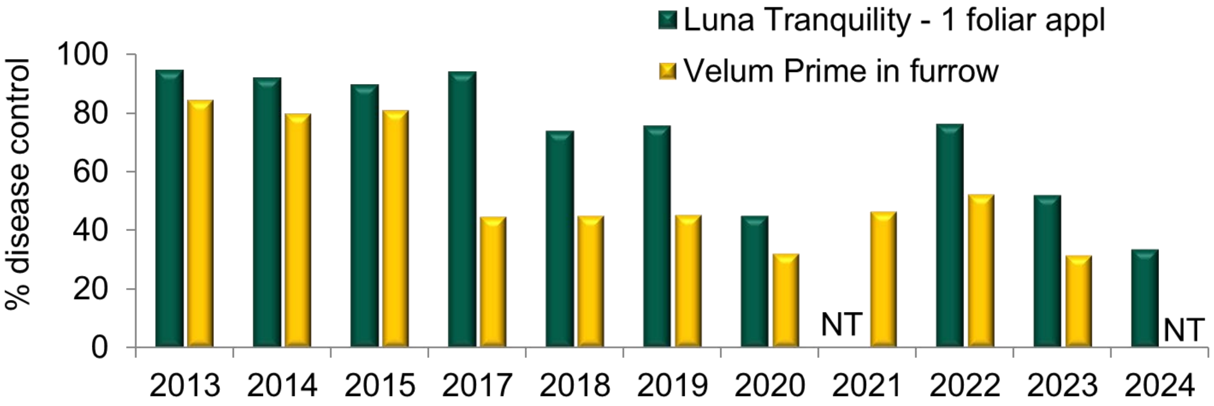

Figure 3. Percentage early blight control compared to non -treated plots in trials conducted from 2013 to 2024 at the NPGA irrigated research site near Inkster. Early blight severity across the growing season as determined by visual disease ratings collected weekly for 9-11 weeks. Velum Prime was applied in-furrow with no additional fungicide applications. Luna Tranquility was applied at application #5. A Qoi fungicide was applied at #2 and Scala @ #7. The three specialty fungicides (applications 2, 5, and 7) were tank-mixed with mancozeb and rotated with chlorothalonil (applications 1, 3, 4, 6, 8-10). Luna Tranquility was not tested (NT) in 2021 and Velum Prime was not tested in 2024.

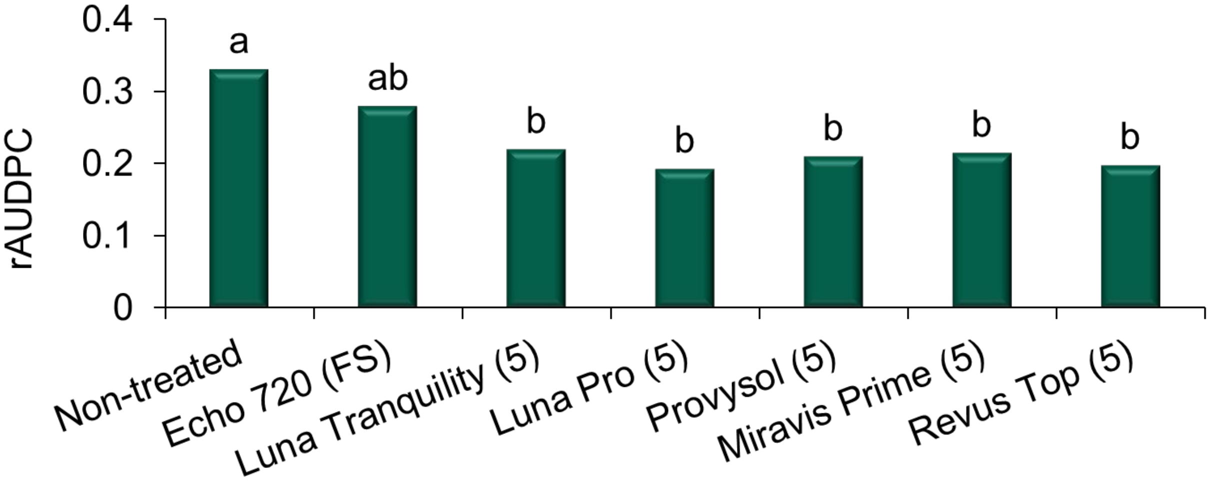

Figure 4. Relative area under the disease progress curve (rAUDPC) representing early blight severity across the 2024 growing season as determined by visual ratings collected weekly for 10 weeks. The trial was conducted under high disease pressure at the NPGA irrigated research site near Inkster. Bars with different letters above are significantly different. The number in (5) represents the fifth application in a 10-application program or full-season (FS) applications. Treatments included A Qoi fungicide @ application 2 and Scala @ application 7. The three specialty fungicides (applications 2, 5, and 7) were tank-mixed with mancozeb and rotated with chlorothalonil (applications 1, 3, 4, 6, 8-10).

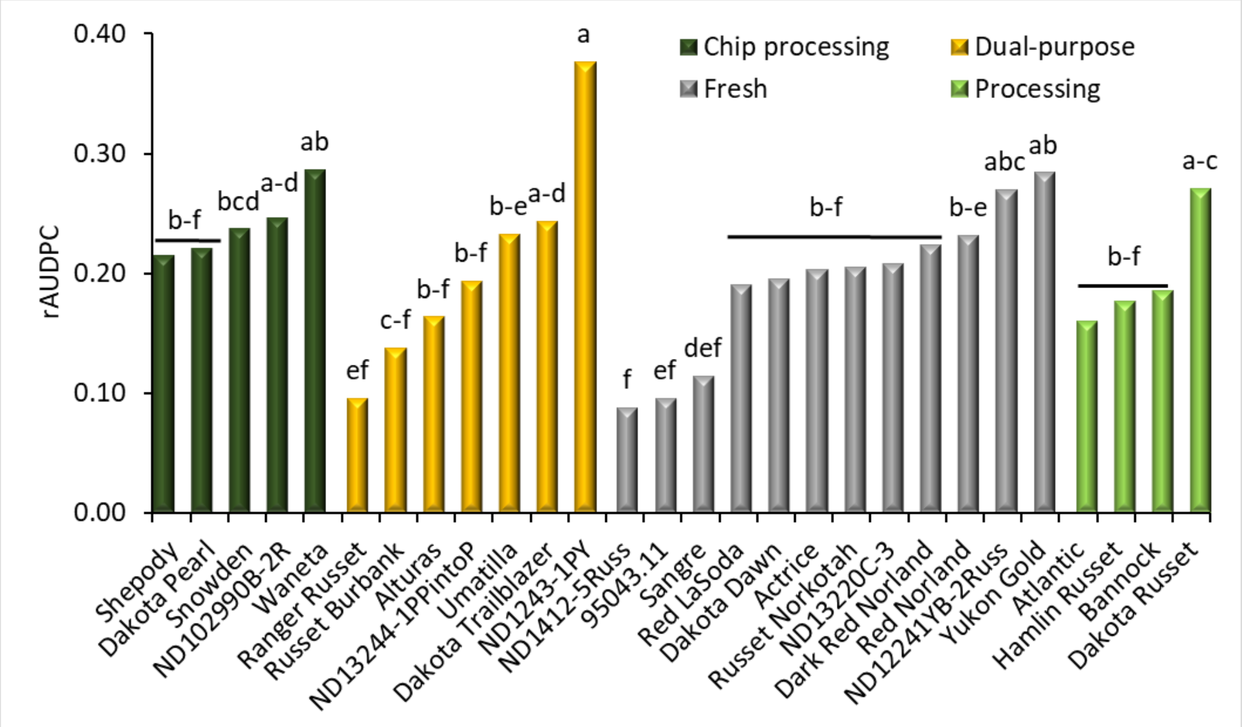

Figure 5. Relative area under the disease progress curve (rAUDPC) representing black dot stem lesion incidence across the 2024 growing season as determined by visual ratings collected weekly for 5 weeks. Cultivars/NDSU breeding lines were grown under inoculated conditions at the NPGA irrigated research site near Inkster. Bars with different letters are significantly different.

Report for Proposal Title: Examining Pink Rot and Leak Pathogens in North Dakota and Minnesota

Submitted to Northland and MN Area II Potato Growers Associations

Principle Investigator: Julie Pasche, Department of Plant Pathology, North Dakota State University, Fargo, ND 58102. Julie.Pasche@NDSU.edu; 701-231-7547

Executive Summary:

Pink rot is caused by *Phytophthora erythroseptica*, leak is mainly caused by *Globisporangium*

(formerly *Pythium*) *ultimum*, but several other related organisms may cause leak. Mefenoxam (Ridomil®, and other products) is used on many potato acres across the region to manage pink rot and suppress leak. Insensitivity to mefenoxam has been reported in pathogens causing both pink rot and leak in MN and ND, but a widespread survey has not been conducted in the region in 10-15 years. In the last 2 to 3 years, growers and crop consultants have reported a change from typical symptoms of leak and have noted that the disease progression in storage appears to be changing with respect to temperature. To address these situations, we have collected 98 pink rot and leak pathogen isolates from potato storages in ND and MN. We have tested a small representative selection for sensitivity to mefenoxam but will complete testing all isolates in the coming months. Evaluation of genetic differences of the isolates causing varying leak symptoms, and characterizing pathogens causing leak for infection characteristics and aggressiveness under a range of temperature regimes are underway.

Objectives:

1. Determine mefenoxam (Ridomil ®) sensitivity of *P. erythroseptica* and *Pythium*/*Globisporangium* isolates collected from tubers with pink rot and leak symptoms.
2. Characterize the genetic diversity in the *Pythium*/*Globisporangium* isolate complex affecting potatoes.
3. Define the effect of temperature on pathogen growth and infection rate / severity in *Pythium*/*Globisporangium* isolates causing classic and 'white' leak.

Report:

Table 1. Current isolate collection from potatoes with pink rot symptoms 2024.

Location	Number of samples	Number of isolates
Osage	3	8
Ottertail	1	7
Brooten	1	2
MN Total	**5**	**17**

Larimore	1	2
Oakes	2	5
ND Total	**3**	**7**
Overall Total	**8**	**24**

From September through November of 2024, we surveyed storage facilities in Minnesota and North Dakota for tubers displaying symptoms of pink rot and leak (Figure 1). A total of 5 to 10 tubers were sampled from each storage facility. Tubers were cut lengthwise and observed for classic leak, white leak, and pink rot symptoms (Figure 2).

White leak symptoms include all the same characteristics as classic leak except infected tuber tissue appears creamy to white. Two-cm sections were excised from areas where the symptomatic tissue meets the non-symptomatic tissue, plated onto *Pythium*/*Globisporangium,* and *Phytophthora* selective media, and incubated for 48 hr. Cultures were examined for oomycete characteristics and selected for purification. Isolates were placed into long-term storage until further use.

To date, 24 *Phytophthora* isolates have been collected from tubers expressing pink rot symptoms (Table 1) and 74 *Pythium*/*Globisporangium* isolates have been collected from tubers expressing classic (54 isolates) or white (20 isolates) leak symptoms (Table 2).

Initial experiments (1 trial) indicate that there are significant differences between isolates of white and classic leak pathogen across three incubation temperatures (Figure 3). These data should be interpreted with extreme caution as only 1 isolate of each pathogen was evaluated.


Figure 1. Tubers displaying rot symptoms in a storage facility.

Mefenoxam (Ridomil®, and others) sensitivity has been measured on seven isolates

Table 2. Current isolate collection from potatoes with leak symptoms 2024.

Location	Leak Symptoms	Number of samples	Number of isolates
Brooten	White Leak	1	2
	Classic Leak	1	2
Osage	White Leak	5	6
	Classic Leak	6	18
Ottertail	White Leak	1	1
	Classic Leak	4	7
Perham	White Leak	0	0

to date. These preliminary experiments are

or intermediate reactions to the fungicide (Figure 4).

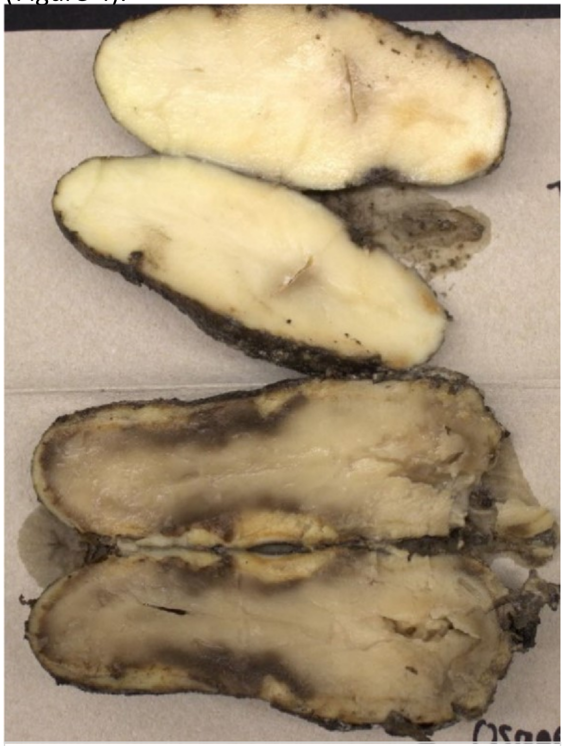

Figure 2. Tubers sampled from the same storage facility displaying white (top) and classic (bottom) leak symptoms.

	Classic Leak	3	7
Vining	White Leak	1	2
	Classic Leak	1	4
Wadena	White Leak	1	2
	Classic Leak	1	1
MN Total	**White Leak**	**9**	**13**
	Classic Leak	**16**	**39**
Oakes	White Leak	3	3
	Classic Leak	3	5
Hoistad	White Leak	1	2
	Classic Leak	0	0
Larimore	White Leak	1	2
	Classic Leak	1	4
Lisbon	White Leak	0	0
	Classic Leak	1	6
ND Total	**White Leak**	**5**	**7**
	Classic Leak	**5**	**15**
Overall	**White Leak**	14	20
Total	**Classic Leak**	21	54

encouraging in that all isolates display sensitive

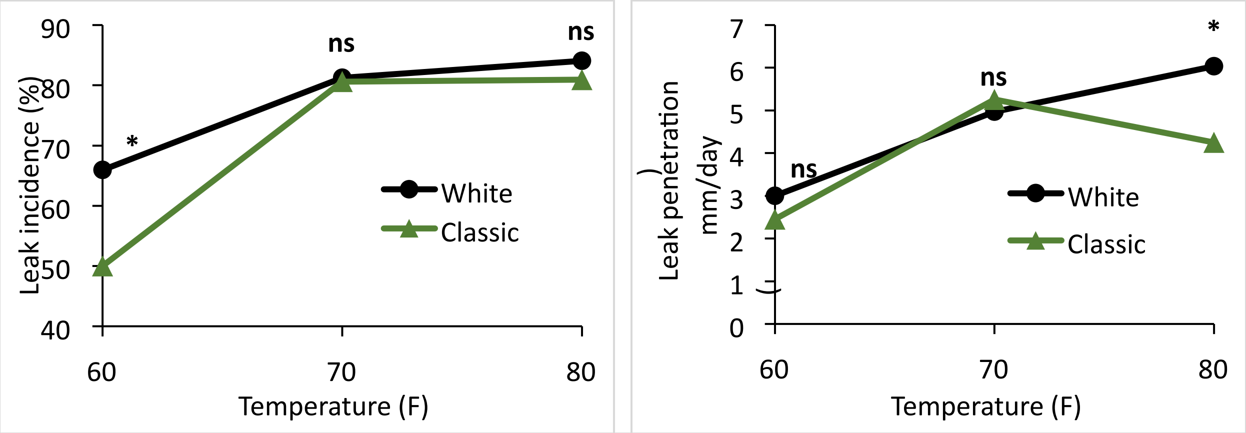

Figure 3. Incidence and penetration of white and classic leak on tubers inoculated with a single isolate of each pathogen and incubated at three temperatures.

Future work will include species identification of isolates collected in 2024, determining the mefenoxam sensitivity of the remaining isolates, and further defining the effect of temperature on pathogen growth and infection rate/severity in *Pythium*/*Globisporangium* isolates causing classic and white leak.

We will continue to collect tubers with symptoms of pink rot and leak and encourage growers to reach out so we can include samples from across the region in our research. Please see the instructions below for packing and shipping information. Future work will include species identification of isolates collected in 2024, determining the mefenoxam sensitivity, and defining the effect of temperature on pathogen growth and infection rate/severity in Pythium/Globisporangium isolates causing classic and white leak.

Table 3. EC_{50} values for seven leak isolates collected in 2024.

Isolate	Leak Symptoms	Collection Year	EC^{50} Value
24MN8-2	Traditional Leak	2024	0.025
24MN5-1	Traditional Leak	2024	0.030
24MN3-5	White Leak	2024	4.500
24MN15-1	Traditional Leak	2024	0.035
24MN9-1	Traditional Leak	2024	0.032
24MN16-1	Traditional Leak	2024	1.000
24MN14-1	White Leak	2024	0.050
08MN17-3[1]	Traditional Leak	2008	0.010
09MN4-1[2]	Traditional Leak	2009	> 100

Packing rotted tubers:

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[1] Isolate was collected in 2008 and used as a mefenoxam sensitive control with a previously documented EC50 value of 0.02.

[2] Isolate was collected in 2009 and was used as a mefenoxam resistant control with a previously documented EC50 value of > 100.

- Choose tubers with some healthy tissue – we cannot isolate from completely rotted tubers
- Dry tubers as is possible, wrap them in a dry paper towel
- Place into a plastic bag, but DO NOT SEAL the bag, or punch some holes
- Ship in a sturdy box with some padding
- 8-12 tubers per field is optimum, but send what you can find
- Send an email with tracking information before shipping
- Ship to: Julie Pasche : NDSU Plant Path Dept. : 1402 Albrecht Blvd. : Walster Hall, 306 :
  Fargo, ND 58102 : 701-231-7547

Report for Proposal Title: Soil Health SCRI Continuation Funding

Submitted to Northland Potato Growers Association

Principle Investigator: Julie Pasche, Department of Plant Pathology, North Dakota State University, Fargo, ND 58102. Julie.Pasche@NDSU.edu; 701-231-7547

Executive Summary: Potatoes USA has provided each state involved with the Soil Health SCRI project with funding to continue the rotations uninterrupted during the 2024 growing season until the next SCRI (or similar) funding award is secured. The email below confirms the intent of the funding from Potatoes USA to the PI from each state involved in the objective 1 replicated trials.

Pasche, Julie

From:	Donavon Johnson <djohnson@nppga.org>
Sent:	Monday, November 13, 2023 2:48 PM
To:	Pasche, Julie
Subject:	Fwd: Invoice to PUSA for Soil Health teams
Follow Up Flag:	Follow up
Flag Status:	Flagged

See email below

Donavon Johnson
Sent from my iPhone

Begin forwarded message:

> **From:** John Lundeen <JohnL@potatoesusa.com>
> **Date:** September 6, 2023 at 4:39:04 PM CDT
> **To:** gary@oregonspuds.com, Travis Blacker <travis.blacker@potato.idaho.gov>, Chris Voigt <cvoigt@potatoes.com>, jehrlich@coloradopotato.org, "Donavon Johnson (djohnson@nppga.org)" <djohnson@nppga.org>, thoulihan@wisconsinpotatoes.com, "Kelly Turner (kelly@mipotato.com)" <kelly@mipotato.com>, "Donald Flannery (flannery@mainepotatoes.com)" <flannery@mainepotatoes.com>, pngray@frontiernet.net
> **Cc:** Chris Voigt <cvoigt@potatoes.com>, Alyssa Green <Alyssa@potatoesusa.com>, "Ken Frost (Kenneth.Frost@oregonstate.edu)" <Kenneth.Frost@oregonstate.edu>
> **Subject: Invoice to PUSA for Soil Health teams**
>
> Hello state managers,
>
> I need your assistance in the distribution of funds to the soil health team. PUSA passed a special budget request for $100,000 to help this science team keep their crop rotations and sampling intact – they did not receive the USDA/SCRI funding they were seeking this year.
>
> Potatoes USA would like to receive an invoice for $11,111.11 from your state. Once you receive the funds, we would like you to forward these funds to the appropriate scientist in your state who works on the Soil Health team.
>
> Invoice Details:
> Potatoes USA
> 3675 Wynkoop Street
> Denver, CO 80216
> Email: johnl@potatoesusa.com and alyssa@potatoesusa.com
>
> I have cc'd contacts who can help with the logistics on this matter:
> 1. Alyssa Green here at Potatoes USA for W-9's.
> 2. Ken Frost at Oregon State can provide the name of the lead scientist in your state to whom the funds should be forwarded.
>
> Thank you for your help.
>
> John Lundeen

Procedures: The experiment consists of a 2-year and a 3-year rotation with six treatments replicated five times (Table 1). The 2-year rotation was planted to potatoes in 2024 and the 3year rotation was planted to field peas. Due to the irrigator at this site being moved by the cooperator, potato planting was delayed until June 14. Potatoes cvs Russet Burbank and Bannock Russet were planted on 36-inch rows at 14-inch seed spacing (Figure 1). Field peas were planted on June 26 in 6-in rows at 4 bushels/acre. Both crops were managed per local recommendations and agronomic practices. Emergence was recorded on July 25, visual foliar vine senescence assessments were taken on August 23 and 29, and soil samples were collected from each potato plot on August 20 and pea plot on October 18. Potato tubers were collected for yield and quality assessments at harvest on Sept. 17. Soils were subsampled and stored for microbial community functional analysis (at -80C) and analysis of soil physical, chemical, and biological properties (dried for long-term storage).

Table 1. North Dakota crop rotations for objective 1 for years 2019-2024.

	2019		2020		2021		2022[c]	2023[c]	2024[c]
Treatment[a]	Crop	Cover Crop	Crop[b]	Cover Crop	Crop	Cover Crop	Crop	Crop	Crop
1	Russet Burbank	Rye	Corn		Wheat		Russet Burbank	Oats	Russet Burbank
2	Russet Burbank	Rye	Corn + 3t TM		Wheat		Russet Burbank	Oats	Russet Burbank
3	Russet Burbank	Rye	Corn		Wheat	Mustard	Russet Burbank	Oats	Russet Burbank
4	Russet Burbank	Rye	Corn + 6t TM		Wheat	Wheat	Russet Burbank	Oats	Russet Burbank
5	Russet Burbank	Rye	Corn + 3t TM		Mustard		Russet Burbank	Oats	Russet Burbank
6	Bannock Russet	Rye	Corn		Wheat		Bannock Russet	Oats	Bannock Russet
7	field pea	Rye	Russet Burbank	Rye	Wheat		Russet Burbank	Oats	Field Pea
8	field pea	Rye	Russet Burbank	Rye	c3t		Russet Burbank	Oats	Field Pea
9	field pea	Rye	Russet Burbank	Rye	Wheat	Mustard	Russet Burbank	Oats	Field Pea
10	field pea	Rye	Russet Burbank	Rye	c6t		Russet Burbank	Oats	Field Pea
11	field pea	Rye	Russet Burbank	Rye	Wheat	Mustard	Russet Burbank	Oats	Field Pea
12	field pea	Rye	Bannock	Rye	Wheat		Bannock	Oats	Field Pea

[a] Treatments highlighted green indicate 3 year rotation. Treatments highlighted yellow indicate 2 year rotation.

[b] 3t TM indicates 3 tons of turkey manure was applied in spring

[b] 6t TM indicates 6 tons of turkey manure was applied in spring

[c] No cover crop was planted in 2022, 2023, and 2024

Results to Date

Visual evaluations of foliar senescence indicate that plants of cv Bannock Russet were most healthy (displayed the least amount of senescence), significantly so compared to some Russet Burbank treatments (Table 2). This is likely due to Bannock's Verticillium wilt resistance. No significant difference was observed among the Russet Burbank treatments. Significant differences in total yield were observed but no differences in tuber grade or marketable yield were observed (Table 2). Due to the delays in planting and early harvest, yields were very depressed. Assessments for specific gravity and tuber disease are ongoing. Testing soil physical, chemical, and biological properties and microbial community are waiting for future funding.

Preliminary Conclusions

This funding was intended to continue the 5-yr SCRI Soil Health project. We have a massive amount of data from these 6 years. We have presented only the results from data collected from this funding for potato plots during the 2024 growing season. These data will be combined with data collected previously at our site and at the nine other sites across the US to increase our knowledge of how the cropping systems evaluated can help to improve soil health in potato production. It is unclear where additional funding will come to continue these long-term studies in the future.

Figure 1. Row marking and mid -season disease assessments in the 2024 SCRI Soil Health trial.

Table 2. Total and marketable yield, tuber grade, and vine senescence for the Soil Health SCRI trial conducted near Hubbard, MN in 2024.

Treatment	Total Yield (cwt/a)*	Total US No. 1 (cwt/a)	Total US No. 2 (cwt/a)	Marketable Yield (cwt/a)	Total > 6oz (%)	Total > 10oz (%)	Vine health 8/29 (%)*
1	224.4 A	101.0 A	17.7 A	110.7 A	26.7 A	7.1 A	86.0 AB
2	216.6 A	94.8 A	15.6 A	106.1 A	26.1 A	6.8 A	83.3 B
3	207.6 A	90.3 A	12.1 A	102.0 A	24.7 A	5.1 A	82.8 B
4	205.1 A	83.5 A	11.7 A	101.2 A	22.1 A	4.9 A	86.3 AB
5	202.7 A	81.3 A	11.3 A	96.9 A	21.5 A	4.0 A	82.5 B
6	143.7 B	73.1 A	3.3 A	75.7 A	21.0 A	3.8 A	100.0 A

*Signficant differences were observed among treatments ($P < 0.05$) using a combination of the method of least squares fit and Tukey's honestly significant difference analyses.

Northland Potato Growers Association

Minnesota Area II Potato Growers Council

Title: Storage quality of advanced processing and yellow fleshed potato clones.

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Executive Summary:

Processing Quality of Yellow Flesh and New Public Varieties: Storage quality of Fontane, a yellow flesh variety, grown under ND dryland conditions was examined. Fontane produced in ND (2023) yielded excellent fry color throughout 12 months of 45 and 48°F storage. Potato clones from NDSU, UMN, 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 2024 crop year is presented from select public clones.

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. Results from a 2023-24 replicated storage trials are presented as well as an update on 2024 pressure bruise storage evaluations.

Rational:

Postharvest processing quality: With the announcement of Agristo's potato processing plant coming to North Dakota, quantifying processing quality of yellow flesh varieties (commercial and public) under ND/MN environments is critical. In addition, understanding the postharvest management of new public processing clones (chip or fry) is crucial to understand varietal differences that may impact postharvest storage quality.

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.

Procedures:

Plant Material: Potato samples for the 2024-25 storage evaluations were sampled across several ND/MN field trials and grower production fields. Hoople Farmer's Coop provided Fontane tuber samples, advanced public processing clones were provided by University or USDA-ARS researchers, and several chip clones were sampled from a Potatoes USA sponsored SNAC chip trial.

Processing quality in storage: After suberization for two weeks at 55°F, 95% RH, processing clones were stored at 48, 45, and 42°F. Sucrose rating and tuber glucose concentrations were determined with a YSI 2900 biochemical analyzer (Yellow Springs Instruments). Samples for sugar and fry photovolt % reflectance were obtained after suberization and after 3, 6, and 9 months from each respective storage temperature. At each time point, specific gravities (weight in air/weight in water) and sucrose rating, %glucose were measured. Potato planks (7/8''W x 5/16''D) were prepared with a pneumatic knife and fried in a batch fryer at 375°F for 3.5 minutes. Immediately after frying, photovolt % reflectance was quantified; photovolt reflectance corresponds to the USDA color scale (USDA 1 > 44%; USDA 2 = 35 to 44%, USDA 3 = 26 to 35%; USDA 4 < 26 %).

Black Spot Bruise Evaluation -out of field:
*Tuber samples from 12 chip fields were collected in 2024 containing an equal mix of commercial varieties and public breeding program numbered lines. Black spot bruise evaluation procedures were according to published procedures by C. Long (MSU, Potatoes USA). Briefly, f*or each treatment 50 tubers were hand harvested. One half of the sample (25 tubers) was held at 72°F and served as a check control. The remaining 25 tuber sample was held at 50°F for 12 hours and then placed in a rotating 3-baffle drum for 1 minute to simulate handling impact forces conducive to bruising. The check and 'handled' samples were held for 10 days at 72°F before bruise data was collected after steam peeling. The percent bruise free tubers and average bruises per tuber data were calculated.

Storage Pressure Bruising:
Bruising data was collected from 6 chip clones included in a Potatoes USA National Chip processing trial grown under dryland conditions in Hoople, ND (2023 crop). To test impact of simulated pile height on water loss/bruise severity, tuber samples were also collected from three grower fields. 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, 1/2 of the bottle jack pressure (1.1 lb/in^2) was applied to one treatment tote from the three commercial grower fields. After 6 months storage (March 2024) the totes were removed, and sample bag weights recorded to determine water loss. The total number of flattened depressions per tuber and total bruised area was measured with a digital caliper.

Results:

Processing Quality of Yellow Flesh Varieties: **Fontane, North Dakota Location**

Processing quality of Fontane produced in ND (2023 crop year) is reported. Fry quality was excellent from potatoes stored at either 48°F or 45°F through nearly 12 months of storage (Figure 1). Storage analysis of select yellow flesh varieties from the 2024 crop year is ongoing.

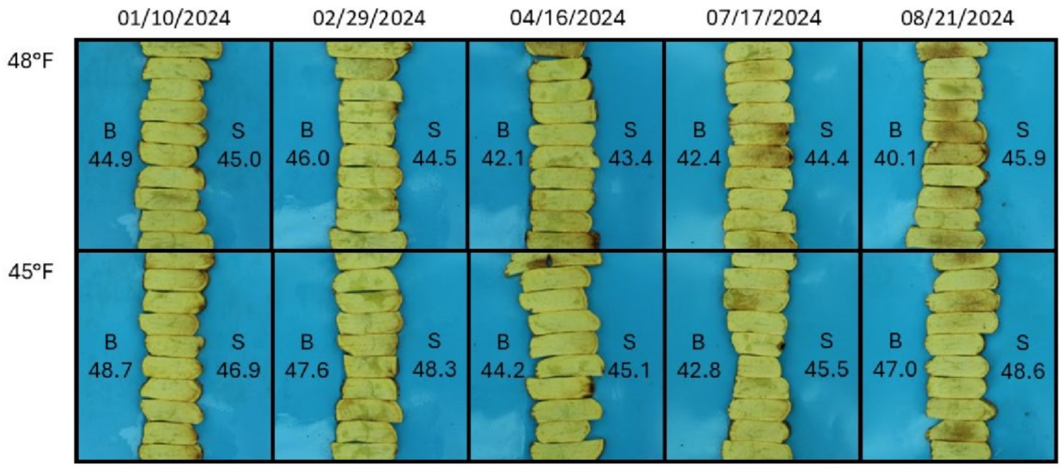


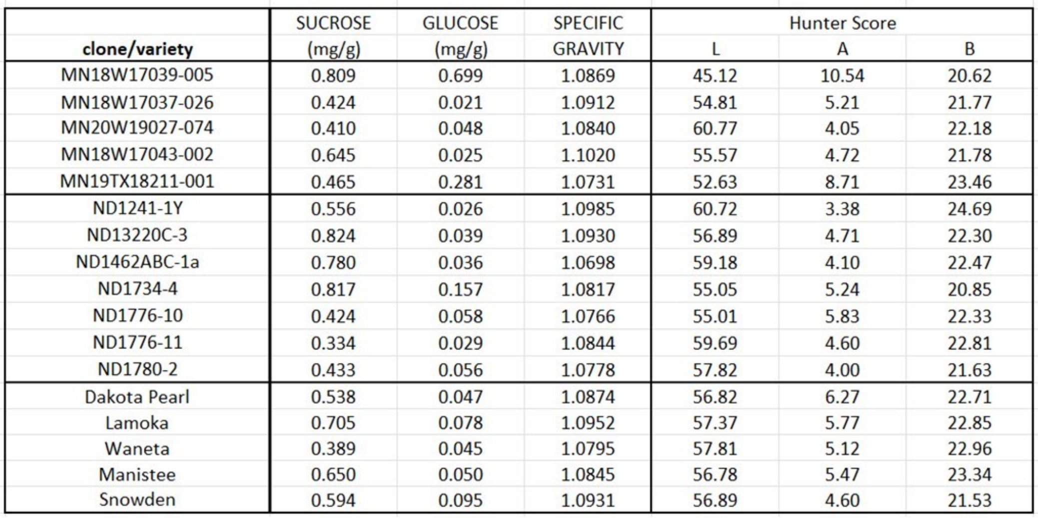
Figure 1. Fry processing of Fontane stored 48 or 45°F (2023 Crop). Samples were fried for 3.5 minutes at 375°F and photovolt % reflectance of bud (B) and stem (S) is reported.

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.

Processing quality of advanced public processing clones

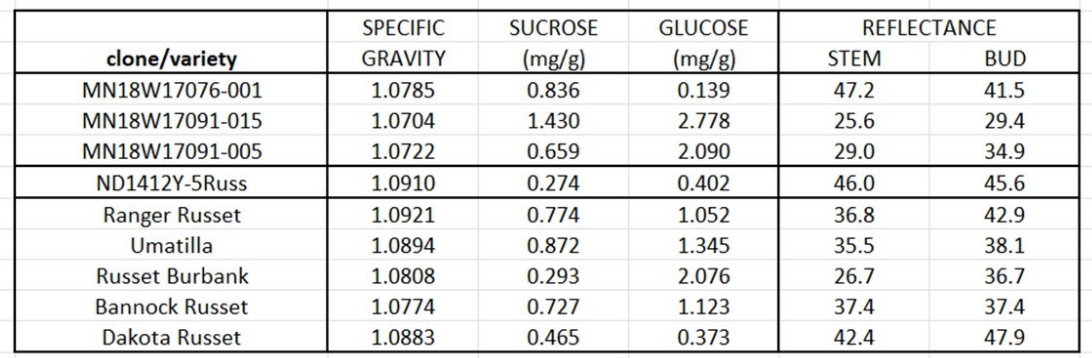
The results summarizing the 2023-24 storage campaign were published in the Northland Potato Grower Magazine (October 2024 issue, p 16-19). For the 2024 crop year, sugar data from select NDSU and UMN advanced processing clones is reported in Tables (1, 2) and Figure (2).

Table 1. Sugar and chip quality data from NDSU and UMN Chip Clones (December 2024):



clone/variety	SUCROSE (mg/g)	GLUCOSE (mg/g)	SPECIFIC GRAVITY	Hunter Score L	A	B
MN18W17039-005	0.809	0.699	1.0869	45.12	10.54	20.62
MN18W17037-026	0.424	0.021	1.0912	54.81	5.21	21.77
MN20W19027-074	0.410	0.048	1.0840	60.77	4.05	22.18
MN18W17043-002	0.645	0.025	1.1020	55.57	4.72	21.78
MN19TX18211-001	0.465	0.281	1.0731	52.63	8.71	23.46
ND1241-1Y	0.556	0.026	1.0985	60.72	3.38	24.69
ND13220C-3	0.824	0.039	1.0930	56.89	4.71	22.30
ND1462ABC-1a	0.780	0.036	1.0698	59.18	4.10	22.47
ND1734-4	0.817	0.157	1.0817	55.05	5.24	20.85
ND1776-10	0.424	0.058	1.0766	55.01	5.83	22.33
ND1776-11	0.334	0.029	1.0844	59.69	4.60	22.81
ND1780-2	0.433	0.056	1.0778	57.82	4.00	21.63
Dakota Pearl	0.538	0.047	1.0874	56.82	6.27	22.71
Lamoka	0.705	0.078	1.0952	57.37	5.77	22.85
Waneta	0.389	0.045	1.0795	57.81	5.12	22.96
Manistee	0.650	0.050	1.0845	56.78	5.47	23.34
Snowden	0.594	0.095	1.0931	56.89	4.60	21.53

Table 2. Sugar and fry reflectance data from NDSU and UMN Russet Clones (December 2024):



clone/variety	SPECIFIC GRAVITY	SUCROSE (mg/g)	GLUCOSE (mg/g)	REFLECTANCE STEM	BUD
MN18W17076-001	1.0785	0.836	0.139	47.2	41.5
MN18W17091-015	1.0704	1.430	2.778	25.6	29.4
MN18W17091-005	1.0722	0.659	2.090	29.0	34.9
ND1412Y-5Russ	1.0910	0.274	0.402	46.0	45.6
Ranger Russet	1.0921	0.774	1.052	36.8	42.9
Umatilla	1.0894	0.872	1.345	35.5	38.1
Russet Burbank	1.0808	0.293	2.076	26.7	36.7
Bannock Russet	1.0774	0.727	1.123	37.4	37.4
Dakota Russet	1.0883	0.465	0.373	42.4	47.9

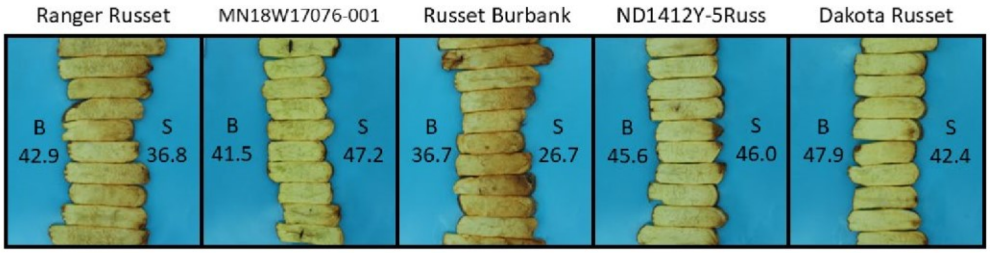


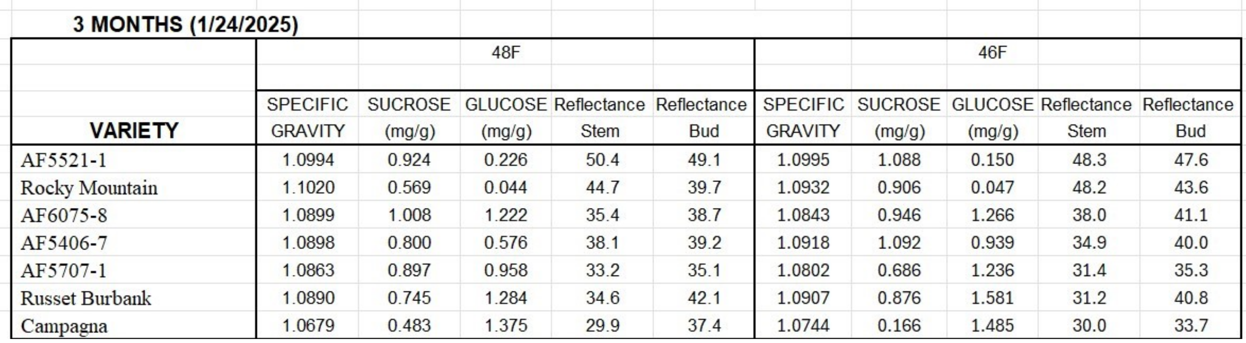
Figure 2. Fry color from Select NDSU and UMN russet clones (2024 Crop)

Tubers were grown under irrigation at Larimore, ND and processing quality of Advanced UMN (MN18W17076-001) and NDSU (ND1412Y-5Russ) russet clones is highlighted in comparison with check cultivars. Planks 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.

Chips from MN20W19027-074 and ND1241-1Y had the lightest color with both having Hunter L values of 60.7. Hunter L values for the commercial chip checks did not exceed 57.8 (Table 1). Similarly, two numbered russet clones (MN18W17076-001 and ND1412Y-5Russ) provided excellent fry color when compared to the commercial russet check (Table 2, Figure 2). The observed fry color was closely associated with decreased glucose concentrations detected among these lines in early December. Trends in tuber sugar concentrations and processing color will be assessed throughout 9 months of storage.

In a separate processing storage trial, tubers from several clones were kindly provided by Black Gold Farms. At three months of storage (Table 3, Figure 3), AF5521-1 (University of Maine) had the lowest glucose concentrations that was closely associated with excellent fry color. This analysis will continue through 9 months of storage, June 2025.

Table 3. Sugar and fry reflectance data at 3 month of storage (2024 crop).



3 MONTHS (1/24/2025)

	48F					46F				
VARIETY	SPECIFIC GRAVITY	SUCROSE (mg/g)	GLUCOSE (mg/g)	Reflectance Stem	Reflectance Bud	SPECIFIC GRAVITY	SUCROSE (mg/g)	GLUCOSE (mg/g)	Reflectance Stem	Reflectance Bud
AF5521-1	1.0994	0.924	0.226	50.4	49.1	1.0995	1.088	0.150	48.3	47.6
Rocky Mountain	1.1020	0.569	0.044	44.7	39.7	1.0932	0.906	0.047	48.2	43.6
AF6075-8	1.0899	1.008	1.222	35.4	38.7	1.0843	0.946	1.266	38.0	41.1
AF5406-7	1.0898	0.800	0.576	38.1	39.2	1.0918	1.092	0.939	34.9	40.0
AF5707-1	1.0863	0.897	0.958	33.2	35.1	1.0802	0.686	1.236	31.4	35.3
Russet Burbank	1.0890	0.745	1.284	34.6	42.1	1.0907	0.876	1.581	31.2	40.8
Campagna	1.0679	0.483	1.375	29.9	37.4	1.0744	0.166	1.485	30.0	33.7

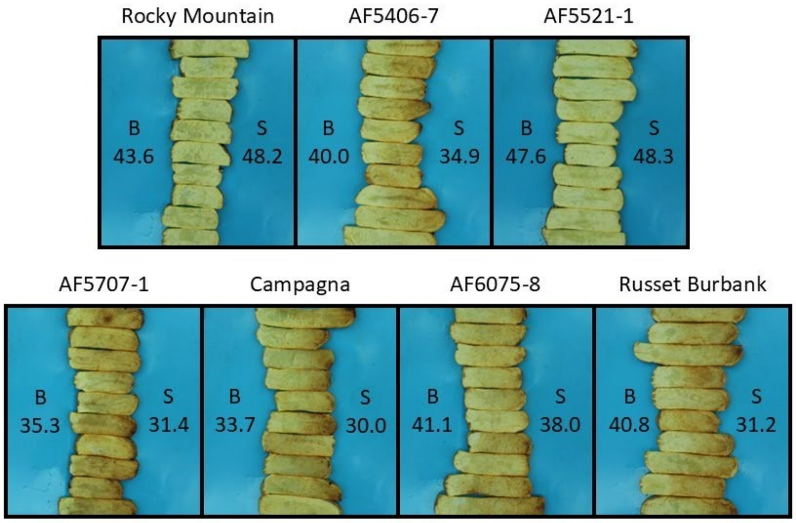


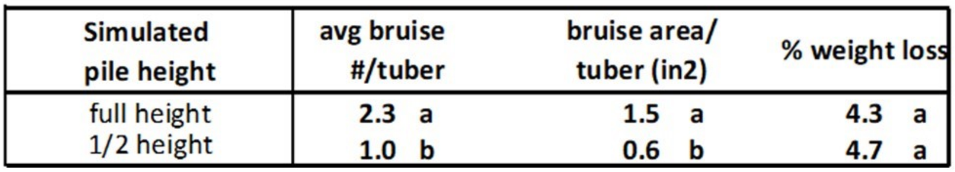
Figure 3. Fry processing quality at 3-month storage at 46°F (2024 crop).

Samples were fried for 3.5 minutes at 375°F and photovolt % reflectance of bud (B) and stem (S) is reported.

Black spot bruise evaluation – 2024 out of field

No difference in black spot bruise incidence were detected among the 12 chip varieties examined in 2024 (data not shown).

Storage Bruising: the impact of simulated pile height (hydraulic pressure) on bruise incidence and severity was examined across three commercial chip fields in 2023-24 (Table 4). No differences in water loss were detected among the three commercial chip fields. However, samples treated at full height (2.1lb/in^2) had a nearly a 2.5-fold increase in bruise incidence and bruise area per tuber when compared to the half pile height pressure treatment (1.1lb/in^2). **Table 4**. Impact of simulated pile height pressure on pressure bruise ratings (2023 crop)

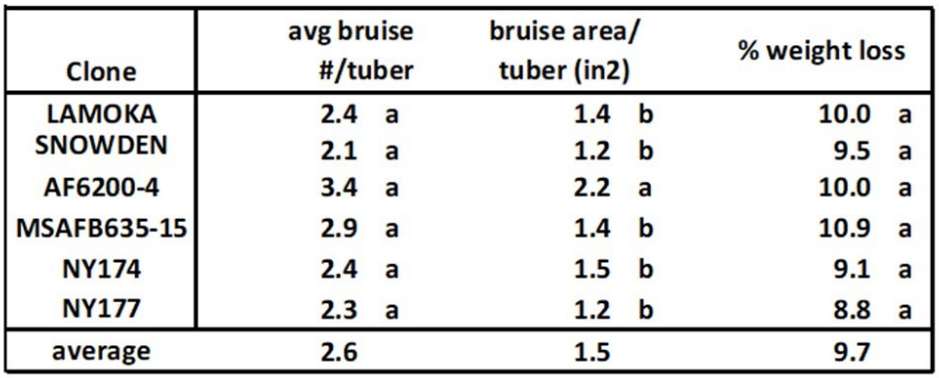


Simulated pile height	avg bruise #/tuber	bruise area/ tuber (in2)	% weight loss
full height	2.3 a	1.5 a	4.3 a
1/2 height	1.0 b	0.6 b	4.7 a

treatment means followed by the same letter are not significantly different ($P<0.05$)

Varietal differences in pressure bruising were evaluated among six chip clones included in a Potatoes USA National Chip trial sampled under dryland conditions in Hoople, ND. No significant difference in tuber water loss nor bruise number/tuber were detected in 2023-24 (Table 5). However, average bruise area/tuber from AF6200-4 was significantly higher than that from the other clones examined in 2023. Several clones (chip processing, red, and yellow) from the 2024 crop year are currently being stored in EGF with pressure bruise assessment scheduled for early March, 2025.

Table 5. Pressure bruising ratings of ND SNAC chip clones (2023 crop)



Clone	avg bruise #/tuber	bruise area/ tuber (in2)	% weight loss
LAMOKA	2.4 a	1.4 b	10.0 a
SNOWDEN	2.1 a	1.2 b	9.5 a
AF6200-4	3.4 a	2.2 a	10.0 a
MSAFB635-15	2.9 a	1.4 b	10.9 a
NY174	2.4 a	1.5 b	9.1 a
NY177	2.3 a	1.2 b	8.8 a
average	2.6	1.5	9.7

treatment means followed by the same letter are not significantly different ($P<0.05$)

Northland Potato Growers Association and Minnesota Area II Potato Growers Council

Research Report

Title: Development of a real-time quantitative PCR assay for direct and rapid detection of the root-lesion nematode, *Pratylenchus penetrans* in potato roots

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Summary

This study aimed to develop a sensitive and specific real-time quantitative PCR (qPCR) assay for detecting the root-lesion nematode, *Pratylenchus penetrans*, directly from potato roots. To achieve this objective, nematode species was identified and confirmed using PCR amplification and sequencing of two genomic regions. DNA was extracted from both infected and uninfected potato root tissues, and primers previously developed for *P. penetrans* were tested. qPCR inhibitors in potato root DNA extracts were assessed and mitigated by adding bovine serum albumin (BSA). Specificity tests confirmed that the assay amplified only *P. penetrans* DNA, without cross-reacting with other nematode species. Sensitivity of the qPCR assay evaluated through two-fold dilution series revealed a reliable detection limit equivalent to 1.56×10^{-2} nematodes per 0.2 g of potato roots. A standard curve was generated by inoculating potato roots with known numbers of *P. penetrans* nematodes, and the assay demonstrated a high amplification efficiency (E=100.75%). Additionally, greenhouse experiments were conducted to evaluate the assay's performance using five potato cultivars, confirming its suitability for detecting and quantifying this nematode species in infected potato roots. A strong correlation (*r*=0.902) was observed between the qPCR assay results and the nematode counts obtained using traditional methods (Whitehead tray extraction and microscopic counting). This assay offers a rapid, efficient alternative to labor-intensive manual extraction, facilitating early nematode detection for better disease management.

Background

Root-lesion nematodes, *Pratylenchus penetrans*, are economically important nematode pests of potato crop, causing considerable yield losses and reducing tuber quality. As migratory endoparasites, these nematodes infect plants by penetrating the roots, where they cause damage to the root system, impairing the plant's ability to uptake water and nutrients, which eventually leads to reduced plant health and productivity. Traditionally, root-lesion nematodes have been detected through morphological identification of the nematodes and their symptoms on plant roots; however, these methods are labor-intensive, time-consuming, and often require expert knowledge for accurate identification. Molecular assays for detection and quantification of *P. penetrans* from soil and tuber samples have been developed (Baidoo et al., 2017; Figueiredo et al., 2021). However, no assay has been specifically developed to detect *P. penetrans* directly from potato roots, despite being the primary site of infection.

Given the endo-parasitic nature of *P. penetrans*, early detection from root tissue is crucial for effective pest management. Development of a sensitive and specific qPCR assay for detecting and quantifying *P. penetrans* DNA in potato roots addresses this gap in diagnostics. Such an assay would allow for early detection of infection, even before the nematodes cause visible symptoms. The assay eliminates the need for manual extraction of nematodes from roots, a labor-intensive process that can be challenging to implement on a large scale. Additionally, it may aid in the selection of resistant cultivars by enabling researchers to monitor nematode presence in root systems more efficiently, ultimately contributing to improved pest management strategies. Development of the qPCR assay can play a pivotal role in enhancing early detection capabilities, leading to timely interventions, and ultimately minimizing the impact of *P. penetrans* on potatoes.

The main objective of this study is to develop a rapid and sensitive qPCR assay for detecting and quantifying *P. penetrans* directly from potato root DNA extracts.

Materials and Methods

Nematode species confirmation

Root-lesion nematodes, *Pratylenchus penetrans* maintained on carrot discs at 22°C, were extracted. Nematodes were picked manually, and DNA was extracted from individual nematode using the Proteinase K method (Baidoo et al., 2017; Huang and Yan, 2017). Two genomic regions were amplified: (i) the D2–D3 expansion region of the 28S rRNA gene using the primer pair D2A (forward) and D3B (reverse) (Subbotin et al., 2008), and (ii) the internal transcribed spacer (ITS) region of ribosomal DNA (rDNA) using two primer sets: rDNA2 (forward)/rDNA1.58s (reverse) (Cherry et al., 1997) and TW81 (forward)/AB28 (reverse) (Joyce et al., 1994). PCR products were sequenced by MC Lab (South San Francisco, CA, USA), and the resulting sequences were compared to reference sequences using BLAST in the NCBI database to confirm species identity.

DNA extraction and primer selection

DNA from infected and uninfected potato root tissues were extracted using Fast DNA spin kit (MP Biomedicals, Solon, OH) following manufacturer's protocol. Before DNA extraction, roots were washed thoroughly to remove the debris from the soil in continuous stream of tap water for five minutes. The roots were then dipped in 70% ethanol solution for 1 minute and then blot dried using clean paper towels. The roots were then cut into 1-2 cm pieces using a pair of surface sterilized scissors. The primer pair Pp-F (5′-GGTTTTCGGGCTCATATGGGTTC-3′)/Pp-R (5′-TTTACGCCG AGAGTGGGATTGTG-3′) used in this study were previously designed from D2-D3 expansion region of the 28S rRNA gene of *P. penetrans* (Baidoo et al., 2017).

Detection of qPCR inhibitors in potato roots

The presence of inhibitors in potato root DNA that might interfere with qPCR was assessed by analyzing DNA extracted from 'Red Norland' potato roots collected at four different growth stages: 20, 25, 30, and 35 days after planting. Root DNA was added to the qPCR reaction mixture, along with a test plasmid vector, pGEM-T Easy vector (Promega Corp., Madison, WI) and primers targeting the vector: T7 (forward: 5′-TAATACGACTCACTATAGGG-3′) and SP6 (reverse: 5′-TATTTAGGTGACACTATAG-3′). Negative controls, which contained no root DNA, were included to establish a baseline for comparison. The presence of qPCR inhibitors was determined by statistically analyzing the quantification cycle (Cq) values from qPCR between positive controls and reactions containing root DNA extracts using SAS version 9.4 (SAS Institute Inc., Cary, NC, USA).

With the detection of qPCR inhibitors, four different concentrations of Bovine Serum Albumin (BSA) were tested to evaluate its ability to neutralize the qPCR inhibitors present in the root DNA extracts. The concentrations of BSA tested were 0.2, 0.3, 0.4, and 0.5 µg/µl, each added to the qPCR reaction mixtures. The Cq values obtained from the qPCR assay at different BSA concentrations were compared with the positive controls (plasmid DNA and ddH_2O without root DNA) to determine the optimal level of BSA that can reduce PCR inhibition and improve qPCR accuracy.

Reaction and amplification of qPCR

The qPCR assay was carried out in a 96-well plate on a Bio-Rad CFX96 Touch Real-Time PCR Detection System (Bio-Rad Laboratories, Inc., Hercules, CA, U.S.A.) with the cycling conditions of: incubation at 95°C for 5 minutes, followed by 35 cycles of 95°C for 10 seconds, 66°C for 20 seconds, and 72°C for 30 seconds, with melting curve analysis using the default settings to assess specificity. qPCR reactions were set up with a 10 µl mix containing 1.5 µl of DNA template, 0.5 µl of each primer (10 µM), 5.0 µl of Sso Advanced Universal SYBR Green Supermix (Bio-Rad Laboratories, Inc., Hercules, CA, U.S.A.), 0.2 µl of BSA (20 µg/µl), and 2.3 µl of ddH_2O. Data analysis was done using Bio-Rad CFX Manager Software version 3.1, and Cq values were determined for each reaction at default settings.

Specificity and sensitivity of the qPCR assay

Fresh roots of non-inoculated 'Red Norland' potato plants grown in autoclaved field soil was harvested after 30 days of planting. Roots were cleaned thoroughly, followed by treatment with 70% ethanol and then by blot drying and cutting into 1-2 cm pieces. *P. penetrans* harvested from fresh carrot culture, four other species of *Pratylenchus* (*P. dakotaensis, P. neglectus, P. scribneri,* and Hg51 unnamed root-lesion nematode in ND) and four nematodes of other genera were used to detect the specificity of the primers. Individual nematodes were picked and artificially inoculated in 0.2 g of potato roots. DNA was extracted from the artificially inoculated 0.2 grams of potato roots and the qPCR was performed. Two negative controls, DNA extracted from non-inoculated potato roots of 'Red Norland', and ddH_2O were included in the qPCR assay, while DNA extracted from *P. penetrans* using Proteinase K method was used as a positive control in the qPCR assay.

For determination of the detection sensitivity of the qPCR assay, four nematodes of *P. penetrans* extracted from fresh carrot culture were artificially inoculated in 0.2 g of fresh potato roots and DNA was extracted as described before. The extracted DNA was diluted in two-fold to create a serial dilution, and qPCR was performed on each dilution. The lowest detection limit was determined as the highest dilution at which a consistent amplification signal was observed across replicates. Similar to the specificity test, the positive and negative controls were included in the qPCR assay.

Development and validation of standard curve

The qPCR standard curve was developed by inoculating 'Red Norland' potato roots with known number of *P. penetrans* (1, 4, 16, 64, and 256 nematodes per 0.2 g of roots) obtained from fresh carrot cultures. DNA was extracted from artificially inoculated potato roots, and qPCR assay was run to measure how the Cq values changed with increasing nematode densities. The standard curve was generated in Microsoft Excel by plotting Cq values against the corresponding $\log_{10}$ of *P. penetrans* nematode densities used to inoculate the uninfected potato roots. This curve provided a reference for estimating *P. penetrans* populations in subsequent samples. The amplification efficiency of the qPCR assay was calculated from the slope of the standard curve.

The qPCR standard curve was validated using DNA extracts from 'Red Norland' potato roots inoculated with *P. penetrans* at densities different (3, 9, 27, 81, and 243) from those used during initial curve development. The same protocol as standard curve generation was used for validation. The qPCR standard curve validation was evaluated by correlating the qPCR estimates of *P. penetrans* derived from the standard curve equation with the actual *P. penetrans* densities used for inoculation.

Detection and quantification of *P. penetrans* from potato plant roots

Five potato cultivars (Red Norland, Caribou Russet, Modoc, Colomba, and Yukon Gold) were grown in a greenhouse with five replications in completely randomized design (CRD). A mixture of infested *P. penetrans* soil and autoclaved river sand (1:3 ratio) was used for planting. The initial *P. penetrans* population in the soil mix was determined by extracting nematodes using centrifugal sugar flotation (Jenkins, 1964) and counting under the microscope. Each plant was inoculated with a suspension of root-lesion nematodes and eggs to ensure a nematode population of 1,500 per kilogram of soil. The potato plants were harvested after 72 days and the roots were cleaned and cut into small pieces. For qPCR analysis, one gram of root tissue was separated and the remaining roots was used for nematode extraction by the Whitehead tray method (Whitehead and Hemming, 1965), followed by microscopic counting.

DNA was then extracted from 0.2 grams of infected root sample following the protocol described before. Positive controls (DNA extracts of 1 and 256 *P. penetrans* per 0.2 g; used in standard curve generation) and negative controls (ddH_2O or non-inoculated root DNA) were included. The number of nematodes in 0.2-gram root tissue was calculated using the standard curve equation ($y = -3.304x + 29.961$) and extrapolated to 1 gram of root tissue. Nematode suspensions were collected after 48 hours, and nematode counts were determined microscopically, with values converted to a 1-gram root equivalent. Correlation analysis was conducted to compare nematode estimates obtained by qPCR with those from Whitehead tray extractions and microscopic counting.

Results and Discussion

Nematode species confirmation

Species confirmation of *P. penetrans* was achieved by sequencing two genomic regions followed by BLAST analysis in the NCBI database. The D2-D3 expansion of the 28S rRNA gene, amplified with the D2A/D3B primer pair, yielded a sequence with 98.15% similarity to the reference sequence MN251258 from the NCBI database. The internal transcribed spacer (ITS) region of ribosomal DNA was amplified using two primer pairs: rDNA2/rDNA1.58s and AB28/TW81. Sequences obtained from these primers showed 99.85% similarity to the reference sequence LC030330 (with rDNA2/rDNA1.58s) and 99.88% similarity to LC030330 (with AB28/TW81) in the NCBI database, confirming the nematode species as *P. penetrans*.

Detection of PCR inhibitors

The qPCR analysis showed that DP2 had the highest average Cq value (21.09 ± 0.15), indicating the most significant PCR inhibition (Table 1). In contrast, DP1, DP3, and DP4 exhibited similar Cq values (19.32 ± 0.11, 19.15 ± 0.13, and 19.19 ± 0.09, respectively), which were not significantly different from one another but remained higher than the positive control. The positive control, with the lowest average Cq value (16.92 ± 0.10), demonstrated effective PCR performance without inhibitors. These findings confirm the presence of PCR inhibitors in the root DNA extracts and highlight the necessity of optimizing the qPCR assay to mitigate their inhibitory effects.

The addition of BSA to the qPCR reaction mixture demonstrated its effectiveness in reducing the inhibitory effects of root DNA extracts, as evidenced by decreasing Cq values observed. Without BSA, the average Cq value was 19.69 ± 0.85, significantly higher than all BSA-treated reactions. The Cq values for 0.4 µg/µl (17.72 ± 0.48) and 0.5 µg/µl (17.78 ± 0.33) were statistically similar to the positive control

(16.92 ± 0.10), which consisted of plasmid DNA and ddH_2O without root DNA. This indicates that at these BSA concentrations, the inhibitory effects of root DNA extracts were effectively neutralized, achieving performance comparable to the control. These results indicated that BSA concentrations of 0.4 µg/µl and 0.5 µg/µl are optimal for mitigating PCR inhibitors in root DNA extracts, enhancing qPCR assay accuracy.

Specificity and sensitivity of the qPCR assay

The specificity test of the PpF/PpR primer pair confirmed its ability to specifically detect *P. penetrans* in potato roots. Amplification was observed only in positive controls and DNA extracts from roots inoculated with *P. penetrans*, while no amplification occurred for DNA from other *Pratylenchus* species or plant-parasitic nematodes tested (Table 2). The Cq values for positive controls ranged from 23.43±0.17 (DNA extracted using the Proteinase K method with four *P. penetrans* as the DNA template) to 27.41±0.12 (DNA extracted by the same method with one *P. penetrans*). DNA extracted from 0.2 grams of potato roots inoculated with a single *P. penetrans* yielded Cq values ranging from 29.92±0.06 to 31.21±0.22. All other DNA extracts included in the specificity test showed no amplification (Figure 1). A single melting peak with a melting temperature of 85°C was observed in the qPCR assay, confirming the amplification of a single, specific amplicon (Figure 2).

The detection sensitivity of the qPCR assay was evaluated using two-fold serial dilutions of DNA extracted from 0.2 grams of potato roots artificially inoculated with four *P. penetrans*, down to a 1/1024 dilution (equivalent to 3.91×10^{-3} nematodes) (Table 3). The qPCR assay detected DNA at dilutions as low as 1/256 (1.56×10^{-2} nematodes per 0.2 g of roots), yielding a Cq value of 34.77 ± 0.07. Amplification was not observed at the 1/512 or 1/1024 dilutions. Across the serial dilutions, Cq values ranged from 27.72 ± 0.14 for undiluted DNA to 34.77 ± 0.07 at the detection threshold, with no amplification in negative controls. Positive controls included DNA extracted from one and four *P. penetrans* using the Proteinase K method, yielding Cq values of 27.30 ± 0.07 and 23.38 ± 0.08, respectively, demonstrating good amplification.

Development and validation of standard curve

The standard curve was developed by artificially inoculating different numbers (1, 4, 16, 64 and 256) of *P. penetrans* in 0.2 grams of potato roots. The relationship between the Cq values and corresponding $\log_{10}$ *P. penetrans* densities was described by the equation $y=-3.304+29.961$ (Figure 3). The Cq values for nematode densities of 1, 4, 16, 64, and 256 per 0.2 g of roots were 21.84 ± 0.20, 24.20 ± 0.13, 26.08 ± 0.17, 27.79 ± 0.22, and 29.99 ± 0.18, respectively. No amplification was observed in the negative controls, which used either ddH_2O or DNA extracted from uninfected potato roots as the template. A strong inverse linear relationship was observed between Cq values and the $\log_{10}$ *P. penetrans* densities ($R^2=0.993$), and the amplification efficiency was calculated to be 100.75%.

To validate the standard curve, DNA extracted from potato roots artificially inoculated with *P. penetrans* (3, 9, 27, 81, and 243) not used in the standard curve development was tested using the qPCR assay. The

Cq values ranged from 22.10 ± 0.11 for 243 nematodes to 28.19 ± 0.26 for 3 nematodes per 0.2 g of roots. The qPCR-based estimates of *P. penetrans* densities, derived from the standard curve equation, exhibited a strong positive correlation (R^2=0.988) with the densities derived from inoculation. This relationship was described by the equation y= 0.982x-0.836 (Figure 4).

Detection and quantification of *P. penetrans* from infected potato roots

The developed qPCR assay was applied to detect and quantify *P. penetrans* in infected root samples of five potato cultivars grown under the greenhouse conditions. The qPCR assay was validated by comparing nematode densities quantified directly from infected roots with those obtained through microscopic counting from the Whitehead tray extraction method. The average numbers of nematodes per gram of root were consistent between the two methods across all cultivars, with Red Norland showing the highest densities (393±47 qPCR; 389±29 Whitehead tray), followed by Caribou Russet (337±71; 350±61), Yukon Gold (275±57; 263±20), Modoc (167±11; 143±12), and Colomba (164±32; 158±21) (Table 4). A strong positive correlation (*r*=0.902) was observed between the qPCR estimates and microscopic counts, described by the equation y=0.923x+14.286, indicating the assay's high accuracy in quantifying nematode densities in potato roots (Figure 5).

Conclusions

The study developed and validated a real-time quantitative PCR (qPCR) assay for detecting and quantifying the root-lesion nematode, *P. penetrans*, directly from potato root DNA extracts. The assay demonstrated high specificity, sensitivity (detection limit of 1.56×10^{-2} nematodes per 0.2 g of potato roots), and reliability, with an amplification efficiency of 100.75%. Validation across five potato cultivars showed a strong correlation (*r* = 0.902) with traditional counting methods. This assay offers a rapid, efficient alternative to labor-intensive manual extraction, facilitating early nematode detection and improving pest management. More research is required to study the temporal dynamics of *P. penetrans* infection in potato roots, tracking nematode densities over time, identifying critical periods of peak infection, examining the progression of the nematode's life cycle within potato roots, and facilitating screening of potato cultivars for resistance to this important nematode pest.

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Tables and Figures

Table 1: Quantification cycle (Cq) values for root DNA extracts harvested at 20 days after planting (DAP) (DP1), 25 DAP (DP2), 30 DAP (DP3), and 35 DAP (DP4) for detection of PCR inhibitors in the DNA extracts.

Days after planting	Cq[u]
DP1	19.32±0.11 [b]
DP2	21.09±0.15 [a]
DP3	19.15±0.13 [b]
DP4	19.19±0.09 [b]
Positive control[v]	16.92±0.10 [c]
Negative control[w]	N/A

[u] Quantification cycle (Cq) values represented as the mean ± standard deviation of three technical replicates (n=3). Means followed by same letters are not significantly different as indicated by Tukey's test at *P*<0.05. N/A indicates no amplification in quantitative PCR.

[v] Positive control consisting of plasmid DNA and ddH_2O without root DNA.

[w] Negative control containing only ddH_2O with no plasmid or root DNA.

Table 2: Plant-parasitic nematode species used to evaluate the specificity of primers for detecting *Pratylenchus penetrans* in the qPCR assay.

Nematode species	Cq[a]	Origin	Reference
Positive control 1[b]	27.41±0.12	MN, U.S.A.	This study
Positive control 2[c]	23.43±0.17	MN, U.S.A.	This study
Negative control 1[d]	N/A		
Negative control 2[e]	N/A		
Pratylenchus penetrans	29.92±0.06	MN, U.S.A.	This study
P. penetrans	31.21±0.22	MN, U.S.A.	This study
P. dakotaensis	N/A	ND, U.S.A.	Chowdhury et al. 2022
P. neglectus	N/A	ND, U.S.A.	Yan et al. 2016a
P. scribneri	N/A	ND, U.S.A.	Huang and Yan 2017
Hg 51 unnamed root-lesion nematode	N/A	ND, U.S.A.	Yan et al. 2017a
Helicotylenchus microlobus	N/A	ND, U.S.A.	Yan et al. 2017b
Heterodera glycines	N/A	ND, U.S.A.	This study
Paratrichodorus allius	N/A	ND, U.S.A.	Yan et al. 2016b
Paratylenchus nanus	N/A	ND, U.S.A.	Upadhaya et al. 2019

[a] Quantification cycle (Cq) values represented as the mean ± standard deviation of three technical replicates (n=3). N/A indicates no amplification in quantitative PCR.

[b] Positive control 1 indicates that DNA from one *P. penetrans* nematode extracted by Proteinase K method was used as DNA template.

[c] Positive control 2 indicates that DNA from four *P. penetrans* nematodes extracted by Proteinase K method was used as DNA template.

[d] Negative control 1 indicates ddH$_2$O in place of DNA template.

[e] Negative control 2 indicates that DNA from uninfected roots of 'Red Norland' was used as DNA template.

Table 3: Quantification cycle (Cq) values from serial dilution of DNA extract of 'Red Norland' potato roots artificially inoculated with four *P. penetrans* nematodes for analysis of detection sensitivity of the qPCR assay.

Serial dilution	***P. penetrans* equivalents/0.2 g of roots**	**Cq**[a]
1	4	27.72±0.14
1:2	2	27.95±0.12
1:4	1	28.31±0.07
1:8	5×10^{-1}	29.43±0.10
1:16	2.5×10^{-1}	30.51±0.09
1:32	1.25×10^{-1}	31.75±0.11
1:64	6.25×10^{-2}	32.88±0.12
1:128	3.13×10^{-2}	33.85±0.07
1:256	1.56×10^{-2}	34.77±0.07
1:512	7.81×10^{-3}	N/A
1:1024	3.91×10^{-3}	N/A
Negative control 1[b]		N/A
Negative control 2[c]		N/A
Positive control 1[d]		27.30±0.07
Positive control 2[e]		23.38±0.08
Coefficient (R^2)		0.98
Efficiency (E)		106.47%

[a] Quantification cycle (Cq) values represented as the mean ± standard deviation of three technical replicates (n=3). N/A indicates no amplification in quantitative PCR.

[b] Negative control 1 indicates ddH$_2$O in place of DNA template.

[c] Negative control 2 indicates DNA from uninfected roots of 'Red Norland' was used as DNA template.

[d] Positive control 1 indicates DNA extracted by Proteinase K method from one *P. penetrans*. [e] Positive control 2 indicates DNA extracted by Proteinase K method from four *P. penetrans* nematodes.

Table 4: Comparison of *Pratylenchus penetrans* densities in potato roots using qPCR assay and conventional microscopic method following Whitehead tray extraction method across five potato cultivars.

Potato cultivar	qPCR estimation[a]	Microscopic estimation[b]
Colomba	164±32	158±21
Caribou Russet	337±71	350±61
Modoc	167±11	143±12
Yukon Gold	275±57	263±20
Red Norland	393±47	389±29

[a] Number of *P. penetrans* in 1 gram of root tissue estimated by the qPCR assay based on quantification cycle (Cq) value and standard curve equation. Values represent mean±standard deviation (n = 45). For each cultivar, five greenhouse replicates were established in a completely randomized design. From each replicate, three root samples were collected for DNA extraction, and qPCR was run with three technical replicates per DNA sample.

[b] Number of *P. penetrans* in 1 gram of root tissue quantified by microscopic counting following the Whitehead tray extraction. Values represent mean±standard deviation (n=15). For each cultivar, five greenhouse replicates were established in a completely randomized design. From each replicate, three root samples were processed using the Whitehead tray method.

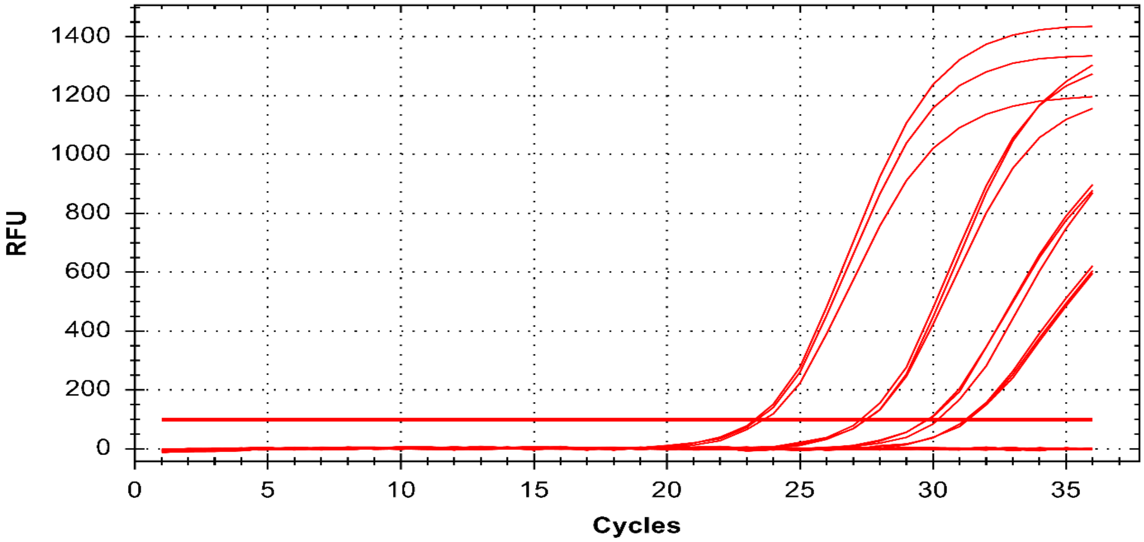

Figure 1: Amplification curve of *P. penetrans* used to determine the specificity of the primers Pp-F/Pp-R. Negative controls without *P. penetrans* DNA template did not show any amplification.

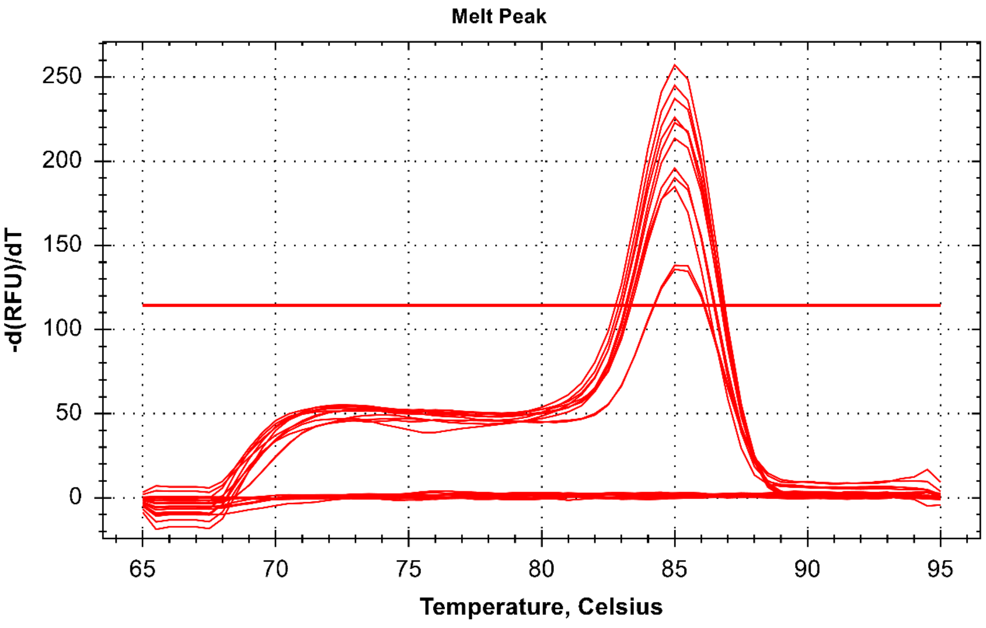

Figure 2: Melting curve profiles of *Pratylenchus penetrans*. Amplicons with a single peak were observed for populations of *P. penetrans* at melting temperature of 85°C.

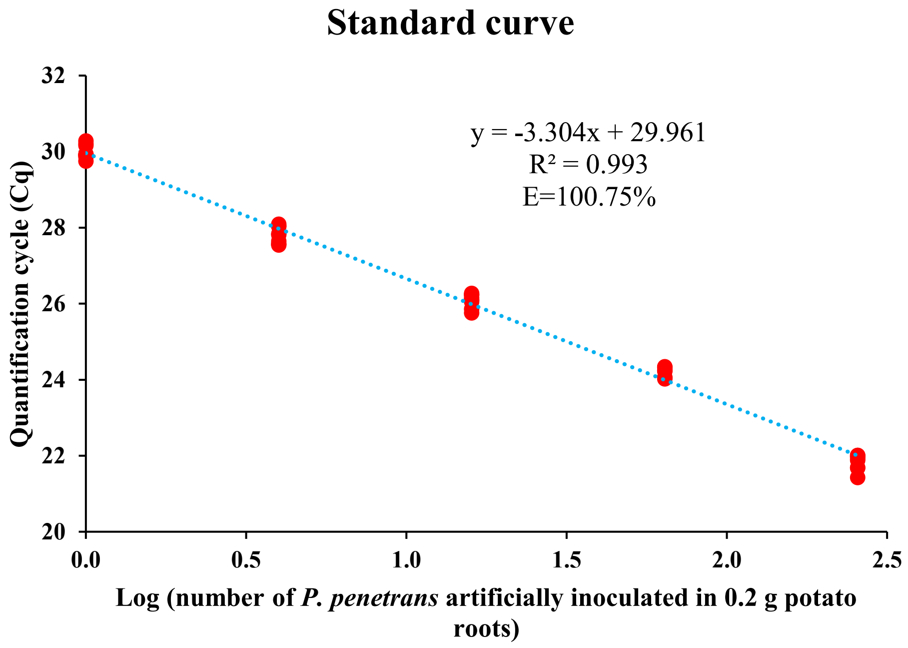

Figure 3: Standard curve of the qPCR assay for *P. penetrans*, showing the relationship between the quantification cycle (Cq) and the logarithm ($\log_{10}$) of *P. penetrans* densities (1, 4, 16, 64, and 256) inoculated in 0.2 g of 'Red Norland' potato roots. Each red dot represents the mean Cq value from three

biological replicates, with each replicate analyzed in triplicate in qPCR assay. Amplification efficiency (E) was calculated as, $E = 10^{(1/-m)} - 1$, where m is the slope of the standard curve equation.

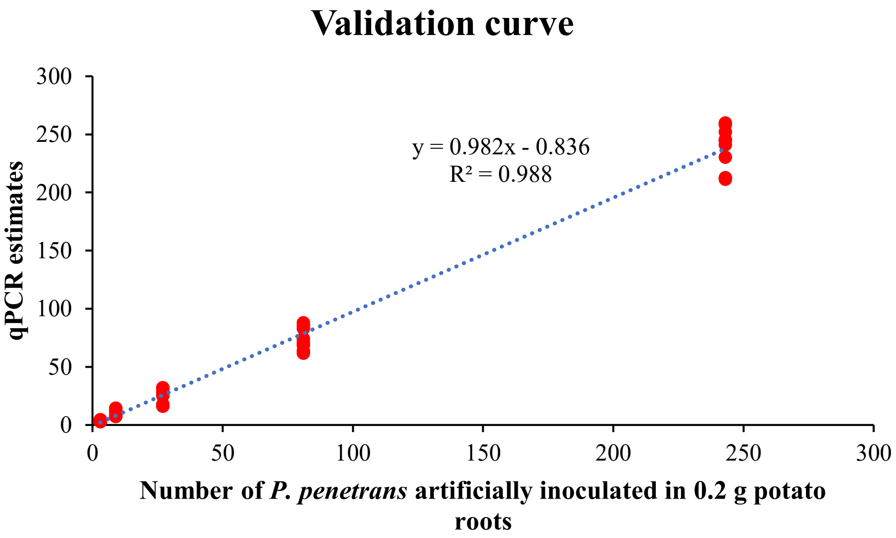

Figure 4: Validation curve obtained by plotting qPCR estimates obtained from the standard curve equation against the actual *P. penetrans* densities (3, 9, 27, 81 and 243). Each red dot represents the mean quantification cycle (Cq) value from three biological replicates, with each replicate analyzed in triplicate in qPCR assay.

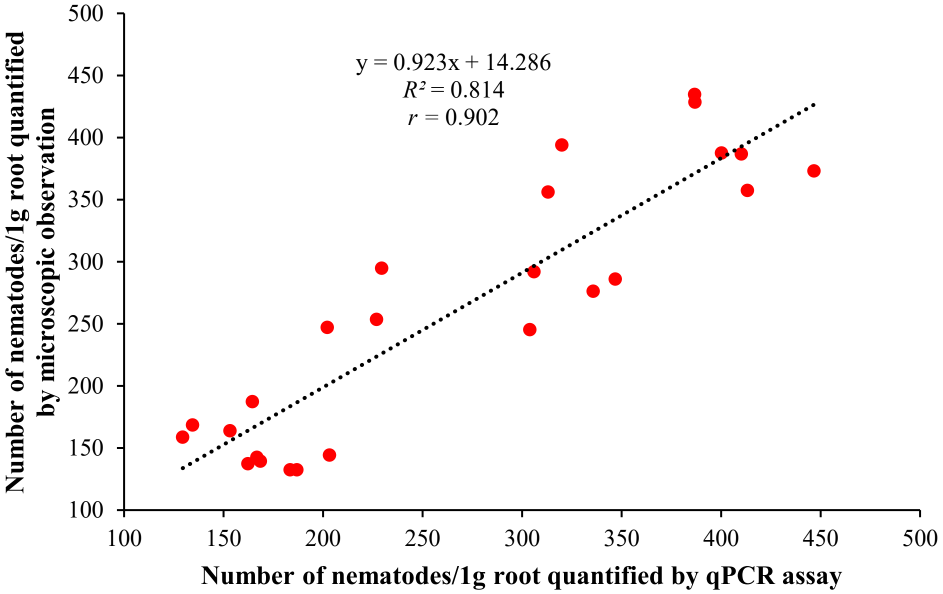

Figure 5: Correlation analysis between *Pratylenchus penetrans* densities obtained through Whitehead tray extraction followed by microscopic counting and those quantified using the qPCR assay from five potato cultivars. Each red dot represents a root sample analyzed using both methods. For each cultivar, five greenhouse replicates were established in a completely randomized design. From each replicate, three root samples were analyzed: DNA was extracted for qPCR (run in three technical replicates), and nematode densities were quantified using the Whitehead tray method and microscopic counting.

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

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Summary

High nitrogen (N) fertilizer and irrigation water uses to achieve potato yield is often accompanied by poor N and water use efficiencies and high nitrate leaching losses due to the shallow root system of potato plants and sandy soils. Innovative management practices are needed that optimize N and water use for high tuber yield, quality, and profit and reduced nitrate leaching. The objectives of this research project are to 1) evaluate the response of Hamlin Russet (HR) to N and irrigation rates and management in comparison with Russet Burbank (RB), 2) evaluate the potential benefits of variable rate N and irrigation for potato production and 3) develop practical, innovative, and effective variable rate N and irrigation management strategies using sensing technologies. In 2023 and 2024, plot-scale field experiments were 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, fixed-split, and three precision N management (PNM) treatments), and two varieties (i.e. HR; Hamlin Russet and RB; Russet Burbank). Destructive samples, proximal and unmanned aerial vehicle remote sensing data were collected at key growth stages. The two years had contrasting total precipitation. HR demonstrated high N use efficiency and economic return in both years, despite apparent sensitivity to water stress. The 80% irrigation had the highest WUE in most cases. The PNM treatments achieved one of the highest N use efficiency and net return values and demonstrated the potential to mitigate nitrate leaching especially in 2023. Further analysis will be conducted to evaluate the use of sensor-based data collected in these experiments to optimize variable rate N and irrigation management strategies for potato production in Minnesota.

Background

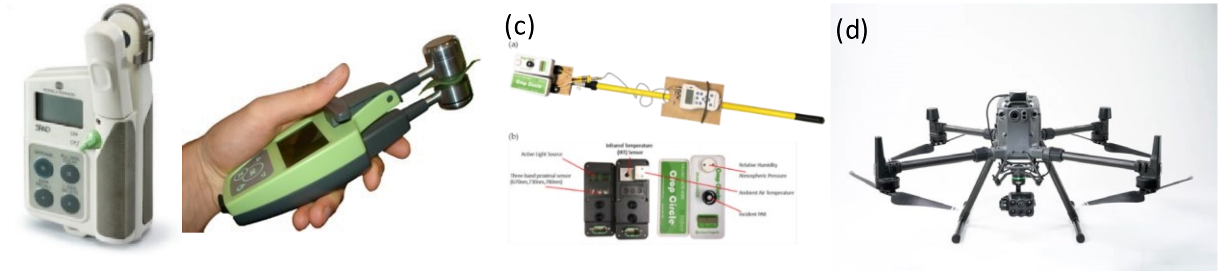
Improving nitrogen (N) management has been a focus for potato (*Solanum tuberosum L.*) nutrient management in Minnesota. In addition, improving water use efficiency, tuber yield/quality and profitability while mitigating water resource contamination for environmental protection are also incentives for the growers and their neighboring communities.

The adoption of N efficient varieties (e.g., Hamlin Russet) is an efficient strategy to improve N use efficiency. Another strategy is to optimize the application of N fertilizer by accounting for the inefficient N uptake ability of potato crop due to the shallow roots and cultivation on coarse-textured soils (Errebhi et al., 1998; Lesczynski and Tanner, 1976). The technologies and strategies to improve N use efficiency have been investigated and implemented (Rosen and Bierman, 2008). Bohman et al.

(2019) highlighted the importance of optimizing both N fertilizer and irrigation management using variable rate technologies to reduce nitrate leaching for potato production in Minnesota. This integrative approach is reasonable considering the close interaction between N and water in the soil and needs to be developed.

Leaf chlorophyll (Chl) meter SPAD-502 (SPAD; Konica Minolta, Tokyo, Japan; Figure 1a) and leaf fluorescence sensor Dualex Scientific+ (Dualex; METOS® by Pessl Instruments, Weiz, Austria; Figure 1b) proved to be useful in diagnosing potato N status under non-water stressed conditions (Wakahara et al., 2025). SPAD and Dualex provide Chl readings by measuring leaf transmittance in red (R) or red-edge (RE) and near infrared (NIR). Dualex also provides flavanol and anthocyanin readings, which are N and phosphorus stress-induced substances, by measuring Chl fluorescence under their screening effects in the epidermis. A new innovative integrated multi-parameter proximal active sensor, Crop Circle Phenom (Figure 1c), measures not only the canopy reflectance of three spectral bands (R, RE, NIR) but also meteorological parameters (e.g., canopy and air temperatures, relative humidity, and air pressure) (Cummings et al., 2021) at the same time as spectral measurements. Unmanned aerial vehicle remote sensing system using 6X thermal sensor (Sentera, St. Paul, MN, USA; Figure 1d) collects multispectral visible-NIR reflectance and thermal longwave infrared emission. Crop Circle Phenom and 6X thermal have the potential to diagnose potato N and water status simultaneously.

Plot-scale experiments were continued from last year using the abovementioned technologies to 1) evaluate the response of Hamlin Russet (HR) to N and irrigation rates and management in comparison with Russet Burbank (RB), 2) evaluate the potential benefits of variable rate N and irrigation for potato production and 3) 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 economic returns for farmers to support sustainable potato production in Minnesota. This report focused on summarizing the agronomic data over two years comparing two potato varieties grown under different N and irrigation treatments.



(a) (b)

Figure 1. Proximal and remote sensing technologies used in this study. (a) SPAD, (b) Dualex, (c) Crop Circle Phenom, (d) UAV remote sensing system using 6X thermal camera.

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 and 2024. The two years had similar average air temperatures (i.e., 67.0 °F in 2023 and 65.1 °F in 2024) but contrasting total precipitation (i.e., 14.2 inches in 2023 and 26.8 inches in 2024) during the growing seasons (Figure 2). Rain events occurred much more frequently and with higher intensity in May and June. Soil samples were collected in the top 2 feet of the soil profile and analyzed for NO_3-N and NH_4N at the beginning and end of the season and in the top 6 inches of the soil profile for other macro- and micro-nutrients at the beginning of the season. The soil test results from the beginning of the season were averaged and summarized in Table 1.

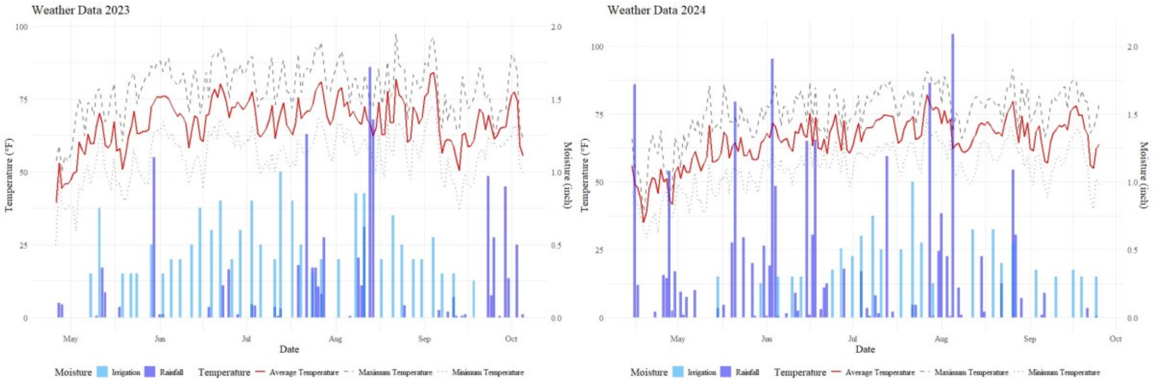


Figure 2. Temperature, precipitation, and irrigation summary for the 2023 and 2024 growing seasons.

Table 1. Soil test results from the beginning of the season in 2023 amd 2024. NO3-N and NH4-N are from the 0-2 ft depth, all other anayses are for the 0-6 inch depth.

2023

Irrigation Block			Primary Nutrients				Secondary Nutrients			Micronutrients				
	-	%	mg/kg soil (ppm)											
	pH	OM	NO_3[1]	NH_4[1]	P	K[2]	Ca[2]	Mg[2]	S[3]	Fe[4]	Mn[4]	Zn[4]	Cu[4]	B[5]
60%	7.1	1.1	2.5	4.7	54.5	90.0	626.3	115.2	7.4	10.4	5.6	6.7	0.7	0.2
80%	6.7	2.0	3.6	4.9	63.0	145.0	917.6	170.5	12.2	19.3	11.4	11.9	0.9	0.2
100%	6.8	1.2	3.2	5.5	58.8	94.8	631.2	122.0	9.7	13.7	7.8	8.3	0.8	0.2

2024

Irrigation Block	pH	OM	NO_3^{1*}	NH_4^{1*}	P	K^2	Ca^2	Mg^2	S^3	Fe^4	Mn^4	Zn^4	Cu^4	B^5
			Primary Nutrients				Secondary Nutrients			Micronutrients				
	-	%	mg/kg soil (ppm)											
60%	6.1	2.5			27.0	113.0	1277.9	241.6	12.1	34.3	32.3	1.9	0.8	0.3
80%	6.1	2.4			22.3	111.7	1009.1	180.2	11.5	47.2	43.1	2.8	1.0	0.3
100%	6.3	2.4			18.7	106.7	1328.5	247.6	9.4	49.6	28.1	2.7	1.0	0.4

[1] KCl extraction [2] NH_4-OAc extraction, [3] Ca-phosphate extraction, [4] DTPA extraction, [5] Hot water extraction. *In the process of being analyzed at the time of this report.

Study design and cultural practices

Three irrigation rates (i.e., 60%, 80%, and 100% based on the checkbook method), two varieties (i.e., HR and RB), and nine N treatments (i.e., 40, 80, 160, 240, 320 lb N/ac (response curve treatments), fixed-rate split, and three precision N management (PNM) treatments) were used in both years. In 2023, the irrigation rates were used as blocks without replications and the varieties and N treatments were used as the main plot and subplot treatments in a split-plot design with three replications. In 2024, the irrigation rates, varieties, and N treatments were used as the main plot, subplot, and sub-subplot treatments in a splitsplit plot design with three replications. All of the nine N treatments received 40 lb N/ac as diammonium phosphate (DAP; 18-46-0) at planting. The five 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. HR and RB received 40 and 120 lb N/ac as ESN at emergence in the fixed- rate split and PNM treatments, respectively. The fixed-rate split treatment received 15 lb N/ac as urea ammonium nitrate (UAN; 28-0-0) after emergence about every two weeks starting in mid- or late-June (i.e., 6/26. 7/13, 7/24, and 8/4 in 2023; 6/17, 7/1, 7/18, and 7/29 in 2024). The three PNM treatments received or skipped a 15 lb N/ac UAN application based on the sensor-based N status diagnosis. The 60% and 80% irrigation blocks only included 80, 160, 240 lb N/ac and PNM3 for both varieties due to practical constraints.

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 between-row spacing except the plots on the edge of each irrigation block had 5 extra feet of buffer. A 10- and 12-inch within-row spacing were used for HR and RB, respectively. Seed tubers were planted on April 26, 2023, and April 15, 2024, and emerged on May 19, 2023, and April 15, 2024. The vines were killed on September 13, 2023, and September 4, 2024, and the tubers were harvested on October 5, 2023, and September 25, 2024. The harvested tubers were 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.). Tuber quality parameters (e.g. internal disease occurrences, specific gravity, tuber dry matter, and sugar content) were evaluated. The field was irrigated twice a week with 17.8 inches of water applied in 35 irrigation events in 2023 and 10.76 inches of water applied in 24 irrigation events in 2024. 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 each year, 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, 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 fresh weight. Vine and tuber sub-samples were dried at 140 F and dry matter weights were recorded to determine percent dry matter. Dried subsamples were ground and tissue nitrogen concentration was determined using combustion techniques. Suction-cup lysimeters were installed to a 4foot depth in the second outermost 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 40, 160, 240 lb N/ac, fixed-split and PNM3 N treatments. Starting in the middle of June, lysimeter water samples were collected on a weekly basis and stored in the freezer for future NO_3 concentration determination. Plant N concentration data in 2024 are in the process of being analyzed. Sampling dates are summarized in Table 2.

Proximal and remote sensing

Leaf sensor data were collected using SPAD and Dualex on the twenty terminal leaflets of the fourth leaf from the apex of the shoot and the fifteen terminal leaflets of the top fully expanded leaves from the same rows as petiole sampling in each plot. Crop Circle Phenom data were collected from the second outmost row by holding the sensor on a pole 19.7 to 39.4 inches above the canopy from the field edge and walking at a constant pace. 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 using 6X Thermal Sensor five times. Access tubes were installed next to the lysimeters, and volumetric water content data were collected on a weekly basis using PR2/6 profile probe (PR2; Delta-T Devices Ltd., Cambridge, UK) at the 3.9/7.9/11.8/15.7/23.6 and 39.4 inch depths. Lastly, hourly weather information including temperature, dew point, wind speed, rainfall, and total solar radiation was collected at the SPRF weather station. Sensing dates are summarized in Table 2.

Table 2. Summary of sampling and sensing dates in 2023 and 2024.

2023

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	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		7/11	7/13	7/12	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	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	

2024

Week	Samples			Sensors				
	Petiole	WP	Water[1]	Dualex	SPAD	CCP[2]	PR2	UAV
1	6/11		6/12	6/12	6/11	6/12	6/12	6/17
2			6/20			6/19	6/19	
3	6/26	6/25	6/26	6/25	6/26	6/25	6/25	7/1
4			7/3			7/3	7/3	
5	7/10	7/9	7/11	7/9	7/10	7/11	7/11	7/18
6			7/17			7/17	7/17	
7	7/24	7/23	7/24	7/23	7/24	7/24	7/24	7/29
8			7/30			7/30	7/30	
9	8/6		8/5	8/5	8/6	8/5	8/5	
10			8/13			8/13	8/13	

[1] Water samples were collected until November, [2] Crop Circle Phenom

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

The decision to prescribe the post-emergence UAN applications in the three PNM treatments (i.e., PNM1 – PNM3) was based on petiole nitrate-N concentration (PNNC) prediction, nitrogen sufficiency index (NSI) calculation, and nitrogen nutrition index (NNI) prediction. The PNNC and NNI were predicted using random forest and support vector regression models, respectively.

These machine learning (ML) models were trained based on Dualex readings, variety, accumulated growing degree days, and as-applied N rates from the 2018, 2019, and 2021 potato experimental data. The true NNI values in PNM3 were calculated using the vine-based critical N dilution curves proposed by Giletto et al. (2020). Figure 3 shows the validation analysis results for the two ML models. The NSI values were calculated using SPAD readings collected from plots receiving 160 lb N/ac and 240 lb N/ac as a reference for HR and RB, respectively. The PNNC sufficiency thresholds developed by Rosen and Bierman (2008) were used. For NNI and NSI, the sufficiency range of 0.95-1.05 was used. When the PNM treatment plots were considered N deficient, a 15 lb N/ac UAN application was made.

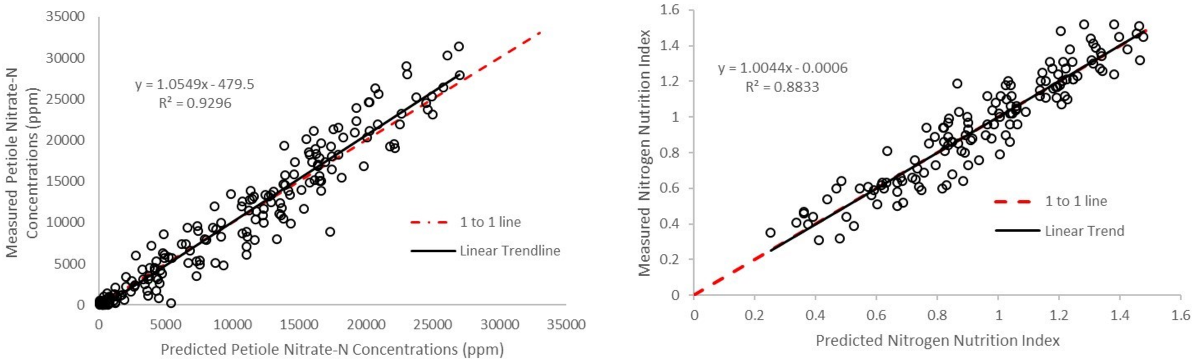


Figure 3. The correlations between the measured and predicted petiole nitrate-N concentrations (left) or Nitrogen Nutrition Index (right) based on sensor-based machine learning models.

Evapotranspiration (ET) calculation

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

$$EEEE = II + PP - \Delta SS - DD - RR \qquad (1)$$

where I is irrigation (inch), P is precipitation (inch), ΔSS is the difference in soil water contents between day i and day i-1(mm/60 cm), D is deep percolation (inch), and R is runoff (inch). 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: 0.64 inches at 0-3.9 inches, 0.64 inches at 3.9-7.9 inches, 0.61 inches at 7.911.8 inches, 0.61 inches at 11.8-15.7 inches, 0.61 inches at 15.7-19.7 inches, and 0.56 inches at 19.7-23.6 inches in 2023 and 2024. Runoff was considered negligible. Assuming that the study plot was at field capacity at planting and the ET was negligible at the late senescence stage, the ET was accumulated from the planting date until the last PR2 measurement date using the PR2 data. All of the data cleaning, statistical, and visualization procedures were conducted in R (R Core Team, 2024).

Results and Discussion

Tuber yield and size under different N and irrigation rates in two years

The optimum N rates for HR and RB under 100% irrigation in 2023 were 80 lb N/ac and 160 lb N/ac, respectively. In 2024, the total and marketable yields for HR and RB continued to increase to 320 lb N/ac. Despite the difference in the optimum N rates, HR produced similar total and marketable yields in both years. Meanwhile, total and marketable yields of RB were approximately 60 CWT/ac and 130 CWT/ac lower than 2023 (Figure 4).

Under 80% irrigation, total and marketable yields of HR and RB continued to increase to 240 lb N/ac in both years. The total and marketable yields of HR were 70 CWT/ac and 90 CWT/ac lower in 2024 than 2023, whereas the total and marketable yields of RB were 100 CWT/ac and 230 CWT/ac lower in 2024 than 2023 (Figure 5).

Under 60% irrigation, HR showed little response to different N rates in both years, while the total and marketable yields of RB had peaks at 160 lb N/ac and 240 lb N/ac in 2023 and 2024, respectively. HR and RB produced 30 CWT/ac more and 40 CWT/ac less total yield in 2024 than 2023. The marketable yield of HR was comparable in both years, while RB were 200 CWT/ac lower in 2024 than 2023 (Figure 6).

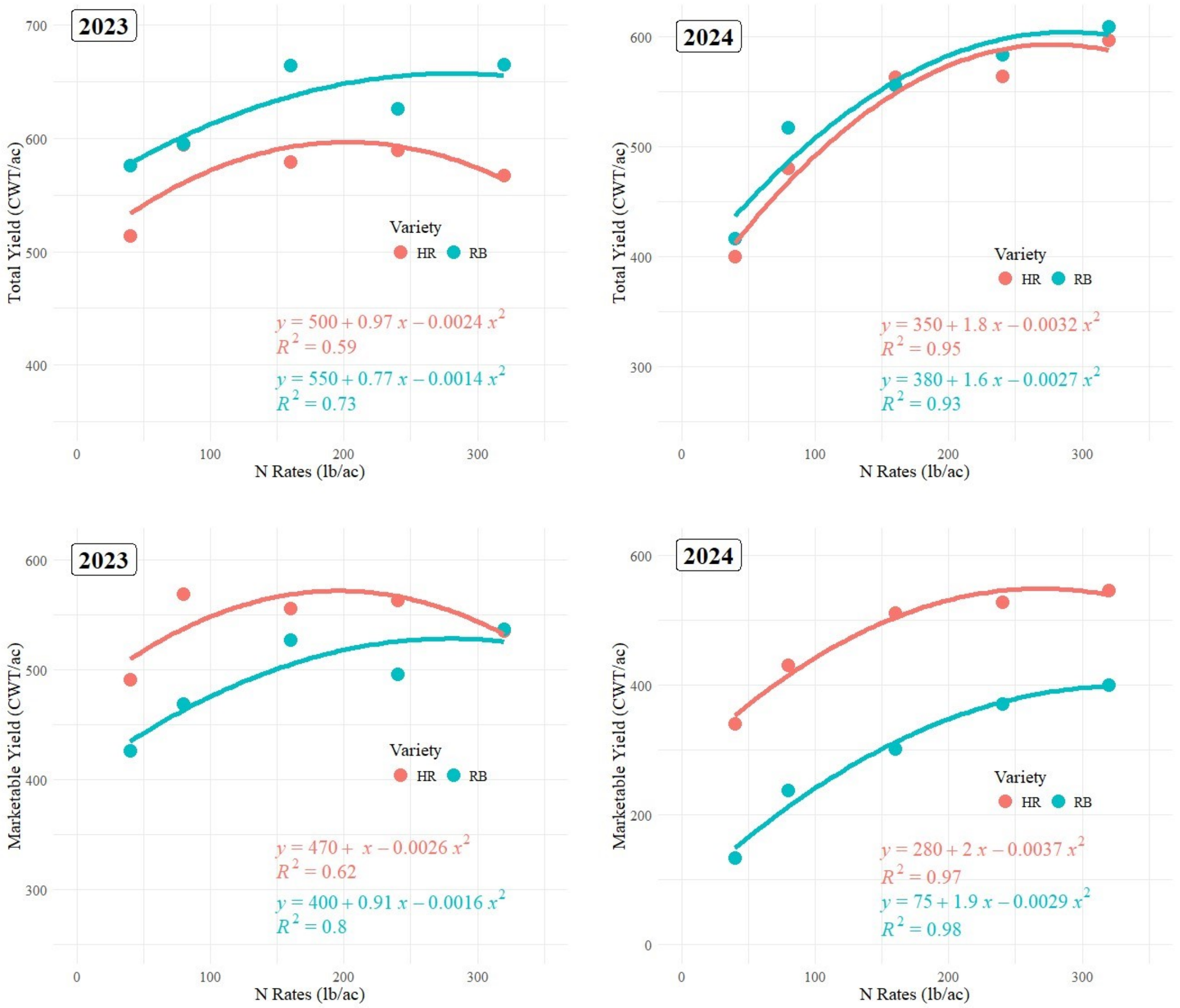


Figure 4. Total and marketable yields of Hamlin Russet and Russet Burbank under 100% irrigation in 2023 and 2024.

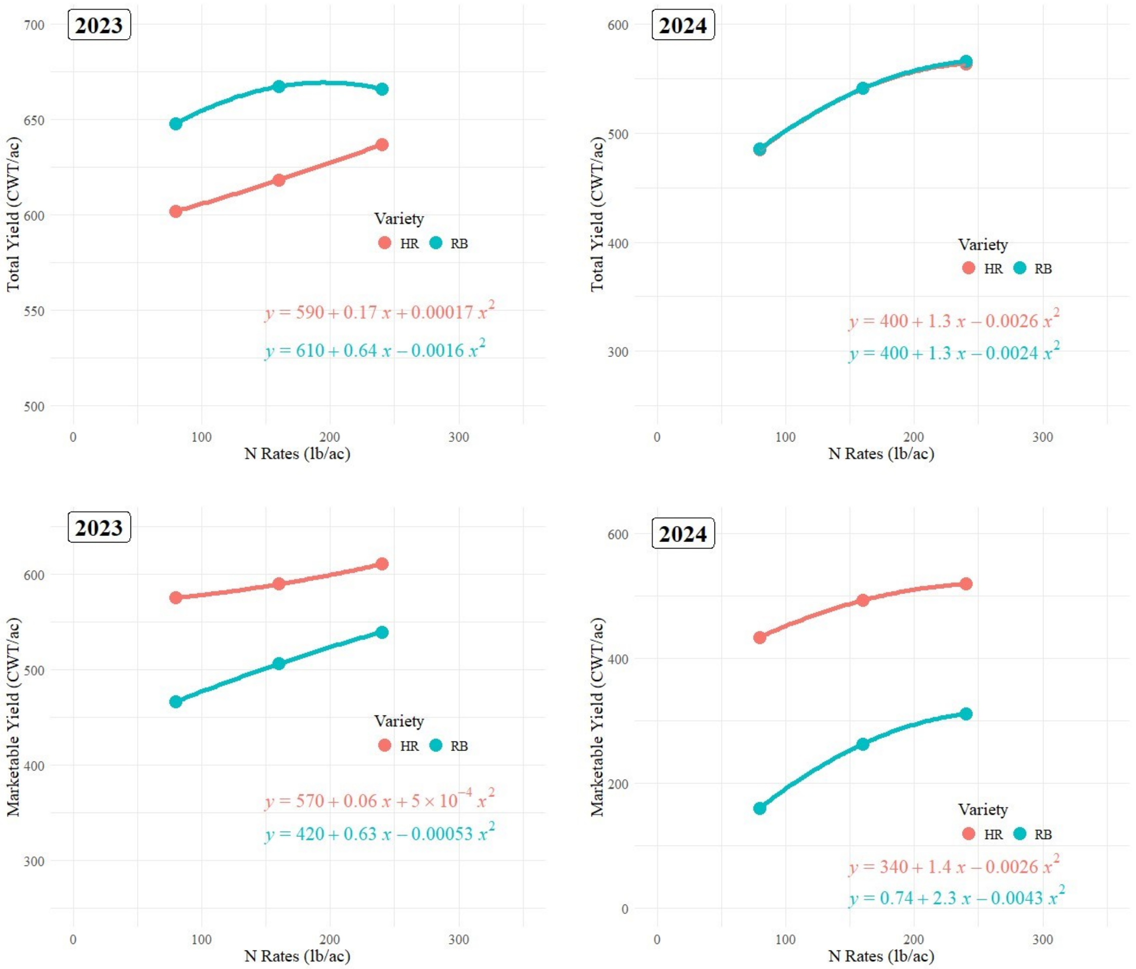
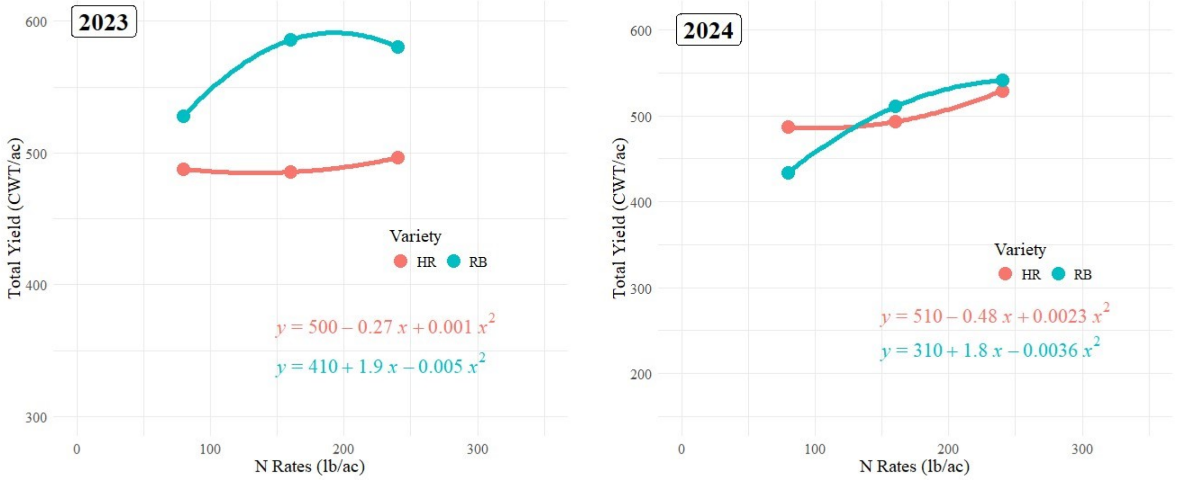


Figure 5. Total and marketable yields of Hamlin Russet and Russet Burbank under 80% irrigation in 2023 and 2024.



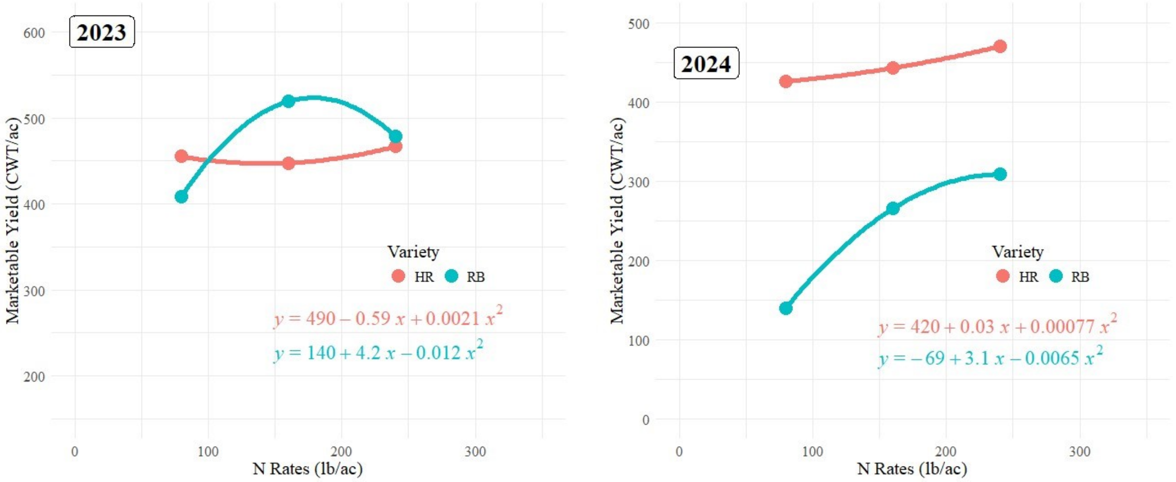


Figure 6. Total and marketable yields of Hamlin Russet and Russet Burbank under 60% irrigation in 2023 and 2024.

In 2023, HR produced more tubers of the two largest size classes under 80% and 100% irrigation but not under 60% irrigation. RB produced more tubers of the three smallest classes under 80% and 100% irrigation but not as much under 60% irrigation. In 2024, there was not much difference in tuber size distribution patterns across the three irrigation rates for either HR or RB. HR produced tubers of the 6-10 oz. classes most, while RB produced tubers of the 0-4 oz. class most. In 2024, increases in tuber yields of larger size classes with higher N rates were noticeable. Overall, the two-year results indicated that HR had higher N use efficiency and lower water stress resistance. HR's comparable or higher yields at lower N requirement than RB under 100% irrigation in 2023 presented straightforward evidence. HR's highest yields in the heavier leaching year (i.e., 2024) were comparable to the dryer year (i.e., 2023) despite higher N requirement, which is also likely attributed to HR's N use efficiency. The reduced yields of HR were more pronounced than under 60% irrigation in 2023. However, HR's ability to produce larger tubers helped maintain as much marketable yield as RB even in water-stressed conditions.

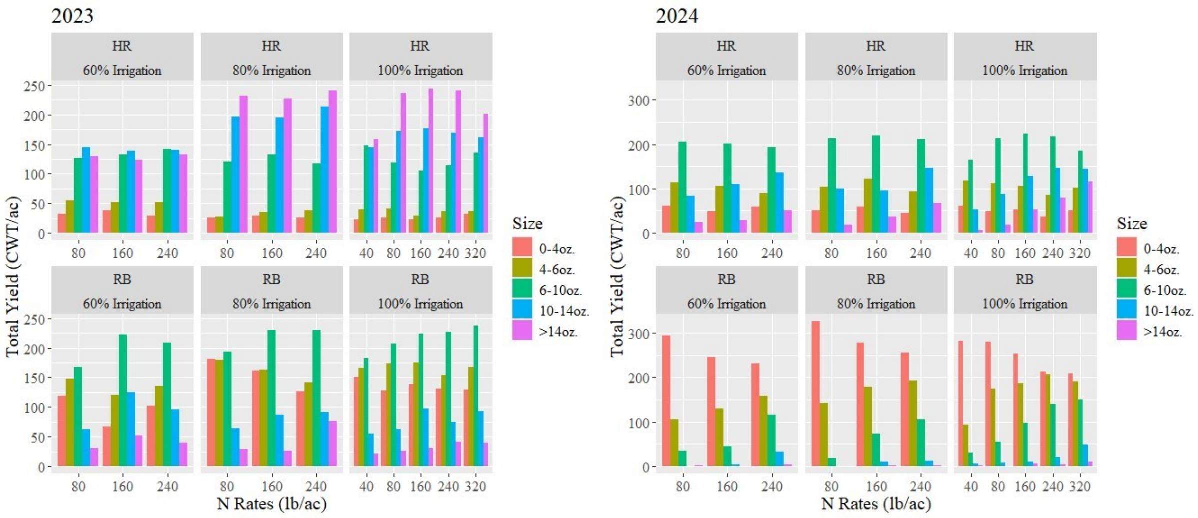


Figure 7. Total yields of HR and RB by the five size classes in 2023 and 2024.

Tuber yield and size in the PNM treatments

Table 3 summarized the averaged total N application rates in the three PNM treatments in 2023 and 2024. Figure 8 compared the total and marketable yields of HR and RB receiving 80, 160, and 240 lb N/ac vs. PNM3 (i.e., Dualex-based NNI prediction) under 60% and 80% irrigation in each year. Under 100% irrigation, the yields receiving optimum N rates were compared with fixed-split and PNM1 (i.e., Dualexbased PNNC prediction), PNM2 (i.e., SPAD-based NSI), and PNM3 in each year. In 2023, the PNM treatments had similar total and marketable yields to other treatments. In 2024, higher N rates (i.e., 240 and 320 lb N/ac) produced higher yields, particularly marketable yield. In both years, the tuber size class distribution was similar across all of the N treatments (Figure 9).

Table 3. Summary of averaged total N application rates in the PNM treatments in 2023 and 2024.

2023

Treatment	Irrigation	Var
PNM1	100	H
PNM1	100	R
PNM2	100	H
PNM2	100	R
PNM3	60	H
PNM3	80	H
PNM3	100	H
PNM3	60	R
PNM3	80	R

2024

Treatment	Irrigation	Variety	Total N (lb N/ac)
PNM1	100	HR	140
PNM1	100	RB	220
PNM2	100	HR	100
PNM2	100	RB	185
PNM3	60	HR	90
PNM3	80	HR	100
PNM3	100	HR	90
PNM3	60	RB	170

PNM3	100	RB	175

PNM3	80	RB	170
PNM3	100	RB	175

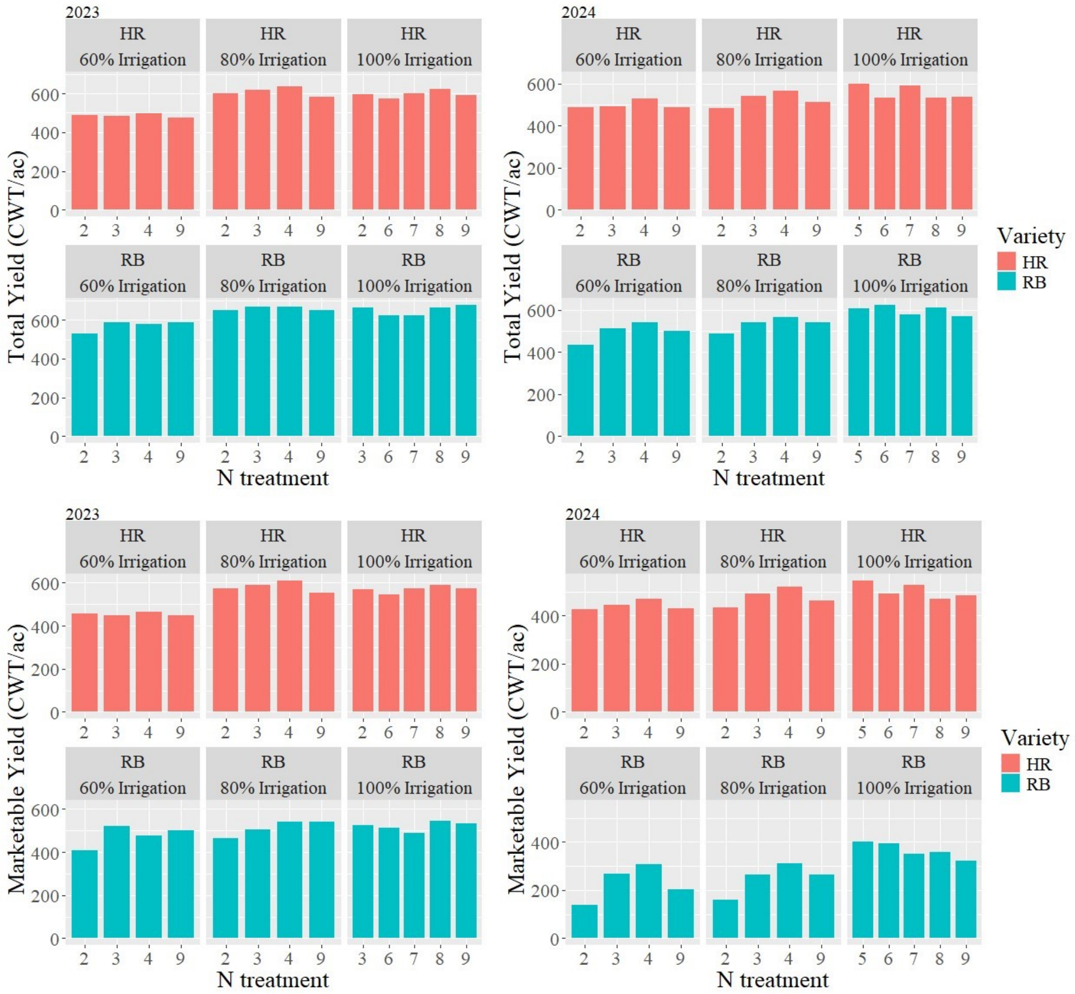


Figure 8. Total and marketable yields of HR and RB in the PNM treatments in 2023 and 2024.

N treatments 2 to 4 are 80, 160, 240 lb N/ac; N treatments 6 to 9 are fixed-split, PNM1 to 3.

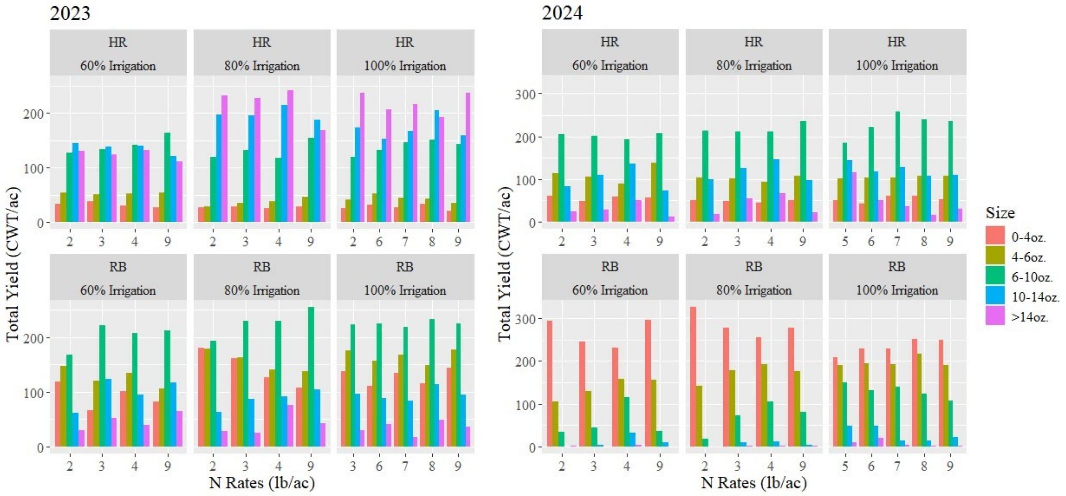


Figure 9. Total yields of HR and RB in the PNM treatments by the five size classes.

N treatments 2 to 4 are 80, 160, 240 lb N/ac; N treatments 6 to 9 are fixed-split, PNM1 to 3.

Figure 10 shows the partial factor productivity (PFP; total yield over total N rate) and economic return of 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. HR demonstrated high N use efficiency and net returns, particularly in 2024. The 80% and 100% irrigation achived similar net returns. The PNM treatments had similar or higher PFP and net return than most optimum N rates except HR's optimum N rate was 80 lb N/ac (e.g., 100% irrgation in 2023 and 60% irrigation in both years). The PNM algorithms would have to be updated with more HR and reduced irrigation data to improve the UAN prescription accuracy.

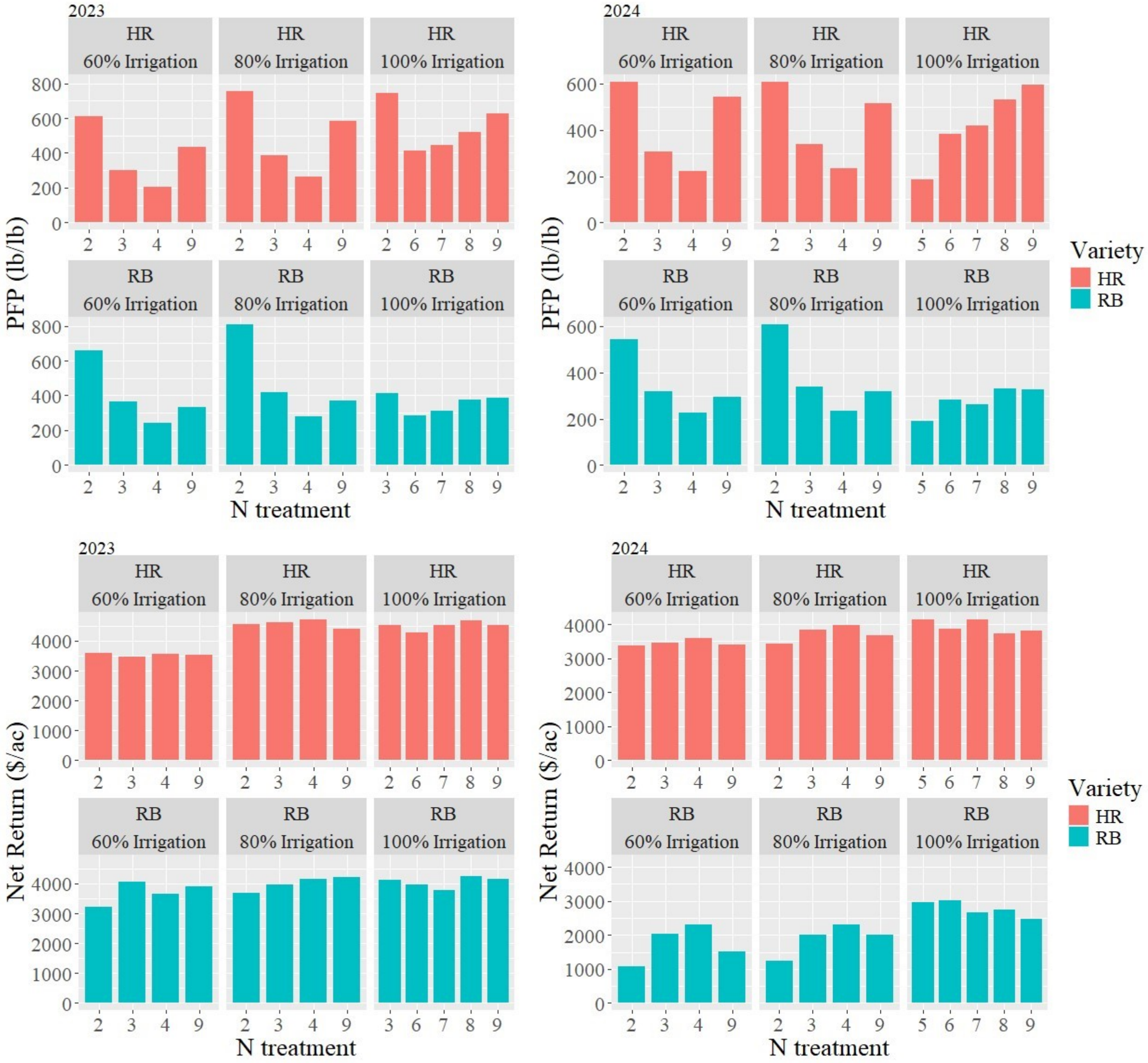


Figure 10. Partial factor productivity and economic return of HR and RB in the PNM treatments in 2023 and 2024. N treatments 2 to 4 are 80, 160, 240 lb N/ac; N treatments 6 to 9 are fixed-split, PNM1 to 3.

Water use efficiency and nitrate leaching

Figure 11 shows the water use efficiency (WUE; total yield over ET) for each variety by N and irrigation treatments in 2023 and 2024. In 2023, WUE was highest when receiving 160 lb N/ac or PNM3. In 2024, WUE was higher when receiving 240 lb N/ac or the fixed-split N treatment than PNM3, while the highest WUE would have been at 320 lb N/ac (moisture data was not collected for this treatment). Except for HR in 2024, WUE was highest under 80% irrigation, coinciding with the findings of Bohman et al. (2019).

Figure 12 illustrated the changes in nitrate leaching loads as more progressive PNM strategies (i.e., N efficient variety and PNM treatments) were employed. The 160 lb N/ac and 240 lb N/ac rates represented farmer's N rates for HR and RB in this comparison. Most notably, the nitrate leaching loads in 2024 were significantly higher than 2023 because of twice as much total precipitation. In 2023, the fixed-split N treatment or PNM3 under 100% irrigation reduced RB's nitrate leaching load, while this effect was absent for HR. Both in 2023 and 2024, PNM3 similarly reduced nitrate leaching loads under 80% irrigation, while the 80% irrigation treatment did not reduce nitrate leaching compared to the 100% irrigation treatment.

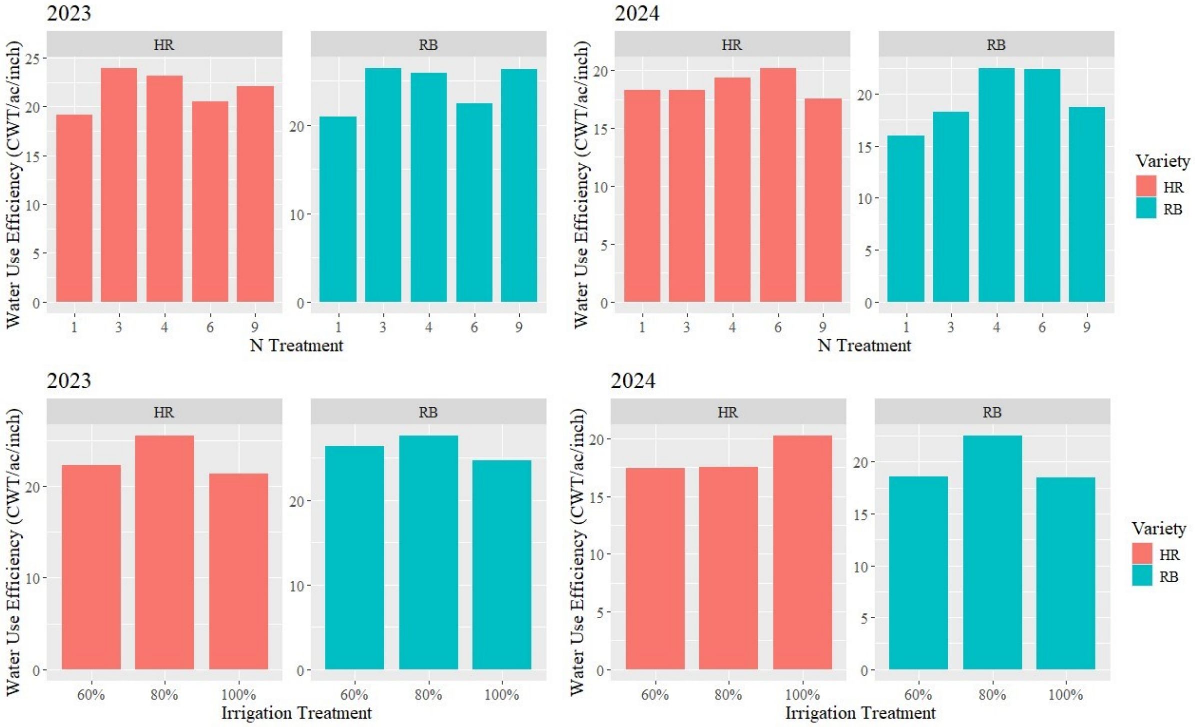


Figure 11. Water use efficiency of HR and RB by N and irrigation treatments in 2023 and 2024. N treatments 1, 3, and 4 are 40, 160, 240 lb N/ac; N treatments 6 and 9 are fixed-split, PNM3.

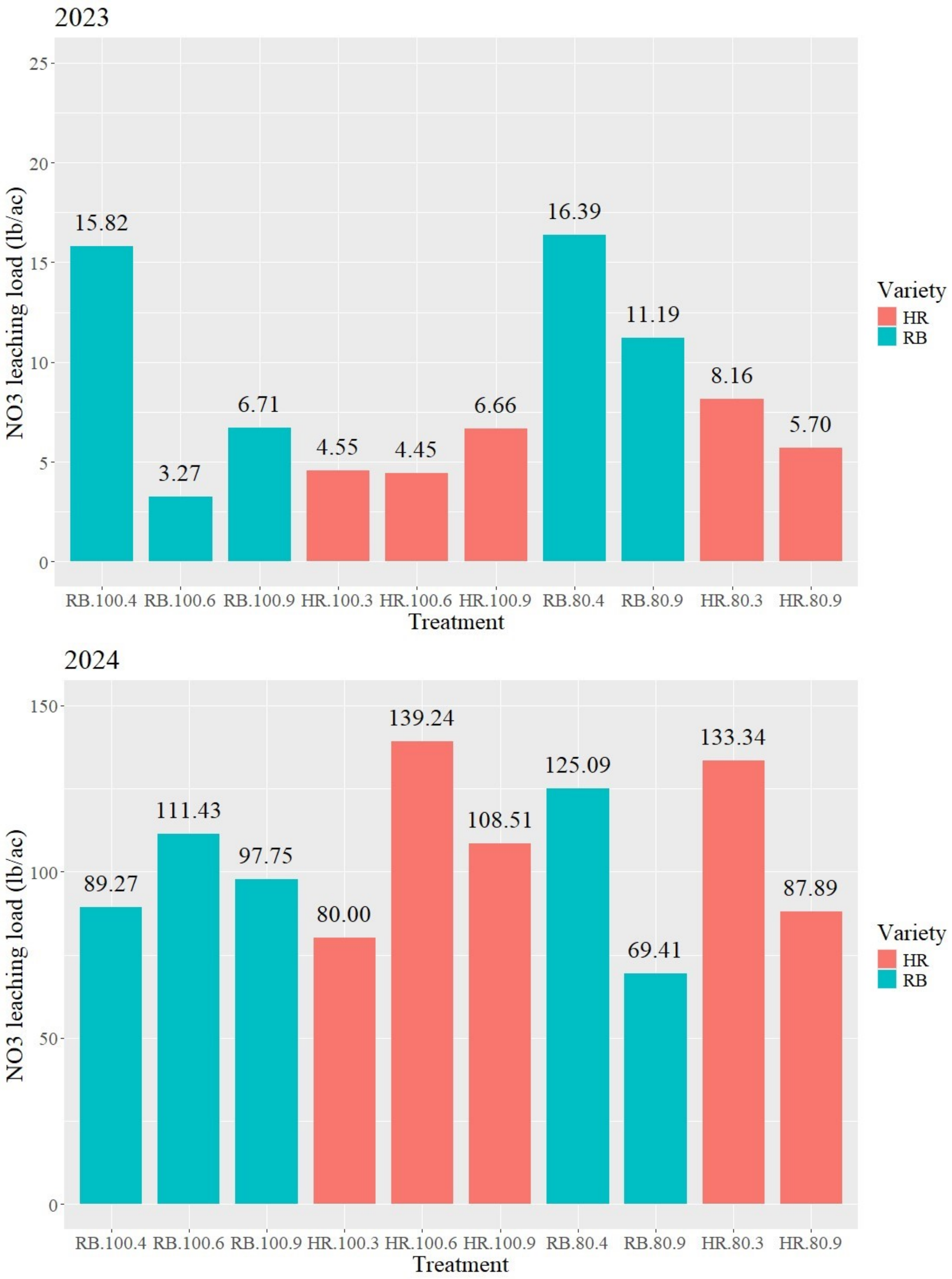


Figure 12. Progressive changes in nitrate leaching loads in 2023 and 2024.

X axis label: Variety.Irrigation.N treatments. N treatments 3, 4, 6, 9 are 160 lb N/ac, 240 lb N/ac, fixedsplit, and PNM3.

Conclusion

The 2023 and 2024 growing seasons had contrasting total precipitation. The optimum N rates for HR and RB were 80 lb N/ac and 160 lb N/ac under 100% irrigation in 2023, while the yields of HR and RB continued to increase to 320 lb N/ac under 100% irrigation in 2024. HR demonstrated high N use efficiency and economic return in both years, despite apparent sensitivity to water stress. The 80% irrigation had the highest WUE in most cases. The PNM treatments produced as much yield as the optimum N rates in 2023, while the higher N rates (i.e., 240 lb N/ac and 320 lb N/ac) had higher yields in 2024. More data including HR and reduced irrigation will improve the sensor-based N prescription accuracy. Meanwhile, the PNM treatments achieved one of the highest N use efficiency and net return values and demonstrated the potential to mitigate nitrate leaching. Further analysis will be conducted to evaluate the use of sensor-based data collected in these experiments to optimize variable rate N and irrigation management strategies for potato production in Minnesota.

Acknowledgements

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Evaluation of polyhalite as a source of sulfur in fertilizer blends with KCl for potatoes

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Summary

Polyhalite is a naturally occurring mineral that may have potential as a nutrient source for crop production, with a fertilizer value of 0-0-14-19S-3.6Mg-12Ca. Because it has a relatively low K:S ratio, the best fertilizer use of polyhalite may be as an S source in a blend with KCl (0-0-60) as the primary K source. It may be especially useful in low-organic, sandy, acidic soils, which are often low in K, S, Mg, and Ca. The objective of this study was to evaluate polyhalite as a nutrient source for potatoes on such soils in central Minnesota. Blends of polyhalite with KCl were compared to conventional fertilizer blends in terms of tuber yield, grade, size, number, and quality. Each of these blends was broadcast before planting. In addition, two fertilizer blends with polyhalite were evaluated in split applications, with half of the blend broadcast before planting and the other half side dressed before hilling. The treatment receiving only ammonium sulfate (21-0-0-24S) without K had significantly lower total yield, U.S. No. 1 yield, and marketable yield than most or all treatments receiving K in any form. Among the treatments receiving K, those receiving a single, pre-planting application performed similarly to each other in terms of tuber yield, size, and quality. However, the treatments receiving split applications of polyhalite blends had lower total yields and, to a lesser extent, marketable yields than those receiving either conventional blends or polyhalite blends in a single, pre-planting application. Tuber quality variables were not significantly related to treatment. Overall, polyhalite appears to be an effective S source when used in blends with KCl to meet potato crop K requirements, and it may also be an effective source of Mg and Ca in sites where these elements are in limited supply.

Background

Polyhalite is a naturally occurring mineral composed of sulfates of potassium, magnesium and calcium with the approximate chemical formula $K_2SO_4 \cdot MgSO_4 \cdot 2CaSO_4 \cdot 2H_2O$. Once mined, it can be granulated and used as a fertilizer with a value of 0-0-14-19S-3.6Mg-12Ca. Because there are large deposits worldwide, polyhalite may have potential as an economical nutrient source for crop production.

Polyhalite has a low K:S ratio compared to sulfate of potash (0-0-50-17S), meaning that a high rate of S would be applied if sufficient polyhalite were applied to meet potato crop K demands. The best fertilizer use of polyhalite might therefore be as an S source when applied in combination with other K sources such as muriate of potash (KCl: 0-0-60). It may be especially beneficial in low-organic-matter, acidic, sandy soils, which are often low in S, Mg, and Ca, as well as K. Such soils are commonly used for potato production in central Minnesota.

The purpose of this study was to determine the effectiveness of polyhalite (Anglo American Crop Nutrients Ltd.) as a nutrient source for potato production in the Anoka Sand Plain of central Minnesota.

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 2024. Initial soil characteristics from samples collected on April 23 are presented in Table 1.

Nine treatments were applied to Russet Burbank potato plants in a randomized complete block design with four replicates. These treatments are summarized in Table 2. Each plot was 12 feet (4 rows) wide and 20 feet long. The central 18 feet of the middle two rows of each plot were used for tuber harvest samples. Each end of these two rows was marked with a red potato plant. The field was 3 plots (36 rows) wide and 12 plots long. A 3-foot buffer strip of potatoes was planted around the field on all sides to reduce edge effects.

Fertilizer was broadcast by hand according to treatment just prior to planting on April 24. In addition to treatment-specific fertilizers, 200 lbs/ac monoammonium phosphate (11-50-0) and 6.7 lbs/ac Boron15 were applied in all treatments, providing 22 lbs/ac N, 100 lbs/ac P_2O_5, and 1 lb/ac B. Planting rows were then opened mechanically with 36-inch spacing between rows. Whole "B" and cut "A" 3- to 4-oz. seed pieces were planted by hand in with 12-inch spacing within rows. Belay was applied in-furrow at planting for beetle control, along with the systemic fungicide Quadris. Weeds, diseases, and insects were controlled using standard practices. Rainfall was supplemented with sprinkler irrigation using the checkbook method of irrigation scheduling.   On May15, the rows in all treatments were side dressed with 299 lbs/ac ESN (Nutrien: 440-0), supplying 132 lbs/ac N. Rows in treatments 8 and 9 were also side dressed with polyhalite, ammonium sulfate, and KCl at rates indicated by treatment. All treatments received 20 lbs/ac N as 28% UAN in each of 3 applications, on July 1, 18, and 29.

The petiole of the fourth mature leaf from the shoot tip was collected from 20 plants per plot on June 20 and July 17. The petioles were dried at 140°F until their weight was stable, ground, and sent to A&L Western Laboratories (Fort Wayne, IN) to be analyzed for NO_3^--N, K, S, Mg, and Ca concentrations.

Tubers were harvested from the central 18 feet of the middle two rows of each plot on September 19. On September 19 and 20, the tubers were sorted into five size categories: 0-4 oz., 4-6 oz., 6-10 oz., 10-14 oz., and over 14 oz. Tubers over 4 oz. were sorted into U.S. No. 1 and U.S. No. 2 categories based on USDA standards for processing potatoes. Cull tubers were sorted into a single category, regardless of size. The tuber sample in each size-grade category was weighed to estimate per-acre yield.

A size-representative subsample twenty-five U.S. No. 1 tubers was collected from each plot's harvest for quality assessments. This subsample was used to estimate the prevalence of hollow heart, brown center, common scab, and vascular browning, as well as tuber specific gravity and dry matter content.

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 as a fixed effect and block as a random effect. Denominator degrees of freedom were determined by the KenwardRoger 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.

Four contrast statements were applied in each analysis to compare pairs of treatments. The first three contrasts compared the treatment receiving ammonium sulfate and KCl (treatment 3) to (1) the treatment receiving ammonium sulfate without KCl (treatment 1), (2) the treatment receiving KCl without ammonium sulfate (treatment 2), and (3) the treatment receiving KCl with potassium-magnesium sulfate (langbeinite: 0-0-22-21S-11Mg; treatment 4). The fourth contrast compared the treatment receiving KCl plus langbeinite with the treatment receiving a blend of KCl and polyhalite providing 30 lbs/ac S (treatment 5), as these treatments were the most similar to each other in nutrient application rates between the treatments receiving only conventional fertilizers (treatments 1 – 4) and those receiving polyhalite (treatments 5 – 9).

Results

Rainfall and irrigation

Daily and cumulative rainfall and irrigation in the study site from April through September are presented in Figure 1. The average rainfall totals for these months in Becker, MN, are 2.83” in April, 3.78” in May, 4.37” in June, 3.91” in July, 4.15” in August, and 3.07” in September, for a total of 22.11”. In 2024, the season was much wetter than average until September, with aboveaverage rainfall in April (4.93”), June (7.67”), and August (6.14”), close to average rainfall in May (4.39”) and July (4.25”), and less rainfall than average in September (0.28”) for a total of 27.66” of rainfall. After April, rainfall was supplemented with irrigation as needed, supplying 0.55” of water in May, 1.76” in June, 4.85” in July, 2.25” in August, and 1.00” in September, for a total of 10.41” of irrigation in May through September. Between planting (April 24) and harvest (September 19), 24.72” of rain fell, for a total of 35.13” of rainfall plus irrigation during that period.

Tuber yield, size, grade, and number

Results for tuber yield, size, grade, and number are presented in Table 3. Total tuber yield, U.S. No. 1 yield, total marketable yield, and the yields of 4- to 6-ounce tubers and 6- to 10-ounce tubers were significantly greater in the treatment receiving KCl with ammonium sulfate (treatment 3) than the treatment receiving ammonium sulfate alone (treatment 1). This suggests that tuber yield was K-limited in this field. The percentage of total yield represented by tubers over 6 ounces was numerically greater with KCl (treatment 3) than without it (treatment 1), with the difference approaching statistical significance. Contrasts did not indicate that the addition of S or Mg significantly affected tuber yield, size, grade, or number.

Among the treatments receiving polyhalite (treatments 5 – 9), the treatments receiving the two lowest rates of polyhalite in a single application (treatments 5 and 6) had significantly higher total yields than the others. The treatment receiving 45 S as polyhalite (i.e., 237 lbs/ac polyhalite – treatment 6) also had significantly higher marketable yield than the treatment receiving split applications of KCl and polyhalite without ammonium sulfate (treatment 9). None of the treatments receiving polyhalite had higher total, marketable, or U.S. No. 1 yield than the treatments receiving KCl with ammonium sulfate or KCl with langbeinite before planting (treatments 3 and 4). Indeed, the treatment receiving KCl, polyhalite, and ammonium sulfate in split applications (treatment 8) had lower total yield than either of these two treatments, and the treatment receiving split applications KCl and polyhalite without ammonium sulfate (treatment 9) had lower total and marketable yield than these two.

The treatment receiving the 30-S polyhalite blend before planting (treatment 5) had significantly higher U.S. No. 2 yield than any treatment but the one receiving KCl and langbeinite (treatment 4). It is not clear why this treatment had relatively high U.S. No. 2 yield, since it did not have exceptional nutrient or fertilizer application rates relative to other treatments. However, one plot in this treatment had unusually high U.S. No. 2 yield (85 cwt/ac), and nearby plots also had relatively high U.S. No. 2 yields (47 – 63 cwt/ac), possibly indicating that conditions in this part of the field were conducive to tuber malformations, especially in the exceptional plot.

Tuber quality

Results for tuber quality are presented in Table 4. Hollow heart, brown center, and common scab were uncommon, and their prevalence was not significantly related to treatment. Vascular browning, which may be associated with *Verticillium* wilt, was relatively common in the treatment receiving KCl and ammonium sulfate before planting (treatment 3), with the result that the three contrasts involving that treatment approached statistical significance, though the overall treatment effect was not significant. Tuber specific gravity was numerically highest in the treatment receiving no fertilizer K (treatment 1), and the difference between this treatment and the treatment receiving KCl and ammonium sulfate (treatment 3) approached statistical significance. Tuber dry matter content was not related to treatment.

Petiole NO_3^--N, K, S, Mg, and Ca concentrations

Results for petiole NO_3^--N, K, S, Mg, and Ca concentrations on June 20 and July 17 are presented in Table 5. The effect of fertilizer treatment was significant for all concentrations on both dates. Based on the contrast comparing the treatment receiving ammonium sulfate alone (treatment 1) with the treatment receiving ammonium sulfate with KCl (treatment 3), providing K in fertilizer increased petiole K concentrations but decreased the concentrations of the other elements (except for Ca in the July 17 sample). Presumably, K fertilizer promoted plant vine and tuber growth, diluting the concentrations of the other elements in petiole tissues. Based on the contrast comparing the treatment receiving KCl alone (treatment 2) with the treatment receiving KCl and ammonium sulfate (treatment 3), providing S increased S concentration on June 20 and decreased Ca concentration (and, to a smaller degree, Mg concentration) on July 17. It is not clear why applying S apparently affected petiole Mg and Ca concentrations in July. Based on the contrast comparing the treatment receiving KCl and langbeinite (treatment 4) with the treatment receiving KCl and polyhalite to provide 30 lbs/ac S (treatment 5), the use of polyhalite as an S source increased petiole Mg and S concentrations in the July 17 sample.

Summary and conclusions

Our results indicate that polyhalite was an effective S source for potato at this site when applied in a blend with KCl to meet crop K requirements. Numerically, among the polyhalite blends, the treatment in which polyhalite provided 45 lbs/ac S (treatment 6) performed most similarly to conventional treatments (treatments 3 and 4), with somewhat better results than the treatments using either less polyhalite (treatment 5) or more (treatment 7). The treatments receiving split applications of polyhalite treatments 8 and 9) had significantly lower total yields and numerically lower marketable yields than the conventional treatments (treatments 3 and 4), suggesting that split application was not advantageous in this site and year. Based on petiole element concentrations, polyhalite was an effective source of Mg and Ca as well as S, which may be valuable in locations where the irrigation water contains less of these elements than the water at SPRF.

Table 1. Initial soil characteristics in the study site at the Sand Plain Research Farm in Becker, MN, in April 2024, before fertilizer applications.

0 - 6 inches											
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)
6.6	1.5	21	85	869	147	14	27	2.2	0.7	0.2	8

Table 2. Treatments applied to Russet Burbank potato plants to evaluate polyhalite as a nutrient source for potatoes in sandy, acidic, low-organic-matter soils.

Treatment #	Product applied	Method of application	K_2O (lbs/ac)	S (lbs/ac)	Mg (lbs/ac)	Ca (lbs/ac)	Poly (lbs/ac)	MOP (lbs/ac)	AmSulf (lbs/ac)	Urea[5] (lbs/ac)	Langb. (lbs/ac)

1	AmSulf[5]	Broadcast preplant	0	30	0	0	0	0	125	0	0
2	KCl[6]	Broadcast preplant	200	0	0	0	0	333	0	57	0
3	KCl + AmSulf	Broadcast preplant	200	30	0	0	0	333	125	0	0
4	KCl + Langbeinite[7]	Broadcast preplant	200	30	16	0	0	281	0	57	143
5	KCl + Polyhalite[8,9] 30 S	Broadcast preplant	200	30	6	19	158	297	0	57	0
6	KCl + Polyhalite 45 S	Broadcast preplant	200	45	9	29	237	278	0	57	0
7	KCl + Polyhalite 60 S	Broadcast preplant	200	60	11	38	316	260	0	57	0
8	KCl + Polyhalite + AmSulf	Half broadcast preplant, half sidedressed at hilling	200	15 + 15	3	10	40 + 40	158 + 158	31 + 31	29	0
9	KCL + Polyhalite	Half broadcast preplant, half sidedressed at hilling	200	15 + 15	6	19	79 + 79	148 + 148	0	57	0

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[5] Ammonium sulfate: 21-0-0-24S

[6] Potassium chloride: 0-0-60

[7] Langbeinite: 0-0-22-21S-11Mg

[8] Polyhalite: 0-0-14-19S-3.6Mg-12Ca

[9] Urea: 46-0-0

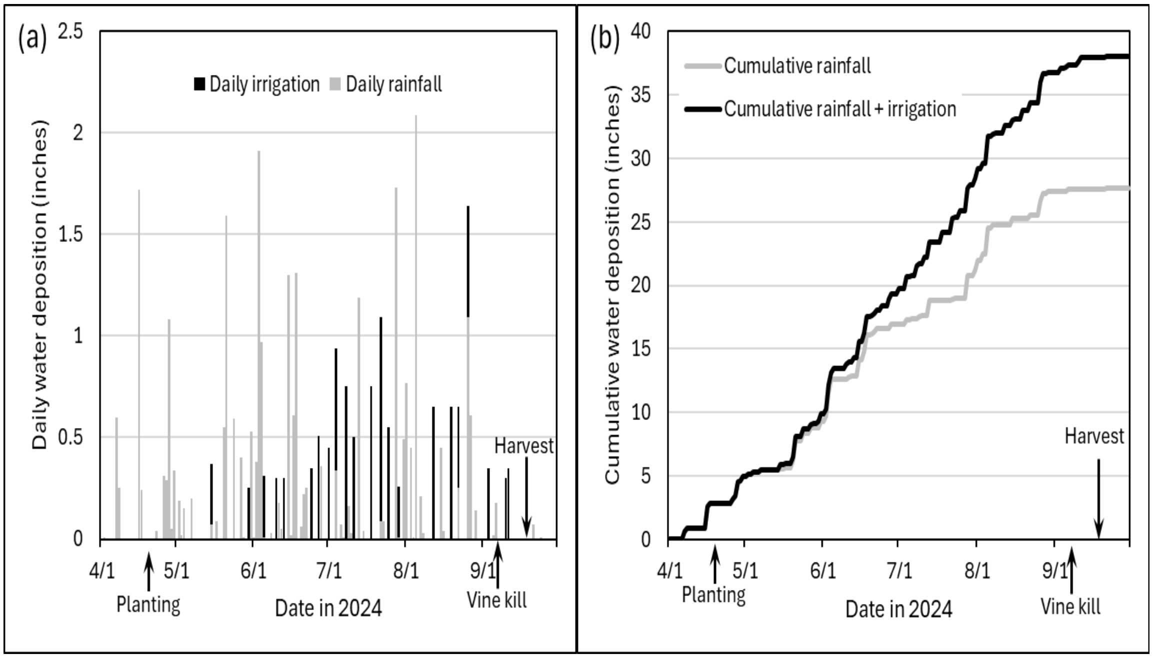

Figure 1. (a) Daily and (b) cumulative rainfall and irrigation in April through September at the study site at SPRF in 2024.

Table 3. Effects of fertilizer treatments on tuber yield, size, grade, and number. 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 where the effect of trea

Treatment			Yield (cwt/ac)										% yield in tubers over:		Tubers / plant
umber	Product applied	Timing	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	AmSulf	Preplant	0.2	261	117 c	43 c	4	0	424 d	139 b	25 bc	164 c	11	1	12.0
2	KCl	Preplant	0	255	164 a	73 ab	6	0	497 ab	223 a	19 c	242 ab	16	1	13.5
3	KCl+AmSulf	Preplant	0	249	165 a	81 a	10	0	506 a	227 a	30 bc	256 a	18	2	12.9
4	KCl+Langbeinite	Preplant	0	258	164 a	77 ab	10	1	509 a	216 a	35 ab	251 a	17	2	13.3
5	KCl+Polyhalite 30 S	Preplant	0.6	264	148 ab	66 abc	19	4	502 a	190 a	48 a	238 ab	18	4	12.7
6	KCl+Polyhalite 45 S	Preplant	0	247	162 a	86 a	7	0	503 a	228 a	28 bc	256 a	19	1	12.9
7	KCl+Polyhalite 60 S	Preplant	0	242	140 b	73 ab	20	1	476 bc	206 a	27 bc	233 ab	20	4	12.8
8	KCl+Polyhalite+AmSulf	Preplant+hilling	0	257	146 ab	58 bc	9	2	472 bc	197 a	18 c	215 ab	15	2	12.7
9	KCL+Polyhalite	Preplant+hilling	0	258	137 bc	54 bc	11	2	461 c	184 a	20 c	203 bc	14	3	12.6
		Treatment effect (P-value)	0.4613	0.9831	**0.0112**	*0.0742*	0.4672	0.6256	**<0.0001**	**0.0486**	*0.0593*	**0.0147**	0.4489	0.4417	0.6753
ontrasts P-value)		K addition (1 v 3)	0.4726	0.5875	**0.0010**	**0.0093**	0.3997	1.0000	**<0.0001**	**0.0024**	0.6110	**0.0008**	*0.0676*	0.4973	0.2264
		S addition (2 v 3)	1.0000	0.7971	0.9556	0.5146	0.5732	1.0000	0.5639	0.8821	0.2655	0.5651	0.5345	0.6438	0.4717
		Mg addition (3 v 4)	1.0000	0.6738	0.9369	0.7192	0.9556	0.6489	0.8132	0.6746	0.5329	0.8276	0.8258	0.9390	0.5750
		Poly vs. conventional (5 v 4)	**0.0479**	0.7975	0.2479	0.4579	0.2483	0.1615	0.6305	0.3304	0.1582	0.6059	0.9094	0.2176	0.3611

Treatment			Petiole NO_3^--N (%)		Petiole K (%)		Petiole S (%)		Petiole Mg (%)		Petiole Ca (%)	
Number	Product applied	Timing	June 20	July 17	June 20	July 17	June 20	July 17	June 20	July 17	June 20	July 17
1	AmSulf	Preplant	2.4 a	1.6 a	6.5 c	1.8 c	0.29 ab	0.41 a	1.05 a	2.16 a	1.33 a	1.56 bc
2	KCl	Preplant	1.8 cd	1.0 b	9.4 ab	5.1 ab	0.23 e	0.28 cd	0.66 b	1.55 b	1.12 b	1.70 a
3	KCl+AmSulf	Preplant	1.7 d	0.8 b	9.0 b	5.5 a	0.27 d	0.28 d	0.64 b	1.42 cd	1.03 bc	1.57 bc
4	KCl+Langbeinite	Preplant	2.0 bc	0.7 b	9.3 ab	5.5 a	0.27 cd	0.31 bc	0.67 b	1.34 d	1.08 bc	1.48 c
5	KCl+Polyhalite 30 S	Preplant	1.8 cd	0.9 b	8.8 b	5.1 ab	0.28 bc	0.31 bc	0.71 b	1.52 bc	1.09 bc	1.60 b
6	KCl+Polyhalite 45 S	Preplant	1.8 bcd	0.8 b	9.2 ab	5.3 ab	0.29 ab	0.33 b	0.66 b	1.56 b	0.99 c	1.61 b
7	KCl+Polyhalite 60 S	Preplant	1.9 bcd	0.8 b	9.6 a	5.0 ab	0.30 a	0.32 b	0.65 b	1.55 b	1.04 bc	1.59 b
8	KCl+Polyhalite+AmSulf	Preplant+hilling	1.9 bc	0.9 b	9.2 ab	5.2 ab	0.26 d	0.31 bc	0.67 b	1.46 bcd	1.11 b	1.63 ab
9	KCL+Polyhalite	Preplant+hilling	2.0 b	1.0 b	9.3 ab	4.8 b	0.27 d	0.32 bc	0.69 b	1.54 b	1.11 b	1.59 b
		Treatment effect (P-value)	**0.0001**	**0.0083**	**<0.0001**	**<0.0001**	**<0.0001**	**0.0003**	**<0.0001**	**<0.0001**	**0.0013**	**0.0502**
Contrasts (P-value)		K addition (1 v 3)	**<0.0001**	**0.0003**	**<0.0001**	**<0.0001**	**0.0201**	**<0.0001**	**<0.0001**	**<0.0001**	**<0.0001**	0.9556
		S addition (2 v 3)	0.8047	0.2697	0.2852	0.3005	**0.0002**	0.7947	0.7736	*0.0797*	0.1351	**0.0196**
		Mg addition (3 v 4)	*0.0726*	0.6055	0.4702	0.9752	0.7582	*0.0782*	0.6322	0.2618	0.4355	0.1278
		Poly vs. conventional (5 v 4)	0.1375	0.4288	0.2127	0.2057	0.1326	1.0000	0.3914	**0.0164**	0.8140	**0.0324**

Table 4. Effects of fertilizer treatments 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 where the effect of treatment has $P \leq 0.10$.

Treatment			Tuber defects (% of tubers)				Specific gravity	Dry matter content (%)
Number	Product applied	Timing	Disqualifying hollow heart	Disqualifying brown center	Common scab	Vascular browning		
1	AmSulf	Preplant	1	1	3	0	1.0821	20.8
2	KCl	Preplant	0	0	1	0	1.0800	20.4
3	KCl+AmSulf	Preplant	0	0	0	25	1.0791	20.8
4	KCl+Langbeinite	Preplant	1	1	2	0	1.0785	20.1
5	KCl+Polyhalite 30 S	Preplant	1	0	0	0	1.0791	19.9
6	KCl+Polyhalite 45 S	Preplant	0	0	0	17	1.0793	20.1
7	KCl+Polyhalite 60 S	Preplant	1	1	3	5	1.0789	20.7
8	KCl+Polyhalite+AmSulf	Preplant+hilling	0	0	1	17	1.0813	20.4
9	KCL+Polyhalite	Preplant+hilling	3	3	0	8	1.0798	19.8
		Treatment effect (P-value)	0.3825	0.2677	0.5257	0.4446	0.3206	0.6899
Contrasts (P-value)		K addition (1 v 3)	0.4485	0.4214	0.1233	*0.0656*	*0.0567*	0.9474
		S addition (2 v 3)	1.0000	1.0000	0.6002	*0.0656*	0.5731	0.5818
		Mg addition (3 v 4)	0.4485	0.4214	0.2982	*0.0656*	0.6737	0.3204
		Poly vs. conventional (5 v 4)	1.0000	0.4214	0.2982	1.0000	0.6864	0.6868

Table 5. Effects of fertilizer treatments on petiole NO_3^--N, K, S, Mg, and Ca concentrations on June 20 and July 17, 2024. 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 where the effect of treatment has $P \leq 0.10$.

Assessment of different phosphorus acid products on pink rot control

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Executive summary

Phosphorous acid products are long been applied in the Upper Midwest. However, there can be a high leaf burn potential. The objective of this study was to evaluate 11 different phosphorous acid products applied at similar amount of active ingredient and determine what effects they have on foliar injury, tuber yield, and pink rot. Little injury was observed in 2024. Yield did not differ between treatments. Challenge inoculations found differences in pink rot inoculations. All treatments were better than the non-treated check for pink rot incidence percentage and penetration. Within the treatments utilized some treatment performed better than others. Alloy, Vitaliphite K, and Reliant were similar in that they had the lowest incidence percentage. Pink rot penetration followed a similar patter and was lowest for Vitaliphite K, Alloy, Reliant, and BlueLogic. Because this is one year's data, further research is needed confirm

Rationale for conducting the research

Phosphorous acid is applied to foliage of potato plants three to four times during the growing season. It can be applied in fewer treatments, but the rate of phosphorous acid is higher risking more foliar injury. While some may apply it in more treatments than four to reduce the rate applied and risk of injury, but this increases application costs. Potatoes grown in the Upper Midwest seem to be more susceptible to phosphorous acid injury. The leaf necrosis could be a result of the high humidity or long-lasting dew in combination with the high salt content of phosphorous acid. Or it might be explained as plants under stress being grown in challenging environmental conditions. Grower response to crop injury is unacceptable, so they have been trying various methods to eliminate injury by reducing product, increasing carrier volume, timing, and application methods. Previous work by Robinson and Gudmestad (2016) evaluated the effect of adjuvants to spread and reduce injury. There was little reduction in phosphorous acid injury from the use of spreader adjuvants. Other work evaluated higher rates of phosphorous acid applied to potato plants at early growth stages when plants were robustly growing and less stressed (Robinson and Gudmestad, 2017). This work showed a reduction in injury, but not sufficient uploading of phosphorous acid into tubers.

Other challenges are the response of new varieties to phosphorous acid and the number of new products on the market. As in any crop, new varieties play an important role for future sustainability and improved yield. However, some new potato varieties have demonstrated severe injury from phosphorous acid treatments. It is unknown why some varieties respond with such injury, but preventing substantial losses is important to maintain sustainable economic production of potatoes. As in any business, growers are looking for the most cost-effective product. Recently, many newer phosphorous acid products have come to the market. Many products are formulated differently, indicating the burn potential will likely vary.

The objective of this project was to describe differences in foliar burn and pink rot control of different products applied to Dakota Russet.

Procedures

We evaluated 11 products being used or labelled for pink rot control in tubers. A randomized complete block design with four replications was used. Plots were established in Oakes, ND. On May 22 Dakota Russet was planted as it tends to have more leaf burn from phosphorous acid treatments. A non-treated check was used as a standard comparison. Phosphorous acid was applied following standard grower practices of three application times with a similar amount of active ingredient from each product. Using the same active ingredient allows a fair comparison of products, rather than applied the amount labelled. Phosphorus acid treatments were applied on 11, 18, and 25 July, 2024 with a hand boom calibrated to deliver 15 gal/a. Injury symptoms were recorded visually one week after treatment on 18 and 25 July and on 1 August. Tubers were harvested on the 8 and 11 of October and thereafter graded. A sub sample of tubers from the study were challenge inoculated with the pink rot pathogen by Dr. Pasche's laboratory. The challenge inoculation provides data on each product's ability to control pink rot in storage in a typical irrigation regime. This challenge inoculation protocol has been used by NDSU potato pathology for many years to successfully evaluate products for control of pink rot. Additionally, tubers are being sent out to measure the phosphoric acid concentration.

Treatment list:

1. Non-treated control
2. Zinc Phosphate
3. Phiticide
4. Kphite
5. Phostrol
6. Alloy
7. Fosphite
8. Reliant
9. Revielle
10. BlueLogic
11. Max set MZ
12. Vitaliphite K

Data from these trials was statistically analyzed using an analysis of variance. Differences were determined at p=0.05. A Tukey pair-wise comparison was used to separate mean differences. Challenge inoculations were evaluated with an analysis of variance with a separation of data by least significant difference.

Results

There was little injury from the products applied and no data is shown. This could have been because a higher water use rate was used of 15 gal/a, or because of good plant health no to little injury was observed. No differences were found in yield or the components measured (Tables 1 and 2). Nor were there any differences in tuber number per acre on yield, except for tubers less than 4 oz there were some differences. Because foliar injury was not an issue, there was not many challenges that would reduce yield in this study.

Pink rot challenge inoculation did have differences between treatments (Table 3). All 11 treatments provided better pink rot control when compared to the non-treated check. Alloy, Vitaliphite K, and Reliant were similar in that they had the lowest incidence percentage. There were more similarities in the penetration depth among treatments. Pink rot penetration followed a similar patter and was lowest for Vitaliphite K, Alloy, Reliant, and BlueLogic. Overall, it is interesting to note the differences in incidence and penetration. Because of these differences we are sending tubers to a laboratory to be tested for phosphoric acid. Further research is needed to validate the results of this first year of study.

References

Robinson, A. and N.C. Gudmestad. (2016) Minimizing Phytotoxicity and Quantify Efficacy of Phosphorous Acid. Minnesota Area II Potato Research and Promotion Council and Northern Plains Potato Growers Association Research Reports p. 92-97.

Robinson, A. and N.C. Gudmestad. (2017) Minimizing Phytotoxicity and Quantify Efficacy of Phosphorous Acid. Minnesota Area II Potato Research and Promotion Council and Northern Plains Potato Growers Association Research Reports p. 127-133.

Table 1. Graded yield of Dakota Russet with numerous phosphorus acid treatments in Oakes, ND in 2024.

Treatment		**Rate**	**<4 oz**	**4-6 oz**	**6-10 oz**	**10-14 oz**	**>14 oz**	**Total yield**	**Total marketable**	**>6 oz**	**>10 oz**	**Specific gravity**
		lb ai/a	———————————— cwt/a —————————————							—— % ——		
1	Non-treated	0	46	95	160	52	21	375	328	62	19	1.086
2	Zinc Phosphate	0.67	39	79	153	54	24	349	309	66	22	1.085
3	Phiticide	3.9	45	93	174	56	14	382	337	64	18	1.088
4	Kphite	3.9	67	94	143	35	8	347	281	54	12	1.088
5	Phostrol	3.9	50	92	166	72	20	399	349	64	23	1.083
6	Alloy	3.9	48	84	155	95	27	410	362	68	30	1.090
7	Fosphite	3.9	54	95	139	39	18	346	292	56	16	1.090
8	Reliant	3.9	31	75	145	64	20	335	303	67	25	1.088
9	Revielle	3.9	43	85	157	50	17	353	309	63	19	1.088
10	BlueLogic	3.9	41	81	171	78	18	389	349	69	25	1.090
11	Max set MZ	3.9	40	96	147	50	17	350	310	60	19	1.087
12	Vitaliphite K	3.9	44	93	137	61	16	351	307	61	22	1.087

Table 2. Tuber number of graded yield of Dakota Russet with numerous phosphorus acid treatments in Oakes, ND in 2024.

Treatment			**<4 oz**		**4-6 oz**	**6-10 oz**	**10-14 oz**	**>14 oz**	**Total yield**	**Total marketable**	**>6 oz**	**>10 oz**
			———————————— tuber number/a ———————————————								—— % ——	
1	Non-treated	0	25,410	ab	30,492	35,211	7,623	2,178	100,914	75,504	45	10
2	Zinc Phosphate	0.67	24,321	ab	27,770	36,300	8,531	2,723	99,644	75,323	48	12
3	Phiticide	3.9	25,410	ab	31,944	38,115	8,168	1,452	105,089	79,679	46	9
4	Kphite	3.9	38,841	a	33,033	33,578	5,627	908	111,986	73,145	36	6
5	Phostrol	3.9	28,677	ab	32,489	37,752	11,072	2,178	112,167	83,490	46	12
6	Alloy	3.9	27,044	ab	27,951	33,759	13,794	2,904	105,452	78,408	48	16
7	Fosphite	3.9	30,855	ab	33,215	31,037	5,990	1,997	103,092	72,237	37	7
8	Reliant	3.9	19,784	b	26,136	33,033	9,801	2,178	90,932	71,148	49	13
9	Revielle	3.9	25,410	ab	29,040	34,848	7,442	1,634	98,373	72,963	45	9
10	BlueLogic	3.9	21,962	b	26,681	36,663	11,253	1,815	98,373	76,412	51	14
11	Max set MZ	3.9	22,869	ab	31,581	31,037	7,260	1,815	94,562	71,693	43	10
12	Vitaliphite K	3.9	24,503	ab	30,674	30,492	8,712	1,452	95,832	71,330	42	11

Table 3. Incidence and penetration of pink rot (*phytophthora erythroseptica*) challenge inoculation as affected by treatment from tubers grown at Oakes, ND in 2024.

Treatment		*P. erythroseptica* challenge inoculation	
		Incidence (%)	Penetration (mm/day)
1	Non-treated	85.0	6.5
2	Zinc Phosphate	21.3	1.3
3	Phiticide	20.0	1.2
4	Kphite	17.5	0.9
5	Phostrol	25.0	1.4
6	Alloy	6.3	0.4
7	Fosphite	22.5	1.3
8	Reliant	11.3	0.6
9	Revielle	13.8	0.9
10	BlueLogic	16.3	0.8
11	Max set MZ	18.8	1.0
12	Vitaliphite K	5.0	0.3
$LSD_{P = 0.05}$		7.7	0.5
P-value		<.0001	<.0001
Coefficient of Variation		61.9	64.1

Incidence and penetration of *Phytophthora erythroseptica* were significantly different between trials 1 and 2. Both variances were homogeneous. There was no interaction between trial and treatment.

North Dakota Fresh Market Potato Cultivar/Selection Trial Results for 2024

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Potato cultivars or selections included in this report were selected from recently released cultivars, advancing selections with release potential (numbered lines progressing through the trial process), or cultivars that are new to the U.S. Standard potato cultivars used by growers served as checks. For comparison, studies conducted in 2019, 2020 and 2021 evaluated several red and yellow-skinned fresh potatoes.

In 2024, two trials were conducted to identify traits of red- and yellow-skinned potato cultivars and advanced selections near Crystal, North Dakota. Thirteen red-skinned cultivars and 17 yellow-skinned cultivars were evaluated. Plots were established in a commercial, non-irrigated potato field utilizing common potato-production practices. The authors acknowledge J.G. Hall & Sons for hosting these trials.

Prior to planting, urea at 120 lbs. of nitrogen (N) per acre was broadcast and incorporated. A randomized complete block design with four replicates was utilized. Seed tubers were hand cut to approximately two-ounce seed pieces and suberized prior to planting.

Tubers were planted on June 10 in a single row with nine-inch within-row spacing. Plots were three feet wide and 30 ft. long.

The number of emerged plants in the entire plot were counted to determine emergence rate. The number of stems per plant was determined by counting the number of stems on 10 plants in a row in each plot. Vines were killed with diquat on Sept. 9 and Sept. 15. Plots were harvested on Oct. 1 and Oct. 3 with a with a single-row lifter and thereafter bagged by hand.

After harvest, potatoes were stored at 55 F until grading. The tuber size profile distribution was determined by sorting all potatoes harvested into C size (less than 1.875 in.), B size (1.875 to 2.25 in.), A size (2.25 to 3.5 in.) and Chef size (greater than 3.5 in.). Total yield is a summation of C + B + A + Chef.

The 2024 agronomic data presented in Tables 1 and 2 were analyzed statistically. These analyses allow the reader to ascertain, at a predetermined level of confidence, if the differences observed among cultivars/selections are reliable or if they might be due to error inherent in the experimental process.

The least significant difference values (LSD) beneath the columns apply only to the numbers in the column in which they appear. If the difference between two cultivars/selections exceeds the LSD value at 0.05 or 0.10, it means that with 95% or 90% confidence, respectively, the higher-yielding cultivar/selection has a significant yield advantage. When the difference between two cultivars/selections is less than the LSD value, no significant difference was found between the two under these growing conditions.

The coefficient of variation (CV) is a measure of variability in the trial and is expressed as a percentage. Large CVs mean a large amount of variation that could not be attributed to differences in the cultivars/selections.

The data provided does not indicate endorsement nor approval by the authors, nor by North Dakota State University Extension or by the University of Minnesota Extension. Reproduction of the tables is permissible if presented with all the same information found in this publication (meaning no portion is deleted and the order of the data is not rearranged).

The authors acknowledge the contribution of cultivars and advanced selections for this work from public and private breeding programs and industry partners.

Figure 1. Harvesting research plots near Crystal, ND on October 1, 2024.

Table 1. Agronomic performance and yield of yellow-skinned potato cultivars/selections grown near Crystal, ND in 2024.

Cultivar	**Stand[1]**	**Stems/plant[2]**	**C[3]**	**B**	**A**	**Chef**	**Total yield**	**Specific gravity**
	%	number	cwt/a					
Actrice	97	3.6	4	98	404	23	529	1.067
Agata	93	3.1	2	119	221	10	352	1.068
Alegria	92	3.9	2	99	214	4	319	1.085
Bernice	89	3.2	6	186	239	1	431	1.075
Challenger	91	4.0	7	195	128	0	330	1.086
Camelia	95	3.3	1	107	250	7	366	1.072
Columba	88	4.6	3	117	343	18	482	1.064
Decibel	89	3.2	8	166	60	0	234	1.073
Georgina	97	4.5	2	92	222	8	324	1.069
Malou	89	4.8	9	165	190	1	365	1.075
MN18CO16154-009	94	4.1	16	173	66	0	255	1.105
MN19AF6945-003	95	4.2	3	79	255	15	353	1.086
MN19TX18206-002	96	4.5	28	169	17	0	214	1.089
Montana	92	3.8	9	189	149	1	348	1.068
Musica	94	4.4	6	177	200	1	384	1.079
ND1241-1Y	95	3.8	9	174	158	0	341	1.107
Sensation	92	3.2	5	106	187	8	307	1.066
Mean	93	4	7	142	194	6	349	1.079
CV	8	25	43	23	24	108	16	0.2
LSD p=0.05	*ns*[4]	*ns*	4	46	67	9	79	0.003
LSD p=0.1	*ns*	*ns*	4	39	56	8	66	0.003

[1] Stand count was taken on July 23 (six weeks after planting) by counting every emerged plant and dividing by the number planted.

[2] Stems per plant were counted on 10 plants on July 23 (six weeks after planting) and are shown as the average number of stems per plant.

[3] Harvested potato tubers were sorted on a Kerian Speed sizer as C = less than 1.875, B = 1.875-2.25, A = 2.25-3.5 and Chef = greater than 3.5 inches.

[4] *ns* indicate data was not significant at p=0.05

Table 2. Agronomic performance and yield of red-skinned potato cultivars/selections grown near Crystal, ND in 2024.

Cultivar	**Stand**[1]	**Stems/plant**[2]	**C**[3]	**B**	**A**	**Chef**	**Total yield**	**Specific gravity**
	%	number	———	———	cwt/a	———	———	
Becca Rose	95	3.8	4	97	220	7	328	1.071
Dark Red Norland	99	4.2	2	67	261	5	335	1.075
MN18W17009-001	96	4.0	8	154	79	0	241	1.073
MN18W17026-002	95	4.9	7	181	136	3	327	1.076
MN19ND1759-001	95	4.1	11	142	65	0	218	1.071
Modoc	100	3.2	3	98	181	6	288	1.074
ND113207-1R	98	4.0	8	163	210	7	388	1.067
ND14324B-7R	93	3.2	13	88	93	3	197	1.077
PSS14/083/14	94	3.7	16	222	53	0	292	1.081
PSS14/083/33	98	4.0	27	232	46	0	305	1.080
Red Norland	93	3.1	2	57	226	15	300	1.072
Rediva	97	4.4	18	249	104	2	373	1.085
Sangre	97	1.8	3	63	164	10	239	1.077
Mean	96	3.7	9	139	141	4	295	1.075
CV	7	24	62	19	32	6	19	0.3
LSD p=0.05	*ns*[4]	1.3	8	39	65	9	80	0.005
LSD p=0.1	*ns*	1.1	7	32	54	7	67	0.004

[1] Stand count was taken on July 23 (six weeks after planting) by counting every emerged plant and dividing by the number planted.

[2] Stems per plant were counted on 10 plants on July 23 (six weeks after planting) and are shown as the average number of stems per plant.

[3] Harvested potato tubers were sorted on a Kerian Speed sizer as C = less than 1.875, B = 1.875-2.25, A = 2.25-3.5 and Chef = greater than 3.5 inches.

[4] *ns* indicate data was not significant at p=0.05

Increasing stem and tuber number on Mountain Gem Russet and Dakota Russet

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Executive summary

Mountain Gem Russet and Dakota Russet are important varieties being planted to more acres in our area. However, low tuber number, a result of low stem number, is making the cost of production higher and potentially unsustainable. The objective of this project was to determine the best method to increase stem and tuber number of Mountain Gem Russet and Dakota Russet by manipulating the storage temperature and applying spring treatments to the seed to increase the number of sprouts and concomitantly tuber number. Seed was treated with three storage temperature regimes (165, 375, and 750 growing degree units (GDU)) and three spring seed treatments (non-treated, gibberellic acid (GA) (ProGibb LV Plus) plus naphthalene acetic acid (NAA) (Rejuvenate), and 1,4-Seed). Field trials were planted near Inkster, ND at the NPGA irrigated field site. Mountain Gem Russet stem number, stem width, average tuber size, and yield was affected by the fall storage treatment of 165 GDU plus GA + NAA. Physiological age increased at 375 or 750 GDU had a greater effect on seed of Mountain Gem Russet than Dakota Russet. The GA + NAA treatment caused Dakota Russet seed to have more stems, more tubers, smaller stem width, smaller tubers on average, and less yield. The late planting date shortened the season, not allowing smaller tubers to size. The project found that increasing GDU in the fall and seed treatments of GA + NAA increased stem number and tuber number for Mountain Gem. However, the seed treatment of GA + NAA did increase stem and tuber number, while in general the fall treatment did not affect Dakota Russet. Further research would be beneficial to determine the effects of a longer growing season on the effects of increased stem and tuber number in North Dakota and Minnesota.

Rationale for conducting the research

Dakota Russet and Mountain Gem Russet are highly desirable varieties to grow in North Dakota as they demonstrate improved traits over older varieties. Furthermore, they have been accepted for French fries from major quick service restaurants. The demand for seed is greater than the seed available. One of the reasons for this for this is these varieties have a low stem count, resulting in fewer but larger tubers. To fix this issue, growers have planted these varieties closer, moving from a traditional 12-inch within row spacing to 9-inch within row space. This is a 33% increase in seed, limiting the acres planted to these varieties in North Dakota, and increasing the cost dramatically.

Growers commonly plant at 12-inch row spacing in 36-inch rows for most russet-skinned varieties. Using 2 oz sized seed, this means every acre planted needs 1,820 pounds of seed and at an estimated cost of $35 per 100 lbs, results in a cost of $637 per acre for seed alone. Additional costs include transporting the seed, storing the seed, cutting and treating seed with crop protectants, and suberizing the seed. The cutting processes is estimated to cost $4/cwt of seed, adding an additional $73 to the cost per acre. Seed planted at 9 inch within-row spacing, using the previous costs, adds an additional cost of $234 per acre for seed and cutting, not including additional shipping, cutting, or handling costs.

Limited methods have been found through research to improve stem number in other potato varieties, allowing for wider within-row spacing. However, there is not knowledge available on these newer varieties for what method or methods work best. The objectives of this project are to 1) determine the best method to increase stem and tuber number of Dakota Russet and Mountain Gem Russet by manipulating the storage temperature in the fall and applying seed treatments in the spring to increase the number of sprouts and concomitantly tuber number.

Procedures

Dakota Russet and Mountain Gem Russet seeds were obtained from commercial growers in North Dakota (late September to early October). A total of 600 lb of each variety were separated into three lots (200 lb per lot) to receive three different storage temperature treatments. At the beginning of storage, all tubers received a conditioning treatment of 168 degree-days at 54 °F, 95-99% relative humidity for 21 days to facilitate wound healing. Control seeds were stored at 40 °F (base temperature) after wound healing throughout the entire season (approximately 180 days of total storage period). Seed aging treatments consisted of storing seeds at the 54 °F for the appropriate number of days to accumulate 375 or 750 growing degree units (GDU). It has been reported by Rick Knowles in Washington state that aging seed in the fall after harvest advances physiological age more than warming seed prior to planting. After aging treatments, age-primed seeds were held at 40 to 42 °F during the rest of the storage season, then rewarmed at 54 °F prior to planting. Each aged seed lot was divided into three subplots of approximately 73 lb. Treatments to subplots were no additional treatments or non-treated (plant as is with temperature aging), a combination of gibberellic acid and naphthalene acetic acid applied on 26 May

2024, and the use of 1,4-DMN (1,4-dimethylnaphthalene). Seed was treated with 0.057 mL active ingredient/ton of seed of gibberellic acid (1 mL of ProGibb LV Plus) plus 0.25 mL active ingredient naphthene acetic acid/ton of seed (4 mL/ton seed of Rejuvenate) on 26 May 2024. The 1,4-Seed treatment was completed on 11 April 2024 at 10 ppm in an enclosed container. To clearly describe treatments they are listed below.

Fall treatments

1. 165 growing degree units
2. 375 growing degree units
3. 750 growing degree units

Spring seed treatments

1. Non-treated
2. Gibberellic acid (ProGibb) + naphthene acetic acid (Rejuvenate) (GA + NAA)
3. 1,4-Seed

The field trial was planted at Inkster, ND on May 27, 2024. Plots were arranged in a randomized complete block design, with a 10 inch within-row spacing, and 36 inches between rows. Each treatment plot consisted of two rows. Stand and stem count was completed on 9 July by counting the number of plants and stems in each row. Stem width was measured on 19 July by measuring every stem width near the soil surface for 10 consecutive plants. Plants naturally desiccated by mid-September and were harvested on the 4 and 7 October with a single row harvester.

Statistical analyses were run to determine the effects of fall and spring seed treatments. An analysis of variance was used to determine differences of treatments. Varieties were separated in the analysis because of differences found. There was an interaction of fall treatments with spring seed treatments for Mountain Gem Russet. The results for Mountain Gem Russet will show all interactions, except for stand, stem number, and stem width where there was no interaction. There was no interaction for the fall treatment and spring seed treatment for Dakota Russet. The results show the effects of fall treatment and spring seed treatment separately for Dakota Russet.

Results

Mountain Gem Russet

Mountain Gem Russet stand, stems per plant, and stem width had no interaction between fall and spring treatments, but differences existed in other measurements within the fall and spring treatment (Table 1). The stand was affected by the spring seed treatment with the GA + NAA having a better stand than the other treatments. Mountain Gem russet stem number was increased by 0.3 to 0.4 stems per plant from growing degree units accumulated in fall on the seed stored, but stem width was not changed. The spring seed treatments had a greater effect on Mountain Gem Russet. The GA + NAA increased stem number by almost 0.5 to 0.6 stems per plant, but the average stem width decreased by approximately 1 mm compared to the other treatments. The 1,4-Seed treatment did not differ from the non-treated treatment in stand, stem number or stem width as affected by fall or spring treatment for Mountain Gem Russet.

Mountain Gem Russet yield was affected by the fall and spring treatments (Table 3). There was an interaction between the two factors for yield, thus the data is presented as such. Total yield was not affected by the treatments, but marketable yield had some differences. The treatment of 165 GDU with GA + NAA had the highest yield compared to the 750 GDU with GA + NAA that had the lowest yield. The cwt of tubers of each size category followed these yield results. The cwt of tubers <6 oz were higher and the percent of tubers >6 and 10 oz were lower for the higher marketable yield for the 750 GDU with GA + NAA treatment. The yield or marketable yield tuber number was not statically different (Table 3), however there was a numerical increase in tuber number when GA + NAA was used. Differences did exist for tubers from 4 to 6 oz, with the 375 and 750 GDU x GA + NAA treatments causing an increase in smaller tubers, but a decrease in larger tubers (10-14 oz). Furthermore, the average tuber size was lowest for the treatments of 375 and 750 GDU x GA + NAA when compared to the other treatments (Table 4). These results could be explained by the increased stem number, causing more tubers to be developed. However, because these plots were planted about a month late, there was not sufficient time to fill smaller tubers. These data indicate that the aging of seed after harvest and the GA + NAA increased stem number and tuber number (of some size categories). Further work is needed to confirm these results.

Dakota Russet

Dakota Russet stand, stem number, or stem width was not changed by the fall treatments (Table 5). However, seed treatments in the spring had an effect on stem number and stem width. Stem number increased by 0.31 to 0.36 stems per plant with GA + NAA and stem width decreased by 0.8 to 1 mm compared to the other treatments. These data indicate the stem number can increase, but stem will have a smaller diameter.

The effects of spring treatments resulted in some differences in graded tuber yield and tuber number (Tables 6 and 7). The 375 GDU fall treatments reduced the cwt of tubers from 10 to 14 oz and also the percent of tubers >6 and >10 oz. Tuber number followed a similar pattern as the hundred weight. Average tuber number decreased when 375 or 750 GDU were accumulated in the fall compared to the 165 GDU (Table 8). Although stem number was not statistically affected by fall treatments, the decrease in larger tubers, and a smaller average tuber, indicate the fall treatments did have some effects on Dakota Russet production, but not in all measurements.

Spring seed treatments affected tuber yield (Tables 6 and 7). The hundredweight of tubers <6 oz were more when the GA + NAA treatment was used compared to the other treatments and less for tubers >10 oz. Marketable yield and the percent of tubers >6 and >10 oz and average tuber size (Table 8) was less for the GA + NAA treatment compared to the other treatments. In general, tuber number mirrored the hundredweight for the yield parameters measured on the spring treatments. The total yield tuber number was increased by 23% when GA + NAA treatment was used. In this study, the tuber number increased from the GA + NAA, but because of the limited growing season there was not time for these tubers to gain the necessary size for marketable yield.

Conclusion

The results of this study indicate that aging seed in the fall and spring seed treatments of GA + NAA can manipulate stem number, tuber size, and yield. Although tubers were undersized, the growing season was not long enough to allow smaller tubers to size up. Because of the late planting date, the season was shortened. If there was another three weeks of growth it is likely the yield results would have been different. This study provides information on how to adjust stem number, tuber size, and yield for Mountain Gem Russet and Dakota Russet. It also shows the variability of potato genetics in their response to physiological aging and growth regulators. As found in this study Mountain Gem Russet was responsive to the fall and spring treatments, while Dakota Russet was most responsive to the spring seed treatment. The GA + NAA treatment rate used in this study numerically increased Mountain Gem Russet stems more than Dakota Russet stems. Slight adjustments in growth regulator rates or adjusting heat units in the fall could change stem number differently (followed by tuber number and yield), but this would need to be studied and trialed in small amounts. It is important to recognize that testing is needed for each variety to ensure that the proper treatments are being utilized to maximize performance of production.

Table 1. Stand, stems per plant, and stem width of Mountain Gem Russet as effected by fall growing degree units (GDU) and spring seed treatments, then grown near Inkster, ND in 2024. Letters that are different in columns within fall or spring treatment are statistically different at p=0.05 according to Tukey pair-wise comparison. No letter indicates no statistical difference.

Variety	**Treatment**	**Stand**	**Stems/plant**	**Stem width**
		%	**number**	**mm**
Fall GDU treatment				
Mountain Gem	165 GDU	97	2.46 b	12.0
Mountain Gem	375 GDU	94	2.72 ab	11.6
Mountain Gem	750 GDU	94	2.85 a	12.2
Spring seed treatment				
Mountain Gem	1,4 Seed	93 b	2.58 b	12.2 ab
Mountain Gem	GA + NAA	99 a	3.04 a	11.1 b
Mountain Gem	Non-treated	94 b	2.40 b	12.5 a

Table 2. Tuber yield and size profile for Mountain Gem Russet as effected by fall growing degree units (GDU) × spring seed treatments, then grown near Inkster, ND in 2024. Letters that are different in columns are statistically different at p=0.05 according to Tukey pair-wise comparison. No letter indicates no statistical difference.

Variety	GDU fall	Seed treatment	<4 oz	4-6 oz	6-10 oz	10-14 oz	>14 oz	Total yield	Total marketable	>6 oz	>10 oz
			———————————————— cwt/a ————————————————							———— % ————	
Mountain Gem	165	1,4 Seed	23 cd	56 c	158	85 abc	62 abc	383	360 ab	80 ab	39 abc
Mountain Gem	165	GA + NAA	46 bc	82 b	191	107 a	58 abc	484	438 a	73 bcd	34 bcd
Mountain Gem	165	Non-treated	14 d	44 c	156	108 a	107 a	429	415 ab	87 a	50 a
Mountain Gem	375	1,4 Seed	21 d	52 bc	152	101 ab	61 abc	387	366 ab	81 ab	41 abc
Mountain Gem	375	GA + NAA	59 b	133 a	156	49 c	19 c	416	356 ab	54 c	16 de
Mountain Gem	375	Non-treated	23 cd	48 bc	156	114 a	96 ab	437	414 ab	83 ab	47 ab
Mountain Gem	750	1,4 Seed	23 cd	45 bc	149	121 a	101 a	439	416 ab	84 ab	50 ab
Mountain Gem	750	GA + NAA	86 a	124 a	140	59 bc	19 bc	428	342 b	49 c	17 cde
Mountain Gem	750	Non-treated	23 cd	61 bc	180	84 abc	74 abc	421	398 ab	80 ab	38 abcd

Table 3. Tuber yield number and size profile number for Mountain Gem Russet as effected by fall growing degree units (GDU) × spring seed treatments, then grown near Inkster, ND in 2024. Letters that are different in columns are statistically different at p=0.05 according to Tukey pair-wise comparison. No letter indicates no statistical difference.

Variety	GDU fall	Seed treatment	<4oz	4-6 oz	6-10 oz	10-14 oz	>14 oz	Total yield	Total marketable	>6 oz	>10 oz
			——— tuber number/a ———							——— % ———	
Mountain Gem	165	1,4 Seed	11,435	16,517 cd	30,674	11,253 ab	5,627	75,504	64,070	63 ab	23 abc
Mountain Gem	165	GA + NAA	26,681	28,496 bc	43,560	16,335 a	5,990	121,061	94,380	55 b	18 bc
Mountain Gem	165	Non-treated	8,168	14,157 d	32,126	15,246 ab	9,620	79,316	71,148	72 a	32 a
Mountain Gem	375	1,4 Seed	11,435	17,061 cd	31,218	13,794 ab	5,990	79,497	68,063	64 ab	25 ab
Mountain Gem	375	GA + NAA	35,211	47,190 a	36,482	7,260 b	1,997	128,139	92,928	36 c	8 cd
Mountain Gem	375	Non-treated	13,068	15,065 cd	32,670	16,154 a	9,257	86,213	73,145	67 ab	29 ab
Mountain Gem	750	1,4 Seed	10,600	12,197 d	25,555	13,794 ab	7,696	69,841	59,242	64 ab	30 ab
Mountain Gem	750	GA + NAA	45,557	38,297 ab	29,222	8,349 ab	1,997	123,420	77,864	32 c	8 c
Mountain Gem	750	Non-treated	11,979	18,876 cd	36,300	11,798 ab	6,716	85,668	73,689	65 ab	23 abc

Table 4. Average tuber size, length to width ratio, specific gravity of 6 to 10 oz tubers, and specific gravity of tubers >10 oz for Mountain Gem Russet as effected by fall growing degree units (GDU) × spring seed treatments, then grown near Inkster, ND in 2024. Letters that are different in columns are statistically different at p=0.05 according to Tukey pair-wise comparison.

Variety	**GDU**	**Seed Treatment**	**Average tuber size oz**		**Length:width**		**SG (6-10 oz)**	**SG (>10 oz)**	
Mountain Gem	165	1,4 Seed	7.7	b	1.91	a	1.088	1.087	ab
Mountain Gem	165	GA + NAA	7.0	bc	1.77	bcd	1.087	1.085	ab
Mountain Gem	165	Non-treated	8.9	a	1.88	a	1.086	1.087	ab
Mountain Gem	375	1,4 Seed	7.9	ab	1.83	ab	1.087	1.084	b
Mountain Gem	375	GA + NAA	5.7	cd	1.76	cd	1.090	1.089	a
Mountain Gem	375	Non-treated	8.3	ab	1.86	ab	1.086	1.085	ab
Mountain Gem	750	1,4 Seed	8.6	ab	1.86	abc	1.088	1.088	ab
Mountain Gem	750	GA + NAA	5.4	d	1.71	d	1.091	1.088	ab
Mountain Gem	750	Non-treated	8.0	ab	1.86	ab	1.087	1.083	b

Table 5. Stand, stems per plant, and stem width of Dakota Russet as effected by fall growing degree units (GDU) and spring seed treatments, then grown near Inkster, ND in 2024. Letters that are different in columns within fall or spring treatment are statistically different at p=0.05 according to Tukey pair-wise comparison. No letter indicates no statistical difference.

Variety	**Treatment**	**Stand**	**Stems/plant**		**Stem width**	
		%	**number**		**mm**	
Fall GDU treatment						
Dakota Russet	165 GDU	93	2.15		12.7	
Dakota Russet	375 GDU	94	1.99		12.2	
Dakota Russet	750 GDU	95	2.06		12.0	
Spring seed treatment						
Dakota Russet	1,4 Seed	95	1.93	b	12.5	ab
Dakota Russet	GA + NAA	95	2.29	a	11.7	b
Dakota Russet	Non-treated	92	1.98	b	12.7	a

Table 6. Tuber yield and size of Dakota Russet as effected by fall growing degree units (GDU) and spring seed treatments, then grown near Inkster, ND in 2024. Letters that are different in columns within fall or spring treatment are statistically different at p=0.05 according to Tukey pair-wise comparison. No letter indicates no statistical difference.

Variety	**Treatment**	**<4 oz**	**4-6 oz**	**6-10 oz**	**10-14 oz**	**>14 oz**	**Total yield**	**Total marketable**	**>6 oz**	**>10 oz**
		——— cwt/a ———							——— % ———	
Fall GDU treatment										
Dakota Russet	165 GDU fall	28	62	133	90 a	65	378	350	76 a	41 a
Dakota Russet	375 GDU fall	32	74	133	60 b	48	347	315	69 b	30 b
Dakota Russet	750 GDU fall	40	62	129	68 ab	49	348	308	71 ab	34 ab
Spring GDU treatment										
Dakota Russet	1,4 Seed	23 b	56 b	133	81 a	70 a	363	340 a	78 a	41 a
Dakota Russet	GA + NAA	52 a	91 a	138	53 b	16 b	351	299 b	59 b	19 b
Dakota Russet	Non-treated	24 b	51 b	123	84 a	76 a	359	334 ab	79 a	45 a

Table 7. Tuber yield number and size number of Dakota Russet as effected by fall growing degree units (GDU) and spring seed treatments, then grown near Inkster, ND in 2024. Letters that are different in columns within fall or spring treatment are statistically different at p=0.05 according to Tukey pair-wise comparison. No letter indicates no statistical difference.

Variety	**Treatment**	**<4 oz**	**4-6 oz**	**6-10 oz**	**10-14 oz**	**>14 oz**	**Total yield**	**Total marketable**	**>6 oz**	**>10 oz**
		——— tuber number/a ———							——— % ———	
Fall GDU treatment										

Dakota Russet	165 GDU fall	15,730		20,328		27,891	12,947	a	6,171		83,067		67,337	58	a	24	a
Dakota Russet	375 GDU fall	17,485		23,958		27,709	8,531	b	4,477		82,159		64,675	50	b	16	b
Dakota Russet	750 GDU fall	21,599		20,752		27,467	9,499	ab	4,659		83,974		62,376	52	ab	19	ab
Spring GDU treatment																	
Dakota Russet	1,4 Seed	12,645	b	17,364	b	26,983	11,072	ab	6,413	a	74,476	b	61,831	60	a	24	a
Dakota Russet	GA + NAA	28,314	a	29,948	a	29,161	7,442	b	1,573	b	96,437	a	68,123	40	b	9	b
Dakota Russet	Non-treated	13,855	b	17,727	b	26,923	12,463	a	7,321	a	78,287	b	64,433	60	a	26	a

Table 8. Average tuber size, length to width ratio, specific gravity of 6 to 10 oz tubers, and specific gravity of tubers >10 oz for Dakota Russet as effected by fall growing degree units (GDU) and spring seed treatments, then grown near Inkster, ND in 2024. Letters that are different in columns within fall or spring treatment are statistically different at p=0.05 according to Tukey pair-wise comparison. No letter indicates no statistical difference.

Variety	Seed Treatment	Average tuber size oz		Length:width		SG 6-10 oz	SG >10 oz
Fall GDU treatment							
Dakota Russet	165	7.55	a	1.78		1.087	1.082
Dakota Russet	375	6.81	b	1.78		1.090	1.084
Dakota Russet	750	6.85	b	1.77		1.089	1.084
Spring GDU treatment							
Dakota Russet	1,4 Seed	7.71	b	1.76	b	1.087	1.083
Dakota Russet	GA + NAA	5.91	a	1.80	a	1.090	1.083
Dakota Russet	Non-treated	7.88	b	1.76	b	1.089	1.084

Effects of PhosphoActive and PhosphoActive-C on Russet Burbank Potato Production

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Executive summary

Phosphorous is an essential nutrient for potato production to achieve high tuber yield and quality. A study was developed to evaluate the effects of PhosphoActive and PhosphoActive-C in potato production, added as an additional treatment in-furrow or at preemergent herbicide treatment timing. At p=0.1 an increase in total yield tuber number was found when PhosphoActive was applied in-furrow compared to the grower standard. Additionally, PhosphoActive applied at the preemergent timing increased marketable yield tuber number compared to the grower standard. Higher tuber counts can benefit seed growers and all potato growers that struggle with low setting tubers cultivars. Further work should be completed to understand the benefits of PhosphoActive and PhosphoActive-C in potato production in North Dakota and Minnesota.

Rationale for conducting the research

Phosphorus is an essential nutrient necessary for high-quality potato production. Phosphorous enhances emergence; ensures healthy foliar growth; and improves potato tuber set, size, and quality. Potatoes are a poor rooted plant, often causing much fertilizer to be underutilized. Additionally, concerns of rising fertilization costs, possible leaching into water sources, and potential government regulations may limit the amount of fertilizer growers can apply to crops in the future. Discovering ways to improve phosphorous uptake of potato plants is important for the long-term production and economical sustainability of potato growers. Fertinagro has developed PhosphoActive and PhosphoActive-C to increase microbial activity to make phosphorous more available to plant roots. PhosphoActive-C contains 10% carbon source, mainly in the form of humates. The objective of this study was the determine the effects of PhosphoActive and PhosphoActive-C on potato tuber yield.

Procedures

A field study was established in a commercial field near Wadena, MN, managed by RD Offutt Farms. A randomized complete block with four replicates was utilized. The cultivar Russet Burbank was planted on 20 May 2024 with whole seed pieces that averaged 2 oz per seed piece. Plots measured 12 ft wide by 20 ft long. Rows were spaced at 36 inches apart and seed was planted within-rows at 12 inches between seed pieces. Red potato seed were planted at the between plots to mark plots and border edge plants.

This study was fertilized to match the total amount of recommend nutrients RD Offutt Farms would use in the commercial field, but adjusted to fit the needs of this project. Fertility included KCl applied at an average of 817 lb/a in the fall of 2023 by RD Offutt Farms. NDSU Potato Agronomy applied 25 gal/a of 10-34-0 at planting in a band 2 inches below the seed piece and 2 inches to the side. Prior to hilling on 12 June 2024, 200 lb/a AMS + 272 lb/a ESN + 163 lb/a urea + 7 lb/a B were blended and applied with a 6-foot Gandy drop spreader. The total amount of nutrients applied was 265 lb/a N, 99 lb/a P, 48 lb/a S, and 1 lb/a B. All irrigation, in-season crop protection, and management was completed by RD Offutt Farms.

Treatments utilized for this study were as follows:

1. Check / grower standard
2. Grower standard + 25 fl oz/a PhosphoActive in furrow at planting
3. Grower standard + 25 fl oz/a PhosphoActive-C in furrow at planting (PhosphoActive-C contains 10% carbon source, mainly humates)
4. Grower standard + 25 fl oz/a PhosphoActive applied at pre-emergence herbicide timing
5. Grower standard + 25 fl oz/a PhosphoActive-C applied at pre-emergence herbicide timing

Treatments of PhosphoActive and PhosphoActive-C were applied at two different times. Treatments 2 and 3 were applied at planting as in-furrow treatments on 20 May 2024. Treatments 4 and 5 were applied on 14 June 2024 with a CO_2 pressured backpack sprayer and 6-foot wide hand boom. Treatments were applied at timings that would correspond to times when commercial growers would be applying products. This would make adding PhosphoActive or PhosphoActive-C easy to incorporate in typical potato production practices and not make a separate application.

Plots were harvested on 11 September 2024 with a customized single row harvester. The middle two rows of each plot were harvested. One row was weighed and left in the field. The other row was bagged and placed into storage to allow wound healing at 55 ºF. Subsequently these tubers were graded on 12 November 2024. Tubers were sized into the following categories, <3 oz, 3-6 oz, 6-10 oz, 10-14 oz, and > 14 oz. The number of tubers >6 oz and >10 oz was calculated based on the grade out. Marketable yield is what a grower is paid for, it excludes undersized tubers (<3 oz; however, some contracts consider undersized as any tuber <4 oz) and any culls. Specific gravity was measured on 13 November 2024 using the weight in water method.

Data were analyzed using SAS. The proc mixed model was used with replicates considered random and a p-value of 0.05. Data were separated with a Tukey pair-wise comparison. Late season aphids were extremely high in the area of this project and as a result aphid holes were scattered throughout the field. An aphid hole appeared in the 3rd and 4th replicate of this trial. Data analysis indicated that there were no differences in yield of the replicates. Therefore, all replicates were utilized in the statistical analysis. It is assumed that the aphid hole appeared late enough in the season to not affect yield by replicate.

Results

At a p-value of 0.05 there were no significant differences between treatments in this study. It is possible that the aphid hole in the plot could have caused more variation in the data, causing fewer significant values. It is important to keep in mind that this as a small study, with 20 total plots and replication of this work could help find more differences.

At a p-value of 0.1 differences were observed in tuber number/a of total yield and marketable yield. The tuber number/a for PhosphoActive in furrow at planting was 19% more than the grower standard. PhosphoActive applied at the pre-emergence herbicide timing at 25 fl oz/a had 23% more marketable tubers than the grower standard. The numerical trend suggests that the number of tubers counted in total yield and marketable yield were higher than the grower standard. Again further studies could help clarify this. The yield data corresponds with the numerical difference of 34 to 56 cwt/a of total yield and 19 to 56 cwt/a total marketable yield when PhosphoActive or PhosphoActive-C were applied.

Higher tuber number is important to different aspects of potato production. Seed producers are focusing more on higher tuber number for smaller seed that does not need to be cut. Consistently increasing tuber number can benefit all seed growers, especially those with a focus of producing single drop seed or growing cultivars that have a genetic propensity to have a low tuber set. Additionally, many newer cultivars tend to have low set, causing oversized tubers and higher seeding rates. Growers are looking for ways to increase tuber count for these newer cultivars to improve tuber quality and save money on seeding rates and fertilizer. More research data could help clarify these numerical trends and tuber number increases that may benefit potato growers.

Table 1. Graded yield of Russet Burbank grown near Wadena, MN in 2024 and treated with PhosphoActive and PhosphoActive-C in-furrow or at preemergent herbicide timing.

Treatment	**<3 oz**	**3-6 oz**	**6-10 oz**	**10-14 oz**	**>14 oz**	**Total yield**	**Total marketable**	**>6 oz**	**>10 oz**	**Specific gravity**
	——————————————— cwt/a ———————————————							—— % ——		
1 Grower standard	63	149	143	53	36	444	381	52	20	1.081
2 PhosphoActive in furrow at planting at 25 fl oz/a	78	184	134	52	30	478	400	45	17	1.080
3 PhosphoActive-C in furrow at planting at 25 fl oz/a	70	180	158	46	34	489	419	48	16	1.079
4 PhosphoActive applied at preemergence herbicide timing at 25 fl oz/a	53	167	180	67	23	490	437	55	18	1.081
5 PhosphoActive-C applied at preemergence herbicide timing at 25 fl oz/a	48	151	158	74	49	481	433	58	25	1.079
Mean	62	166	155	59	35	476	414	52	19	1.080
p-value	0.1257	0.4693	0.3561	0.4835	0.5014	0.5656	0.5313	0.3584	0.4913	0.7749

Table 2. Number of tubers of graded yield of Russet Burbank grown near Wadena, MN in 2024 and treated with PhosphoActive and PhosphoActive-C in-furrow or at preemergent herbicide timing.

Treatment	**<3 oz**	**3-6 oz**	**6-10 oz**	**10-14 oz**	**>14 oz**	**Total yield**	**Total marketable**	**>6 oz**	**>10 oz**
	——————————————— tuber number/a ——————————————— ——							—— % ——	
1 Grower standard	51,365	45,557	24,684	6,171	2,904	128,684	79,316	26	7
2 PhosphoActive in furrow at planting at 25 fl oz/a	67,881	59,169	24,866	6,353	2,541	158,631	92,928	22	6
3 PhosphoActive-C in furrow at planting at 25 fl oz/a	52,998	56,991	28,859	5,445	2,723	146,289	94,017	26	6
4 PhosphoActive applied at preemergence herbicide timing at 25 fl oz/a	45,920	56,084	35,937	8,712	1,997	147,741	102,729	31	7
5 PhosphoActive-C applied at preemergence herbicide timing at 25 fl oz/a	39,023	50,094	29,766	9,075	4,175	131,951	93,110	33	10
Mean	51,437	53,579	28,822	7,151	2,868	142,659	92,420	28	7
p-value	0.1104	0.3165	0.1176	0.3756	0.4717	0.0652	0.0616	0.2429	0.4608

Effects of potassium in the tuber for bruise control

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Executive summary

Tuber bruising is costly and frustrating for growers. The purpose of this study was to evaluate the effects of potassium on tuber skin potassium concentration, yield, and bruise. The first two sampling of tubers in August found differences in potassium in the skin of tubers. When ≥ 300 lb of MOP or MOP + SOP was applied in a field with low soil K, Russet Burbank skins had a higher amount of potassium. There were no differences in yield. Bruise testing and post-harvest evaluations are ongoing.

Rationale for conducting the research

Bruising of potato tubers costs growers significant money every year. Bruising provides an entry point for disease, water loss, and causes tissue to become discolored and unsuitable for final product. Some research has shown and others have indicated in other areas of the world that potassium can help reduce bruising of tubers, especially when the available potassium levels are low in the soil

Potassium is an important nutrient for potatoes, as high amount of potassium are typically used to not have a deficiency in crops. Research from the 1940-1950s reported a deficiency in potassium caused reduced blackspot bruising, but this could have been because of a deficiency of available potassium in the soil. Since the green revolution, potassium and phosphorous have been applied in abundance to fields, causing the potassium and phosphorous levels to rise dramatically. Potassium is known to increase specific gravity of tubers, but typically with an increase in specific gravity, blackspot bruising increases. However, Schenk (1981) found that varieties with higher potassium levels tended to have less blackspot bruises. There has been interested from growers in ND and MN to reduce bruising, but less is known about potassium on the effects of blackspot bruising.

The objective of this project is to apply potassium to potatoes during the growing season and evaluate them for bruise potential.

Procedures

A field study was conducted near Park Rapids, MN where there had only been one potato crop grown in this field. A randomized complete block was utilized for statistical purposes with Russet Burbank being the variety planted. Treatments utilized muriate of potash from 0 to 500 lb/a of K_20 and when rates were high than 500 lb/a of K_20, sulfate of potash (SOP) was used. Treatments included the following:

1. Non-treated check (0 lb/a K_2O/a)
2. 250 lb KCL/a (150 lb K_2O/a) at hilling
3. 500 lb KCL/a (300 lb K_2O/a) at hilling as
4. 600 lb KCL + 180 lb SOP (450 lb K_2O/a) at hilling
5. 600 lb KCL + 500 lb SOP/a (600 lb K_2O/a) at hilling
6. 210 lb QROP KN/a (97 lb K_20/a) at hilling + 146 lb/a Ultrasol K ProP applied 3 times (27 Jul, 16 and 30 Aug)
7. 428 lb QROP KN/a (197 lb K_20/a) at hilling + 146 lb/a Ultrasol K ProP applied 3 times (27 Jul, 16 and 30 Aug)
8. 646 lb QROP KN/a (297 lb K_20/a) at hilling + 146 lb/a Ultrasol K ProP applied 3 times (27 Jul, 16 and 30 Aug)

Thirty tubers, approximately 3 to 6 oz, were dug approximately every two weeks to evaluate cortex and medullary tissue for nutrient concentration. Sampling was completed on 2 August, 19 August, 7 September, and 24 September. Tubers were washed to remove soil and specific gravity was measured. A 10 mm longitudinal slice was taken from the middle of each tuber. The periderm/cortex tissue was cut away from the medullary tissue at approximately 3mm. Samples were sent to AgVise Laboratory for nutrient analysis.

Plots were harvested on 24 September and subsequently graded. Bruise testing is ongoing at the time of writing this report. The procedure for bruising is taking a subsample of 60 tubers (>6 oz and 20 for each drop height) from each plot test for bruising on the stem and bud end. Tubers will be held at about 45 °F and a free-falling weight of 100 g will be dropped from a height of 3, 7, and 12 inches on a predetermined location without any defects. Tubers will be held at room temperature (72 °F) for 5 to 8 hours. Thereafter, skins will be peeled with a standard vegetable peeler and evaluated. Following methods from Hendricks et al. (2022): "Blackspot bruise color intensity will be rated on the darkest color observed on a scale from 1 to 5: 1= no discoloration, 2=pink, 3=light brown, 4=dark brown, and 5=black discoloration. Blackspot bruise depth will be evaluated by recording the number of slices removed by the peeler until no color is present." Using the thickness of each slice, this will be used to calculate the depth of the bruise. Data will be analyzed to determine if differences exist from the treatments applied.

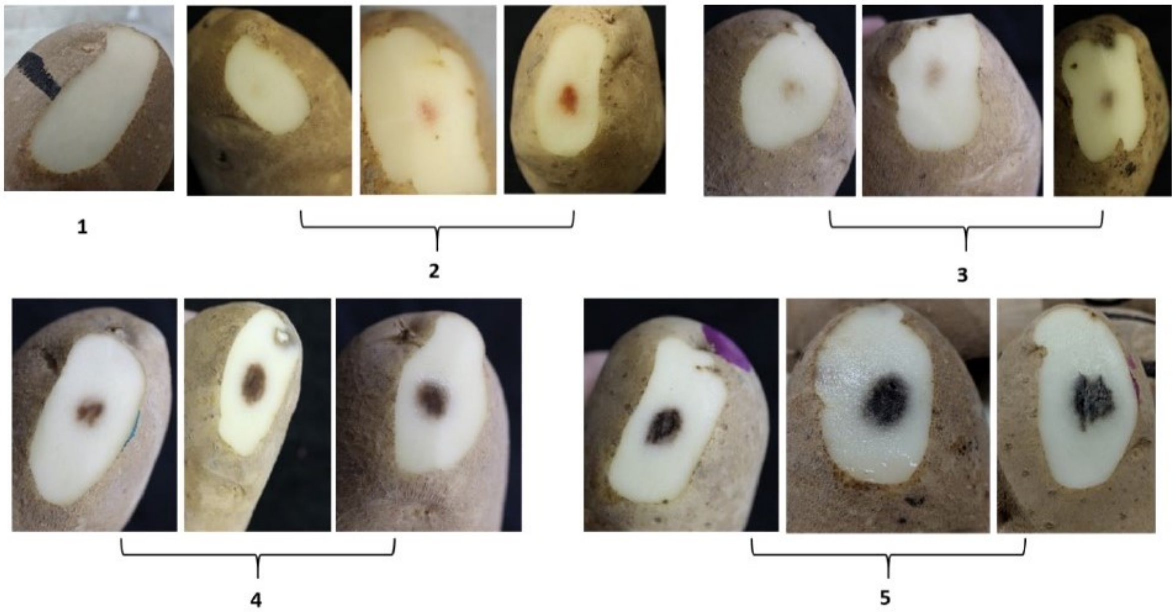

Figure 1. Blackspot bruise color intensity scale of 1 to 5: 1= none, 2=pink, 3=light brown, 4=dark brown, to 5=black discoloration from Hendricks et al. (2022).

Results

Potassium concentration in tuber skin was affected by the treatments (Table 1). In the first three samplings, potassium in tuber skin was increased when ≥ 300 lb of MOP or MOP + SOP was applied in a field with low soil K. There were no differences in potassium concentration in the medulla tissue until the third sampling (Table 1). The fourth sampling had no differences in K in the skin or medulla. Because tubers were very large, we were not able to sample tubers in the 4 to 6 oz range as desired. It is possible the larger tubers may have changed the concentration differences between treatments.

Stand and stem number per plant were similar across treatments. No differences in graded yield were found (Table 2). Tuber number was also similar across the size categories graded.

Bruising will be provided at a later date as this is still in progress.

Table 1. Potassium (K) concentration in Russet Burbank periderm/cortex and medulla tissue sampled on 2 and 19 August, 2024 near Park Rapids, MN.

Date	Tissue	Treatment	K (ppm)	
8/2/24	Cortex	1	25,115	bc
8/2/24	Cortex	2	23,423	c
8/2/24	Cortex	3	27,773	ab
8/2/24	Cortex	4	26,370	abc
8/2/24	Cortex	5	28,915	a
8/2/24	Cortex	6	23,735	c
8/2/24	Cortex	7	24,486	c
8/2/24	Cortex	8	25,078	bc
8/2/24	Medulla	1	21,308	a
8/2/24	Medulla	2	23,268	a
8/2/24	Medulla	3	24,743	a
8/2/24	Medulla	4	25,243	a
8/2/24	Medulla	5	24,998	a
8/2/24	Medulla	6	22,880	a
8/2/24	Medulla	7	23,552	a
8/2/24	Medulla	8	25,005	a
8/19/24	Cortex	1	20,958	b
8/19/24	Cortex	2	22,220	b
8/19/24	Cortex	3	23,325	ab
8/19/24	Cortex	4	24,315	ab
8/19/24	Cortex	5	26,245	a
8/19/24	Cortex	6	22,610	b
8/19/24	Cortex	7	21,343	b
8/19/24	Cortex	8	22,858	ab

8/19/24	Medulla	1	18,070	a
8/19/24	Medulla	2	19,873	a
8/19/24	Medulla	3	21,155	a
8/19/24	Medulla	4	21,318	a
8/19/24	Medulla	5	20,355	a
8/19/24	Medulla	6	18,570	a
8/19/24	Medulla	7	19,060	a
8/19/24	Medulla	8	20,900	a
9/7/24	Medulla	1	20,440	ab
9/7/24	Medulla	2	18,578	ab
9/7/24	Medulla	3	17,555	b
9/7/24	Medulla	4	20,968	ab
9/7/24	Medulla	5	20,828	ab
9/7/24	Medulla	6	20,335	ab
9/7/24	Medulla	7	19,893	ab
9/7/24	Medulla	8	21,310	a
9/7/24	Cortex	1	21,990	c
9/7/24	Cortex	2	22,940	abc
9/7/24	Cortex	3	25,945	ab
9/7/24	Cortex	4	24,863	abc
9/7/24	Cortex	5	26,675	a
9/7/24	Cortex	6	22,348	bc
9/7/24	Cortex	7	23,443	abc
9/7/24	Cortex	8	24,638	abc
9/24/24	Medulla	1	19,973	
9/24/24	Medulla	2	20,070	

9/24/24	Medulla	3	21,098
9/24/24	Medulla	4	22,115
9/24/24	Medulla	5	20,628
9/24/24	Medulla	6	20,845
9/24/24	Medulla	7	20,565
9/24/24	Medulla	8	22,730
9/24/24	Cortex	1	26,225
9/24/24	Cortex	2	26,725
9/24/24	Cortex	3	26,423
9/24/24	Cortex	4	28,593
9/24/24	Cortex	5	27,628
9/24/24	Cortex	6	25,760
9/24/24	Cortex	7	26,405
9/24/24	Cortex	8	26,355

Table 2. Graded yield of Russet Burbank grown near Parks Rapids, MN effected by potassium treatments.

Treatment	MOP	SOP	ESN	Gypsum	QROP KN	Ultrasol K Plus ProP	<3 oz	3-6 oz	6-10 oz	10-14 oz	>14 oz	Total yield
	lb/a						cwt/a					
1	0	0	311	600	0	0	26	110	227	184	129	677
2	250	0	311	600	0	0	24	92	196	172	217	702
3	500	0	311	600	0	0	35	134	204	152	170	695
4	600	180	311	428	0	0	34	111	188	167	188	688
5	600	500	311	33	0	0	40	126	211	144	196	717
6	0	0	210	600	210	438	34	117	186	158	168	664
7	0	0	59	600	428	438	25	123	174	182	188	692
8	0	0	0	600	646	438	24	114	214	178	172	701
Average							30	116	200	167	179	692
p-value							0.0605	0.2992	0.3111	0.1572	0.5739	0.4591

Table 3. Tuber number of graded yield of Russet Burbank grown near Parks Rapids, MN effected by potassium treatments.

Treatment	MOP	SOP	ESN	Gypsum	QROP KN	Ultrasol K Plus ProP	<3 oz	3-6 oz	6-10 oz	10-14 oz	>14 oz	Total yield	Total marketable	>6 oz	>10 oz
	lb/a						tuber number/a							%	
1	0	0	311	600	0	0	19,360	37,752	45,012	24,200	11,374	137,698	118,338	58	26
2	250	0	311	600	0	0	19,965	34,122	41,019	24,140	20,328	139,574	119,609	62	33
3	500	0	311	600	0	0	27,225	49,368	42,653	20,873	14,702	154,820	127,595	51	23
4	600	180	311	428	0	0	29,222	41,927	41,927	24,321	18,150	155,546	126,324	55	27
5	600	500	311	33	0	0	34,848	45,920	44,831	20,873	18,513	164,984	130,136	51	24
6	0	0	210	600	210	438	27,407	43,379	39,749	22,143	15,972	148,649	121,242	52	26
7	0	0	59	600	428	438	21,417	46,827	38,478	26,136	18,513	151,371	129,954	55	30
8	0	0	0	600	646	438	20,691	45,738	49,005	26,318	16,154	157,905	137,214	58	27
average							25,017	43,129	42,834	23,625	16,713	151,318	126,301	55	27
p-value							0.0348	0.1526	0.6019	0.0798	0.4083	0.1964	0.2475	0.1016	0.3880

Effects of Calcium Ammonium Nitrate on Russet Burbank Potato Production in Minnesota

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Executive summary

Increased desire to reduce GHG in potato production are driving fertilizer manufactures and potato growers to develop improved production systems. Atlas Agro is building fertilizer plants that will produce carbon-free nitrogen products that can be used in potato production. The objective of this study was to define the effects of calcium nitrate (CAN) in Russet Burbank production. Compared to the grower standard, the different treatments of CAN did not change yield, tuber number, or any other yield metric measured. These first-year results indicate that CAN could be an effective fertilizer in potato production to reduced GHG and maintain similar yield. Further work should continue to evaluate CAN in different environments and varieties.

Rationale for conducting the research

Nitrogen is one of the most important nutrients to manage for optimal potato growth and production. With increasing demand for nitrogen products that utilize less carbon, Atlas Agro is developing fertilizer production plants that produce carbon-free nitrogen in the form of ammonium nitrate, calcium ammonium nitrate (CAN), and other calcium nitrate products. This eliminates the use of fossil fuels to make synthetic fertilizer. A disadvantage of calcium nitrate is the water solubility, making it more leachable than polymer-coated urea (ESN). However, the use of polymer coated urea has concerns with plastics being placed in the soil. Growers must continually improve production and quality of tubers to maintain economic sustainable production. Another concern with CAN is the amount of product that needs to be moved with a lower percent of nitrogen. Having a fertilizer plant in North Dakota or Minnesota could help alleviate the shipping concerns. Calcium nitrate can be beneficial by providing more calcium to potato plants. Determining the best way to utilize calcium nitrate can help with reducing carbon use in potato production. The objective of this study was to define the effects of calcium nitrate (CAN-27) in Russet Burbank production.

Procedures

A field study was established in a commercial field near Perham, MN, managed by RD Offutt Farms. A randomized complete block with four replicates was utilized. The cultivar Russet Burbank was planted on 17 May 2024 with whole seed pieces that averaged 2 oz per seed piece. Plots measured 12 ft wide by 20 ft long. Rows were spaced at 36 inches apart and seed was planted within-rows at 12 inches between seed pieces. Red potato seed were as plot borders to assist in harvest and ensure no oversized potatoes on edge plants.

This study was fertilized to match the total amount of recommend nutrients RD Offutt Farms would use in the commercial field, but adjusted to fit the needs of this project. Prior to planting and field work, turkey manure was applied by RDO farms at 3 tons/a with an analysis of 27 lb N/ton, 90 lb P/ton, and 57 lb K/ton. The base fertility for all the plots with calcium nitrate included 158 lb/a MAP + 267 lb/a gypsum + 7 lb/a boron was applied on 11 June 2024 and hilled after spreading fertilizer. The grower standard treatment received the same fertilizer as previously stated, except no gypsum was applied. This base fertilizer provided 98 lb N/a + 352 lb P/a + 171 lb K/a+ 48 lb S/a + 1 lb B/a. The remainder of nitrogen was provided by plot treatments. These treatments were applied on 11 June 2024, prior to the final hilling. One fertigation of 28-0-0-5 (S) was applied at 6.25 gal/a on 11 July 2024. This was applied because of excessive rainfall, there was concern there would not be enough nitrogen on the crop in the entire field. All irrigation, in-season crop protection, and management was completed by RD Offutt Farms.

Treatments utilized for this study were as follows:

6. 58 lb N/a AMS + 244 lb N/a ESN (grower standard)
7. 244 lb N/a CAN-27
8. 195 lb N/a CAN-27
9. 61 lb N/a ESN + 183 lb N/a CAN-27
10. 122 lb N/a ESN + 122 lb N/a CAN-27
11. 183 lb N/a ESN + 61 lb N/a CAN-27

During the season plant emergence and stem number was counted on 20 June 2024. Every emerged planted was counted in the middle two rows. The average number of stems per plant was determined by counting the stems on 10 consecutive plants in one of the middle rows. These data are taken to ensure consistent stand and stem number to ensure a healthy plot for the trial.

Plots were harvested on 20 September 2024 with a customized single row harvester. The middle two rows were harvested on each plot. One row was weighed and left in the field. The other row was bagged and placed into storage to allow wound healing at 55 ºF. Subsequently these tubers were graded on 12

November 2024. Tubers were sized into the following categories, <3 oz, 3-6 oz, 6-10 oz, 10-14 oz, and > 14 oz. The number of tubers >6 oz and >10 oz was calculated based on the grade out. Marketable yield is what a grower is paid for, it excludes undersized tubers (<3 oz; however, some contracts consider undersized as any tuber <4 oz) and any culls. Specific gravity was measured on 12 November 2024 using the weight in water method.

Data were analyzed using SAS. The proc mixed model was used with replicates considered random and a p-value of 0.05. Data were separated with a Tukey pair-wise comparison.

Results

In all the data collected there were no significant differences (Tables 1 to 3). Plant emergence and stem counts were the same between plots (Table 1). This indicates the plots were well established and suitable for research. Total yield and marketable yield were not different between treatments, indicated that the treatments used had a similar yield as the grower standard (Table 2). Tubers >6 oz was not different between treatments; however, all treatments with CAN had a numerically higher number of tubers. The tuber number mirrored the graded yield (Table 3). Specific gravity and the ratio of tuber length to width were similar across treatments. Tuber nutrient in the medulla or skin was not changed by the CAN, except Zn was changed in the skin (Tables 4 and 5). What test data indicate is that the CAN treatments were able to maintain a similar yield to the grower standard of ESN and AMS. Although partial nitrogen was applied to the field with the turkey manure, MAP, and the fertigation, CAN was able to play a similar role in a Russet Burbank fertility program. The fertility was a higher than normal for this location because of the turkey manure that was applied. A last-minute field change occurred and the amount of nitrate in the turkey manure was unknown. Potato plants took advantage of this fertilizer. Tuber sets were higher than normal and the additional nitrogen helped plants be able to size tubers. As a result, the yield was higher than average Russet Burbank production in MN and ND.

The use of CAN could also be important with some cultivars, such as Umatilla Russet that need a higher calcium concentration to reduce premature seed rot. Tubers are being tested for calcium content in the skin or periderm and medullary tissue to see if any differences exist.

The results of this study show the ability of CAN to play an important role in potato fertility. This is especially important as many buyers of potatoes desire potatoes produced with less carbon. The carbon-free CAN product being developed by Atlas Agron can be an important tool in reducing carbon in potato production. Future research should continue to explore the benefits of CAN in potato production.

Table 1. Plant emergence, stem number, specific gravity, and tuber length to width ratio of Russet Burbank potatoes grown near Perham, MN in 2024 with calcium ammonium nitrate (CAN-27).

Treatment		Emergence	Stems/plant	Specific gravity	Tuber length:width
		%	number		number
1	Grower standard	90	3.7	1.082	1.78
2	244 lb N/a CAN-27	84	3.6	1.080	1.78
3	195 lb N/a CAN-27	84	3.4	1.082	1.81
4	61 lb N/a ESN + 183 lb N/a CAN-27	83	3.8	1.080	1.76
5	122 lb N/a ESN + 122 lb N/a CAN-27	89	3.6	1.083	1.79
6	183 lb N/a ESN + 61 lb N/a CAN-27	86	3.5	1.085	1.77
Mean		86	3.6	1.082	1.78
p-value		0.2295	0.9266	0.2815	0.0816

Table 2. Graded yield of Russet Burbank grown near Perham, MN in 2024 with calcium ammonium nitrate (CAN-27).

Treatment		<3 oz	3-6 oz	6-10 oz	10-14 oz	>14 oz	Total yield	Total marketable	>6 oz	>10 oz
		——————————————— cwt/a ———————————————							—— % ——	
1	Grower standard	40	203	232	77	40	592	551	59	20
2	244 lb N/a CAN-27	34	169	225	98	56	582	549	65	27
3	195 lb N/a CAN-27	30	162	226	101	46	565	535	66	26
4	61 lb N/a ESN + 183 lb N/a CAN-27	38	169	210	91	56	564	526	63	26
5	122 lb N/a ESN + 122 lb N/a CAN-27	35	168	244	80	33	560	525	64	20
6	183 lb N/a ESN + 61 lb N/a CAN-27	31	182	214	101	57	586	555	63	27
Mean		35	175	225	91	48	575	540	63	24
p-value		0.7552	0.2016	0.1478	0.2919	0.5757	0.1613	0.1736	0.6744	0.3873

Table 3. Number of tubers of graded yield of Russet Burbank grown near Perham, MN in 2024 with calcium ammonium nitrate (CAN-

Treatment	<3 oz	3-6 oz	6-10 oz	10-14 oz	>14 oz	Total yield	ma
	tuber number/a						
1 Grower standard	29,766	77,501	51,002	11,253	3,993	173,514	1
2 244 lb N/a CAN-27	24,321	63,888	50,094	14,339	5,627	158,268	1
3 195 lb N/a CAN-27	21,780	57,354	47,432	13,552	4,356	144,474	1
4 61 lb N/a ESN + 183 lb N/a CAN-27	28,556	63,404	45,980	13,068	5,566	156,574	1
5 122 lb N/a ESN + 122 lb N/a CAN-27	25,592	61,710	52,272	11,616	3,449	154,638	1
6 183 lb N/a ESN + 61 lb N/a CAN-27	23,777	69,878	47,735	15,065	5,990	162,443	1
Mean	25,632	65,622	49,086	13,149	4,830	158,318	1
p-value	0.8387	0.2296	0.2906	0.3090	0.5731	0.3638	

Table 4. Tuber medulla nutrient content from Russet Burbank grown near Perham, MN in 2024 with calcium ammonium nitrate (CAN-27).

Treatment		P	K	S	Ca	Mg	Na	Zn	Fe	Mn	Cu	B
		%						ppm				
1	Medulla	0.26	1.90	0.13	0.02	0.10	0.01	12.3	24.3	8.3	4.8	4.8
2	Medulla	0.28	1.94	0.14	0.02	0.10	0.01	11.8	24.3	8.0	3.5	4.8
3	Medulla	0.28	1.93	0.14	0.02	0.10	0.01	11.0	23.5	8.5	3.5	4.5
4	Medulla	0.26	1.85	0.14	0.02	0.10	0.01	10.8	23.0	8.3	4.5	4.3
5	Medulla	0.26	1.79	0.13	0.02	0.10	0.01	11.5	24.8	8.0	3.3	4.5
6	Medulla	0.25	1.90	0.14	0.03	0.11	0.01	11.5	36.0	9.0	3.3	4.8
Mean		0.26	1.88	0.14	0.02	0.10	0.01	11.46	25.96	8.33	3.79	4.58
p-value		0.2780	0.4130	0.2653	0.4457	0.2521	-	0.1712	0.2986	0.4298	0.5649	0.8036

Developing Robust Potato Cultivars for the Northern Plains

2024 Summary

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Potato (*Solanum tuberosum* L.) ranks fourth globally behind wheat, corn and rice production (FAO), and is a widely grown vegetable crop in North Dakota (ND) and Minnesota (MN). The Northern Plains region made up of ND and MN ranks third in US potato production (NASS 2024a). In 2024, approximately 115,000 acres were harvested in the two-state area (NASS 2024b). In 2023, the farmgate value exceeded $671.7 million, with sales of more than $628.8 million, combined (NASS 2024a). Production utilization in the two states is about 60% for French fry/frozen processing, 16% fresh (tablestock) market, 12% chip processing, and 10% certified seed production. This region has a short production window, growers produce potatoes for an array of end-uses, there is both irrigated and non-irrigated production, and the crop is susceptible to a range of pests and abiotic stresses. Potato is management, labor, and input intensive compared to other crops. The primary aim of the NDSU potato project is to release improved potato cultivars addressing shortcomings of industry standard cultivars and to provide potato producers, industry partners, and consumers with environmentally resilient, economically sustainable, and nutritious cultivars across market types. The potato improvement team, including collaborators in Plant Sciences, Plant Pathology, and Agricultural and Biosystems Engineering, conducts agronomic, disease and pest screening, and evaluation trials across North Dakota and western Minnesota in an effort to identify early maturing selections with high marketability and yield potential, possessing pest and environmental stress resistances, with reduced requirements for inputs, and that possess key market-type quality attributes.

To address the needs of potato producer and industry partners in the Northern Plains (Northland Potato Growers and Minnesota Area II Potato Research and Promotion Council) two research objectives were proposed for 2024:

1.) Develop improved potato genotypes adapted to the Northern Plains, and

2.) Identify and exploit genes of interest for resistance to abiotic and biotic stressors.

Highlights of our 2024 research trials addressing these objectives are reported here.

In our crossing block, 1,265 flower clusters were pollinated with a success rate of 45.7% of clusters forming fruit; 263 new families were created. Creation of new families focused on incorporation of disease and pest resistance with nearly 50% of families having a PVY resistant parent. The dedicated crossing block also contained germplasm for incorporation of late blight, Colorado potato beetle and Verticillium wilt resistance genes, and those possessing good chip and frozen processing quality attributes including high specific gravity and low sugar accumulation in the field and storage for potential processing, and vibrant skin color and good skin finish for fresh market types.

Our certified seed potato production is conducted near Baker, MN. In the single-hill nursery, 129 NDSU families, more than 25,000 genotypes were grown, with 215 selections from the NDSU seedling production retained. More than 25,000 unselected seedling tubers (sizes 2-4) were shared with the breeding programs in Idaho, Maine, Texas, Colorado and Minnesota. Out-of-state unselected seedlings were received from ID, ME, TX and CO; 122 out-of-state selections were retained. Significant losses were experienced at this site due to heavy rains in May and June totaling over 15 inches. However, 67 second year, 62 third year, and 79 fourth year and older selections were retained from the field; specific gravity was determined for each and light box imagery obtained. Few clones were lost from the program as we had retained 2023 seed.

Field trials were conducted at three irrigated sites (Larimore and Oakes, ND, and Hubbard, MN) and three non-irrigated locations (Crystal, Hoople and Fargo) predominantly in grower-cooperator fields. The Larimore processing trial included 12 advancing selections compared to six standard frozen processing standards (please see results in Tables 1 and 2). No materials have been fried to date and information will be provided when available. Several selections look promising based on yield and quality attributes. The PreProcessing trial included 88 dual-purpose russet selections with processing potential compared to six check cultivars. Additional trials at this site included the North Central (NC) Regional trial with 90 entries from MSU, NDSU, and UMN compared to nine check cultivars, the National French Fry Processing trial (NFPT), the National Chip Processing Trial, 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. The trials at Larimore 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 seven selections compared to six industry standards, and a fresh market trial evaluating 18 red- and yellow-skinned selections compared to four industry standards. Trials at Hubbard included a scab screening trial in collaboration with Drs. Julie Pasche and Laura Shannon, a replicated *Verticillium* wilt resistance assessment trial using a mapping population compared to six industry standards with known resistance/susceptibility, and a replicated *Verticillium* wilt trial evaluating 25 genotypes; the Verticillium trials 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 25 advancing selections with red, purple and yellow skin/flesh to five fresh market cultivars (Tables 3-5). Several selections look promising including ND113207-1R, ND1241-1Y, ND1243-1PY, and many more. The preliminary fresh market trial (two replicates) had 29 entries, primarily with red skin and white or yellow flesh, compared to our fresh market controls. Trials at Crystal are hosted by Dave and Andy Moquist. The focus at the Hoople trial site hosted by Lloyd, Steve and Jamie Oberg is chip processing. The Hoople chip trial included 17 advancing selections compared to seven cultivars in the four-replicate trial (please see Tables 6-8). There were many outstanding selections, despite not being able to process yet (this information will be reported later) ND7519-1, ND7799c-1, ND1241-1Y, ND13220C-3, ND1734-4, and ND1852-10. The ND13220C-3 was in the SNAC trial in 2024 with excellent performance at many locations. The preliminary chip processing trial evaluated 46 selections compared to six commercial chip cultivars. Fifteen selections with interesting skin/flesh colors and possessing pest/stress resistance(s) were compared to 4 specialty cultivars in the organic demonstration trial on the NDSU campus. Urban agriculturalists and food artisans are the focus for these selections with improved nutritional attributes, organic potential and unique culinary opportunities. The NDSU potato breeding project participated in an extension opportunity at the Minnesota Arboretum (Farm at the Arb) with RD Offutt Company, the NDSU/UMN extension project, and the UMN potato breeding program, and Michaels Foods. NDSU advancing selections, ND1241-1Y and ND13244-1PPintoP were included with Red Norland and Russet Burbank and a red-skinned, white fleshed selection from UMN.

Based on our trials, outstanding selections continuing in the potato breeding pipeline are ND113207-1R (an attractive, high yielding, red skinned white fleshed selection for the fresh market), ND1241-1Y (a dual-purpose, yellow skinned and fleshed, high yielding selection), ND13220C-3 (an environmentally resilient chip processing selection with very high yield potential, and moderate resistance to Verticillium wilt and other diseases), ND13244-1PPintoP (specialty fresh market with purple and white splashed skin and violet flesh), ND1762-19Russ (a russet skinned selection with French fry processing potential and low sugar accumulation), and many others across all market types. To date we have not been able to conduct chip and fry quality assessments due to electrical and air-handling issues in our new quality laboratory. Additional trial information will be submitted to the Northland Potato Grower magazine, and will be presented at field days and potato industry meetings in 2025.

The NDSU potato breeding program is supported by Kelly Peppel (research specialist, USDA-NIFA Special Potato funding), Peter Ihry (research specialist, Northland/MN Area II funding), and Hashim Andidi (USDA-ARS funding for Predictive Crop Performance).

We are grateful to the many supporters of our research efforts including the Northland Potato Growers Association, the Minnesota Area II Research and Promotion Council, JR Simplot, Cavendish Farms, Lamb Weston and RDO Frozen, our many certified seed and commercial potato 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.

Table 1. Agronomic and quality evaluations for advanced processing selections and cultivars grown at Larimore, ND. The processing trial was planted on June 1, flailed September 24 (116 DAP) and harvested October 10 (132 DAP), 2024, using a single-row Grimme harvester. Entries were replicated four times; plots were twenty feet long, with a within-row spacing of 12 inches and 36 inches between rows.

Clone	Vine Size[1]	Vine Maturity[2]	Hollow Heart/ Brown Center %	Specific Gravity[3]	Black-spot Bruise[4]	Shatter Bruise[5]	General Rating[6]
AND08368-1Russ	4.3	3.6	4	1.0756	4.6	2.8	2.6
AND195394-2Russ	3.8	2.9	1	1.0954	5.0	2.1	3.0
AND18332-1Russ	4.0	3.5	3	1.0963	3.7	2.3	2.9
AND18452-2Russ	3.8	3.6	0	1.0874	4.5	3.1	2.5
ND060735-4Russ	3.5	3.1	5	1.0950	3.9	2.2	4.0
ND12241YB-2Russ	2.8	3.3	0	1.1030	4.4	2.9	3.8
ND1412Y-5Russ	4.0	4.0	4	1.0941	4.2	2.5	3.2
ND1762-19Russ	3.0	3.4	5	1.0936	4.7	2.7	3.5
ND181Y-3Russ	4.3	3.6	0	1.0917	3.9	3.2	2.9
ND1860-3Russ	2.3	3.1	0	1.0888	4.2	3.0	2.6
ND1954-3Russ	3.5	3.9	3	1.0932	5.0	2.8	3.0
ND2016-1Russ	4.0	3.1	0	1.0867	5.0	2.9	3.5
Bannock Russet	5.0	4.0	15	1.0886	4.1	2.6	3.5
Dakota Russet	3.5	3.1	4	1.0907	3.7	2.3	4.3
Ranger Russet	3.8	3.5	3	1.1009	5.0	2.4	3.4
Russet Burbank	4.0	3.4	5	1.0894	5.0	2.7	2.8
Russet Norkotah	2.8	2.0	15	1.0867	4.9	2.4	4.3
Umatilla Russet	3.8	3.6	6	1.0942	4.8	2.4	2.8
Mean	3.7	3.4	4	1.0917	4.5	2.6	3.2

LSD (∝=0.05)	0.7	0.5	8	0.0072	0.7	0.9	0.5

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

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

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

[4] Blackspot bruise potential determined by the abrasive peel method, scale 1-5, 1=none, 5=severe. As an example, Ranger Russet typically rates as a 4.0 or greater.

[5] Shatter bruise – scale 1-5, 1= none; 5 = severe.

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

Table 2. Yield and grade for advanced processing selections and cultivars grown at Larimore, ND, 2024. The processing trial was planted on June 1, flailed September 24 (116 DAP) and harvested October 10 (132 DAP), 2024, using a single-row Grimme harvester. Entries were replicated four times; 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 %
AND08368-1Russ	371	121	33	7	8	25	29	31
AND195394-2Russ	484	306	63	26	26	37	9	2
AND18332-1Russ	323	185	57	26	25	32	12	5
AND18452-2Russ	303	161	52	23	24	28	6	20
ND060735-4Russ	295	197	67	16	24	43	15	1
ND12241YB-2Russ	306	215	70	12	26	44	15	3
ND1412Y-5Russ	311	201	64	4	15	49	27	5
ND1762-19Russ	263	151	58	15	20	38	22	4
ND181Y-3Russ	322	162	50	5	14	35	31	13
ND1860-3Russ	196	112	56	39	30	26	3	1
ND1954-3Russ	379	230	62	15	19	43	20	4
ND2016-1Russ	296	183	62	12	21	41	19	7
Bannock Russet	353	184	52	8	13	40	30	10
Dakota Russet	376	256	68	12	25	43	17	3
Ranger Russet	367	236	64	16	24	41	14	5
Russet Burbank	494	280	57	14	23	33	11	19
Russet Norkotah	291	142	49	9	12	37	36	6
Umatilla Russet	362	176	49	28	20	29	13	10
Mean	336	193	57	16	21	37	18	8
LSD (∝=0.05)	110	71	8	7	6	9	8	6

Table 3. Agronomic evaluations for advanced fresh market selections and cultivars, Crystal, ND, 2024. The trial was planted on June 5, vines desiccated on August 30 (86 DAP), and harvested with a single-row Grimme harvester on September 11 (98 DAP). The plots were 20 feet long, with a 12-inch with-in row spacing, and 36 inches between rows, replicated four times.

Clone	Stand %	Stems Per Plant	Vine Size[1]	Vine Maturity[2]	Tubers per Plant	Shape[1]	Color[2]
ND102990B-2R	100	2.9	3.5	3.8	8.5	1.0	4.0
ND113207-1R	99	2.6	3.8	3.3	8.3	2.0	4.0
ND1241-1Y	100	2.6	4.5	2.8	9.7	1.0	Y
ND1243-1PY	94	2.1	4.0	4.0	5.5	1.0	P
ND14324B-7R	96	2.7	2.4	3.8	6.2]	1.0	4.0
ND17122-1R	99	3.1	3.3	2.9	8.4	1.0	2.1
ND17134-3R	96	2.8	4.5	3.4	6.6	1.8	2.9
ND1835B-1Y	99	2.7	5.0	2.9	8.2	1.5	Y
ND1835B-2Y	83	2.2	3.8	3.5	6.5	1.8	Y
ND1837B-3Y	100	3.9	4.3	2.5	13.3	1.3	Y
ND1840B-1R	98	2.8	4.0	3.6	9.2	1.5	2.4
ND1842B-4R	98	2.1	2.8	2.5	6.0	1.5	2.1
ND1859-1R	99	2.9	2.8	3.3	7.3	1.3	3.3
ND1859-2R	98	3.3	3.3	3.3	7.6	1.8	3.6
ND1859-4R	98	3.2	3.5	3.6	5.8	2.1	3.9
ND1942B-2R	99	2.3	4.0	3.3	8.2	1.0	3.3
ND2010-2R	95	2.8	3.5	3.0	10.3	1.0	2.0
ND2036-1R	100	3.7	3.0	3.0	14.2	1.8	3.4
ND2037-2R	99	3.3	2.8	2.5	6.7	2.3	3.9
ND2076-1R	98	2.9	3.3	3.6	4.9	1.5	3.1
ND2089-8R	100	2.3	3.0	3.6	6.9	1.0	3.1
ND2090-5R	96	2.9	3.0	3.6	7.2	1.0	3.1

ND2092-17R	98	2.1	3.5	3.9	7.3	1.0	3.5
ND2093-8R	99	2.5	2.8	4.0	5.4	1.0	3.9
TXND98480-1Y	100	3.7	4.5	4.0	18.8	1.0	Y
All Blue	99	2.1	4.0	3.8	6.2	5.0	P
Dakota Ruby	96	2.7	3.0	3.9	6.6	1.0	4.1
Red LaSoda	96	1.9	3.8	3.5	4.6	3.0	2.8
Red Norland	96	2.6	3.3	2.9	3.0	3.0	3.0
Yukon Gold	93	1.6	4.0	1.9	4.6	2.5	Y
Mean	97	2.7	3.5	3.3	7.7	1.6	na
LSD (∝=0.05)	5	0.5	0.7	0.6	2.3	0.8	na

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

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

[3] Shape = 1-5; 1 = round, 2 = oval, 3 = oblong, 4 = blocky, 5 = long.

[4] Color = 1-5; 1 = white/buff, 2 = pink, 3 = red, 4 = bright red, 5 = dark red, RSY = Red splashed yellow, Y = yellow, P = purple.

na = not applicable

Table 4. Yield and grade for advanced fresh market selections and cultivars, Crystal, ND, 2024. The trial was planted on June 5, vines desiccated on August 30 (86 DAP), and harvested with a single-row Grimme harvester on September 11 (98 DAP). The plots were 20 feet long, with a 12-inch with-in row spacing, and 36 inches between rows, replicated four times.

Clone	Total Yield Cwt./A	A Size Tubers Cwt./A	A Size %	0-4 oz. %	4-6 oz. %	6-10 oz. %	>10 oz. %	Defects %
ND102990B-2R	134	7	6	94	5	1	0	0
ND113207-1R	201	60	30	67	27	3	1	3
ND1241-1Y	190	41	22	77	20	2	0	0
ND1243-1PY	122	39	32	66	28	5	0	2
ND14324B-7R	96	15	16	80	14	2	2	2
ND17122-1R	80	1	1	99	1	0	0	0
ND17134-3R	149	37	24	76	21	3	0	0
ND1835B-1Y	158	26	16	83	14	2	0	1
ND1835B-2Y	113	28	27	72	23	3	0	1
ND1837B-3Y	208	14	7	93	5	1	0	0
ND1840B-1R	170	21	12	88	11	1	0	0
ND1842B-4R	112	14	12	86	12	0	2	0
ND1859-1R	134	13	10	90	10	0	0	0
ND1859-2R	94	2	3	97	3	0	0	0
ND1859-4R	109	16	14	84	14	1	0	1
ND1942B-2R	182	49	27	72	24	3	1	1
ND2010-2R	228	54	24	75	21	2	1	0
ND2036-1R	154	12	4	96	4	0	0	0
ND2037-2R	157	44	27	70	25	3	3	0
ND2076-1R	126	56	44	54	34	10	2	0
ND2089-8R	121	17	13	86	13	1	0	1
ND2090-5R	155	38	25	75	24	1	0	0

ND2092-17R	122	15	11	86	10	2	0	3
ND2093-8R	93	15	16	83	15	1	0	1
TXND98480-1Y	261	10	4	95	4	0	0	1
All Blue	139	24	17	74	15	2	0	9
Dakota Ruby	130	19	14	86	14	0	0	1
Red LaSoda	183	116	65	25	44	20	9	2
Red Norland	99	58	58	33	48	10	3	6
Yukon Gold	107	43	40	57	38	2	0	3
Mean	144	30	21	77	18	3	1	1
LSD (∝=0.05)	44	57	9	4	8	3	3	2

Table 5. Quality attributes, including specific gravity, hollow heart/brown center, bruise potential and the general rating (breeder merit score) for advanced fresh market selections and cultivars, Crystal, ND, 2025. The trial was planted on June 5, vines desiccated on August 30 (86 DAP), and harvested on September 11 (98 DAP).

Clone	Scurf[1]	Hollow Heart/ Brown Center %	Specific Gravity[2]	Black-spot Bruise[3]	Shatter Bruise[4]	General Rating[5]
ND102990B-2R	3.8	0	1.0754	3.2	2.5	3.5
ND113207-1R	4.0	0	1.0648	3.9	2.9	3.5
ND1241-1Y	4.6	3	1.0973	3.4	2.0	4.0
ND1243-1PY	2.8	5	1.0754	4.3	3.4	3.5
ND14324B-7R	3.8	0	1.0844	3.6	2.2	2.6
ND17122-1R	2.5	8	1.1179	4.0	1.4	2.5
ND17134-3R	3.3	0	1.0902	3.0	1.9	3.2
ND1835B-1Y	3.3	0	1.0828	4.0	2.1	2.6
ND1835B-2Y	3.9	0	1.0773	2.9	2.2	3.1
ND1837B-3Y	4.0	0	1.0821	3.7	1.7	4.0
ND1840B-1R	1.8	0	1.0780	4.4	1.4	2.8
ND1842B-4R	2.3	0	1.0830	3.5	1.9	2.9
ND1859-1R	4.1	0	1.0766	3.9	1.8	3.5
ND1859-2R	3.9	0	1.0756	2.4	2.0	2.9
ND1859-4R	4.0	0	1.0703	2.3	3.0	3.8
ND1942B-2R	3.3	0	1.0798	3.7	3.4	3.1
ND2010-2R	1.8	0	1.0801	4.7	1.9	2.6
ND2036-1R	3.3	0	1.0775	4.2	2.6	3.4
ND2037-2R	4.0	0	1.0652	3.7	2.3	3.4
ND2076-1R	2.5	0	1.0690	4.0	2.9	3.1
ND2089-8R	2.8	0	1.0691	4.4	2.6	3.0
ND2090-5R	4.3	0	1.0746	3.1	2.3	3.6

ND2092-17R	3.3	0	1.0743	3.6	2.2	3.3
ND2093-8R	4.4	0	1.0709	3.4	2.4	3.1
TXND98480-1Y	4.3	0	1.0845	3.2	1.8	4.4
All Blue	1.8	0	1.0763	4.6	2.3	2.4
Dakota Ruby	4.3	0	1.0741	2.7	2.9	3.9
Red LaSoda	3.5	0	1.0706	4.1	3.5	2.6
Red Norland	2.3	0	1.0729	4.1	1.4	2.5
Yukon Gold	4.1	0	1.0788	3.9	1.9	3.9
Mean	3.4	1	1.0782	3.6	2.3	3.2
LSD (∝=0.05)	0.9	3	0.0077	0.8	0.9	0.6

[1] Scurf incidence – scale 1-5, 1 = completely covered, 5 = none (not determined if silver scurf or blackdot sclerotia)

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

[3] Blackspot bruise potential determined by the abrasive peel method, scale 1-5, 1=none, 5=severe. As an example, Ranger Russet typically rates as a 4.0 or greater.

[4] Shatter bruise – scale 1-5, 1= none; 5 = severe.

[5] General Rating = 1-5; 1 = poor and unacceptable, 3 = fair, 4 = excellent, 5 = perfect.
na = not applicable

Table 6. Agronomic assessments for advancing chip processing selections and check cultivars, Hoople, ND, 2024. The trial was planted on June 5, flailed on September 10 (97 DAP), and harvested on September 12 (99 DAP) using a single-row Grimme harvester. The replicated 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 Matur-ity[2]	Tubers per plant
ND7519-1	95	2.3	3.5	2.3	5.1
ND7799c-1	95	1.9	3.5	2.4	3.9
ND102631AB-1	93	2.0	2.3	1.3	6.4
ND1241-1Y	97	2.9	4.0	2.3	8.8
ND12209C-2	99	2.6	3.0	2.5	4.9
ND13220C-3	91	2.7	5.0	4.3	7.7

ND1451CAB-3	94	3.1	3.8	2.5	8.5
ND1462ABC-1a	95	2.5	2.0	1.3	5.1
ND1734-4	95	2.9	3.3	1.6	8.4
ND1846-6	95	2.8	2.3	1.5	8.3
ND1848-1	99	1.7	2.8	2.3	5,4
ND1852-6	94	2.3	3.5	2.9	6.5
ND1852-10	99	2.5	3.5	2.6	6.0
ND1853-2	98	2.4	3.0	1.8	4.7
ND1853-3	98	2.8	4.5	3.0	6.0
ND1853-19	94	2.9	3.0	2.3	6.3
ND1888-2	99	3.0	4.0	2.5	5.9
Atlantic	95	2.3	3.8	3.3	4.8
Bliss (NY163)	95	1.9	4.0	2.8	7.4
Dakota Pearl	88	2.3	2.5	1.9	5.3
Lady Liberty (NY152)	98	1.9	5.0	4.0	6.9
Lamoka	100	2.5	4.0	3.0	5.4
Snowden	100	2.8	4.5	3.3	5.0
Waneta	95	1.5	4.0	2.6	4.5
Mean	96	2.4	3.5	2.5	6.1
LSD (∝=0.05)	7	0.5	0.8	0.6	1.9

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

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

Table 7. Yield and grade for advancing chip processing selections and check cultivars, Hoople, ND, 2024. The trial was planted on June 5, flailed on September 10 (97 DAP), and harvested on September 12 (99 DAP) using a single-row Grimme harvester. The replicated plots were 20 feet long, with a 12-inch with-in row spacing, and 36 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	179	111	64	30	32	32	6	0
ND7799c-1	193	113	58	16	20	38	24	2
ND102631AB-1	169	72	42	53g	28	14	1	3
ND1241-1Y	197	59	30	69	22	8	1	0
ND12209C-2	136	57	38	55	22	17	6	0
ND13220C-3	228	122	52	40	30	22	7	0
ND1451CAB-3	233	98	42	55	26	16	3	0
ND1462ABC-1a	169	89	51	39	28	23	9	1
ND1734-4	245	114	46	48	27	20	5	0
ND1846-6	201	60	31	62	19	11	6	1
ND1848-1	167	68	40	54	22	18	6	0
ND1852-6	206	98	47	46	28	19	2	5
ND1852-10	217	131	60	32	32	29	7	1
ND1853-2	165	87	53	32	26	26	14	1
ND1853-3	259	145	56	26	24	33	17	0
ND1853-19	155	51	32	64	17	15	4	1
ND1888-2	186	98	52	40	25	27	7	0
Atlantic	205	125	60	21	25	35	16	2
Bliss (NY163)	218	105	46	52	29	17	2	0
Dakota Pearl	153	88	55	42	29	26	3	0
Lady Liberty (NY152)	256	149	59	35	32	26	7	0
Lamoka	205	126	61	33	30	31	6	0

Snowden	185	106	56	37	33	23	7	0
Waneta	191	118	62	23	21	41	15	0
Mean	197	100	50	42	26	24	8	1
LSD (∝=0.05)	63	46	12	14	9	11	8	2

Table 8. Quality assessments for advancing chip processing selections and check cultivars, Hoople, ND, 2024. The trial was planted on June 5, flailed on September 10 (97 DAP), and harvested on September 12 (99 DAP) using a single-row Grimme harvester. The replicated plots were 20 feet long, with a 12-inch with-in row spacing, and 36 inches between rows.

Clone	Hollow Heart & Brown Center %	Specific Gravity[1]	Black-spot Bruise[2]	Shatter Bruise[3]	General Rating[4]
ND7519-1	0	1.099	3.5	2.5	4.0
ND7799c-1	1	1.090	3.5	2.1	3.9
ND102631AB-1	0	1.092	2.9	2.5	3.8
ND1241-1Y	0	1.110	3.3	1.8	4.3
ND12209C-2	0	1.094	2.8	2.4	3.8
ND13220C-3	0	1.106	3.1	2.2	4.0
ND1451CAB-3	0	1.104	3.2	2.3	4.1
ND1462ABC-1a	0	1.089	2.9	1.8	4.0
ND1734-4	0	1.090	2.5	1.7	4.4

ND1846-6	0	1.103	4.1	2.5	4.1
ND1848-1	0	1.088	3.4	2.0	3.8
ND1852-6	0	1.099	3.9	2.5	3.7
ND1852-10	0	1.101	3.9	2.6	4.1
ND1853-2	5	1.092	3.7	2.6	4.0
ND1853-3	0	1.091	3.4	2.6	3.6
ND1853-19	1	1.098	3.9	3.5	3.4
ND1888-2	0	1.098	3.1	3.1	3.5
Atlantic	4	1.108	3.4	1.8	3.8
Bliss (NY163)	0	1.107	3.9	1.6	4.0
Dakota Pearl	0	1.095	2.9	1.7	3.9
Lady Liberty (NY152)	1	1.101	3.9	2.0	4.3
Lamoka	0	1.106	3.6	2.0	3.8
Snowden	0	1.095	3.3	2.0	3.7
Waneta	0	1.095	2.9	1.8	3.8
Mean	1	1.098	3.4	2.2	3.9
LSD (∝=0.05)	3	0.0072	0.8	0.7	0.6

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

[2] Blackspot bruise potential determined by the abrasive peel method, scale 1-5, 1=none, 5=severe. As an example, Ranger Russet typically rates as a 4.0 or greater.

[3] Shatter bruise – scale 1-5, 1= none; 5 = severe.

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

Table 5. Tuber skin nutrient content from Russet Burbank grown near Perham, MN in 2024 with calcium ammonium nitrate (CAN-27).

Treatment		**P**	**K**	**S**	**Ca**	**Mg**	**Na**	**Zn**		**Fe**	**Mn**	**Cu**	**B**
		——————————— **%** ————————————						————————— **ppm** —————————					
1	Skin	0.23	2.08	0.13	0.05	0.10	0.01	14.0	a	89.8	12.8	3.0	5.5
2	Skin	0.24	2.06	0.14	0.05	0.11	0.01	12.8	ab	97.3	12.5	3.5	5.3
3	Skin	0.25	2.02	0.14	0.05	0.11	0.01	11.8	b	81.0	11.8	3.8	5.3
4	Skin	0.24	2.08	0.14	0.05	0.12	0.01	12.5	ab	104.3	13.8	5.5	5.8
5	Skin	0.25	2.10	0.14	0.05	0.10	0.01	13.0	ab	76.3	12.3	3.3	5.3
6	Skin	0.24	2.00	0.14	0.04	0.11	0.01	12.5	ab	85.5	13.3	3.8	5.3
Mean		0.24	2.06	0.14	0.05	0.11	0.01	12.75		89.00	12.71	3.79	5.38
p-value		0.8353	0.7192	0.1261	0.5662	0.2284	-	0.0105		0.7780	0.8192	0.3388	0.9106