MN Area II Potato Research and Promotion Council

and

Northland Potato Growers Association

2025 Research Reports

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Developing Dakota Russet Irrigation and Disease Management Guidelines for Black Dot and Potato Early Dying (PED)

Principle Investigators:
Megan McCaghey, Assistant Professor, Department of Plant Pathology, University of Minnesota. mmccaghe@umn.edu
Vasudha Sharma, Assistant Extension Professor, Department of Soil, Water, and Climate, University of Minnesota. vasudha@umn.edu

Carl Rosen, Department of Soil, Water, and Climate, University of Minnesota. rosen006@umn.edu

Yuxin Miao, Department of Soil, Water, and Climate, Minnesota, University of Minnesota. ymiao@umn.edu

Graduate Students:
Jasper Tao, Department of Plant Pathology, University of Minnesota. tao00143@umn.edu
Sukhdeep Singh, Department of Soil, Water, and Climate, University of Minnesota. rosen006@umn.edu

Executive Summary: This project utilized yield, quality, and disease evaluations to assess impacts of deficit irrigation on Dakota Russet. A 2024 field study at the Sand Plains Research Farm in Becker MN tested three irrigation treatments (100% full irrigation (FI), 80% FI, and 60% FI using checkbook method) to evaluate effects of irrigation rate on tuber diseases. **In 2025, fields were infested with the black dot pathogen, *Colletotrichum coccodes,* to better understand impacts of irrigation on disease incidence and severity.** Prevalence of foliar, stem, and soilborne tuber diseases (Alternaria, black leg, common scab, black dot, Verticillium wilt, soft rots) and abiotic disorders (hollow heart and greening) were recorded from a subplot while yield was assessed through mechanical harvesting and sorting.

Rationale: 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. High soil moisture and humidity can favor disease development. 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. 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 caused by *Pectobacterium* and *Erwinia* spp. Additionally, water stressed plants in under-irrigated systems may be susceptible to disease and yields can be reduced (Boguszewska-Mankowska et al. 2022). This project aims to provide information on Dakota Russett yields and disease under irrigation. More work is needed to understand the impact of irrigation on tuber diseases in Dakota Russett, a stress tolerant variety of interest. In this project, soil water monitoring paired with yield and disease assessments will allow us to inform irrigated production of Dakota Russet.

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. Using the checkbook method, applied irrigation treatments were: I100) 100% of full irrigation, I80) 80% of full irrigation, and I60) 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 RCBD with each treatment replicated four times. 3 rows from each plot were infested with black dot inoculum right before planting.

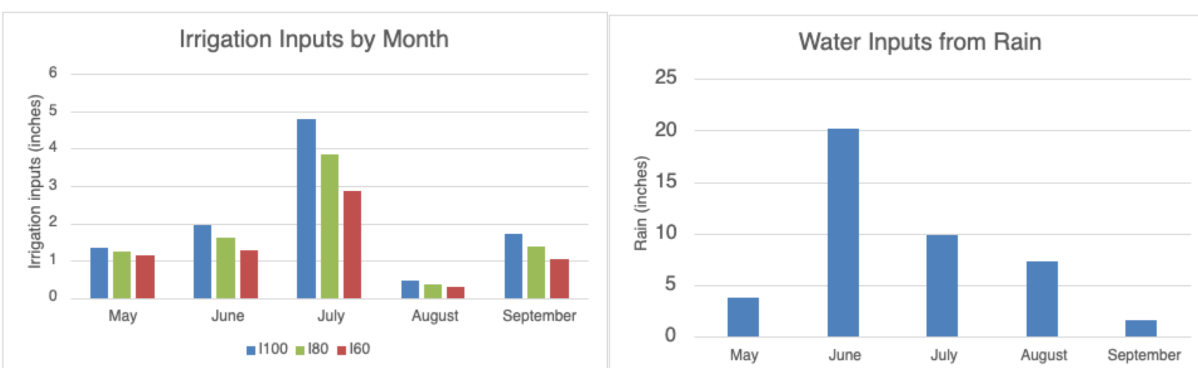

Figure 1. Heavy rains were noted in the early season, adding an additional 20 inches of water and peaking in June (left). Irrigation treatments were implemented 3 weeks after planting to allow the crop to establish. Irrigation treatments included I100 added 13.05 inches, I80 added 10.65 inches, and I60 added 8.25 inches of water, with inputs peaking during the tuber bulking stage (right)

Disease Incidence: Incidence of stem and foliar diseases were assessed early (June 26), mid(July 28), and late season (August 8) by assessing 10 plants from 1 row in each plot. Vine decline caused by Potato Early Dying (PED, caused by black dot and Verticillium wilt) was rated on a scale of 1-5, with 1 showing early wilting symptoms and 5 showing complete necrosis of the plant. Stem samples were collected for qPCR during early and late season to track black dot and Verticillium wilt inoculum load. Incidence of foliar, stem, and tuber diseases (*Alternaria spp.,* black leg, common scab, black dot, Verticillium wilt, soft rots) were taken from 10' subplots at harvest (September 19). Samples of diseased potatoes were collected for downstream diagnostics to confirm their causal agents.

Yield, Grading, and Quality assessments: Tubers were mechanically harvested (September 19) and sorted by size. 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 10 potatoes per plot were dissected to scout for hollow heart.

Results:

Yield, Size, and Grade: No significant effects were detected for tuber yield, size, and grade (ANOVA p < 0.95). On average, I60 had smaller tubers (> 6 oz) and I100 saw the most tubers over 6 oz. I80 had the largest proportion of cull tubers (> 4 oz). Irrigation Water Productivity (IWP) is calculated by average total yield divided by the total irrigation input.

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

Treatment	Total Irrigation (in)	% Cull	% > 6 oz	Total Marketable Yield (cwt/ac)	Irrigation Water Productivity
I100	13.05	25	68	697	53

I80	10.65	29	67	635	59
I60	8.25	23	66	669	81

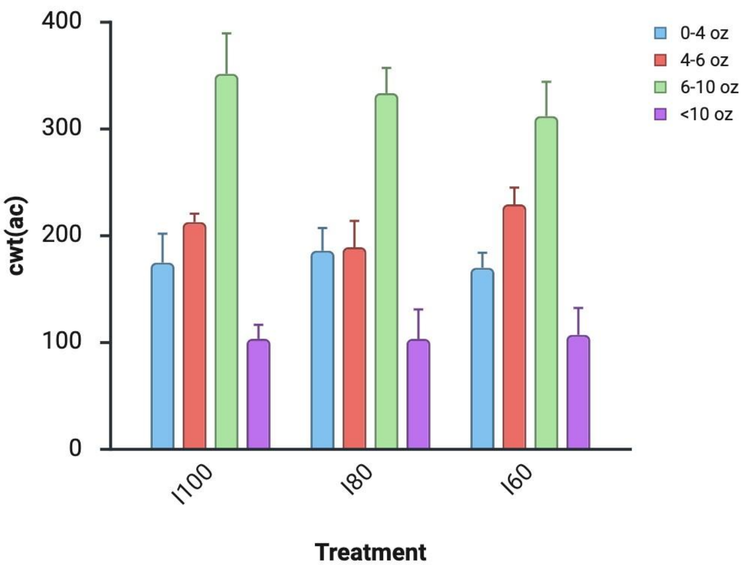

Fig 2. Tuber size classes by treatment. I100 had the largest proportion in the 6-10 oz range, and cull tubers (> 4 oz) was higher under I80.

Stem and foliar disease evaluations: Low incidence of foliar diseases (early blight, brown spot caused by *Alternaria spp.*) was recorded. No symptoms of disease were recorded early season (June 26). Black leg, caused by *Pectobacterium and Erwinia spp.,* had the highest incidence in the later season (August 18). No significant effects of irrigation were detected for black leg and *Alternaria* foliar diseases (Poisson regression, p > 0.95).

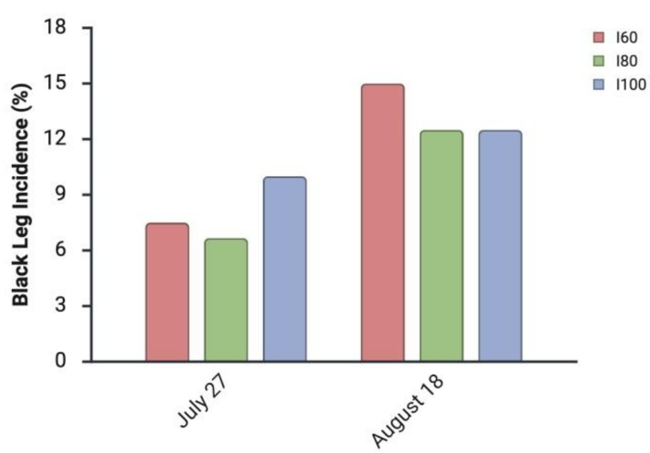

Fig 3. Black leg incidence by treatment and date scouted. Incidence ranged from 018%.

Potato Early Dying (PED) Incidence and Severity: No symptoms of PED were noted early in the season (June 23). Incidence of PED reached 100% in some plots late season (August 18). No significant effects were found (Beta regression, $p > 0.95$). High incidence was noted overall, though symptoms were relatively mild (PED rating 1-2).

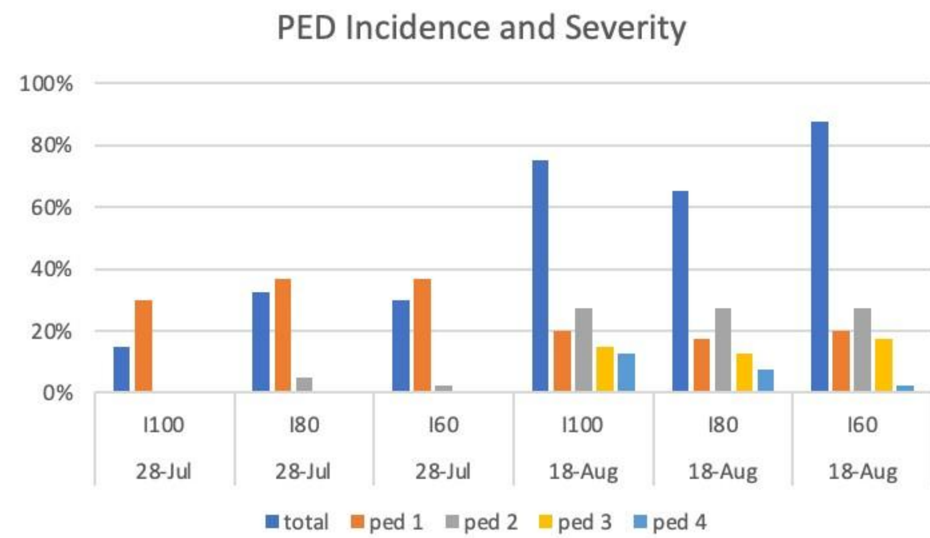

Fig 4. Potato Early Dying incidence and severity. High incidence was noted overall, and conditions were conducive to disease development.

Tuber disease evaluations: No significant irrigation effects were detected for soft rots, though incidence trended upwards with increased irrigation. Common scab had high incidence overall as Dakota Russet is susceptible to it.

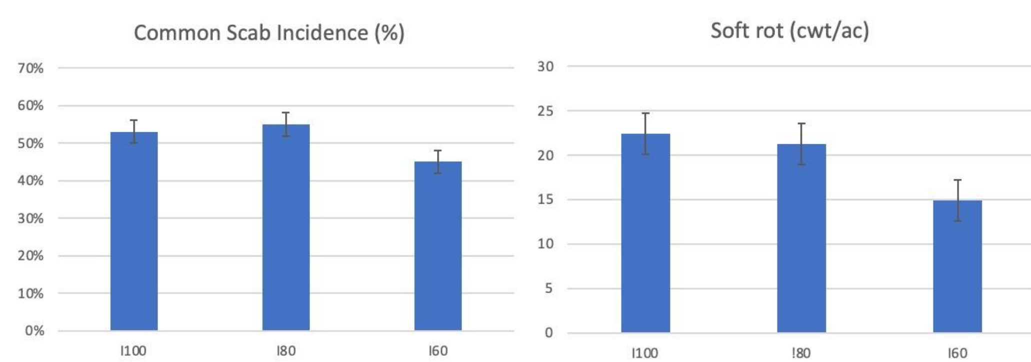

Fig 5. Average proportion of common scab incidence (left) and incidence of soft rots (right). Common scab was equally represented by the treatments while soft rots were more common under higher irrigation.

Discussion: This project demonstrates that deficit irrigation strategies can significantly enhance irrigation water productivity in Dakota Russet production without sacrificing marketable yield or exacerbating key diseases like PED even under high inoculum pressure. It is possible that abundant moisture provided suitable conditions for all irrigation treatments and differences in treatments were not distinguishable for disease. Additional field seasons would be useful to assess treatments in growing season with average and/or below average rainfall. Effective disease management in irrigated systems requires an integrated approach. Strategic irrigation management, informed by real-time soil and disease monitoring, can be used to conserve water and N inputs without impacting prevalence of foliar, stem, and tuber diseases.

Data Report for UMN Potato Breeding Program 2025

Dr. Laura Shannon

Department of Horticultural Science

University of Minnesota

306 Alderman Hall

1970 Folwell Ave, Saint Paul MN 55104
lmshannon@umn.edu

608-333-5216

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, to breed for a trait, we must first be able to measure it precisely, accurately, and quantitatively. Our previous efforts to develop methods to quantify quality traits have 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 quantitatively measure blackspot bruise susceptibility in our breeding program and calculate heritability as a first step toward selecting for resistance.

*Meth
ods:*

In order to identify bruise resistant clones we screened the UMN breeding program from year 3 (FY3) on as well as 30 clones each from North Dakota, Michigan, and Wisconsin, and the following checks: Modoc, Chieftain, Dark Red Norland, Red Pontiac, Red LaSoda, Atlantic, Snowden, Cascade, Superior, Bannok Russet, Russet Norkotah, Russet Burbank, Umatilla Russet, Goldrush, Dakota Russet, and Elk River Russet. All clones were grown at the Sand Plains Research Farm in Becker, MN. Clones from other programs were grown in a single replicate, but all other clones were grown in two replicates. Fresh market red and yellow clones were vine killed after 90 days and harvested 18 days later, while russet and chipping clones were vine killed after 110 days and harvested two weeks after that. After harvest, clones were graded using an Exeter grader and 10 tubers per clone were selected at random to enter storage. These samples were stored for at least 48 hours at 40F in a cold room. Then they were tumbled in sample bags for ten minutes in a heatless clothes dryer. After tumbling, they were placed in a 70°F, no-light growth chamber for another 48 hours, after which they were peeled with an electric peeler. Peeled tubers were cut in half and photographed using 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).

Bruise was quantified using an R-script. 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 across 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. Data from 2025 was combined with data from 2024 to calculate best linear unbiased estimates (BLUEs), which reflect genetic values of bruise separate from environmental effects.

Results: Across two years examining chips and fresh market clones, bruising had a broad sense heritability of 0.452. This suggests that almost half the variation in bruising in clones is due to genetics. The error in this experiment is high, as clones experienced different incidental damage at harvest, we tried multiple lighting settings over the duration of this experiment and time between harvest and bruising varied across clones and year. The high error means the heritability we calculated is likely an under estimate. However it points to breeding as a promising strategy for reducing bruise susceptibility in potatoes.

The check least susceptible to bruise was Columba with an average bruise index of 0.82 across two years, and ten breeding clones outperformed it (3 chips and 2 yellows from MN, a red and 2 chips from MI, 2 chips from ND). Dark Red Norland was our next best performing check, with a bruise index of 1.77. Clones which performed between Columba and Dark Red Norland included 2 reds from ND; 8 chips, a red, and 3 yellows from MN; and a yellow, 2 chips, and a red from MI. The third best check was Yukon Gold, with a bruise index of 3.944. It was outperformed by 38 clones in addition to those listed above: 3 reds, 1 yellow, and 3 chips from ND; 14 chips, 3 reds, and 5 yellows from MN; 3 chips, 2 reds, and 3 yellows from MI; and a chip from WI. Red Norland, Red Pontiac, Modoc, Red LaSoda, and Chieftain all had bruise indexes between 4.9 and 6.2. Also within that range were a chip from ND, 2 reds and 13 chips from MN. The least bruise prone chip was Snowden, with a bruise index of 6.82 and then Atlantic with an index of 8.69. There were 14 additional clones with bruise scores lower than Atlantic including 3 reds, a yellow, and 3 chips from MN, 4 reds from ND, and 2 reds from MI. Individual bruise scores are included in clone summary tables in the next objective.

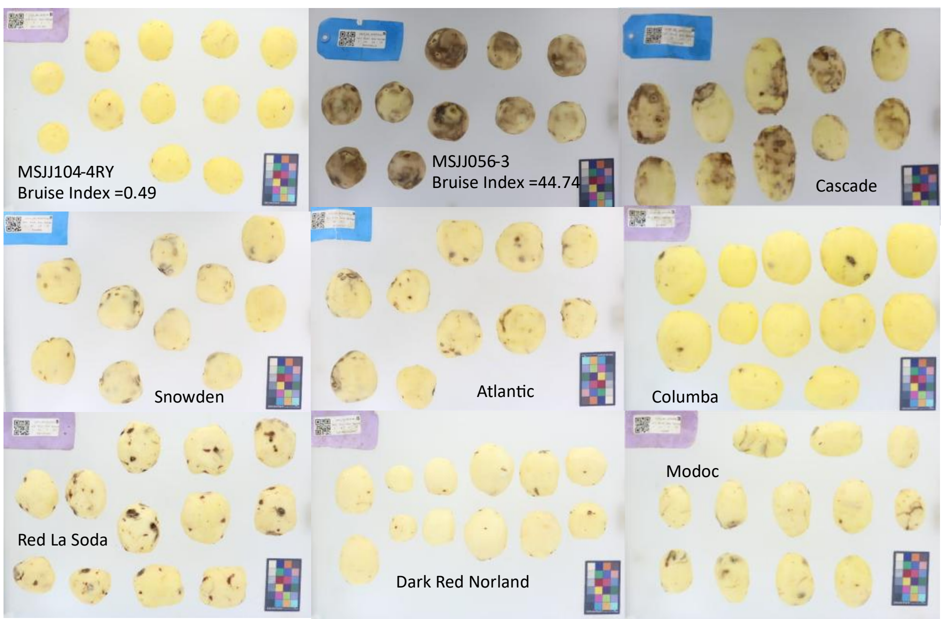

Figure 1. The range of bruising phenotypes. MSJJ104-4RY exhibited the lowest bruising with a bruising index of 0.49, while MSJJ056-3 exhibited the most sever bruising with an index of 44.74. Representative pictures of checks are shown, although the bruise index scores indicated elsewhere are a mean across multiple images.

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 that 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 produce 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 and in later stages we focus on potentially identifying commercially viable clones.

Methods: FY 1

We planted 18,500 single hills from 147 different crosses. Of these, 24 families were from crosses done at UMN. The rest were kindly provided by our partnering institutions; North Dakota State University (56 families), Texas A&M University (33 families), and Colorado State University (34 families). All single hills were planted at the North Central Research and Outreach Center (NCROC) and selected visually.

FY 2

We evaluated 242 FY2 clones this year in 12-hill plots. Of these clones, 46% were chips, 21% were russet, 26% were red, and 6% were yellow. All clones were planted at the NCROC and selected visually.

FY
3-8

We grew FY3-7 as a replicated field trial in Becker, MN, with two 15-hill plots each. These were grown as single replicate samples from North Dakota, Wisconsin, and Michigan. Blackberry, Columba, Modoc, Dark Red Norland, Paisley Purple, and Red LaSoda were used as checks for the fresh market potatoes. Snowden, Cascade, and Atlantic were used as checks for the chippers. Bannock Russet, 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 18 days and 14 days after vine desiccation, respectively.

For each market class (FY3-7), checks and clones from the North Central Region were grown in a partially replicated randomized design. The trial included 23 chips from MN, 8 from ND, and 11 from MI. The russet trial included 14 russets from MN, 7 from ND, and 35 from WI. The fresh market trial included 6 clones from MN, 2 from MI, and one from ND. Thirty MN clones were also grown in North Dakota, Wisconsin, and Michigan as part of the North Central Regional trial, and six were entered into the National Chip Processing Trial.

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 above, the second to test specific gravity and chip and fry color. 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. A manual fry cutter created 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.

Resul ts:

FY 1

We selected 2% of the individuals over all to continue on in the program to year 2, resulting in 422 clones to be evaluated in 12 hills in 2026.

FY2

We selected 31% of the clones, resulting in 76 clones to be evaluated in preliminary yield trials in 2026.

FY 3+

In 2024 our seed field at the NCROC became heavily infested with scab. We eliminated all clones with seed with a scab score of 3 or more (Figure 2). This resulted in a reduction in advanced germplasm, but all the advanced germplasm should be at least somewhat resistant to scab. We have also moved to a new seed location in Rosemount which resulted in minimal scab on our harvested seed.

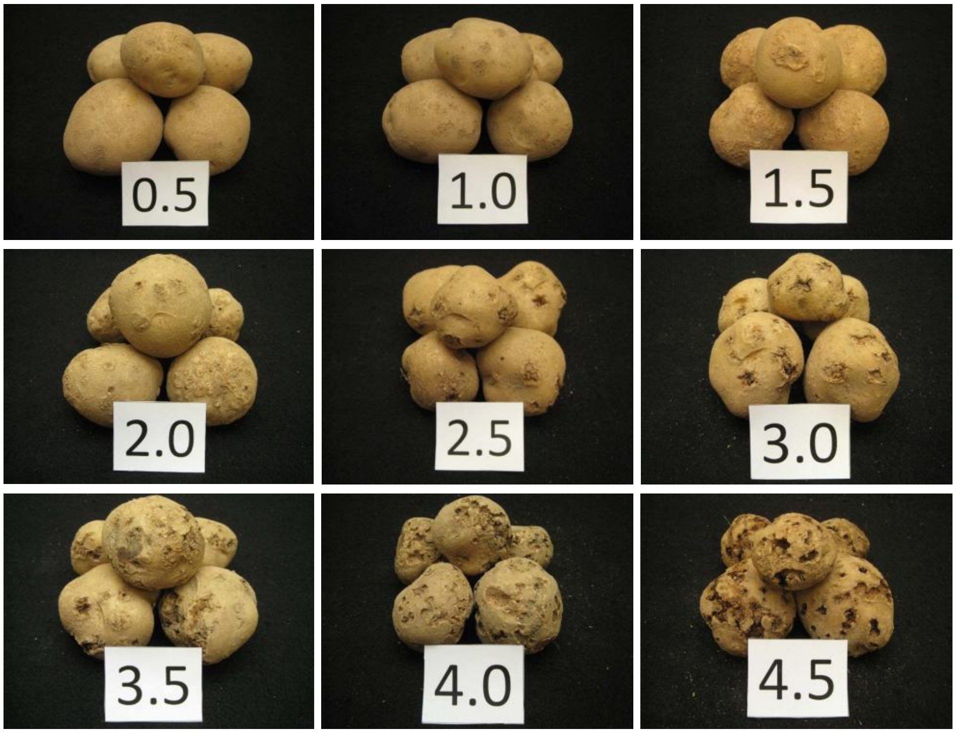

Figure 2. Common scab rating scale 0 (none) to 5 (severe). Images and scale from MSU Potato breeding program

Chips: We have six advanced chipping clones. Among our most advanced clones is MN18W17037-033 (Figure 3). It has exhibited tolerance to verticillium wilt in the field in Dr. Ashish Ranjan's experiments and it has PVY resistance from the *S. andigena* source as indicated by genetic markers. It was in the Early Generation Southern Selection trial in North Carolina in 2020 and the NCPT in 2022 and 2023 (Table 1). It has repeatedly out yielded Atlantic in Minnesota and exhibits less bruise than all checks (Table 2). It is at Valley Tissue Culture for seed increase.

Figure 3. MN18W17037-033 a promising chipping clone with verticillium and PVY resistance.

MN18W17037-026 is one of the least prone to bruise chips we tested (Table 2, Figure 4). It has varied somewhat in yield across the years but has consistently high specific gravity (Table 2). It will be in the EGSS and NCRT this year. MN20AF7174-001 has been in the National Chip Processing Trial over the past two years and done particularly well in warm locations like Texas (Table 3, Figure 5). In the next year we will do further testing in Florida and collaborate with Dr. Ashish Ranjan to test for disease resistance. Additionally we have three newer chips moving into trials (Table 4).

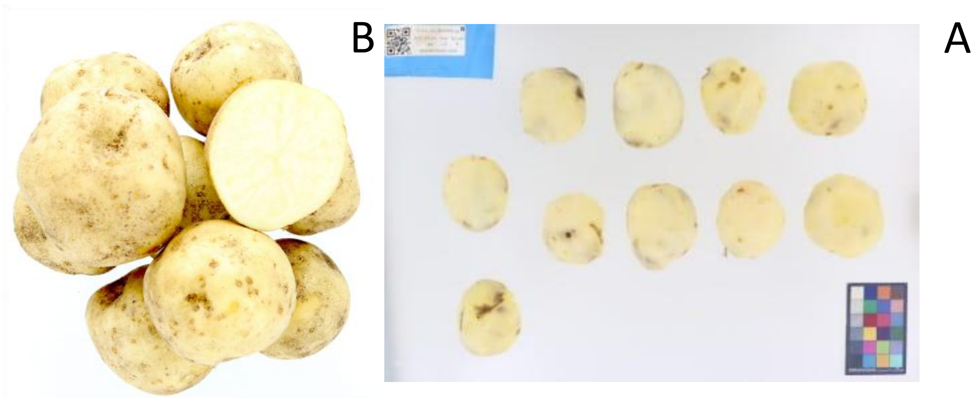

Figure 4. MN18W17037-026 a promising chipping clone with low bruise susceptibility. Part B shows bruising.

Figure 5. MN20AF7174-001, a heat resistant chipping clone.

Table 1. MN18W17037-033 performance in National Trials. Heat necrosis rating on a scale from 9 being absent to 1 being severe.

Trial	Trait	MN18W17037-033	Atlantic
EGSS 2020	Yield	18.4	19.6
	SG	1.069	1.079
	Heat Necrosis Rating	8	7.5
NCPT 2022	ND Yield	112.0	118.8

	ND SG	1.093	1.110
	FL Yield	466.0	398.6
	FL SG	1.089	1.088
	WI SG	1.070	1.074
	NC Yield	165.0	245.8
	NC SG	1.066	1.081
	TX Yield	589.0	416.5
	TX SG	1.070	1.082
	MI Yield	552.0	1.074
	MI SG	286.0	1.081
	CA SG	1.092	1.100
	NY SG	1.076	1.084
	OR Yield	733.0	606.3
	OR SG	1.086	1.090
	MD Yield	133	337.5
	MD SG	1.053	1.072
NCPT 2023	ND Yield	15.8	NA
	ND SG	1.098	NA
	FL Yield	308.5	323.3
	FL SG	1.063	1.076
	WI Yield	760.0	635.5
	WI SG	1.070	1.076
	NC Yield	386.5	314.8
	NC SG	1.059	1.076
	TX Yield	434.0	NA
	TX SG	1.076	NA
	MI Yield	27.3	27.7
	MI SG	1.076	1.085
	CA SG	1.086	1.084
	NY SG	1.081	1.091
	OR Yield	1066.3	1.081
	OR SG	655.3	1.088
	MD Yield	95.5	149.3
	MD SG	1.048	1.065

Table 2. 2025 Advanced chipping selections (NAs indicate unmeasured phenotypes, Yields are presented as % Atlantic)

Clone	MN18W17037-033	Atlantic	Cascade	MN18W17037-026	Snowden	Lamoka	Superior	MN20AF7174-001

Bruise Index	6.23	8.69	13.7	1.06	6.82	NA	NA	12.57
Yield MN 2025	104	100	135	59	112	NA	NA	98
SG MN 2025	1.076	1.091	1.075	1.084	1.081	NA	NA	1.077
Yield MN 2024	114	100	98	88	88	83	61	81
SG MN 2024	1.083	1.091	1.074	1.086	1.078	1.08	1.067	1.081
Yield MN 2023	58	100	90	86	81	68	48	102
SG MN 2023	1.077	1.075	1.065	1.082	1.072	1.077	1.067	1.071
Yield MN 2022	153	100	82	40	19	59	27	NA
SG MN 2022	1.075	1.073	1.06	NA	1.075	1.071	1.064	NA
Yield MN 2021	87	100	NA	64	92	77	NA	NA
SG MN 2021	1.07	1.075	NA	1.064	1.071	1.068	NA	NA
Yield MN 2020	88	100	NA	94	NA	NA	NA	NA
SG MN 2020	1.067	1.064	NA	1.063	NA	NA	NA	NA
Yield WI 2021	NA	100	NA	85	NA	98	NA	NA
SG WI 2021	NA	1.085	NA	1.080	NA	1.084	NA	NA
Yield MI 2021	NA	100	NA	77	NA	87	NA	NA
SG MI 2021	NA	1.088	NA	1.079	NA	1.081	NA	NA
PVY	Yes	NA	NA	NA	NA	NA	NA	NA
Vert	Yes	NA	NA	NA	NA	NA	NA	NA

Table 3. MN20AF7174-001 performance in National Trials. Heat necrosis rating on a scale from 9 being absent to 1 being severe.

Trial	Trait	MN20AF7174-001	Atlantic
EGSS 2023	Yield	10.6	8.1
	SG	1.067	1.075
	Heat Necrosis Rating	9	8
NCPT 2024	ND Yield	163.0	173.5
	ND SG	1.095	1.107
	FL Yield	330.0	301.5
	FL SG	1.101	1.089
	WI Yield	77.2	62.9
	WI SG	1.071	1.088
	NC Yield	30.5	25.3

	NC SG	1.072	1.089
	TX SG	1.065	1.064
	MI Yield	340.0	429.3
	MI SG	1.070	1.087
	NY SG	1.071	1.093
	OR Yield	465.4	449.0
	OR SG	1.084	1.090
	MD Yield	36.0	214.8
NCPT 2025	ND Yield	259.5	392.0
	ND SG	1.094	1.102
	FL Yield	344.0	379.0
	FL SG	1.073	1.078
	WI Yield	742.5	587.5
	WI SG	1.070	1.086
	NC Yield	222.5	253.8
	NC SG	1.064	1.067
	TX Yield	891.0	164.0
	TX SG	1.073	1.074
	MI Yield	279.0	269.5
	MI SG	1.059	1.073
	CA Yield	187.4	336.2
	CA SG	1.067	1.087
	NY SG	1.071	1.088
	OR Yield	520.5	660.0
	OR SG	1.077	1.083
	MD Yield	403.0	464.8
	MD SG	1.063	1.072

Table 4. 2025 new chipping selections (NAs indicate unmeasured phenotypes, Yields are presented as % Atlantic)

Clone	Bruise Index	Yield MN 2025	SG MN 2025	Yield MN 2024	SG MN 2024
Atlantic	8.69	100	1.091	100	1.091
Cascade	13.70	135	1.075	98	1.074
Snowden	6.82	112	1.081	88	1.078
MN21ND1845B-088	6.87	105	1.072	86	1.079
Lamoka	NA	NA	NA	83	1.080
Superior	NA	NA	NA	61	1.067
MN23AF7648-001	0.977	100	1.086	NA	NA
MN23AF7759-001	20.96	135	1.081	NA	NA

Russets: We have 9 advanced russet clones from the trials this year. We did not have sufficient seed to include MN21CO19073-001 in the trials this year but it performed well in 2024 and has a specific gravity about 1.080 in MN and WI (Figure 6). Notably, it is resistant to PVY with the *S. stoloniferum* source of resistance and exhibits resistance to verticillium wilt in Dr. Ashish Ranjan's field experiments. MN19AOR16061-007 continues to show promise as a fresh market russet (Table 5, Figure 7). Of the newest russet clones (Table 6) all out performed at least one check and had specific gravities above 1.080. The exception to this is MN23AOR2000-004, which is under consideration as a fresh market russet.

Figure 6. MN21CO19073-001, a russet clone with PVY and verticillium wilt resistance, submitted to the National Fry Processing Trial.

Figure 7. MN19AOR16061-007 a promising fresh market russet clone.

Table 5. 2025 Advanced Russet Selection (NAs indicate unmeasured phenotypes, Yields are presented as % Russet Burbank)

Clone	Yield MN 2025	SG MN 2025	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	98	1.082	105	1.079	79	1.075	114	1.066	NA	NA	NA	NA	NA	NA
Russet Burbank	100	1.076	100	1.076	100	1.073	100	1.067	100	1.075	100	1.071	100	1.060
Goldrush	99	1.078	89	1.065	81	1.062	98	1.058	NA	NA	113	1.064	98	1.054
MN19AOR16061-007	87	1.072	74	1.072	75	1.069	129	1.066	67	1.066	101	1.066	63	1.056
Dakota Russet	83	1.085	74	1.083	70	1.072	NA	NA	NA	NA	NA	NA	NA	NA
Elk River Russet	85	1.093	70	1.090	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Russet Norkotah	73	1.076	65	1.065	83	1.060	113	1.060	54	1.061	112	1.070	54	1.055
Bannock Russet	63	1.073	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

Table 6. 2025 New Russet Selections (Yields are presented as % Russet Burbank)

Clone	Yield	Specific gravity
MN23022-002	118	1.091
Russet Burbank	100	1.076
Goldrush	99	1.078
MN23ND20205-001	98	1.085
Umatilla Russet	98	1.082
MN23ND20213-001	96	1.093
MN23012-002	91	1.089
Elk River Russet	85	1.093
Dakota Russet	83	1.085
MN23AOR2000-004	82	1.071
MN23012-001	79	1.091
Russet Norkotah	73	1.076
MN190014-130	67	1.092
Bannock Russet	63	1.073

Yellows: We have two advanced yellow clones. MN19AF6945-003 is a high yielding, low bruise, round yellow clone with PVY resistance (Table 7, Figure 8). Test cooks have praised its ability to hold its shape in soups and stews and its buttery, "potato-y" flavor. MN18CO16154-009 is a yellow clone with verticillium wilt resistance and bruise resistance which has been consistently high yielding as compared to Yukon Gold.

*Table 7. Advanced yellow selections (NAs indicate unmeasured phenotypes, Yield is percent Yukon Gold except in * trials where it is percent Red Norland)*

Clone	Bruise Index	Yield MN 2024	Yield MN 2023	Yield MN 2022	Yield MN 2021*	Yield WI 2021	Yield MI 2021*	Yield MN 2020	PVY	Vert
Columba	0.82	317	68	NA	NA	NA	NA	NA	NA	NA
MN18CO16154-009	3.32	123	203	141	93	95	441	57	No	Yes
MN19AF6945-003	1.86	114	471	162	168	NA	NA	NA	Yes	No
Yukon Gold	3.94	100	100	100	NA	100	NA	100	NA	NA

Figure 8. MN19AF6945-003, a promising yellow clone with bruise and PVY resistance

Figure 9. *MN18CO16154-009 a promising yellow clone with verticillium wilt and bruise resistance.*

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

Yuxin Miao, Sukhdeep Singh, Carl Rosen, Vasudha Sharma, Megan McCaghey, Jasper Tao Precision Agriculture Center, University of Minnesota, St. Paul, MN 55108

Summary

High nitrogen (N) and irrigation rates are critical for potato (*Solanum tuberosum* L.) productivity, yet they pose significant sustainability challenges. Poor resource use efficiency and nitrate leaching often accompany these inputs, and these issues are compounded by the crop's shallow root system and sandy soils. Innovative management practices are needed that optimize N and irrigation for high tuber yield, quality, and profit and reduced nitrate leaching. The primary objective of this research project is to evaluate how Russet Burbank (RB), Hamlin Russet (HR), and Dakota Russet (DR) respond to varying irrigation regimes and N rates in terms of yield, tuber quality, N use efficiency (NUE) and N leaching, both individually and relative to each other. A plot-scale field trial was conducted at the Sand Plain Research Farm in Becker, MN in 2025. The study design included three experiments 1) A full-factorial design with all three cultivars, three irrigation rates (i.e. 60%, 80%, and 100%), and three whole-season N rates (i.e. 160, 240 lbs N ac^{-1}, and a precision N application (PA) treatment), 2) An irrigation-focused experiment in which the same three cultivars each received a single N rate (240 lbs/ac N for Burbank; 160 lbs N ac^{-1} for Hamlin and Dakota) and were irrigated at all six rates (i.e. 60%, 80%, and 100% and three variable rates), 3) An N-focused experiment in which Russet Burbank was irrigated at 100% of the recommended rate based on the checkbook method and received N at six total rates (i.e. 40, 80, 160, 240, 320 lbs N ac^{-1}, and PA treatment). Furthermore, the research seeks to advance precision management strategies by validating SPAD-based thresholds for variable rate N applications through PA treatment. The project also aims to leverage proximal and remote sensing data to construct optimized, scalable management algorithms for site-specific irrigation and N management. Finally, the project included a disease management component to evaluate

the impact of variety selection, irrigation, and N management practices on disease development. Destructive samples, proximal and unmanned aerial vehicles (UAV) remote sensing data were collected at key growth stages. Due to substantial early season rainfall in 2025 growing season, no significant differences were observed among irrigation regimes. However, cultivar performance varied significantly, with HR achieving the highest marketable and US No. 1 yields. N rates also significantly influenced RB performance at 100% irrigation, with N rates 240 and 320 lbs N ac^{-1}, as well as the PA treatment, proving significantly superior to lower rates. Notably, the PA treatment performed on par with the 240 lbs N ac^{-1} standard across yield components, despite receiving a lower 225 lbs N ac^{-1}. Regarding disease development, the absence of significant treatment effects suggests that growers have flexibility in water and N management without substantially impacting disease pressure, based on the 2025 results. Further analysis is currently underway to use sensorbased data for developing optimized N management algorithms, alongside an evaluation of N leaching dynamics.

Background

In Minnesota, potatoes (*Solanum tuberosum* L.) are mainly grown on coarse-textured sandy soils with a very high potential for nitrate leaching losses. Hence, the nitrogen (N) use efficiency (NUE) of potato production systems remains low at about 40-60%. High N fertilizer demand and combined high irrigation water application rates, present a significant challenge in safeguarding water resources. As water-use restrictions have tightened across Central Minnesota, potato growers consistently identify irrigation compliance as a major challenge. These pressures have raised questions about whether carefully timed deficit irrigation can be implemented without compromising yield or tuber quality. Evaluating N management under both season-long and growth-stage–specific deficit irrigation is needed to identify whether, and when, potatoes can tolerate reduced water inputs while maintaining yield and NUE.

Improving NUE and water use efficiency (WUE) is critical in potato production due to the crop's shallow root system, which limits nutrient uptake capacity. To address this physiological constraint, producers can adopt N-efficient varieties, such as Hamlin Russet (HR). However, genetics alone are insufficient; fertilizer applications must also be optimized to match uptake capabilities and patterns. Because soil N dynamics are heavily influenced by moisture, successful management in Minnesota requires tight integration of N and irrigation practices. The intent of this integrated approach is to minimize nitrate leaching and protect groundwater resources without compromising tuber yield or quality.

To achieve these sustainability goals an integrated potato resource management study was carried out at the Sand Plain Research Farm (SPRF) in Becker, MN in 2025. This study is a continuation of our research efforts in optimizing N and irrigation management in the past few years by using a new N-efficient cultivar Hamlin Russet, controlled-release N fertilizer, sensorbased in-season N management, and reduced irrigation. The 2025 study focused on effects of irrigation rate and timing (six treatments) across three cultivars at various N rates on yield, tuber quality, NUE, WUE and N leaching dynamics.

To evaluate the environmental and agronomic impacts of these management regimes, a multi-faceted monitoring approach has been employed. Suction cup lysimeters were utilized to characterize subsurface N leaching dynamics, while a suite of sensors monitors crop health complemented by destructive sampling. Among these, the SPAD-502 chlorophyll meter has proven effective for diagnosing potato N status, particularly under non-water-stressed conditions (Wakahara et al., 2025). For more comprehensive monitoring, the Crop Circle Phenom (CCP) sensor was used as an integrated proximal sensor, simultaneously measuring canopy reflectance (Red, Red Edge, NIR) and meteorological parameters such as canopy temperature and relative humidity (Cummings et al., 2021). These along with the UAV-based remote sensing technology which captures multispectral and thermal longwave infrared data as well as *in situ* soil moisture sensors offer the potential to diagnose N and water status concurrently.

Beyond irrigation and nutrient inputs, disease pressure plays a pivotal role in determining final yield and quality. Consequently, characterizing the effects of integrated management strategies on disease development and mitigation is essential for a comprehensive production system. Managing the pathogens is challenging because disease development under different management strategies and environmental conditions are difficult to predict. Oversaturated soils may promote soilborne disease development and a fuller canopy from increased N inputs could increase prevalence of stem and foliar pathogens due to increased canopy closure. However, drought and N stress often contribute to decreased plant defenses, leading to higher incidence and severity from opportunistic pathogens. Variety responses also differ in tolerance to both abiotic and biotic stress. The disease complex known as potato early dying (PED), comprising of *Verticillium dahliae* and *Colletotrichum coccodes*, can reduce tuber size and yield losses typically ranging from 20–30%, with higher incidence leading up to 50% losses.

The main objectives of the 2025 study were to 1) evaluate how different potato cultivars respond to varying irrigation regimes and N rates in terms of yield, tuber quality, NUE, WUE and N leaching dynamics, both individually and relative to each other, 2) evaluate the potential benefits of SPAD sensor-based precision N management and integrated precision potato management, 3) develop newer, optimized and scalable management algorithms for site-specific water and N management using proximal and remote sensing technologies, and 4) evaluate the interactive effects of various cultivars, irrigation and N management practices on disease development in potatoes.

Materials and Methods

Study site and design

The 2025 study was conducted at the SPRF in Becker, MN on a Hubbard (Sandy, mixed, frigid Entic Hapludolls)-Mosford (Sandy, mixed, frigid Typic Hapludolls) complex soils. The soil test results from the beginning of the season are summarized in Table 1. A total of 20.57 inches of rainfall was recorded during the growing season, and the corresponding weather conditions are summarized in Figure 1. The previous crop grown at the study site was soybean. The irrigation rates, cultivars, and N treatments were used as the main plot, subplot, and sub-subplot treatments respectively in a split-split plot design with three replications. A total of six irrigation regimes were implemented: three fixed-rate treatments (60-60-60%, 80-80-80%, and 100-100-100% of the recommended irrigation rate applied uniformly across the early, mid, and late season) and three variable-rate treatments (80-100-80%, 60-100-60%, and 60-80-60%), in which irrigation rates were adjusted by growth stage (Figure 2 and Table 2). All percentages were based on the recommended seasonal irrigation schedule derived from the checkbook method. Three cultivars (Russet Burbank (RB), Hamlin Russet (HR), and Dakota Russet (DR)) and six N treatments ((40, 80, 160, 240, and 320 lb N ac^{-1} (response curve treatments, full range for RB only), plus a SPADbased variable-rate N treatment, PA) were tested. The experimental design was not fully balanced, meaning that not all combinations of factors were represented across all levels. Detailed descriptions of the specific treatment combinations are provided in Table 3.

Table 1. Soil test results from the beginning of the season in 2025. NO_3-N and NH_4-N are from the 0-2 ft depth, all other anayses are for the 0-6 inch depth.

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]

[1] KCl extraction [2] NH4-OAc extraction, [3] Ca-phosphate extraction, [4] DTPA extraction, [5] Hot water extraction.

Fixed	6.7	1.7	10.7	5.5	27.3	136.0	1052	196.2	4.7	24.4	15.6	3.3	1.1	0.2
Variable	6.8	1.4	11.6	1.1	35.0	161.0	912	167.4	3.5	19.7	13.6	2.8	0.9	0.2

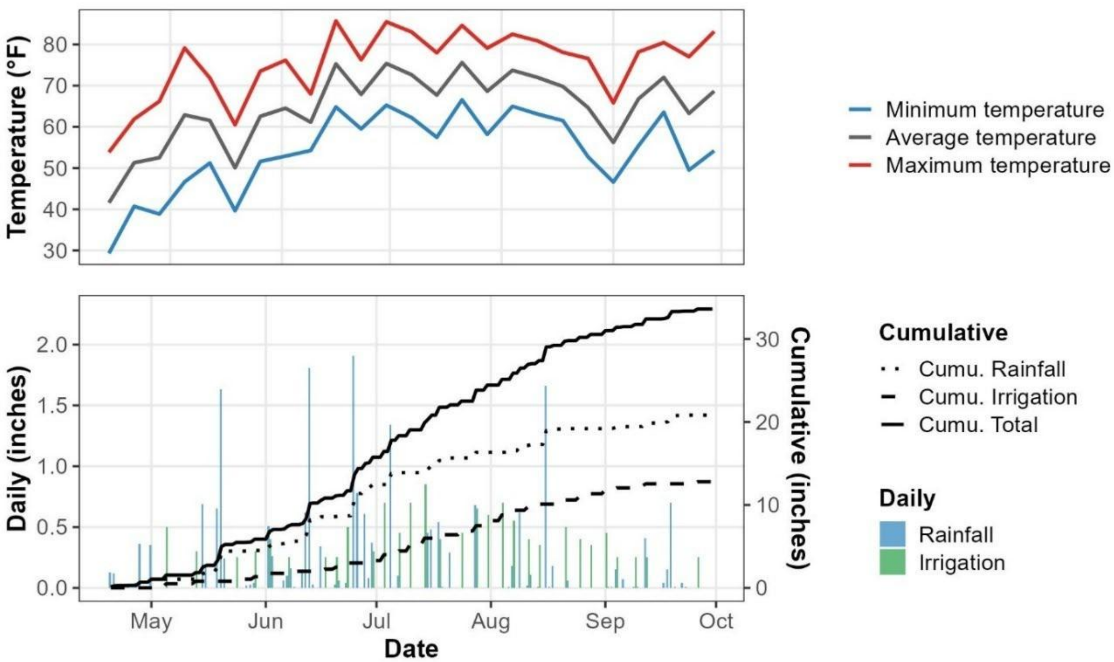

Figure 1. Temperature, precipitation, and irrigation (100% only) summary for the 2025 growing seasons.

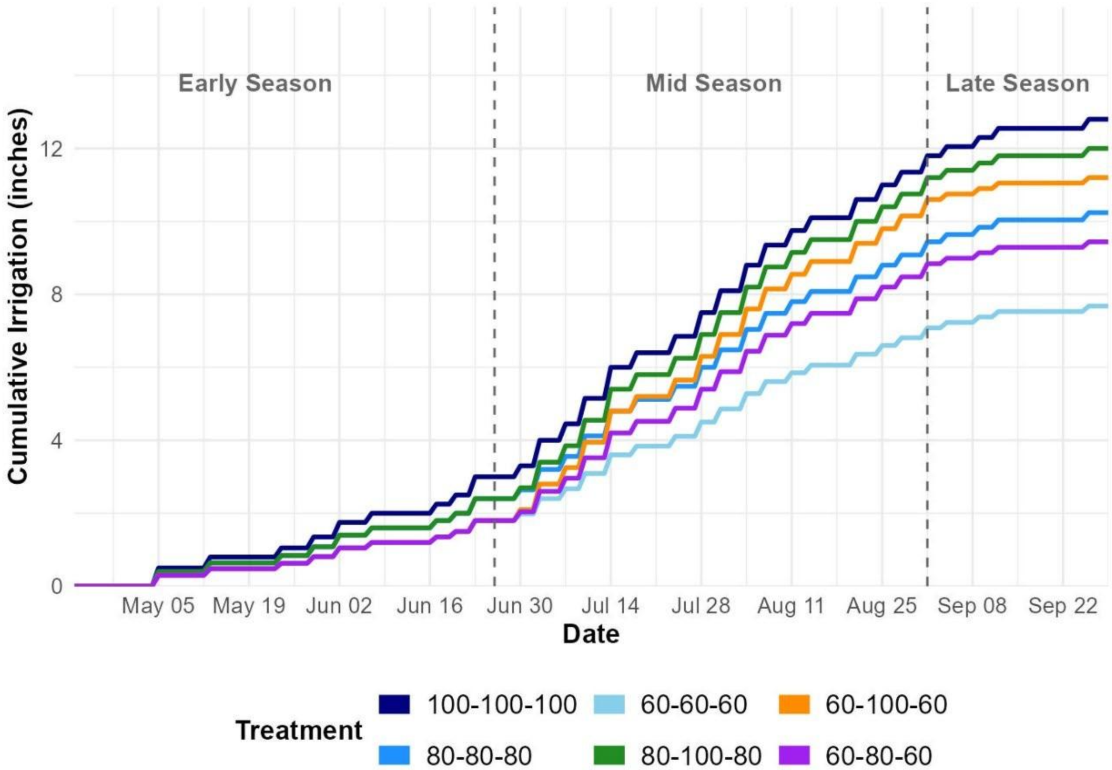

Figure 2. Cumulative irrigation applied to six irrigation treatments during the 2025 growing season. Vertical dashed lines demarcate the early, mid, and late-season periods.

Table 2. Seasonal irrigation application depths (inches) by growth stage (early, mid, late) for six irrigation treatments.

Treatment	100-100-100	80-80-80	60-60-60	80-100-80	60-100-60	60-80-60
Timing	Inches					
Early	3	2.4	1.8	2.4	1.8	1.8
Mid	8.8	7.04	5.28	8.8	8.8	7.04
Late	1	0.8	0.6	0.8	0.6	0.6
Total	12.8	10.24	7.68	12	11.2	9.44

All treatments received a starter application of 40 lb N ac^{-1} as diammonium phosphate (DAP) at planting. Much of the remaining N was supplied as environmentally smart nitrogen (ESN), as detailed in Table 2. For the higher N rate treatments (160, 240, and 320 lb N ac^{-1}), postemergence applications of urea–ammonium nitrate (UAN) solution were applied in four split doses of 15 lb N ac^{-1} each. The decision to prescribe the post-emergence UAN applications in the PA treatment plots was based on petiole nitrate-N concentration (PNNC) prediction. The PNNC was predicted using an XGboost machine learning (ML) model trained using SPAD readings, cultivars, accumulated growing degree days, and accumulated moisture from 20 site-years of potato experimental data. The PNNC sufficiency thresholds developed for RB by Rosen and Bierman (2008) were used. When the PA treatment plots were considered N deficient based on the algorithm, a 15 lb N/ac UAN application was made.

Table 3. Summary of irrigation regimes and nitrogen treatments, including DAP, ESN, and UAN application splits, across three potato cultivars.

Trmt #	Variety	Irrigation (% of recommended)	N Trmt	Total N (lb/ac)	Planting as DAP (18-46-0)	Emergence as ESN (44-0-0)	Posthill as UAN (28-0-0)
1	RB	100-100-100	N1	40	40	0	0
2	RB	100-100-100	N2	80	40	40	0
3	RB	100-100-100	N3	160	40	60	4x15
4	RB	100-100-100	N4	240	40	140	4x15
5	RB	100-100-100	N5	320	40	220	4x15
6	RB	100-100-100	N6 PA	225	40	140	3x15
7	HR	100-100-100	N3	160	40	60	4x15
8	HR	100-100-100	N4	240	40	140	4x15
9	HR	100-100-100	N7	145	40	60	3x15
10	DR	100-100-100	N3	160	40	60	4x15
11	DR	100-100-100	N4	240	40	140	4x15
12	DR	100-100-100	N7 PA	145	40	60	3x15
13	RB	80-80-80	N1	40	40	0	0
14	RB	80-80-80	N2	80	40	40	0
15	RB	80-80-80	N3	160	40	60	4x15
16	RB	80-80-80	N4	240	40	140	4x15
17	RB	80-80-80	N5	320	40	220	4x15
18	RB	80-80-80	N6 PA	225	40	140	3x15
19	HR	80-80-80	N3	160	40	60	4x15
20	HR	80-80-80	N4	240	40	140	4x15
21	HR	80-80-80	N7 PA	145	40	60	3x15
22	DR	80-80-80	N3	160	40	60	4x15

23	DR	80-80-80	N4	240	40	140	4x15
24	DR	80-80-80	N7 PA	145	40	60	3x15
25	RB	60-60-60	N1	40	40	0	0
26	RB	60-60-60	N2	80	40	40	0
27	RB	60-60-60	N3	160	40	60	4x15
28	RB	60-60-60	N4	240	40	140	4x15
29	RB	60-60-60	N5	320	40	220	4x15
30	RB	60-60-60	N6 PA	225	40	140	3x15
31	HR	60-60-60	N3	160	40	60	4x15
32	HR	60-60-60	N4	240	40	140	4x15
33	HR	60-60-60	N7 PA	145	40	60	3x15
34	DR	60-60-60	N3	160	40	60	4x15
35	DR	60-60-60	N4	240	40	140	4x15
36	DR	60-60-60	N7 PA	145	40	60	3x15
37	RB	80-100-80	N4	240	40	140	4x15
38	HR	80-100-80	N3	160	40	60	4x15
39	DR	80-100-80	N3	160	40	60	4x15
40	RB	60-100-60	N4	240	40	140	4x15
41	HR	60-100-60	N3	160	40	60	4x15
42	DR	60-100-60	N3	160	40	60	4x15
43	RB	60-80-60	N4	240	40	140	4x15
44	HR	60-80-60	N3	160	40	60	4x15
45	DR	60-80-60	N3	160	40	60	4x15

All irrigation blocks were sufficiently spaced considering the wetted diameter of the lateral moving irrigator. Each plot consisted of four (middle plots) or five (outer plots) 24-foot rows with a 3-foot between-row spacing with a 9 - inch within-row spacing used for HR and DR and 12-inch spacing for RB. Seed tubers were planted on April 22, 2025, and emerged on May 12, 2025, with the harvest date of September 29, 2025. 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.). The field was irrigated with 12.55 (100% treatments) inches of water applied across 29 irrigation events. 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 six and two times, respectively. Twenty petioles on the fourth leaf from the apex of the shoot were collected from a border row in each plot. Petioles were oven-dried, ground and analyzed for nitrate-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 N concentration was determined using combustion techniques. Suction-cup lysimeters were installed to a 4-foot depth in the second outermost row after emergence to quantify the nitrate N movement below the root zone. Due to practical constraints, the lysimeter installation was limited to plots receiving 40, 240 N ac^{-1} and PA in case of RB and, 160 N ac^{-1} and PA in case of HR and DR at 60, 80 and 100% irrigation rates only. Starting in the middle of June, lysimeter water samples were collected on a weekly basis and stored in the freezer for future nitrate concentration determination. Water and plant N concentration data are in the process of being analyzed.

Proximal and remote sensing and soil moisture monitoring

Leaf sensor data were collected using SPAD chlorophyl meter 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. CCP data were collected from the second outmost row by holding the sensor on a pole 20 to 40 inches above the canopy from the field edge and walking at a constant pace. Multispectral and thermal UAV images were collected by Sentera using 6X Thermal Sensor four times in the season. Access tubes were installed next to the lysimeters, and volumetric water content data were collected on a weekly basis using PR2 profile probe (PR2; Delta-T Devices Ltd., Cambridge, UK) at the 4, 8, 12, 16, 24 and 40 inch depths. Lastly, hourly weather information including temperature, dew point, wind speed, rainfall, and total solar radiation was collected at the SPRF weather station.

Disease monitoring

Plots were surveyed for disease across three irrigation treatments: 80% and 100% fixed rates applied to both RB and DR cultivars, plus a variable rate treatment (80-100-80) on RB only (Table 4). The impact of irrigation and N inputs (160 and 240 lb N ac^{-1}) on disease development was assessed through three seasonal evaluations (early: 6/23/25, mid: 7/28/25, late: 8/18/25). Foliar (caused by *Alternaria spp*., early blight and brown spot) and stem diseases (bacterial blackleg) were evaluated for incidence and severity. PED incidence and severity was rated per plant on a 0–4 scale (1 = early wilting, 4 = complete necrosis) for 10 plants in each plot. Disease Severity Index (DSI) is calculated as: DSI = [Σ (Frequency of Class × Score of Class)] / [(Total Number of Observations) × (Maximum Disease Index)] × 100. Tuber diseases (soft rot and common scab) were assessed post-harvest after washing.

Table 4. Treatment overview, with variety (RB = Russet Burbank, DR = Dakota Russet), recommended irrigation rate according to checkbook method (80, 100, 80-100-80 variable rate irrigation), and N rate (160 and 240 lb/ac).

Treatment Name	Variety	Irrigation Rate	Total N (lb/ac)
RB80160	Russet Burbank	80%	160
RB80240	Russet Burbank	80%	240
RB100160	Russet Burbank	100%	160
RB100240	Russet Burbank	100%	240
RBVRI160	Russet Burbank	80-100-80%	160
RBVRI240	Russet Burbank	80-100-80%	240
DR80160	Dakota Russet	80%	160
DR80240	Dakota Russet	80%	240
DR100160	Dakota Russet	100%	160
DR100240	Dakota Russet	100%	240

Statistical analysis

All statistical analyses were performed using R software. Data were analyzed using linear mixed-effects models fitted with the *lmer* function from the *lme4* package. The experimental design was modeled with cultivar, irrigation rate, N rate, and their interactions as fixed effects. To account for the split-plot design structure, block and the *block × irrigation* interaction were treated as random effects.

Analysis of Variance was conducted to test the significance of fixed effects using the Kenward-Roger approximation for denominator degrees of freedom via the *lmerTest* package. Treatment means were estimated using the *emmeans* package. Pairwise comparisons were performed using Fisher's Protected Least Significant Difference (LSD) test at a significance level of $P < 0.05$. Data visualization was generated using the *ggplot2* package.

Regression analysis was also conducted to determine the yield response of RB to increasing N rates (40 to 320 lb N ac^{-1}) under 100% irrigation. Linear and quadratic mixed-effects models were fitted using the *lme4* package. To improve model convergence, N rates were centered and standardized prior to fitting, then back-transformed for parameter estimation and visualization.

Results

Yield components and tuber size distribution across fixed rate irrigation, three cultivars and common N rates

Linear mixed effect models across fixed rate irrigation (60, 80 and 100%), three cultivars and common N rates (160, 240 lb N ac^{-1} and PA) showed that cultivar had a strong effect on all yield components ($P < 0.0001$) (Table 5). HR consistently produced the highest total and marketable yield (defined here as tubers > 3 oz), averaging 628 cwt ac^{-1} and 617 cwt ac^{-1} respectively, outperforming both RB and DR (Figure 3). In contrast, main effects of irrigation and N variables were largely nonsignificant (Figure 4 and 5). Irrigation rate did not influence any yield component ($P > 0.05$), and N rate only significantly affected the percentage of tubers greater than 6 oz ($P = 0.0217$), with the 160 lb N ac^{-1} rate resulting in a slightly higher percentage (60%) compared to the PA rate (56%).

However, significant interactions revealed that the main effects did in fact mask some of the cultivar specific responses. Significant interactions between cultivar and irrigation for total yield ($P = 0.0095$), marketable yield ($P = 0.0011$), U.S. No. 2 yield ($P = 0.0029$), and percentage of tubers greater than 6 oz ($P = 0.0333$) indicated that cultivars responded differently to water stress (Table 5). Both HR and DR were highly stable, maintaining consistent yields regardless of water application. In contrast, RB drove this interaction through a non-linear response to water deficit where total and marketable yields were significantly lower at the 80% irrigation rate (~490 cwt ac^{-1}) compared to the 100% (~586 cwt ac^{-1}) (Figure 6). However, this decline was not observed at the 60% rate, representing a deviation from a standard linear dose-response to reduced irrigation. Furthermore, the cultivar × N interaction for marketable yield ($P = 0.0139$) and U.S. No. 1 yield ($P = 0.0194$) highlighted how RB responded positively to increased N fertilizer, with higher marketable yield at rates 240 and PA in comparison to lower 160 lbs N, while HR and DR showed no yield benefit. Finally, the cultivar × N interaction significantly affected size distribution, particularly the percentage of tubers over 10 oz (P = 0.0442) (Figure 7). No significant differences were observed for the three-way interaction (Cul × Irri × N).

Table 5. Results from the linear mixed models for various yield components across fixed rate irrigation (60, 80 and 100%), three cultivars and common N rates (160, 240 lb N ac^{-1} and PA)

Source of Variation	0-3 oz.	3-4 oz.	4-6 oz.	6-10 oz.	10-14 oz.	> 14 oz.	Total Yield	U.S. No. 1	U.S. No. 2	% over 6 oz	% over 10 oz	Marketable Yield	Specifi Gravit
Cultivar	<0.0001 ***	<0.0001 ***	<0.0001 ***	0.0030 **	<0.0001 ***	<0.0001 ***	<0.0001 ***	<0.0001 ***	<0.0001 ***	<0.0001 ***	<0.0001 ***	<0.0001 ***	<0.000 1 ***
Irrigation	0.8848 ns	0.7740 ns	0.9688 ns	0.6134 ns	0.8034 ns	0.9458 ns	0.4938 ns	0.8974 ns	0.2158 ns	0.9275 ns	0.9438 ns	0.6719 ns	0.6930 ns
N rate	0.0718 ns	0.3225 ns	0.4539 ns	0.5415 ns	0.4245 ns	0.1352 ns	0.6776 ns	0.4172 ns	0.8889 ns	0.0217 *	0.0749 ns	0.3050 ns	0.0642 ns
Cul × Irri	0.2157 ns	0.4355 ns	0.5412 ns	0.0543 ns	0.2535 ns	0.4367 ns	0.0095 **	0.1001 ns	0.0028 **	0.0333 *	0.1462 ns	0.0010 **	0.8411 ns
Cul × N	0.0003 ***	0.2084 ns	0.2590 ns	0.1364 ns	0.8400 ns	0.0131 *	0.2886 ns	0.0194 *	0.9582 ns	0.2027 ns	0.0441 *	0.0139 *	0.2925 ns
Irri × N	0.1181 ns	0.2288 ns	0.6593 ns	0.9119 ns	0.5735 ns	0.7917 ns	0.7460 ns	0.90671 ns	0.8243 ns	0.6091 ns	0.5886 ns	0.7083 ns	0.4442 ns
Cul × Irri × N	0.2227 ns	0.1839 ns	0.8932 ns	0.9906 ns	0.9297 ns	0.7296 ns	0.9540 ns	0.96575 ns	0.9976 ns	0.9247 ns	0.7622 ns	0.9720 ns	0.9427 ns

ns, *, **, *** non-significant or significant at P ≤ 0.05, 0.01, or 0.001, respectively.

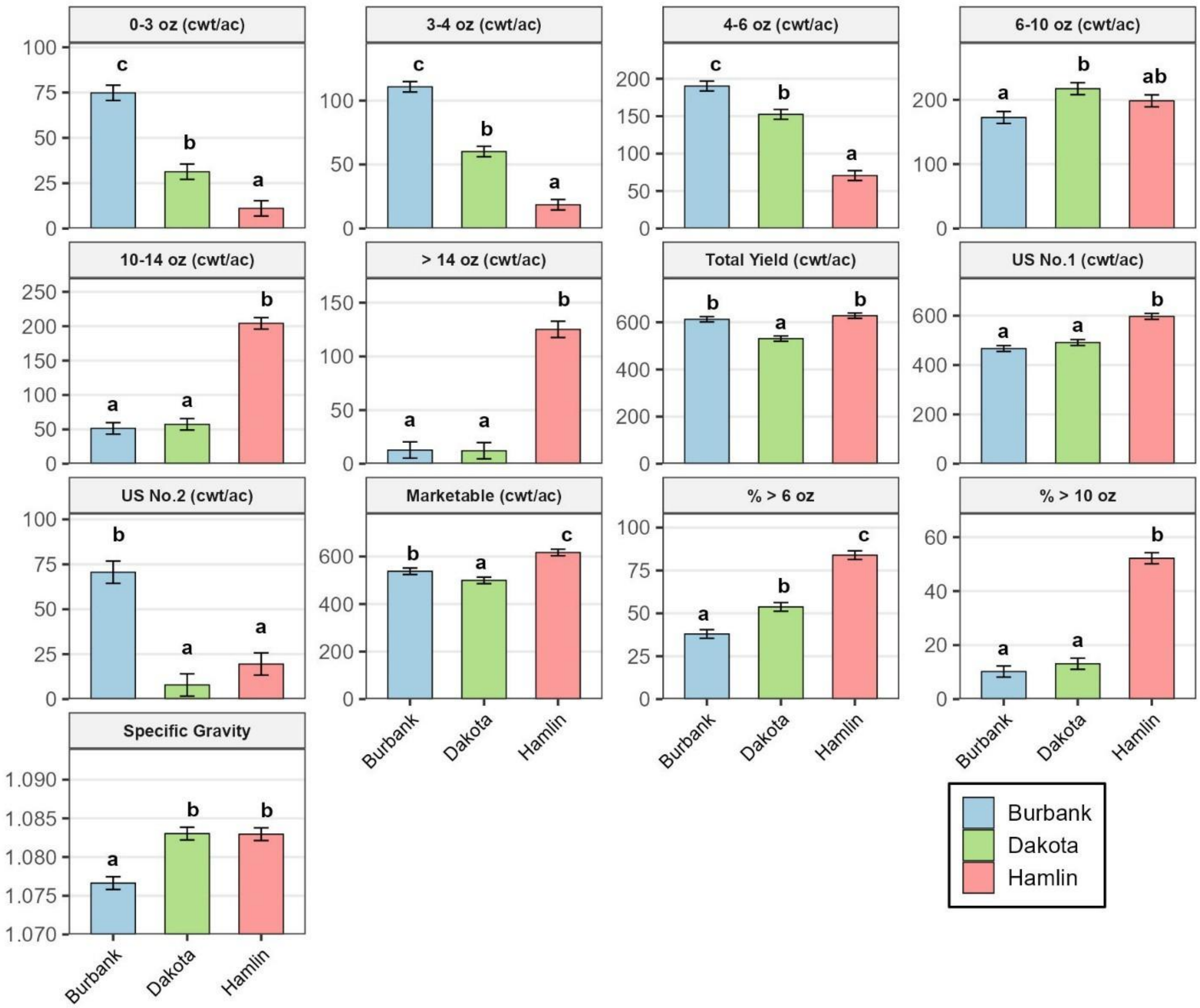

Figure 3. Cultivar differences in various yield categories (averaged across irrigation rates 60, 80 and 100% and N rates 160, 240 lb N ac^{-1} and PA). Bars with same letter are not significantly different.

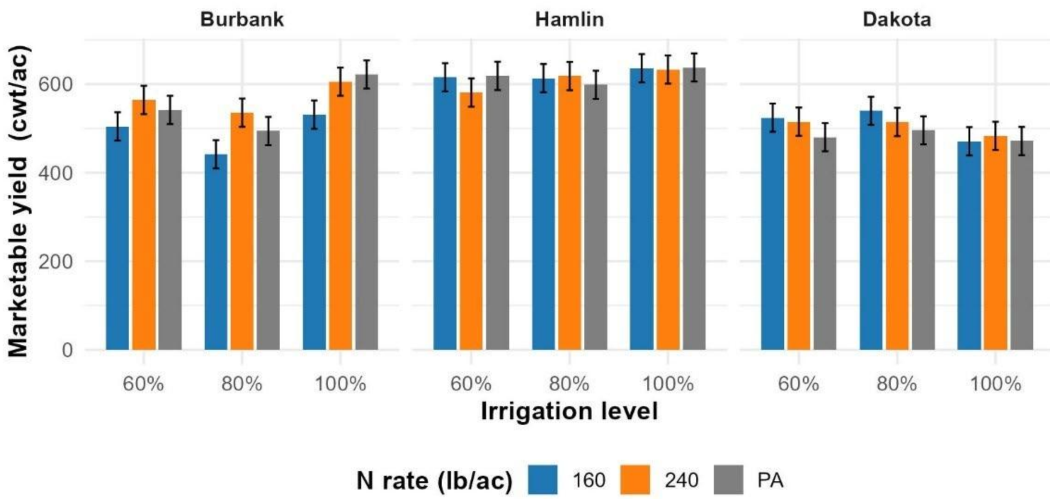

Figure 4. Marketable yield across irrigation (60, 80 and 100%) regimes and N rates (160, 240 lb N ac^{-1} and PA) for three cultivars.

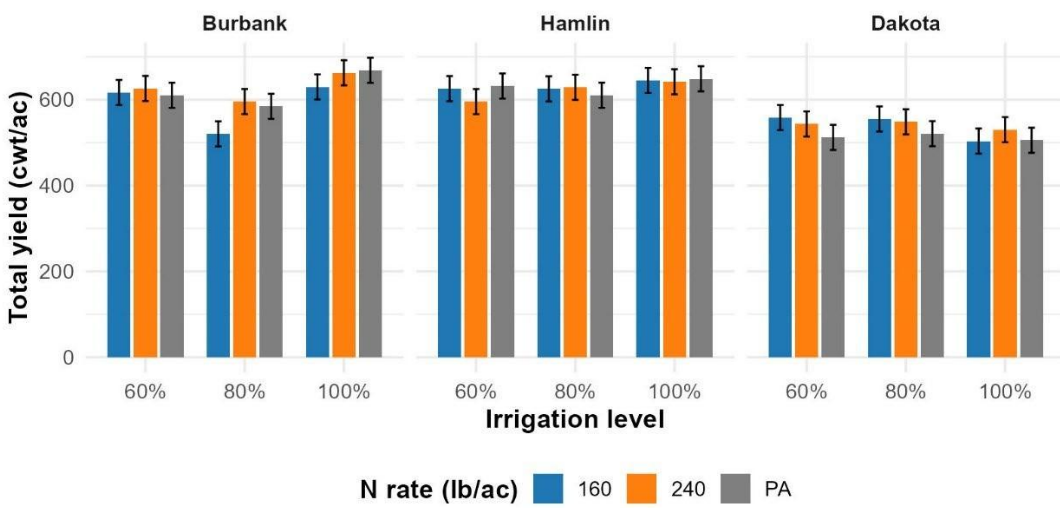

Figure 5. Total yield across irrigation (60, 80 and 100%) regimes and N rates (160, 240 lb N ac^{-1} and PA) for three cultivars.

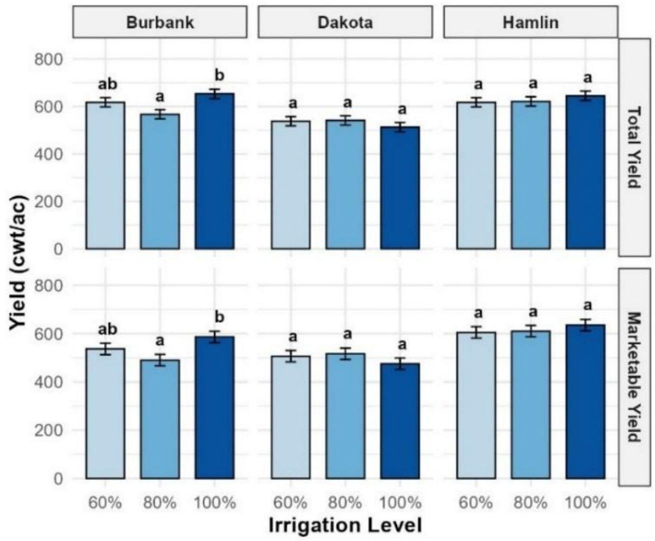

Figure 6. Interaction of irrigation regime and cultivar on total and marketable potato yield. Bars represent means ± SE; different letters indicate significant differences (Fisher's LSD, P < 0.05).

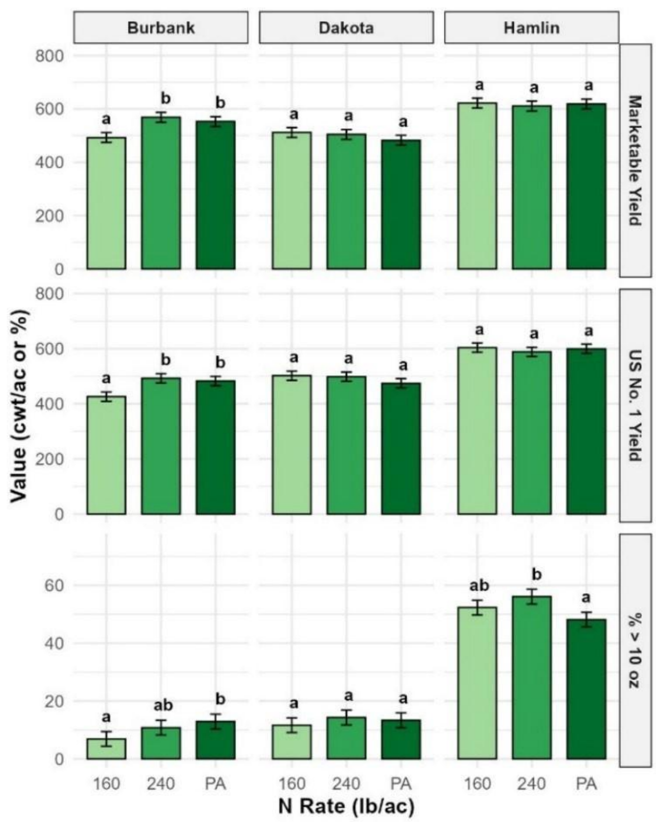

Figure 7. Interaction of N rate and cultivar on marketable yield, U.S. No. 1 yield, and tuber size. Bars represent means ± SE; different letters indicate significant differences (Fisher's LSD, P <

0.05).

Tuber size distribution differed markedly among cultivars and was not strongly influenced by irrigation or N rate at 160 and 240 lb N ac^{-1} (figure 8). HR consistently produced the most favorable size profile, with fewer culled and undersized tubers and a higher proportion in the 4+ oz classes across all fixed rate irrigation regimes. RB produced the highest percentage of tubers below 4 oz. DR showed a little better distribution, generally producing moderate amounts of medium-sized tubers and the few oversized (>14 oz) tubers.

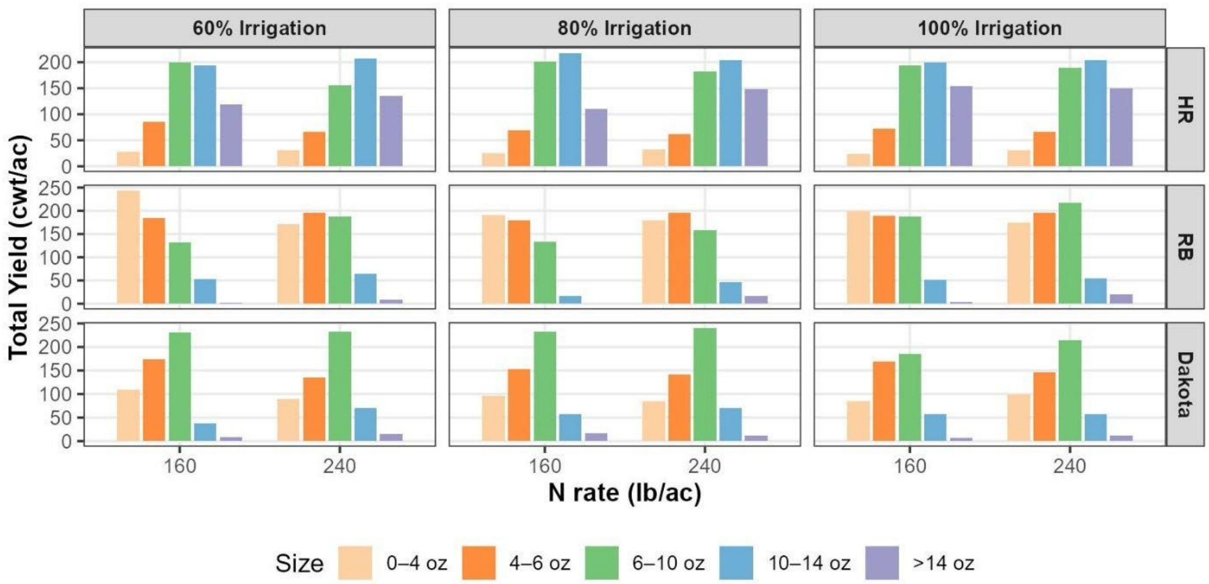

Figure 8. Total yields of HR, RB and DR by the five size classes in 2025 across fixed rate irrigation

(60, 80 and 100%), three cultivars and common N rates (160 and 240 lb N ac^{-1})

Yield components across all irrigation regimes, three cultivars and optimum N rates

Linear mixed effect models across all irrigation regimes (three fixed and three variable), three cultivars and optimum N rates (160 lb N ac^{-1} for HR and DR, and 240 lb N ac^{-1} for RB) shows that cultivar had a strong influence on all yield and size-class traits ($P < 0.0001$). HR again showed the most favorable yield profile, producing the highest U.S. No. 1 and marketable yields, along with the largest proportion of 6-oz and 10-oz tubers. RB and DR produced similar U.S. No. 1 yields, but RB had a much larger U.S. No. 2 fraction, indicating greater defect or misshape incidence (Figure 9). HR produced markedly more 6-oz and 10-oz tubers than either RB or DR. Irrigation rate did not affect any trait and no cultivar × irrigation interaction was detected. Thus, RB, HR, and DR maintained consistent relative performance across irrigation levels (Table 6).

Table 6. Results from the linear mixed models for various yield components across all irrigation regimes, three cultivars and optimum N rates (160 lb N ac^{-1} for HR and DR, and 240 lb N ac^{-1} for RB)

	0-3 oz.	**3-4 oz.**	**4-6 oz.**	**6-10 oz.**	**10-14 oz.**	**> 14 oz.**	**Total Yield**	**U.S. No. 1**	**U.S. No. 2**	**% over 6 oz**	**% over 10 oz**	**Marketable Yield**	**Specifi Gravit**
Cultivar	<0.0001 ***	<0.0001 ***	<0.0001 ***	0.2246 ns	<0.0001 ***	<0.0001 ***	<0.0001 ***	<0.0001 ***	<0.0001 ***	<0.0001 ***	<0.0001 ***	<0.0001 ***	<0.000 ***
Irrigation	0.759 ns	0.5269 ns	0.9701 ns	0.3909 ns	0.8722 ns	0.6581 ns	0.8383 ns	0.7791 ns	0.6565 ns	0.8814 ns	0.8754 ns	0.8214 ns	0.6392 ns
Cul × Irri	0.3320 ns	0.3127 ns	0.9841 ns	0.6425 ns	0.4349 ns	0.1185 ns	0.7786 ns	0.7458 ns	0.6637 ns	0.9946 ns	0.0745 ns	0.6180 ns	0.3143 ns

ns, *, **, *** non-significant or significant at P ≤ 0.05, 0.01, or 0.001, respectively.

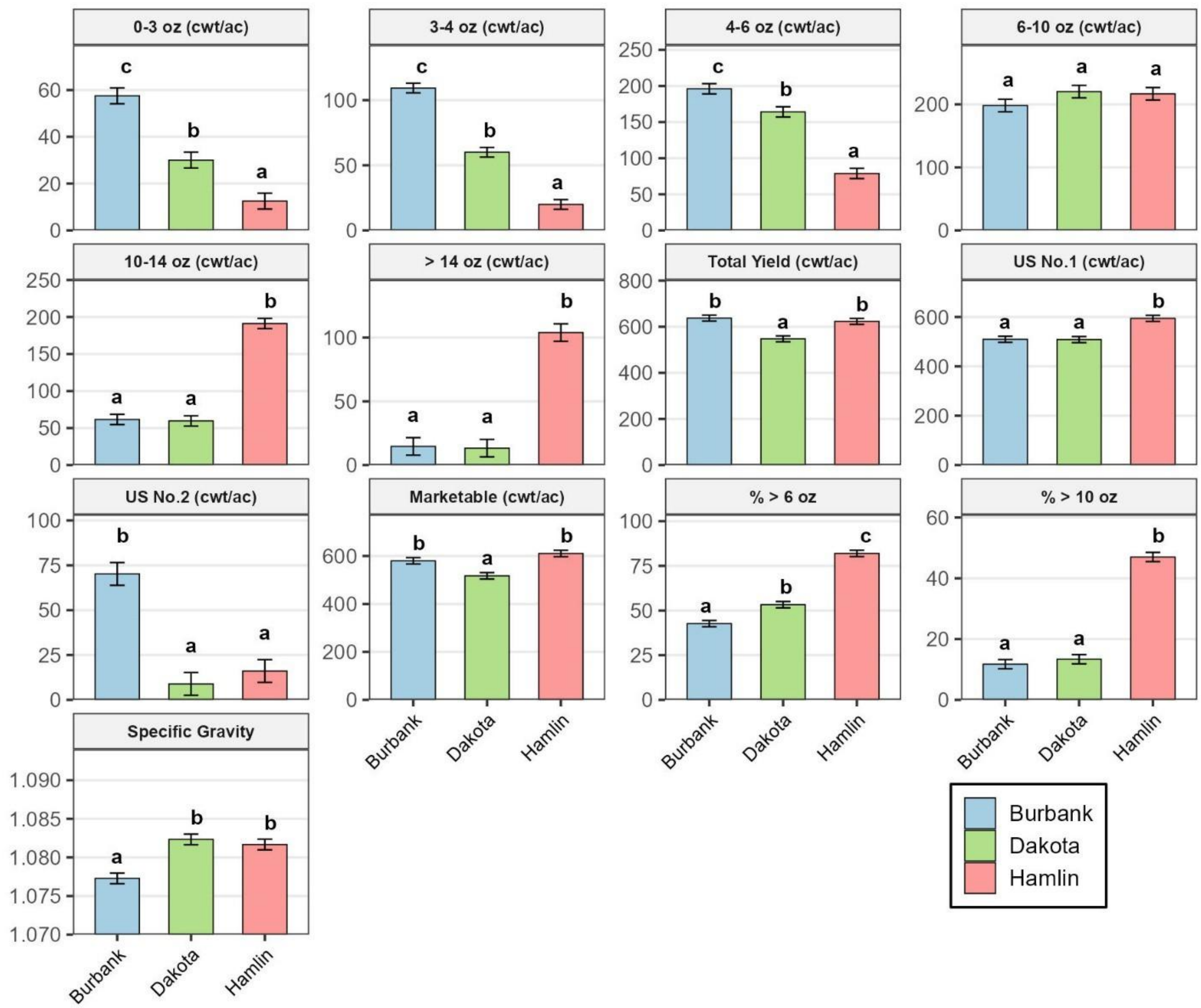

Figure 9. Cultivar differences in various yield categories (averaged across all six irrigation regimes). Bars with same letter are not significantly different.

Yield components and tuber size distribution of Russet Burbank at different N rates under full irrigation conditions

N rate significantly influenced total, marketable, and U.S. No. 1 tuber yields ($P < 0.0001$), while U.S. No. 2 yields showed no significant response to N treatment ($P = 0.5634$). Total yield exhibited a strong positive response to increasing N, rising from a low of 447 cwt/ac at the 40 lb N/ac rate to a peak of 629 cwt/ac at the 320 lb N/ac rate. However, yield benefits plateaued at higher rates as no statistical difference in total yield was observed between the 240 lb/ac (628 cwt/ac), 320 lb/ac (629 cwt/ac), and the PA treatment (621 cwt/ac). Marketable yield followed a similar, maximizing at 568 cwt/ac with the 240 lb/ac rate, which was statistically comparable to both the 320 lb/ac rate and the PA treatment.

Beyond overall yield numbers, N rate also influenced the tuber size distribution from smaller to larger size classes. Low N environments favored the production of smaller tubers, with the 40 lb/ac rate producing the highest yield of 0–3 oz tubers (141 cwt/ac). Conversely, yields of larger tuber classes increased linearly with N application. The yield of 6–10 oz tubers increased five-fold from 40 cwt/ac at the lowest rate to 200 cwt/ac at the 320 lb/ac rate (P < 0.0001). The percentage of tubers greater than 6 oz increased significantly (P < 0.0001) with N rate, rising from 10% at 40 lb N/ac to a maximum of 48% at 320 lb N/ac. Likewise, the percentage of tubers greater than 10 oz increased from 1% to 16% across the same range (table 7 and figure 11).

Table 7: Effect of N rate on potato tuber yield and size distribution at 100% irrigation level.

N Rate (lbs/ac)	0 - 3 oz.	3 - 4 oz.	4 - 6 oz.	6 - 10 oz.	10 - 14 oz.	> 14 oz.	Total Yield	U.S. No. 1	U.S. No. 2	% over 6 oz	% over 10 oz	Marketable Yield
40	141 a	132 ab	126 c	40 d	5 c	2 d	447 d	243 d	60	10 e	1 e	307 d
80	108 b	145 a	168 b	89 c	14 c	4 cd	527 c	358 c	61	20 d	3 de	419 c
160	97 b	114 bc	185 ab	151 b	40 b	2 d	589 b	426 b	66	32 c	7 cd	492 b
240	60 c	115 bc	196 a	187 a	56 ab	15 bc	628 a	493 a	76	40 b	11 bc	568 a
320	69 c	88 d	172 ab	200 a	70 a	31 a	629 a	477 a	83	48 a	16 a	561 a
PA	68 c	103 cd	191 ab	179 a	58 ab	21 ab	621 ab	483 a	70	41 b	13 ab	553 a
Pvalue	**<0.0001**	**0.0012**	**0.0008**	**<0.0001**	**<0.0001**	**0.0005**	**<0.0001**	**<0.0001**	**0.5634**	**<0.0001**	**<0.0001**	**<0.0001**

Means within a column followed by the same letter are not significantly different. Yield values are reported in cwt/ac.

Dose–response analysis for total and marketable yield using the N response curve treatments (40, 80, 160, 240, and 320 lb N ac^{-1}) at 100% irrigation for RB revealed a clear N response for both marketable and total yield. Yield increased sharply between 40 and 160 lb N ac^{-1}, after which the response began to level off. RB exhibited a quadratic response, with estimated optimal rate of near 180–220 lb N ac^{-1} for both marketable and total yield. Coefficient of Determination for marketable yield was approximately 0.70 and for total yield it was a moderate

0.53 (Figure 10).

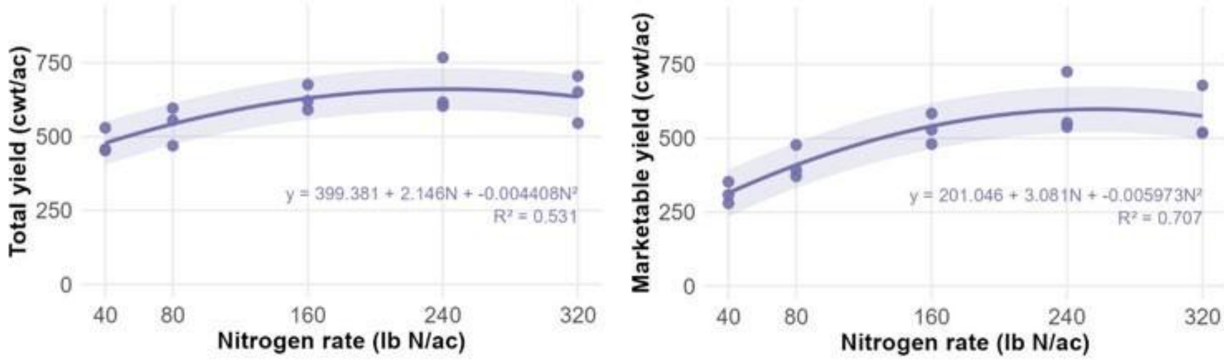

Figure 10: Total and marketable yield response of RB to N rates at 100% irrigation.

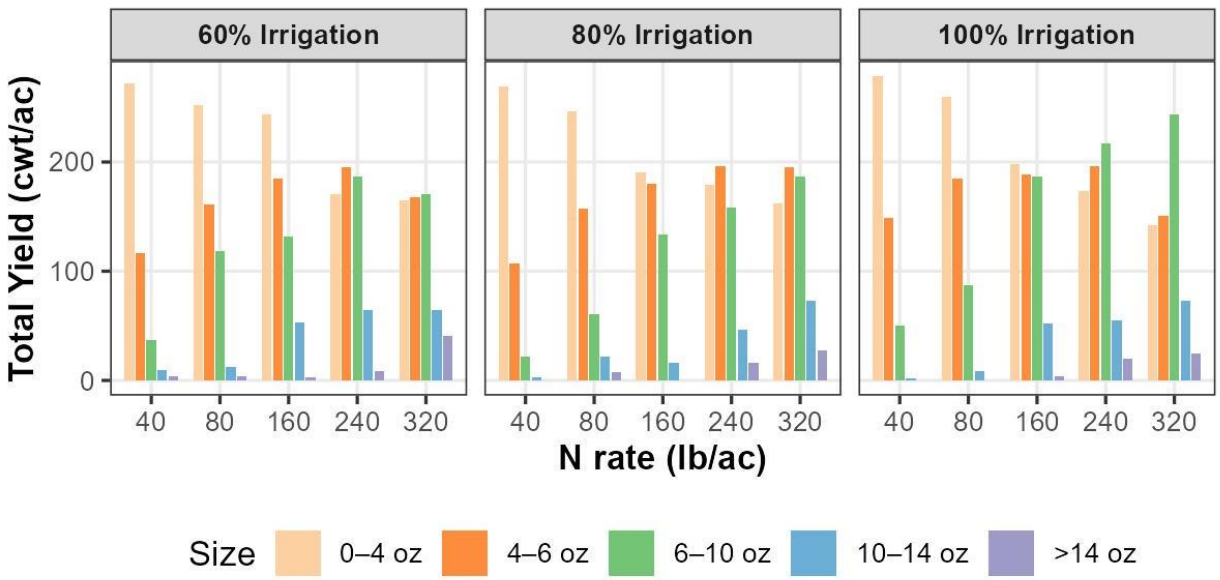

Figure 11. Total yields of RB by the five size classes in 2025

Partial factor productivity and economic returns

Figures 9 and 10 show the partial factor productivity (PFP; total yield divided by total N rate) and economic return of different treatments. The following prices were used for the net return calculation according to DTN report: $10 for a cwt of processing potatoes, $0.81/lb N for ESN, and $0.74/lb N for UAN. The N contribution from the DAP application at planting was not considered in net returns calculations.

Across all cultivars and irrigation levels, PFP was consistently highest under PA, followed by 160 lb N/ac, with 240 lb N/ac producing the lowest efficiency. Net return, however, was similar among the three N strategies, with PA matching or slightly exceeding the returns from 160–240 lb N/ac in most cases (figure 12). In the case of RB with a wider range of N rates, PFP decreased with increasing N at all irrigation levels, with the highest efficiency at 40 lb N/. In contrast, net return increased with N rate, peaking around 240–320 lb N/ac, while PA produced returns comparable to the highest N rates across all irrigation regimes (Figure 13).

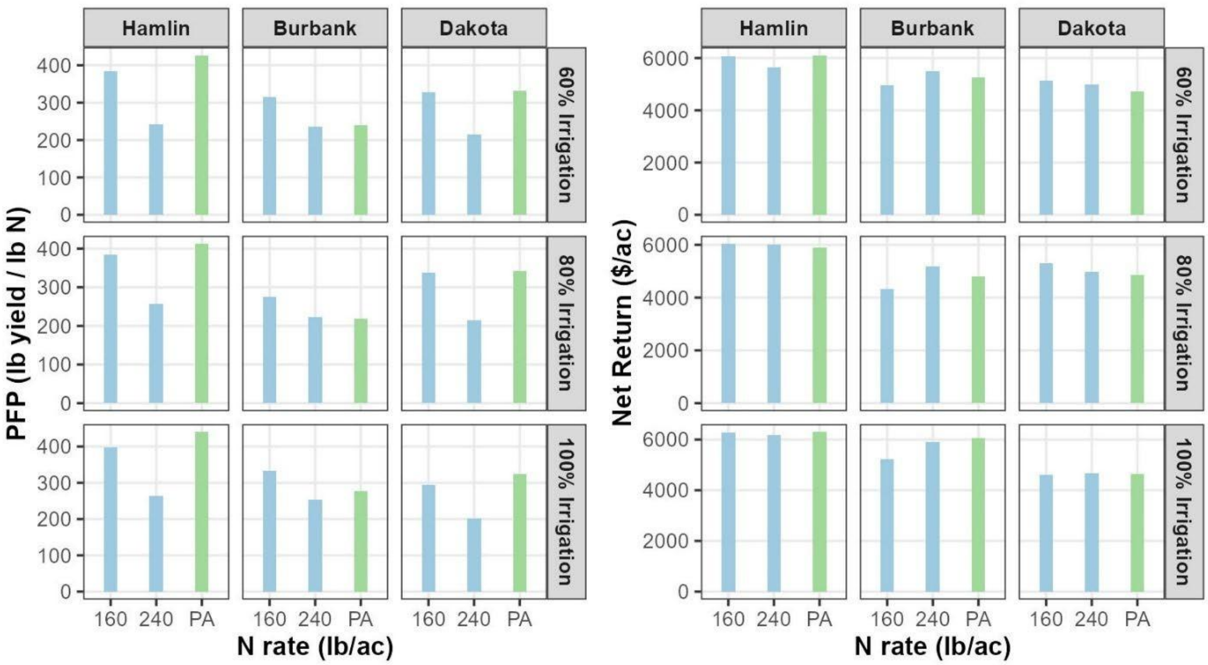

Figure 12. Partial factor productivity and net return across irrigation, cultivar, and nitrogen strategies (160, 240 lb N/ac & PA).

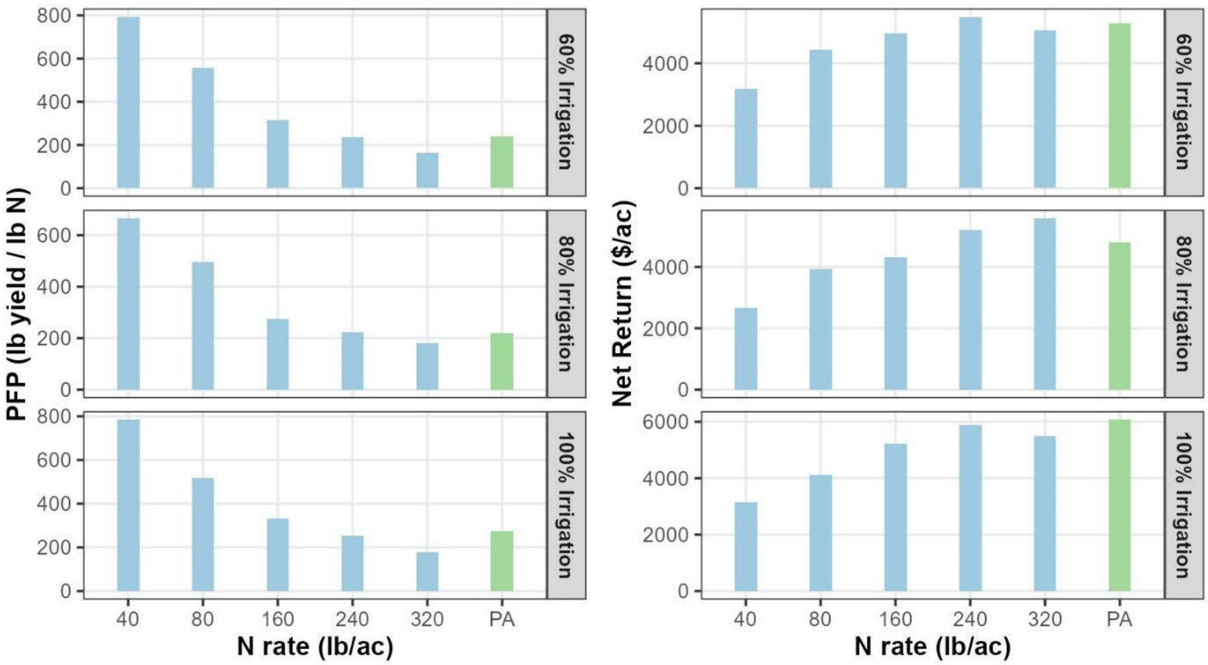

Figure 13. N rate effects on PFP and net return for RB across irrigation levels.

Irrigation water use efficiency and soil moisture dynamics

Irrigation water use efficiency (IWUE) was calculated as the ratio of total tuber yield to total irrigation applied. It was evaluated across all three cultivars at their respective optimum N rates (160 lb N ac^{-1} for HR and DR and 240 lb N ac^{-1} for RB). Analysis revealed an inverse relationship between total water input and efficiency. The full irrigation treatment (100-100-100) consistently exhibited the lowest IWUE due to diminishing yield returns at higher application volumes, whereas the most restrictive deficit treatments (60-60-60 and 60-80-60) maximized production per inch of water. Regarding the cultivars, all of them seem to perform similarly across irrigation regimes (Figure 14).

Temporal dynamics of soil moisture content revealed distinct grouping across soil depths and irrigation regimes throughout the season (Figure 15). In the deeper soil profiles (120, 160, 240, and 400 inches), treatment separation was pronounced and consistent. The full irrigation treatment (100%) maintained higher moisture levels compared to the deficit scenarios at the 400 inches depth. Surprisingly, 60% maintained higher moisture at 120-, 160- and 240-inch depths and the 100% and 80% were similar at these depths. The moisture dynamics in the upper profile (40 and 80 inches) were characterized by higher temporal variability, but lesser irrigation treatment difference.

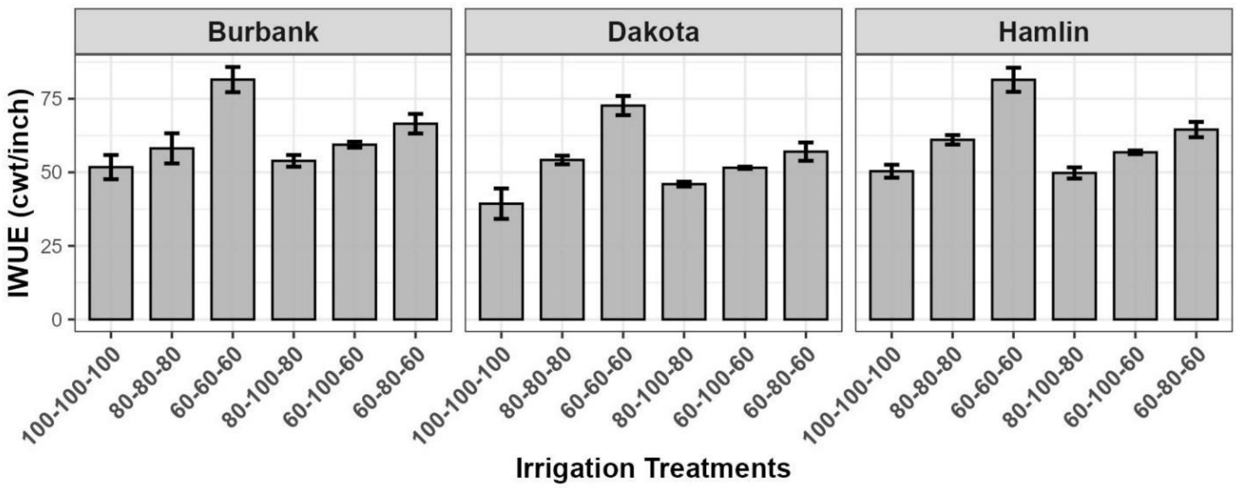

Figure 14. IWUE for three cultivars at optimum N rates (160 lb N ac^{-1} for HR and DR, and 240 lb N ac^{-1} for RB) across all irrigation regimes.

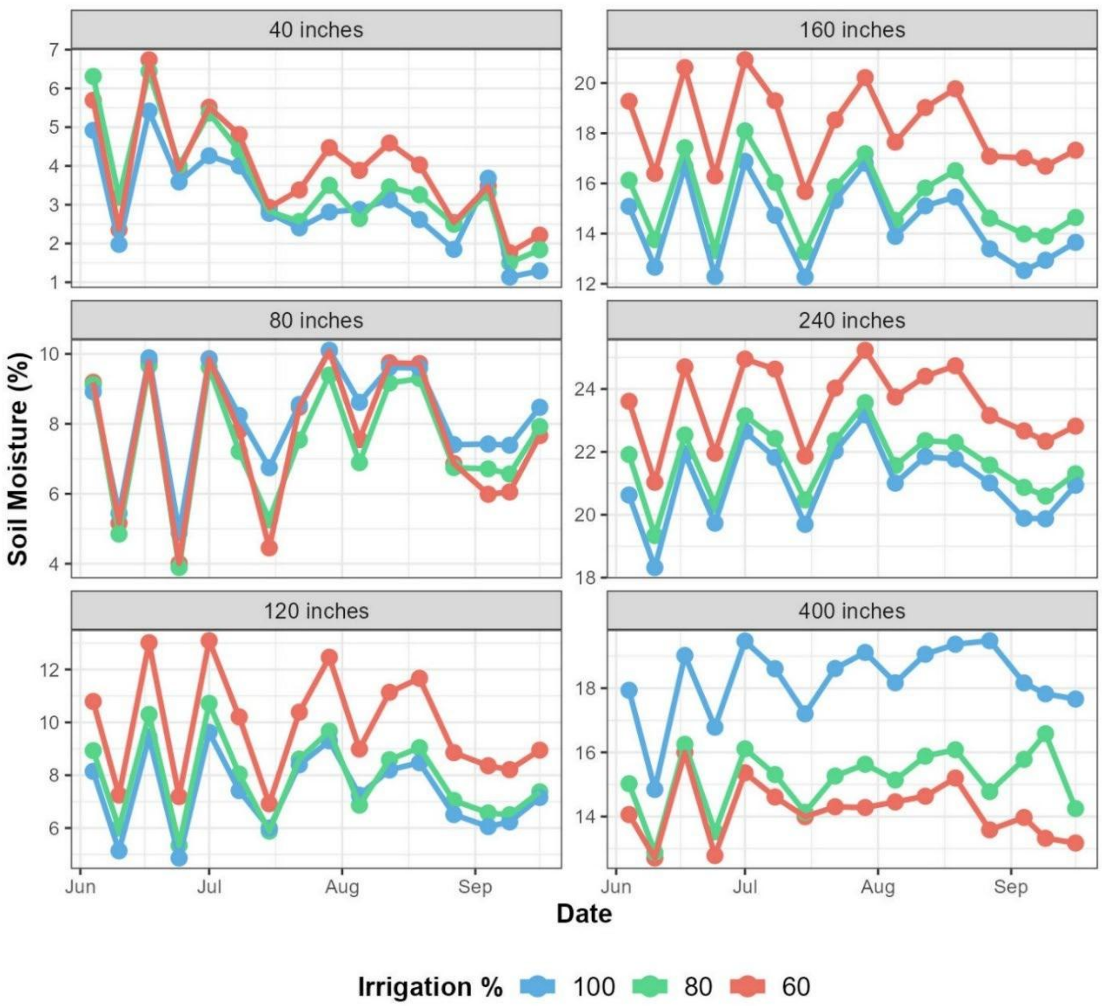

Figure 15. Seasonal soil moisture dynamics by depth under fixed-rate irrigation treatments. Data are averaged across N rates and cultivars.

Disease evaluations

4.6.1 Stem and foliar disease evaluations:

Generalized linear mixed models (Beta regression, $p < 0.05$) across fixed rate irrigation (80 and 100%), variable rate irrigation (80-100-80), two N rates (160, 240 lb N ac^{-1}) (Table 8) showed that *Alternaria* and blackleg incidence were not significantly impacted by irrigation or N rate ($p <$

0.05). Higher irrigation rates increased incidence of *Alternaria* and blackleg on average.

Table 8. Results from the generalized linear mixed models (Zero-Inflated Poisson, $p < 0.05$) for Alternaria and blackleg disease incidence across fixed rate irrigation (80 and 100%), two cultivars (RB and DR) and common N rates (160 and 240 lb N ac^{-1}).

Source of variation	Alternaria spp. incidence	Blackleg incidence
Cultivar	0.381 ns	0.082 ns
Irrigation	0.078 ns	0.252 ns
N Rate	0.490 ns	0.072 ns
Cul x Irri	0.518 ns	0.896 ns
Cul x N	0.749 ns	0.083 ns
Irri x N	0.734 ns	0.82 ns
Cul x Irri x N	0.948 ns	0.081 ns

ns, *, **, *** non-significant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively.

4.6.2 Potato Early Dying (PED) Incidence and Severity: Generalized linear mixed models (Beta regression, $p < 0.05$) showed no significant impacts on PED disease incidence and severity (table 9). High incidence was noted overall, with incidence rates reaching 90% for some plots.

Table 9. Results from the generalized linear mixed models (Zero-Inflated Poisson regression, $p < 0.05$) for PED incidence and severity index across fixed rate irrigation (80 and 100%), two cultivars (RB and DR) and common N rates (160 and 240 lb N ac^{-1}).

Source of variation	Mid-season PED incidence	Mid-season PED DSI	Late-season PED Incidence	Late-season PED DSI
Cultivar	0.462 ns	0.770 ns	0.199 ns	0.196 ns
Irrigation	0.09 ns	0.105 ns	0.7148 ns	0.718 ns
N Rate	0.449 ns	0.366 ns	0.573 ns	0.573 ns
Cul x Irri	0.205 ns	0.183 ns	0.434 ns	0.435 ns
Cul x N	0.459 ns	0. 229 ns	0.288 ns	0.288 ns
Irri x N	0.111 ns	0.652 ns	0.606 ns	0.606 ns
Cul x Irri x N	0.877 ns	0.601 ns	0.542 ns	0.542 ns

ns, *, **, *** non-significant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively.

4.6.3 Tuber disease evaluations:

Linear mixed effect models (Beta regression, $p < 0.05$) across irrigation and N showed no significant effects while variety had a highly significant effect ($p = 0.0003$) on common scab incidence (Table 10 and Figure 16). Irrigation treatment 80-100-80 had significantly lower common scab. No significant effects were detected for soft rot incidence.

Table 10. Results from the linear mixed models ($p < 0.05$) for soft rot and common scab incidence across fixed rate irrigation (80 and 100%), two cultivars (Russet Burbank and Dakota Russet) and common N rates (160 and 240 lb N ac^{-1}).

Source of variation	Soft rot incidence	Common scab incidence
Cultivar	0.939 ns	0.003 ***
Irrigation	0.109 ns	0.081 ns
N Rate	0.931ns	0.192 ns
Cul x Irri	0.144 ns	0.089 ns
Cul x N	0.779 ns	0.399 ns
Irri x N	0.111 ns	0.097 ns
Cul x Irri x N	0.197ns	0.137 ns

ns, *, **, *** non-significant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively.

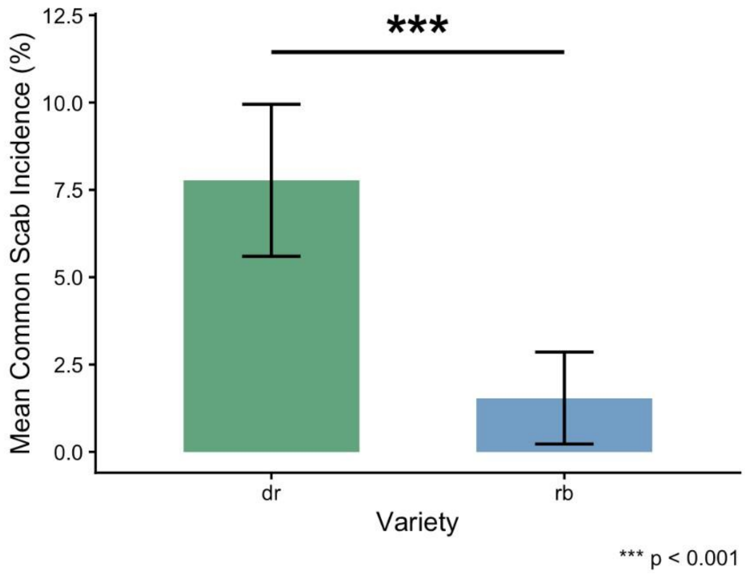

Figure 16. Dakota Russet had significantly higher common scab incidence compared to Russet Burbank.

Conclusions

The results demonstrated that cultivar selection was the dominant factor determining yield potential and tuber size distribution, often overriding the main effects of water and N management in 2025 growing season. Among the cultivars tested, HR consistently outperformed RB and DR in total, marketable, and large-size tuber yields. HR displayed a high degree of stability, maintaining superior performance across varying irrigation and N environments. In contrast, RB exhibited significant sensitivity to management practices. The significant *cultivar* × *irrigation* and *cultivar* × *N* interactions highlighted that while HR and DR remained stable under reduced inputs, RB required higher resource input specifically N and to maximize marketable yield and tuber quality.

The high amount of early season precipitation received over the 2025 growing season made it difficult to detect differences among irrigation treatments. Overall irrigation research in humid climates is a challenge due to unpredictable rainfall. This means multiple years are required to ensure that responses to irrigation are evaluated in drier years. N rates significantly influenced RB performance at 100% irrigation, with N rates 240 and 320 lbs N ac^{-1}, as well as the PA treatment, proving significantly superior to lower rates. Notably, the PA treatment performed on par with the 240 lbs N ac^{-1} standard across yield components, despite receiving a lower 225 lbs N ac^{-1}. Regarding resource efficiency, even for the input-responsive RB, PFP was highest at lower N rates, and economic net returns for Precision Agriculture (PA) treatments were comparable to the highest N rates. Similarly, IWUE was maximized under deficit irrigation strategies (60% and variable rates), suggesting that reduced water applications can sustain viable production levels, particularly for robust cultivars in wetter years.

Regarding disease incidence, lack of significant irrigation and N effects on most diseases suggest that growers may have flexibility in water and N management without substantially impacting disease pressure in years with high moisture, allowing them to optimize these inputs for yield or quality objectives rather than disease control. However, cultivar selection is an important factor in common scab control, where DR exhibited over three times the incidence of common scab compared to Russet Burbank ($p < 0.003$). Ongoing analysis of N leaching dynamics, plant N uptake, pathogen colonization, and remote sensing metrics will be essential to fully understand the physiological mechanisms driving the yield responses observed in this trial.

Project Title: Optimum Potato Seed Preparation Practices for Agronomically Relevant Cultivars of Northland Potato Growing Region

Munevver Dogramaci, Ph.D.

USDA-ARS, Edward T. Schafer Agricultural Research Center

1616 Albrecht Blvd N, Fargo, ND 58102-2765

Office: 701-239-1257 | Work Cell: 701-552-0496 Email**:** munevver.dogramaci@usda.gov

Dipayan Sarkar, Ph.D.

USDA-ARS, Edward T. Schafer Agricultural Research Center

1616 Albrecht Blvd N, Fargo, ND 58102-2765

Office: 701-239-1380

Email**:** dipayan.sarkar@usda.gov

Executive Summary: In recent years, Northland potato growers have expressed their concerns about the decay of cut seed tuber pieces in the field after planting under unfavorable soil and weather conditions. Optimum preparation of potato seed tuber pieces through suberization or formation of protective barriers on cut or bare surfaces is the most effective way to protect seed pieces against pathogens or physical decay under dry or wet soils. Therefore, it is important to build research driven insights regarding the ideal temperature and duration for suberization of cut seed tuber pieces for agronomically relevant potato cultivars. To achieve this, we have conducted two years (2024 & 2025) of field trials and parallel greenhouse experiments using seed tubers of three russet cultivars (Bannock Russet, Dakota Russet, and Russet Burbank). In our experimental procedure, we used nine subsets of seed tubers for different treatments to compare planting tubers with or without cutting, and with or without suberization of cut pieces, along with suberized and delayed planting scenarios. Suberized cut seed pieces and non-suberized/fresh cut seed tubers were simultaneously planted along with whole tubers. Emergence, plant growth, and stem count data from the field and greenhouse experiment were

collected. Results of the field study revealed early emergence (4-7 days early emergence) from suberized and stored pieces when compared to fresh cut/non-suberized treatment. However, planting whole tubers also generated higher emergence and growth compared to fresh cut in the field trial. Suberization of cut seed tubers led to higher plant height in Bannock Russet and Dakota Russet. During the 2026 crop year, follow-up experiments will be conducted to further validate these findings.

Background: Optimum performance of potato seed tubers in the field with timely and uniform emergence is important for robust growth and higher productivity. The current pre-planting practice in Northland potato growing region usually does not include suberization (curing) of cut seed pieces. Cut seed tubers with bare and open surface are generally susceptible to pathogen attack or prone to decay in the field when planted under unfavorable conditions, such as too cold/warm weather or too wet/dry soil conditions. In this context, pre-planting curing of cut potato seed tubers under optimum temperature and duration can allow the formation of protective suberin layer in open surface of the seed tubers, which subsequently prevent/minimize seed tuber pieces from decaying and support uniform emergence and crop growth. However, one of the challenges for pre-planting suberization is facilitating the optimum conditions and duration in the storage to promote the suberization process. Additionally, while some potato cultivars have rapid wound-healing trait, others may be slower to heal. Therefore, the curing conditions, especially temperature and duration to improve suberization of cut seed tuber pieces, should be optimized for agronomically relevant potato cultivars to achieve uniform emergence and growth, and high yield.

Procedure: For 2025 field and greenhouse trial, seed tubers of Bannock Russet, Dakota Russet, and Russet Burbank were obtained in the spring of 2025 from commercial seed tuber producers; Thompson Brothers (Park River, ND), Nilson Farms (Hoople, North Dakota), Bjornstad Potato Farm (Walhalla, ND). After receiving the tubers at USDA Labs, one subset of seed tubers were kept at 38°F and used as whole tuber and fresh cut treatments, while a second subset of tubers were warmed up (from 38 to 50°F over 7-day), and used for fresh cut, suberized, and delayed planting treatments (Table 1); two subsets of cut seeds were incubated (at 50°F, 95% RH) to allow suberization for 1- or 2-weeks. After the suberization period, each subset was further divided in three groups. One set from each suberization duration was planted immediately, while second and third subset were further stored under 45°F for 1- or 2-weeks to mimic delayed planting scenario (Table 1). All suberized and stored cut seed tuber pieces were warmed up to 50°F (over 3-day) prior to the planting and all seed preparation treatments were synchronized for simultaneous planting. In 2025, the field experiment was conducted at Arvilla (Hoverson Farms, ND) under commercial production practices with total nine treatments and four

replications/treatment. A parallel greenhouse experiment was conducted at the Jack Dalrymple Agricultural Research Complex on NDSU campus (Fargo, ND). Emergence and growth of the potato plants were monitored on a weekly basis.

Table 1. Details of the seed preparation treatments of potato tubers for the 2025 field experiment.

Treatments	Fresh Cut/Suberization	Delayed Planting Scenario
Treatment 1	Whole tubers from 38°F storage	
Treatment 2	Fresh cut from tubers stored at 38°F	
Treatment 3	Fresh cut from tubers warmed up to 50°F for 1-week prior to cutting and planting	
Treatment 4	Suberized at 50°F for 1-week	
Treatment 5	Suberized at 50°F for 1-week	Stored at 45°F for 1-week after suberization
Treatment 6	Suberized at 50°F for 1-week	Stored at 45°F for 2-weeks after suberization
Treatment 7	Suberized at 50°F for 2-weeks	
Treatment 8	Suberized at 50°F for 2-weeks	Stored at 45°F for 1-week after suberization
Treatment 9	Suberized at 50°F for 2-weeks	Stored at 45°F for 2-weeks after suberization

Results: Results from 2025 field experiment revealed that suberized seed tuber pieces emerged 4-7 days earlier when compared to non-suberized/fresh cut treatment; these results corroborated with 2024 field trial results. However, in 2025 field trial, emergence rate of whole tubers, as well fresh cut tubers, reached similar range as some of the suberized treatments after

30 days of planting (Figure 1). Response to pre-planting curing conditions varied significantly among cultivars as 1- (Treatment 4) and 2-weeks (Treatment 7) suberization treatments led to higher plant height in Bannock Russet, while 2-weeks suberization and 1-week additional storage at 45°F (Treatment 8) resulted in higher plant height in Dakota Russet (Figure 2). For Russet Burbank, no significant differences in plant height were observed among suberized and nonsuberized seed preparation treatments after 45 days of planting (Figure 2). Overall, differences in plant growth were observed among whole tuber, fresh cut, and suberized seed preparation treatments for Dakota Russet at 45 days after planting (Figure 4, 5, & 6). However, no significant differences in plant growth among seed preparation treatments were observed for Russet Burbank (Figure 7, 8, & 9). Follow-up experiment is needed to confirm these findings from the last two years field trial; we will repeat the experiment in the field and in the greenhouse in 2026.

Figure 1. Field emergence (%) of Bannock Russet, Dakota Russet, and Russet Burbank plants from different seed preparation treatments after 30 days of planting.

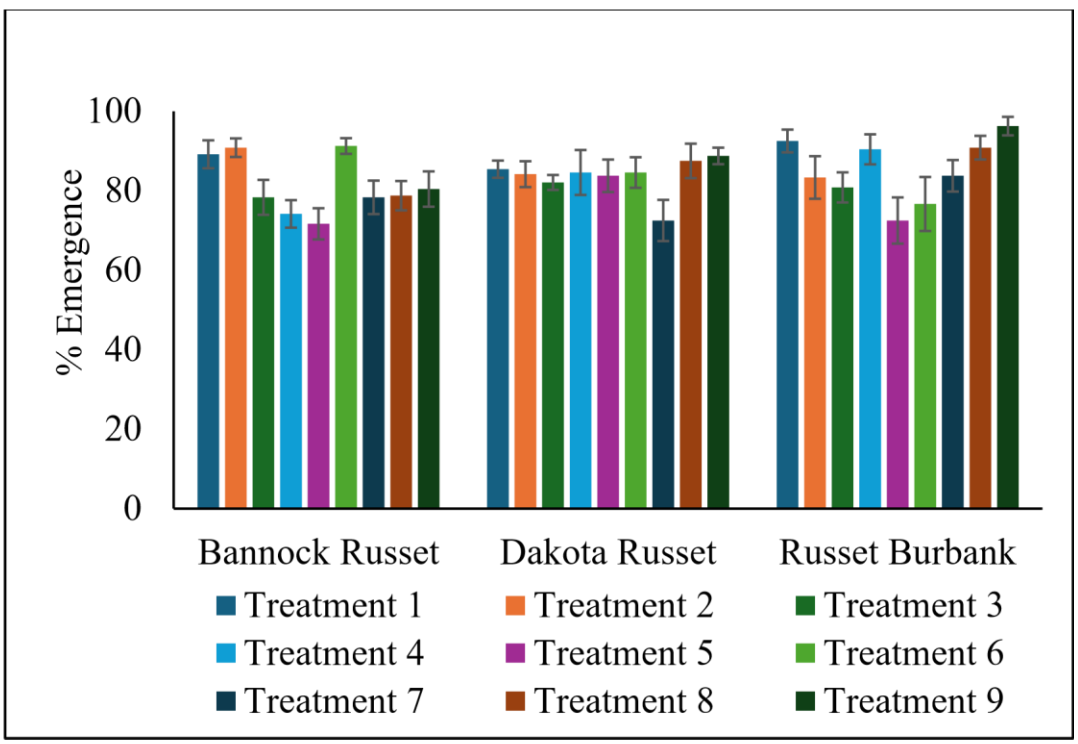

Figure 2. Height (inches) of Bannock Russet, Dakota Russet, and Russet Burbank plants grown from different seed preparation treatments after 45 days of planting.

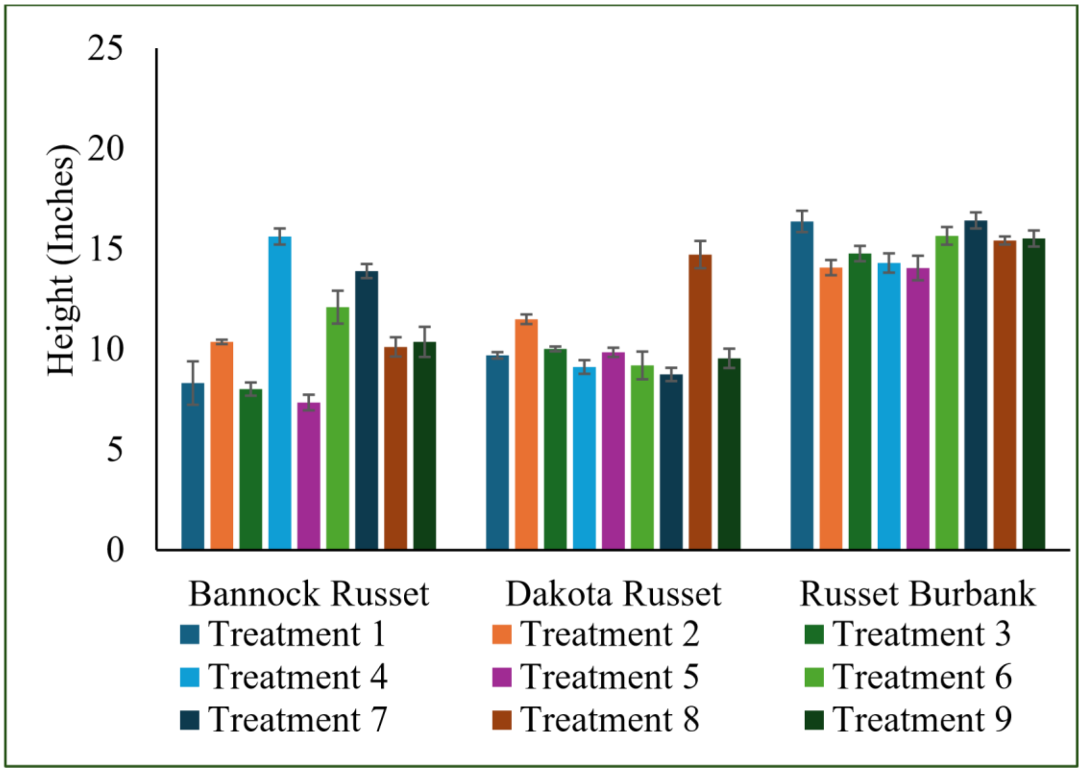

Figure 4. Growth (45 days after planting) of Dakota Russet plants grown from whole tubers (Treatment 1) in 2025 field trial.

Figure 5. Growth (45 days after planting) of Dakota Russet plants grown from fresh cut seed tubers stored at 38°F (Treatment 2) in 2025 field trial.

Figure 6. Growth (45 days after planting) of Dakota Russet plants from suberized cut seed at 50°F for 2-weeks along with additional storage at 45°F for 1-week (Treatment 8) in 2025 field trial. For Dakota Russet, robust growth and greater vigor was observed with this seed preparation treatment.

Figure 7. Growth (45 days after planting) of Russet Burbank plants grown from whole tubers (Treatment 1) in 2025 field trial.

Figure 8. Growth (45 days after planting) of Russet Burbank plants grown from fresh cut seed tubers stored at 38°F (Treatment 2) in 2025 field trial.

Figure 9. Growth (45 days after planting) of Russet Burbank plants from suberized cut seed at 50°F for 2-weeks along with additional storage at 45°F for 1-week (Treatment 8) in 2025 field trial.

Effects of Novofert and Novofert with Humic on Russet Burbank Potato Production

Investigator contact:

Andy Robinson

Potato Extension Agronomist, NDSU / U of M

PO BOX 6050, Fargo, ND 58108

701.219.9646

Andrew.p.robinson@ndsu.edu

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 Novofert and Novofert with humic in potato production, added as an additional treatment in-furrow or at preemergent herbicide treatment timing. At p=0.1 there were no differences in total or marketable yield.

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 Novofert and Novofert with humic to increase microbial activity to make phosphorous more available to plant roots. Novofert with humic contains 10% carbon source, mainly in the form of humates. The objective of this study was the determine the effects of Novofert and Novofert with humic on potato tuber yield.

Procedures

A field study was established in a commercial field near Perham, MN, managed by RD Offutt Farms and on a non-irrigated commercial field near St. Thomas, ND. Each trial utilized a randomized complete block with four replicates.

At Perham, MN Russet Burbank was planted on 6 May 2025 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. Treatments were applied in-furrow over the top of the seed piece at planting and after hilling on 11 June 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 Novofert or Novofert with humic easy to incorporate in typical potato production practices and not make a separate application.

Treatments utilized for this study were as follows:

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

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 muriate of potash applied at an average of 600 lb/a plus sulfate of potash at 295 lb/a in the spring of 2025 by RD Offutt Farms. Prior to hilling on 27 May 2025, 300 lb/a MAP + 310 lb/a AMS + 7 lb/a B + 193 lb/a Urea was applied. The total amount of nutrients applied was 285 lb/a N, 156 lb/a P, 520 lb/a K, 125 lb/a S, and 1 lb/a B. All irrigation, in-season crop protection, and management was completed by RD Offutt Farms.

Plots were harvested on 11 September 2025. 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 19 September 2025. Tubers were sized into the following categories, <4 oz, 4-6 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 (<4 oz; however, some contracts consider undersized as any tuber <3 oz) and any culls. Specific gravity was measured on 19 September 2025 using the weight in water method.

At St. Thomas, ND the cultivar Dark Red Norland was planted on 30 May 2025 at 9" within row spacing. Seed was precut to approximately 2 oz and suberized prior to planting. Plots were 12 ft wide by 20 ft long. Prior to planting the field was fertilized with 136 lb N/a (239 lb/a urea + 115 lb/a MAP + 63 lb/a AMS), 60 lb P_2O_5/a, 140 lb K_20/a, 2 lb/a Zn, and 2 lb/a Cu. This is a non-irrigated site that relies on rainfall for moisture. A total of 6.9 inches of rain fell between planting and the first vine killing date. Novofert treatments were applied at planting, being sprayed in-furrow over the top of the seed piece and shortly after hilling on 26 June with a CO_2 pressured backpack sprayer and 6-foot-wide hand boom. On September 6 and 16 the vines were desiccated with diquat and ensure strong skin at harvest.

Plots were harvested on 1 October 2025. 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 17 October 2025. The tuber size profile distribution was determined by sorting all potatoes harvested into C size (less than 1.875 inches), B size (1.875 to 2.25 inches), A size (2.25 to 3.5 inches) and Chef size (greater than 3.5 inches). Total yield is a summation of C + B + A + Chef. Specific gravity was measured on 22 October 2025 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 0.1. Data were separated with a Tukey pair-wise comparison. The further analyze the data for the Perham site, contrast statements were applied to compare (1) Novofert vs. Novofert with humic, (2) in-furrow vs. pre-emergent timing, (3) Non-treated vs. Novofert, and (4) Non-treated vs. Novofert with humic. Contstacts were not performed for the

St. Thomas site because there were no significant differences in the data when the analysis of variance was run.

Results

Russet Burbank at a p-value of 0.1 had significant differences in yield for the tubers <4 oz and for tuber form 6-10 oz (Table 1). No significant differences were found in tuber number (Table 2). The Novofert with humic had a greater volume of tubers <4 oz and from 6-10 oz compared to the non-treated check. Total and marketable yield was not affected by treatment in the analysis of variance. However, the contrast of non-treated vs. Novofert with humic had a significant difference in the number of tubers in total yield. The contrast comparing Novofert vs. Novofert with humic found differences in the <4 oz, 10-14oz, and percent of tubers >6 oz in cwt/a and in tuber number. Novofert with humic increased tuber number but decreased size as a result to a higher tuber count when compared to Novofert.

Specific gravity was affected by the treatments (Table 3). Novofert and Novofert with humic had a higher specific gravity compared to the non-treated check. Novofert with humic had a lower ratio of tuber length:width. Longer potato tubers can make longer French fries. Novofert with humic applied at the pre-herbicide timing reduced average tuber size compared to all other treatments. These data support the previous yield results, that Novofert with humic resulted in smaller tubers than the Novofert.

At the St. Thomas site there were no differences in tuber size categories or total yield (Tables 4 and 5). Specific gravity was not affected by treatment. The percent of tubers that were A size was less for the pre-herbicide timing treatments compared to the non-treated check. The percent of A + B sized tubers was less for the Novofert treatment at pre-herbicide timing compared to the non-treated check. Numerically these data suggest that the pre-herbicide timing treatments had more oversized or chef sized tubers that resulted in the lower percentage of A and A+B sized tubers.

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. The size for chipping potato tubers is being requested to be smaller so chips can fit into smaller bag sizes. An increase in tuber number may decrease the volume of seed needed if seed can be spaced further apart and maintain the same number of tubers per acre.

Table 1. Graded yield of Russet Burbank tubers grown in Perham, MN in 2025 and treated with Novofert and Novofert with humic in-furrow or at preemergent timing.

Treatment		<4 oz		4-6 oz	6-10 oz		10-14 oz	>14 oz	Total yield	Total marketable	>6 oz	>10 oz
		---------- cwt/a ----------									---- % ----	
1 Non-treated		62	b	86	164	b	120	62	494	432	70	37
2 Novofert (in-furrow at 25 oz/a)		67	ab	93	187	ab	121	61	529	462	70	34
3 Novofert with humic (in-furrow at 25 oz/a)		78	ab	91	166	ab	95	64	493	415	66	32
4 Novofert (pre-herbicide timing at 25 oz/a)		71	ab	84	163	b	113	70	501	430	69	36
5 Novofert with humic (pre-herbicide timing at 25 oz/a)		93	a	97	197	a	82	31	500	408	62	22
Mean		74		90	176		106	57	504	429	67	32
Treatment effect (P-value)		**0.0985**		0.6954	**0.0941**		0.2205	0.4200	0.5799	0.2474	0.2576	0.1284
Contrasts	Novofert vs Novofert with humic	**0.0499**		0.4685	0.5608		**0.0495**	0.2474	0.3313	0.1043	**0.0739**	**0.0596**
	In-furrow vs Pre emergent timing	0.2408		0.8552	0.7434		0.4359	0.4505	0.5648	0.3317	0.4259	0.3342
	Non-treated vs Novofert	0.4829		0.7742	0.4013		0.8713	0.8640	0.3663	0.5747	0.8274	0.7460
	Non-treated vs Novofert with humic	**0.0265**		0.3826	0.1973		**0.0755**	0.4315	0.9125	0.4150	**0.0935**	**0.0647**

Table 2. Number of tubers of graded yield of Russet Burbank grown near Perham, MN in 2025 and treated with Novofert and Novofert with humic in-furrow or at preemergent herbicide timing.

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		35,574	25,592	31,944	15,428	5,808	114,345	78,771	47	19
2 Novofert (in-furrow at 25 oz/a)		40,293	29,948	38,297	16,698	5,990	131,225	90,932	47	17
3 Novofert with humic (in-furrow at 25 oz/a)		45,375	27,770	33,033	12,705	5,627	124,509	79,134	41	15
4 Novofert (pre-herbicide timing at 25 oz/a)		40,656	27,044	34,122	15,609	6,353	123,783	83,127	45	18
5 Novofert with humic (pre-herbicide timing at 25 oz/a)		52,817	30,674	39,930	11,072	2,904	137,396	84,579	40	10
Mean		42,943	28,205	35,465	14,302	5,336	126,251	83,309	44	16
Treatment effect (P-value)		0.1281	0.3850	0.1609	0.2497	0.5553	0.1865	0.2404	0.2817	0.1380
Contrasts	Novofert vs Novofert with humic	**0.0730**	0.7188	0.9145	**0.0400**	0.2433	0.6035	0.2134	**0.0613**	**0.0472**
	In-furrow vs Pre emergent timing	0.3967	1.0000	0.5931	0.4840	0.4638	0.6812	0.7710	0.6088	0.4006
	Non-treated vs Novofert	0.3851	0.2494	0.1828	0.7589	0.8527	0.1191	0.1109	0.8658	0.7457
	Non-treated vs Novofert with humic	**0.0261**	0.1549	0.1580	0.1484	0.4346	**0.0544**	0.5363	**0.0883**	**0.0535**

Table 3. Plant stand, stem number, specific gravity, tuber length to width ratio, and tuber size of Russet Burbank grown near Perham, MN in 2025 and treated with Novofert and Novofert with humic in-furrow or at preemergent herbicide timing.

Treatment		Stand	Stems/plant	Specific Gravity		Tuber length: width		Tuber size	
		%	no			number		oz	
1 Non-treated		90.0	2.7	1.075	b	1.88	a	6.50	a
2 Novofert (in-furrow at 25 oz/a)		88.8	3.0	1.084	a	1.87	a	6.46	a
3 Novofert with humic (in-furrow at 25 oz/a)		90.6	2.8	1.080	ab	1.81	b	6.12	a
4 Novofert (pre-herbicide timing at 25 oz/a)		88.8	2.6	1.079	ab	1.90	a	6.50	a
5 Novofert with humic (pre-herbicide timing at 25 oz/a)		87.5	2.5	1.082	ab	1.79	b	5.67	b
Mean		89.1	2.7	1.080		1.85		6.25	
Treatment effect (P-value)		0.8866	0.7393	**0.0473**		**<0.0001**		**<0.0001**	
Contrasts	Novofert vs Novofert with humic	0.9012	0.6443	0.9449		**<.0001**		**<.0001**	
	In-furrow vs Pre emergent timing	0.5371	0.2103	0.3756		0.8454		0.1548	
	Non-treated vs Novofert	0.6858	0.7058	**0.0166**		0.7848		0.9186	
	Non-treated vs Novofert with humic	0.7613	1.0000	**0.0186**		**<.0001**		**0.0036**	

Table 4. Yield of Dark Red Norland grown near St. Thomas, ND in 2025 and treated with Novofert and Novofert with humic in-furrow or at preemergent timing

Treatment		C	B	A	Chef	Total yield	Marketable yield	A+B	A	B
		--- cwt/a ---						------------- % -------------		
1	Non-treated	0.3	62	249	7	318	311	98 a	78 a	20
2	Novofert (in-furrow at 25 oz/a)	0.9	71	226	11	309	298	96 ab	73 ab	23
3	Novofert with humic (in-furrow at 25 oz/a)	0.2	67	264	22	353	331	94 ab	75 ab	20
4	Novofert (pre-herbicide timing at 25 oz/a)	0.8	65	231	27	324	297	91 b	71 b	20
5	Novofert with humic (pre-herbicide timing at 25 oz/a)	0.9	63	221	31	316	285	90 ab	70 b	20
Mean		0.6	66	238	20	324	304	94	73	21
P-value		0.4756	0.8773	0.4416	0.1278	0.5333	0.5198	0.0631	0.0330	0.7488

Table 5. Plant stand, stem number, and tuber size of Dark Red Norland grown near St. Thomas, ND in 2025 and treated with Novofert and Novofert with humic in-furrow or at preemergent herbicide timing

Treatment		Stand	Stems/plant		Specific gravity
		%	no		
1	Non-treated	89.3	3.9	a	1.076
2	Novofert (in-furrow at 25 oz/a)	88.8	3.3	b	1.077
3	Novofert with humic (in-furrow at 25 oz/a)	83.5	4.0	a	1.077
4	Novofert (pre-herbicide timing at 25 oz/a)	89.7	3.5	ab	1.075
5	Novofert with humic (pre-herbicide timing at 25 oz/a)	89.3	3.9	a	1.076
Mean		88.1	3.7		1.076

P-value	0.3128	0.0196	0.8260

A1783-25 (December 2025)

North Dakota Fresh Market Potato Cultivar/Selection

Trial Results for 2025

Figure 1. Yellow selections and cultivars growing on July 22, 2025, near St. Thomas, ND. (Robinson, NDSU/UMN)

Extension Potato Agronomist and

Andy Robinson

Professor, NDSU/UMN

Eric Brandvik

Research Specialist, NDSU

Anderson Melo

Research Scientist, NDSU

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 new to the U.S. Standard potato cultivars used by growers served as checks. For comparison, studies conducted in 2019, 2020, 2021 and 2024

e v a l u a t e d s e v e r a l r e d -

and yellow-skinned fresh potatoes.

In 2025, two trials were conducted to identify traits of red- and yellowskinned potato cultivars and advanced selections near St. Thomas, North Dakota. Thirteen red-skinned cultivars and 14 yellow-skinned clones were evaluated. Plots were established in a commercial, nonirrigated potato field utilizing common potato production practices. The authors acknowledge J.G. Hall and Sons for hosting these trials.

University of Minnesota EXTENSION

NDSU EXTENSION

North Dakota State University

Fargo, North Dakota

Prior to planting, urea at 120 pounds of nitrogen (N) per acre was broadcast and incorporated. A randomized complete block design with four replicates was utilized. Plots were 3 feet wide and 30 feet long. Seed tubers were hand-cut to approximately 2-ounce seed pieces and suberized prior to planting.

Tubers were planted on May 30, 2025, in a single row with 9-inch withinrow spacing. The number of emerged plants in the entire plot was counted to determine the emergence rate. The number of stems per plant was determined by counting the stems on 10 plants in a row in each plot. Vines were killed with diquat on Sept. 6 and 16, 2025. Plots were harvested on Oct. 2, 2025, with a single-row lifter and thereafter bagged by hand.

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

The 2025 agronomic data presented in Tables 1 and 2 were analyzed statistically. These analyses allow the reader to ascertain, at a predetermined level of confidence, whether the differences observed among cultivars/ selections are reliable or due to error inherent in the experimental process.

The LSD (least significant difference) values 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 CV stands for coefficient of variation and is expressed as a percentage. The CV is a measure of variability in the trial. Large CVs indicate a large amount of variation that could not be attributed to differences among the cultivars/ selections.

The data provided does not indicate endorsement or approval by the authors, NDSU Extension, or 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 2. Red selections and cultivars growing on July 22, 2025, near St. Thomas, ND.
(Robinson, NDSU/UMN)

Table 1. Agronomic performance and yield of yellow-skinned potato cultivars/selections grown near St. Thomas, ND, in 2025.

Cultivar	Stand[1]	Stems/plant[2]	C[3]	B	A	Chef	Total yield	Specific gravity
	%	number	--------------------------------- cwt/a ---------------------------------					
Actrice	84	2.4	0.1	55	230	74	370	1.068
Agata	77	2.8	0.4	80	228	45	367	1.071
Alegria	78	2.6	1.1	69	219	39	340	1.090
Bernice	89	2.7	0.1	59	241	65	379	1.071
Caledonia Pheonix	83	2.9	0.5	77	194	74	359	1.072
Camelia	67	3.1	0.0	72	238	92	418	1.075

Columba	82	2.4	0.5	89	189	42	332	1.067
Decibel	82	3.0	1.6	132	172	19	339	1.076
Fontaine	84	3.0	2.5	149	152	32	350	1.093
Mondak Gold	79	3.2	0.8	116	178	12	323	1.090
MSHH224-1Y	76	2.3	1.8	117	118	32	281	1.069
Musica	82	3.6	2.5	147	210	18	395	1.079
ND1241-1Y	80	2.3	1.9	119	153	9	295	1.106
Vincenta	89	2.6	1.9	108	153	13	288	1.073
Mean	81	2.8	1.1	99	191	41	345	1.079
CV	10	21	97	40	35	96	21	0.5
LSD p=0.05	11	*ns*[4]	1.6	56	*ns*	*ns*	*ns*	0.007
LSD p=0.1	9	*ns*	1.3	47	*ns*	46	*ns*	0.006

[1] Stand count was taken on July 7 (five 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 7 (five 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* indicates that no significant differences between the cultivars/selections were found.

Figure 3. Harvest of yellow tubers from plots on October 1, 2025, near St. Thomas, ND.
(Robinson, NDSU/UMN)

Table 2. Agronomic performance and yield of red-skinned potato cultivars/selections grown near St. Thomas, ND, in 2025.

Cultivar	Stand[1]	Stems/plant[2]	C[3]		B Chef	Total	A yield	Specific gravity
	%	number	---------------------------------- cwt/a ----------------------------------					
AAF11546-3	86	2.4	1.3	98	120	4	223	1.079
AG 1540	89	3.4	3.3	167	102	0	273	1.075
Becca Rose	79	3.3	3.1	136	139	2	280	1.072
Dark Red Norland	83	3.7	0.8	54	192	15	261	1.076
Dark Red Norland (NE)	83	4.0	0.6	67	186	18	272	1.076
Malbec	93	2.9	1.1	111	159	6	277	1.088
Modoc	74	2.2	0.5	85	109	2	197	1.076
ND113207-1R	86	2.5	2.5	111	164	1	279	1.075

Red LaSoda (NY)	91	2.8	0.6	65	214	38	318	1.081
Red Norland	88	2.9	0.5	45	212	56	314	1.078
Red Port	91	2.1	0.5	44	153	12	210	1.076
Sangre	86	2.4	0.2	60	160	22	243	1.081
Spartan Red	86	3.4	0.4	106	171	14	291	1.087
Mean	86	2.9	1.2	88	160	15	264	1.078
CV	13	19	99	20	30	131	23	0.3
LSD p=0.05	*ns*	0.8	2	25	69	29	*ns*	0.0069
LSD p=0.1	*ns*	0.7	1	21	57	24	*ns*	0.0058

[1] Stand count was taken on July 7 (five 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 7 (five 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* indicates that no significant differences between the cultivars/selections was found.

Figure 4. Harvest of red tubers from plots on October 1, 2025, near St. Thomas, ND. (Robinson, NDSU/UMN)

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REPORT for Proposal Title: 2025 Support of Irrigated Potato Research for North Dakota and Minnesota

Submitted to Northland & MN Area II Potato Growers Associations

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

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

Co-Principal Investigator: Gary Secor
Collaborators: Susie Thompson, Harlene Hatterman-Valenti, Andy Robinson

Executive Summary: The region's potato growers have graciously supported a site to conduct irrigated research; in return, they have access to a wide array 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. Without the Inkster site, the industry's ability to react to management changes 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 benefited from the work conducted at the Inkster site.

The researchers who work at the Inkster site greatly appreciate the generous assistance from the Forest River Colony with tillage, irrigation, and general support. Also, 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.

Procedures: Funding for the management of the Inkster irrigated research site facilitates its use by Team Potato projects from NDSU, the USDA, and the ND State Seed Department. Research trials conducted at the NPGA irrigated research site in 2025 include, but were not limited to, general management practices; nutrient management, cultivar improvement, weed control, and management of the foliar diseases early blight and black dot, and seed-borne Rhizoctonia, among others (Figure 1). 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 all maintenance fertilizer, herbicides, fungicides, and insecticides, etc.). The potato pathology management team also assists with planting and harvest operations as needed, monitors soil-borne pathogens to make the irrigated research site useful to everyone, plants cover crops, and assists in planning and executing the annual field day.

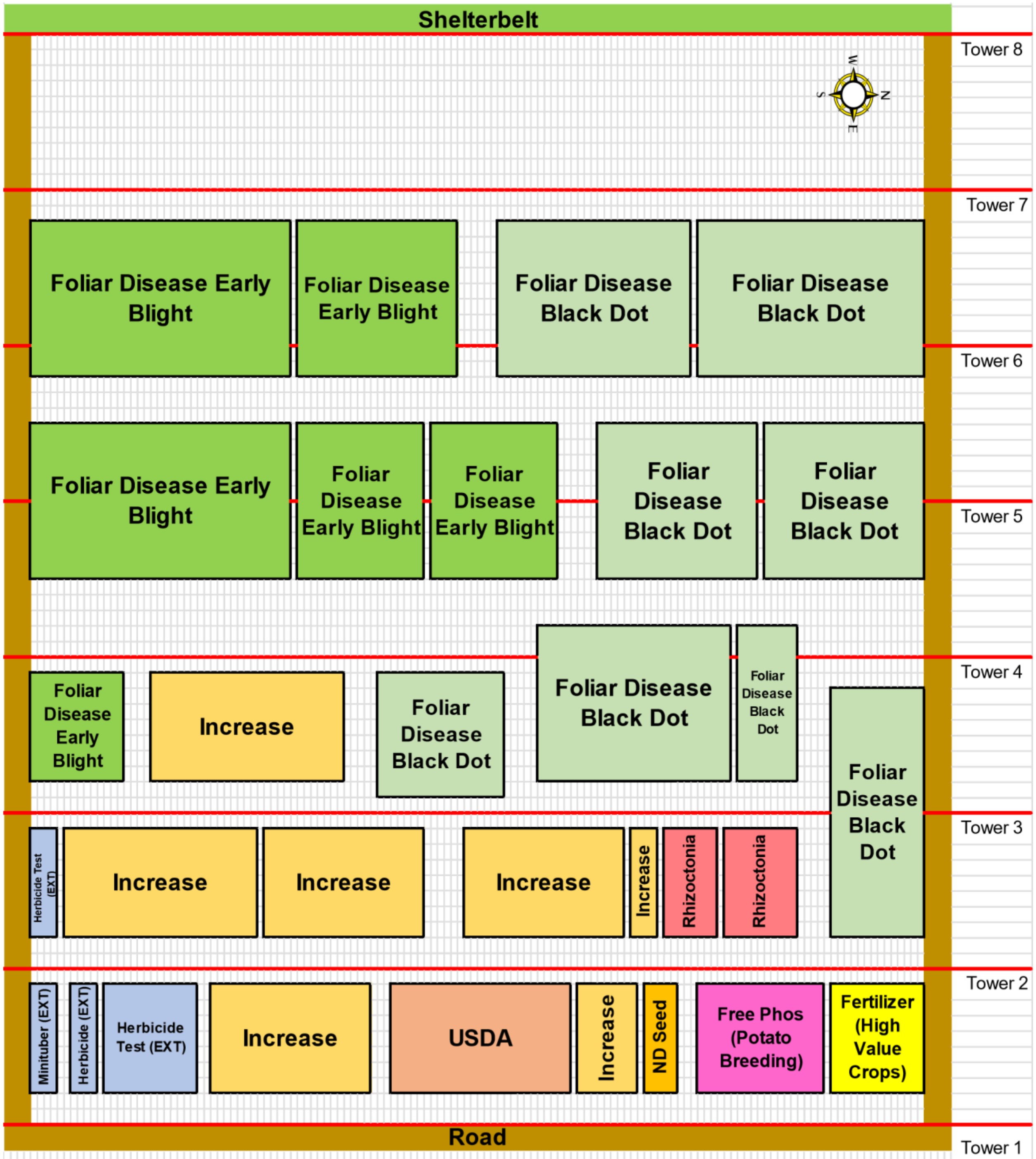


Figure 1. 2025 Inkster irrigated research site field map.

Figure 2. Inkster irrigated research site, 2025 photos.

Results

In 2025, 29 trials were conducted on nearly 24 acres at the Inkster research site (Figures 1 and 2). These trials span the range of expertise of the potato improvement team. In many cases, trial results are confidential because products are not yet registered for use. The Inkster site allows Team Potato to generate data under local irrigated growing conditions over several years, facilitating regionally relevant recommendations if/when the product is registered. Additionally, data generated at Inkster contribute to decisions on product registration and marketing by cooperators.

We experienced low early blight disease pressure in 2025 (Figure 2). This is similar to 2002, and in contrast to 2023 and 2024. We continue to have concerns over the development of fungicide resistance; however, currently recommended fungicides remain effective against the pathogen population in our region (Figure 3). Results from our early blight fungicide efficacy trials indicate that growing fungicide insensitivity determined in the lab and greenhouse has resulted in only small reductions in field efficacy. We will continue to monitor fungicide sensitivity in the early blight and brown spot pathogens, and have initiated monitoring the black dot pathogen.

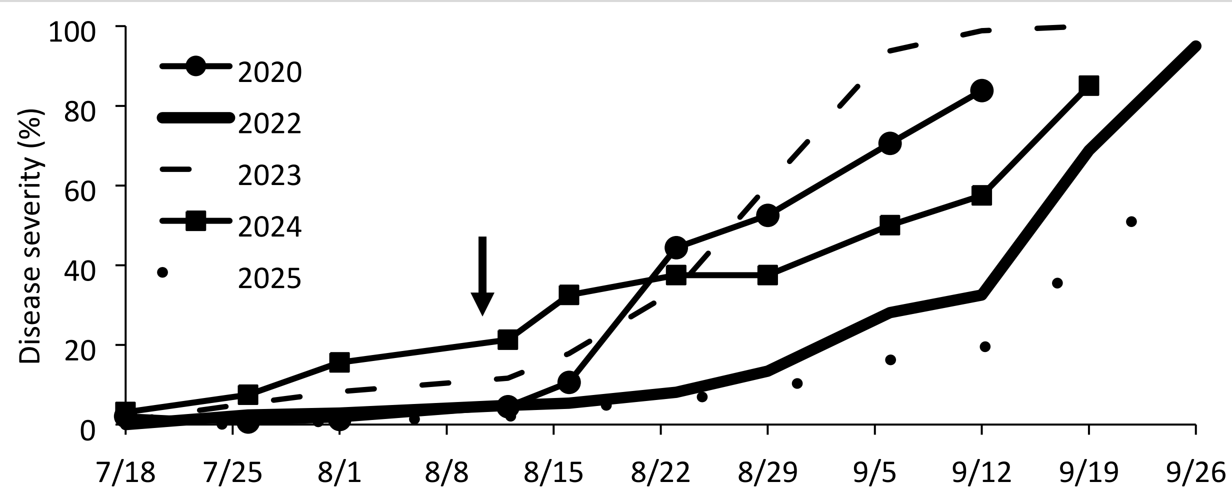


Figure 2. Early blight disease progression in non-treated control plots at the Inkster irrigated research site from 2020 to 2025, as determined by visual disease ratings collected weekly for 9 to 11 weeks at the NPGA irrigated research site near Inkster. The arrow indicates the approximate timing of application #5 in a 10-application fungicide program, when we typically recommend the first premium fungicide.

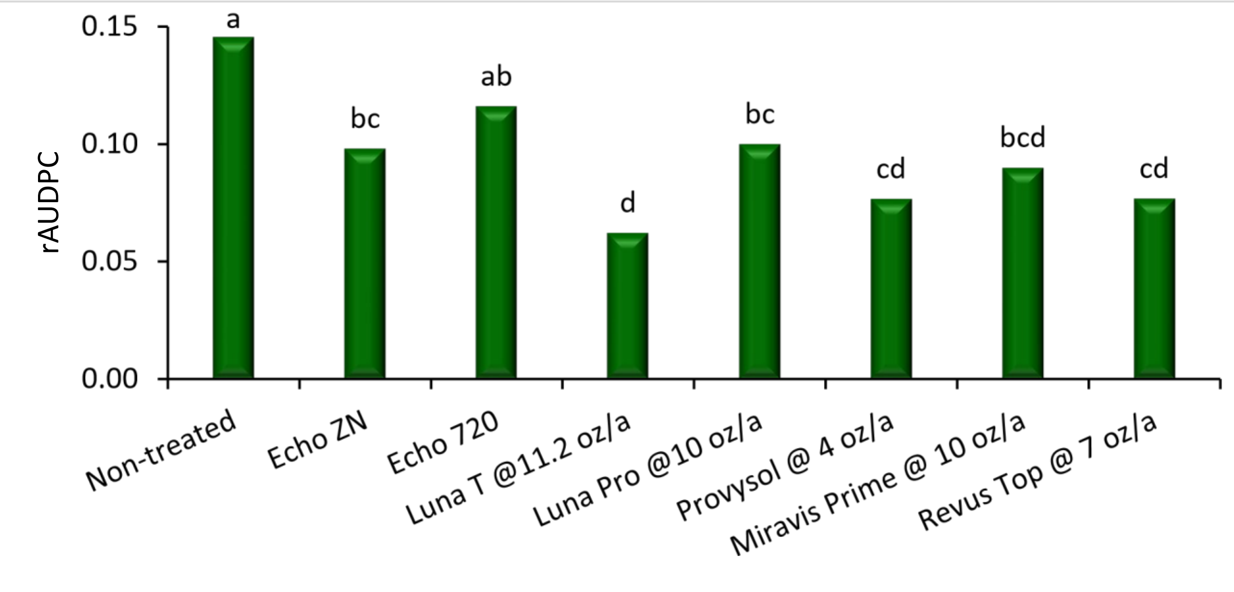


Figure 3. Relative area under the disease progress curve (rAUDPC) representing early blight severity across the 2025 growing season as determined by visual ratings collected weekly for 9 weeks. The trial was conducted under low disease pressure in 2025 at the NPGA irrigated research site near Inkster. Bars with different letters above are significantly different.

The product listed was applied fifth in a 10-application program. Echo ZN and Echo 720 were applied full-season (1-10). Treatments included a QoI fungicide @ application #2 for black dot management and Scala @ application #7. The three specialty fungicides (applications 2, 5, and 7) were tank-mixed with mancozeb and rotated with chlorothalonil (Echo 720; applications 1, 3, 4, 6, 8-10).

Julie Pasche's pathology team has been evaluating products for the management of black dot for several years; in 2024, we added tuber blemish to our black dot cultivar resistance screening trial. Results from 2024 and 2025 evaluations indicate a difference in the progression of black dot stem lesions across the growing season among cultivars and NDSU breeding lines (Figure 4). It is encouraging to see NDSU breeding lines with some resistance to black dot stem lesions, and important for us to understand that some lines are very susceptible. However, large differences between black dot reactions were observed between years. Quantification of the pathogen in stem tissue via PCR and tuber blemish quantified visually and via PCR for this trial is in process and will provide further valuable data about current cultivars and NDSU breeding lines. Black dot tuber blemish has been quantified for eight trials evaluating fungicides for black dot management. Similar to 2024, in 2025, no fungicides reduced tuber blemish, even when stem lesions were significantly reduced. Black dot tuber blemish has been increasing in importance in recent years, with a higher emphasis being placed on skin quality, particularly in fresh market red and yellow-fleshed cultivars.

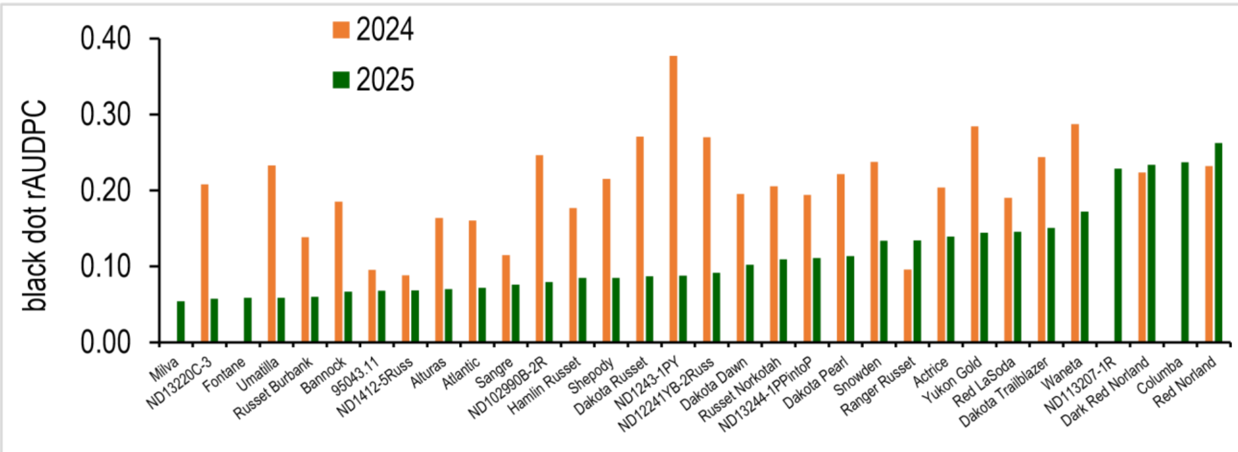


Figure 4. Relative area under the disease progress curve (rAUDPC) representing black dot stem lesion incidence across the 2024 growing season as determined by visual ratings collected weekly for 5 weeks. Cultivars/NDSU breeding lines were grown under inoculated conditions at the NPGA irrigated research site near Inkster.

Gary Secor's pathology team conducted a field trial in 2025 at the Inkster site to evaluate the efficacy of 9 seed and in-furrow-at-planting treatments to reduce Rhizoctonia. Registered fungicides, experimental fungicides, and natural products were applied as seed treatments and infurrow 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. Tubers of cv. Russet Burbank were planted, and barley kernels colonized by *Rhizoctonia solani* were infested at planting, and plots were grown using local agronomic practices. Tubers were harvested, and yield and grade were collected. Tubers are incubating at 50F and will be evaluated for Rhizoctonia scurf after 4 months. Some new products were promising from this one year of data. We will continue to follow those products and release our recommendations as more data are generated.

Other members of Team Potato, Andy Robinson, Susie Thompson, Harlene Hatterman-Valenti, USDA researchers, and the ND State Seed Department, conducted trials at Inkster in 2025. Those results will be presented in their research reports.

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.

Potato Insect Management 2025

Dr. Ian MacRae,
Dept. of Entomology,
U. Minnesota Northwest
Research & Outreach Center
2900 University Ave. Crookston, MN 56716 imacrae@umn.edu 218 281-8611 Office 218 281-8603 Fax

Executive Summary – This is a project to develop and refine management tactics for 2 of the major insect pests of potato, Colorado Potato Beetles (CPB), and Aphid Vectors of virus disease in Minnesota and North Dakota. This proposal will: 1) update the geographic patterns of insecticide resistance in Minnesota and North Dakota Colorado Potato Beetle populations, 2) examine early-season variety preference by Colorado Potato Beetle, and 3) maintain the Aphid Alert monitoring network for aphid vectors of virus disease in potatoes (especially PVY) 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.

In 2025, we:

1) continued to update the geographic patterns of insecticide resistance in Minnesota and North Dakota Colorado Potato Beetle population,
2) assessed the potential varietal preference by emerging overwintered beetles, and,
3) maintained the Aphid Alert trapping network, monitoring 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.

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 adults do some feeding to replace energy spent in overwintering, mate, lay eggs and then die. The resulting larvae are significant early season defoliators, feeding voraciously (esp the older stages) as they grow and molt. After 4 larval stages, the last 2 causing the greatest damage, 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 behavior that allows the insect to avoid the insecticide) has resulted in a delayed emergence of overwintering adults (Huseth & Groves 2010, 2013). This means we see this dual-peak population distribution less frequently. Many years, growers are now facing adults, larvae and eggs in the same field as late as July.

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 increased defoliation in particular varieties. For example, some commercial growers have commented that 'purples' are the first plants CPB attack. This may be the result of earlier sprouting potato varieties; overwintered adult CPB entering potato fields are well known to 'arrest' on the first potato plant they encounter and feed. Preference for feeding on specific species and/or 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. This may contribute to decreasing early season egg deposition and lowering within-year populations making management easier later in the season.

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, Huseth et al. 2014) (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, 2023). The decreasing efficacy of at-plant applications of neonicotinoid insecticides has resulted in an increasing reliance on foliar insecticides.

Colorado Potato Beetle is often referred to as a 'SuperPest' because of its ability to develop resistance to insecticides (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 a site mutation had modified 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 [Clements et al. in 2019 reported that exposure to fungicide can upregulate resistance to insecticides in CPB]. Considered together, Colorado Potato Beetle's development of resistance to insecticide modes of action should likely be considered a when, not an if.

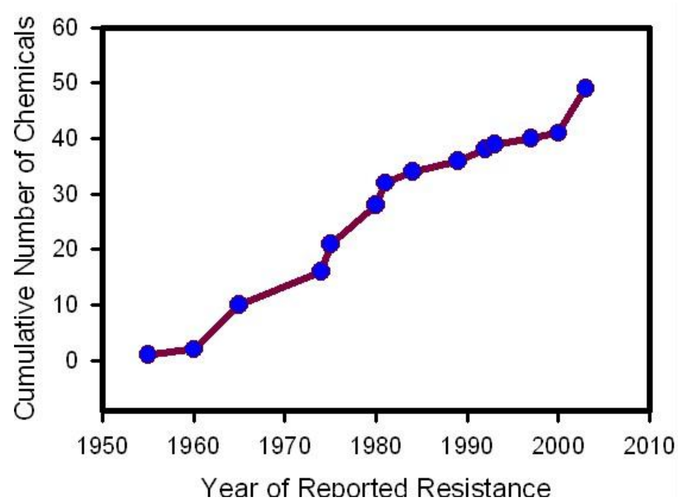


Figure 1. The cumulative number of insecticide active ingredients to which Colorado Potato Beetle has developed resistance, 1950-2006. (Andrei Alyokin 2023, https://www.potatobeetle.org/history-of-insecticide-

Data from MN and ND gathered 2017-23 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, 2023). 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 confirmed these pattern to be well-established (MacRae 2023).

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 'naïve' laboratory population (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). We currently maintain such a colony at the UMN-NWROC in Crookston.

There are other insect management issues facing potato production in MN & ND. The 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 nonpersistent (circulative) virus; that means after the insect acquires the virus from an infected plant, 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, feeds (acquiring the virus) and decides it's a suitable food species and deposits a daughter aphid. The daughter will begin to feed ad have offspring, 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).

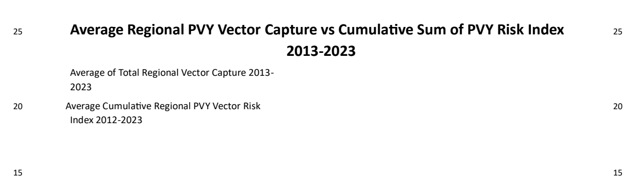
Conversely, PVY is a non-persistent virus; there is no latency period. The virus can be acquired by an insect vector from an infected plant and transmitted to an uninfected plant in minutes (Bradley 1954,) with some newer virus strains being even more readily transmitted (e.g. Verbeek et al. 2010, Mello et al 2011, Mondal et al. 2016). 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 (e.g. Pymetrozine and Flonicamid). This rapid transmission results from PVY's ability to be transmitted mechanically as well as biologically. Infection is also 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. Aphids don't differentiate between plant species by sight and, unaware they're in a monoculture field, will simply fly a few meters to 'try again'. Aphid species that colonize potato (such as Potato Aphid or Green Peach Aphid) take time to feed and to deposit a daughter nymph. So non-colonizing aphids tend to visit more plants in a shorter period of time, and, therefore, likely transfer more inoculum. Because non-colonizing aphid species spend shorter periods on multiple plants in a field there is a lower 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 noncolonizing aphids aren't in the field long enough for traditional insecticides to have sufficient time to kill the vector. Consequently, alternative methods of monitoring vector presence are necessary for timing management strategies.

There are a number of aphid species that vector virus diseases to seed potatoes, the most efficient is green peach aphid, *Myzus persicae* (Sulzer) with other vector species having varying levels of transmission efficacy. 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 mineral oils and anti-feeding insecticides can limit the transmission of PVY by 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, MacKenzie et al 2022). 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 realtime information on virus vector flight activity.

Over the past several years, *Aphid Alert* has provided timely information on aphid vector presence and the seasonal patterns of vector population dynamics. It provides an estimate of risk of PVY transmission for seed producers by estimating the amount of exposure to hazard. The species of aphids that we monitor have a biological ability to transmit PVY (hazard) and Aphid Alert measures their relative presence, providing a



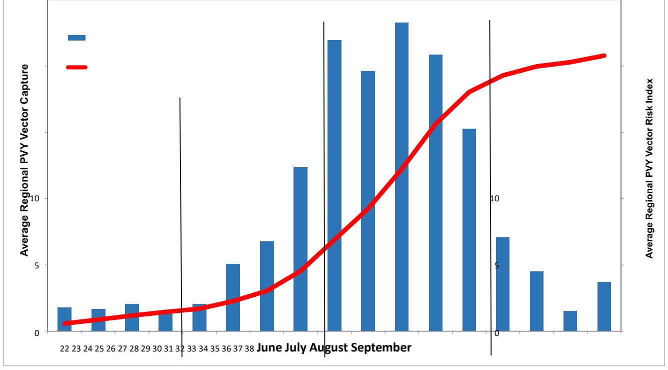


Figure 2. The average number of PVY vectoring aphids from the total Aphid Alert traps by week (vertical bars) with the Cumulative Weekly Regional PVY Risk Index (red line curve) averaged over 2012-2023. The dates were standardized to ISO-8610 week numbers so the data could be compared across years. Note that the greatest increase in cumulative PVY vector risk is from late July, ending in late August. This is not only a reflection of the number but of the species of aphid vectors captured.

measurement of relative risk. Because we have multiple years of data acquired at the same sites by the same methods, producers can estimate their risk as a comparison to previous years.

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

The total number of vectors, however, does not tell the complete story. Not all species of aphids are equal in their ability to transmit PVY virus; some species are much more efficient vectors than others. As mentioned, the Green Peach Aphid (GPA) is the most efficient species when it comes to transmitting PVY. We've developed an index, The PVY Vector Risk Index (fig 3), 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.

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

All of our cooperators have received the historical averaged data for their site, this will be updated to include 2021-2024 this winter. Some sites have fewer years of trapping data than others but those data still provide insights into their vector activity.

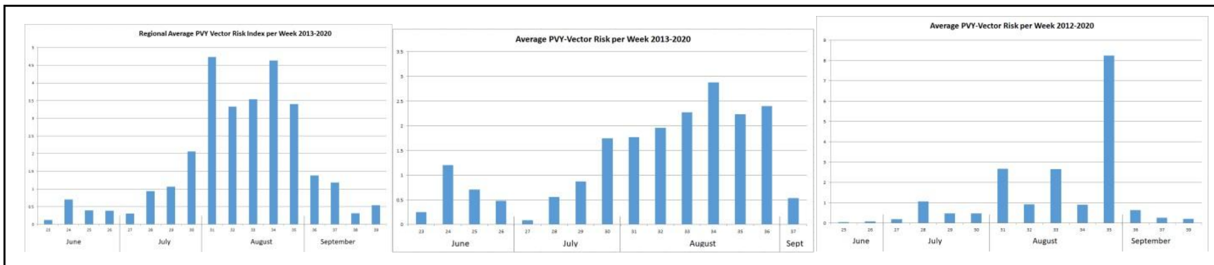


Figure 3. The seasonal PVY Vector Risk Index by week, averaged from 2012 -2020 data, for all of MN & ND (left), Perham (middle) and Lake of the Woods (right). Note the steady ramping of the Index values at Perham vs the concentration of Index values in August at Lake of the Woods.

Over the past several years, the Aphid Alert Network has grown to provide region-wide coverage, estimating the aphid vector populations. The network relies on grower cooperators to maintain and change traps throughout the growing season and send weekly

trap catches to the entomology lab at the University of Minnesota's Northwest Research & Outreach Center
(NWROC). There the trap contents are sorted, aphid vector species identified and PVY Vector Risk Index values calculated. Since 2012, the *Aphid Alert* network has provided excellent regional coverage of the Minnesota and North Dakota seed producing areas.

In 2025, we propose to:

1) continue to update the geographic patterns of insecticide resistance in Minnesota and North Dakota Colorado Potato Beetle population,
2) assess potential varietal preference by emerging overwintered beetles, and,
3) maintain 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

New methods

Colorado Potato Beetle will be sampled by UMN personnel from potato production areas within Minnesota and North Dakota. Samples will be collected from production fields in early to midseason. Adults will be returned to the NWROC for traditional lab bioassays. Larvae will be tested using treated potato leaves; this bioassay can be started in the field. To adequately test each insecticide with adequate replication, ~1500 beetles will be collected from each location. Insecticide resistance in insects is genetic. The only way to determine if a population of insects is truly resistant is to calculate the LD_{50} of a suspected resistant population and compare it to that of population known to be susceptible to the insecticide. We have obtained and are maintaining an insecticide 'naïve' (never exposed to insecticides) CPB colony in the NWROC lab, which should facilitate this research.

A number of evenly geographically dispersed locations across the growing area of MN and ND will be sampled. In 2025, we will not be waiting to be contacted by growers, rather we will be contacting growers in locations and seeking areas with emerging adults and hatched larvae. However, if growers report heavy populations, we will respond to collect from those locations. Summer adults will be preferentially sampled, although emerging beetles may also be sampled if available in sufficient numbers. However, overwintered beetles tend not to have as active detoxification mechanisms as summer emerging beetles, consequently, attempts will be made to resample areas where overwintered beetles were tested. Larval transport was attempted in 2024, but it had high handling and transportation mortality. At that time we were returning large numbers of larvae in containers to be used in lab bioassays; this led to mortality during collection, transportation and bioassay handling. Especially damaging was the direct application of insecticide to the larvae. In 2025 we will be using a method that hopefully decreases handling mortality.

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 Plains.

Baseline mortality rates will be established using the insecticide-susceptible colony (fig 4) maintained at the UMN NWROC in Crookston. This colony has never been exposed to insecticides in its history. Colony beetles will be assessed for susceptibility to registered insecticides. We will produce baseline data for Abamectins (e.g. Reaper, AgriMek), Anthranilic Diamides (e.g. Corragen), Spinosyns (e.g. Blackhawk, Delegate), and METIs (e.g. Torac). Depending on the potential issues presented by collecting and testing, we may also assess Neonicotinoids, Butenolides (Sivanto Prime), and Oxidiazines (e.g. Avaunt). A gradient of concentrations of active ingredient (ai), the actual toxin in the insecticide, will be 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}'). This needs to be for each insecticide mode of action with fresh insecticide every year.

Resistance/tolerance of CPB from each sampled area will be assessed using direct exposure tests for adults and treated leaf exposure for larvae. Direct exposure trials are conducted by applying 10µl (microliter) drops of insecticide directly to the insect using a micro-applicator or a micro-pipette (Fig 5). After the insecticide has dried, beetles will be placed onto a potato leaf in Petri plates and left to feed for 5-7 days (120h). Beetles will be initially assessed for mortality at 24h (to assess handling mortality) and then daily to assess food consumption. Additional leaf material will be added if necessary. As CPB often appear intoxicated immediately after exposure but recover after several days, mortality will again be assessed 5-7 days post application (min. of 120h). Mortality is assessed by placing

Figure 5. Micropipette with disposable tips . Unit is capable of depositing drops of 2.0-20.0 µ.

beetles on their backs and evaluating movement. Any insect not righting itself within 5 minutes is assessed as dead or moribund.

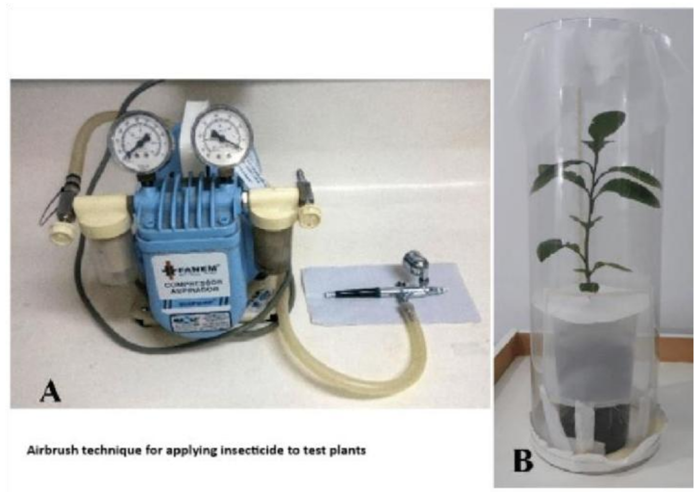


Figure 6. airbrush apparatus for application of insecticide to test plants (Loeblein et al. 2019)

Treated leaf bioassays for larvae involve using an airbrush applicator to coat test plant leaves with varying rages of insecticide (fig 6) (Loeblein et al. 2019). Each rate will be replicated in 4 Petrie plates, and enough Petrie plates prepared to test both small (larvae instars 1&2) and large (larval instars 3&4) larvae. Individual treated leaflets will be placed into Petrie plates, taped into stacks and the stakes wrapped in paper for transportation to the field in

coolers. Larvae (small and large) collected in the sample field will be placed directly into Petrie plates (already containing the treated plant material) in the field (10 larvae/plate). Plates will again be prepared for transport back to the lab where they will be observed in the same manner as the direct application trials. If the larvae totally consume the sprayed leaf prior to final evaluation, additional treated plant material will be added to the Petrie plate. This technique will minimize handling (larvae will be collected directly into testing Petrie plates), thereby increasing the survivorship of small larvae and provide us with better evaluation data. In addition, the use of treated plant material in the bioassays is significantly faster than the direct application method.

The LD_{50} values of field sampled and susceptible lab populations will be compared using

$$\text{Resistance Ratio (RR)} = \frac{LD_{50}(\text{or } LC_{50}) \text{ of field population}}{LD_{50}(\text{or } LC_{50}) \text{ of susceptible strain}}$$

Figure 7. Resistance Ratio (RR)=LD50 (or LC50) of field populationLD50 (or LC50) of susceptible

PROBIT analyses. This comparison will provide a measurement of the insecticide susceptibility of the field population. Resistance levels are expressed as Resistance Ratios

(Fig 7). **strain**

2) Assess potential varietal preference by emerging overwintered beetles.

Different varieties of potato (and eggplant for that matter) have varying levels of attraction for feeding Colorado Potato Beetle. This influence has been suggested as the basis for using trap cropping as a management tactic for this species (e.g. Caprio & Grafius 1993). Trap cropping is a cultural pest management tactic that involves using either earlier emerging or more desirable variety, concentrating a target pest in a location other than the production crop, so it can be treated and/or removed from the field. This technique does have potential for Colorado Potato Beetle, but there are some potential drawbacks.

Post emerging, overwintered Colorado Potato Beetle adults move from overwintering areas to nearby production fields. Upon encountering a suitable host plant, they stop and feed for a period of time before moving deeper into the field (a behavior referred to as 'arresting'). This behavior lends itself as a potential basis for placing desirable early emerging varieties of host plants in the areas surrounding current years potato fields, providing a 'rest stop' for entering beetles, and a target site for spot-spraying that preempts the remainder of their journey into the potato field. In addition, because plant crops are present only for a limited period of time (they are best removed after pest management has been conducted), trap crops can be rapidly planted at the field's edge, they do not require agronomic care and, if arranged appropriately, can be removed during field cultivation.

Trap cropping technique might lend itself well to irrigated field where chemigation at the fields' edge is performed to control entering beetles. The potential difficulty is that many of the suggested varieties are varieties we currently grow. But it may be that several of those varieties may be attractive enough to still cause sufficient arresting to facilitate targeted applications.

Replicated plots of different varieties, that have been confirmed as having significant attraction for Colorado Potato Beetle, will be planted in a Randomized Block design. Initial feeding, arresting behavior and length of time spent in each variety recorded. The potential use of tested varieties will be assessed.

3) Maintain 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.

Aphid Alert is a network of ~20 3m-tall suction traps (fig 8) established in the seed potato production areas of Minnesota and North Dakota and run by cooperating growers (we have requests for 2 additional ND sites in 2025 and will be recruiting additional sites beyond that if the proposal is funded). 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 stainless steel, fine 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' (fig 8) to be sorted and saving operating power. The sample jars are changed weekly by grower cooperators who send them to the UMN-NWROC entomology lab. Insects in the jars are sorted and aphids removed. Aphids are then identified to species and aphid population dynamics at sample locations are determined. Traps are established in June and maintained until the seed field hosting the trap is vinekilled/harvested. At that point a field is no longer attractive to aphids.

Maps are generated weekly showing these dynamics. We use multiple digital communications techniques to disseminate this information. It is made available to growers on a website (aphidalert.blogspot.com), also via X (formerly Twitter) posting (https://twitter.com/mnspudbug), through 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 dissemination program for this project has been successful; the email ListServe includes readers from the U.S. and Canada, the X account is followed by over 200 growers and Ag. Industry personnel, and AphidAlert.blogspot.com has had approximately 83K visits from the U.S., Canada, Europe, and Asia.

Figure 8. An *Aphid Alert* 3m suction trap and the weekly capture of 'bug stew'

We will continue to operate the Aphid Alert suction trap network incorporating the PVY Vector Risk Index maps into 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.

In addition, the averaged data for sites will be used to tailor potential management plans for those areas. The seasonal patterns of vector flights can be used to make decisions on when to focus specific management tactics. For example, the technique of adding insecticide to Aphoil applications (Singh 2019, MacKenzie et al 2022) were recommended to be applied more frequently early in the season and decreased into the end of the season. That technique was, however, developed in New Brunswick, which has much earlier flights of aphids than does
Minnesota or North Dakota. Data from our trapping locations indicates incorporating insecticides into oil applications may be more advantageous later in the season as our aphid populations start to peak in mid-July to August.

Results

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

New methods for larvae – the methodology (using as airbrush to apply insecticide either directly onto larvae or onto plants which larvae then eat) was successful and time comparisons do indicate that it takes less time to conduct a bioassay using this method. However, because of increased mortality from handling beetle larvae, in-field collection times are longer (far more larvae are required than adults for similar replications of the trial). In addition, handling mortality, while lower than traditional bioassays, is still significant, resulting in longer prep times for this method. In addition, the resistance ratios obtained from this method were different than those from adults. This was expected as younger life stages have not developed the same levels of detoxification systems as have adults. Consequently, it was felt that bioassays using adults provide the most conservative estimate of within field resistance and were, subsequently, used in this report.

Using traditional methods for adults (deposit of 1µL **of insecticide to the ventral surface of the beetle's abdomen)** we were able to test from 6 locations (Table 1), but bioassays from 1 location were lost due to a storage issue with our lab refrigerator (i.e. it forgot it was a refrigerator). Specimens were lost to temperatures outside the suitable range for beetle storage. This problem has since been addressed.

Resistance levels are calculated as the ratio of resistance value of the colony to that of the sampled population (i.e. the value presented in the table is how much greater is the resistance of CPB at that field location than that of the susceptible lab colony. Values from 1 - <4 are considered susceptible to the insecticide, from 4 – 10 are considered low resistance, from 11 – 30 are considered moderate resistance, 30-100 considered high resistance, values >100 are considered complete failure and alternate insecticides are required for management. Any value greater than 1, however, indicates decreased efficacy and signals the necessity of incorporating insecticide resistance management tactics such as rotating modes of action.

In 2025, we found that Abamectin (the a.i. in AgriMek) continues to show reduced efficacy in Central Minnesota. We also found the first site in the Red River Valley (RRV) with decreased activity. A field near St Thomas ND, had a failure with abamectin with resistance levels ~4x those of our susceptible colony. This is the first indication that lowered efficacy of abamectin products may be taking hold in the NE ND and NW MN. Experience from populations in Central MN indicate that the addition of Piperonyl Butoxide (PBO) synergists does elevate the insecticide's efficacy to original levels. PBO negatively impacts an insects mixed function oxidase system, lowering the insect's ability to detoxify insecticides, thereby allowing more active ingredient to reach the insecticide's target site. This means relatively more of the a.i. is reaching where it needs to be to work, increasing the insecticide's efficacy. This is generally a temporary solution, however. Over time, as resistance to the insecticide increases, the addition of PBO will have a diminished effect. Consequently, while the insecticide plus PBO may provide

Tablemanagement, the product should not be the only, or even primary, insecticide used in **1. Locations and tested resistance levels (as compared to susceptible colony results) from 2011-2025. Note that early tests focused on neonicotinoid resistance and later tests on alternate insecticides. Red box is 2025 results.**

Year	Location	Imidacloprid (Admire) 4A	Thiomethoxam (Cruiser) 4A	Clothianidin (Belay) 4A	Abamectin (AgriMek) 28	Rynaxypyr (Coragen) 28	Spinosad (Blackhawk) 5	Tolfenpyrad (Torac) 21A	Indoxicarb (Avaunt) 22A
2011	Becker	4x	1.3x	-	-	-	-	-	-
2011	*Long Prairie*	3.5x	2.4x	-	-	-	-	-	-
2011	*Perham*	8x	2.5x	-	-	-	-	-	-
2011	*Crookston*	1x	1x	-	-	-	-	-	-
2012	*Becker*	4.1x	1.9x	1x	-	-	-	-	-
2012	*Browerville2*	10.5x	1.7x	3.2x	-	-	-	-	-
2012	*Browerville1*	1.4x	1x	1x	-	-	-	-	-
2012	*Grand Forks*	3.8x	1x	1x	-	-	-	-	-
2012	*Forest River*	2.5x	1.1x	1.1x	-	-	-	-	-
2012	*Hubbard*	1x	1x	1x	-	-	-	-	-
2012	*Hatton*	1.6x	1x	1x	-	-	-	-	-
2012	*Perham*	5.5x	1.9x	1x	-	-	-	-	-
2012	*Rice*	1.5x	-	3.2x	-	-	-	-	-
2012	*Wadena*	4.5x	1.4x	7.7x	-	-	-	-	-
2013	*Becker*	3.9x	1.5x	1.3x	-	-	-	-	-
2013	*Rice2*	4.8x	2.8x	4.9x	-	-	-	-	-
2013	*Rice1*	-	1.8x	1.9x	-	-	-	-	-
2013	*Staples*	1.7x	-	2.4x	-	-	-	-	-
2013	*Crookston*	1x	1x	1x	-	-	-	-	-
2013	*Forest River*	2x	-	-	-	-	-	-	-
2013	*Langdon*	1.1x	1x	1x	-	-	-	-	-
2013	*Larimore*	3.5x	1x	1x	-	-	-	-	-
2013	*Inkster*	1x	5.4x	1.8x	-	-	-	-	-
2013	*Grand Forks*	4.1x	1x	1x	-	-	-	-	-
2014	*Forest River*	7.5x	4.9x	1x					
2014	*Wadena*	8.8x	4.8x	6.2x					
2014	*Grand Forks*	3.8x	2.9x	1.7x					
2018	*Arvilla*	-	19x	1x	1X	21x	1x	1.5x	-
2018	*Becker*	-	-	-	-	-	1x	-	-
2018	*Bentru*	-	-	-	1x	-	1x	-	-
2018	*Big Lake*	-	6x	7x	3x	-	3.7x	-	-
2018	*Crookston*	-	4x	1x	1x	1x	3x	-	-
2018	*Erskine*	-	2x	-	-	-	-	-	-
2018	*Hubbard*	-	6x	1x	8x	2x	1x	-	-
2018	*Larimore*	-	-	9x	-	-	-	-	-
2018	*Rice*	-	10x	49x	3x	24x	1.5x	-	-
2018	*Sabeka*	-	2x	1x	1x	-	28x	-	-
2019	*Argyll*	-	-	-	1x	-	-	-	-
2019	*Arvilla*	-	14x	1x	1x	21x	1x	1.5x	-
2019	*Becker*	23x	-	113x	-	-	1x	-	-
2019	*Bentru*	-	-	-	-	-	1x	1x	-
2019	*Big Lake*	6x	-	7x	3x	-	4x	-	-
2019	*Clearwater*	27x	-	60x	1.5x	-	-	-	-
2019	*Crookston*	-	4x	1x	1x	1x	3x	-	-
2019	*Erskine*	-	2x	-	-	-	-	-	-
2019	*Forest River*	10x	-	37x	-	-	-	-	-
2019	*Hubbard*	-	6x	1x	8x	2x	1x	-	-

2019	***Larimore***	-	-	9x	-	-	-	-	-
2019	***McCanna***	9x	-	45x	-	-	-	-	-
2019	***Perham***	-	-	-	1x	-	-	-	-
2019	***Rice***	-	10x	48x	3x	1x	1.5x	-	-
2019	***Sabeka***	-	2x	1x	1x	-	28x	-	-
2019	***Sabin***	6x	-	-	-	-	-	-	-
2019	***Stillwater (organic)***	-	-	-	-	-	10x (Entrust)	-	-
2019	***W. Wisconsin***	-	-	-	-	-	-	-	-
2023	***Becker (SPRF)***	1x	-	-	2.6x	1x	1x	1x	-
2023	***Browerville***	-	-	-	-	-	-	-	1x
2023	***Crookston***	2.71x	-	-	1x	-	1x	-	-
2023	***AMD90W Hastings***	-	-	-	-	1x	1.5x	1x	-
2023	***Schuler Hastings***	-	-	-	-	-	-	1.3x	2x
2023	***Perham***	-	-	-	-	-	-	1.5x	2x
2023	***Crookston 2023***	2.7x	-	-	1x	-	1x	1x	-
2024	***Crookston 2024***	2.8x	-	-	1x	1.5x	1x	1x	-
2025	***Chamberlain***				4x	1.3x	1x	1x	2x
2025	***Hubbard***				4x	1x	1x		
2025	***St Thomas***				4x	2x	1x	1x	1x
2025	***Crookston***				1x		1x	1x	
2025	***Crookston2***				1x				1x

management programs.

Other long-used products have also shown some decreased activity in recent years. The active ingredient chlorantraniliprole (e.g. Coragen), while still effective in most locations, has shown some decreased activity in a few locations. The resistance ratios for many products have remained unchanged over successive years of sampling, some have increased. The resistance ratios for neonicotinoid insecticides remains elevated, indicating the widespread development of resistance to this mode of action across Minnesota and much of North Dakota. However, isolated areas, with lower populations of CPB, maintain relatively good efficacy of most products, including some neonicotinoids.

2) Assess potential varietal preference by emerging overwintered beetle (trap cropping).

Different varieties of potato (and eggplant for that matter) were found to have varying levels of attraction for feeding Colorado Potato Beetle. In a trial to develop preliminary data, a main block of Red Norlands (~0.75ac) was planted in a location that had established CPB overwintering areas to the north and northwest. One week prior to planting the main block, we planted replicated plots of paired varieties of potatoes (All Blue, Red Norland, Russet Burbank, Dakota Pearl) at the northern end of the field, ~10m from the edge of the main block planting. The varietal plantings were placed ~half the length of the northern border of the main block, starting from the eastern edge. This left the western and Northwestern edge of the block with no varietal plantings. This should have left at least half of the block open to CPB immigrating from the overwintering area.

All plots and the block were scouted weekly and the number of adults, small and large larvae, eggs and percent defoliation were recorded in each plots at each date. The block was scouted from the entire Northern edge through the block to the southern edge.

Differences in preference at later dates appeared linked to increasing defoliation in plots. Of interest was the main block (all sides, including the NW side with no varietal plantings) were colonized well after the varietal plantings (fig xx). Interestingly, the potatoes in the block planting were not colonized by CPB until ~6 days after the varietal blocks were colonized. This was true across the entirety of the block, not just the edge adjacent to the varietal plantings.

It is important to note this is not a replicated trial, but merely an attempt to identify some testable varieties to use in a more detailed study (currently funded by MDA-AGRI Crop Systems for 2026).

Weekly counts indicated that CPB established on border plants a week prior to establishing on plants within the main block of plants (fig 9). Adults were too infrequent on plants within the main block planting to provide statistical comparison, eggs were more numerous and a General Linear Model analysis (fig 10) indicated there were significantly more eggs per plant on edge plantings than within the main block planting (P<0.001, fig 10).

Trap plants may provide a small, but potentially useful delay in CPB establishing on plants in a production field. Further research is continuing on influence of variety and location of trap crop plantings.

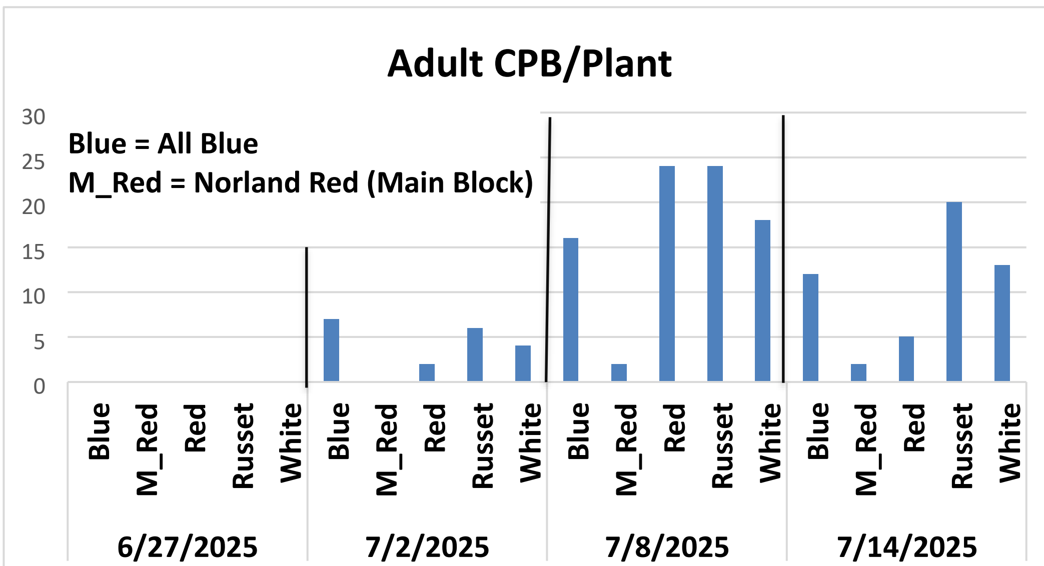


Figure 9. Establishment of adult Colorado Potato Beetle on potatoes. Note the later establishment of CPB on the M_Red variety (these were the Red Norlands in the block planting) despite the earlier, and consistently heavier, populations in the Red varieties (the Red Norlands in the varietal plantings at the northern edge of the block).

Dependent Variable: eggs

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	2233.603[a]	2	1116.802	7.573	<.001
Intercept	1528.510	1	1528.510	10.364	.001
presence	749.912	1	749.912	5.085	.024
loc$	1399.153	1	1399.153	9.487	.002
Error	200131.572	1357	147.481		
Total	229181.000	1360			
Corrected Total	202365.176	1359			

a. R Squared = .011 (Adjusted R Squared = .010)

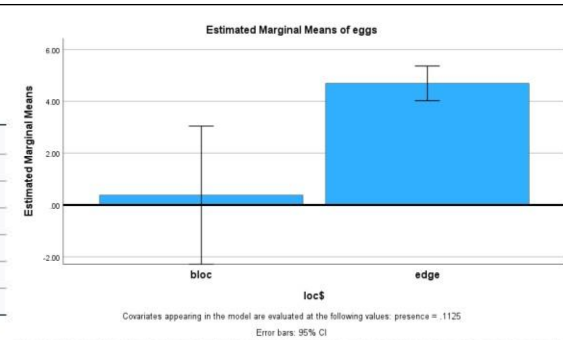


Figure 10. GLM results indicated location (main block vs edge) had a significant effect on the mean number of eggs on a plant (P<0.001). Graph shows the mean number of eggs per plant after 4 weeks within the main block (left bar) and the edge plantings (right bar). Vertical bars are 95% Confidence Intervals.

3) Maintain 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.

The *Aphid Alert* network of 22 3m-tall suction traps established in the seed potato production areas of Minnesota and North Dakota (and 2 traps in Nebraska) and run by cooperating growers. Trapping started June 08 and wrapped up on Sept. 21. Equipment failures were higher than usual in 2025, mostly because of aging components on the traps. We hope to incorporate new photocell relays, new high-efficiency solar panels, and better fans if funded in 2026.

Results were again disseminated via the blog site (aphidalert.blogspot.com), NDSU's Potato Extension site, X (the website formerly known as Twitter), email, and texts (to cooperators). I am open to suggestions for additional digital outreach if possible.

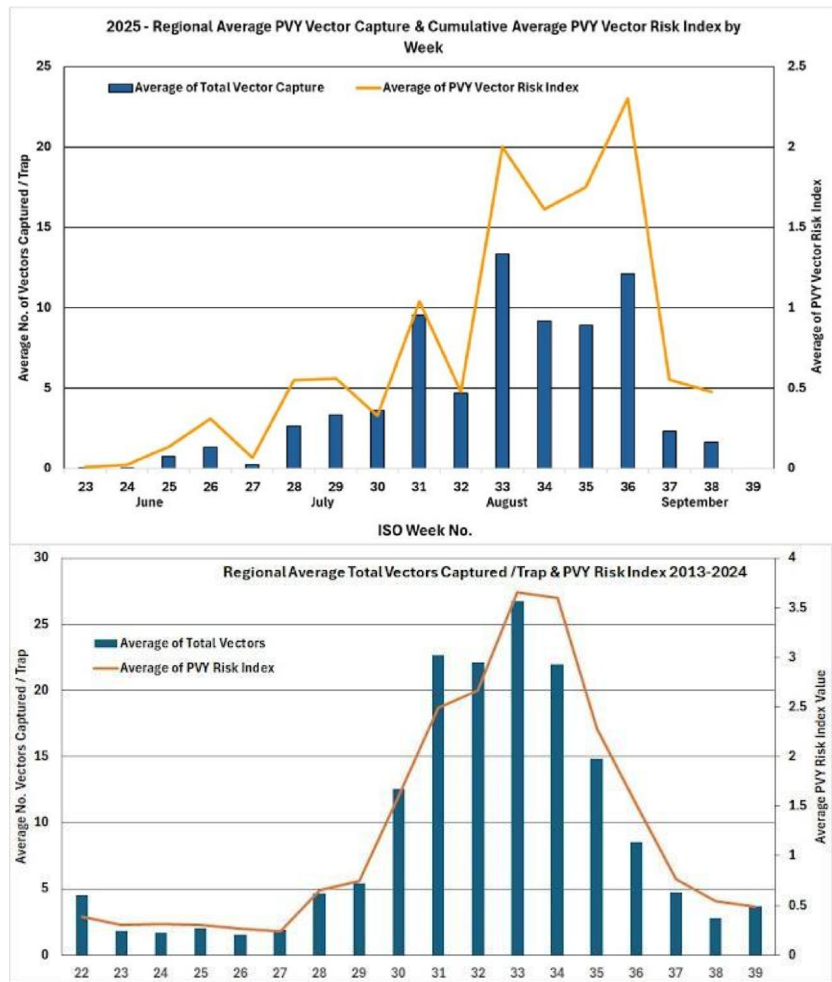


Figure 2. Comparison of Average Regional Vecto r Capture and PVY Vector Risk Index by week for 2025 (top) and 2013 -2024 (bottom).

Aphid vector populations were relatively low compared to our last two years, and the timing of vector peaks was relatively close to the 11-year average for the region (fig 2), with lower levels of PVY Risk Index (fig 3) with a differing dip in August, probably due to wet weather conditions. This pattern of vector presence is somewhat problematic. While the usual late-season peak of vector flights is common in our region, it comes at a time when preventative measures may be slowing in anticipation of harvest. Late season aphid outbreaks (usually Green Peach aphids or Potato aphids) have occurred in several locations in the past 2-3 growing seasons and may serve as sources for in-flights of vectors to nearby seed fields.

Although these flight data are regional, vector flights and vector species differ between site locations (appendix 1). We will continue to develop seasonal and 11 year average patterns for each location to provide higher resolution data for growers.

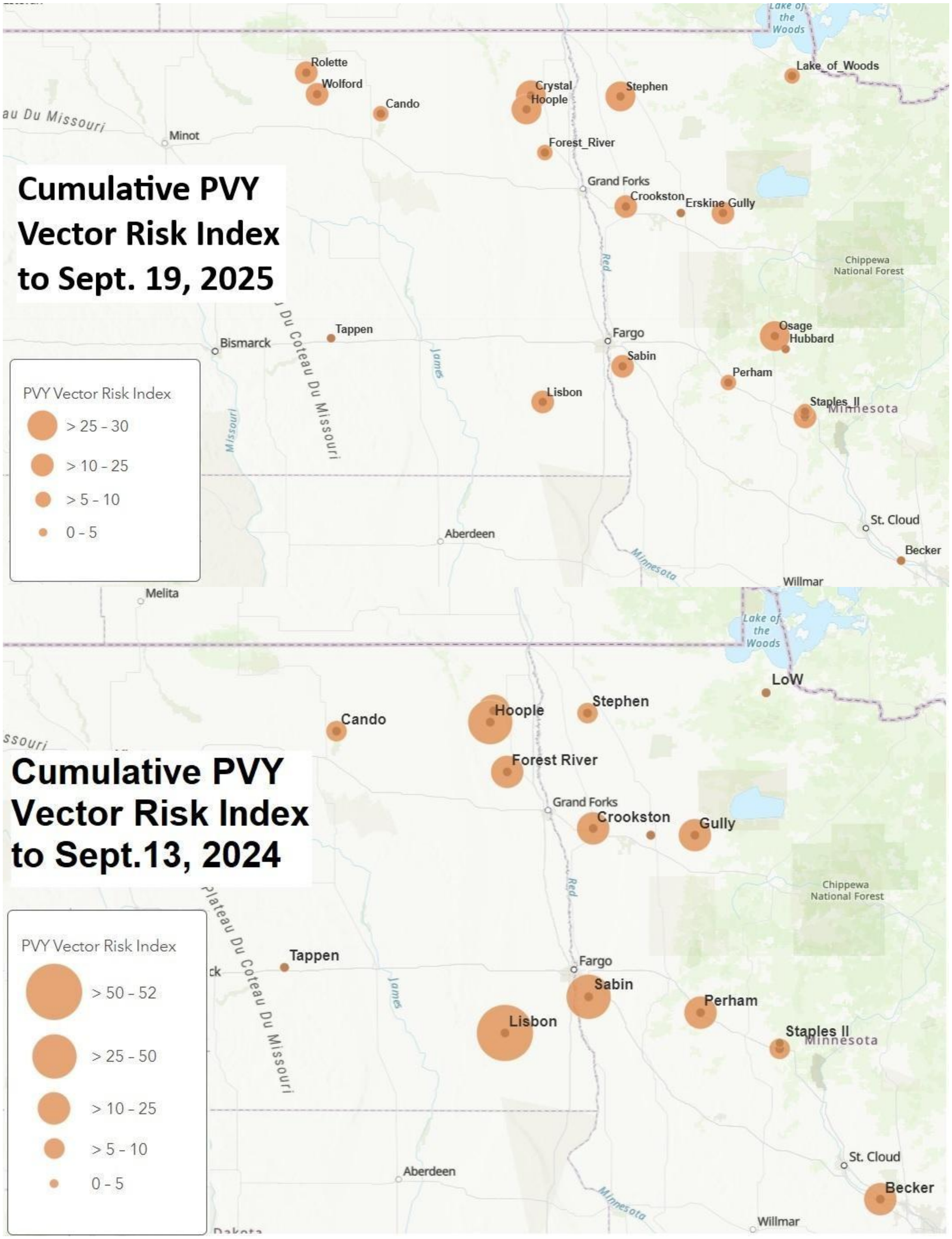
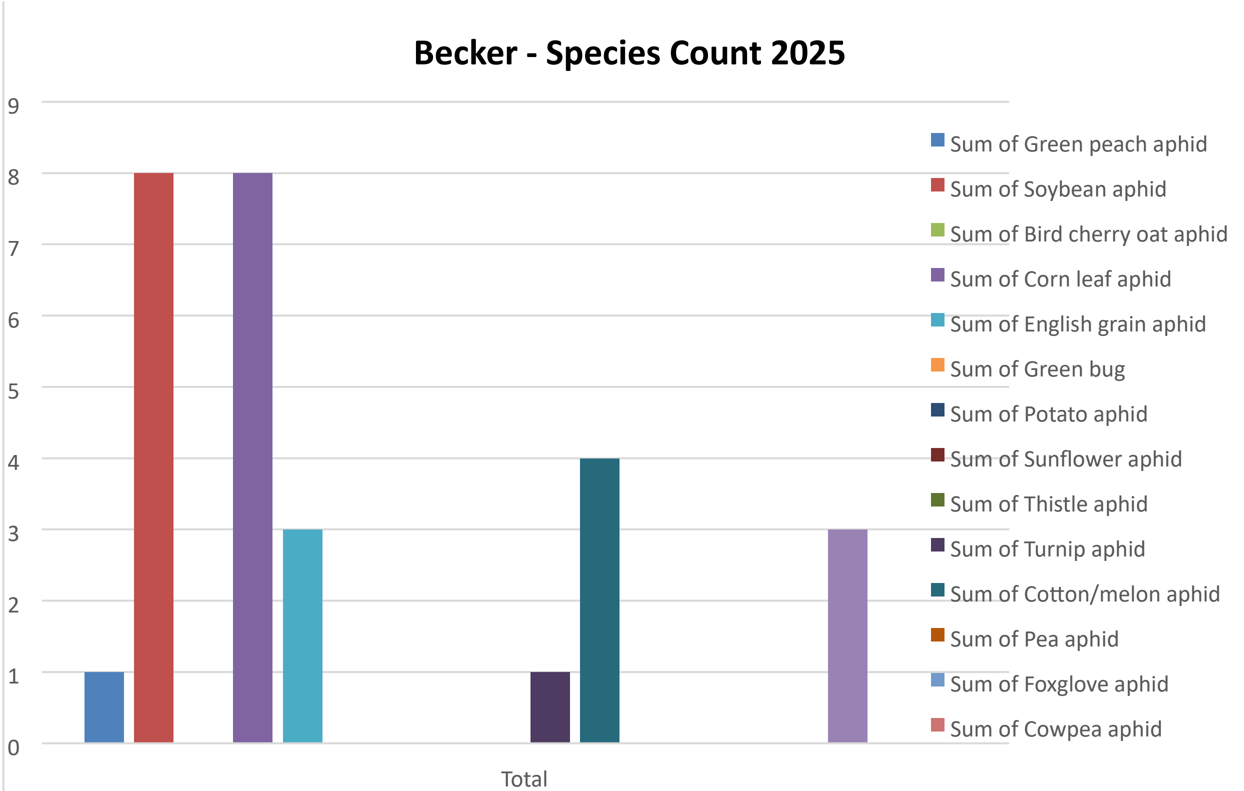
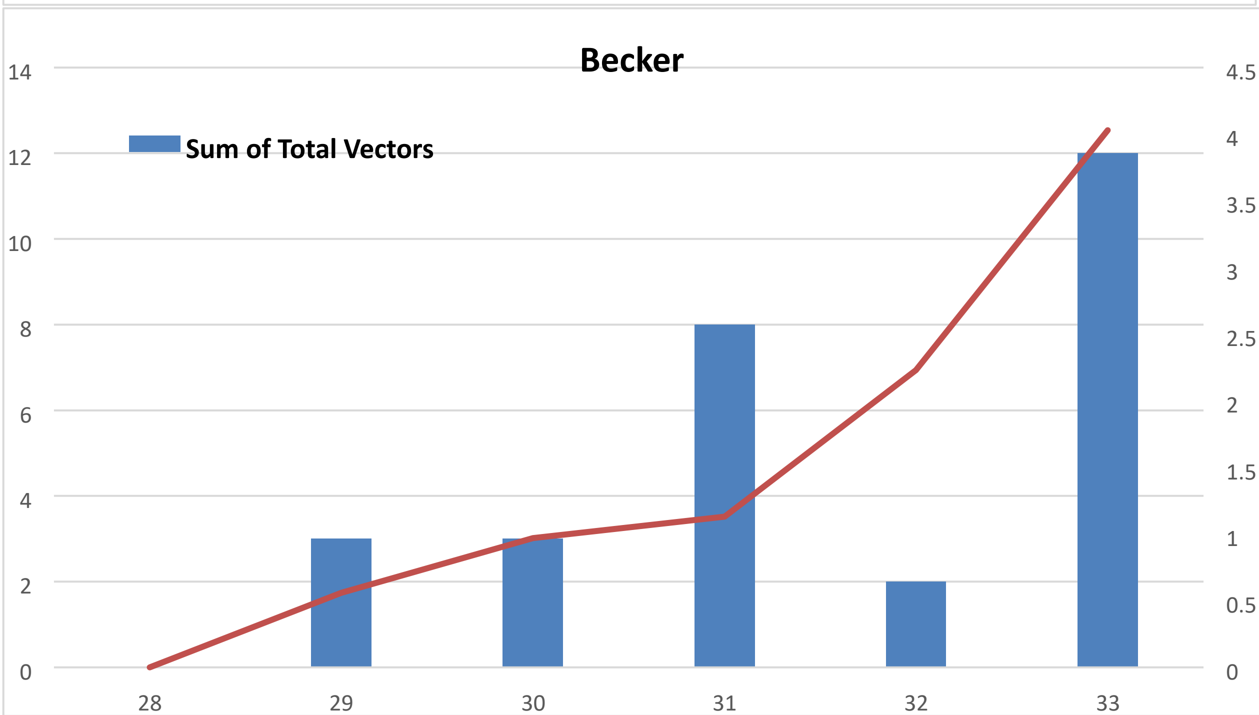


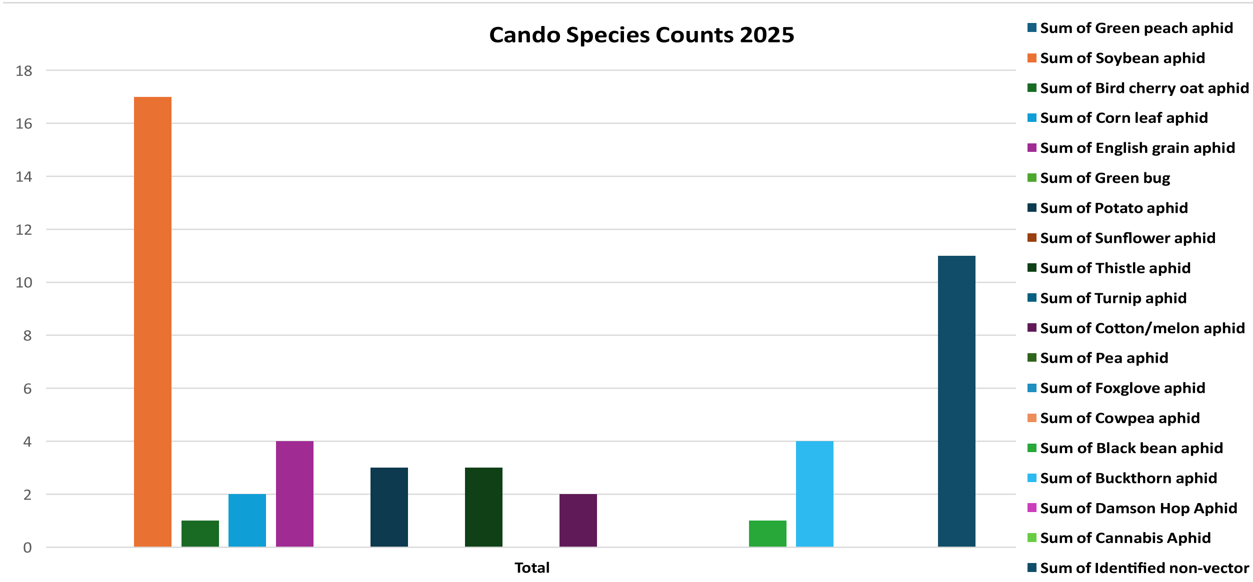
Figure 3. Cumulative PVY Vector Risk Index maps for the individual trapping sites in 2024 & 2025. Please note the higher levels of PVY -VRI on 2024 legend.

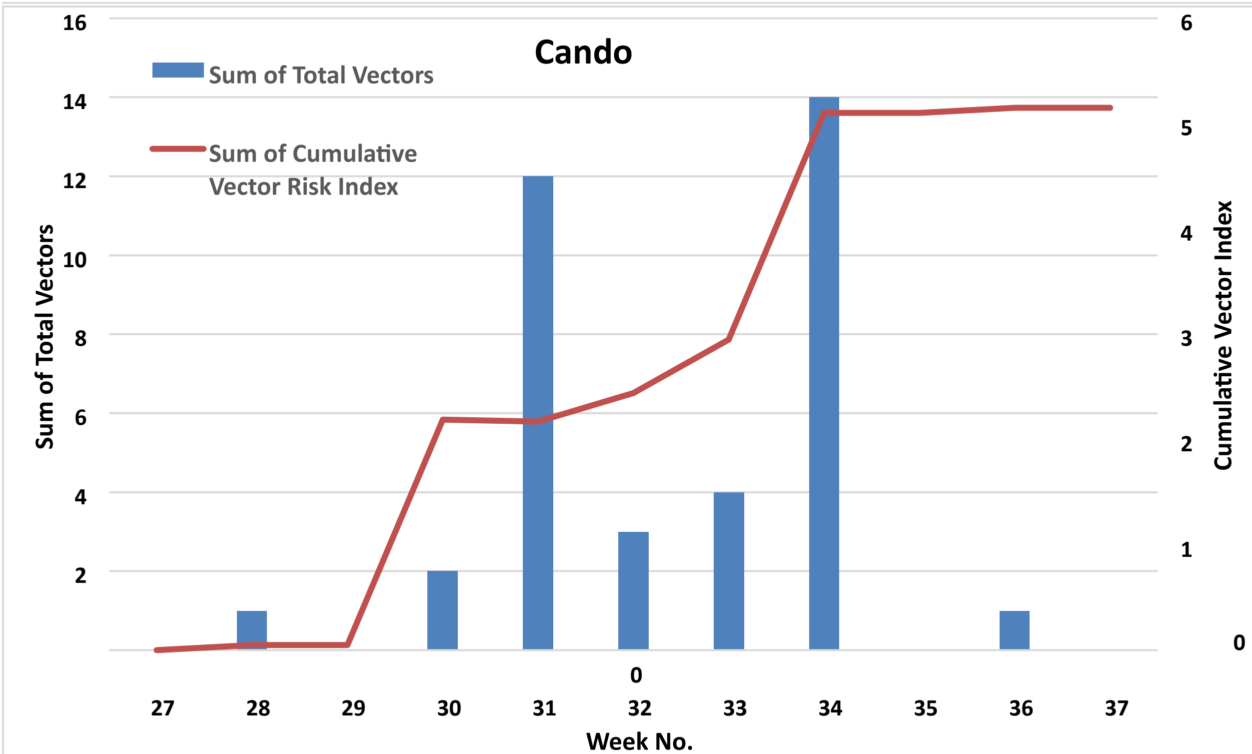
Appendix 1 – Species Compositions and Vector Population Dynamics for Minnesota and North
Dakota Trap Sites



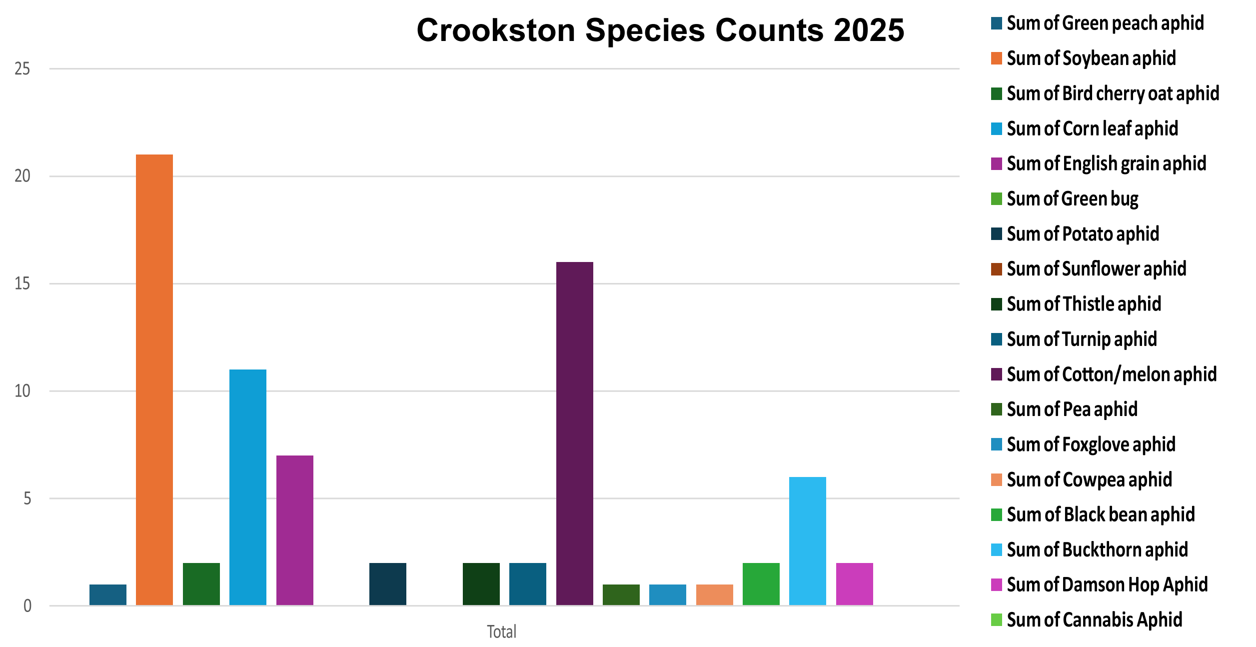


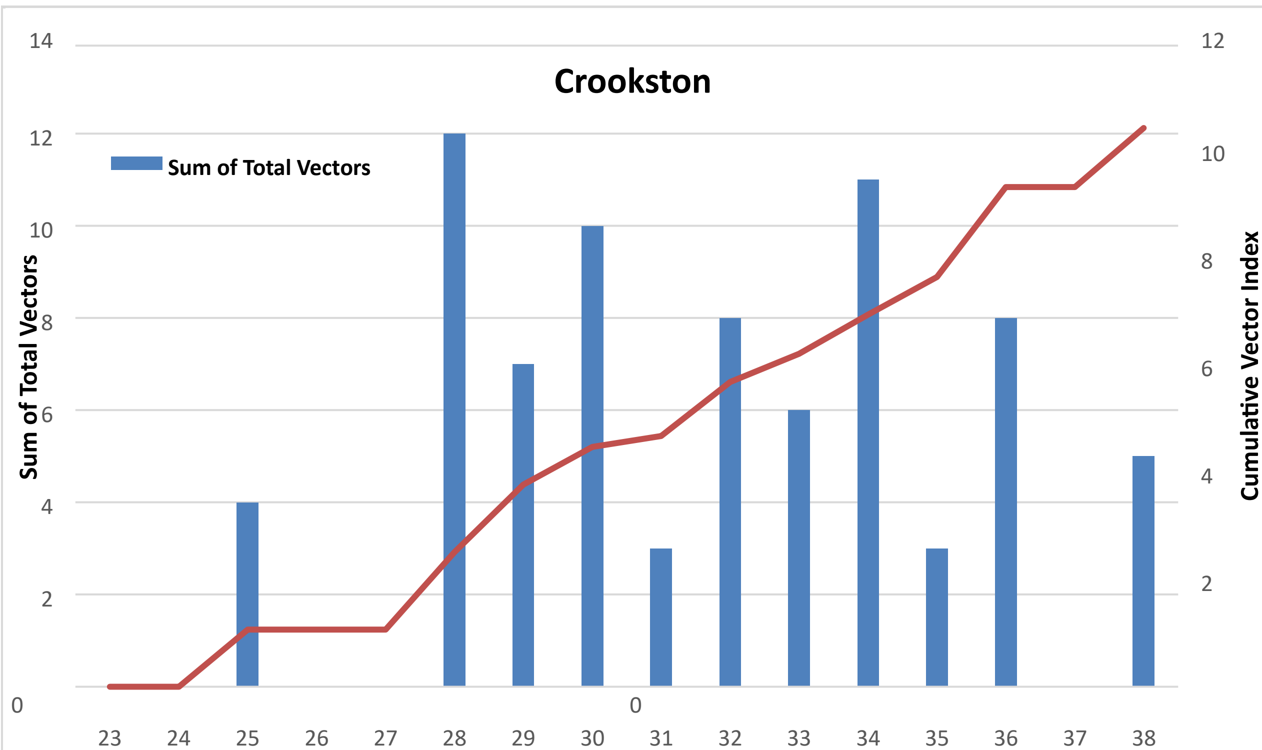
Species composition and vector population dynamics – Becker 2025



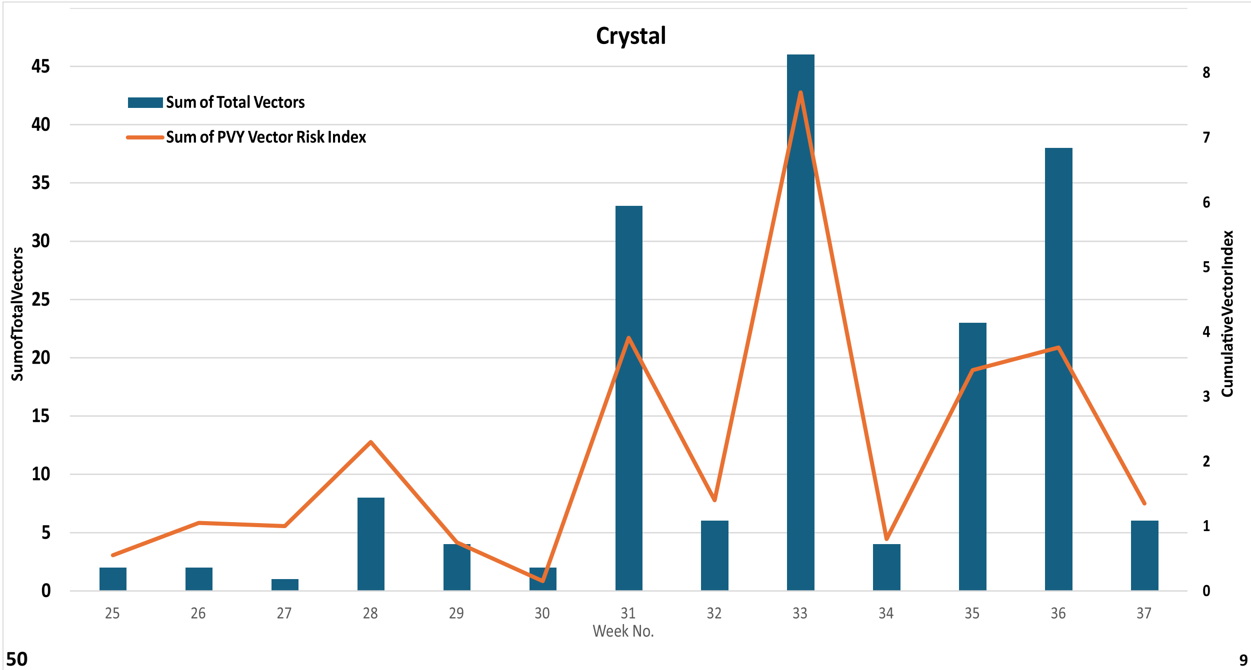


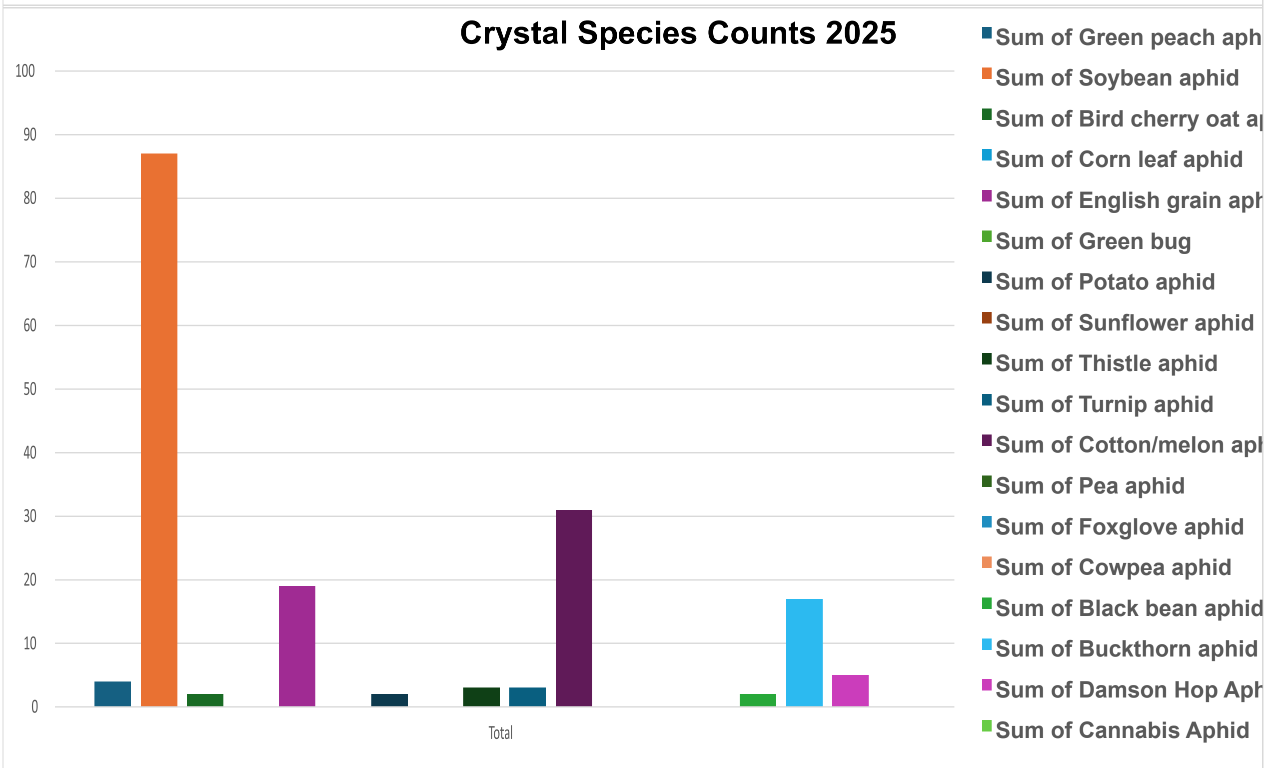
Species composition and vector population dynamics – Cando 2025



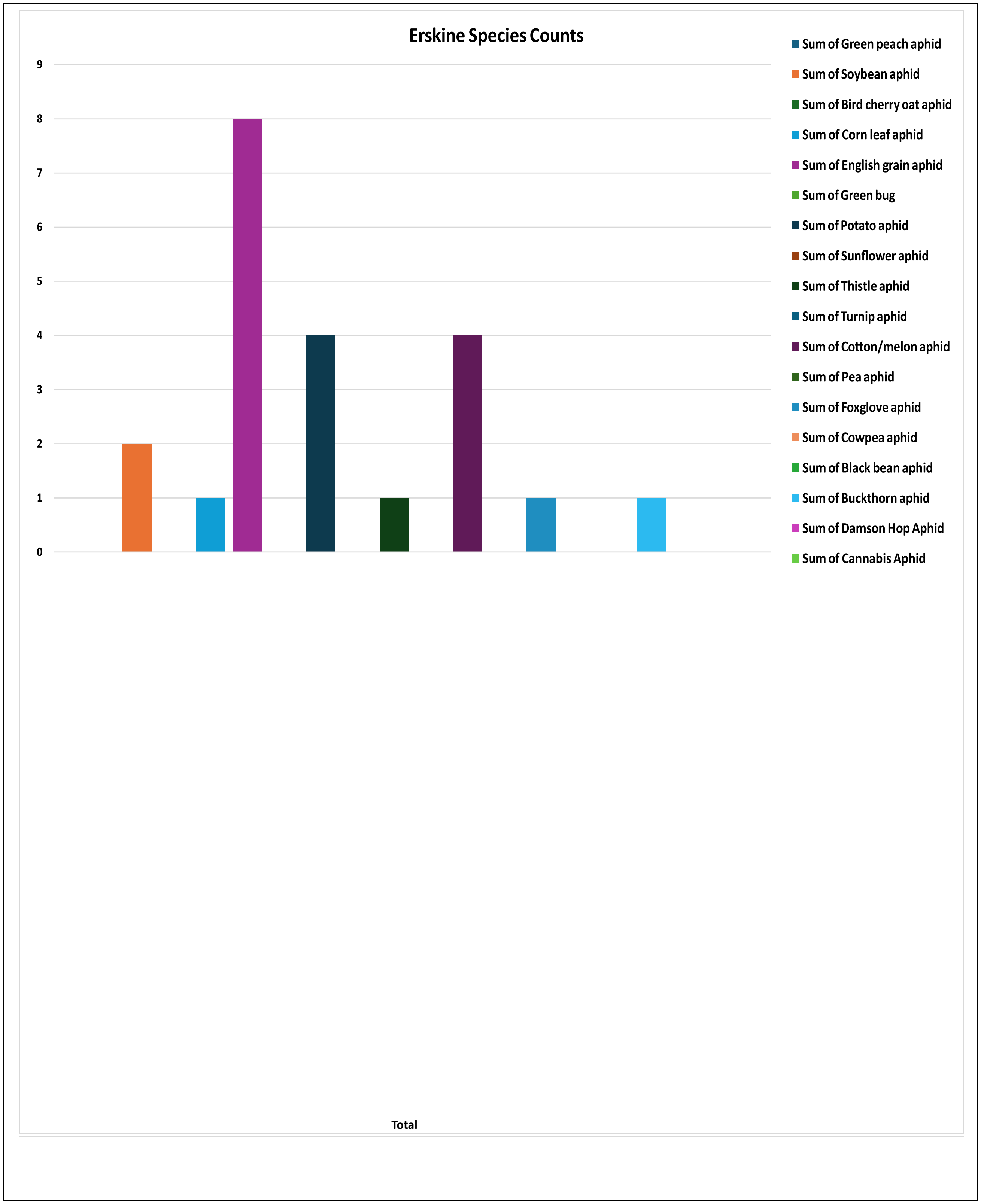


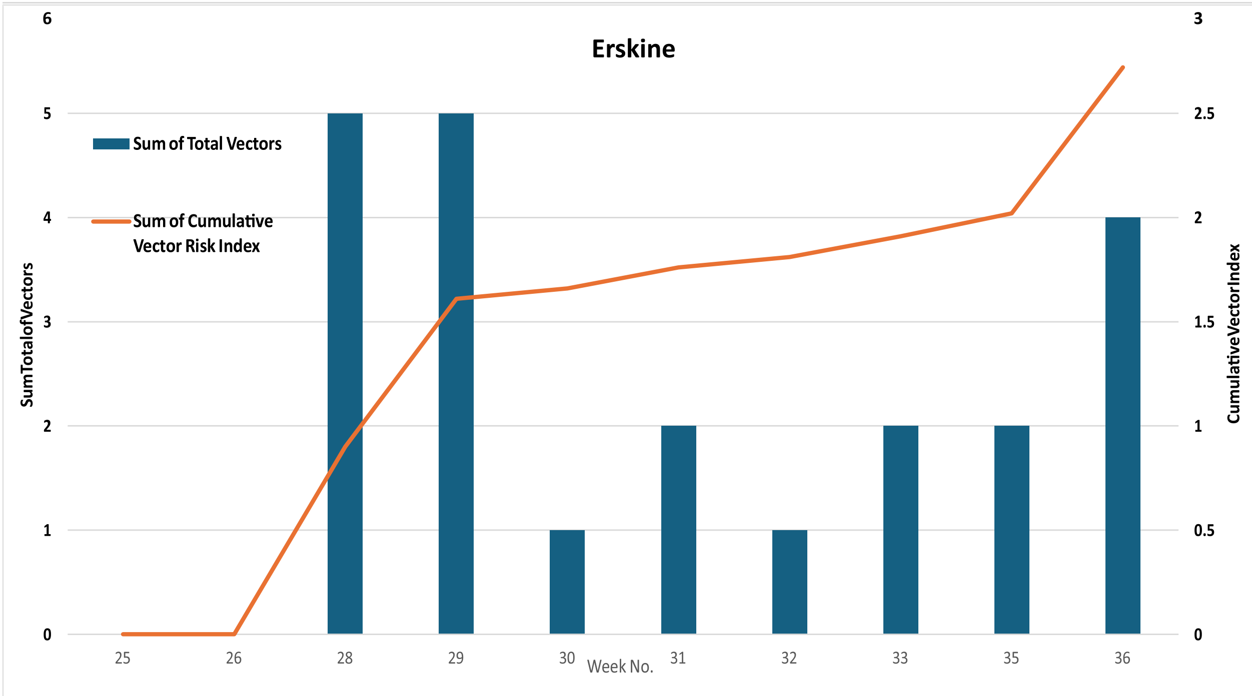
Species composition and vector population dynamics – Crookston 2025



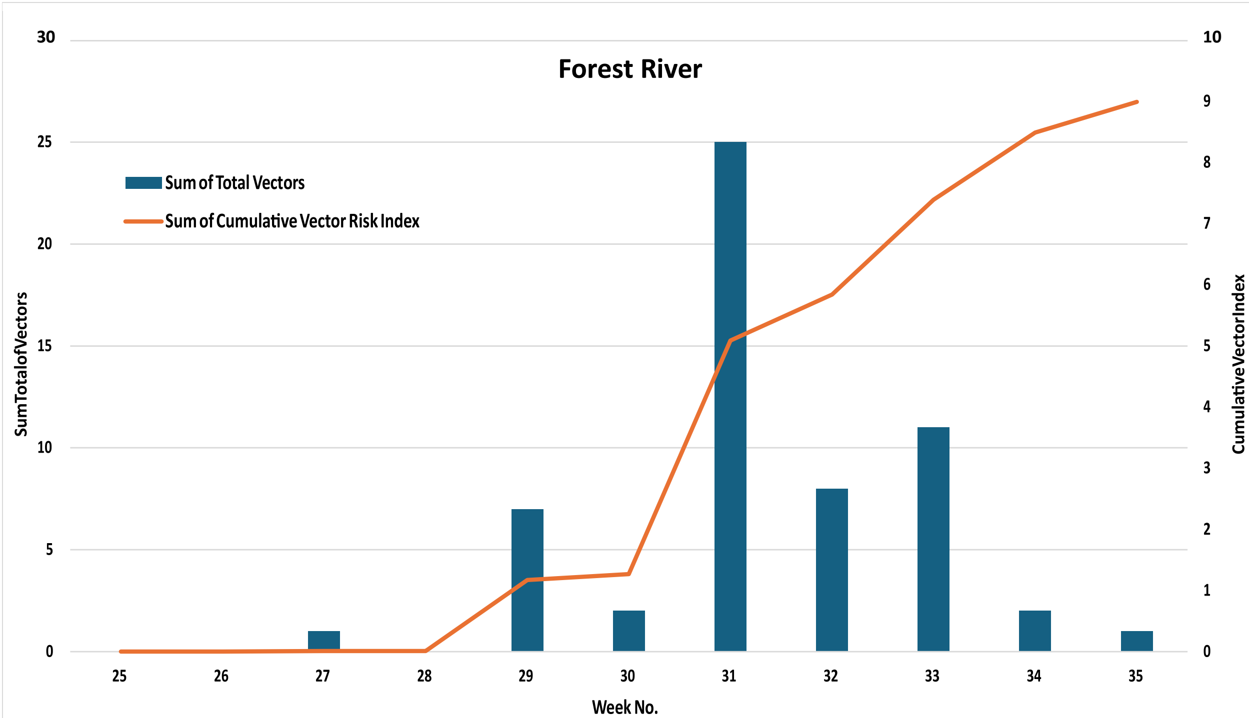


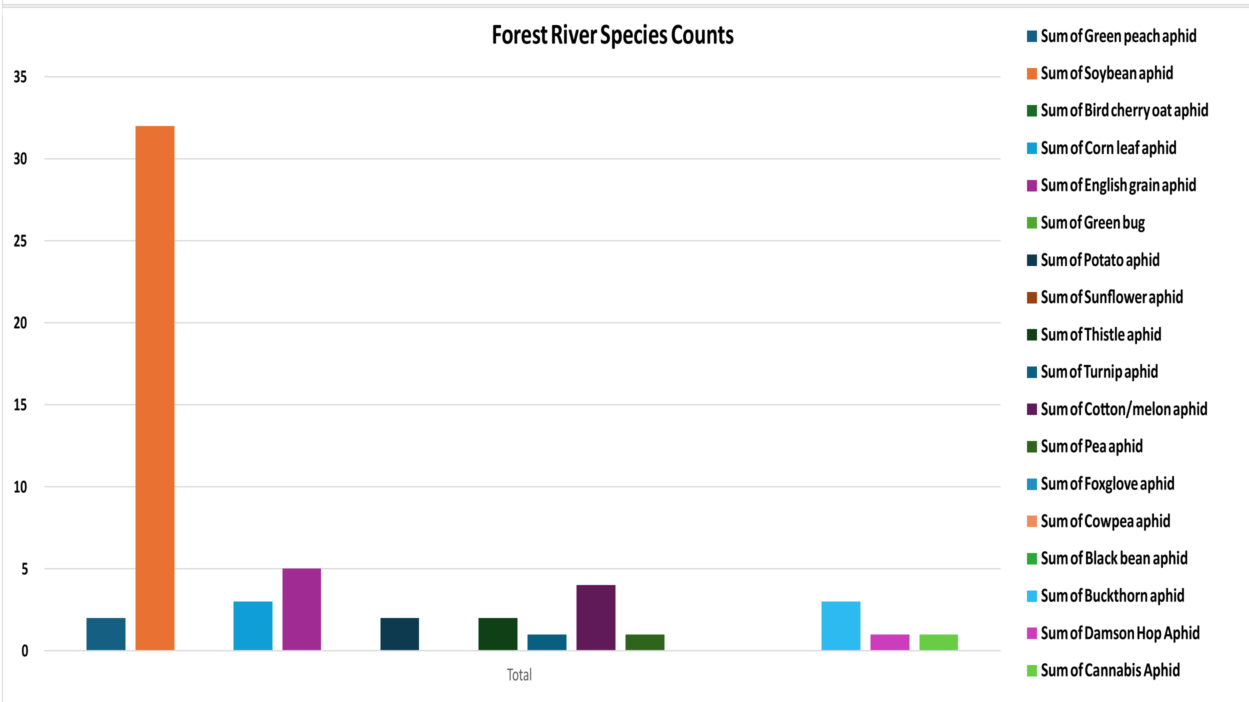
Species composition and vector population dynamics – Crystal 2025


Erskine Species Counts
9
8
7
6
5
4
3
2
1
0
Total
Sum of Green peach aphid
Sum of Soybean aphid
Sum of Bird cherry oat aphid
Sum of Corn leaf aphid
Sum of English grain aphid
Sum of Green bug
Sum of Potato aphid
Sum of Sunflower aphid
Sum of Thistle aphid
Sum of Turnip aphid
Sum of Cotton/melon aphid
Sum of Pea aphid
Sum of Foxglove aphid
Sum of Cowpea aphid
Sum of Black bean aphid
Sum of Buckthorn aphid
Sum of Damson Hop Aphid
Sum of Cannabis Aphid



Species composition and vector population dynamics – Erskine 2025





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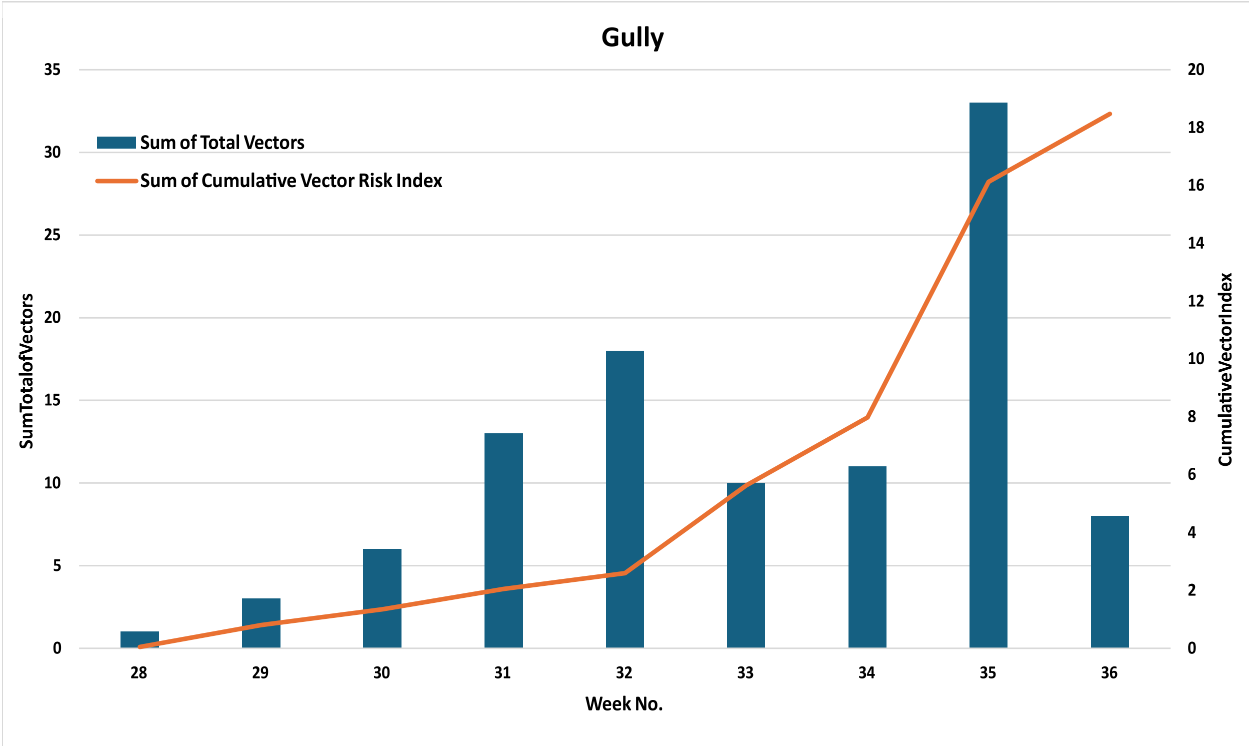
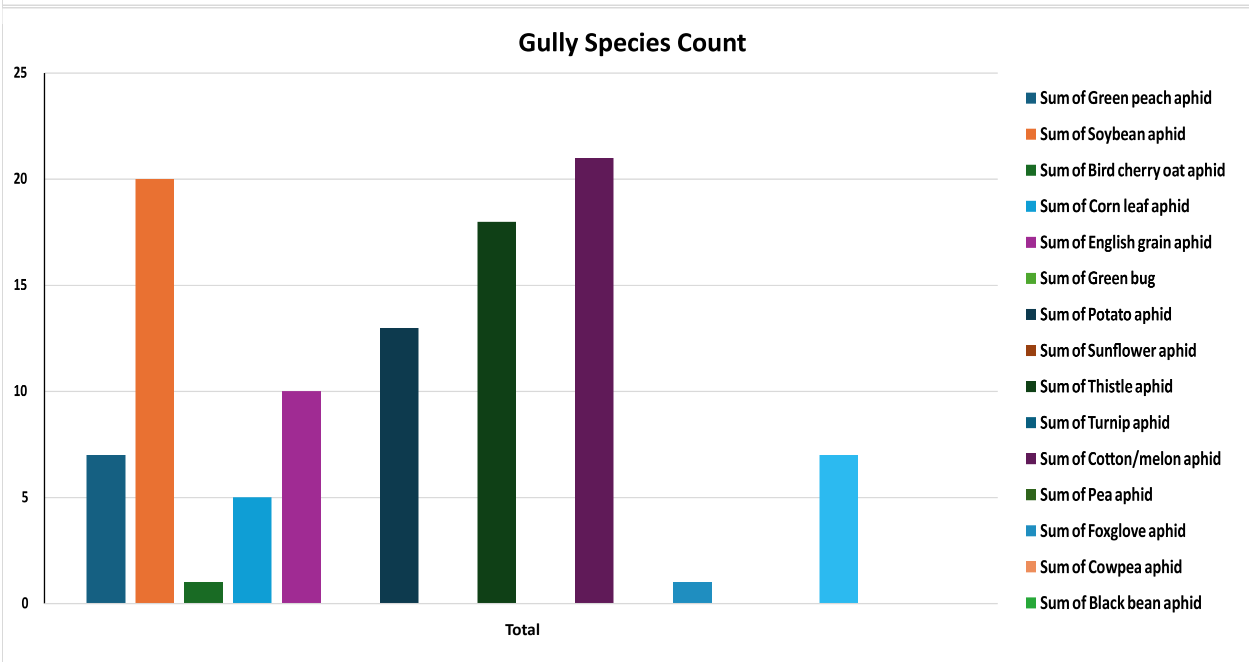
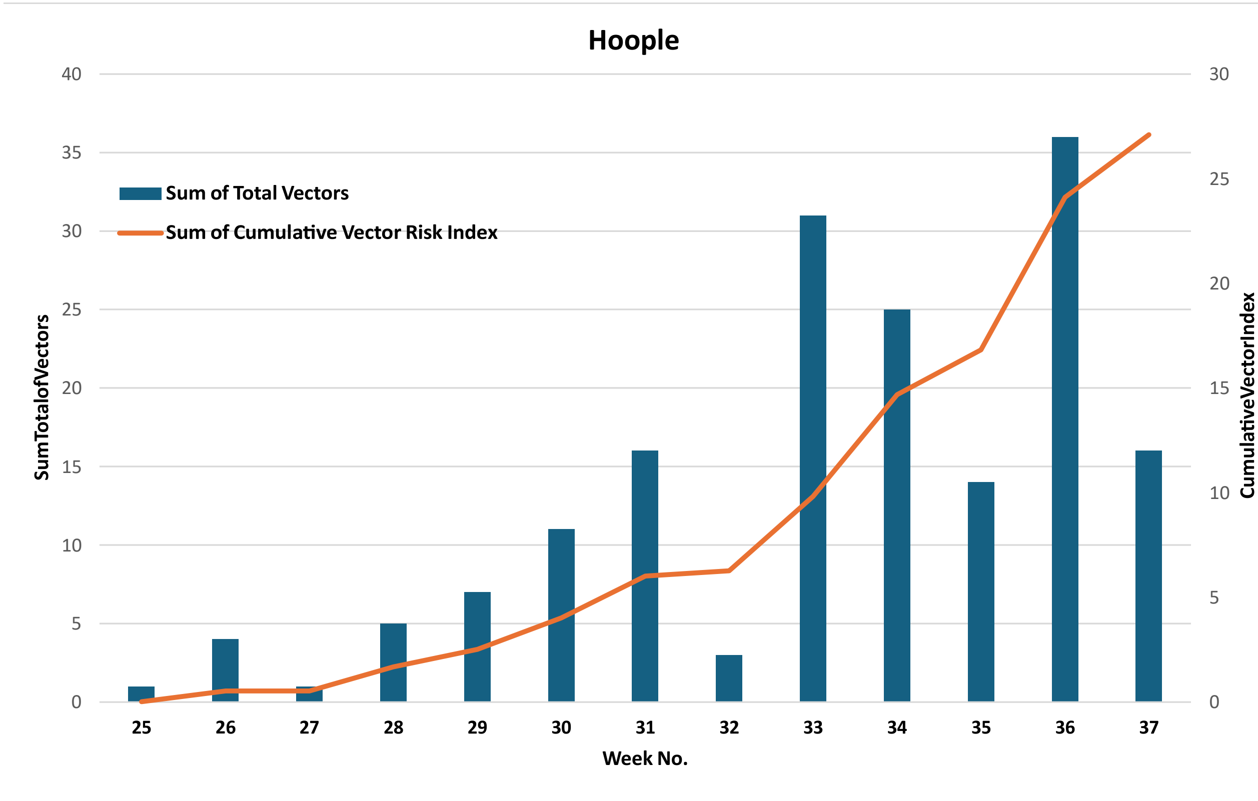
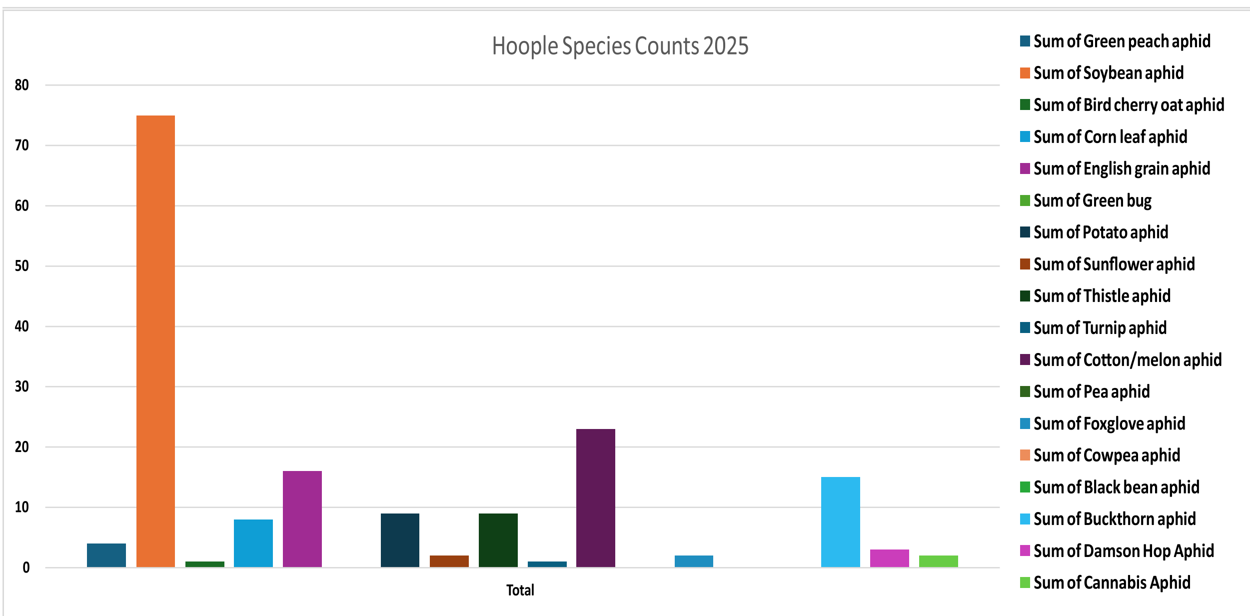


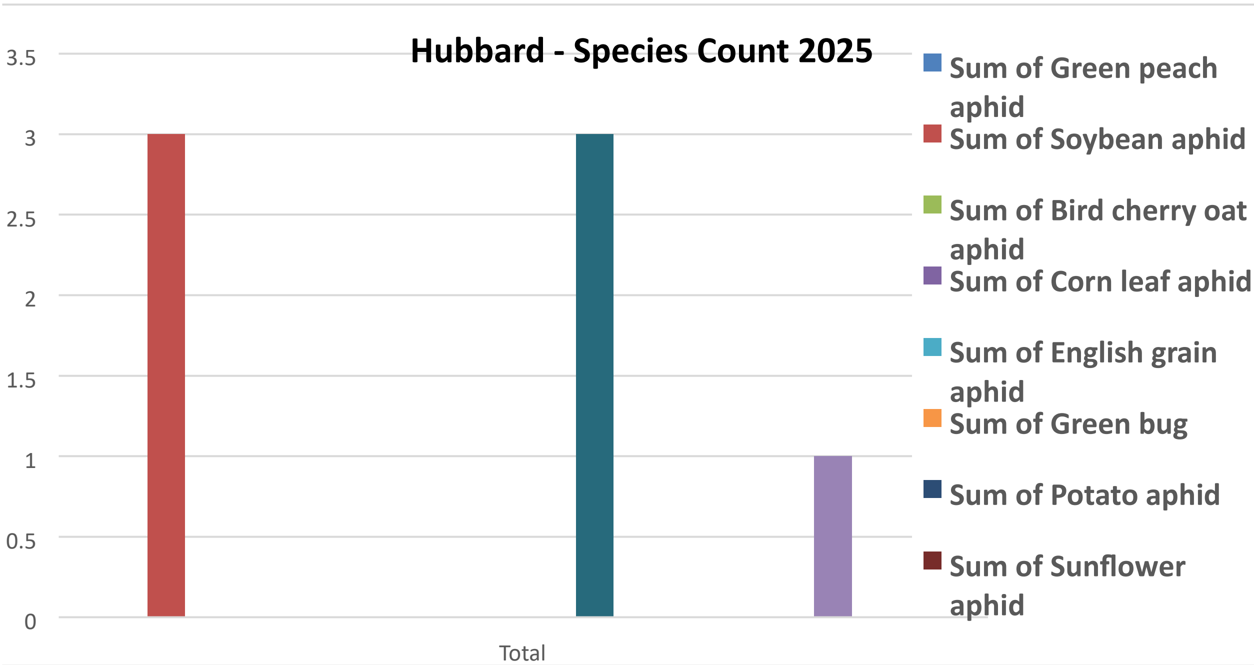


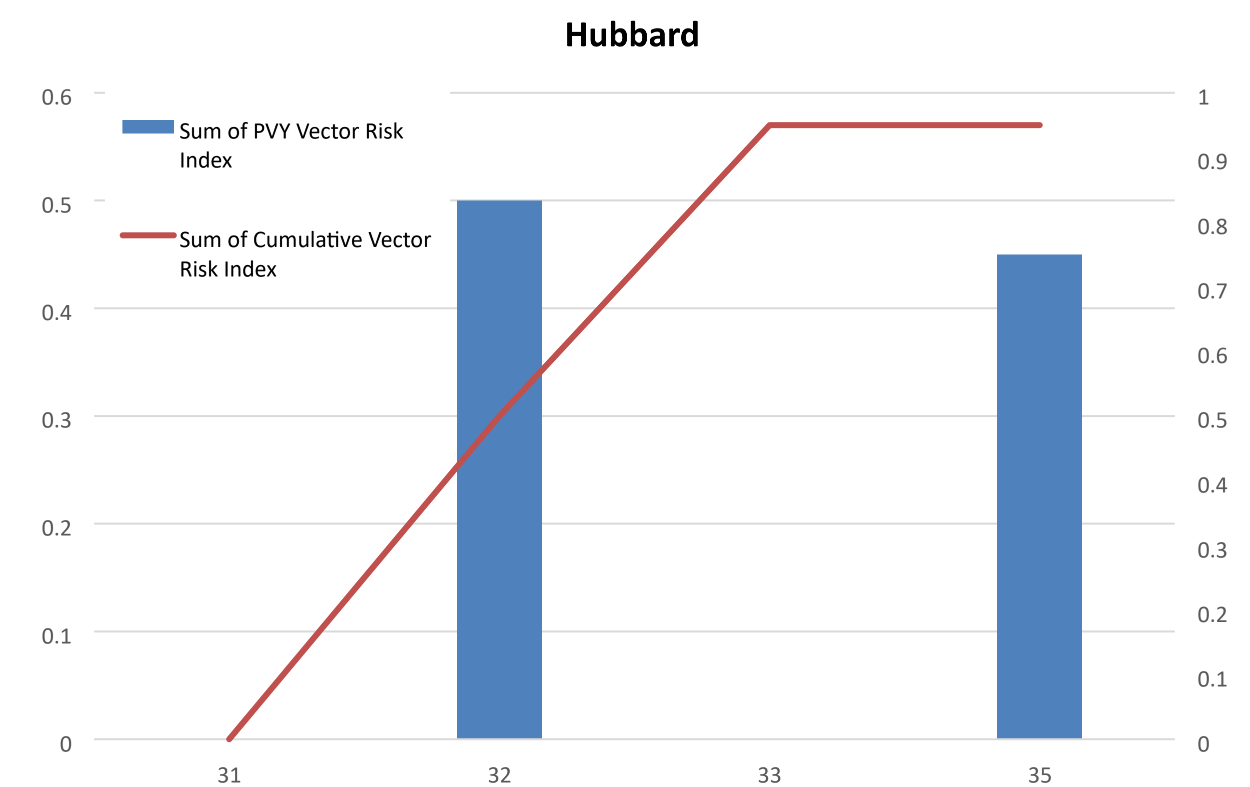
Species composition and vector population dynamics – Gully 2025





Species composition and vector population dynamics – Hoople 2025





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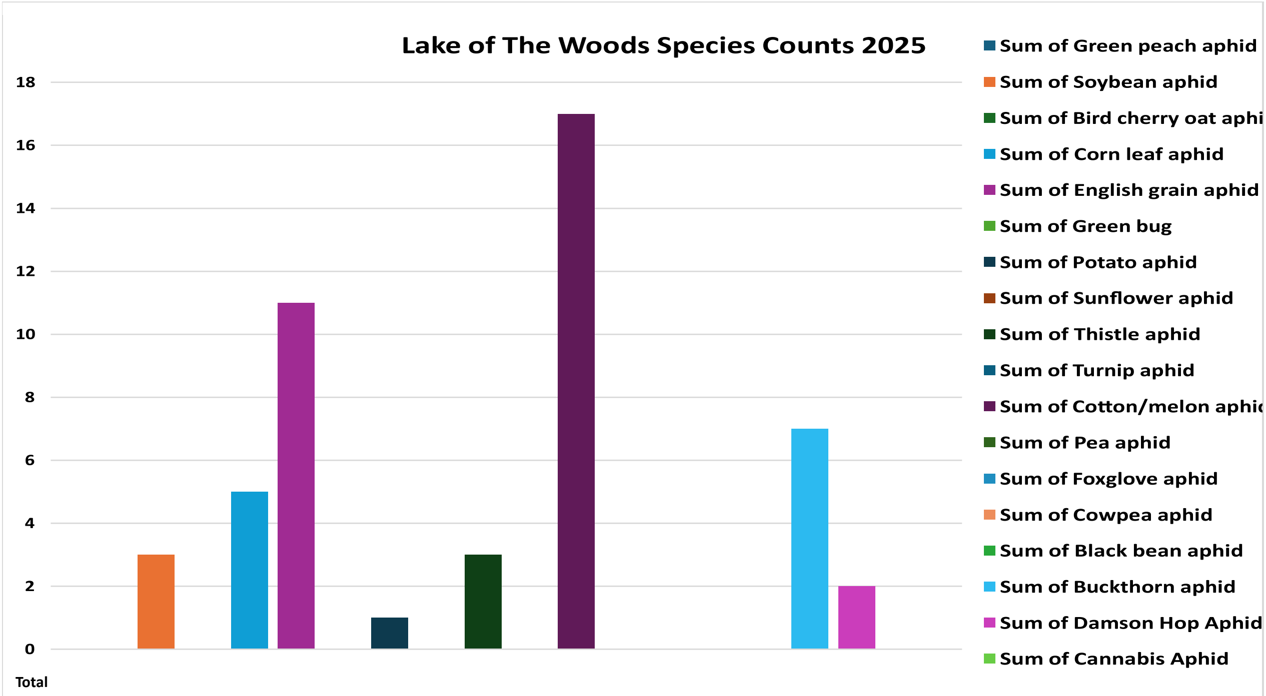
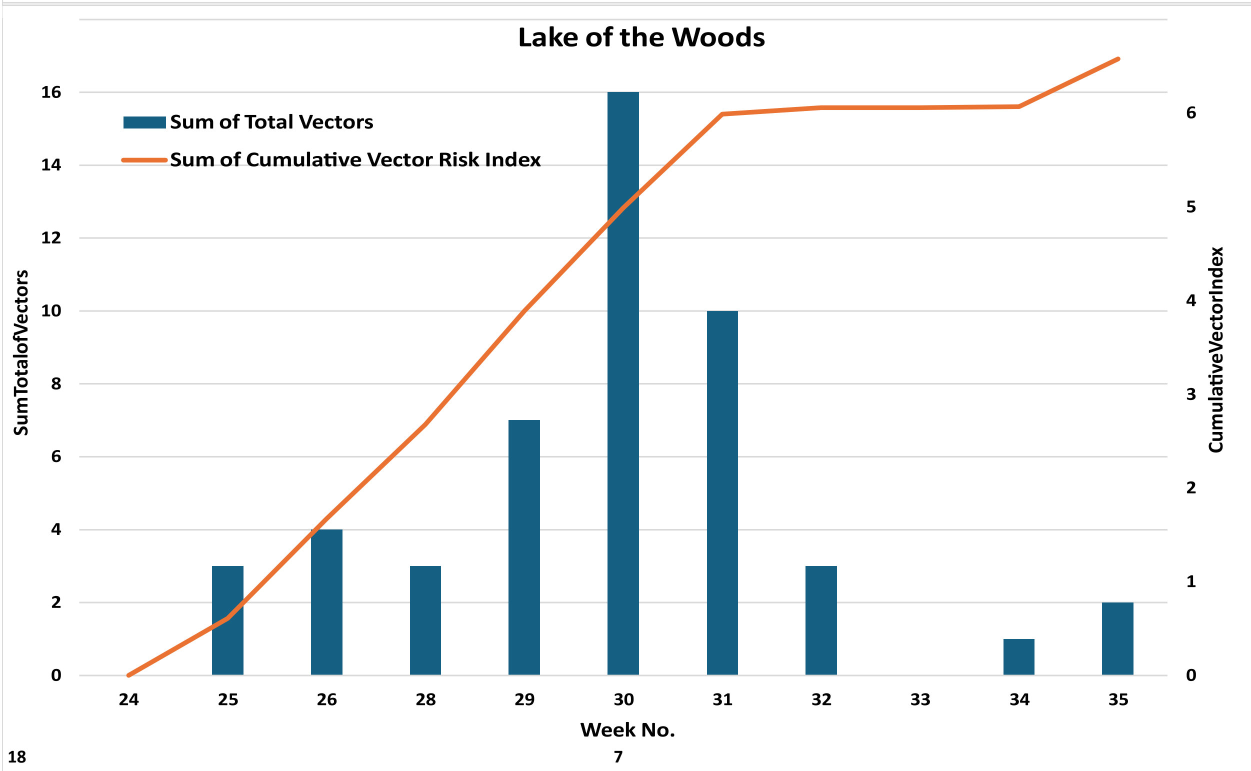
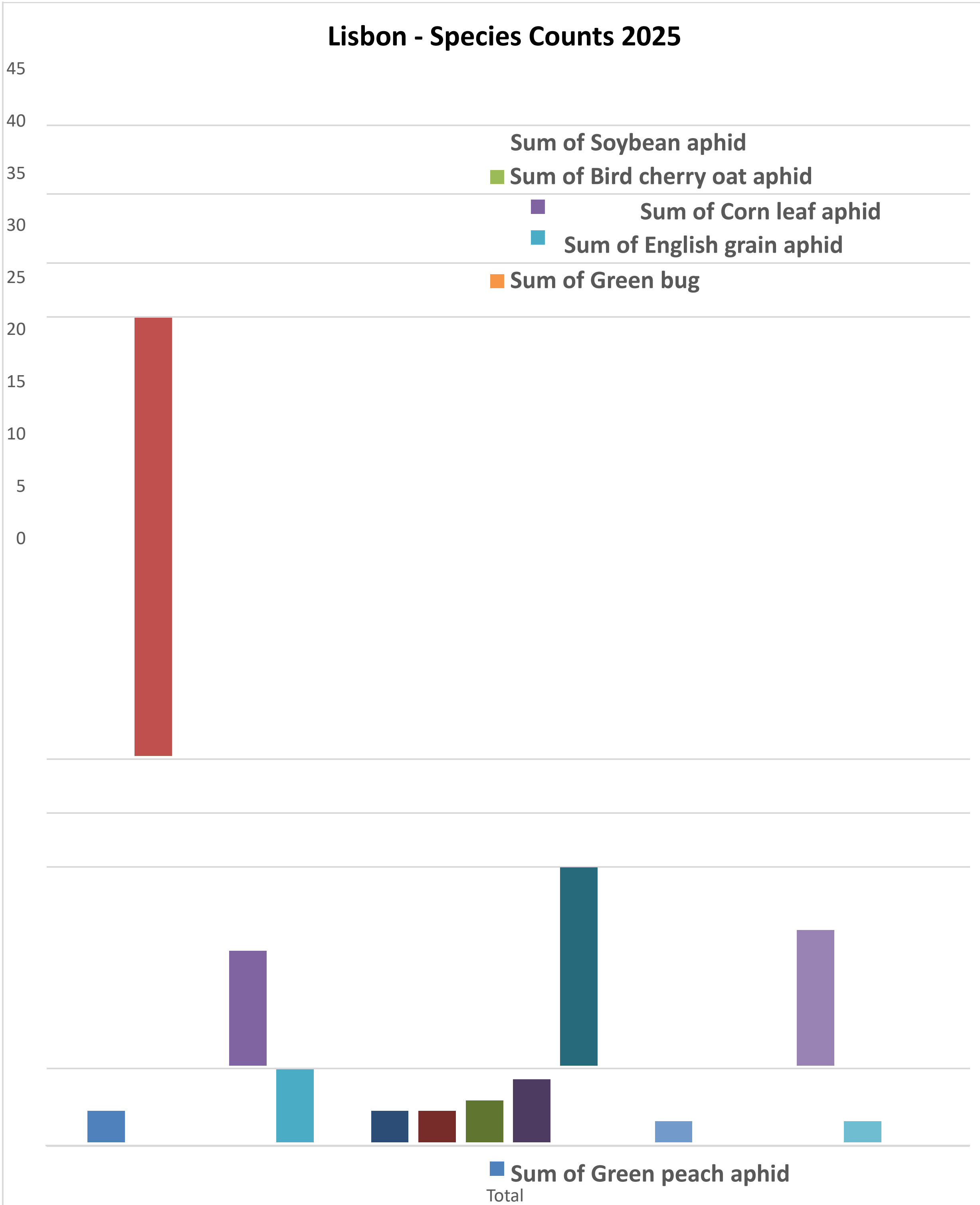
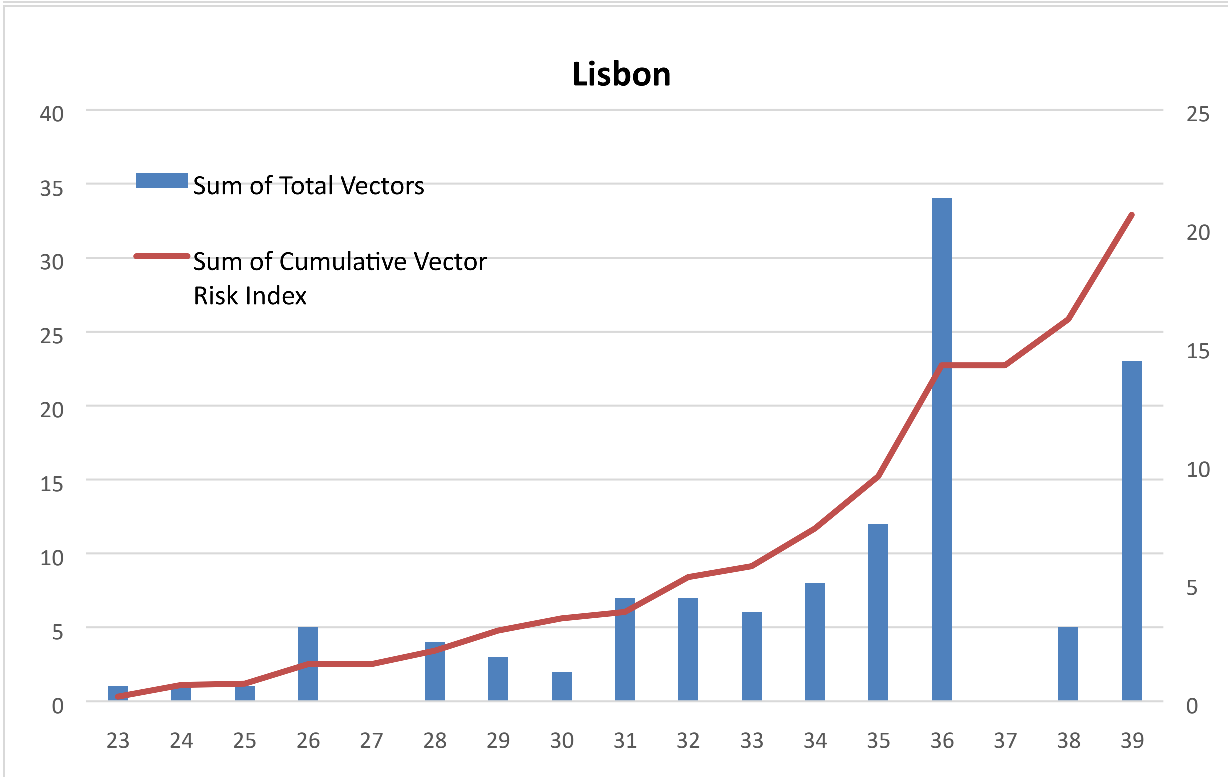


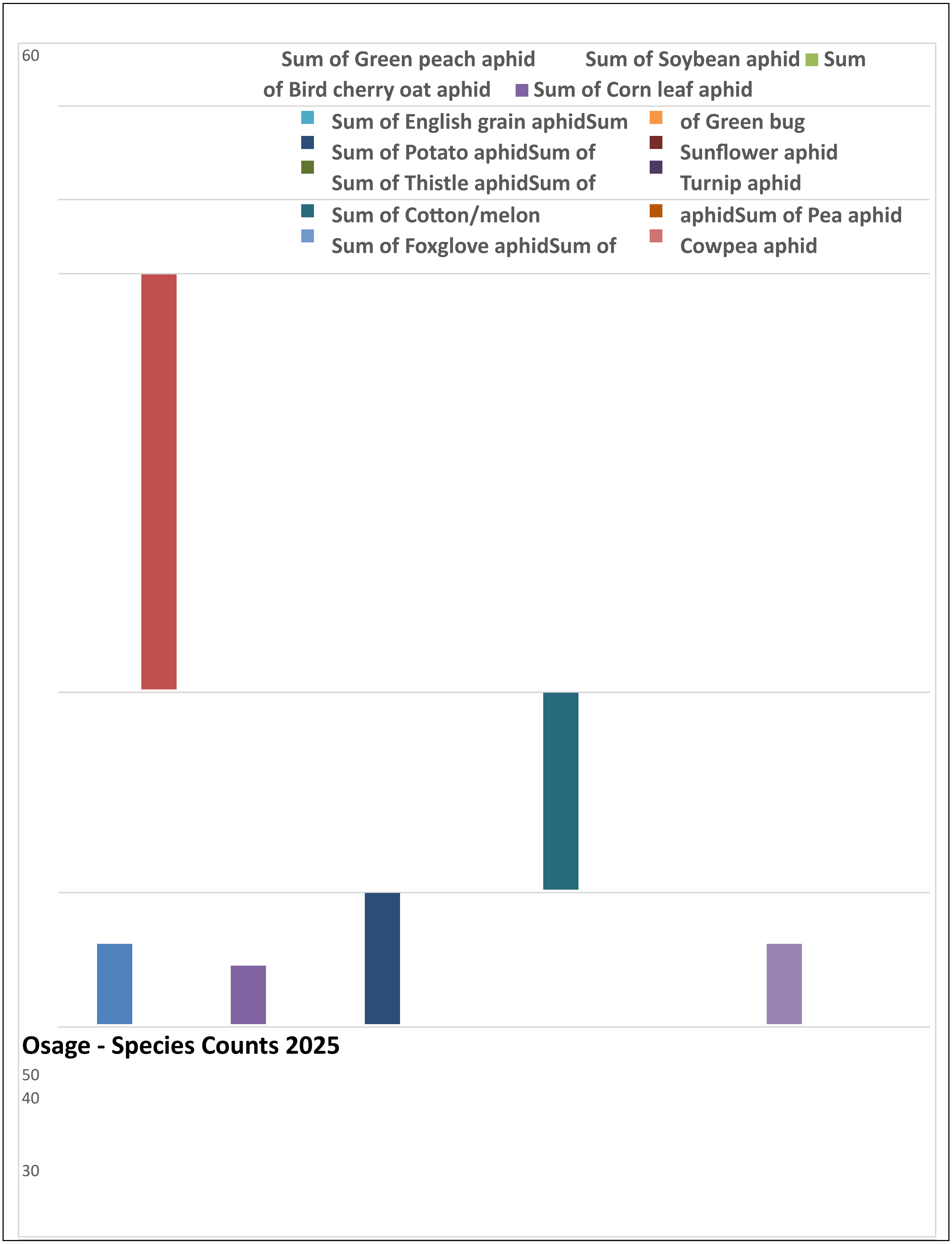


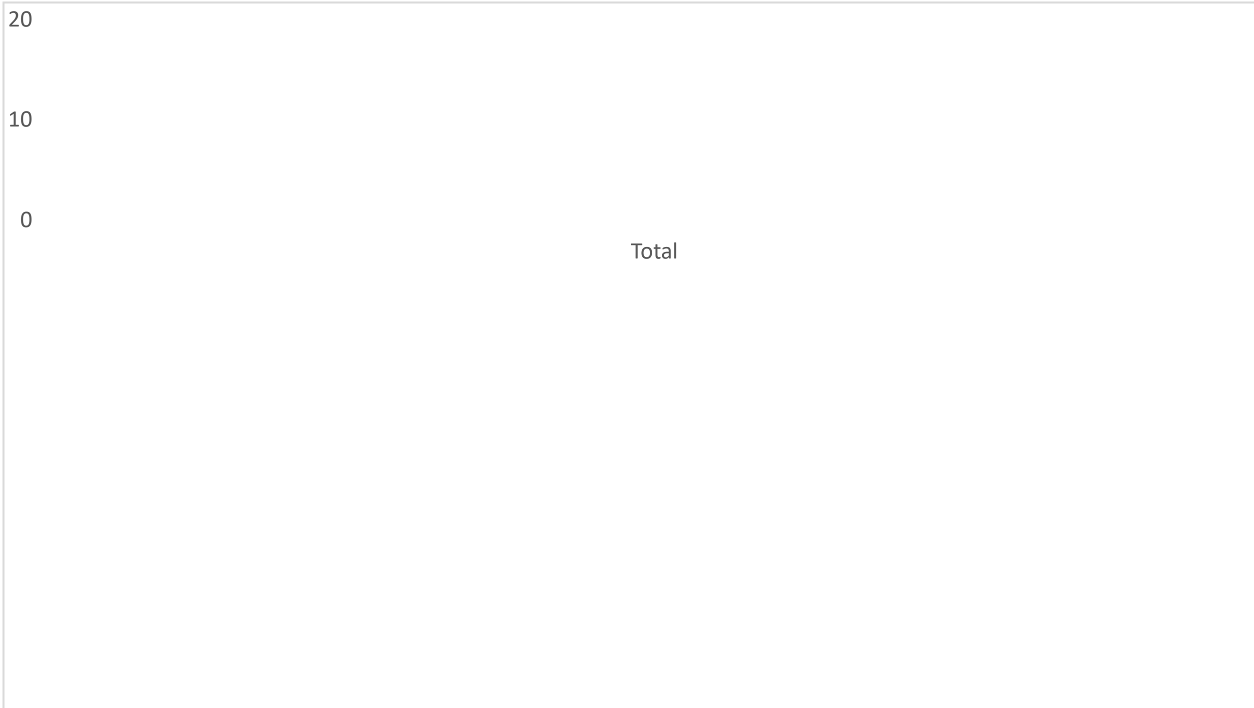
Species composition and vector population dynamics – Lake of the Woods 2025

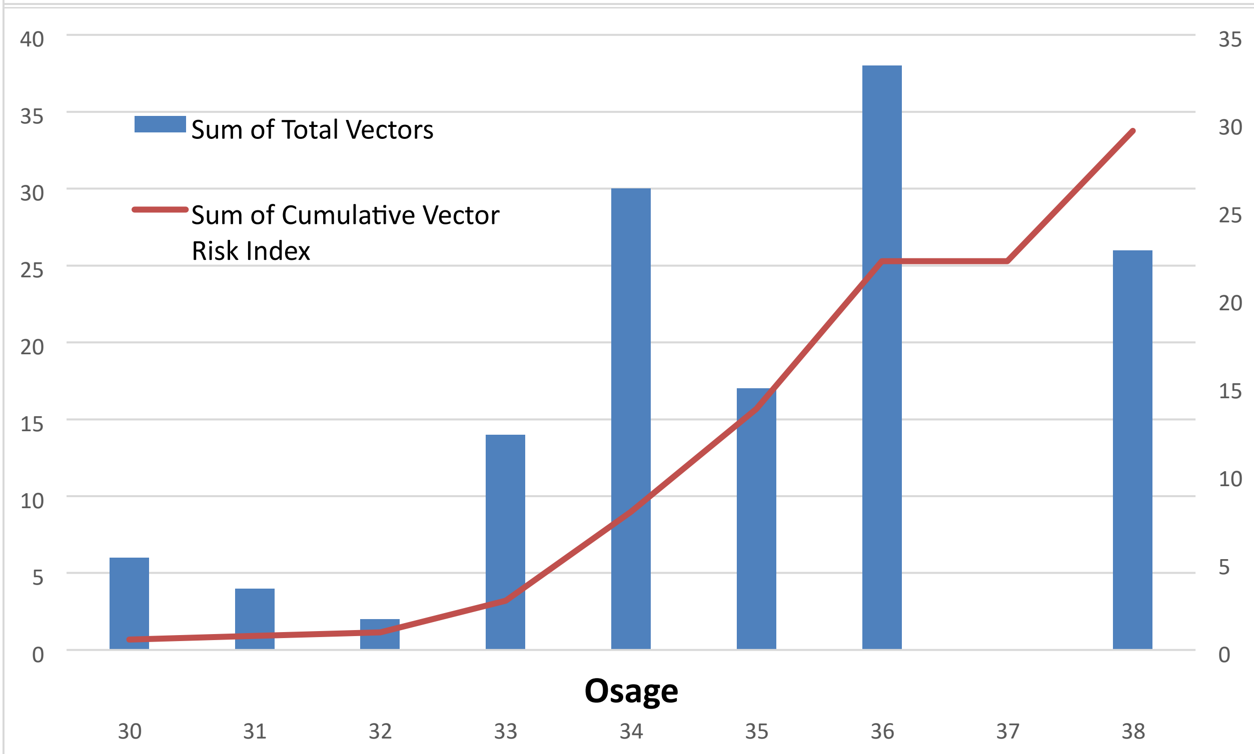

Lisbon - Species Counts 2025
45
40
35
30
25
20
15
10
5
0
Sum of Soybean aphid
Sum of Bird cherry oat aphid
Sum of Corn leaf aphid
Sum of English grain aphid
Sum of Green bug
Sum of Green peach aphid
Total



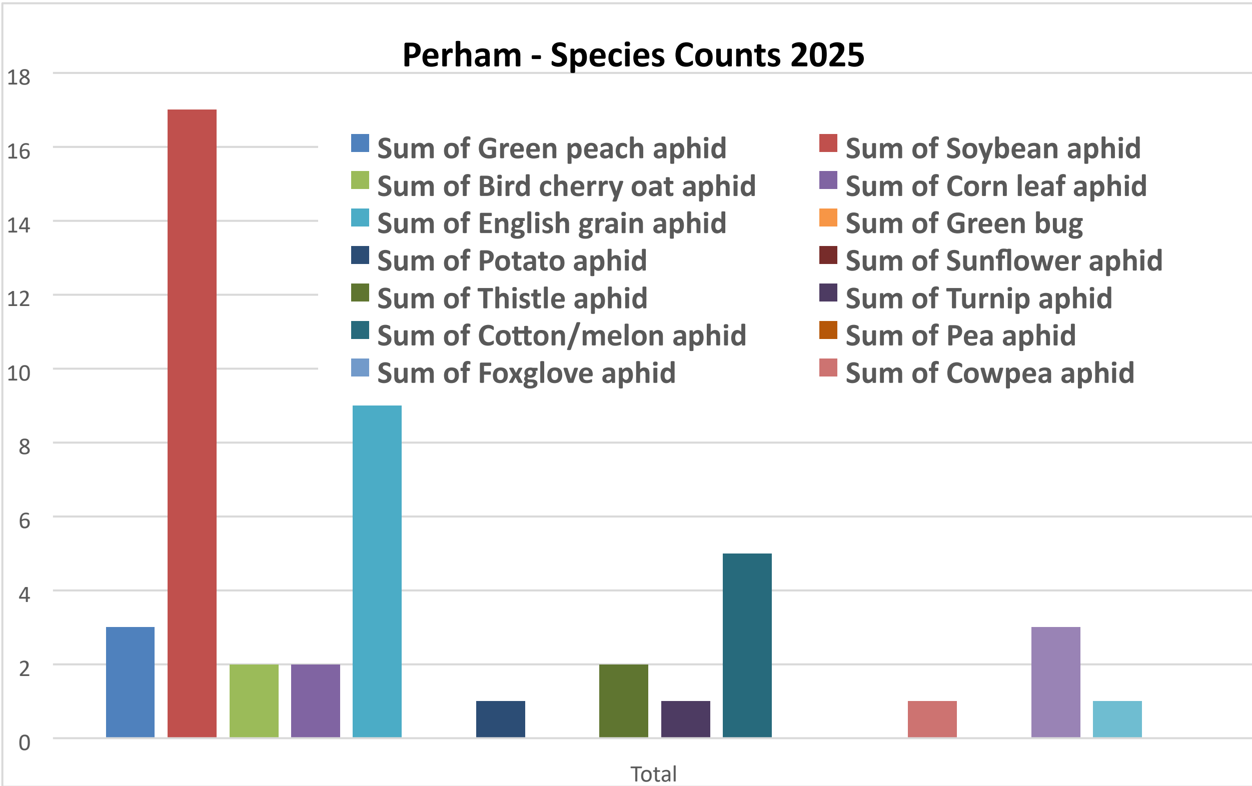
Species composition and vector population dynamics – Lisbon 2025

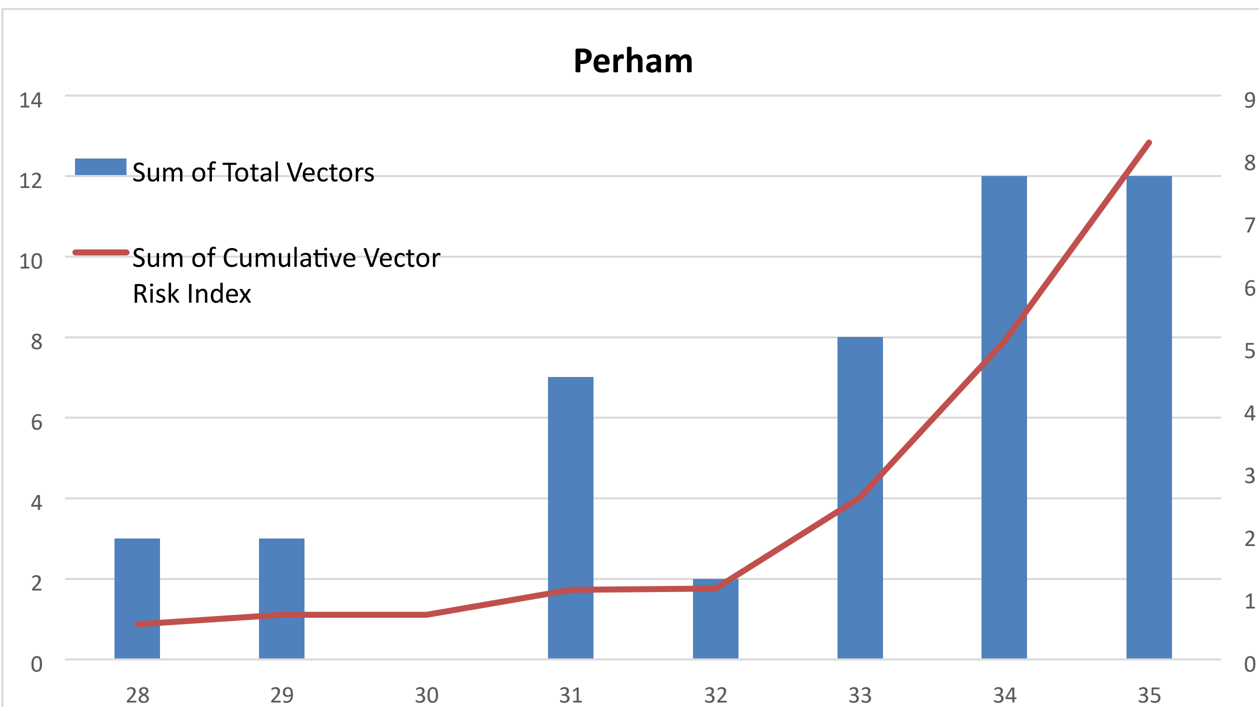

60
Sum of Green peach aphid
Sum of Soybean aphid
Sum of Bird cherry oat aphid
Sum of Corn leaf aphid
Sum of English grain aphid
Sum of Green bug
Sum of Potato aphid
Sum of Sunflower aphid
Sum of Thistle aphid
Sum of Turnip aphid
Sum of Cotton/melon aphid
Sum of Pea aphid
Sum of Foxglove aphid
Sum of Cowpea aphid
Osage - Species Counts 2025
50
40
30



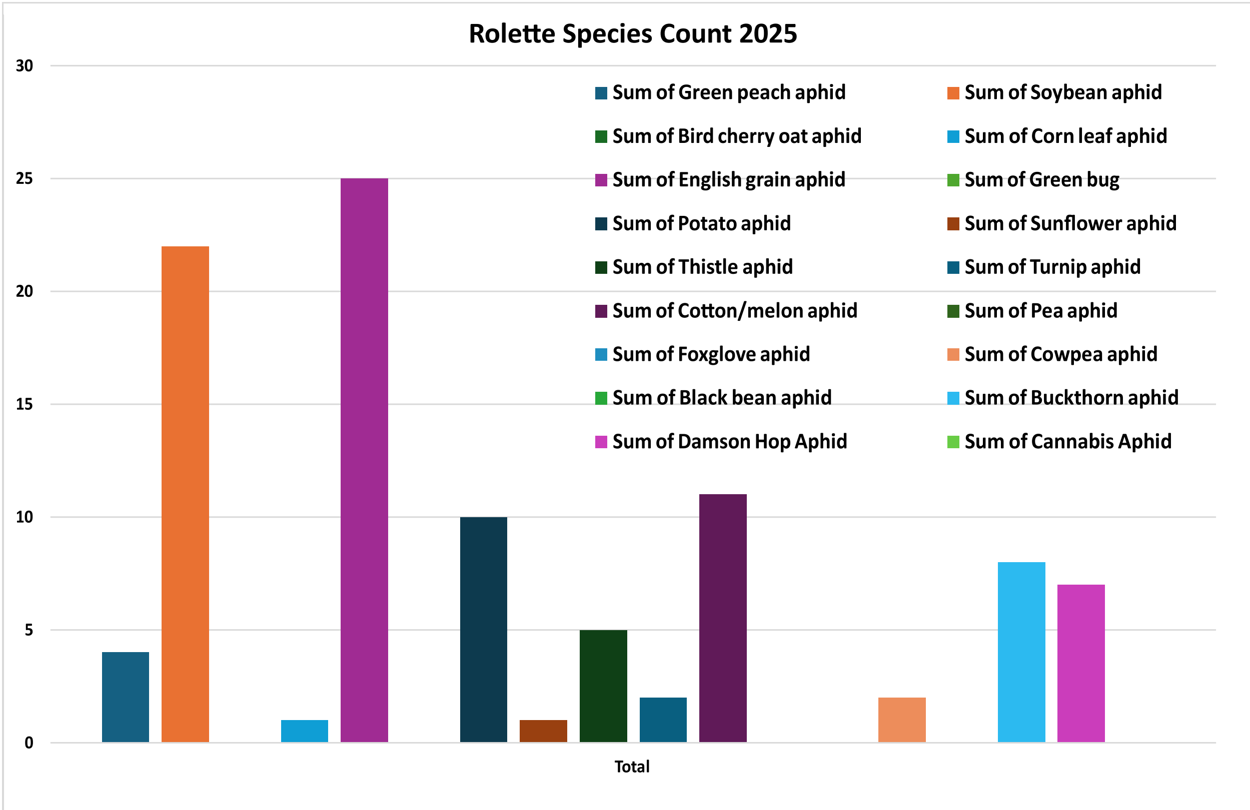


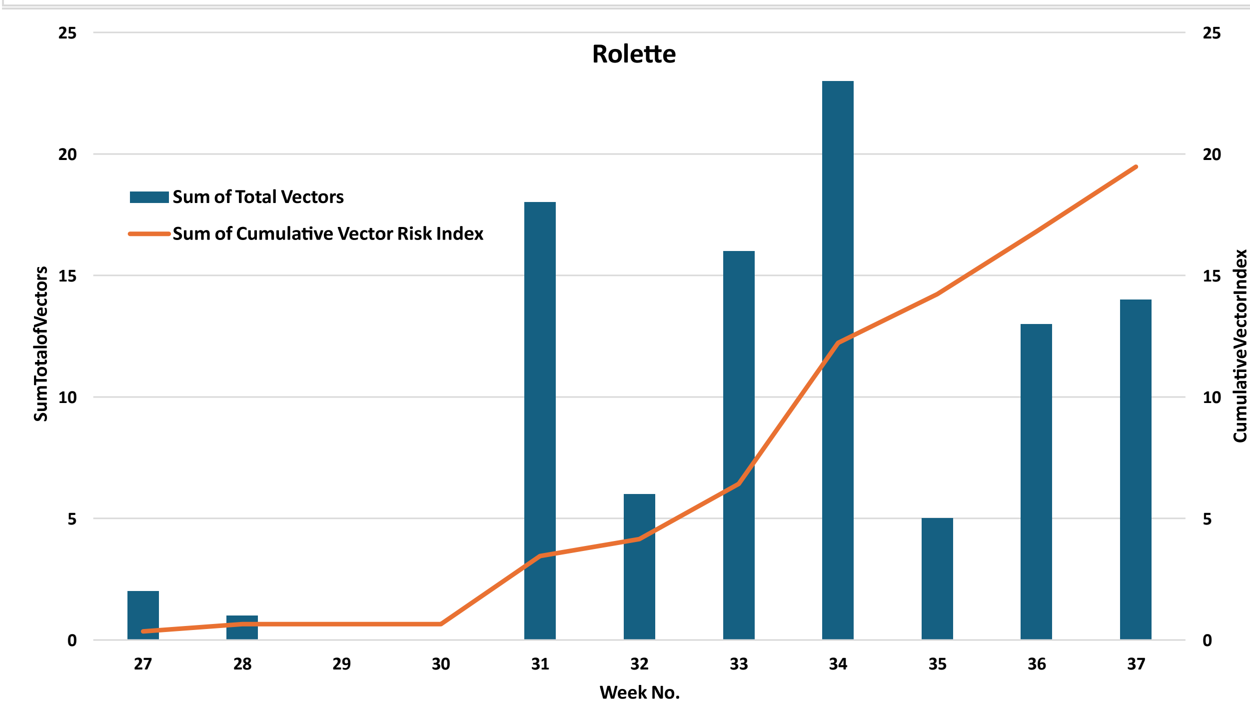
Species composition and vector population dynamics – Osage 2025



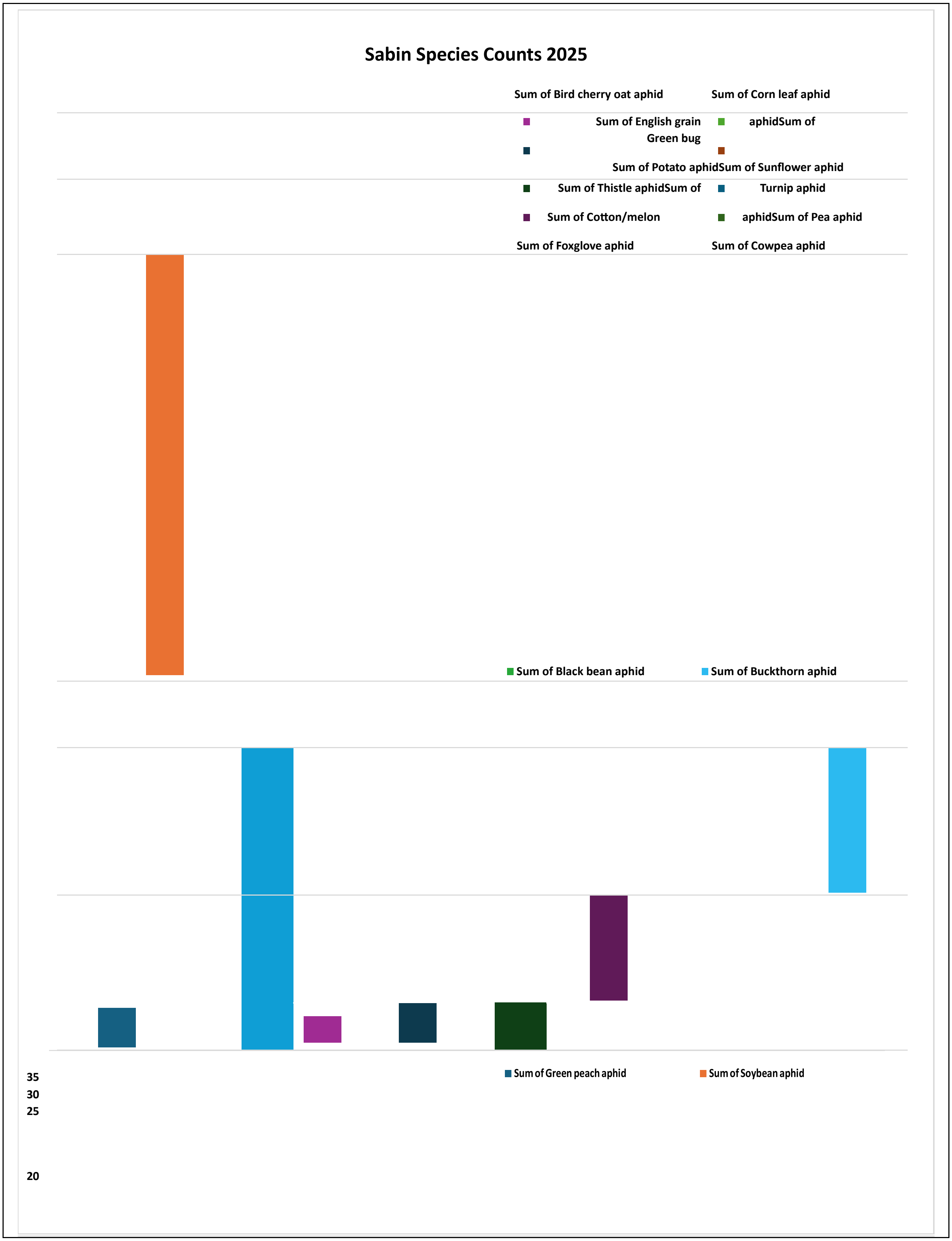


Species composition and vector population dynamics – Perham 2025

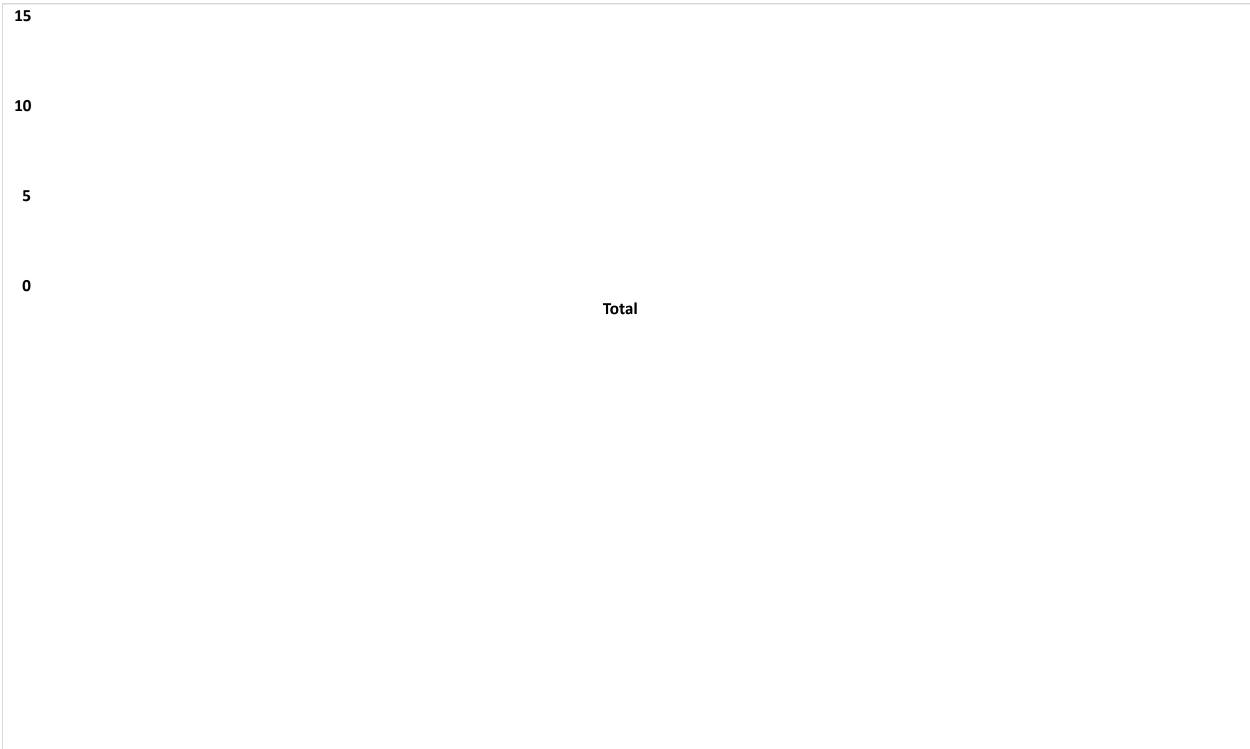


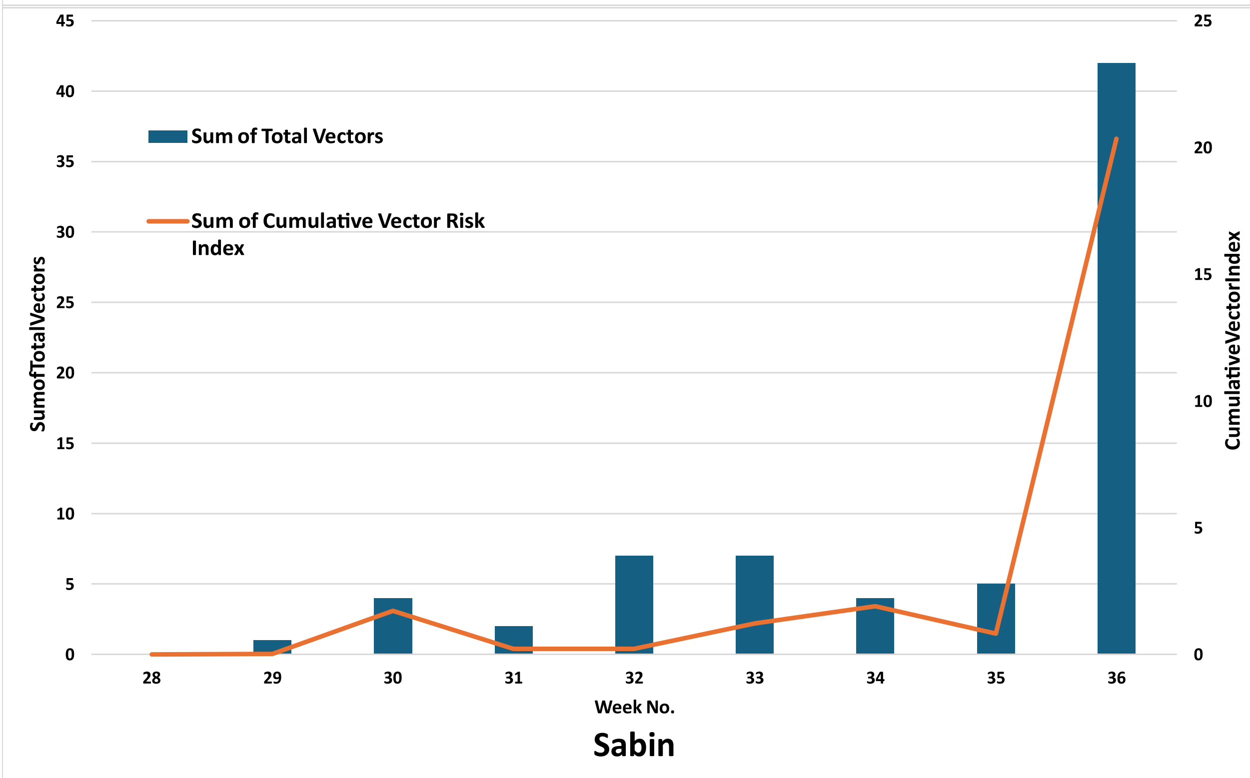


Species composition and vector population dynamics – Rolette 2025

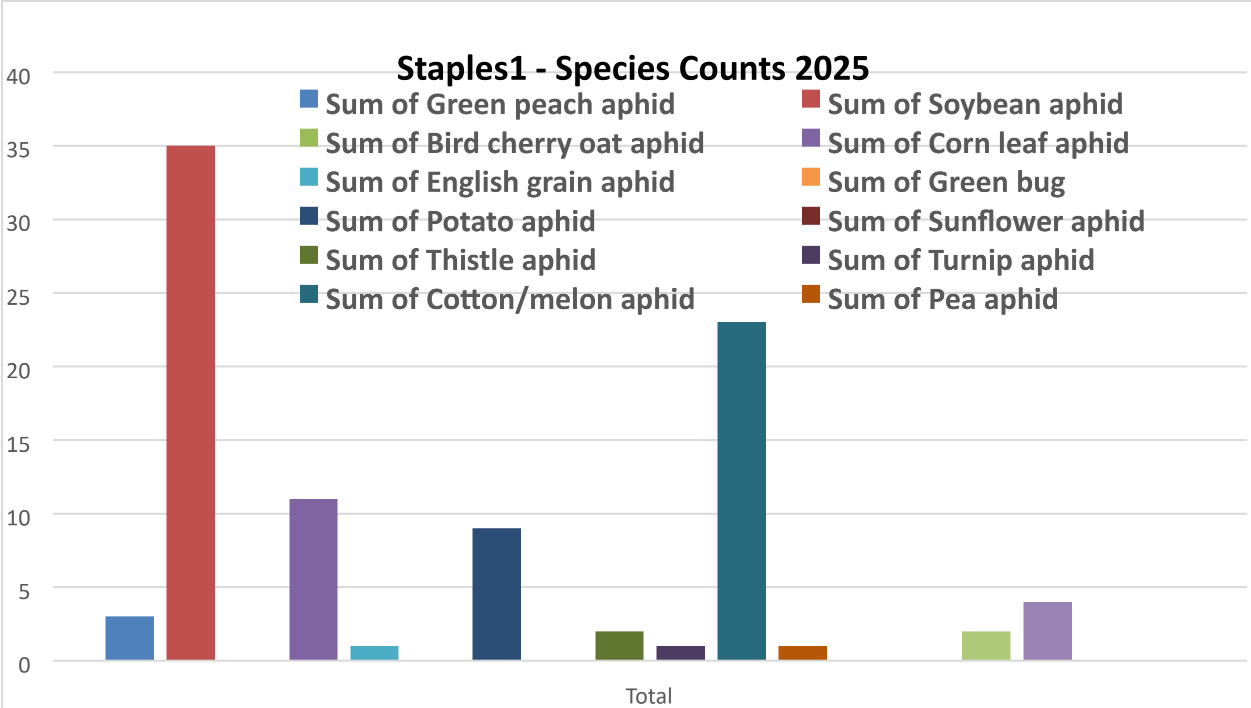


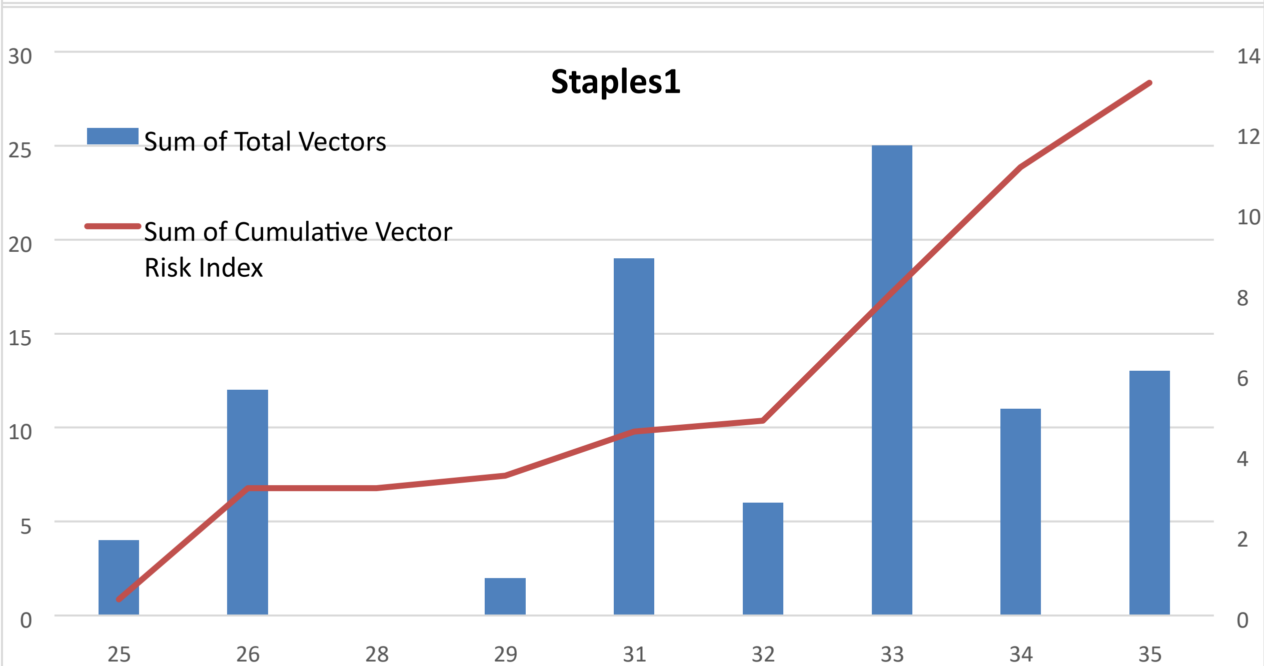
Sabin Species Counts 2025
Sum of Bird cherry oat aphid
Sum of Corn leaf aphid
Sum of English grain
aphidSum of
Green bug
Sum of Potato aphidSum of Sunflower aphid
Sum of Thistle aphidSum of
Turnip aphid
Sum of Cotton/melon
aphidSum of Pea aphid
Sum of Foxglove aphid
Sum of Cowpea aphid
Sum of Black bean aphid
Sum of Buckthorn aphid
Sum of Green peach aphid
Sum of Soybean aphid
35
30
25
20



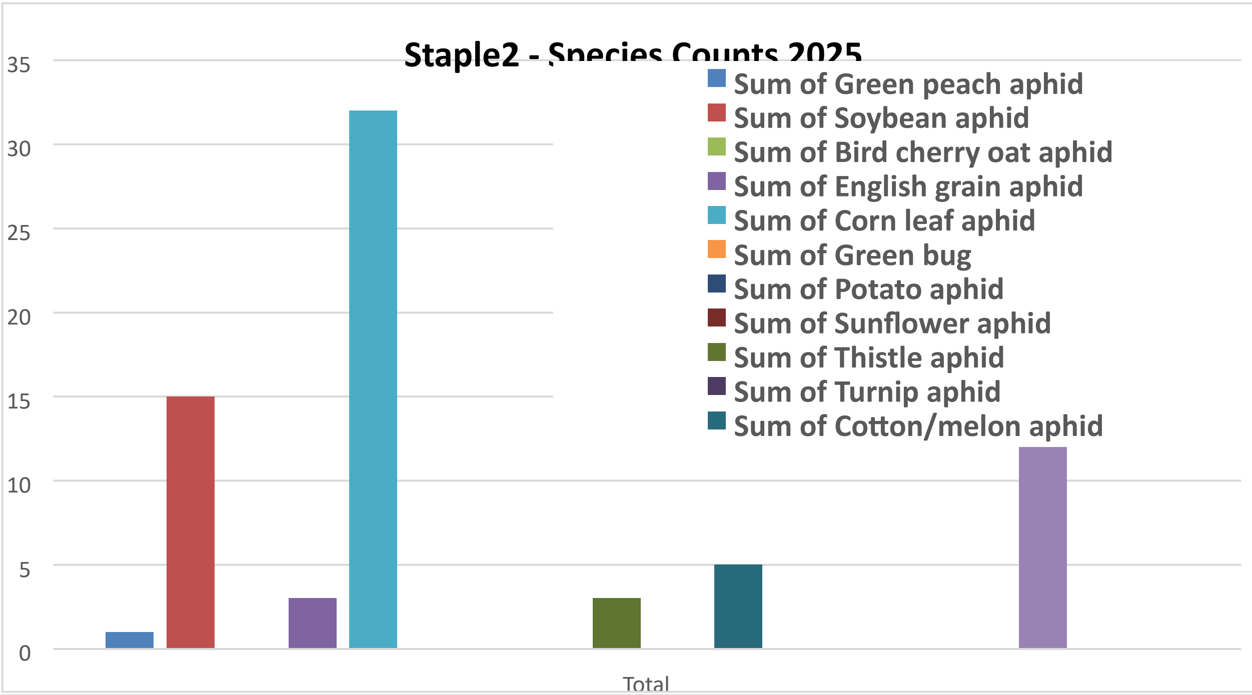


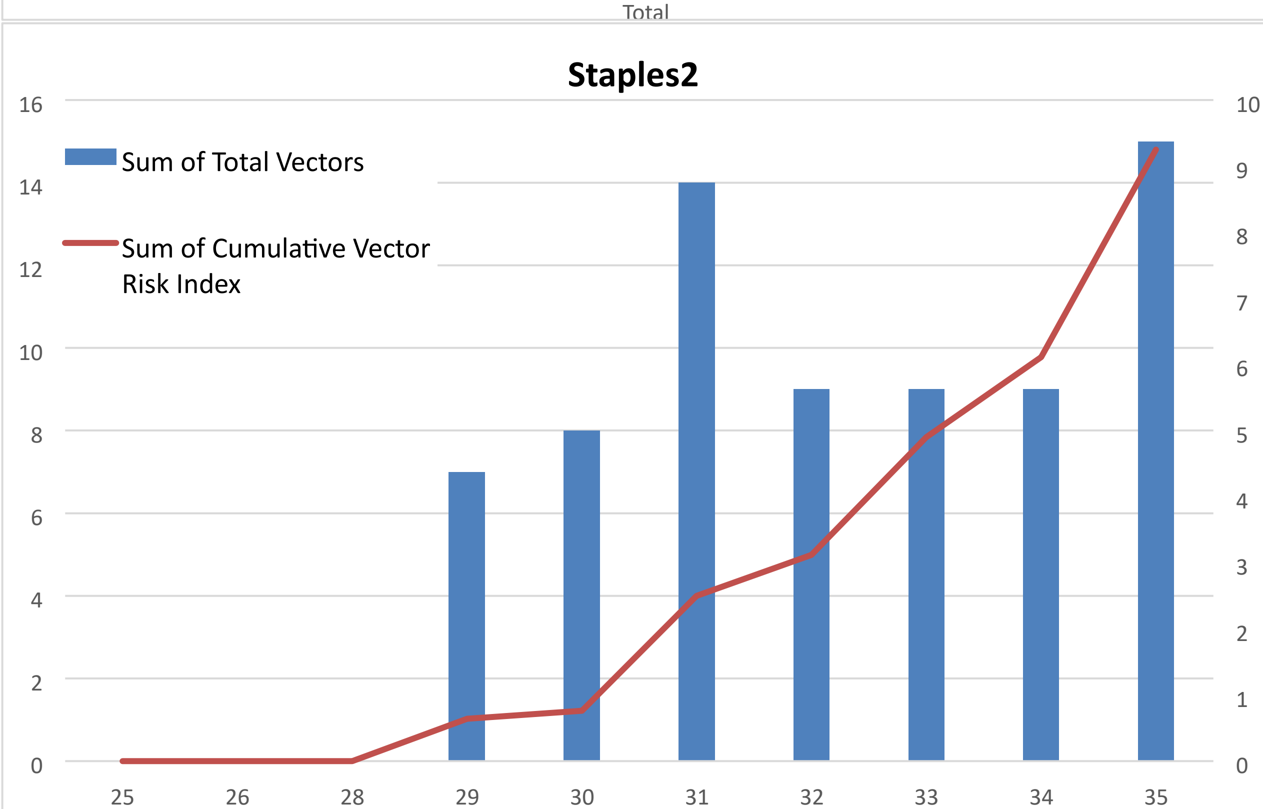
Species composition and vector population dynamics – Sabin 2025



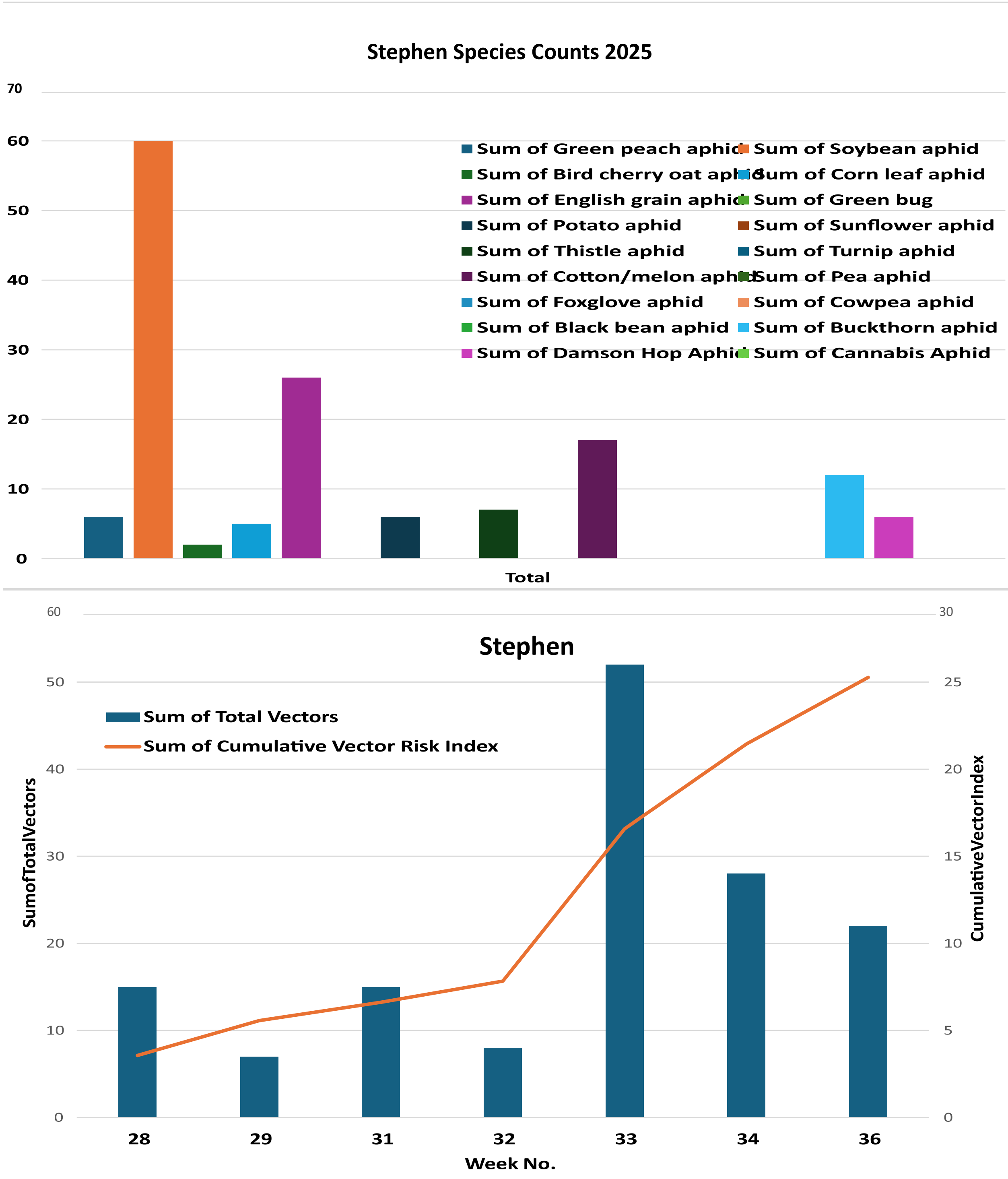


Species composition and vector population dynamics – Staples1 2025

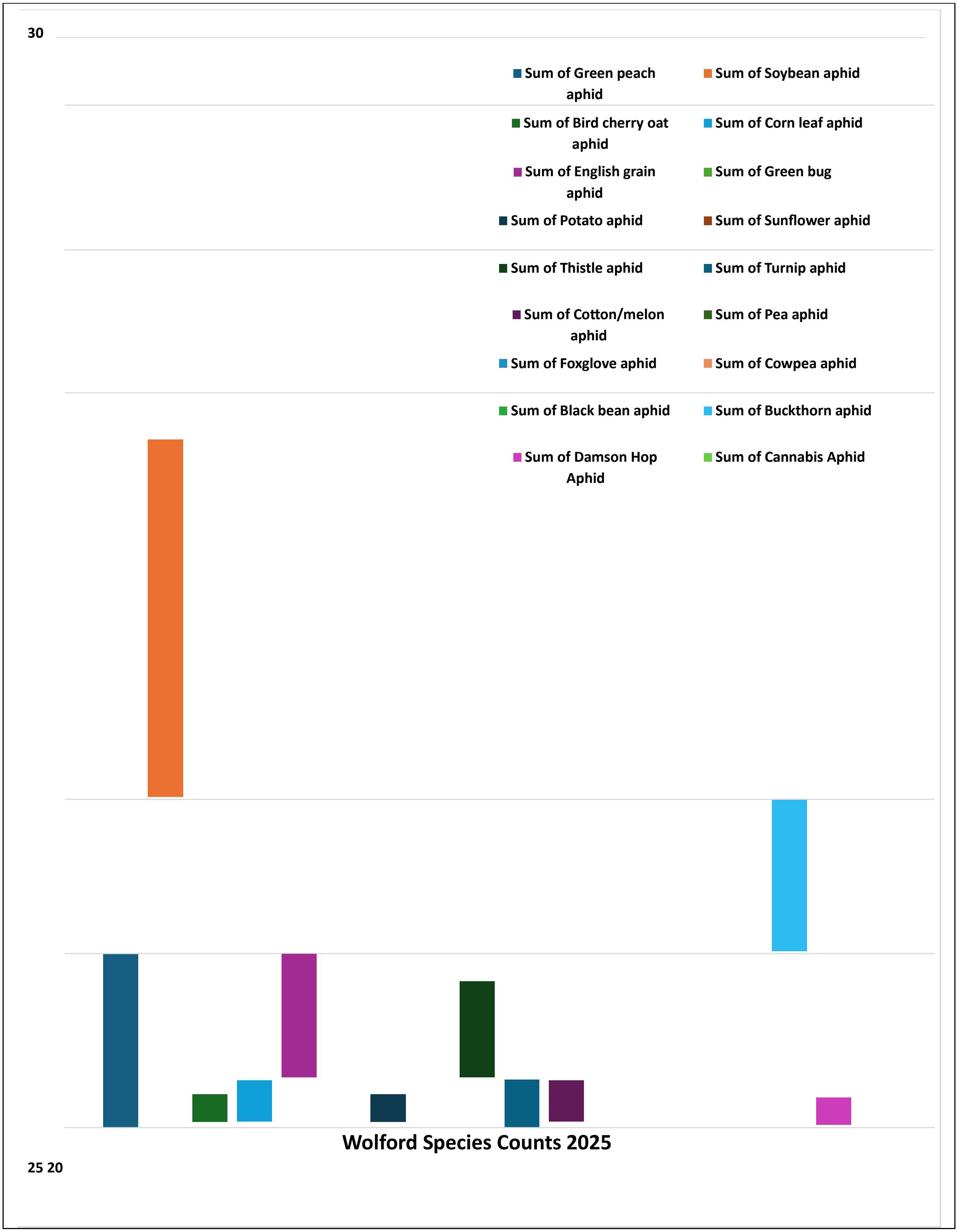




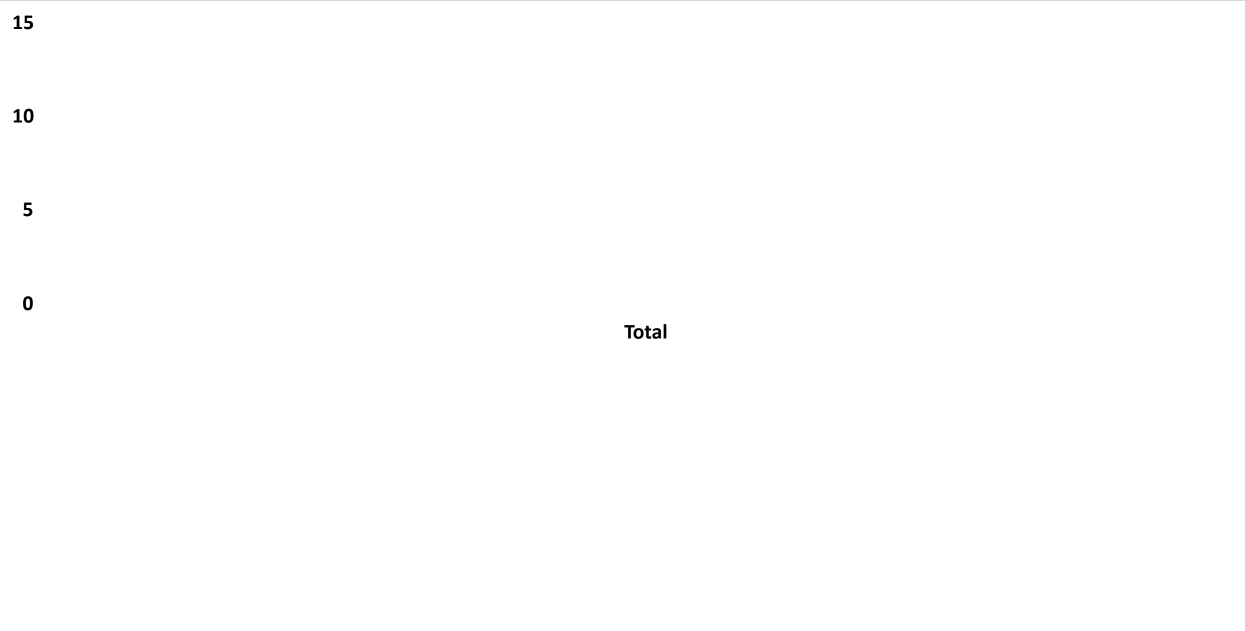
Species composition and vector population dynamics– Staples2 2025

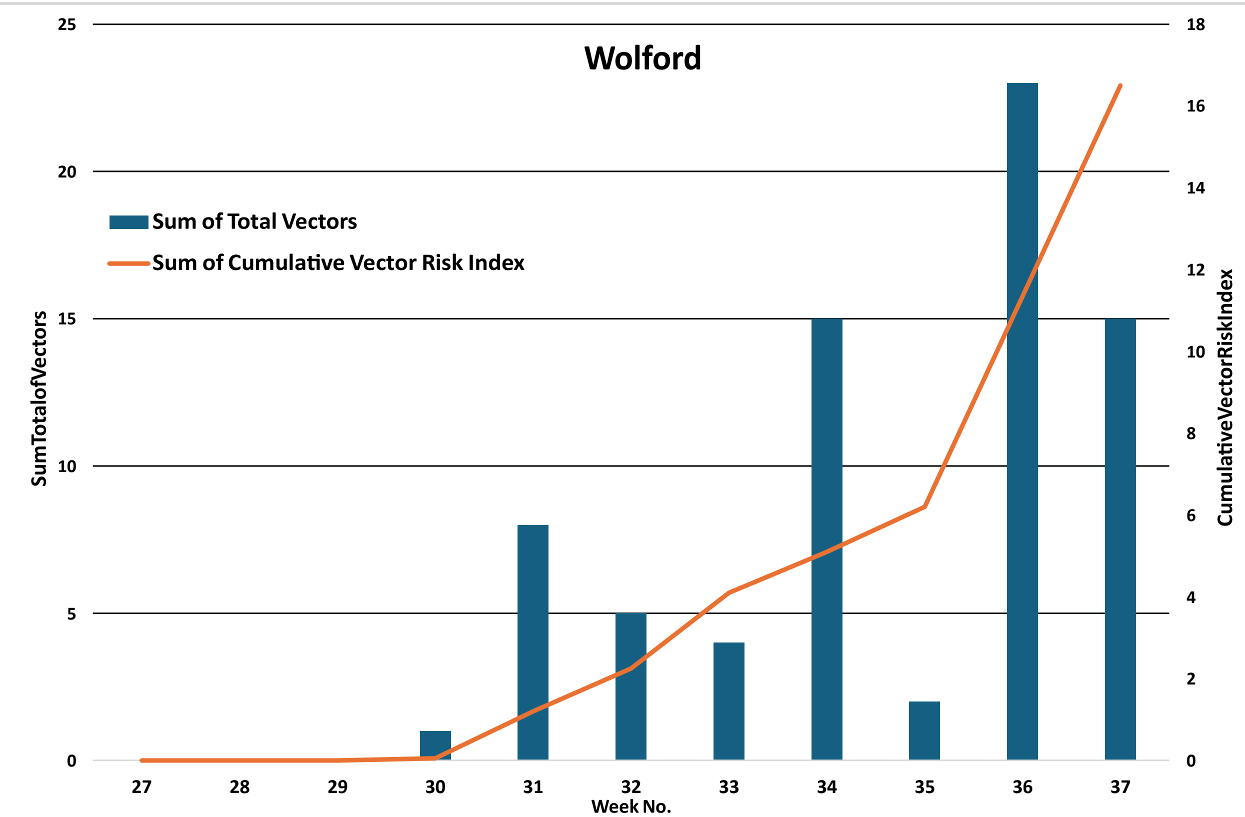


Species composition and vector population dynamics – Stephen 2025



30
Sum of Green peach aphid
Sum of Soybean aphid
Sum of Bird cherry oat aphid
Sum of Corn leaf aphid
Sum of English grain aphid
Sum of Green bug
Sum of Potato aphid
Sum of Sunflower aphid
Sum of Thistle aphid
Sum of Turnip aphid
Sum of Cotton/melon aphid
Sum of Pea aphid
Sum of Foxglove aphid
Sum of Cowpea aphid
Sum of Black bean aphid
Sum of Buckthorn aphid
Sum of Damson Hop Aphid
Sum of Cannabis Aphid
Wolford Species Counts 2025
25 20





Species composition and vector population dynamics – Wolford 2025

Report title – Resistance evaluation of new potato varieties to soil-borne diseases, Common Scab, and Verticillium Wilt in irrigated fields

Principle Investigator: Ashish Ranjan
Institution Address - 495 Borlaug Hall, 1991 Upper Buford Circle
Department of Plant Pathology, University of Minnesota - Twin Cities, St. Paul, MN 55108
Email - aranjan@umn.edu

Executive Summary- Soil-borne potato diseases, Verticillium wilt, and Common scab are the two topmost disease concerns for Minnesota and northern plains potato growers. Verticillium wilt (VW) is a fungal disease primarily caused by two species of fungal pathogens called *Verticillium dahliae,* and *Verticillium albo-atrum,* while Common scab (CS) is a bacterial disease shown to be primarily caused by more than 10 species of bacterial pathogens belonging to the genus Streptomyces, mainly *Streptomyces scabies*, *S. turgidiscabies*, and *S. acidiscabies* (Inderbitzin et al. 2011; Ismail, S. et al. 2020). VW can lead to substantial yield losses of from 10% to 70% in a highly conducive environment (Davis, J.R. et al. 2001). CS can lead to significant economic losses due to the rejection of scabby potatoes. We have established a disease-screening nursery for VW and CS infestations, characterized by high disease pressure, in an irrigated potato field at the Sand Plain Research Farm in Becker, MN.

In 2025, for the Verticillium wilt disease screening study, thirty-six entries, including sixteen commercial cultivars (Red Norland, Modoc, Yellow Fontane, Snowden, Dakota Russet, Hamlin Russet, Columba, Constance, Manistee, Red La Soda, Bannock, Umatilla Russet, Russet Burbank, Atlantic, Dark Red Norland, and Gold Rush), were screened. The study was designed to compare levels of Verticillium wilt resistance in 16 commercial cultivars and 20 potential potato lines bred at the University of Minnesota Potato Breeding Program (led by Dr. Laura Shannon). The study **identified three highly resistant UMN potato breeding lines (MN21CO19073-001, MN190014-115, and MN21ND1835B-106)** and also reconfirmed commercial cultivars Bannock, Dakota Russet, Yellow Fontane, and Umatilla Russet as highly tolerant potato cultivars (Figure 3).

The 2025 common scab screening study included 35 potato cultivars/clones: 14 commercial potato cultivars (Snowden, Red Pontiac, Modoc, Red LaSoda, Dakota Russet, Red Norland, Bannock, Goldrush, Columba, Dark Red Norland, Blackberry, Atlantic, Cascade, and Umatilla Russet) and 21 UMN potato breeding lines (from Dr. Laura Shannon's breeding program). The study **identified seven highly tolerant UMN potato breeding lines (MN18CO15083-006;**

MN21ND1845B-030; MN18CO16154-009; MN21ND1835B-059; MN21ND1835B-031; MN21ND1835B-136; MN21ND1835B-001) and also reconfirmed commercial cultivars Red Norland, Dakota Russet, Goldrush, and Umatilla Russet as highly tolerant potato cultivars for common scab disease (Figure 5).

Rationale:

This research proposal aims to evaluate UMN-bred potato lines for resistance to Verticillium wilt and Common Scab, two of the top disease concerns of Minnesota and Northern plain growers. The goal is to identify genetic solutions that help manage this disease, reducing reliance on fungicides and fumigants while ensuring sustainable yield and marketability protection.

Procedures:

For performing Verticillium wilt screening of 36 potato lines, potatoes were planted on 12th May 2025, four replications of ten-hill plots of each commercial cultivar (representing a range of resistance)/UMN-bred potato clones in a randomized complete block design in a Verticillium dahliae-infested field at the Sand Plain Research Station, Becker, MN. 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 21st July to 18th 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).

For conducting a common scab screening experiment, a total of 35 varieties/clones of potatoes were planted in four replications of ten-hill plots in a randomized complete block design in a *Streptomyces* Spp. infested field at the sand plain research station, Becker, MN, on 12th May 2025. Potatoes were harvested on 16th September, and a random sample of 10-12 tubers was scored for common scab disease severity in a study across all replicates (Figures 4 and 5). We scored above-ground disease symptoms using the following rating system, which included severity and coverage, to calculate disease severity % (Driscoll, J. et al., 2009).

Rating	Severity	Coverage
0	No scab visible	No scab visible
1	Scab <= 1 mm deep	Trace or 1-2 lesions less than 1 cm2
2	Scab 1-2 mm deep	1 to 5 % tuber surface covered.
3	Scab 2-3 mm deep	>5 to 25% tuber surface covered, periderm broken.
4	Scab 3-5 mm deep	>50 to 75% tuber surface covered Periderm broken, and visible pitting.
5	Scab over 5 mm deep	>75 -100% tuber surface covered Deep pitting

We used the following formula to calculate Disease severity %.

$$Disease\ severity\ \% = \frac{[\Sigma(rating\ no. \times no.of\ tubers\ in\ rating)]}{(total\ no.of\ tubers \times highest\ rating)} \times 100$$

Results

Verticillium wilt screening: Verticillium wilt disease screening study included thirty-six entries (16 commercial and 20 UMN bred lines). Figure 1 shows the verticillium wilt disease progression in the commercial highly tolerant cultivar (Bannock) and highly susceptible line cultivar (Mainstee) as observed and rated on 21st July, 28th July, 4th August, 11th August and 18th August 2025. Three commercial varieties (Columba, Russet Burbank, and Hamlin Russet) were excluded from the final analysis due to poor germination.

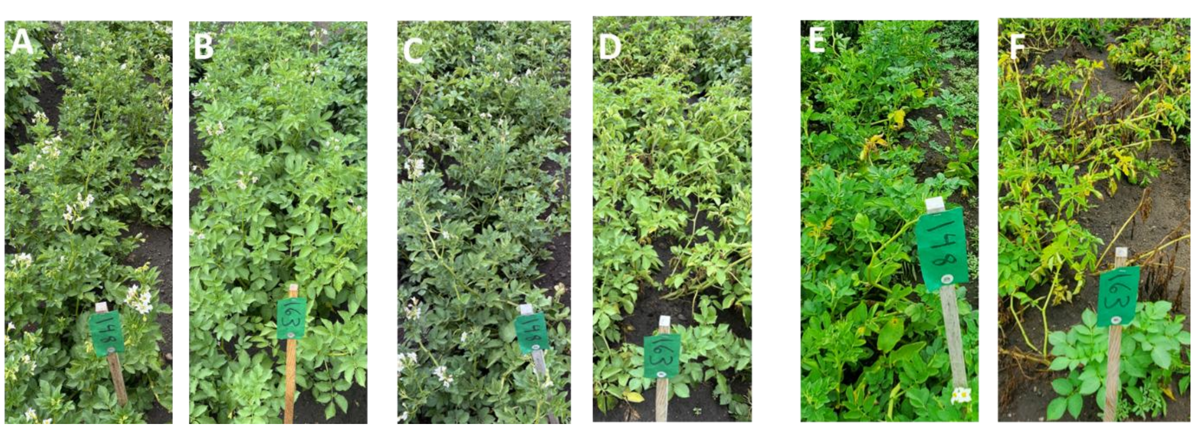


Figure 1. Progression of *Verticillium* wilt disease in Bannock (148, tolerant) and Mainstee (163,

susceptible) potato variety at Sand Plain Research Farm, Becker, MN. Photographed on (A, B) 21st July, (C, D) 4th August, and (E, F) 18th August, respectively.

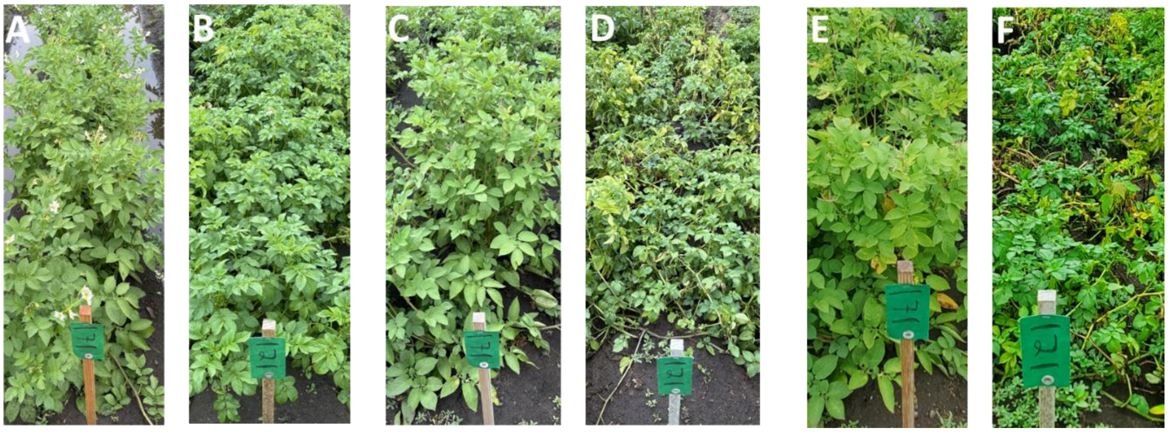


Figure 2 shows the verticillium wilt disease progression in the UMN potato breeding lines, a highly tolerant breeding line (MN21CO19073-001) and a highly susceptible breeding line (MN21ND1845B-030). Photographed on (A, B) 21st July, (C, D) 4th August, and (E, F) 18th August, respectively.

We scored for above-ground disease symptoms using a standardized disease severity scale as discussed above in the procedure section. The area under the disease progress curve (AUDPC) using verticillium wilt disease severity % observation of 21st July, 28th July, 4th August, 11th August, and 18th August 2025 was calculated (Figure 3). The **study identified three highly Verticillium-resistant UMN potato breeding lines (MN21CO19073-001, MN190014-115, and MN21ND1835B-106)** and also reconfirmed commercial cultivars Bannock, Dakota Russet, Yellow Fontane, and Umatilla Russet as highly tolerant potato cultivars (Figure 3).

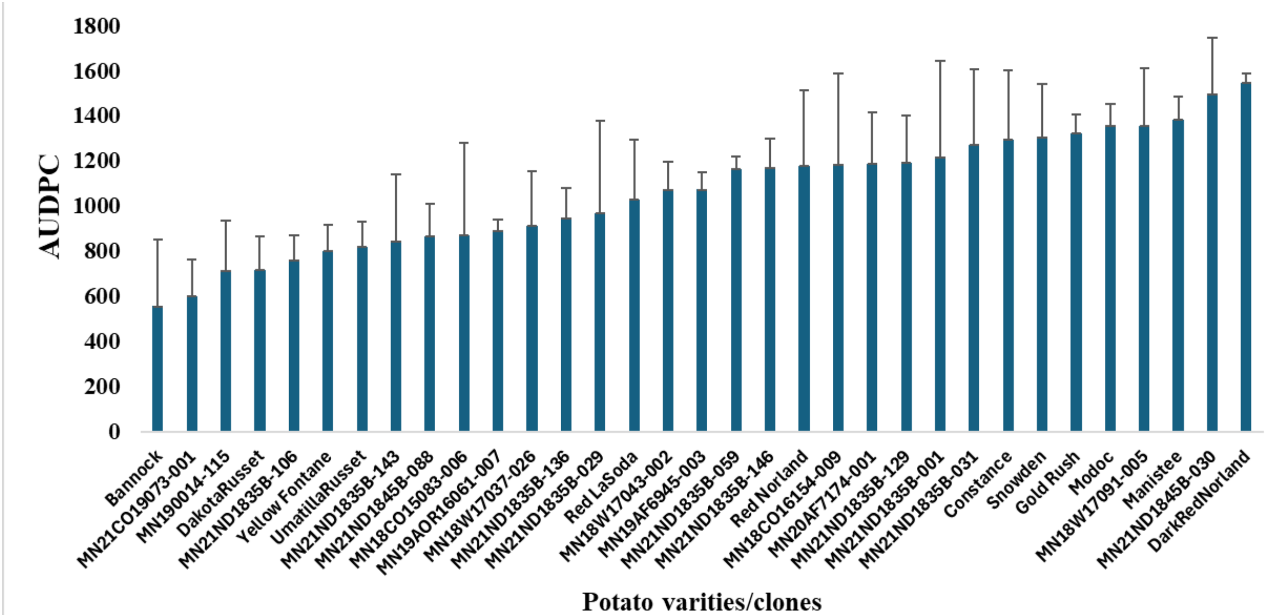


Figure 3. Area under the disease progress curve (AUDPC) of 37 Potato varieties/clones, including twelve commercial cultivars, using percentage disease severity foliage (DS%) from 21st July, 28th July, 4th August, 11th August, and 18th August 2025 observations.

Common scab screening: In 2025, we conducted a common scab screening experiment using 35 potato cultivars/lines (14 commercial potato cultivars and 21 UMN potato breeding lines, from Dr. Laura Shannon's breeding program). Potatoes were harvested on 16th September, and a random sample of 10-12 tubers was scored for common scab disease severity in a study across all replicates (Figures 4 and 5).

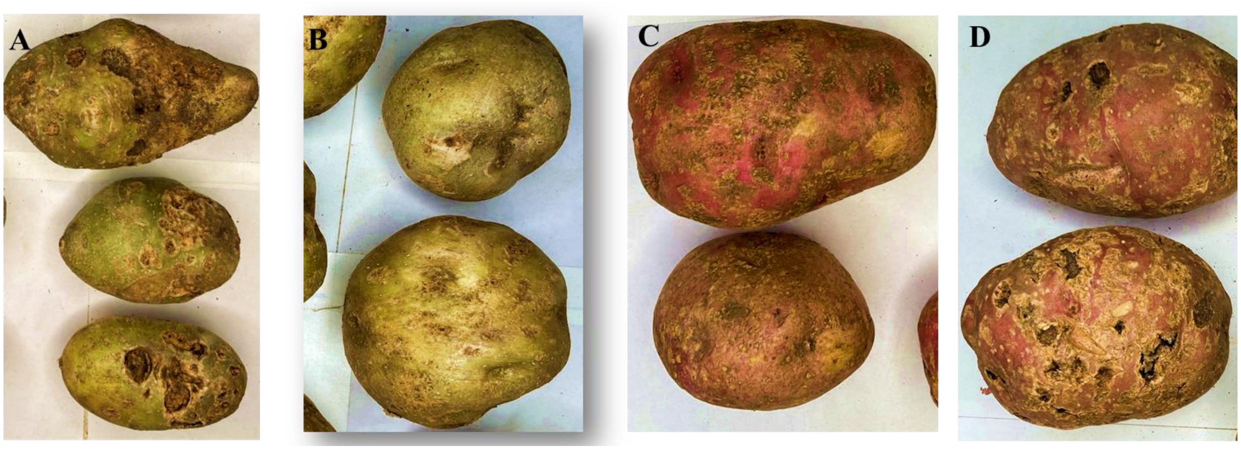


Figure 4. Common scab disease symptoms Cascade (A), MN21ND1835B-106 (B), Snowden (C), and Red LaSoda (D).

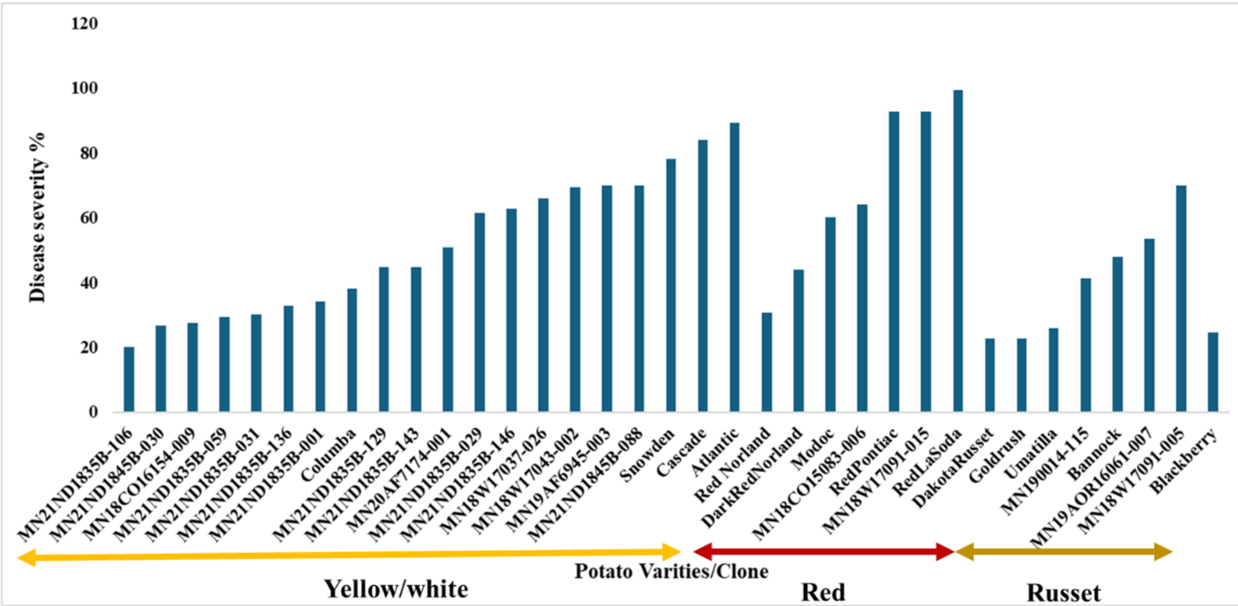


Figure 5. Common scab of potato disease severity percentage data of 35 potato cultivars/UMN-bred lines, including fourteen commercial cultivars (Snowden, Red Pontiac, Modoc, Red LaSoda, Dakota Russet, Red Norland, Bannock, Goldrush, Columba, Dark Red Norland, Blackberry, Atlantic, Cascade, and Umatilla Russet).

We scored above-ground disease symptoms using a standardized rating of disease severity and coverage, as discussed above in the procedure section (Figure 2), to calculate the percentage of disease severity.

The study **identified seven highly common scab-tolerant UMN potato breeding lines (MN18CO15083-006; MN21ND1845B-030; MN18CO16154-009; MN21ND1835B-059; MN21ND1835B-031; MN21ND1835B-136; MN21ND1835B-001)** and also reconfirmed commercial cultivars Red Norland, Dakota Russet, Goldrush, and Umatilla Russet as highly tolerant potato cultivars for common scab disease.

Acknowledgments

We gratefully acknowledge funding from the Minnesota Area II Potato Council and Northern Plains Potato Growers Association. Thanks to Dr. Laura Shannon and lab members for their support with potato lines. Appreciation to Mark Peterson and Blake Kunkel for managing plots at Sand Plain Research Farm, Becker. Special thanks to Ranjan lab members (Kay Lehorl, Sonal Srivastava, Lovepreet Sing, Anshu Alok, Nick Talmo, Jay Kim, Joey Wierzbicki, Mia Copeland, and Henry Rosato) for their hard work in collecting data and conducting the experiments.

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REPORT

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

Submitted to Northland and MN Area II Potato Growers Associations

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

State University, Fargo, ND 58102. Julie.Pasche@NDSU.edu; 701-231-7547 **Co-Principal Investigator:** Kim Zitnick-Anderson

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 ®) is used on many potato acres across the region for the management of these diseases. 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 to 15 years. In the last 3 to 4 years, growers and crop consultants have reported a change from typical symptoms of leak and have noted that disease progression in storage appears to be changing with respect to temperature. To address these situations, we propose to collect pink rot and leak pathogen isolates from potato storages in ND and MN, test a representative selection for sensitivity to mefenoxam, evaluate genetic differences of the isolates causing varying leak symptoms, and characterize pathogens causing leak for growth characteristics and aggressiveness under a range of temperature regimes. Our potato pathology group at NDSU has expertise in testing for fungicide insensitivity and access to collection *P. erythroseptica* and *Pythium*/*Globisporangium* isolates with a range of mefenoxam sensitivities to use as controls for comparison. We have also conducted pathogen sequencing and testing for pink rot and leak severity in the field and post-harvest. Our pathogen collection includes isolates collected over many years that will aid us in determining if changes have occurred in the population over time. Results from these objectives will directly improve pink rot and leak management recommendations specific to growers in the region.

Objectives:

1. Determine mefenoxam (Ridomil ®) sensitivity of *P. erythroseptica* and *Pythium*/*Globisporangium* isolates collected from tubers with symptoms of pink rot and leak.
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.

Results to date:

From September through November of 2024 and 2025 growers submitted tubers and we surveyed storage facilities in Minnesota and North Dakota for tubers displaying symptoms of pink rot and leak. Twenty-four (Table 1; 2024) and six (Table 2; 2025) pink rot pathogen (*P. erythroseptica*) isolates have been collected from tubers expressing pink rot symptoms, and 74 (Table 3; 2024) and 41 (Table 4; 2025) *Pythium/Globisporangium* isolates have been collected from tubers expressing classic (21 samples in 2024; 33 in 2025) or white (14 samples in 2024; 12 in 2025) leak symptoms.

Table 1. Current isolate collecti potatoes with pink rot sympton

Location	Number of samples
Osage	3
Ottertail	1
Brooten	1
MN Total	**5**
Larimore	1
Oakes	2
ND Total	**3**
Overall Total	**8**

Table 2. Current isolate collection from MN and ND potatoes with pink rot symptoms 2025.

Location	Number of samples	Number of isolates
Park Rapids	4	2
Osage	5	4
Ottertail	3	0
MN Total	**12**	**6**

*Tuber samples were received from Lisbon, Larimore, and Jamestown but were diagnosed as having leak, not pink rot.

Table 3. Current isolate colle
potatoes with leak symptom

Location	Leak Symptoms	Num sa
Brooten	White Leak	
	Classic Leak	
Osage	White Leak	
	Classic Leak	
Ottertail	White Leak	
	Classic Leak	
Perham	White Leak	
	Classic Leak	
Vining	White Leak	
	Classic Leak	
Wadena	White Leak	
	Classic Leak	
MN Total	**White Leak**	
	Classic Leak	
Oakes	White Leak	
	Classic Leak	
Hoistad	White Leak	
	Classic Leak	
Larimore	White Leak	
	Classic Leak	
Lisbon	White Leak	
	Classic Leak	
ND Total	**White Leak**	
	Classic Leak	

Table 4. Current isolate collection from MN and ND potatoes with leak symptoms 2025.

Location	Leak Symptoms	Number of samples	Number of isolates
Brooten	White Leak	0	0
	Classic Leak	9	12
Menahga	White Leak	1	2
	Classic Leak	0	0
Osage	White Leak	2	2
	Classic Leak	5	1
Ottertail	White Leak	2	1
	Classic Leak	2	1
Park Rapids	White Leak	2	1
	Classic Leak	4	2
Vining	White Leak	0	0
	Classic Leak	1	2
MN Total	**White Leak**	**7**	**6**
	Classic Leak	**21**	**18**
Jamestown	White Leak	3	2
	Classic Leak	2	8
Larimore	White Leak	2	1
	Classic Leak	3	4
Lisbon	White Leak	0	0
	Classic Leak	7	2
ND Total	**White Leak**	**5**	**3**
	Classic Leak	**12**	**14**
Overall	**White Leak**	12	9

Overall Total	**White Leak**	14	**Total**	20	**Classic Leak**	33	32
	Classic Leak	21		54			

Mefenoxam (Ridomil®, and others) sensitivity has been determined for 42

Globiosporangium/Pythium isolates collected in 2024, to date (Table 5). Among the 42 isolates, 30 are sensitive to mefenoxam (≤0.05-0.99µg/ml), seven are intermediate (1.0-99.9µg/ml), and five are resistant (≥100µg/ml). Isolates recovered from tubers displaying both classic and white leak are represented in each category. Among the 30 sensitive isolates, seven were recovered from white leak tubers, 43% of the intermediate isolates (3 of 7) were from white leak tubers, and 40% (2 of 5) of mefenoxam-resistant isolates were recovered from tubers displaying symptoms of white leak. Additionally, 19 *Phytophthora erythroseptica* isolates collected in 2024 were also evaluated for mefenoxam sensitivity (Table 6; Figure 1). Among the 19 isolates, 10 are sensitive to mefenoxam (≤0.05-0.99µg/ml), four are intermediate (1.0-99.9µg/ml), and five are resistant (≥100µg/ml) to mefenoxam. We know from previously reported data that resistant isolates of both pathogens are present in the region. The data reported here should be interpreted with caution due to the small sample size. Isolates collected in 2025 will be evaluated for mefenoxam sensitivity in the coming months.

Species identification of 42 isolates from leak (classic and white) affected tubers collected in 2024 was performed using whole genome sequencing to extract the entire COXI gene sequence.

The extracted COXI gene sequences were entered into a custom *Pythium/Globiosporangium* COXI gene sequence database using Qiagen's CLC workbench v25 software. Isolates were identified to species level when 99% of the sequence matched a reference sequence. Thirty-six isolates have been confirmed to be *Globiosporangium ultimum*; confirmation of the identity of the remaining six isolates requires further genetic analysis (Table 5). This is the first step in determining if genetic variability may play a role in differing leak symptomologies. Further genetic analyses are ongoing, and comparisons will be made to our historical isolate collection.

Table 5. Species identification and mefenoxam sensitivity (EC_{50} values) for 42 isolates collected from leak-affected tubers in 2024.

Isolate	State	Leak Symptoms	Species Identification[3]	Collection Year	EC_{50} Value	Mefenoxam rating[4]
08MN17-3[1]	MN	Classic Leak	*Globiosporagium ultimum*	2008	0.01	Sensitive
09MN4-1[2]	MN	Classic Leak	Globiosporagium ultimum	2009	> 100	Resistant
24MN8-3	MN	Classic Leak	*Pythium spp.*	2024	0.015	Sensitive
24MN13-1	MN	Classic Leak	*Globiosporagium ultimum*	2024	0.020	Sensitive
24MN2-1	MN	White Leak	*Globiosporagium ultimum*	2024	0.020	Sensitive
24MN8-2	MN	Classic Leak	*Globiosporagium ultimum*	2024	0.025	Sensitive
24MN5-1	MN	Classic Leak	*Globiosporagium ultimum*	2024	0.030	Sensitive
24MN12-1	MN	Classic Leak	*Globiosporagium ultimum*	2024	0.030	Sensitive
24MN9-1	MN	Classic Leak	*Globiosporagium ultimum*	2024	0.032	Sensitive
24MN15-1	MN	Classic Leak	*Globiosporagium ultimum*	2024	0.035	Sensitive
24MN18-3	MN	Classic Leak	*Globiosporagium ultimum*	2024	0.035	Sensitive
24MN14-1	MN	White Leak	*Globiosporagium ultimum*	2024	0.050	Sensitive
24MN2-2	MN	White Leak	*Globiosporagium ultimum*	2024	0.070	Sensitive
24MN6-6	MN	Classic Leak	*Pythium spp.*	2024	0.080	Sensitive
24MN17-3	MN	Classic Leak	*Globiosporagium ultimum*	2024	0.090	Sensitive
24MN18-8	MN	Classic Leak	*Globiosporagium ultimum*	2024	0.090	Sensitive
24MN3-7	MN	Classic Leak	*Globiosporagium ultimum*	2024	0.090	Sensitive
24MN17-2	MN	White Leak	*Globiosporagium ultimum*	2024	0.100	Sensitive
24MN7-3	MN	Classic Leak	*Globiosporagium ultimum*	2024	0.100	Sensitive

24MN10-1	MN	Classic Leak	*Globiosporagium ultimum*	2024	0.125	Sensitive
24MN6-4	MN	Classic Leak	*Globiosporagium ultimum*	2024	0.125	Sensitive
24MN11-1	MN	Classic Leak	*Pythium spp.*	2024	0.150	Sensitive
24MN18-4	MN	Classic Leak	*Globiosporagium ultimum*	2024	0.150	Sensitive
24MN8-1	MN	Classic Leak	*Globiosporagium ultimum*	2024	0.150	Sensitive
24MN1-1	MN	Classic Leak	*Globiosporagium ultimum*	2024	0.200	Sensitive
24MN6-3	MN	White Leak	*Globiosporagium ultimum*	2024	0.200	Sensitive
24MN4-1	MN	Classic Leak	*Globiosporagium ultimum*	2024	0.300	Sensitive
24ND3-1	ND	Classic Leak	*Globiosporagium ultimum*	2024	0.300	Sensitive
24ND3-6	ND	Classic Leak	*Globiosporagium ultimum*	2024	0.300	Sensitive
24MN13-2	MN	Classic Leak	*Globiosporagium ultimum*	2024	0.350	Sensitive
24ND1-1	ND	White Leak	*Globiosporagium ultimum*	2024	0.600	Sensitive
24MN16-3	MN	White Leak	*Globiosporagium ultimum*	2024	0.650	Sensitive
24MN16-1	MN	Classic Leak	*Globiosporagium ultimum*	2024	1.0	Intermediate
24MN6-5	MN	Classic Leak	*Globiosporagium ultimum*	2024	1.0	Intermediate
24MN3-5	MN	White Leak	*Globiosporagium ultimum*	2024	4.5	Intermediate
24ND3-5	ND	White Leak	*Globiosporagium ultimum*	2024	10.8	Intermediate
24MN7-7	MN	Classic Leak	*Globiosporagium ultimum*	2024	11.0	Intermediate
24ND3-8	ND	White Leak	*Pythium spp.*	2024	11.3	Intermediate
24MN8-4	MN	Classic Leak	*Pythium spp.*	2024	13.0	Intermediate
24MN7-1	MN	Classic Leak	*Globiosporagium ultimum*	2024	100	Resistant
24MN11-3	MN	Classic Leak	*Globiosporagium ultimum*	2024	>100	Resistant
24MN17-1	MN	White Leak	*Globiosporagium ultimum*	2024	>100	Resistant
24MN3-1	MN	Classic Leak	*Globiosporagium ultimum*	2024	>100	Resistant
24ND3-4	ND	White Leak	*Pythium spp.*	2024	>100	Resistant

1 Sensitive control (EC_{50} value <0.05-0.99 ug/ml) Taylor et al. unpublished.

2 Resistant control (EC_{50} value >100 ug/ml) Taylor et al. unpublished.

3 Based on sequence analysis of the COX1 gene.

4 Sensitive = < 0.05-0.99 ug/ml; Intermediate = 1.0-99.9 ug/ml; Resistant = >100 ug/ml

Table 6. Mefenoxam sensitivity (EC_{50} values) for 19 *Phytophthora erythroseptica* isolates collected from pink rot-affected tubers in 2024.

Isolate	**State**	**Collection Year**	**EC_{50} Value**	**Mefenoxam rating**
Pe266-2[1]	MN	*	0.02	Sensitive
Pe172-3[2]	MN	*	4.11	Intermediate
Pe89[3]	MN	*	>100	Resistant
24ND3-1	ND	2024	0.00	Sensitive
24MN4-1	MN	2024	0.02	Sensitive

24MN2-3	MN	2024	0.05	Sensitive
24MN2-2	MN	2024	0.07	Sensitive
24MN1-3	MN	2024	0.09	Sensitive
24MN1-2	MN	2024	0.12	Sensitive
24MN1-5	MN	2024	0.13	Sensitive
24MN 4-2	MN	2024	0.15	Sensitive
24MN1-1	MN	2024	0.16	Sensitive
24MN2-4	MN	2024	0.17	Sensitive
24MN1-4	MN	2024	1.71	Intermediate
24ND1-1	ND	2024	5.62	Intermediate
24ND1-2	ND	2024	7.03	Intermediate
24MN3-2	MN	2024	8.01	Intermediate
24MN1-6	MN	2024	>100	Resistant
24ND1-4	ND	2024	>100	Resistant
24MN1-7	MN	2024	>100	Resistant
24MN2-1	MN	2024	>100	Resistant
24MN3-1	MN	2024	>100	Resistant

1 Sensitive control (EC_{50} value <0.05-0.99 ug/ml) Taylor, R.J., Salas, B., and Gudmestad, N.C. 2004. Differences in etiology affect mefenoxam efficacy and the control of pink rot and leak tuber diseases of potato. Plant Dis. 88:301-307.

2 Intermediate control (EC_{50} value = 1.0-99.9 ug/ml) Taylor et al. 2004.

3 Resistant control (EC_{50} value >100 ug/ml) Taylor et al. 2004.

*Collected prior to 2004.

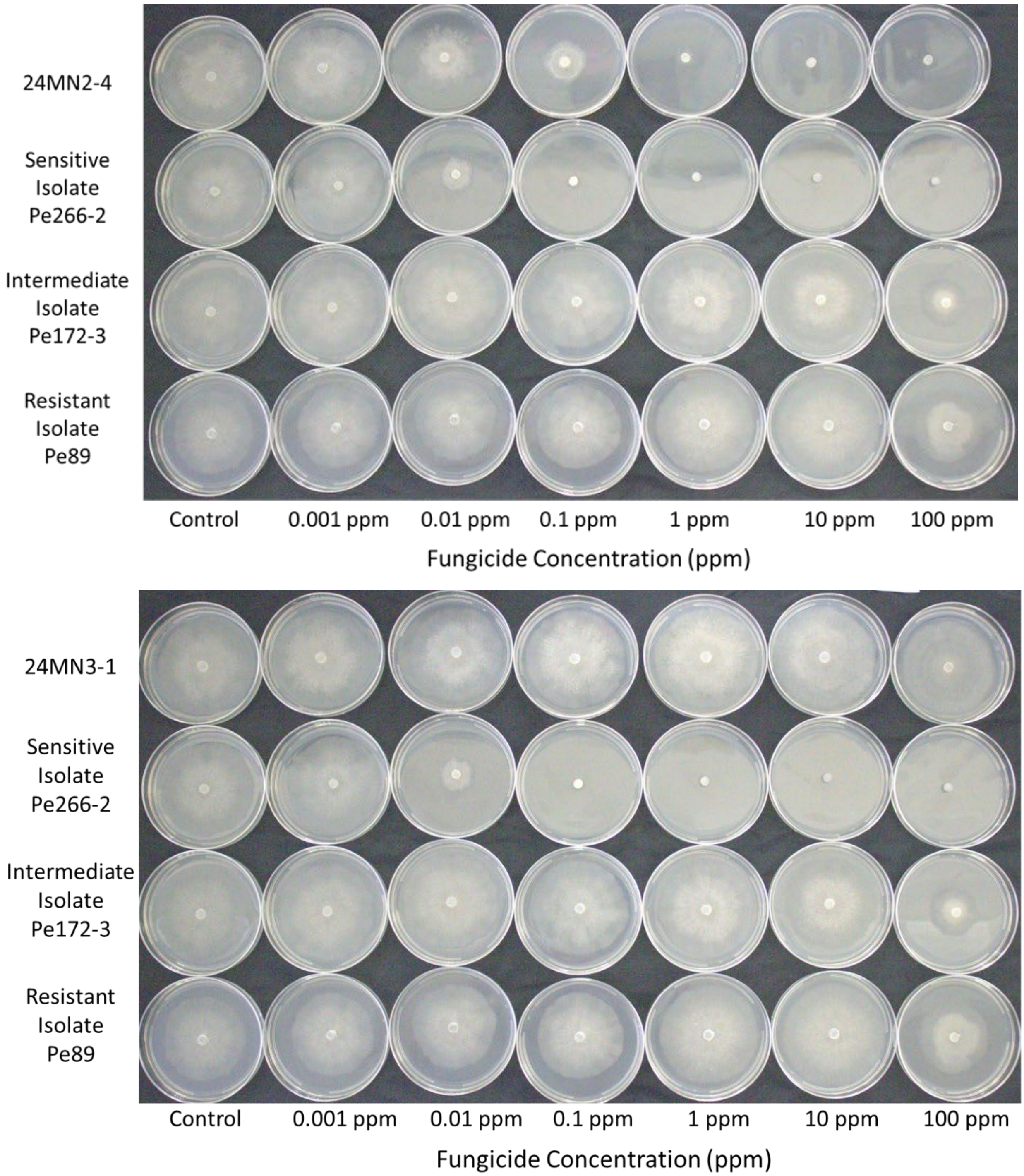

Figure 1. Growth of *Phytophthora erythroseptica* isolates 24MN2-4 (mefenoxam sensitive; upper) and 24MN3-1 (resistant; lower) on culture media containing the fungicide at 6 concentrations and alongside the three control isolates

Initial controlled tuber challenge inoculation experiments indicate the incidence of classic leak infection was lower than white leak at 45F, but at other temperatures, no significant effect on incidence or penetration between white or classic leak symptoms was observed (Figure 2 upper). The incidence and penetration of both white and classic leak symptoms generally increased with increasing temperatures. When combined across temperatures, inoculation with the white leak isolate resulted in significantly greater tuber infection incidence when compared to the classic leak isolate, but penetration was not significantly different between the two (Figure 2 lower). These data should be interpreted with extreme caution, as only 1 isolate of each pathogen was evaluated. Temperature experiments will be repeated across a wider range of temperatures and will include more isolates.

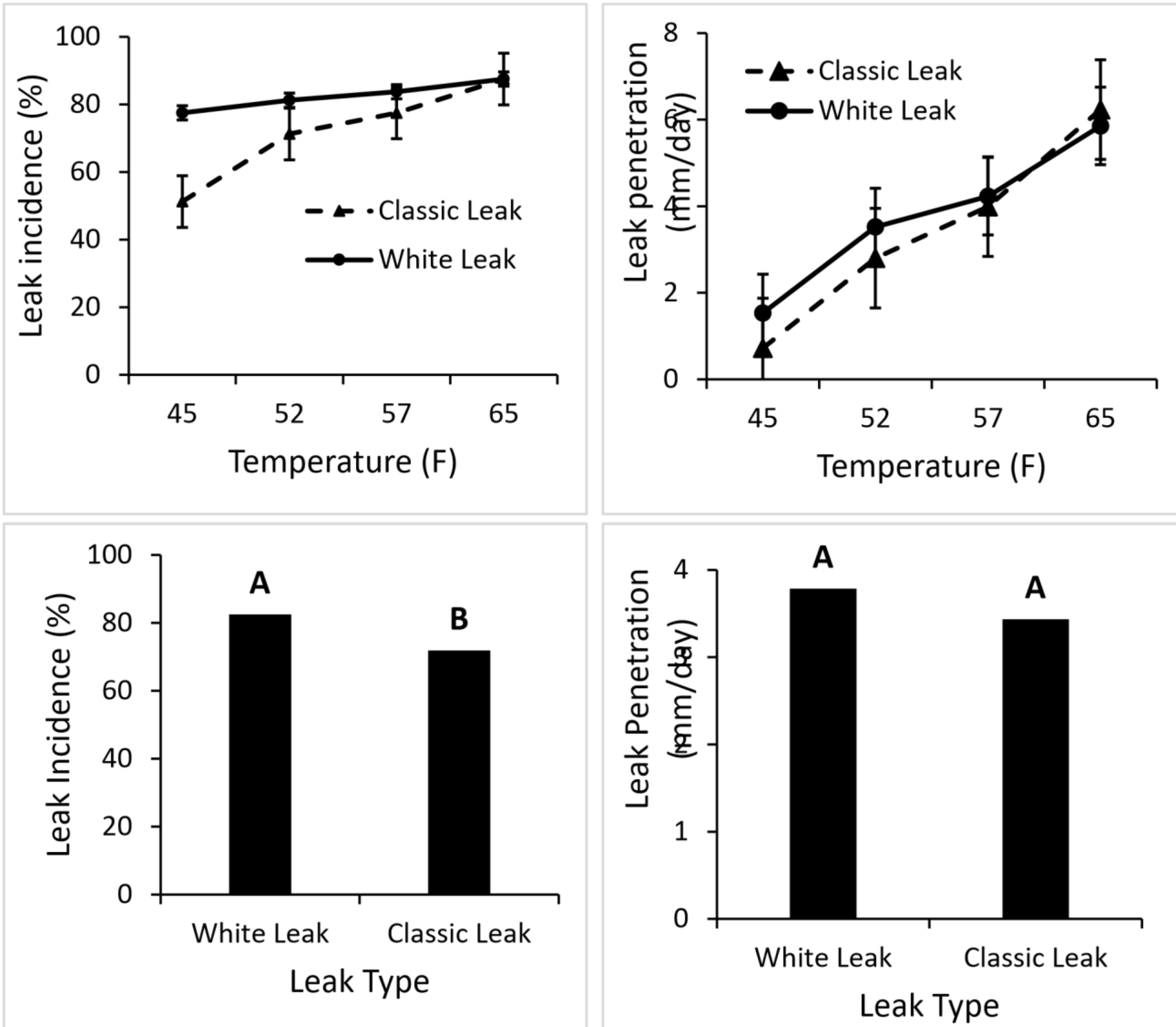

Figure 2. Incidence (left) of tuber infection and penetration (right) of rot into tuber tissue of white and classic leak on tubers inoculated with a single isolate of each pathogen and incubated at four temperatures. Error bars represent the standard error of the mean (upper). Columns with different letters above (lower) are significantly different based on Tukey-Kramer adjusted comparisons of least squares means (α = 0.05) across all temperatures.

Future work will include species identification and mefenoxam sensitivity of isolates collected in 2025, and further defining the effect of temperature on pathogen growth and infection rate/severity in *Pythium/Globisporangium* isolates causing classic and white leak. Additional genetic analyses to elucidate the variability in the *Pythium/Globisporangium* populations that may play a role in white leak are also ongoing.

Packing and sending rotted tubers:

- Choose tubers with some healthy tissue – we cannot isolate from completely rotted tubers
- Dry tubers as much as 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

Assessment of different phosphorus acid products on pink rot control

Investigators contact:

Andy Robinson

Potato Extension Agronomist, NDSU / U of M

PO BOX 6050, Fargo, ND 58108

701.219.9646

Andrew.p.robinson@ndsu.edu

Julie Pasche

Plant Pathologist

Department of Plant Pathology, NDSU

Julie.Pasche@ndsu.edu

701.231.7077

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, and up to 15% foliar injury was observed in 2025. Total and marketable yield did not differ between treatments in either year. In 2024 and 2025, challenge inoculations found differences in pink rot inoculations. All treatments were better than the non-treated check for pink rot incidence percentage and penetration in both years. In 2024 there were differences between phosphate treatments; however, in 2025 there was no difference between phosphorus acid treatments. Because of the discrepancy and data, it is suggested that another year would be an important study to determine the most likely outcome between different phosphorus acid products.

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, 2024 and on May 28, 2024 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. Products were sprayed with an ATV setup with a boom to spray 4 potato rows from the edge of the plot. The sprayer was pressurized with CO_2 and calibrated to deliver 15 gallons per acre. Using the same amount of 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 and on 26 July, 4 and 14 August, 2025 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, 2024 and on 16 and 29 July and 12 August 2025. Tubers were harvested on the 8 and 11 of October, 2024 and on 1 to 2 October, 2025 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.

Treatment list of products the applications

Treatments		Rate	Phosphoric acid	Application date	
		pt/a	lb ai/a	2024	2025
1	Non-treated check				
2	Zinc Phosphite	8	3.9	11-Jul-24	16-Jul-25
	Zinc Phosphite	8	3.9	18-Jul-24	29-July-25
	Zinc Phosphite	8	3.9	25-Jul-24	12-Aug-25
3	Phiticide	6.64	3.9	11-Jul-24	16-Jul-25
	Phiticide	6.64	3.9	18-Jul-24	29-July-25
	Phiticide	6.64	3.9	25-Jul-24	12-Aug-25
4	Kphite	6.7	3.9	11-Jul-24	16-Jul-25
	Kphite	6.7	3.9	18-Jul-24	29-July-25
	Kphite	6.7	3.9	25-Jul-24	12-Aug-25
5	Phostrol	7	3.9	11-Jul-24	16-Jul-25
	Phostrol	7	3.9	18-Jul-24	29-July-25
	Phostrol	7	3.9	25-Jul-24	12-Aug-25
6	Alloy	5.9	3.9	11-Jul-24	16-Jul-25
	Alloy	5.9	3.9	18-Jul-24	29-July-25
	Alloy	5.9	3.9	25-Jul-24	12-Aug-25
7	Fosphite	7.05	3.9	11-Jul-24	16-Jul-25
	Fosphite	7.05	3.9	18-Jul-24	29-July-25
	Fosphite	7.05	3.9	25-Jul-24	12-Aug-25
8	Reliant	8.15	3.9	11-Jul-24	16-Jul-25
	Reliant	8.15	3.9	18-Jul-24	29-July-25

	Reliant	8.15	3.9	25-Jul-24	12-Aug-25
9	Revielle	6.85	3.9	11-Jul-24	16-Jul-25
	Revielle	6.85	3.9	18-Jul-24	29-July-25
	Revielle	6.85	3.9	25-Jul-24	12-Aug-25
10	BlueLogic	18.3	3.9	11-Jul-24	-
	BlueLogic	18.3	3.9	18-Jul-24	-
	BlueLogic	18.3	3.9	25-Jul-24	-
11	Max set MZ	10.7	3.9	11-Jul-24	16-Jul-25
	Max set MZ	10.7	3.9	18-Jul-24	29-July-25
	Max set MZ	10.7	3.9	25-Jul-24	12-Aug-25
12	Vitaliphite K	12.4	3.9	11-Jul-24	16-Jul-25
	Vitaliphite K	12.4	3.9	18-Jul-24	29-July-25
	Vitaliphite K	12.4	3.9	25-Jul-24	12-Aug-25

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

In 2024 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.

In 2025, crop injury differences were found between treatments at all dates injury was evaluated (Table 4). Injury was slight at the first evaluation date. On 4 August 2025 crop injury was greater than the non-treated check for all treatments except Zinc Phosphite and Phiticide. On August 14 crop injury was greater than the non-treated check for Alloy, Fosphite, Maxset MZ, and Vitaliphite K. It is important to remember that the rates used for most of the products were not the typically labelled rates, as the goal was to compare the same amount of active ingredient with Phostrol being the standard ever product to equaled to. Some products may have had a higher rate used than labelled and that could have resulted in more foliar injury than would normally be expected. Although there were differences in foliar injury, there were no differences in total yield or marketable yield (Table 5 and 6). The only difference found was in tubers from 4 to 6 oz where the Maxset MZ had a higher number of tubers than the Phostrol.

Pink rot ant tuber phosphites for 2025 found no differences between phosphoric acid treatments (Table 7). However, they were different from the nontreated check. Because of the differences in 2024 and 2025 another year of study would be helpful to clarify the effects that have been found in this work.

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.

Table 4. Crop injury rating (from 0 to 100% with 0 meaning no injury and 100 meaning no green leaves) from treatments applied on Dakota Russet grown in Oakes, ND in 2025.

Treatment		Stand	Crop injury 7/26/25		Crop Injury 8/4/25		Crop Injury 8/14/25	
			————————————— % —————————————					
1	Non-treated	84	0.0	b	0.0	d	0.0	d
2	Zinc Phosphite	81	0.5	ab	3.3	cd	5.5	cd
3	Phiticide	81	0.0	b	3.3	cd	7.3	bcd
4	Phostrol	80	0.0	b	6.3	bc	7.0	bcd
5	Alloy	84	2.3	a	13.8	a	15.5	a
6	Fosphite	87	0.3	ab	7.3	bc	8.8	bc
7	Reliant	79	0.0	b	6.8	bc	5.5	cd
8	Revielle	83	0.3	ab	6.0	bc	6.8	bcd
9	Kphite	86	0.3	ab	9.5	ab	5.0	cd
10	Maxset MZ	79	0.0	b	7.8	bc	12.8	ab
11	Vitaliphite K	84	1.3	ab	9.0	abc	11.3	abc
Mean		83	0.4		6.6		7.9	
Treatment effect (P-value)		0.2494	0.0246		<0.0001		<0.0001	

Table 5. Graded yield of Dakota Russet with numerous phosphorus acid treatments in Oakes, ND in 2025.

	Treatment	<4 oz	4-6 oz	6-10 oz	10-14 oz	>14 oz	Total yield	Total marketable	>6 oz	>10 oz
		————————————— cwt/a —————————————							—— % ——	
1	Non-treated	33	62 ab	159	146	107	506	473	81	50
2	Zinc Phosphite	32	64 ab	180	131	89	497	464	81	44
3	Phiticide	35	61 ab	169	119	110	494	460	80	46
4	Phostrol	39	57 b	172	116	98	483	443	80	44
5	Alloy	40	61 ab	162	108	61	431	391	76	38
6	Fosphite	35	60 ab	177	135	81	488	452	81	44
7	Reliant	37	62 ab	160	107	101	467	430	78	44
8	Revielle	43	77 ab	197	112	67	496	453	76	36
9	Kphite	34	67 ab	162	104	105	471	438	79	44
10	Maxset MZ	33	82 a	185	96	61	457	424	75	34
11	Vitaliphite K	42	69 ab	159	139	89	498	455	78	46
Mean		37	66	171	119	88	481	444	79	43
Treatment effect (P-value)		0.7112	0.0211	0.6816	0.2171	0.2236	0.5458	0.6386	0.3159	0.1003

Table 6. Tuber number of graded yield of Dakota Russet with numerous phosphorus acid treatments in Oakes, ND in 2025.

	Treatment	<4 oz	4-6 oz	6-10 oz	10-14 oz	>14 oz	Total yield	Total marketable	>6 oz	>10 oz
		cwt/a							%	
1	Non-treated	18,695	20,510	33,033	20,328	9,983	102,548	83,853	62	30
2	Zinc Phosphite	16,698	19,239	35,574	17,061	7,623	96,195	79,497	63	26
3	Phiticide	18,695	19,239	35,211	16,335	10,527	100,007	81,312	62	27
4	Phostrol	21,236	18,332	35,030	15,428	8,894	98,918	77,682	60	25
5	Alloy	21,962	18,695	31,763	13,794	5,264	91,476	69,515	55	21
6	Fosphite	19,058	18,695	35,756	18,513	7,079	99,099	80,042	62	26
7	Reliant	18,876	18,150	30,674	13,794	8,531	90,024	71,148	58	25
8	Revielle	24,684	25,410	40,475	15,428	6,534	112,530	87,846	56	19
9	Kphite	18,513	21,962	33,759	14,157	9,438	97,829	79,316	59	24
10	Maxset MZ	17,787	24,321	35,030	12,161	5,082	94,380	76,593	55	18
11	Vitaliphite K	21,780	21,780	31,581	18,150	8,349	101,640	79,860	57	26
Mean		19,817	20,576	34,353	15,923	7,937	98,604	78,788	59	24
Treatment effect (P-value)		0.6688	0.1198	0.7278	0.0832	0.1211	0.0836	0.3289	0.5660	0.0762

Table 7. Incidence and penetration of pink rot (*phytophthora erythroseptica*) challenge inoculation as affected by treatment from tubers grown at Oakes, ND in 2025.

Treatment	Chemical name	*P. erythroseptica* challenge inoculation		Pink Rot Sensitivity Rating
		Incidence (%)	Penetration (mm/day)	
1	Non-treated	62.5	4.1	S
2	Zinc	2.5	0.1	R
3	Phiticide	3.8	0.2	R
4	Kphite/Blue Logic	8.8	0.5	R
5	Phostrol	2.5	0.1	R
6	Alloy	0.0	0.0	R
7	Fosphite	6.3	0.2	R
8	Reliant	1.3	0.0	R
9	Revielle	5.0	0.3	R
10	Kphite	1.3	0.1	R
11	Max set MZ	2.5	0.1	R
12	Vitaliphite K	1.3	0.1	R
$LSD_{P = 0.05}$		11.5	0.8	
P-value		<.0001	<.0001	
Coefficient of Variation		142.9	168.1	

Incidence and penetration of *Phytophthora erythroseptica* were not significantly different between trials 1 and 2. Both variances were homogeneous.

Precutting dormancy seed to improve emergence

Investigator contact:

Andy Robinson

Potato Extension Agronomist, NDSU / U of M

PO BOX 6050, Fargo, ND 58108

701.219.9646

Andrew.p.robinson@ndsu.edu

Executive summary

Bannock Russet and Reveille Russet are extremely dormant varieties, and often slow to emerge, resulting in yield loss. This study evaluated precutting seed in the fall, winter, and spring as well as holding seed at 45 F during storage. Six seed lots of Bannock Russet and Reveille Russet were evaluated in Tappen, ND in 2025. There were no differences in tuber yield or tuber number per acre from the different precut seed treatments. However, differences were found between seed lots on yield and tuber number. These data to indicate that in this one-year study precutting had no effect on potato production; however, seed genetics can vary in their response to yield and tuber size.

Rationale for conducting the research

Bannock Russet and Reveille Russet are extremely dormant varieties. Emergence is often slow, sporadic, and the stand can look quite ugly. Slow emergence reduces yield potential, as fewer green days are obtained. Varied emergence dates cause large differences in tuber size profile and yield. This can be frustrating as the more dormant varieties are desirable for storage, but not so desirable to grow.

Research has reported that cycling temperature during storage and cutting seed can speed up sprout development. In Australia growers will often precut seed in the middle of winter storage. Cutting seed tubers can increase the gibberellic acid production, encouraging physiological ageing. Because these varieties are difficult to grow, if there were a way to age seed more and have consistent emergence and higher yield, that would be desirable. To address the slow emergence of these cultivars, our objective was to determine if pre-cutting in the fall, winter, or spring influences emergence, stem number, tuber number, and yield.

Procedures

Five lots of Bannock Russet from G3 to G5 and one lot of Reveille Russet G3 were collected in the fall of 2024. These lots were separated into four sub-samples. One sub-sample suberized from harvest wounds and was cut in the fall on October 24 and suberized, the second one was warmed and cut on February 12 and suberized, and the third sub-sample was warmed and cut on April 23 and suberized before planting, and one sample was kept at 45 F for the storage duration and cut on April 23 and suberized.

Seed was planted near Tappen, ND in a randomized complete block with four replications. Plots were two rows wide, measuring 20 feet long by 68 inches wide. Seed tubers were planted at 12 inch within-row spacing on May 7, 2025. Plant emergence was counted on June 10. Plots were harvested with a single row harvester on September 24. Specific gravity was measured after grading tubers on 27 October 2025.

Results

There were no differences found between any precutting or warming seed treatment on yield (Table 1) or tuber number (Table 2). Nor were any differences found between stand, stem number, or specific gravity (Table 3).

Differences were found between seed lots for tuber yield (Table 4), tuber number (Table 5) and potato emergence, stem number, and specific gravity (Table 6). In general, Reveille Russet had higher total yield, marketable yield, and a larger tuber size profile than Bannock G3 #2 lot and sometimes with the Bannock G5 and Bannock G3 #3. There was not an obvious trend, as differences varied by Bannock seed lot. A similar result was found with tuber number with Reveille generally having a higher total tuber number and larger tubers.

From this one-year study it was found that seed precutting timing did not have an effect, indicating the current practices of warming, cutting, and suberizing seed prior to planting continues to be the most efficient method. Differences in seed lots did not have a clear trend, but these data indicate that seed potato lots can vary somewhat in their yield potential. Another year of study on this topic will be important to see if the same results are obtained.

Table 1. Yield (cwt/a) of Bannock Russet and Reveille Russet as affected by precut seed treatment timing or temperatures in Tappen, ND in 2025.

Seed treatment	<3 oz	3-6 oz	6-10 oz	10-14 oz	>14 oz	Total yield	Total marketable	>6 oz	>10 oz
	cwt/a							%	
Fall cut	9	49	108	117	149	431	423	86	61
Winter cut	9	49	110	117	168	452	444	87	62
Spring cut	7	50	129	120	152	457	451	87	58
Held at 45 F	10	48	123	117	155	453	443	86	59
Mean	8	49	117	118	156	448	440	86	60
p-value	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*

Table 2. Tuber number/a of Bannock Russet and Reveille Russet as affected by precut seed treatment timing or temperatures in Tappen, ND in 2025.

Seed 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							%	
Fall cut	6,262	18,543	23,353	16,789	14,187	79,134	72,872	69	40
Winter cut	6,232	17,908	23,202	16,849	15,851	80,042	73,810	70	41
Spring cut	4,659	18,725	27,588	17,031	13,885	81,887	77,228	72	38
Held at 45 F	6,958	17,606	25,985	16,819	14,762	82,129	75,171	70	39

Mean	5,717	18,392	24,714	16,890	14,641	80,354	74,637	70	40
p-value	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*

Table 3. Potato emergence, stem number, and specific gravity of Bannock Russet and Reveille Russet as affected by precut seed treatment timing or temperatures in Tappen, ND in 2025.

Seed treatment	Stand	Stems/plant	Specific Gravity
	%	number	
Fall cut	74	3.3	1.080
Winter cut	79	3.5	1.079
Spring cut	80	3.8	1.081
Held at 45 F	79	3.3	1.079
Mean	78	3.5	1.080
p-value	*ns*	*ns*	*ns*

Table 4. Yield of Bannock Russet and Reveille Russet as affected by seed lot Tappen, ND in 2025.

Seed lot generation 2025	<3 oz		3-6 oz		6-10 oz		10-14 oz		>14 oz		Total yield		Total mark
			-- cwt/a --										
Bannock G3 #1	6	bc	46	b	100	b	111	b	178	ab	441	ab	43
Bannock G3 #2	12	a	54	ab	120	ab	104	b	117	b	407	b	39
Bannock G3 #3	9	abc	45	b	110	ab	111	b	141	ab	416	b	40
Bannock G4	9	abc	65	a	142	a	121	ab	158	ab	494	ab	48
Bannock G5	11	ab	47	ab	110	ab	113	b	141	ab	421	ab	41
Reveille G3	5	c	38	b	122	ab	145	a	202	a	511	a	50

Mean	8	49	117	118	156	448	44
P-value	0.0026	0.0014	0.0226	0.0064	0.0187	0.0026	0.001

Table 5. Tuber number/a of Bannock Russet and Reveille Russet as affected by seed lot in Tappen, ND in 2025.

Seed lot generation 2025	<3 oz	3-6 oz	6-10 oz	10-14 oz	>14 oz	Total yield	Total marketable	>6 oz	>10 oz
	--- Tuber number/a ---							--------- % ---------	
Bannock G3 #1	4,447 bc	17,379 b	21,825	16,063 ab	16,108 ab	75,822 b	71,375 ab	71 ab	43 ab
Bannock G3 #2	8,485 a	19,602 ab	25,319	14,928 b	11,298 b	79,633 ab	71,148 ab	65 b	33 b
Bannock G3 #3	6,216 abc	16,834 b	23,368	15,972 ab	13,159 ab	75,549 b	69,333 b	70 b	39 ab
Bannock G4	5,944 abc	23,640 a	30,038	17,106 ab	14,792 ab	91,521 a	85,577 a	68 b	36 b
Bannock G5	7,805 ab	18,014 ab	24,049	16,471 ab	13,749 ab	80,087 ab	72,282 ab	68 b	38 ab
Reveille G3	3,267 c	13,703 b	25,592	20,691 a	18,921 a	82,174 ab	78,907 ab	80 a	49 a
Mean	6,027	18,195	25,032	16,872	14,671	80,798	74,770	70	40
P-value	0.0021	0.0008	0.0991	0.0191	0.0190	0.0268	0.0167	0.0006	0.0038

Table 6. Potato emergence, stem number, and specific gravity of Bannock Russet and Reveille Russet as affected by seed lot in Tappen, ND in 2025.

Seed lot generation 2025	Stand		Stems/plant		Specific Gravity	
	%		number			
Bannock G3 #1	79	ab	3.5	a	1.081	a
Bannock G3 #2	68	b	3.7	a	1.083	a
Bannock G3 #3	86	a	3.7	a	1.083	a
Bannock G4	78	ab	3.5	ab	1.081	a
Bannock G5	87	a	3.7	a	1.079	a
Reveille G3	72	b	2.7	b	1.072	b
Mean	78		3.5		1.080	
P-value	<.0001		0.0033		<.0001	

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

Carl Rosen[1], James Crants[1], Matt McNearney[1], Seonghyun Seo[1],
Laura Shannon[2], Thomas Stefaniak[2], and Sanjay Gupta
[1]Department of Soil, Water, and Climate, University of Minnesota
[2]Department of Horticultural Science, University of Minnesota

Summary

Elk River Russet is a mid-season potato cultivar from the University of Minnesota suitable for the fresh market or French fry processing. It has a uniform and pleasing size and shape, good skin set, and high specific gravity. It produces lower total yields than Russet Burbank, but it typically produces similar or larger yields of U.S. No. 1 tubers, and it has shown better bulking in years when poor bulking with Russet Burbank has been an issue. In 2023, a grower reported complaints of after-cooking darkening (ACD). The purpose of this study was to continue evaluations of Elk River Russet grown from certified grower seed, including the second year of evaluations of ACD. Elk River Russet was compared to Russet Burbank, and both were grown with total season nitrogen (N) rates of 80 and 220 lbs/ac. Elk River Russet produced lower total and U.S. No. 2 yields but greater U.S. No. 1 and total marketable yields than Russet Burbank. The percentages of yield represented by tubers over six and ten ounces were greater in Elk River Russet than Russet Burbank, while the number of tubers per plant was much smaller. Elk River Russet also had higher tuber specific gravity and dry matter content than Russet Burbank. These results are consistent with those from the previous two years of field studies. In 2025, unlike in 2024, Elk River Russet tubers at harvest showed very minor ACD in almost half of evaluated tubers while Russet Burbank showed none. ACD was less prevalent in tubers harvested four to five weeks early, indicating that the problem can be mitigated by early harvesting. ACD was also more prevalent in the treatment receiving 220 lbs/ac N than in the lower-N treatment. Additional research may clarify further approaches to controlling ACD.

Background

Elk River Russet is a mid-season potato cultivar from the University of Minnesota suitable for the fresh market or processing into French fries. It has a relatively uniform and pleasing size and shape, strong russeting, good skin set, and high specific gravity. While it generally has lower total yields than Russet Burbank, a larger percentage of its yield is represented by U.S. No. 1 tubers, and it has demonstrated superior tuber bulking in years when poor bulking is an issue.

One potential issue with Elk River Russet, based on a 2023 report from a grower, is that it may be prone to after-cooking darkening (ACD). We assessed this issue in tubers grown at SPRF in 2024 and found no difference from Russet Burbank in that year. However, the problem is known to be affected by environmental factors, and it is possible that Elk River Russet is prone to ACD under some growing conditions and not others.

The purpose of this study was to evaluate the performance of Elk River Russet relative to Russet Burbank at two nitrogen (N) application rates: 80 and 220 lbs/ac N. Crop responses to N rate were evaluated in terms of tuber yield, size, grade, and quality, as well as the prevalence of ACD.

Methods

The study was conducted at SPRF in 2025 on a Hubbard loamy sand soil. The previous crop was soybeans. To measure initial soil characteristics, soil samples to depths of six inches and two feet were collected on April 16. Samples were dried at 95 °F to a constant weight and then ground. Six-inch samples were sent to the University of Minnesota's Research Analytical Laboratory (UM-RAL) to be analyzed for pH, loss-on-ignition organic matter; Bray P; ammonium acetate extractable K, Ca, and Mg; DTPA-extractable Mn, Fe, Zn, and Cu; and hot water extractable B. Two-foot samples were analyzed for their NO_3^--N concentrations using a Wescan Nitrogen Analyzer . Results are presented in Table 1.

Four treatments were applied in a full-factorial randomized complete block design with four replicates. The treatments were defined by cultivar (Elk River Russet or Russet Burbank) and total N application rate (80 or 220 lbs/ac N). Each plot was 18 feet (six rows) wide and 20 feet long. The field was two plots wide, with each pair of plots placed adjacent to each other, and 8 plots long, with an alley between each pair of plots. In each plot, the central 18 feet of the fourth and fifth rows from the outside edge 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. In the second row from the outside, red potatoes were planted at the ends of the row and between every five russet potatoes to define three groups of five potatoes to be harvested for early-season yield and quality assessments. A three-foot buffer was planted on all sides of the field to reduce edge effects.

Planting rows were then opened mechanically with 36-inch spacing between rows on April 21. 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 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.

The rows were re-hilled on May 12. Just prior to hilling, Environmentally Smart Nitrogen (ESN, Nutrien; 44-0-0) was side dressed by hand in each plot to provide either 40 or 160 lbs/ac N, according to N rate treatment. The high-N treatments received an additional application of 20 lbs/ac N as 28% UAN on August 11.

Five adjacent plants were hand-dug from the second row from the outside edge of each plot on each of three sampling dates: July 29, August 12, and August 26. The tubers were sorted into five size categories: 0 – 3 oz., 3 – 4 oz., 4 – 6 oz., 6 – 10 oz., and over 10 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. Total yield was calculated as the sum of all non-cull yield and marketable yield as the sum of all yield over three oz. Tuber dry matter content was determined for a size-representative subset of the tubers. Three tubers over 6 oz. were taken from each five-plant sample to assess susceptibility to ACD.

Tubers were machine harvested from the designated harvest rows on September 23. On the same day, the tubers were sorted into six size categories: 0 - 3 oz., 3 – 4 oz., 4 – 6 oz., 6 – 10 oz., 10 – 14 oz., and over 14 oz. Total yield is considered all tubers harvested except the cull tubers. Tubers over 3 oz were sorted into U.S. No. 1 and U.S. No. 2 grade categories based on USDA standards for French fry processing potatoes. Cull tubers were sorted into a single category regardless of size. Marketable yield was the sum of U.S. No. 1 and U.S. No. 2 yield. Plot yields were converted to hundredweight per acre.

A sample of 25 U.S. No. 1 tubers was collected from each plot at 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, three-tuber sample was collected to be evaluated for ACD.

Two of the three tubers taken for ACD assessments from all four timepoints (the three hand-dug samples and the final harvest) were baked for two hours at 300 °F. These tubers were then sliced in half lengthwise and assessed for darkening on a subjective scale from 1 (no darkening) through 2 (minor darkening) to 3 (major darkening).

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 and discussion

Rainfall and irrigation

Daily and cumulative rainfall and irrigation from April 1 through October 8 are presented in Figure 1. The average rainfall totals 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 2025, rainfall was below average in April (1.45”), August (2.86”), and September (1.62”); close to average in May (3.83”) and July (3.89”); and above average in June (7.93”). Total rainfall in May through September was close to the average for the location, at 21.58”.

This rainfall was supplemented by 1.35” of irrigation in May, 1.95” in June, 5.00” in July, 3.25” in August, and 1.95” in September, for a total of 13.5” of irrigation in these months.

Tuber yield, size, grade, and number

Results for tuber yield, size, grade, and number are presented in Table 2. Russet Burbank had higher total yield and U.S. No. 2 yield than Elk River Russet. However, Elk River Russet had greater U.S. No. 1 yield and total marketable yield than Russet Burbank, as well as greater percentages of total yield represented by tubers over 6 and 10 ounces. U.S. No. 2 yield in Elk River Russet was negligible. Russet Burbank had more tubers per plant, but these tubers were disproportionately small in size compared to Elk River Russet, with significantly greater yield of tubers under 4 ounces and significantly lower yields of 6 – 10-oz. and 10 – 14-oz. tubers. Elk River Russet had greater yields of culled tubers (mostly due to greening) than Russet Burbank, but culls represented only 0.4% of Elk River Russet yield.

The higher N rate produced higher total, U.S. No.1, U.S. No. 2, and total marketable yields than the lower N rate, as well as greater percentages of total yield in tubers over 6 and 10 ounces. N rate did not affect the number of tubers per plant. Its effects on yield reflected greater tuber bulking under the higher N rate compared to the lower rate.

The effects of N rate on U.S. No. 1, U.S. No. 2, and total marketable yield were greater in Russet Burbank than in Elk River Russet, resulting in significant or marginally significant effects of the cultivar*N rate interaction. In contrast, the effect of N rate on the percentage of tubers over 10 ounces was stronger in Elk River Russet than in Russet Burbank. The size threshold for inclusion in the marketable yield categories was three ounces, and 35% of Russet Burbank yield was under this threshold when N was applied at 80 lbs/ac, compared to 11% of Elk River Russet yield. Thus, the potential for Elk River Russet to respond to a higher N rate by bulking more tubers above the three-ounce threshold was small compared to Russet Burbank. In contrast, 38% of Elk River Russet yield at 80 lbs/ac N was between six and ten ounces, versus 7% of Russet Burbank yield, indicating a greater potential for Elk River Russet to respond to a higher N rate by bulking tubers above the ten-ounce threshold.

Tuber quality

Results for tuber quality characteristics are presented in Table 3. The prevalences of hollow heart, brown center, and common scab were not significantly related to cultivar, N rate, or their interaction. Elk River Russet had higher tuber specific gravity and dry matter content than Russet Burbank. In Elk River Russet, but not in Russet Burbank, tuber specific gravity was significantly greater in tubers grown at 80 lbs/ac N than those grown at 220 lbs/ac N, resulting in marginally significant effects of N rate and the interaction between cultivar and N rate on tubers specific gravity.

After-cooking darkening (ACD)

Results for ACD are presented in Table 4. In the darkening assessment, ACD was scored at 1 if there was no darkening, 2 if there was minor darkening, and 3 if there was major darkening. Tubers collected by digging five plants by hand on July 29, August 12, and August 26 showed no effect of cultivar, N rate, or their interaction on ACD, which was absent or of low average severity in all treatment groups on those dates. At harvest, although ACD was again absent or of low average severity in all treatment groups, the average severity was greater in Elk River Russet than in Russet Burbank, which showed no darkening. ACD was more severe in Elk River Russet tubers grown at 220 lbs/ac N than those grown at 80 lbs/ac N, resulting in marginally significant effects of N rate and the interaction between N rate and cultivar. At harvest, 7 of 16 Elk River Russet tubers were rated 1.5 for ACD, indicating that darkening was widespread but minor. Darkening was detected only at the stem ends of the tubers in which it was present. The lower average severity of ACD among hand-dug tubers earlier in the season indicates that this problem can be mitigated with earlier harvest.

Conclusions

Elk River Russet potatoes from certified grower seed have now been evaluated at SPRF for three consecutive years. It has consistently produced lower total yields than Russet Burbank, but it has also consistently greater U.S. No. 1 yields. In addition, in both 2024 and 2025, it produced greater total marketable yields than Russet Burbank, though it produced a lower total marketable yield than Russet Burbank in 2023 due to a 79-cwt difference in U.S. No. 2 yields between the two cultivars.

Elk River Russet has also had greater percentages of its total yield in tubers over six ounces in all three years, with greater percentages over ten ounces in 2024 and 2025. These differences in tuber bulking, as well as Elk River Russet's advantage in producing marketable yield, are partly attributable to a difference in tuber number per plant. Elk River Russet produced 8.1, 9.8, and 9.7 tubers per plant in 2023, 2024, and 2025, respectively, compared to 9.1, 14.3, and 14.3 tubers per plant, respectively, for Russet Burbank.

A third consistent difference between the two cultivars is the greater tuber specific gravity and dry matter content of Elk River Russet tubers compared to Russet Burbank tubers. Tubers with higher specific gravity tend absorb less oil during French frying than lower-specific-gravity tubers.

In 2024, neither cultivar showed susceptibility to ACD, but in 2025, at harvest but not before, Elk River Russet did show some susceptibility to this issue. Although no tubers had major darkening after baking at 300 °F for two hours, nearly half of the Elk River Russet tubers showed minor darkening in this year. Results from tubers harvested by hand a month to two months before vine kill indicate that the problem can be mitigated through early harvesting.

The results of three years of research on certified grower seed for Elk River Russet confirm prior conclusions based on research with breeder seed that this cultivar produces somewhat lower but substantially higher-quality yields of potatoes for French frying or the fresh market than Russet Burbank. The high percentage of yield in U.S. No. 1 tubers seen in Elk River Russet indicates that the cultivar may be especially well-suited to the fresh market. However, ACD may be an issue for this cultivar, and further research may be needed to identify methods for reducing its prevalence and severity.

Table 1. Characteristics of six-inch and two-foot soil samples taken at the Sand Plain Research Farm in Becker, MN, in 2025 prior to treatment application.

0 - 6 inches												0 - 2 feet
pH	Organic matter (%)	Bray P (mg/kg)	NH_4OAc-K (mg/kg)	NH_4OAc-Ca (mg/kg)	NH_4OAc-Mg (mg/kg)	DTPA-Mn (mg/kg)	DTPA-Fe (mg/kg)	DTPA-Zn (mg/kg)	DTPA-Cu (mg/kg)	Hot water B (mg/kg)	SO_4^{2-}-S (mg/kg)	NO_3^--N (mg/kg)
7.0	1.5	31	129	840	153	10	18	2.0	0.9	0.2	3	6.3

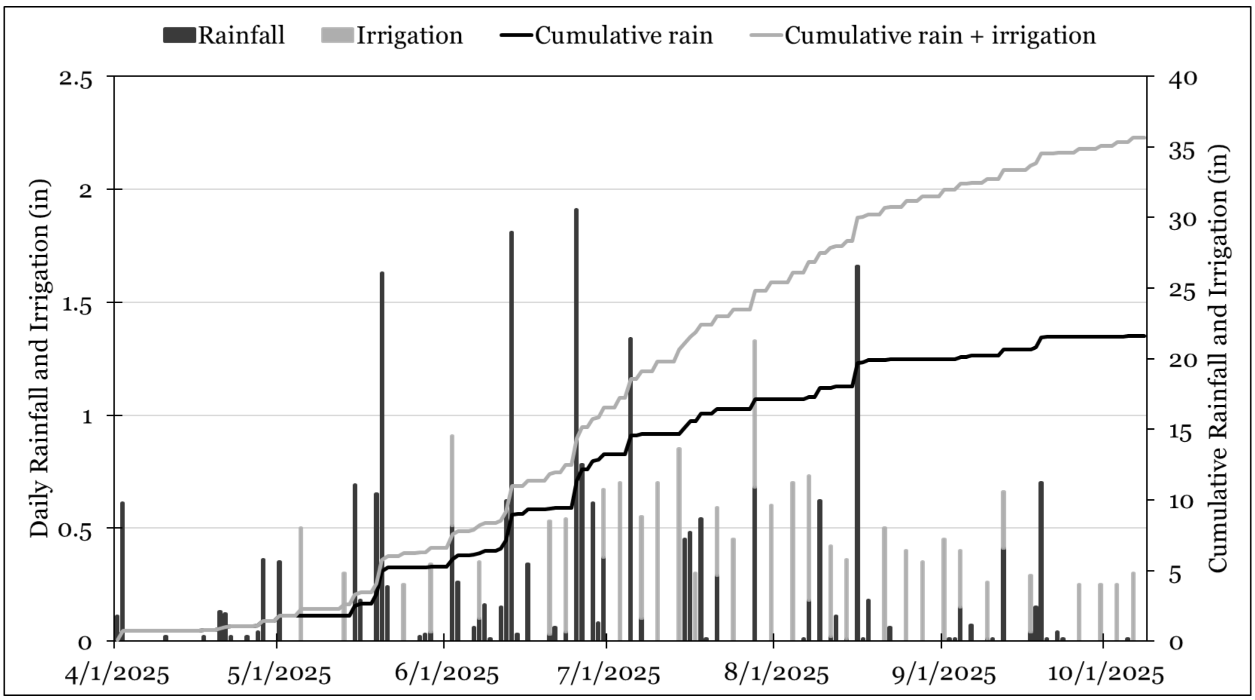

Figure 1. Daily and cumulative rainfall and irrigation at SPRF in Becker, MN, from April 1 through October 8, 2025.

Table 3. Tuber yield, size, grade, and number per plant of Elk River Russet and Russet Burbank tubers grown under 80 or 220 lbs/ac N at the Sand Plain Research Farm in Becker, MN, in 2025. 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 $P \leq 0.10$.

Cultivar	Total N applied (lbs/ac)	Yield (cwt/ac)											% yield in tubers over:		Tubers / plant
		Culled	0-3 oz.	3-4 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	2.1 a	51 b	43 b	162	205 a	29 a	1	494 b	442 a	0 b	443 a	47 a	6 a	9.7 b
Burbank		0 b	149 a	128 a	176	79 b	5 b	0	536 a	341 b	46 a	387 b	15 b	1 b	14.3 a
Effect of cultivar (P-value)		**0.0398**	**<0.0001**	**<0.0001**	0.2360	**<0.0001**	**0.0004**	0.3370	**0.0080**	**<0.0001**	**0.0001**	**0.0036**	**<0.0001**	**0.0005**	**<0.0001**
Average of both cultivars	80	0.8	112 a	96 a	161	108 b	8 b	0	485 b	358 b	15 b	373 b	24 b	2 b	11.8
	220	1.3	88 b	78 b	177	175 a	26 a	1	545 a	425 a	31 a	457 a	38 a	5 a	12.2
Effect of N rate (P-value)		0.6452	**0.0015**	**0.0012**	0.1845	**<0.0001**	**0.0034**	0.3370	**0.0007**	**0.0010**	*0.0506*	**0.0002**	**<0.0001**	**0.0068**	0.1448
Elk River Russet	80	1.7	53 c	52 c	176 b	180	15 b	0	476	423 ab	0 c	423 b	41	3 b	9.5
	220	2.5	50 c	41 d	147 c	229	44 a	2	512	462 a	1 c	462 a	54	9 a	9.8
Russet Burbank	80	0	171 a	141 a	145 c	36	2 c	0	495	293 c	30 b	324 c	7	0 c	14.1
	220	0	127 b	114 b	206 a	121	9 bc	0	578	389 b	62 a	451 ab	23	2 bc	14.5
Effect of cultivar*N rate (P-value)		0.6452	**0.0037**	*0.0882*	**0.0017**	0.1462	*0.0523*	0.3370	0.1059	*0.0936*	*0.0567*	**0.0145**	0.6568	*0.0552*	0.8477

Table 3. Tuber quality characteristics of Elk River Russet and Russet Burbank tubers grown under 80 or 220 lbs/ac N at the Sand Plain Research Farm in Becker, MN, in 2025. 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.

Cultivar	Total N applied (lbs/ac)	Prevalence (% of tubers)					Specific gravity	Dry matter content (%)
		Hollow heart		Brown center		Common scab		
		Total	Disqualifying	Total	Disqualifying			
Elk River	Average of both rates	3	2	3	2	2	1.0833 a	21.6 a
Burbank		1	0	2	0	2	1.0727 b	18.7 b
Effect of cultivar (P-value)		0.3243	0.1827	0.6943	0.1827	1.0000	**<0.0001**	**<0.0001**
Average of both cultivars	80	0	0	1	0	2	1.0789 a	20.1
	220	4	2	5	2	1	1.0771 b	20.2
Effect of N rate (P-value)		0.1757	0.1827	0.1332	0.1827	0.4269	***0.0636***	0.6770
Elk River Russet	80	0	0	0	0	2	1.0850 a	21.7
	220	6	4	6	4	1	1.0815 b	21.6
Russet Burbank	80	0	0	1	0	2	1.0727 c	18.5
	220	1	0	3	0	1	1.0728 c	18.9
Effect of cultivar*N rate (P-value)		0.3243	0.1827	0.4363	0.1827	1.0000	***0.0561***	0.5204

Table 4. Average severity of after-cooking darkening (1= no darkening; 2 = minor darkening; 3 = major darkening) in Elk River Russet and Russet Burbank tubers grown under 80 or 220 lbs/ac N at the Sand Plain Research Farm in Becker, MN, in 2025. 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.

Cultivar	Total N applied (lbs/ac)	After-cooking darkening (ACD)			
		July 29	August 12	August 26	Harvest
Elk River	Average of both rates	1.00	1.06	1.13	1.22 a
Burbank		1.00	1.06	1.03	1.00 b
Effect of cultivar (P-value)		1.0000	1.0000	0.3835	**0.0006**
Average of both cultivars	80	1.00	1.03	1.03	1.06 b
	220	1.00	1.09	1.13	1.16 a
Effect of N rate (P-value)		1.0000	0.2948	0.3835	***0.0731***
Elk River Russet	80	1.00	1.00	1.06	1.13 b
	220	1.00	1.13	1.19	1.31 a
Russet Burbank	80	1.00	1.06	1.00	1.00 c
	220	1.00	1.06	1.06	1.00 c
Effect of cultivar*N rate (P-value)		1.0000	0.2948	0.7682	***0.0731***

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

Carl Rosen, James Crants, Matt McNearney, and Seonghyun Seo

Department of Soil, Water, and Climate, University of Minnesota

crosen@umn.edu

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. Two blends of the polyhalite product Poly4 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. The treatment receiving only ammonium sulfate (21-0-0-24S) without K had significantly higher yield of tubers over 14 ounces than any treatment except the treatment receiving KCl plus ammonium sulfate. The treatment receiving the KCl/Poly4 blend providing 45 lbs/ac S had a lower yield of U.S. No. 2 tubers than any other treatment. The treatments receiving either KCL plus K-Mag (0-0-22-21S-11Mg) or KCl plus Poly4 to provide 30 lbs/ac S had lower tuber specific gravity than the treatment receiving KCL alone or the Poly4/KCl blend providing 45 lbs/ac S. 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 (specifically, the product Poly4, 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 2025. Initial soil characteristics from samples collected on April 16 are presented in Table 1.

Six 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 8 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 18. In addition to treatment-specific fertilizers, on April 23, 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 May 12, the rows in all treatments were side dressed with 299 lbs/ac ESN (Nutrien: 44-0-0), supplying 132 lbs/ac N. All treatments received 20 lbs/ac N as 28% UAN in each of 3 applications, on June 23 and July 7 and 21.

Vines were shredded with a flail mower on September 19. Tubers were harvested from the central 18 feet of the middle two rows of each plot on October 8. On October 13, the tubers were sorted into six size categories: : 0 - 3 oz., 3 – 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 grade categories based on USDA standards for French fry processing potatoes. Cull tubers were sorted into a single category regardless of size. Total yield was measured as the sum of all non-cull yield. U.S. No. 1 yield included all 3 – 4-oz. tubers plus larger tubers graded as U.S. No. 1. U.S. No. 2 yield included tubers over 4 oz. graded as U.S. No. 2. Marketable yield was the sum of U.S. No. 1 and U.S. No. 2 yield. Plot yields were converted to hundredweight per acre.

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, and common scab, 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 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.

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 K-Mag (Mosaic: 0-0-22-21S-11Mg; treatment 4). The fourth contrast compared the treatment receiving KCl plus K-Mag with the treatment receiving a blend of KCl and Poly4 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 from April through September are presented in Figure 1. The average rainfall totals 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 2025, rainfall was below average in April (1.45”), August (2.86”), and September (1.62”); close to average in May (3.83”) and July (3.89”); and above average in June (7.93”). Total rainfall in May through September was close to the average for the location, at 21.58”.

This rainfall was supplemented by 1.35” of irrigation in May, 1.95” in June, 5.00” in July, 3.25” in August, and 1.95” in September, for a total of 13.5” of irrigation and 35.08 total inches of water from April through September.

On average, rainfall contained very little K (0.16 ppm), depositing approximately 0.6 lbs/ac K over the course of the season. Irrigation water contained a substantially higher concentration of K (2.28 ppm) and deposited about 7.6 lbs/ac K throughout the season.

Tuber yield, size, grade, and number

Results for tuber yield, size, grade, and number are presented in Table 3. Treatment had few statistically significant effects on yield. The treatment receiving no K (treatment 1) had a higher yield of tuber over 14 ounces than any other treatment except the treatment receiving ammonium sulfate with KCl (treatment 3), which had a higher yield in this size category than the treatment receiving KCl alone (treatment 2) or the treatment receiving the KCl/Poly4 blend that provided 30 lbs/ac S (treatment 5). The treatment receiving the KCl/Poly4 blend that provided 45 lbs/ac S had a lower yield of U.S. No. 2 tubers than any other treatment. Treatment did not significantly affect total yield, U.S. No. 1 yield, total marketable yield, or the percentages of tubers over 6 and 10 ounces.

Tuber quality

Results for tuber quality are presented in Table 4. The prevalences of hollow heart, brown center, and common scab were not significantly related to treatment. Tuber specific gravity was significantly higher in the treatment receiving KCl (treatment 2) and the treatment receiving the KCl/Poly4 blend that provided 45 lbs/ac S (treatment 6) than in the treatments receiving KCl with K-Mag (treatment 4) or the KCl/Poly4 blend providing 30 lbs/ac S (treatment 5). Tuber dry matter content was not related to treatment.

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. The KCl/Poly4 blend providing 30 lbs/ac S (treatment 5) produced numerically higher yields, but more U.S. No. 2 tubers and lower specific gravity, than the KCl/Poly4 blend providing 45 lbs/ac S.

Table 1. Initial soil characteristics in the study site at the Sand Plain Research Farm in Becker, MN, in April 2025, before fertilizer applications.

0 - 6 inches												0 - 2 feet
pH	Organic matter (%)	Bray P (mg/kg)	NH_4OAc-K (mg/kg)	NH_4OAc-Ca (mg/kg)	NH_4OAc-Mg (mg/kg)	DTPA-Mn (mg/kg)	DTPA-Fe (mg/kg)	DTPA-Zn (mg/kg)	DTPA-Cu (mg/kg)	Hot water B (mg/kg)	SO_4^{2-}-S (mg/kg)	NO_3^--N (mg/kg)
6.9	1.5	27	134	1017	181	11	17	2.2	0.8	0.2	4	8.9

Table 2. Treatments applied to Russet Burbank potato plants to evaluate Poly4 (a polyhalite product) as a nutrient source for potatoes in sandy, acidic, low-organic-matter soils.

Treatment #	Product applied	K_2O (lbs/ac)	S (lbs/ac)	Ca (lbs/ac)	Mg (lbs/ac)	Poly (lbs/ac)	MOP (lbs/ac)	AmSulf (lbs/ac)	Urea[5] (lbs/ac)	K-Mag (lbs/ac)
1	AmSulf[1]	0	30	0	0	0	0	125	0	0
2	KCl[2]	200	0	0	0	0	333	0	57	0
3	KCl + AmSulf	200	30	0	0	0	333	125	0	0
4	KCl + K-Mag[3]	200	30	0	16	0	282	0	57	143
5	KCl + Poly4[4] 30 S	200	30	19	5	158	296	0	57	0
6	KCl + Poly4 45 S	200	45	29	7	237	278	0	57	0

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

[2] Potassium chloride: 0-0-60

[3] K-Mag: 0-0-22-21S-11Mg

[4] Poly4: 0-0-14-19S-11Ca-3Mg

[5] Urea: 46-0-0

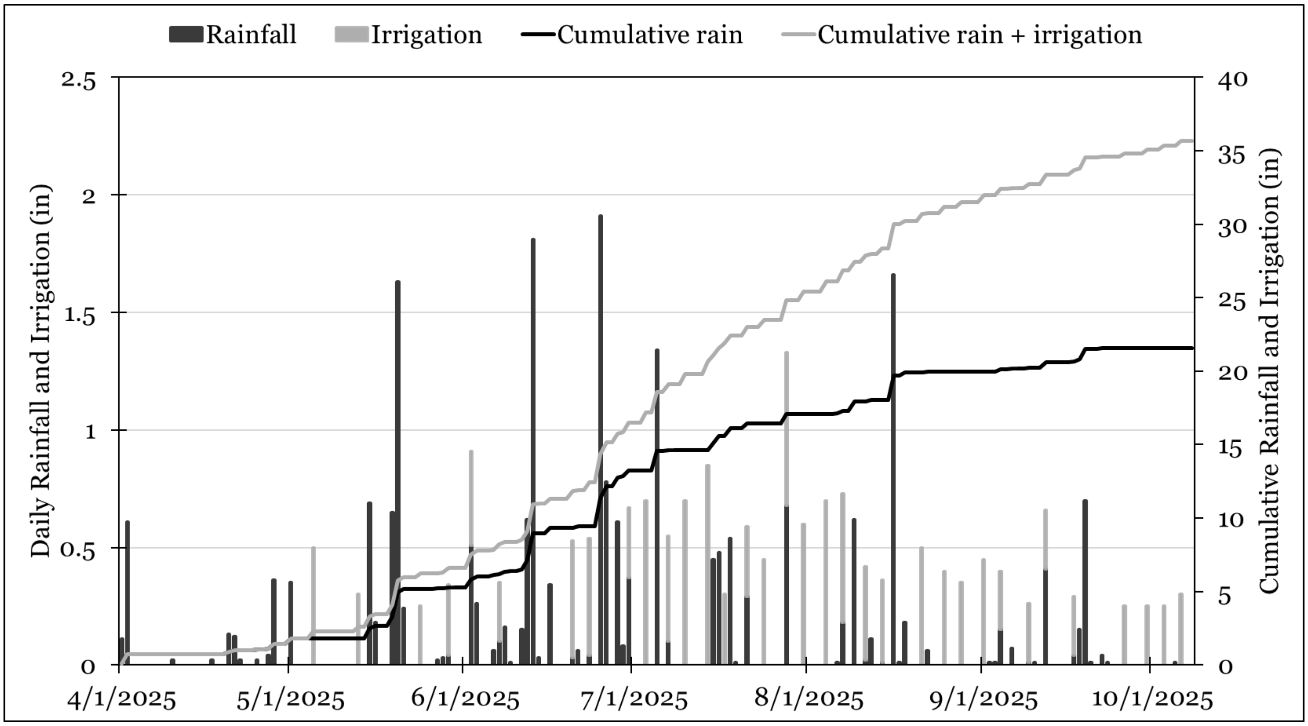

Figure 1. Daily rainfall and irrigation and cumulative rainfall and rainfall plus irrigation from April 1 through October 8.

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 ($P \leq 0.10$) 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	Product applied	Culled	0-3 oz.	3-4 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	1.4	98	74	208	203	66	22 a	671	537	36 a	573	43	13	13.1
2	KCl	0.5	90	83	222	221	58	10 c	683	546	48 a	593	42	10	13.4
3	KCl + AmSulf	2.9	94	95	211	222	55	19 ab	695	561	40 a	601	42	10	14.4
4	KCl + K-Mag	1.9	100	83	227	200	61	13 bc	683	541	42 a	584	40	11	14.4
5	KCl + POLY4 30 S	0.5	95	87	218	218	57	10 c	685	546	44 a	590	41	10	14.4
6	KCl + POLY4 45 S	0.4	93	76	231	180	49	10 bc	640	526	21 b	546	37	9	13.2
	Treatment effect (P-value)	0.6090	0.9113	0.5567	0.4105	0.2323	0.6956	***0.0930***	0.2320	0.7762	**0.0461**	0.2947	0.3437	0.2089	0.4567
Contrasts (P-value)	K addition (1 v 3)	0.3701	0.6737	***0.0958***	0.8186	0.3258	0.2788	0.5148	0.2931	0.3144	0.6533	0.2522	0.8166	0.1219	0.1734
	S addition (2 v 3)	0.1730	0.6472	0.3374	0.3745	0.9618	0.7654	***0.0796***	0.5893	0.5176	0.3329	0.7454	0.9277	0.6835	0.2830
	Mg addition (3 v 4)	0.5600	0.5672	0.3335	0.1984	0.2467	0.5494	0.2553	0.5954	0.4060	0.7370	0.4704	0.4101	0.8209	0.9464
	Poly vs. conv. (5 v 4)	0.5010	0.6175	0.7364	0.4865	0.3308	0.6842	0.5085	0.9446	0.8435	0.8391	0.7917	0.6300	0.4148	0.9940

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	Disqualifying hollow heart	Disqualifying brown center	Common scab		
1	AmSulf	7	6	1	1.0804 ab	20.9
2	KCl	5	5	0	1.0809 a	20.8
3	KCl + AmSulf	7	7	3	1.0803 ab	20.8
4	KCl + K-Mag	7	7	1	1.0787 b	20.9
5	KCl + POLY4 30 S	3	3	1	1.0787 b	20.9
6	KCl + POLY4 45 S	6	6	2	1.0821 a	21.4
	Treatment effect (P-value)	0.8205	0.8124	0.4929	**0.0419**	0.3036
Contrasts (P-value)	K addition (1 v 3)	1.0000	0.7580	0.2081	0.9328	0.5099
	S addition (2 v 3)	0.5691	0.5395	***0.0672***	0.6058	0.8119
	Mg addition (3 v 4)	1.0000	1.0000	0.2081	0.1419	0.5144
	Poly vs. conv. (5 v 4)	0.2612	0.2269	1.0000	0.9819	0.9895

Effects of soil health management strategy and cultivar on potato yield and quality in a three-year rotation

Carl Rosen, James Crants, Seonghyun Seo, and Matt McNearney

Department of Soil, Water, and Climate

and

Ashish Ranjan, Sonal Srivastava and Lovepreet Singh

Department of Plant Pathology

University of Minnesota

Summary

Managing farmland for improved soil health has been found to be economically beneficial in some corn and soybean systems. However, because reduced tillage is an important component of improving soil health in such systems, it is not known whether similar results can be obtained in potato systems. Addressing this question was 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, to evaluate conventional, no-fumigant, and promicrobial potato management systems. In 2025, potatoes were grown for the third time in the 3-year rotation plots, in a full-factorial randomized complete block design with five replicates in which cultivar and management system were the two factors. Based on soil propagule densities, the promicrobial system was moderately effective at suppressing *Verticillium* in the Russet Burbank plots, but not in the Bannock Russet plots. For both Russet Burbank and Bannock Russet, the conventional management system resulted in greater total, U.S. No. 1 and marketable yields than the pro-microbial system or the no-fumigant system. The promicrobial system had fewer tubers per plant than the conventional system, averaged between cultivars, with Bannock Russet in the promicrobial system having the fewest tubers per plant. These tuber yield and number results may reflect the presence of blackleg in the Bannock Russet seed and a tendency for the promicrobial treatment to exacerbate blackleg when it is present. Tuber number per plant was estimated from tuber number per plot assuming 100% stand, and it would have been depressed in plots with lower stand. The promicrobial system also produced tubers with lower specific gravity than the other systems. These results suggest that the pro-microbial management approach used in this study may have controlled *Verticillium* populations somewhat effectively, but it was not beneficial in terms of tuber yield or quality. In contrast, Bannock Russet had higher yields, more large tubers, higher

tuber specific gravity, and fewer *Verticillium* propagules per gram than Russet Burbank. The use of resistant cultivars may be a more effective method for eliminating the need for chemical soil fumigation than is the use of biofumigation.

Background

The long-term sustainability of agricultural systems depends in part on maintaining and improving soil health. Research by the Soil Health Institute published in 2022 found that managing for improved soil health increased net income for 85% of farmers growing corn and 88% of farmers growing soybeans, with average net income increasing by $51.60 and $44.89 per acre for corn and soybeans, respectively. These gains rely heavily on reduced or zero tillage, and it is therefore not clear whether these results are relevant to potato cropping systems, in which significant soil disturbance is inevitable during potato years.

The Potato Soil Health Project was started in 2018 to evaluate the potential for soil health promoting practices to improve soil health in potato cropping systems while maintaining or improving profitability. One objective of this project involved small-plot studies conducted by eight university research teams across the country. Each study evaluated six treatments in a two-year rotation and six in a three-year rotation. The USDA SCRI grant supporting the study expired in 2022 and has not been renewed, but for the small-plot studies that continue operating, 2025 was the third potato year of the three-year rotation.

For the first two potato years of the three-year rotation in Minnesota, three potato cultivars were grown under a total of three management systems. Russet Burbank was grown under conventional, no-fumigant, and promicrobial management systems; Norkotah Russet was grown under the conventional and promicrobial systems; and Bannock Russet was grown under the no-fumigant system. In 2025, Norkotah Russet was replaced by Bannock Russet, so that the study had a full-factorial randomized complete block design with five replicates and two factors defined by cultivar (Russet Burbank or Bannock Russet) and management system (conventional, no-fumigant, or promicrobial).

In the conventional system, potatoes were grown with entirely conventional nutrient sources, and the soil was fumigated with metam sodium in the fall before potato years. A potato-corn-soybean rotation was used. The no-fumigant system was the same as the conventional system, except that no soil fumigant was applied in any year. The promicrobial system differed from the conventional system in that: (1) aged turkey manure was applied in potato years; (2) manure was applied in 2020, when the first corn crop was grown, (3) corn was replaced by camelina (which followed a hybrid rye cover crop) in 2023, the second year corn was grown in the conventional and no-fumigant systems, (4) soy was replaced in the rotation by field peas followed by mustard (as a biofumigant), and (5) no chemical fumigant was used after the first potato year.

The purpose of the study was to evaluate the potential for the promicrobial treatment to improve soil health without compromising yield or disease control.

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 2025. 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.

In 2025, six treatments were applied in a full-factorial randomized complete block design with treatments defined by cultivar (Russet Burbank or Bannock Russet) and soil health management approach (conventional, no fumigant, or promicrobial). The treatments are summarized in Table 1. Each plot was 30 feet long and 18 feet (6 rows) wide. Each block was surrounded by a 3-foot buffer of potato plants to reduce edge effects.

The conventionally managed plots were fumigated with metam sodium applied at 50 gallons/ac on October 24, 2024. Aged turkey manure (3.2-2.3-2.5) was applied to the promicrobially managed plots on April 17, 2025, at a rate of 3 T/ac, providing 191 lbs/ac total N, of which 134 lbs/ac N (70% of the total) was assumed to be available to plants in 2025, including 50 lbs/ac inorganic N. In addition, 34 lbs/ac N was assumed to be released by manure applied in 2024, for a total of 167 lbs/ac available N. After the manure application, 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, and all plots were tilled.

On April 30, 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 13, 104 lbs/ac N was applied as side-dressed urea (46-0-0) in all treatments. An additional 36 lbs/ac N as urea was side dressed by hand in the conventional and no-fumigation treatments. The rows were then hilled. On June 23 and July 7, 24 lbs/ac N was applied as 28% UAN to the plots receiving the conventional and no-fumigant treatments. On July 21, all plots received 12 lbs/ac N as 28% UAN. In total, the conventional and no-fumigant plots received 240 lbs/ac N. The promicrobial plots received 240 lbs/ac mineral N plus residual N from 2024 manure applications, plus an estimated 83 lbs/ac available organic N from the 2025 manure application.

On September 19, vines were beaten with a flail mower. Tubers were harvested on October 6 and sorted on October 7. The tubers were sorted into six size categories: 0 - 3 oz., 3 – 4 oz., 4 – 6 oz., 6 – 10 oz., 10 – 14 oz., and over 14 oz. Tubers over 3 oz were sorted into U.S. No. 1 and U.S. No. 2 grade categories based on USDA standards for French fry processing potatoes. Cull tubers were sorted into a single category regardless of size. Total yield was calculated as the sum of all non-cull yield. Marketable yield was the sum of U.S. No. 1 and U.S. No. 2 yield. Plot yields were converted to hundredweight per acre. The number of tubers per plant was calculated as the number of machine-counted tubers in the plot divided by 56, the number of plants expected in the harvest rows (minus the four marker reds) at 100% stand.

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.

Data were analyzed using the GLIMMIX procedure in SAS 9.4 (SAS Institute, Inc., 2016). Each response variable was analyzed as a function of cultivar, management, and their interaction as fixed effects 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.

Results

Soil test results

Soil characteristics before planting in 2022 are presented in Table 1, and 2025 soil characteristics are presented in Table 3. In both years, the conventional management system had lower soil pH than the other two systems. The promicrobial treatment had numerically lower pH than the no-fumigant treatment in both years. The difference was only significant in 2025, but the average pH for each of these two treatments was nearly identical between years. In 2025, but not 2022, the pre-planting soil NH_4^+-N concentration was higher in the promicrobial treatment than in the other two treatments. The effects of cultivar and management system on NO_3^--N concentrations were quite different between years. In 2022, plots with Russet Burbank had higher NO_3^--N concentrations than those with Bannock Russet or Russet Norkotah, and the conventional system produced higher soil NO_3^--N than the no-fumigant system, which produced higher NO_3^--N than the promicrobial system. In 2025, soil NO_3^--N was not significantly related to cultivar, and the promicrobial system had higher soil NO_3^--N than the other two systems. In both years, the promicrobial system had higher Bray P and K concentrations than the other two management systems.

Soil organic matter content was not related to cultivar or management system in either year. However, in 2025 (and not 2022), the effect of the interaction between cultivar and system on soil organic matter was significant. While the conventional system had the lowest organic matter content among plots planted with Bannock Russet, the opposite was true with Russet Burbank.

In both years, the number of *Verticillium* propagules per gram of soil (VPPG) was lower in blots with Bannock Russet than those with Russet Burbank. The plots designated for Bannock

Russet potatoes and the conventional or promicrobial management systems in 2025 were planted with Russet Norkotah potatoes in 2019 and 2022 (unlike the no-fumigant system plots, which were planted in Bannock Russet in all potato years). Thus, the low 2022 VPPG in the conventional and promicrobial plots designated for Bannock Russet may be attributable to an effect of cultivar rather than management system. However, since the same two management systems produced lower VPPG than the no-fumigant system in the Russet Burbank plots in 2022, it is likely that fumigation in the conventional plots and biofumigation in the promicrobial plots were both effective at reducing VPPG. In 2025, while the general pattern of lower VPPG in the conventional and promicrobial systems compared to the no-fumigant system held in Russet Burbank plots (with somewhat better *Verticillium* control under conventional fumigation than biofumigation in both years), in plots planted in Bannock Russet, the no-fumigant system had the lowest VPPG. This may reflect the fact that 2025 was the third potato year in which the no-fumigant plots designated for Bannock Russet were planted with that cultivar, while it was only the first year in which the conventional and promicrobial plots designated for Bannock Russet were planted with Bannock Russet, having been planted with Russet Norkotah in 2019 and 2022.

In both years, the effect of the interaction between cultivar and management system on the depth to 300 PSI penetrometer resistance was marginally significant. Whether plots were designated for Bannock Russet or Russet Burbank in 2025, the depth the 300 PSI resistance was deeper in the conventional system than the promicrobial system. However, the no-fumigant system produced a similar depth to 300 PSI resistance to the conventional system in plots designated for Bannock Russet, while in plots designated for Russet Burbank, the no-fumigant system had results more similar to the promicrobial system.

Rainfall and irrigation

Results for rainfall and irrigation from April 1 through October 6 are presented in Figure 1. The average rainfall totals 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 2025, rainfall was below average in April (1.45”), August (2.86”), and September (1.62”); close to average in May (3.83”) and July (3.89”); and above average in June (7.93”). Total rainfall in May through September was close to the average for the location, at 21.58”.

This rainfall was supplemented by 1.00” of irrigation in May, 1.85” in June, 5.07” in July, 3.35” in August, and 1.70” in September, for a total of 12.97” of irrigation in these months.

Tuber yield, size, grade, and number

Results for tuber yield, size, grade, and number are presented in Table 4. Russet Burbank had numerically greater total yield, averaged across management systems, than Bannock Russet, though the difference was not significant. However, much of Russet Burbank's yield advantage was in tubers under three ounces, with the rest in 3 – 4-oz. tubers and 4 – 6-oz. tubers. As a result, Bannock russet had significantly higher U.S. No. 1 yields and total marketable yields than Russet Burbank. Bannock Russet also had more of its total yield in tubers over six and ten ounces then Russet Burbank. Russet Burbank had slightly greater U.S. No. 2 yield than Bannock Russet. Russet Burbank also had more tubers per plant than Bannock Russet, suggesting that its poorer tuber bulking was due to having set more tubers than it could effectively bulk up.

The conventional management system had greater total yield and total marketable yield than the no-fumigant and promicrobial systems, as well as significantly greater U.S. No. 1 yield than the promicrobial system and numerically greater U.S. No. 1 yield than the no-fumigant system. The no-fumigant system had significantly less of its total yield in tubers over ten ounces than the promicrobial system and a lower yield of tubers over 14 ounces than either of the other two systems. The conventional system produced more tubers per plant than the promicrobial system, with the no-fumigant system producing an intermediate number of tubers per plant.

The only effect of the interaction between cultivar and management system on yield that approached statistical significance was the effect on U.S. No. 2 yield. While Russet Burbank had higher U.S. No. 2 yield than Bannock Russet in the conventional and promicrobial systems, the difference between the two cultivars was not significant in the no-fumigant system.

Tuber number results for both cultivar and management system may have been affected by the prevalence of blackleg disease in the plots. Blackleg was more abundant in Bannock Russet than Russet Burbank due to contamination in the seed. The issue was more severe in the promicrobial plots. Blackleg depressed plant stand and presumably tuber number. However, tuber number per plant was calculated as the number of tubers in the harvest sample divided by 56, the number of plants that would have been represented in the harvest sample if stand were 100%. In plots with substantially depressed stand, this would depress the calculated number of tubers per plant even if the actual number of tubers per plant remained constant.

Tuber quality

Results for tuber quality are presented in Table 5. The prevalences of hollow heart and brown center were lower in the no-fumigant treatment than in the other treatments, though the difference in hollow heart prevalence between the no-fumigant and conventional treatments was not significant. These effects of management on internal defects may have been related to differences in tuber bulking. The no-fumigant system produced fewer very large tubers than the other two systems, and hollow heart and brown center are more common in very large tubers.

Averaged across management systems, tuber specific gravity and dry matter content were both higher in Bannock Russet than Russet Burbank. The promicrobial system produced numerically lower specific gravity than the other two systems with either cultivar. However, while the no-fumigant system produced numerically higher specific gravity than the conventional system in Bannock Russet, the opposite was true in Russet Burbank, resulting in a significant effect of the interaction between cultivar and management system.

Conclusions

A major goal of this research is to examine one approach to improving soil health in a potato cropping system without compromising disease control or yield. This approach involved applying an organic amendment (aged poultry manure) in years when potatoes were grown (2019, 2022, and 2025) and the year when corn was grown (2020), planting a rye cover crop after each potato harvest, and replacing soybeans with field peas and mustard (in 2021 and 2024). This approach was compared to a conventional approach (a potato-corn-soy rotation with conventional fertilizers and soil fumigation) and a no-fumigant approach (the conventional approach without soil fumigation). The purpose of these comparisons was to determine whether the promicrobial system could match or exceed the performance of the conventional approach or, failing that, at least improve substantially on the performance no-fumigant approach.

The results from 2025 indicate that the promicrobial system provided moderate control of *Verticillium* propagules in plots used to grow Russet Burbank. However, in plots used to grow Bannock Russet in 2025, the no-fumigant system had the lowest densities of *Verticillium* of the three systems. The no-fumigant system was the only one in which Bannock Russet was grown in 2019 and 2022 as well as 2025; the other two systems were planted in Russet Norkotah in the first two potato years. These results suggest that, while the biofumigation approach used in the promicrobial system may control *Verticillium* populations better than no fumigant at all (though not as well as soil fumigation with metam sodium), the use of a *Verticillium*-resistant cultivar may be more effective yet. However, contrary to the 2025 soil test results, in 2022, before Bannock Russet was ever planted in the conventional or no-fumigant systems, these two systems had lower propagule densities than the no-fumigant system, indicating the Russet Norkotah was even an even less conducive host for propagule production than Bannock Russet.

In terms of total, U.S. No. 1, and total marketable yield, the conventional system performed better than the other two systems, which did not differ significantly from each other. Russet Burbank yields in the no-fumigant system were similar to those in the promicrobial system, while in Bannock Russet, the no-fumigant system performed similarly to the conventional system. Blackleg was found to be an issue in Bannock Russet and, to a smaller degree, in Russet Burbank, probably as a result of contaminated Bannock Russet seed and insufficient hygiene during seed cutting. The impact of blackleg was greater in the promicrobial system than the other two systems, possibly due to an interaction between the disease and the manure applied to the promicrobial system. The promicrobial system also produced tubers with lower specific gravity than the other two management systems.

In the third potato year of the three-year rotation, the promicrobial management system failed to equal the performance of the conventional system and, in some ways, fell short of the no-fumigant system, although it was somewhat effective in controlling *Verticillium* with Russet Burbank. The use of the *Verticillium*-resistant cultivar Bannock Russet showed a more promising approach to reducing soil fumigation needs, although this cultivar can be challenging in some years due to Minnesota's short growing season and a tendency toward late emergence in Bannock Russet.

Funding Acknowledgement

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Table 1. Treatments applied over eight years in a three-year rotation on soil known to be difficult for potato cultivation at SPRF in Becker, MN.

Rotation	Management	Cultivar	2018	2019	2020	2021	2022	2023	2024	2025
3-year	Conventional	Bannock Russet	Soybeans, fall Vapam	Russet Norkotah, fall rye	Corn	Soybeans, fall Vapam	Russet Norkotah, fall rye	Corn	Soybean, fall metam	Bannock Russet
	No fumigant	Bannock Russet	Soybeans	Bannock Russet, fall rye	Corn	Soybeans	Bannock Russet, fall rye	Corn	Soybean	Bannock Russet
	Pro-microbial	Bannock Russet	Soybeans, fall Vapam	Manure, Russet Norkotah, fall rye	Manure, corn	Field peas, then mustard, fall rye	Manure, Russet Norkotah, fall rye	Hybrid rye, camelina	Field peas, then mustard	Manure, Bannock Russet
	Conventional	Russet Burbank	Soybeans, fall Vapam	Russet Burbank, fall rye	Corn	Soybeans, fall Vapam	Russet Burbank, fall rye	Corn	Soybean, fall metam	Russet Burbank
	No fumigant	Russet Burbank	Soybeans	Russet Burbank, fall rye	Corn	Soybeans	Russet Burbank, fall rye	Corn	Soybean	Russet Burbank
	Pro-microbial	Russet Burbank	Soybeans, fall Vapam	Manure, Russet Burbank, fall rye	Manure, corn	Field peas, then mustard, fall rye	Manure, Russet Burbank, fall rye	Hybrid rye, camelina	Field peas, then mustard	Manure, Russet Burbank

Table 2. Effects of cultivar and management system on selected soil characteristics in the second potato year of the study, 2022. In both 2019 and 2022, the plots in the conventional and promicrobial management systems assigned to Bannock Russet in 2025 were instead planted in Russet Norkotah.

Cultivar	Management	Pre-planting soil characteristics							
		pH	NH_4^+-N (ppm)	NO_3^--N (ppm)	P-Bray (ppm)	K (ppm)	Soil organic matter (%)	VPPG	Depth to 300 PSI resistance
Bannock Russet		6.7	6.7	5.6 b	124	176	1.8	6 b	9.2
Russet Burbank		6.7	7.1	7.1 a	119	184	1.9	28 a	10.0
Effect of cultiar (P-value)		0.8179	0.6047	**0.0127**	0.5873	0.3983	0.2089	**<0.0001**	0.2337
	Conventional	6.5 b	6.4	9.1 a	118 b	170 b	1.8	10 b	11.2 a
	No fumigant	6.9 a	6.8	5.7 b	109 b	170 b	1.9	27 a	9.8 b
	Promicrobial	6.8 a	7.6	4.4 c	138 a	201 a	1.8	9 b	7.8 c
Effect of management (P-value)		**0.0002**	0.2895	**<0.0001**	**0.0127**	**0.0184**	0.7766	**0.0009**	**0.0015**
Bannock Russet	Conventional	6.6	6.3	8.3	122	166	1.7	6 d	10.0 bc
Bannock Russet	No fumigant	6.8	6.6	4.4	109	169	1.8	14 c	10.4 b
Bannock Russet	Promicrobial	6.8	7.3	4.1	140	193	1.8	3 e	7.2 d
Russet Burbank	Conventional	6.5	6.4	9.8	113	173	1.9	16 bc	12.4 a
Russet Burbank	No fumigant	7.0	7.0	6.9	108	172	2.0	52 a	9.2 bc
Russet Burbank	Promicrobial	6.7	7.8	4.7	137	208	1.8	27 b	8.4 cd
Effect of cultivar*management (P-value)		0.2793	0.9537	0.4004	0.9003	0.8719	0.6180	***0.0825***	***0.0962***

Table 3. Effects of cultivar and management system on selected soil characteristics in the second potato year of the study, 2025.

Cultivar	Management	Pre-planting soil characteristics						50 DAP soil characteristics	
		pH	NH_4^+-N (ppm)	NO_3^--N (ppm)	P-Bray (ppm)	K (ppm)	Soil organic matter (%)	VPPG	Depth to 300 PSI resistance
Bannock Russet		6.8	2.5	6.6	130	189	2.0	13 b	10.8 a
Russet Burbank		6.7	2.5	5.9	131	200	2.0	30 a	9.5 b
Effect of cultiar (P-value)		0.2535	0.9324	0.4546	0.8282	0.5303	0.6293	**0.0002**	**0.0285**
	Conventional	6.6 c	3.5 a	4.3 b	118 b	175 b	2.0	14 b	10.6
	No fumigant	6.9 a	2.4 b	5.0 b	113 b	165 b	2.1	22 a	10.5
	Promicrobial	6.8 b	1.6 b	9.3 a	160 a	243 a	2.0	24 a	9.4
Effect of management (P-value)		**<0.0001**	**0.0071**	**0.0003**	**<0.0001**	**0.0015**	0.6676	***0.0677***	0.1573
Bannock Russet	Conventional	6.7 c	3.7	3.9	117	183	1.6 c	13 cd	11.0 ab
Bannock Russet	No fumigant	6.8 ab	1.9	5.1	109	158	2.2 ab	8 d	12.0 a
Bannock Russet	Promicrobial	6.8 b	1.8	10.6	163	227	2.1 ab	19 bc	9.4 bc
Russet Burbank	Conventional	6.5 d	3.3	4.7	120	166	2.3 a	15 c	10.2 bc
Russet Burbank	No fumigant	7.0 a	2.8	4.9	117	173	1.9 abc	57 a	9.0 c
Russet Burbank	Promicrobial	6.7 bc	1.4	8.0	156	260	1.9 bc	30 b	9.4 bc
Effect of cultivar*management (P-value)		**0.0369**	0.3444	0.2938	0.6438	0.4654	**0.0089**	**0.0021**	***0.0860***

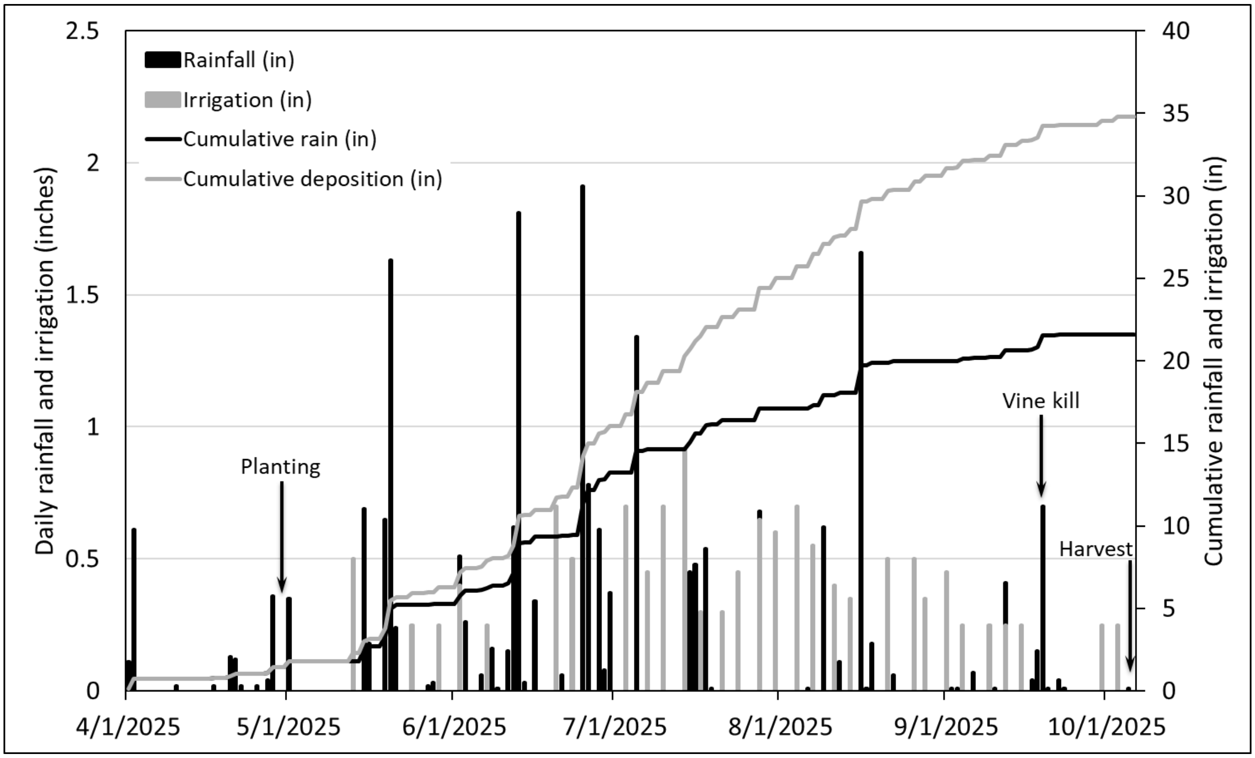


Figure 1. Daily rainfall and irrigation and cumulative rainfall and total water deposition (rainfall plus irrigation) from April 1 through October 6 (harvest) at the field site.

Table 4. Effects of cultivar and management system on tuber yield, size, grade, and number.

Cultivar	Management	Yield ($CWT \cdot ac^{-1}$)											% yield in tubers over:		Tubers / plant
		Culled	0 - 3 oz.	3 - 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	
Bannock Russet		3	61 b	55 b	147	174 a	44 a	5 a	486	422 a	3 b	425 a	46 a	10 a	9.4 b
Russet Burbank		3	136 a	106 a	165	87 b	16 b	2 b	511	366 b	9 a	375 b	21 b	4 b	12.9 a
Effect of cultiar (P-value)		0.8712	**<0.0001**	**<0.0001**	0.1165	**<0.0001**	**<0.0001**	**0.0118**	0.1671	**0.0014**	**<0.0001**	**0.0033**	**<0.0001**	**<0.0001**	**<0.0001**
	Conventional	3	105	87	168	139 a	32	4 a	534 a	422 a	8	429 a	33	7 ab	12.0 a
	No fumigant	4	96	81	156	133 a	26	1 b	492 b	392 ab	5	397 b	32	5 b	11.2 ab
	Promicrobial	3	95	74	144	120 b	31	5 a	469 b	368 b	6	374 b	35	8 a	10.4 b
Effect of management (P-value)		0.6005	0.4241	0.1203	0.2085	**0.0331**	0.3761	**0.0099**	**0.0195**	**0.0320**	0.1273	**0.0253**	0.5369	***0.0886***	***0.0670***
Bannock Russet	Conventional	2	63	59	160	182	41	5	509	441	4 bc	445	45	9	9.9
Bannock Russet	No fumigant	4	58	56	156	184	43	2	499	437	4 bc	441	46	9	9.6
Bannock Russet	Promicrobial	4	61	50	125	158	47	8	450	387	2 c	389	48	13	8.8
Russet Burbank	Conventional	4	147	115	176	96	23	3	560	402	11 a	413	22	5	14.0
Russet Burbank	No fumigant	4	133	105	156	82	8	0	486	347	5 b	352	18	2	12.7
Russet Burbank	Promicrobial	2	129	97	162	82	15	3	488	349	10 a	359	21	4	12.1
Effect of cultivar*management (P-value)		0.2657	0.6510	0.6901	0.4049	0.1658	0.1478	0.3568	0.3024	0.3069	***0.0635***	0.2323	0.4992	0.2532	0.7450

Table 5. Effects of cultivar and management system on tuber quality characteristics.

Cultivar	Management	% of tubers					Specific gravity	Dry matter (%)
		Hollow heart		Brown center		Common scab		
		Total	Disqualifying	Total	Disqualifying			
Bannock Russet		5	4	3	3	7	1.0798 a	22.1 a
Russet Burbank		7	5	7	5	4	1.0707 b	19.8 b
Effect of cultiar (P-value)		0.2103	0.5371	0.1185	0.3909	0.3269	**<0.0001**	**<0.0001**
	Conventional	6 ab	5 ab	6 a	5 a	5	1.0765 a	21.5
	No fumigant	2 b	1 b	1 b	0 b	4	1.0764 a	20.4
	Promicrobial	9 a	8 a	8 a	8 a	8	1.0727 b	21.0
Effect of management (P-value)		***0.0585***	***0.0515***	**0.0354**	**0.0270**	0.4044	**0.0011**	0.2091
Bannock Russet	Conventional	6	4	5	4	7	1.0807 a	23.0
Bannock Russet	No fumigant	2	2	0	0	6	1.0825 a	21.2
Bannock Russet	Promicrobial	6	6	6	6	6	1.0761 b	22.3
Russet Burbank	Conventional	7	6	7	6	3	1.0724 c	20.0
Russet Burbank	No fumigant	2	0	2	0	1	1.0703 cd	19.6
Russet Burbank	Promicrobial	12	10	11	10	9	1.0693 d	19.7
Effect of cultivar*management (P-value)		0.4338	0.5671	0.7797	0.7453	0.3693	**0.0400**	0.4878

Effects of potassium management on chloride cycling and potato yield and quality: year 3

Carl Rosen, James Crants, Matt McNearney, and Seonghyun Seo
Department of Soil, Water, and Climate, University of Minnesota
crosen@umn.edu

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 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, such as lower tuber specific gravity. 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 soil water Cl 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 treatments. Among treatments receiving KCl, total and marketable yield increased with the application rate of K, while tuber size did not. Banded KCl application had no effect on yield compared to broadcast application, but the use of broadcast K_2SO_4 increased yield compared to broadcast KCl. Tuber specific gravity decreased with the application rate of KCl and was higher in treatments receiving broadcast K_2SO_4 than those receiving broadcast KCl at the same rates. These results were largely consistent with those obtained in previous years. In 2023, 2024, and 2025, the application of KCl increased total and marketable yield and the percentage of total yield in tubers over six ounces relative to the treatments receiving zero K. Tuber specific gravity decreased with increasing K rate in all three years. However, unlike in previous years, yield in 2025 was greater in the treatments receiving K_2SO_4 than in treatments receiving K_2O at the same rates as broadcast KCl. Tuber number per plant was high, and tuber bulking was poor, in 2024 and 2025 compared to 2023, which may be related to higher precipitation, cooler daily high temperatures, or smaller daily fluctuations in air temperature in early summer in 2024 and 2025 compared to 2023. This three-year study indicates that potato response to K rate and sources is highly specific to growing conditions within a particular year and that generalizations are difficult make.

Background

Potatoes require large amounts of potassium (K) to maximize yield and tuber bulking and to minimize bruising damage to tubers. Soils used to grow potatoes are often sandy, with low to medium K concentrations. Therefore, K fertilizer is generally applied to irrigated potato crops, typically being broadcast in the fall or spring before the potato crop is planted.

A spike in K fertilizer prices in the U.S. in 2021 – 2023 prompted increased interest in approaches to maximize K use efficiency in crops. One promising approach is banded K application, which places more of the applied K within the crop root zone than broadcast application. A second approach is to apply a portion of the K at hilling, which both places the K fertilizer close to the crop's root zone and reduces the amount of K fixed or lost between the time it is applied and the time when crop roots are available to access it.

Potassium chloride (KCl, also known as muriate of potash; 0-0-60-47Cl) is the most used K fertilizer due to its low cost per unit weight of K. When K is applied as KCl, a significant amount of chloride (Cl) is applied with it. Like K, Cl is an essential plant nutrient, known to improve disease resistance in some plants. However, potato Cl requirements are much lower than K requirements, so that co-applying these nutrients at similar rates can result in Cl excess. In potatoes, excessive Cl availability can result in decreased tuber specific gravity, which has been found to be an issue with KCl as a K source relative to sources such as potassium sulfate (K_2SO_4) that do not contain Cl. While K_2SO_4 is more expensive than KCl, it may be a better option where low specific gravity is a concern, since low tuber specific gravity can decrease a potato crop's value.

In addition to the potential negative impacts of excessive Cl on potato tuber quality, Cl is highly leachable and may be harmful to freshwater ecosystems in large quantities. This presents a second reason to avoid applying Cl at rates well above crop requirements.

In 2025, we repeated a study conducted in 2023 and 2024 on K and Cl management in an irrigated system on sandy soils at the Sand Plain Research Farm (SPRF) in Becker, MN. The objectives of the study were to: (1) evaluate the effects of K rate on tuber yield and quality, (2) determine whether banded application reduced potato crop K requirements, (3) determine whether split application of K reduced crop K requirements, (4) determine whether the use of K_2SO_4 in place of KCl improved tuber specific gravity, and (5) evaluate the effects of Cl application on potato crop performance and Cl concentrations in soil water. In addition to tuber yield and quality, crop responses were evaluated in terms of plant canopy cover; petiole, vine, and tuber element concentrations; vine and tuber element uptake; tuber sugars; and French fry color.

Methods

As in 2023 and 2024, the study in 2025 was conducted at SPRF, on a Hubbard loamy sand soil following a previous crop of soybeans. Soil samples to depths of six inches and two feet were collected on April 18. Samples were dried at 95 °F to a constant weight and ground. Six-inch samples were sent to the University of Minnesota's Research Analytical Laboratory (UM-RAL) to be analyzed for pH, loss-on-ignition organic matter; Bray P; ammonium acetate extractable K, Ca, and Mg; DTPA-extractable Mn, Fe, Zn, and Cu; and hot water extractable B. Two-foot samples were analyzed for their NO_3^--N and Cl concentrations at UM-RAL . Results are presented in Table 1.

Twelve treatments were applied to plots of Russet Burbank potatoes in a randomized complete block design with four replicates: (1) a check treatment receiving no supplemental K or Cl; (2 – 5) treatments receiving broadcast KCl before planting to provide 80, 160, 240, or 320 lbs/ac K_2O; (6 – 8) treatments receiving banded KCl at planting to provide 80, 160, or 240 lbs/ac K_2O; (9) a treatment receiving two equal applications of KCl, one broadcast before planting and one sidedressed at hilling, to provide a total of 240 lbs/ac K_2O; (10 – 11) treatments receiving K_2SO_4 broadcast before planting to provide 160 or 240 lbs/ac K_2O; and (12) a treatment receiving $CaCl_2$ broadcast before planting to provide 180 lbs/ac Cl, equivalent to the rate provided when KCl is applied to provide 240 lbs/ac K_2O. These treatments are summarized in Table 2. Each plot was 12 feet (four 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 three-foot buffer was planted on all sides of the field to reduce edge effects.

KCl, K_2SO_4, and $CaCl_2$ were broadcast by hand according to treatment on April 23. Planting rows were then opened mechanically with 36-inch spacing between rows. A mixture of whole "B" and cut "A" 3 – 4-oz. 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 four 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. Samples of rainfall and irrigation water were collected periodically though the season for chloride and potassium determination.

The rows were re-hilled on May 12. Prior to re-hilling, the rows were side-dress fertilized by hand. The second application of KCl was applied to treatment 9. All treatments except treatments 10 and 11 received 227 lbs/ac ammonium sulfate (21-0-0-24S) to supply 48 lbs/ac N and 54 lbs/ac S (the same amount of S provided by K_2SO_4 in treatment 10). Treatments 10 and 11 received 48 lbs/ac N as urea (46-0-0). Finally, all rows were mechanically-sidedressed with urea at 244 lbs/ac during hilling, supplying 146 lbs/ac N and bringing the total N rate in all plots to 240 lbs/ac.

Plant stand was assessed in the central two rows of each plot on May 28 and June 4. The number of stems per plant was also determined for ten plants in one of these two rows on June 4. Canopy cover was measured with the Canopeo app on May 28; June 2, 10, 16, 23, and 30; July 7, 14, 21, and 30; August 6, 11, 19, and 25; and September 2 and 8. The greenness of the terminal leaflet of the fourth mature leaf from the shoot tip was measured on 20 shoots per plot using a SPAD-502 Chlorophyll Meter (Konica Minolta) on June 17 and 30 and July 15 and 30. The petiole of the terminal leaflet of the fourth mature leaf from the shoot tip was collected from 20 shoots per plant on the same dates. The petiole samples were dried at 140 °F to a constant weight, ground, and sent to Agvise (Benson, MN) to be analyzed for K, Cl, S, and NO_3^--N concentrations.

On September 22, vine samples were collected by hand from ten feet of row in each of the two middle rows in 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.

The remaining vines were killed with a flail mower on September 23. On October 8, tubers were harvested from the central 18 feet of the middle two rows (108 square feet). On October 14 and 15, the tubers were sorted into six size categories: 0 - 3 oz., 3 – 4 oz., 4 – 6 oz., 6 – 10 oz., 10 – 14 oz., and over 14 oz. Tubers over 3 oz. were sorted into U.S. No. 1 and U.S. No. 2 grade categories based on USDA standards for French fry processing potatoes. Cull tubers were sorted into a single category regardless of size. Total yield was measured as the sum of all non-cull yield. U.S. Marketable yield was the sum of U.S. No. 1 and U.S. No. 2 yield. Plot yields were converted to hundredweight per acre.

A sample of 25 U.S. No. 1 tubers was collected from each plot at 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 29 and November 4, soil samples to depths of two feet and six 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.

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).

Results and discussion

Rainfall and irrigation

Daily and cumulative rainfall and irrigation from April through September are presented in Figure 1. The average rainfall totals 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 2025, rainfall was below average in April (1.45”), August (2.86”), and September (1.62”); close to average in May (3.83”) and July (3.89”); and above average in June (7.93”). Total rainfall in May through September was close to the average for the location, at 21.58”.

This rainfall was supplemented by 1.35” of irrigation in May, 1.95” in June, 5.00” in July, 3.25” in August, and 1.95” in September, for a total of 13.5” of irrigation and 35.08 total inches of water from April through September.

On average, rainfall contained very little K (0.16 ppm) or Cl (0.33 ppm), depositing approximately 0.6 lbs/ac K and 1.6 lbs/ac Cl over the course of the season. Irrigation water contained substantially higher concentrations of both K (2.28 ppm) and Cl (36.5 ppm) and deposited about 7.6 lbs/ac K and 122 lbs/ac Cl throughout the season.

Tuber yield, size, grade, and number

Results for tuber yield, size, grade, and the number of tubers per plant are presented in Table 3. Total tuber yield was higher in treatments receiving KCl (treatments 2 – 5), as a group, than in the control treatment, and yield generally increased with the application rate of KCl (among treatments 1 – 5). The yield of U.S. No. 1 tubers also tended to increase with KCl rate, and the treatments receiving broadcast K_2SO_4 (treatments 10 and 11) had higher U.S. No. 1 yields, as a group, than the treatments receiving the same rates of K_2O as broadcast KCl (treatments 3 and 4). In contrast, the treatments receiving broadcast K_2SO_4 had lower yields of U.S. No. 2 tubers than the treatments receiving the same rates of K_2O as broadcast KCl, and total marketable yield was only marginally higher in the K_2SO_4 treatments than the corresponding KCl treatments. Treatments receiving broadcast KCl (treatments 2 – 5) had higher U.S. No. 2 yield and total marketable yield than the zero-K, zero-Cl treatment (treatment 1), while U.S. No. 1 yield and total marketable yield both tended to increase with the application rate of broadcast KCl (among treatments 2 – 5). The treatment receiving Cl without K (treatment 12) had significantly lower total than any other treatment except the zero-K, zero-Cl check (treatment 1) and had lowest U.S. No. 1 and total marketable yields, numerically, of any treatment.

There was no significant effect of broadcast versus banded application of KCl (treatments 2 – 4 vs. treatments 6 – 7) on any yield variable. The split-application treatment (treatment 9) did not differ from the treatments receiving single applications of broadcast or banded KCl at the same K_2O rate (treatments 4 and 8, respectively) in any yield variable, except that it produced more culls than the broadcast treatment (treatment 4) and more 4 – 6-oz. tubers than the banded treatment (treatment 8). The number of tubers per plant was significantly related to treatment, but it was not related to K source, rate, or method of application. The treatment receiving Cl without K (treatment 12) had the fewest tubers per plant, while the treatment receiving 160 lbs/ac K_2O as K_2SO_4 (treatment 9) had the most.

The effect of K source on U.S. No. 1 and total marketable yield was similar in direction (with K_2SO_4 producing higher yields than KCl) to the effect of source on the same variables observed when this experiment was conducted in 2023. In contrast, no effect of K source on yield was observed in 2024. In 2024, the difference in the K source effect on yield between 2023 and 2024 was attributed to a difference in early-summer rainfall and its effect on Cl deposition and leaching. Compared to 2023, the growing season in 2024 was wet, particularly in June. This was thought to have possibly increased the rate of Cl leaching from the crop's root zone while decreasing the amount of Cl deposition from irrigation water, diminishing the potential for Cl excess. The results from 2025 do not support this interpretation, as early-season precipitation was similar to 2024, while the effect of K source on yield was similar to 2023.

Like in 2024 tuber set was high in 2025 (13.0 – 14.7 tubers/plant). The percentage of total yield in tubers over six ounces was intermediate between the previous two years (29 – 40%). Unlike marketable yield, the differences in bulking among years corresponded to differences in early-summer precipitation. Early-summer precipitation would most likely be relevant to bulking if it (1) caused plants to set more tubers than they could adequately bulk or (2) flushed nutrients out of the crop's root zone before they could be taken up.

Alternatively, differences in early-summer air temperatures among years may explain differences among years in tuber bulking. Mean temperatures were warmer in June 2023 (71.5 °F) than in June 2024 (67.3 °F) or June 2025 (67.1 °F), with a similar but smaller difference in May (62.5 °F in 2023; 60.2 °F in 2024; 58.2 °F in 2025). Warmer early-season temperatures in 2023 may have inhibited tuber set in that year compared to 2024 and 2025. In addition, daily temperature variations were greater, on average, in July 2023 than July 2024 or 2025. In July 2023, the mean high temperature was 84.1 °F, versus 83.8 °F in 2024 and 82.8 °F in 2025, while the mean low temperature in July 2023 was 56.7 °F, versus 61.6 °F in 2024 and 62.3 °F in 2025. Thus, the mean daily temperature variation was 27.4 °F in 2023, versus 22.2 °F in 2024 and 20.5

°F in 2025. Thus, the differences among years in both nighttime low temperatures and daily temperature swings were substantial, and either or both may have influenced tuber set and therefore tuber bulking.

Tuber quality

Results for tuber quality are presented in Table 4. The prevalence of both hollow heart and brown center was significantly related to treatment. These conditions were least common in the treatment receiving 160 lbs/ac K_2O as banded KCl (treatment 7) and most common in the treatment receiving Cl with Ca but without K (treatment 12). Both hollow heart and brown center that occurred were numerically less frequent in the treatments receiving broadcast K_2SO_4 (treatments 10 and 11) than in the treatments providing the same K_2O rates as broadcast KCl (treatments 3 and 4), but the difference only approached statistical significance for total brown center. The treatments receiving banded KCl (treatments 6 – 7) had lower total hollow heart and total brown center than the treatments receiving broadcast KCl at the same rates (treatments 2 – 4), though this difference was not observed for disqualifying hollow heart or brown center.

The prevalence of common scab was not significantly related to treatment overall. Because the treatment receiving 80 lbs/ac K2O as banded KCl (treatment 6) had a relatively high prevalence of common scab, there was a marginally significant tendency for the banded KCl treatments (treatments 6 – 8) to have a higher prevalence than the corresponding broadcast KCl treatments (treatments 2 – 4) overall.

Among the treatments receiving 0 to 320 lbs/ac K_2O as broadcast KCl (treatments 1 – 5), tuber specific gravity decreased as the application rate increased. The treatments receiving broadcast K_2SO_4 (treatments 10 and 11) had higher tuber specific gravity than the treatments receiving K_2O as broadcast KCl at the same rates (treatments 3 and 4).

These tuber quality results suggest that excessive Cl application was detrimental to tuber quality in two ways. First, hollow heart and brown center tended to be lower in treatments receiving broadcast K_2SO_4 than treatments receiving broadcast KCl, although the effect was weak. Second, treatments receiving broadcast K_2SO_4 had significantly higher tuber specific gravity than corresponding treatments receiving broadcast KCl, and tuber specific gravity decreased with the application rate of broadcast KCl as well as with Cl applied with Ca (treatment 12).

Plant stand and stems per plant

Results for plant stand and the number of stems per plant are presented in Table 5. Plant stand ranged from 98% to 100% on both May 28 and June 4. The quadratic contrast on KCl rate was significant for May 28 plant stand, but the differences among treatments were very small.

Neither the overall treatment effect nor any of the contrasts was significantly related to plant stand or the number of stems per plant on June 4.

Leaflet greenness (SPAD readings)

Results for leaflet greenness are presented in Table 6. Among treatments receiving broadcast KCl at 0 to 320 lbs/ac K2O (treatments 1 – 5), greenness decreased with increasing K_2O rate on June 30 and July 15 and 30. As a group, treatments receiving banded KCl (treatments 6 – 7) had lower leaflet greenness than treatments receiving broadcast KCl at the same rates (treatments 2 – 4) on July 15 and 30. Given the negative relationship between greenness and broadcast KCl rate on these dates, this result is consistent with banded application providing available nutrients more efficiently than broadcast application. On June 30, the treatments receiving broadcast K_2SO_4 (treatments 10 and 11), as a group, had higher leaflet greenness than the treatments receiving broadcast KCl at the same rates (treatments 3 and 4). However, this difference was due entirely to low greenness in the treatment receiving 240 lbs/ac K_2O as broadcast KCl (treatment 4) on that date, a result that appears to be anomalous given that SPAD readings were higher at both higher and lower KCl rates (treatments 3 and 5).

Canopy cover

Results for canopy cover are presented in Table 7. Canopy cover increased rapidly between May 28 and June 23. It declined gradually between July 14 and August 11, after which it declined more rapidly.

Canopy cover in the treatment receiving no K or Cl (treatment 1) was lower than that of the treatments receiving broadcast KCl (treatments 2 – 4), taken as a group, on May 28, June 2 and 10, and September 2. This trend was reversed on August 6. The treatment receiving 240 lbs/ac K2O as broadcast KCl (treatment 4) had relatively high canopy cover on June 2, contributing to significant contrast statements measuring the quadratic response to KCl rate and comparing the broadcast KCl treatments to both the banded KCl treatments and the broadcast K2SO4 treatments.

Tuber and vine dry biomass yield

Results for tuber and vine dry biomass yield are presented in Table 8. Among treatments receiving 0 to 320 lbs/ac K2O as broadcast KCl (treatments 1 – 5), tuber dry biomass was positively related to the application rate of KCl, though this effect was only marginally significant ($0.05 \leq P < 0.10$). Tuber dry biomass was not otherwise related to treatment. Vine dry biomass yield at vine kill did not correspond significantly to treatment.

Lysimeter soil water Cl concentration

Results for soil water Cl concentration at the 4 ft depth are presented in Table 9. Treatment effects were not significant between May 19 and June 6. From June 10 through November 4, treatment effects were significant on most sampling dates. On all sampling dates from June 10 onward, soil water Cl concentrations were numerically higher in the treatments receiving supplemental Cl (treatments 4, 8, and 12) than in the treatments receiving no supplemental Cl (treatments 1 and 11). From August 12 onward, the treatment receiving banded KCl (treatment 8) had a numerically higher soil water Cl concentration than the other two treatments receiving supplemental Cl (treatments 4 and 12), with the difference usually being significant in pairwise comparisons from September 3 onward. Measured soil water Cl concentrations may have been higher with banded application because the lysimeters were placed in the planting hills, placing the porous ceramic soil water collecting capsule directly below the fertilizer bands.

Among the treatments receiving Cl (treatments 4, 8, and 12), soil water Cl concentrations generally increased rapidly between June 17 and July 15, then declined slowly until August 12. After this, the decline in soil water Cl concentration was more rapid in treatments the treatments receiving broadcast Cl (treatments 4 and 12) than in the treatment receiving banded Cl (treatment 8) until September 26, after which concentrations declined at similar rates in all three treatments.

End-of-season soil K concentration

Results for end-of-season soil K concentrations are presented in Table 10. Soil K concentrations were higher in the treatments receiving 240 lbs/ac K_2O as either KCl or K_2SO_4 (treatments 4 and 11, respectively) than in the treatments receiving no supplemental K (treatments 1 and 12).

Further discussion and conclusions

In 2023, the first year of this study, we found that tuber yield among the treatments receiving broadcast KCl decreased as the application rate of KCl increased, with a similar trend for treatments receiving banded KCl. In that year, the treatment receiving split applications of KCl and those receiving K_2SO_4 in place of KCl had higher yields than those receiving single applications of KCl at the same rates. In contrast, in 2024, total yield did not respond to KCl rate, except that any amount of KCl improved yields compared to the zero-K treatments and that the percentage of tuber greater than 6 oz increased linearly with increasing K rate. Neither split application nor the use of K_2SO_4 improved yields relative to a single broadcast application of KCl before planting in 2024. The differences in yield results between the two years may be attributable to differences in amounts of precipitation and irrigation or to differences in air temperatures, with 2023 having been drier and warmer, with greater daily fluctuations in air temperature, than 2024.

Yield results from 2025 provide mixed support for this hypothesis. In terms of both air temperature and precipitation, particularly in early summer, 2025 was more similar to 2024 than to 2023. Tuber number per plant was high in both 2024 and 2025, and the percentage of yield in tubers over six ounces was much lower in both years than in 2023, although bulking was markedly better in 2025 than in 2024. In all three years, the percentage of yield in tubers over six ounces increased with the application rate of broadcast KCl.

In each of the first two years of the study, specific gravity decreased as the application rate of K increased, regardless of K source or application method. This trend was observed in 2025 between the two treatments receiving K_2SO_4 and, for the most part, among the treatments receiving a single application of broadcast KCl. However, there was no relationship between specific gravity and K rate among the banded treatments. Additionally, while K source had no effect on tuber specific gravity in 2023 or 2024, the treatments receiving broadcast K_2SO_4 in 2025 had substantially higher tuber specific gravity than those receiving broadcast KCl at the same rates. It is not clear why K source affected specific gravity in 2025 and not in the other two years. These results suggest that potato response to K rate is fairly consistent among years, while the benefits of using K_2SO_4 in place of KCl are more variable.

Table 1. Characteristics of six-inch and two-foot soil samples taken at the Sand Plain Research Farm in Becker, MN, in 2025 prior to fertilizer application.

0 - 6 inches												0 - 2 feet	
pH	Organic matter	Bray P	NH_4OAc-K	NH_4OAc-Ca	NH_4OAc-Mg	DTPA-Mn	DTPA-Fe	DTPA-Zn	DTPA-Cu	Hot water B	SO_4^{2-}-S	NO_3^--N	Cl
	(%)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	lbs/ac
6.8	1.7	34	122	938	168	11	17	2.0	1.0	0.2	4	7.5	57

Table 2. Treatments applied to Russet Burbank potatoes at the Sand Plain Research Farm in Becker, MN, in 2025.

Treatment #	Fertilizer source	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	60	0	54
3	KCl	Broadcast preplant	160	120	0	54
4	KCl	Broadcast preplant	240	180	0	54
5	KCl	Broadcast preplant	320	240	0	54
6	KCl	Banded at planting	80	60	0	54
7	KCl	Banded at planting	160	120	0	54
8	KCl	Banded at planting	240	180	0	54
9	KCl	Half broadcast preplant, half sidedressed at hilling	240	180	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	180	0	54

[1]KCl: 0-0-60-45Cl
[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

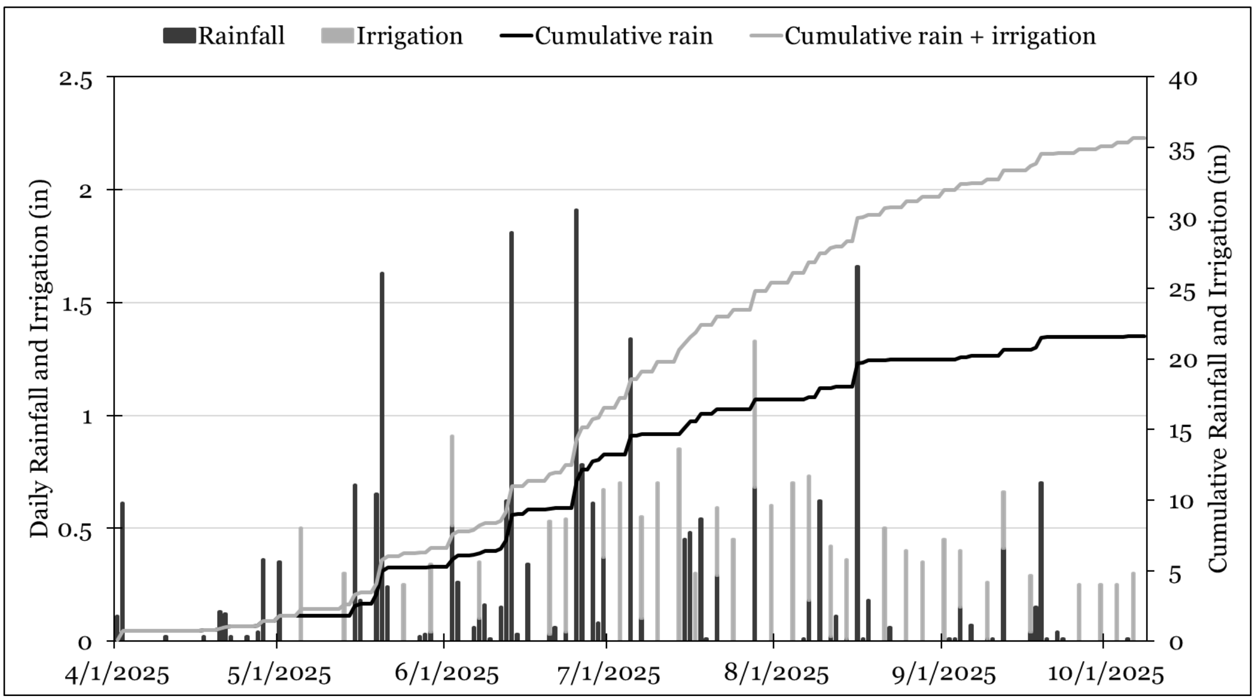


Figure 1. Daily and cumulative rainfall and irrigation at Becker, MN, from April 1 through October 8, 2025.

Table 3. Effect of K and Cl treatments on yield, size, grade, and number per plant of Russet Burbank tubers grown at the Sand Plain Research Farm in Becker, MN, in 2025. 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	0-3 oz.	3-4 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	0 K_2O or Cl	0.6 cd	125	93	200 abc	133	42	2	594 de	443 cd	26 cd	469 cd	29	7	13.7 bcdef
2	80 K_2O, broadcast, KCl	1.6 bcd	122	91	185 cd	172	40	13	624 cd	463 bcd	39 abc	502 abcd	36	9	13.3 ef
3	160 K_2O, broadcast, KCl	0.4 d	128	94	201 abc	158	32	14	626 c	456 bcd	42 ab	499 bcd	32	7	14.1 abcde
4	240 K_2O, broadcast, KCl	0.6 cd	134	85	210 ab	174	43	13	658 ab	490 ab	34 abc	525 ab	35	8	14.3 abc
5	320 K_2O, broadcast, KCl	0.4 d	118	80	206 abc	175	46	11	637 abc	478 bc	40 ab	519 ab	36	9	13.8 bcdef
6	80 K_2O, banded, KCl	1.6 bcd	125	105	219 a	151	32	5	638 abc	483 abc	30 bcd	513 ab	29	6	14.5 ab
7	160 K_2O, banded, KCl	3.0 bcd	125	99	188 cdb	164	42	13	630 bc	471 bcd	34 abc	505 abc	34	8	14.2 abcd
8	240 K_2O, banded, KCl	2.1 bcd	117	84	188 cdb	194	53	8	645 abc	484 ab	43 a	528 ab	40	9	13.6 cdef
9	240 K_2O, broadcast+sidedress, KCl	3.6 ab	125	83	214 a	158	48	7	635 bc	467 bcd	43 a	510 ab	33	9	14.1 abcd
10	160 K_2O, broadcast, K_2SO_4	6.1 a	126	89	221 a	177	40	13	667 a	520 a	21 d	541 a	34	8	14.7 a
11	240 K_2O, broadcast, K_2SO_4	1.2 bcd	111	93	200 abc	186	51	11	652 abc	521 a	20 d	541 a	38	9	13.5 def
12	180 Cl, broadcast, $CaCl_2$	3.3 abc	126	82	176 d	159	38	9	590 e	434 d	26 cd	464 d	35	8	13.0 f
	Treatment effect (P-value)	**0.0504**	0.8093	0.1389	**0.0479**	0.2696	0.7469	0.8273	**0.0054**	**0.0284**	**0.0199**	**0.0398**	0.4057	0.9244	**0.0335**
	Effect of KCl (1 vs. 2-5)	0.9029	0.9796	0.3676	0.9325	**0.0287**	0.8745	***0.0569***	**0.0069**	0.1391	**0.0382**	**0.0302**	***0.0988***	0.5262	0.6962
	KCl rate, linear (1-5)	0.7303	0.9406	***0.0919***	0.2263	***0.0686***	0.6668	0.2703	**0.0065**	***0.0761***	0.1777	**0.0261**	0.1767	0.5154	0.2705
Contrasts	KCl rate, quadratic (1-5)	0.8401	0.3908	0.4621	0.6899	0.4117	0.3440	0.1226	0.1482	0.7253	0.2188	0.4428	0.6955	0.9383	0.5454
	Broadcast v banded (2-4 v 6-8)	0.1614	0.3947	0.2043	0.9590	0.8788	0.5295	0.2302	0.8892	0.4940	0.5373	0.6193	0.9846	0.8683	0.5089
	KCl v K_2SO_4 (3&4 v 10&11)	**0.0119**	0.1211	0.7389	0.6274	0.2866	0.2918	0.7356	0.1868	**0.0081**	**0.0220**	***0.0834***	0.4132	0.6048	0.8596

Table 4. Effects of K and Cl treatments on potato tuber defects, specific gravity, and dry matter content of Russet Burbank tubers grown at the Sand Plain Research Farm in Becker, MN, in 2025. 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 (%)
		Hollow hearrt		Brown center		Common scab		
Number	Nutrient rate (lbs/ac), method, source	Total	Disqualifying	Total	Disqualifying			
1	0 K_2O or Cl	6 bc	3 cd	7 bc	3 cd	1	1.0818	21.7
2	80 K_2O, broadcast, KCl	8 bc	6 bcd	8 bc	5 bcd	0	1.0814	21.4
3	160 K_2O, broadcast, KCl	10 b	3 cd	11 b	3 cd	0	1.0797	21.7
4	240 K_2O, broadcast, KCl	10 b	10 ab	11 b	10 ab	1	1.0770	20.8
5	320 K_2O, broadcast, KCl	5 bc	3 cd	4 c	3 cd	1	1.0785	21.8
6	80 K_2O, banded, KCl	8 bc	7 bc	8 bc	7 bc	4	1.0791	21.2
7	160 K_2O, banded, KCl	2 c	1 d	2 c	1 d	1	1.0798	20.5
8	240 K_2O, banded, KCl	6 bc	6 bcd	6 bc	5 bcd	1	1.0790	21.1
9	240 K_2O, broadcast+sidedress, KCl	4 bc	3 cd	7 bc	3 cd	0	1.0800	22.0
10	160 K_2O, broadcast, K_2SO_4	7 bc	2 cd	7 bc	2 cd	0	1.0820	21.3
11	240 K_2O, broadcast, K_2SO_4	4 bc	3 cd	4 c	3 cd	1	1.0807	21.7
12	180 Cl, broadcast, $CaCl_2$	18 a	14 a	19 a	14 a	0	1.0789	21.9
	Treatment effect (P-value)	**0.0258**	**0.0330**	**0.0250**	**0.0246**	0.3998	0.1485	0.4649
Contrasts	Effect of KCl (1 vs. 2-5)	0.4571	0.3774	0.6394	0.4102	0.6782	***0.0503***	0.6023
	KCl rate, linear (1-5)	1.0000	0.6161	0.7402	0.5168	0.7691	**0.0052**	0.7349
	KCl rate, quadratic (1-5)	0.1193	0.2926	***0.0827***	0.3260	0.4583	0.5348	0.4832
	Broadcast v banded (2-4 v 6-8)	***0.0760***	0.4199	***0.0522***	0.4036	***0.0648***	0.9371	0.3470
	KCl v K_2SO_4 (3&4 v 10&11)	0.1019	0.1190	***0.0612***	0.1068	1.0000	**0.0154**	0.5593

Table 5. Effects of K and Cl treatments on plant stand and the number of stems per Russet Burbank potato plant at the Sand Plain Research Farm in Becker, MN, in 2025.

Treatment		Plant stand (%)		Stems / plant
Number	Nutrient rate (lbs/ac), method, source	May 28	June 4	June 4
1	0 K_2O or Cl	99	100	4.1
2	80 K_2O, broadcast, KCl	100	100	3.9
3	160 K_2O, broadcast, KCl	100	100	4.4
4	240 K_2O, broadcast, KCl	100	100	4.9
5	320 K_2O, broadcast, KCl	98	99	4.0
6	80 K_2O, banded, KCl	99	100	4.6
7	160 K_2O, banded, KCl	99	99	3.9
8	240 K_2O, banded, KCl	99	99	4.2
9	240 K_2O, broadcast+sidedress, KCl	100	100	4.3
10	160 K_2O, broadcast, K_2SO_4	99	99	4.8
11	240 K_2O, broadcast, K_2SO_4	100	100	4.4
12	180 Cl, broadcast, $CaCl_2$	99	100	4.6
	Treatment effect (P-value)	0.4801	0.6700	0.5332
Contrasts	Effect of KCl (1 vs. 2-5)	0.2959	0.5618	0.6506
	KCl rate, linear (1-5)	0.5523	0.1064	0.4671
	KCl rate, quadratic (1-5)	**0.0157**	0.1702	0.3435
	Broadcast v banded (2-4 v 6-8)	0.1301	0.2922	0.5126
	KCl v K_2SO_4 (3&4 v 10&11)	0.3491	0.5169	0.8067

Table 6. Effects of K and Cl treatments on the greenness (SPAD-502 readings) of the terminal leaflet of the fourth mature leaf from the shoot tip of Russet Burbank plants grown at the Sand Plain Research Farm in Becker, MN, in 2025. 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 greenness (SPAD-502)			
Number	Nutrient rate (lbs/ac), method, source	June 17	June 30	July 15	July 30
1	0 K_2O or Cl	37.9	43.9 a	39.4	38.5 a
2	80 K_2O, broadcast, KCl	39.2	43.8 a	40.7	37.4 abc
3	160 K_2O, broadcast, KCl	38.7	43.0 ab	39.5	37.6 abc
4	240 K_2O, broadcast, KCl	37.8	39.8 e	38.2	35.5 cde
5	320 K_2O, broadcast, KCl	37.4	41.7 bcd	37.3	35.2 de
6	80 K_2O, banded, KCl	37.6	42.2 bcd	38.4	35.8 cde
7	160 K_2O, banded, KCl	37.4	41.4 cde	37.6	35.7 cde
8	240 K_2O, banded, KCl	37.6	41.2 de	38.3	35.3 de
9	240 K_2O, broadcast+sidedress, KCl	37.0	41.1 de	37.9	34.2 e
10	160 K_2O, broadcast, K_2SO_4	38.8	42.7 abcd	38.9	36.4 bcd
11	240 K_2O, broadcast, K_2SO_4	38.3	42.8 abc	38.7	36.0 bcde
12	180 Cl, broadcast, $CaCl_2$	38.8	43.0 abc	40.1	38.0 ab
	Treatment effect (P-value)	0.4145	**0.0037**	0.1299	**0.0328**
Contrasts	Effect of KCl (1 vs. 2-5)	0.5983	**0.0212**	0.5761	**0.0338**
	KCl rate, linear (1-5)	0.2697	**0.0003**	**0.0110**	**0.0034**
	KCl rate, quadratic (1-5)	0.1390	0.5901	0.1420	0.8348
	Broadcast v banded (2-4 v 6-8)	***0.0751***	0.2446	**0.0454**	***0.0897***
	KCl v K_2SO_4 (3&4 v 10&11)	0.6118	***0.0562***	0.9626	0.6650

Table 7. Effects of K and Cl treatment on canopy cover of Russet Burbank potato plants grown at the Sand Plain Research Farm in Becker, MN, in 2025. 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		Percent canopy cover (Canopeo)															
Number	Nutrient rate (lbs/ac), method, source	29-May	2-Jun	10-Jun	16-Jun	23-Jun	30-Jun	7-Jul	14-Jul	21-Jul	30-Jul	6-Aug	11-Aug	19-Aug	25-Aug	2-Sep	8-Sep
1	0 K_2O or Cl	8	21 d	55 d	88	97	96	97	96 abc	95 ab	89	89	88	76	66	43	33
2	80 K_2O, broadcast, KCl	10	23 abc	60 abcd	89	97	95	97	95 bcd	93 abc	89	85	86	71	65	57	40
3	160 K_2O, broadcast, KCl	9	22 bcd	55 d	90	98	95	96	94 d	92 bcd	85	82	83	70	65	50	34
4	240 K_2O, broadcast, KCl	10	25 a	64 a	93	99	97	98	97 a	96 a	88	85	88	79	69	61	34
5	320 K_2O, broadcast, KCl	9	21 d	58 cd	90	98	96	97	96 ab	92 bcd	89	84	89	78	73	59	51
6	80 K_2O, banded, KCl	10	24 ab	63 ab	93	98	96	96	96 ab	93 abc	87	83	85	71	60	43	39
7	160 K_2O, banded, KCl	8	20 d	56 d	88	98	96	96	94 cd	89 de	86	88	85	72	62	55	39
8	240 K_2O, banded, KCl	9	22 bcd	57 cd	87	98	96	98	96 ab	94 abc	86	86	85	76	67	58	36
9	240 K_2O, broadcast+sidedress, KCl	10	24 abc	58 bcd	88	97	97	97	95 bcd	91 cde	85	85	85	79	67	55	35
10	160 K_2O, broadcast, K_2SO_4	10	22 bcd	61 abc	90	97	95	96	95 bcd	93 abc	89	90	87	77	68	54	41
11	240 K_2O, broadcast, K_2SO_4	8	22 cd	58 bcd	89	98	95	96	95 bcd	94 abc	90	88	87	74	71	53	38
12	180 Cl, broadcast, $CaCl_2$	8	22 cd	58 bcd	89	95	95	97	94 d	88 e	85	84	83	73	66	52	26
	Treatment effect (P-value)	0.1460	**0.0101**	*0.0706*	0.1616	0.2533	0.5140	0.1934	*0.0667*	**0.0248**	0.8281	0.6375	0.9001	0.7474	0.9396	0.2251	0.3347
	Effect of KCl (1 vs. 2-5)	**0.0201**	**0.0159**	*0.0996*	0.2195	0.1152	0.4153	0.7989	0.9673	0.2683	0.6141	*0.0925*	0.6340	0.6362	0.7806	**0.0164**	0.2707
	KCl rate, linear (1-5)	0.2989	0.2534	0.1790	0.1586	*0.0819*	0.9478	0.7468	0.2670	0.4183	0.8649	0.2774	0.7406	0.4222	0.3378	**0.0269**	*0.0877*
Contrasts	KCl rate, quadratic (1-5)	*0.0520*	**0.0040**	0.2583	0.4335	0.3836	0.4528	0.7341	0.2920	0.8906	0.3317	0.1878	0.2339	0.2264	0.4763	0.4356	0.2081
	Broadcast v banded (2-4 v 6-8)	0.2207	*0.0596*	0.4430	0.3714	0.9985	0.6682	0.9194	0.9290	0.1824	0.7479	0.4239	0.7805	0.9648	0.4576	0.2966	0.7846
	KCl v K_2SO_4 (3&4 v 10&11)	0.4923	**0.0286**	0.8340	0.3836	0.2637	0.1718	**0.0319**	0.7169	0.7383	0.2183	*0.0560*	0.4910	0.8055	0.6738	0.6609	0.4765

Table 8. Effects of K and Cl treatment on tuber and vine dry biomass yield of Russet Burbank potato plants grown at the Sand Plain Research Farm in Becker, MN, in 2025.

Treatment		Tuber dry biomass (T/ac)	Vine dry biomass (T/ac)
Number	Nutrient rate (lbs/ac), method, source		
1	0 K_2O or Cl	6.45	0.80
2	80 K_2O, broadcast, KCl	6.67	0.81
3	160 K_2O, broadcast, KCl	6.81	0.82
4	240 K_2O, broadcast, KCl	6.83	0.85
5	320 K_2O, broadcast, KCl	6.93	0.93
6	80 K_2O, banded, KCl	6.44	0.87
7	160 K_2O, banded, KCl	6.81	0.77
8	240 K_2O, banded, KCl	6.99	0.91
9	240 K_2O, broadcast+sidedress, KCl	7.10	0.94
10	160 K_2O, broadcast, K_2SO_4	7.09	0.82
11	240 K_2O, broadcast, K_2SO_4	6.46	0.87
12	180 Cl, broadcast, $CaCl_2$	6.77	0.81
	Treatment effect (P-value)	0.2628	0.9303
Contrasts	Effect of KCl (1 vs. 2-5)	0.1275	0.5668
	KCl rate, linear (1-5)	***0.0949***	0.2573
	KCl rate, quadratic (1-5)	0.6462	0.6295
	Broadcast v banded (2-4 v 6-8)	0.5630	0.8813
	KCl v K_2SO_4 (3&4 v 10&11)	0.1885	0.6468

Table 9. Effects of K and Cl treatment on soil water Cl concentration at the Sand Plain Research Farm in Becker, MN, in 2025. 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		Soil water Cl concentration (ppm)											
Number	Nutrient rate (lbs/ac), method, source	5/19	5/22	5/27	6/3	6/6	6/10	6/17	7/3	7/8	7/15	7/24	7/30
1	0 K_2O or Cl	19	15	8	4	4	5 c	4	4 b	2 b	4 b	0 b	0 b
4	240 K_2O, broadcast, KCl	22	18	11	12	64	18 a	28	116 a	36 a	129 a	126 a	88 a
8	240 K_2O, banded, KCl	25	31	21	19	72	16 ab	21	94 a	41 a	143 a	135 a	98 a
11	240 K_2O, broadcast, K_2SO_4	15	25	10	8	6	7 c	6	5 b	3 b	4 b	3 b	3 b
12	180 Cl, broadcast, $CaCl_2$	25	24	12	8	51	8 bc	13	116 a	55 a	153 a	131 a	118 a
	Treatment effect (P-value)	0.7004	0.2708	0.2952	0.2540	0.2345	**0.0401**	0.1787	**0.0164**	**0.0307**	**<0.0001**	**<0.0001**	**0.0009**

Treatment		Soil water Cl concentration (ppm)								
Number	Nutrient rate (lbs/ac), method, source	8/7	8/12	8/19	8/26	9/3	9/9	9/26	10/17	11/4
1	0 K_2O or Cl	0 b	0 b	0	2 b	0 c	0 b	1 b	4 b	4 b
4	240 K_2O, broadcast, KCl	88 ab	64 a	59	39 ab	31 bc	11 b	40 ab	23 b	24 b
8	240 K_2O, banded, KCl	108 a	107 a	110	96 a	90 a	79 a	70 a	68 a	54 a
11	240 K_2O, broadcast, K_2SO_4	3 b	2 b	2	2 b	3 bc	3 b	3 b	4 b	6 b
12	180 Cl, broadcast, $CaCl_2$	104 a	68 a	51	48 ab	44 b	34 b	32 b	22 b	21 b
	Treatment effect (P-value)	***0.0626***	**0.0206**	0.1127	***0.0841***	**0.0363**	**0.0141**	***0.0532***	**0.0164**	**0.0230**

Table 10. Effects of K and Cl treatment on end-of-season K concentration in the top six inches of soil at the Sand Plain Research Farm in Becker, MN, in 2025. Values that are followed by the same letter are not significantly different ($P \leq 0.10$) in pairwise comparisons.

Treatment		End-of-season soil K (lbs/ac)
Number	Nutrient rate (lbs/ac), method, source	
1	0 K_2O or Cl	121 b
4	240 K_2O, broadcast, KCl	210 a
11	240 K_2O, broadcast, K_2SO_4	199 a
12	180 Cl, broadcast, $CaCl_2$	120 b
	Treatment effect (P-value)	**0.0023**

Improving Sustainability and Marketability: Potato Breeding and Cultivar Development for the Northern Plains

2025 Summary

Susie Thompson, PhD.
Johansen-Thompson Endowed Professor in Potato
Breeding and
Kelly Peppel and Hashim Andidi
Department of Plant Sciences
North Dakota State University
Fargo, North Dakota 58108
asunta.thompson@ndsu.edu
701.799.8536

Potato (*Solanum tuberosum* L.) is an important foodstuff across the globe and ranks fourth behind wheat, corn and rice production (FAO). It is the most widely grown vegetable crop in North Dakota (ND) and Minnesota (MN). North Dakota and Minnesota, making up the Northern Plains region, combined rank third in US potato production (USDA NASS 2025). In 2025, approximately 108,500 acres were harvested in the two-state area (USDA NASS 2025), down about 6,400 acres from 2024. In 2024, the farmgate value exceeded $585.9 million, with sales of more than $547.1 million, combined (USDA NASS 2025). Utilization in ND and MN is about 60% for French fry/frozen processing, 16% tablestock (fresh market), 12% chip processing, and 10% certified seed production. The Northern Plains has a short growing season, produces potatoes for a myriad of end-uses, is unique in that potatoes are produced under both irrigated and non-irrigated conditions, and potato is sensitive to a variety of abiotic and biotic stressors. Potato, a horticultural specialty crop is management, labor, and input intensive compared to agronomic crops. The primary objective of the NDSU potato breeding project is to release improved potato cultivars providing superior options to industry standard cultivars and to provide potato producers, industry partners, and consumers with environmentally and economically sustainable, and nutritious cultivars across all market types. The potato improvement team, includes 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 discover and develop early maturing selections with elevated quality and marketability combined with high yield potential, possessing stacked pest and stress resistances, and that demonstrate reduced needs for inputs.

Two research objectives were proposed for 2025:

1.) To develop improved potato germplasm adapted to the Northern Plains through conventional breeding, incorporating resistance genes of interest to abiotic and biotic stressors.
2.) To improve marketability attributes for fresh and processing potato germplasm via germplasm enhancement, quality assessments, and sensory evaluation.

A brief summary of our 2025 research trials addressing these objectives is reported here. Additional information may be presented in the Northland Potato Grower magazine, at grower/industry meetings and field day events, and on our project webpage (https://sites.google.com/ndsu.edu/potatobreeding/home).

In the 2025 crossing block, 57 parents were used with 179 new families created. Attributes combined in the families focused on quality traits important for each market type, incorporation of PVY and Verticillium wilt resistance, late blight resistance, and Colorado Potato Beetle (CPB) resistance, amongst other characteristics.

Field trials were planted near Crystal/Hoople, ND; both are non-irrigated. The Crystal site features our fresh market trials, while the Hoople site is focused at chip processing. Both locations were beautiful despite a dry start, with good yields at harvest. Results of the Crystal Fresh Market Trial and the Hoople Chip Processing Trial are reported in Tables 1-3 and 4-6, respectively. Other trials at these locations included a preliminary fresh market trial and a preliminary chip processing trial. Both evaluations provide information used to advance selections within the breeding pipeline and lead to entry into the larger trials if clones perform well. An organic demonstration trial on the campus at NDSU in Fargo included 16 advancing selections compared to four common farmer's market type cultivars. This trial served double duty as we also were able to utilize some foliar materials in our Colorado Potato Beetle resistance screening evaluations.

Irrigated sites included Larimore, Inkster, and Hubbard, MN. Trials at the locations included traditional variety trials, disease screening trials, and three trials evaluating crop enhancement products. Planting across locations was a bit earlier due to a dryer spring in 2025, and our trials had excellent yields and quality. Agronomic characteristics, yield, grade, and quality assessment results are reported in Tables 7-9 for the Larimore Processing Trial. The Simplot Potato Quality Laboratory has been a fantastic addition to our potato breeding research facilities and provides a beautiful and technologically superior space for evaluating potato genotypes moving through our breeding pipeline. A trial of interest to both certified seed potato producers and commercial russet growers included a PVY yield-drag assessment in collaboration with Adam Winchester and Dr. Julie Pasche. Results will be shared at grower events this winter/spring and the trial will be repeated in 2026.

Trials at our commercial locations are often conducted in cooperation with research collaborators including Drs. Pasche, Secor (now retired), Robinson, Hatterman-Valenti, Yan, Shannon, McRae, Dogramaci and Sarkar, amongst others. These projects combine expertise and experience in our efforts to develop superior cultivars to address grower, industry and consumer needs.

The seedling nursery, maintenance lots, and seed increases are produced near Baker, MN. The 2025 growing season was much better than 2024 and we suffered few losses. In the seedling nursery 196 NDSU families were planted totaling more than 34,500 individual genotypes; 283 selections were made. The NDSU breeding program shared unselected seedling tubers with breeding programs in ID, ME, TX, CO and MN in 2025. Out-of-state seedling were received from ID, ME, TX and CO; 152 out-of-state seedlings were retained focusing on disease resistance. Maintenance lots were produced for our second, third and fourth year and older materials; 43 second year, 23 third year and 113 fourth year and older selections were retained. These low retention numbers reflect the significant 'housecleaning' our project did based on PVY susceptibility.

The USDA Plant Variety Protection Office approved the PVP certificate for Dakota Dawn, a 2022 specialty market release during spring 2025. ND113207-1R, ND1241-1Y and ND13220C-3 were presented for pre-release to the North Dakota Agricultural Experiment Station (NDAES) in March 2025. All were advanced forward by the committee. ND1241-1Y continues to look beautiful and progress in the breeding pipeline. Several growers in MN and ND produced it under material transfer agreement (MTA) for evaluation purposes. ND13220C-3 was in its final year of the SNAC Trial. It has exceptional yields and possesses disease resistances; however, it is susceptible to powdery scab if that is a problem on your farm. It was grown by several ND growers for evaluation purposes via MTA and has been chipped regionally this fall and winter with good results. On November 18, ND1138207-1R was presented to the NDAES cultivar release committee on November 18. The committee unanimously recommended release; it was approved by the NDAES with an official release date of February 15, 2026. Additional information will be provided at the NPGA and MN Area II conferences.

The potato breeding program is supported by Kelly Peppel, Hashim Andidi, and Peter Ihry, four graduate students, and an undergraduate student. Graduate student research includes integrated management to heat stress, Colorado Potato Beetle, and tuber skin set.

Our research is not possible without the generosity of so many in North Dakota, Minnesota and beyond. We are grateful for the support of the Northland Potato Growers Association, the Minnesota Area II Research and Promotion Council, JR Simplot, Cavendish Farms, Lamb Weston and RDO

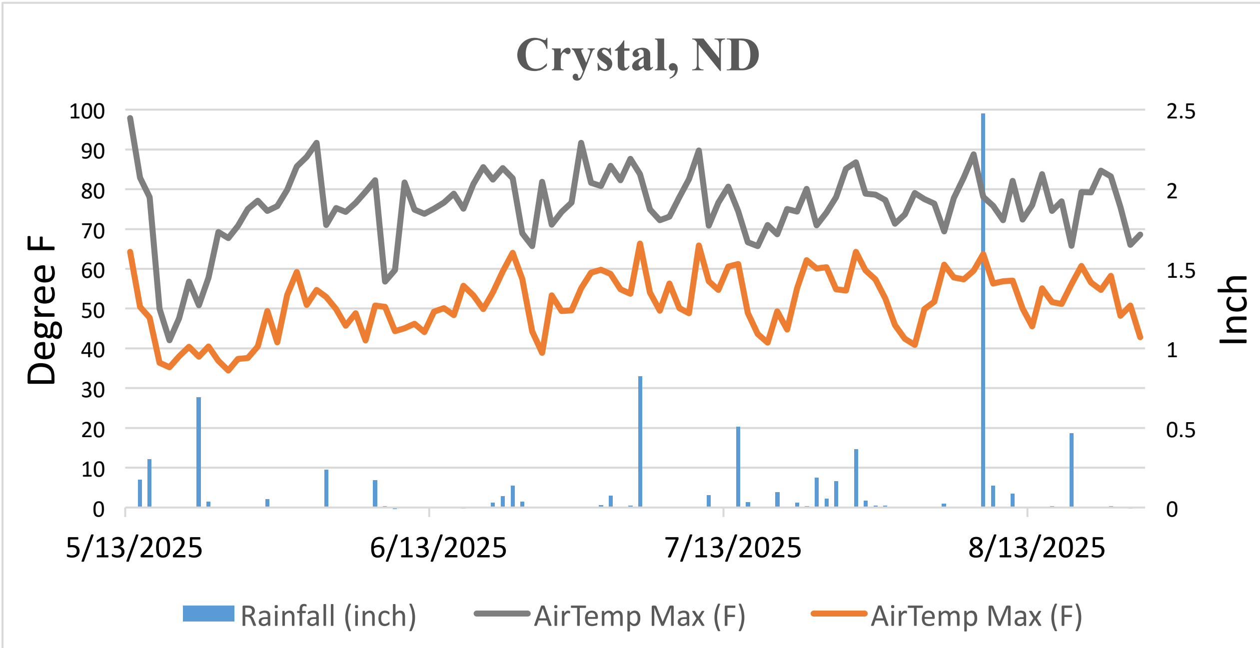
Frozen, the many certified seed potato producers that provide seed for our research trials, to our trial site hosts including Andy and Dave Moquist (Crystal trials), Jamie and Steve Oberg (Hoople trials), Carl, Michael and Casey Hoverson (Larimore trials), in addition to other seed and commercial potato grower cooperators and potato industry reps, and the North Dakota State Seed Department and Minnesota Department of Agriculture. Beyond research funding, you share many resources including hosting trials, supplying certified seed, and agricultural product and services. We are so thankful for all you do in support of the NDSU potato breeding and potato research efforts.

2025 Crystal Agronomic Summary
Potato Breeding

Location:	Crystal, ND
Seed Cutting date:	May 13, 2025 (CFresh, PreFresh) Nubark MZ (1 lb./cwt/)
Planting date:	May 14, 2025
Row width:	36 inches
Within-Row Spacing:	12 inches
Vine Desiccation:	August 30, 2025
Harvest:	September 23, 2025

Temperature and Rainfall 2025, NDAWN, Crystal Station

Table 1



. Agronomic evaluations for advanced fresh market selections and cultivars, Crystal, ND, 2025. The trial was planted on May 14, vines desiccated on August 30 (108 DAP), and harvested with a single-row Grimme harvester on September 23 (132 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[3]	Color[4]
AFND7544-2R	95	3.3	2.8	3.5	7.1	2.8	3.9
AFND7545-3R	91	3.8	3.5	3.3	10.5	1.0	4.0
AFND7672-2P	100	2.6	3.8	4.0	7.2	3.0	P
ND081571-2R	99	2.7	3.3	2.9	6.8	1.0	4.0
ND081571-3R	96	3.5	3.3	3.0	6.9	1.5	3.8
ND113207-1R	99	2.6	2.8	3.4	8.6	2.3	3.9
ND1241-1Y	95	2.9	3.5	3.3	9.5	1.0	Y
ND1757-2R	89	3.0	2.5	3.6	4.4	1.3	40
ND1757-7R	99	3.0	2.5	4.0	9.8	1.0	4.0
ND1757-10R	78	2.5	3.3	3.4	8.0	1.0	4.0
ND1858Y-4R	98	3.4	2.8	3.1	10.2	2.8	3.9
ND1859-1R	98	3.9	3.0	3.0	12.7	1.0	3.3
ND1859-2R	95	4.4	3.3	3.8	12.7	1.4	4.0

Table 2

ND2089-1R	98	2.8	3.8	3.4	6.5	3.0	3.4
ND2089-13R	98	2.7	3.0	3.3	5.6	2.0	3.1
ND2089-17R	99	4.0	3.3	3.3	7.6	2.5	3.5
ND2092-5R	98	3.0	3.3	3.8	6.1	1.5	3.9
ND2096-2R	93	3.7	2.5	2.5	7.6	1.8	2.0
ND2096-4R	100	3.2	2.5	2.3	9.5	1.0	2.0
ND2096-6R	96	4.2	3.0	2.8	7.7	1.3	2.8
ND20102-5R	95	2.2	3.8	3.8	5.8	3.0	3.0
ND20123-2RY	98	3.8	3.0	3.8	6.9	2.0	2.5
ND20137-8R	98	3.0	3.5	3.5	6.2	2.3	3.1
ND20162-1R	93	3.8	2.8	2.9	8.8	1.3	3.9
TXND2119-1R	99	3.4	3.5	2.9	10.4	1.3	3.4
All Blue	99	3.2	4.8	4.4	11.5	5.0	P
Dakota Ruby	95	3.1	3.8	3.3	11.0	1.0	4.1
Red LaSoda	98	2.4	3.3	2.9	5.3	3.0	3.0
Red Norland	100	3.5	3.0	2.5	5.5	3.0	2.8
Yukon Gold	96	1.9	3.5	2.5	5.0	3.0	Y
Mean	96	3.2	3.2	3.2	8.0	2.0	na
LSD (□=0.05)	71*	0.7	0.8	0.7	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.
*Providing an LSD for percentage data is not statistically appropriate, but to aid the reader in ascertaining significant differences, the information is provided here.
na = not applicable

. Yield and grade for advanced fresh market selections and cultivars, Crystal, ND, 2025. The trial was planted on May 14, vines desiccated on August 30 (108 DAP), and harvested with a singlerow Grimme harvester on September 23 (132 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 %
AFND7544-2R	189	84	42	54	32	10	4	1
AFND7545-3R	232	74	31	69	26	5	0	0
AFND7672-2P	320	201	59	27	42	17	14	0
ND081571-2R	178	72	40	59	35	5	0	1

Table 3

ND081571-3R	155	55	33	67	28	5	0	0
ND113207-1R	264	122	42	50	33	9	7	1
ND1241-1Y	226	88	37	63	31	5	0	0
ND1757-2R	112	51	45	47	37	8	4	4
ND1757-7R	189	42	18	81	16	2	0	1
ND1757-10R	169	76	40	58	33	7	1	0
ND1858Y-4R	280	142	47	50	38	8	2	1
ND1859-1R	249	55	21	79	18	2	0	0
ND1859-2R	171	11	6	94	6	0	0	1
ND2089-1R	316	172	54	18	38	16	20	8
ND2089-13R	255	136	52	21	35	17	25	2
ND2089-17R	292	142	49	28	33	16	15	8
ND2092-5R	254	150	60	26	41	18	14	0
ND2096-2R	259	145	54	32	39	15	12	1
ND2096-4R	157	15	9	89	8	2	0	1
ND2096-6R	252	134	53	43	42	10	4	0
ND20102-5R	276	170	62	16	41	21	21	1
ND20123-2RY	257	134	57	37	41	15	6	1
ND20137-8R	257	127	54	54	39	15	10	2
ND20162-1R	221	105	45	53	37	8	3	0
TXND2119-1R	326	171	51	43	40	11	5	0
All Blue	202	53	20	79	17	3	0	1
Dakota Ruby	277	119	41	58	35	6	0	1
Red LaSoda	273	106	39	16	26	13	65	10
Red Norland	344	173	51	8	32	19	39	3
Yukon Gold	232	139	59	18	43	16	21	1
Mean	238	109	42	47	32	10	9	2
LSD (□=0.05)	81	56	14*	15*	11*	5*	8*	3*

*Providing an LSD for percentage data is not statistically appropriate, but to aid the reader in ascertaining significant differences, the information is provided here.

. 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 May 14, vines desiccated on August 30 (108 DAP), and harvested on September 23 (132 DAP). The plots were 20 feet long, with a 12-inch with-in row spacing, and 36 inches between rows, replicated four times.

Table 4

Clone	Scurf[1]	Hollow Heart/ Brown Center %	Specific Gravity[2]	Black-spot Bruise[2]	Shatter Bruise[3]	General Rating[4]
AFND7544-2R	4.4	0	1.0818	3.2	2.7	3.5
AFND7545-3R	4.3	0	1.0906	4.0	2.7	4.1
AFND7672-2P	4.3	0	1.0825	3.8	3.7	3.6
ND081571-2R	3.9	0	1.0819	3.4	2.7	3.4
ND081571-3R	4.0	0	1.0907	3.7	2.9	3.1
ND113207-1R	3.0	0	1.0803	3.5	3.3	3.6
ND1241-1Y	4.4	0	1.0830	3.2	2.9	3.9
ND1757-2R	3.5	0	1.0792	3.0	2.5	3.0
ND1757-7R	4.4	0	1.0807	3.0	2.4	3.6
ND1757-10R	3.9	0	1.0852	3.6	2.4	3.5
ND1858Y-4R	3.5	0	1.0841	3.0	3.0	3.4
ND1859-1R	3.3	0	1.0862	3.3	2.5	3.5
ND1859-2R	4.3	0	1.0776	2.7	2.4	3.1
ND2089-1R	3.3	0	1.0766	3.9	3.2	2.9
ND2089-13R	2.8	0	1.0805	3.9	3.1	3.1
ND2089-17R	3.6	0	1.0758	4.5	3.8	3.3
ND2092-5R	3.9	0	1.0833	4.1	3.0	3.9
ND2096-2R	2.8	1	1.0810	3.9	2.8	3.8
ND2096-4R	2.5	0	1.0835	3.7	3.0	2.6
ND2096-6R	3.8	6	1.0626	3.6	3.2	3.8
ND20102-5R	3.0	0	1.0800	4.1	2.7	2.9
ND20123-2RY	3.0	0	1.0928	3.4	3.4	3.4
ND20137-8R	2.0	0	1.0920	4.0	2.6	3.0
ND20162-1R	3.4	0	1.0782	4.2	3.2	3.6
TXND2119-1R	3.4	0	1.0756	3.9	3.9	3.8
All Blue	2.3	0	1.0813	4.6	3.2	3.1
Dakota Ruby	4.4	0	1.0863	3.0	2.5	4.4
Red LaSoda	3.5	1	1.0766	4.4	3.2	3.1
Red Norland	2.0	1	1.0732	4.3	3.1	3.0

[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.

[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 = 1-5; 1 = poor and unacceptable, 3 = fair, 4 = excellent, 5 = perfect.

*Providing an LSD for percentage data is not statistically appropriate, but to aid the reader in ascertaining significant differences, the information is provided here.

Table 5

Yukon Gold	3.3	1	1.0898	3.7	3.7	3.0
Mean	3.5	0	1.0833	3.7	3.0	3.4
LSD (=0.05)	0.7	4*	0.0082	0.6	0.9	0.5

2025 Hoople Agronomic Summary Potato Breeding

Location:	Oberg Farms, near Crystal/Hoople, ND
Seed Cutting date:	May 13, 2025 (HChip, PreChip)
Seed Treatment:	Nubark MZ (1 lb/cwt)
Planting Date:	May 14, 2025
Row Width:	36 inches
Within-Row Spacing:	12 inches
In-Furrow Treatment:	Generate, Acadia and Acronyx 4F
Vine Desiccation:	September 3, 2025
Harvest:	September 24, 2025

Temperature and Rainfall 2025, NDAWN, Hoople Station

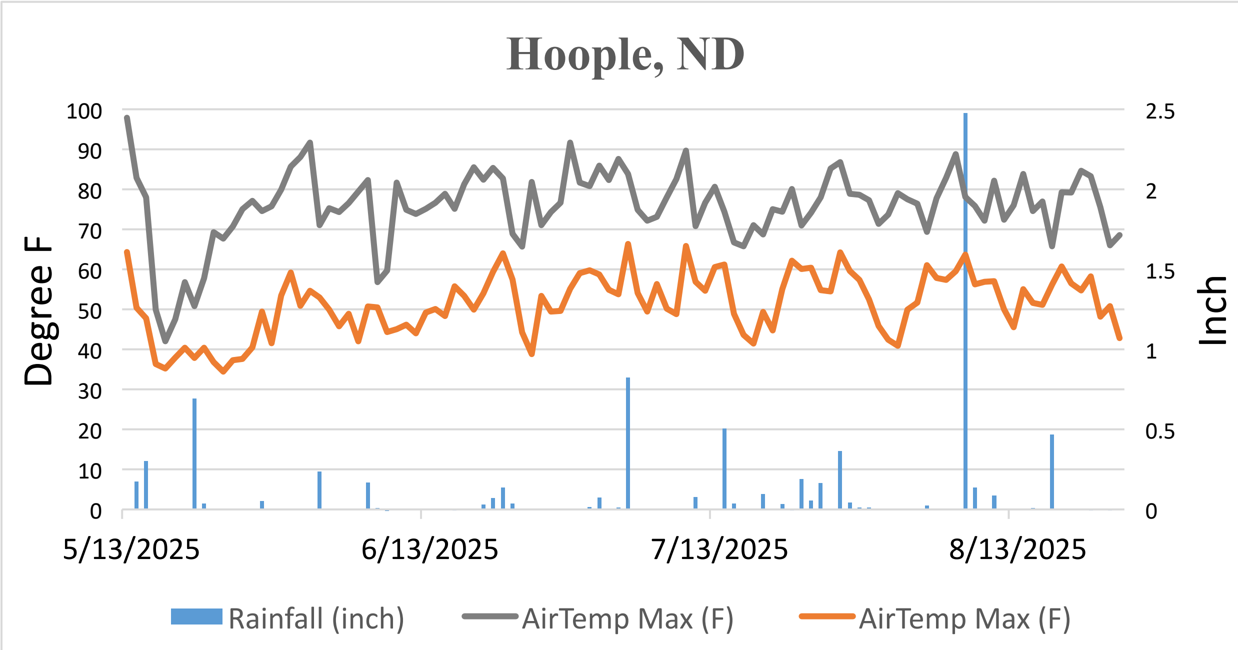


Table 4. Agronomic assessments for advancing chip processing selections and check cultivars, Hoople, ND, 2025. The trial was planted on May 14, and harvested on September 24 (133 DAP) using a single-row Grimme harvester. The replicated plots were 20 feet long, with a 12-inch withinrow spacing, and 36 inches between rows.

Clone	Stand %	Stems per Plant	Vine Size[1]	Vine Maturity[2]	Tubers per plant	Hollow Heart & Brown Center %
ND7799c-1	95	2.0	3.0	2.3	5.4	0
ND1241-1Y	99	2.4	3.0	3.0	8.3	1
ND13220C-3	99	2.4	4.8	3.1	7.1	8
ND1734-4	99	3.2	2.8	1.0	10.6	0
ND1776-8	100	2.0	3.5	3.1	7.3	1
ND1776-10	95	2.7	2.3	1.5	6.5	0
ND1776-11	96	2.3	2.5	1.4	5.0	0

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

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

*Providing an LSD for percentage data is not statistically appropriate, but to aid the reader in ascertaining significant differences, the information is provided here.

ND1844Y-1	98	3.1	3.8	3.4	8.3	9
ND1852-3	100	2.3	3.3	2.9	7.5	1
ND1853-2	98	2.9	2.8	1.1	6.5	20
ND2070-1	99	2.2	2.8	3.0	7.8	1
ND2097-1	95	2.9	2.6	1.9	7.3	0
ND2097-2	96	2.4	2.3	1.6	7.6	0
ND20185-11	95	2.8	3.8	2.0	7.1	0
ND20191-24	95	1.4	3.8	2.1	4.5	0
TXND20051-2	98	2.8	2.8	2.1	6.8	0
TXND20113-2	100	2.5	3.0	2.5	5.0	4
Atlantic	98	2.3	3.0	2.8	5.3	3
Bliss	95	2.3	3.5	2.5	8.1	0
Dakota Pearl	99	2.8	3.0	2.9	8.0	0
Lamoka	91	2.3	4.1	2.8	5.3	0
Mackinaw	99	1.7	4.0	3.3	6.2	0
Snowden	100	2.6	3.8	3.0	6.0	1
Waneta	96	1.1	3.5	3.1	5.1	0
Mean	97	2.4	3.2	2.4	6.8	2
LSD (□=0.05)	5*	0.4	0.6	0.7	1.4	5*

Table 5. Yield and grade for advancing chip processing selections and check cultivars, Hoople, ND, 2025. The trial was planted on May 14, and harvested on September 24 (133 DAP) using a singlerow Grimme harvester. The replicated plots were 20 feet long, with a 12-inch within-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 %
ND7799c-1	302	179	59	10	19	40	30	1
ND1241-1Y	268	148	55	41	34	21	3	0
ND13220C-3	369	237	64	16	21	43	20	1
ND1734-4	289	116	40	59	29	10	1	0
ND1776-8	285	162	57	35	26	31	7	1
ND1776-10	192	84	44	53	26	18	2	1
ND1776-11	143	64	44	55	25	19	0	1
ND1844Y-1	414	251	60	17	21	39	22	1
ND1852-3	313	201	64	25	30	35	7	4
ND1853-2	247	154	62	31	30	32	6	1
ND2070-1	263	143	54	42	30	24	4	0
ND2097-1	220	101	46	52	28	17	3	0

ND2097-2	202	83	41	57	29	12	2	0
ND20185-11	288	190	66	25	27	38	8	1
ND20191-24	249	127	50	12	16	34	36	2
TXND20051-2	268	163	61	29	28	32	10	0
TXND20113-2	234	158	67	20	29	38	12	1
Atlantic	270	169	63	16	21	42	20	2
Bliss	225	84	36	63	27	9	0	1
Dakota Pearl	287	165	57	38	34	24	4	6
Lamoka	294	160	54	11	16	38	35	5
Mackinaw	285	205	72	19	29	43	8	5
Snowden	291	208	72	18	26	46	10	0
Waneta	289	182	62	11	21	42	27	0
Mean	270	156	56	31	26	30	11	1
LSD (□=0.05)	45	40	9*	8*	7*	8*	8*	2*

*Providing an LSD for percentage data is not statistically appropriate, but to aid the reader in ascertaining significant differences, the information is provided here.

Table 6. 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	Specific Gravity[1]	Black-spot	Shatter	Field	Chip[4] 38F (3.3C)	Chip[4] 42F (5.5C)	General

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

		Bruise[1]	Bruise[2]	Chip[3]			Rating[4]
ND7799c-1	1.0906	1.1	2.3	3.8	8.8	4.3	4.1
ND1241-1Y	1.1105	3.4	2.9	4.0	8.6	3.8	3.4
ND13220C-3	1.1189	2.7	3.2	3.3	10.0	4.5	3.6
ND1734-4	1.0969	1.6	1.9	3.5	9.8	5.0	3.3
ND1776-8	1.0934	1.8	2.4	3.3	10.0	5.3	3.5
ND1776-10	1.0912	2.0	2.6	3.5	9.4	4.3	2.6
ND1776-11	1.0925	2.5	2.4	3.0	9.4	3.8	2.8
ND1844Y-1	1.0979	2.6	2.4	4.0	9.5	7.3	4.3
ND1852-3	1.1020	3.8	4.4	3.8	10.0	7.8	3.1
ND1853-2	1.0949	3.6	3.0	4.0	8.5	4.8	3.4
ND2070-1	1.0949	1.9	2.1	4.0	10.0	5.9	3.9
ND2097-1	1.0906	2.1	2.4	3.5	9.8	8.1	3.0
ND2097-2	1.0858	1.9	2.5	3.5	9.5	6.5	2.9
ND20185-11	1.0970	2.3	3.1	3.5	8.4	6.8	3.3
ND20191-24	1.0937	2.2	2.7	4.0	8.9	4.5	2.9
TXND20051-2	1.0978	2.9	2.2	3.5	9.1	5.0	3.3
TXND20113-2	1.1011	2.8	2.9	3.3	9.1	6.8	3.4
Atlantic	1.1116	3.6	3.1	3.0	10.0	6.3	2.8
Bliss	1.1030	3.8	2.6	2.8	7.4	3.3	2.9
Dakota Pearl	1.1017	2.1	2.5	4.0	8.1	4.8	3.8
Lamoka	1.1041	2.4	2.4	3.3	9.3	5.5	3.3
Mackinaw	1.1088	3.5	2.3	3.8	9.9	6.3	3.4
Snowden	1.1062	4.0	2.9	3.0	10.0	7.5	3.0
Waneta	1.0983	1.9	2.0	3.3	9.0	4.5	3.1
Mean	1.0993	2.6	2.6	3.5	9.3	5.5	3.3
LSD (□=0.05)	0.0070	1.0	1.0	0.9	0.8	1.6	0.5

[1] 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.

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

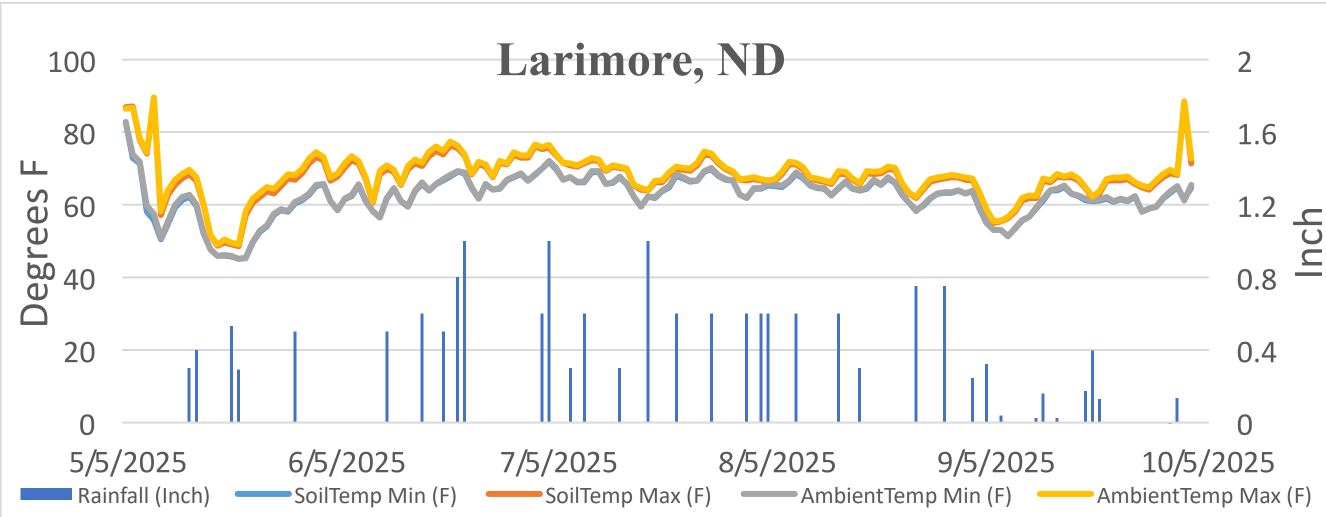
[3] USDA Potato Chip Color Reference Standard, Courtesy of B.L. Thomas, B.L. Thomas and Associates, Cincinnati, Ohio, Potato Chip Institute International. 1 = white, 10 = very dark; 4 and below acceptable.

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

2025 Larimore Agronomic Summary
Potato Breeding

Location:	Larimore, ND
Seed Cutting Date:	May 8, 2025 (LProc)
Seed Treatment:	Nubark MZ (1 lb/cwt)
Planting Date:	May 12, 2025 (LProc)
Row Width:	36 inches
Within-Row Spacing:	12 inches
Fertilizer (Season):	Nitrogen (150 lb/ac), Phosphorus (218 lb/ac), Potassium (326 lb/ac), Sulphur (100 lb/ac), Calcium (118.64 lb/ac)
Fungicide:	May 12 (in-furrow) Acadia 2 SC 11 (11.33 fl oz/ac), Acronyx 4F (10 fl oz/ac), Orondis Gold 4,49 (27.8 oz/ac) May 28 Hinge (1.5 oz/ac), Rancor 4F (1 pt/ac) Jun 11 Hinge (1 oz/ac), Rancor 4F (0.5 pt/ac) Jul 4 Praiz (M5) (1.5 pt/ac), Veltyma 3,11 (8 fl oz/ac) Jul 10 Praiz (M5) (1.5 pt/ac), Scala SC (7 fl oz/ac) Jul 19 Praiz (M5) (1.5 pt/ac), Luna Pro 3,7 (10 fl oz/ac) Jul 25 Sparra (2.5 qt/ac), Praiz (M5) (1.5 pt/ac), Endura (5.5 0z/ac) Jul 31 Praiz (M5) (1.5 pt/ac), Fosphite (1.5 qt/ac) Aug 8 Praiz (M5) (1.5 pt/ac), Fosphite (1.5 qt/ac), Provysol (4 fl oz/ac) Aug 15 Praiz (M5) (1.5 pt/ac), Super Tin 4L (5 fl oz/ac) Aug 26 Super Tin 4L (5 fl oz/ac), Penncozeb 75DF (2lb/ac) Sep 30 Strike 100CP (120 oz/ac)
Herbicide:	May 28 Outlook (12 fl oz/ac)
Insecticide:	Jul 4 Belay (3 fl oz/ac), Enterik 0.15LV (16 fl oz/ac), Minecto Pro 28, 6 (10 fl oz/ac) Aug 8 Cryptoid XL (2.8 fl oz/ac) Aug 15 Enterik 0.15LV (16 fl oz/ac)
Harvest:	October 2, 2025

Temperature and Rainfall 2025, Soil Tech Sensor



Larimore, ND
Degrees F
Inch
100
80
60
40
20
0
2
1.6
1.2
0.8
0.4
0
5/5/2025
6/5/2025
7/5/2025
8/5/2025
9/5/2025
10/5/2025
Rainfall (Inch)
SoilTemp Min (F)
SoilTemp Max (F)
AmbientTemp Min (F)
AmbientTemp Max (F)

. Agronomic and quality evaluations for advanced processing selections and cultivars grown at Larimore, ND, in 2025. The processing trial was planted on May 12, and harvested October 2 (143 DAP), 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. Vine maturity was not rated, as all plants (all trials at this site) were dead prior to preharvest notes on September 25.

Clone	Stand %	Stems Per Plant	Vine Size[1]	Tubers per plant	Hollow Heart/ Brown Center %	Black-spot Bruise[2]	Shatter Bruise[3]	General Rating[4]
ND050032-4Russ	96	1.4	2.8	6.9	1	5.0	2.8	3.8
ND060735-4Russ	94	1.8	3.0	7.7	0	3.1	2.2	3.9
ND091933ABCR-2Russ	99	3.1	2.8	8.3	11	4.9	2.8	2.9
ND1714Y-1Russ	96	3.1	3.8	9.2	1	4.5	2.1	3.5
ND2053-5Russ	98	3.0	4.5	11.3]	5	4.9	3.0	3.4
ND2084-13Russ	91	2.5	2.5	8.7	0	4.9	3.1	2.4
ND2085-1Russ	98	2.5	4.3	9.1	0	4.8	3.0	3.8
ND2087-12Russ	99	2.2	3.3	8.1	0	5.0	2.9	3.5
ND20126-1Russ	100	1.7	2.8	7.7	0	4.2	2.7	3.5
ND21109-1Russ	93	1.9	3.8	6.9	4	4.9	3.4	4.0
TXND20063-1Russ	94	4.3	3.5	9.3	0	5.0	4.1	3.3
Bannock Russet	100	2.4	5.0	6.5	8	4.0	3.2	3.9
Dakota Russet	90	2.5	4.0	8.8	0	3.1	2.2	4.5
Ranger Russet	93	2.1	4.5	6.3	1	5.0	3.0	2.6
Russet Burbank	100	3.2	4.0	10.6	5	4.5	2.7	2.8
Russet Norkotah	100	2.0	3.3	7.0	6	4.7	2.4	4.9
Shepody	100	2.0	3.8	6.8	0	3.7	2.3	2.1.
Umatilla Russet	100	3.0	3.3	10.4	3	4.0	2.6	3.3
Mean	97	2.5	3.6	8.3	3	4.4	2.8	3.4
LSD (□=0.05)	8*	0.5	0.8	1.2	5	0.8	0.5	0.6

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

*Providing an LSD for percentage data is not statistically appropriate, but to aid the reader in ascertaining significant differences, the information is provided here.

. Yield and grade for advanced processing selections and cultivars grown at Larimore, ND, 2025. The processing trial was planted on May 12, and harvested October 2 (143 DAP), 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 %
ND050032-4Russ	350	295	84	13	17	47	20	3
ND060735-4Russ	331	260	79	20	28	41	10	1
ND091933ABCR-2Russ	390	312	80	17	27	40	13	3
ND1714Y-1Russ	461	383	83	15	20	42	21	2
ND2053-5Russ	459	326	70	27	29	33	8	3
ND2084-13Russ	320	225	70	28	25	34	11	2
ND2085-1Russ	365	278	76	24	28	36	12	0
ND2087-12Russ	391	318	81	17	19	37	25	1
ND20126-1Russ	351	279	79	20	32	38	9	1
ND21109-1Russ	349	292	83	14	17	44	22	3
TXND20063-1Russ	467	408	87	12	16	40	32	1
Bannock Russet	431	381	88	6	12	38	38	5
Dakota Russet	414	348	84	15	26	46	13	2
Ranger Russet	333	232	69	12	10	39	20	18
Russet Burbank	516	342	66	19	19	35	12	16
Russet Norkotah	368	311	84	14	16	41	27	2
Shepody	393	256	66	11	13	28	24	23
Umatilla Russet	401	255	63	34	28	27	9	3
Mean	394	306	77	18	21	38	18	5
LSD (=0.05)	68	72	8*	7*	6*	8*	8*	5*

*Providing an LSD for percentage data is not statistically appropriate, but to aid the reader in ascertaining significant differences, the information is provided here.

. French fry evaluations following grading for advanced processing selections and cultivars grown at Larimore, ND, 2025. The processing trial was planted on May 12, and harvested October 2 (143 DAP) using a single-row Grimme harvester. A randomized complete block design with four replicates was utilized; plots were twenty feet long, with a within-row spacing of 12 inches and 36 inches between rows.

		Field Fry			Following 45F (7.7C) Storage		
Clone	Specific Gravity[1]	Fry Color[2]	Stemend Color	% Sugar Ends[3]	Fry Color[2]	Stemend Color	% Sugar Ends[3]
ND050032-4Russ	1.0980	0.40	0.42	8	0.62	1.80	58
ND060735-4Russ	1.0939	0.48	1.01	0	0.50	0.50	0
ND091933ABCR-2Russ	1.0797	0.30	0.36	8	0.70	0.70	0
ND1714Y-1Russ	1.1066	0.65	2.18	49	1.04	1.29	17
ND2053-5Russ	1.1115	0.80	0.85	25	0.90	0.90	0
ND2084-13Russ	1.0955	0.98	1.00	42	1.27	2.83	79
ND2085-1Russ	1.1173	1.08	1.08	0	1.92	2.00	8
ND2087-12Russ	1.0845	0.68	0.94	8	1.08	1.38	42
ND20126-1Russ	1.1000	0.48	0.70	0	0.45	0.66	6
ND21109-1Russ	1.1001	0.40	0.71	0	0.68	1.35	34
TXND20063-1Russ	1.0937	0.95	1.01	17	0.90	1.77	54
Bannock Russet	1.0953	0.53	2.26	67	0.67	1.33	42
Dakota Russet	1.0995	0.30	0.30	0	0.58	0.58	0
Ranger Russet	1.1016	0.58	1.08	8	0.92	2.36	67
Russet Burbank	1.0926	0.53	3.73	92	0.74	3.8	100
Russet Norkotah	1.0802	1.03	3.46	83	1.84	2.67	42
Shepody	1.0918	0.55	2.64	66	1.34	2.58	50
Umatilla Russet	1.0974	0.60	0.60	0	0.70	1.43	25
Mean	1.0968	0.63	1.35	26	0.94	1.66	35
LSD (□=0.05)	0.0051	0.32	1.05	35*	0.37	0.85	43*

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

[2] Fry color scores: 0.3 corresponds to 000, 0.5 corresponds to 00, 0.8 corresponds to 0, 1.0 equals 1.0; subsequent numbers follow French fry rating scale to 4.0. Scores of 3.0 and above are unacceptable because sufficient sugar levels cannot be leached from the tuber flesh to make an acceptable fry of good texture.

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

*Providing an LSD for percentage data is not statistically appropriate, but to aid the reader in ascertaining significant differences, the information is provided here.