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Proximal Sensing-based Non-destructive Diagnosis of Potato Nitrogen Status

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Summary

Proper nitrogen (N) management is critical for potato cultivation. Cultivars grown today depend on high fertilizer inputs, especially N. Excessive N application contributes to low N use efficiency (NUE), elevated nitrate in groundwater, decreased tuber quality through the accumulation of reducing sugars, and reduced profitability. This issue is closely associated with shallow root systems, low retention of N in coarse-textured soils favored by potatoes, unpredictable precipitation, and irrigation management. Because of these concerns, it is imperative to properly manage N. One strategy is to adopt new N efficient cultivars, and another strategy is to develop more efficient non-destructive N status diagnostic methods to guide in-season N management according to potato N demand. Hamlin Russet is a new N efficient cultivar that has not been extensively evaluated in Minnesota. Plant N status assessment through petiole nitrate monitoring is a time-consuming process and does not account for spatial variability within a field. In addition, the window to make changes for optimum N application is narrow. The use of proximal sensing technologies to accurately predict plant N status will allow for timely and effective N management. The objectives of this study were to 1) evaluate the N response of Hamlin Russet in comparison with the commonly planted Russet Burbank, and 2) develop proximal sensing-based in-season non-destructive potato N status diagnosis methods to support potato growers to make in-season N management decisions. A small-plot experiment was conducted in 2021 at Becker, MN involving two cultivars (Hamlin Russet, and Russet Burbank) and five N rates (40, 80, 160, 240, 320 lb N /ac). SPAD meter, Dualex leaf sensor, and Crop Circle Phenom canopy sensor data were collected at four key growth stages during the growing season. Potato petiole, vine, and tuber samples were collected to measure petiole nitrate-N concentration, vine biomass and N concentration, tuber biomass, and N concentration after sensor data collection in each plot. Tuber yield (total and marketable) and quality data were also determined. Preliminary results indicated that the optimum N rates for total and marketable yield were slightly lower for Hamlin Russet than Russet Burbank. The optimal rates in 2021 for both cultivars were lower than expected, possibly due to high N concentration in the irrigation water, dry weather conditions, and reduced tuber bulking due to excessive heat stress. Hamlin Russet produced larger tubers than Russet Burbank regardless of N rate. Hamlin Russet consistently had higher specific gravity than Russet Burbank. Both SPAD meter and Dualex sensor could be combined together with cultivar, environment, and management information using machine learning to reliably predict petiole nitrate-N well across site-years and cultivars, with similar performance ($R^2 = 0.90$-0.91). This preliminary result demonstrated the potential of using N efficient cultivars and real-time nondestructive prediction of petiole nitrate-N to improve potato N management.

Background

Proper nitrogen (N) management is important for potato cultivation due to shallow potato root systems, low retention of N on coarse-textured soils favored by potato, unpredictable precipitation, and irrigation management. Inefficient N use by potato crops as well as their high value often inclines farmers to take an insurance approach and apply relatively high rates of N fertilizers. Excess N fertilizer application can result in nitrate-N losses ranging from 70-200 kg ha^{-1} (Errebhi et al. 1998). Even when best management practices (BMPs) are followed, significant nitrate losses can still occur. This has led policymakers and society in search of mitigating options. Excess N fertilizer usage also decreases tuber quality, frying color, and storability by impacting metabolic processes of reducing sugar, free amino acid, and protein during post-harvest storage (Sun et al., 2019). Economic losses due to these post-harvest problems are significant and

Midwest potato production loses competitiveness. Because of these concerns, it is imperative to develop more efficient N management strategies. One strategy is to adopt new cultivars with higher nitrogen use efficiency (NUE). Hamlin Russet is a new cultivar reported to be N efficient, but it has not been extensively evaluated in Minnesota.

Another strategy is to develop in-season precision N management strategies. Plant N status assessment through traditional petiole nitrate-N monitoring is a time-consuming process and does not account for spatial variability within a field. In addition, the window to make changes for optimum N application is narrow. Thus, traditional tissue analysis often cannot meet growers' needs to improve potato N status diagnosis and management. The SPAD chlorophyll meter has been commonly used in plant N status diagnosis. Dualex Scientific+ is a new innovative handheld leaf sensor capable of non-destructively and accurately measuring leaf chlorophyll (Chl), flavonoid (Flav), and anthocyanin (Anth) contents with GPS location information. The nitrogen balance index (NBI) is calculated as the ratio of Chl over Flav. These parameters were found to be related to corn plant N stress (Dong et al., 2020 and 2021). Crop Circle Phenom (CCP) is a new integrated multi-parameter proximal active canopy sensor capable of measuring reflectance at three wavebands (red, red-edge, near-infrared) and climatic parameters such as canopy and air temperatures, relative humidity, and air pressure (Cummings et al., 2021). Reflectance can be used to calculate vegetative indices related to plant N stress. Air and canopy temperature difference is related to both plant water and N stresses (Cummings et al., 2021). This sensor was evaluated for corn N status diagnosis, but little has been reported about the performance of these sensors for estimating potato N status.

The objectives of this study were to 1) evaluate the N response of Hamlin Russet in comparison with Russet Burbank, and 2) develop proximal sensing-based in-season non-destructive potato N status diagnosis methods to support potato growers to make in-season N management decisions.

Materials and Methods

Experimental design

A field experiment including two cultivars (Russet Burbank and Hamlin Russet) and five N rates (40, 80, 160, 240, 320 lb N /ac) was conducted using a randomized complete block design with 3 replications in a Hubbard loamy sand soil in 2021 at the Sand Plain Research Farm (SPRF), Becker, MN. Dualex (Figure 1) and CCP sensor (Figure 2) data were collected at key growth stages (4 times) during the growing season along with SPAD data for comparison. Dualex sensor measurement was done at different leaf positions to develop a leaf position-based N status diagnosis method. Potato samples were collected after sensor data collection in each plot to measure petiole nitrate-N concentration, vine biomass and N concentration, tuber biomass, and N concentration. Petiole nitrate-N was measured in the fourth leaf from the top of the plant, together with the SPAD sensor. Tuber yield (total and marketable) and quality data (specific gravity, tuber dry matter, and tuber size) were determined at harvest time.

Fig. 1. The Dualex leaf fluorescence sensor (left) and field data collection (right).

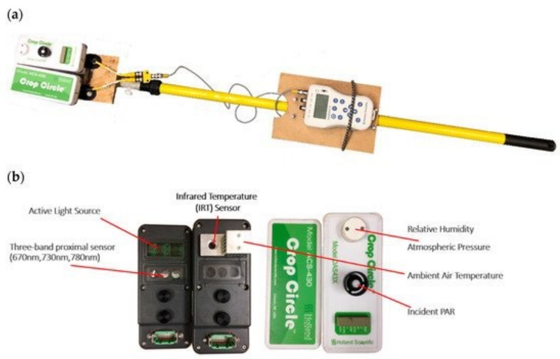

Fig. 2. Crop Circle Phenom sensor (a) custom assembly with extendable pole and (b) close-up view of ACS-430 and DAS43X sensor components (from Cummings et al., 2021).

Data analysis

The collected potato plant samples in 2021 are still being analyzed in the lab for petiole nitrate-N, vine N concentrations, etc., and will be reported later. This report shows cultivar differences in tuber yields and quality and proximal sensing data across N rates. Tuber size and specific gravity were reported as quality parameters. Petiole nitrate-N prediction models were established using SPAD and Dualex data from 2018 and 2019 small-plot experiments at the SPRF to evaluate the potential of using proximal sensing data for petiole nitrate-N prediction.

Results and discussion

Cultivar difference in N responses

In general, Russet Burbank had a slightly higher total tuber yield than Hamlin Russet at N rates of 160 lb/ac or lower, while Hamlin Russet had a slightly higher marketable yield at most of the N rates except 160 lb/ac (Figure 3 and 4). Total and marketable yield of Russet Burbank increased with N rates to about 160 lb/ac and then decreased with higher N rates, while for Hamlin Russet total and marketable yield slightly increased with N to 80 lb/ac and then did not increase further (Figure 3 and 4). The optimum N rates for both cultivars, whether they are based on total yields or marketable yields in 2021, were lower than expected for the achieved yields. Especially, as Figures 3 and 4 show, the Hamlin Russet yields did not vary much across the five N rates. Soil organic matter content before planting was as low as 1%, but N concentration in the irrigation water was reported to be as high as 15 ppm, which can contribute 30 lb/ac of extra N. Rainfall was also lower than average which resulted in much less nitrate leaching. Moreover, the dry weather during the day and night might have restricted tuber bulking and reduced N requirements by tubers. Further investigation is required using environmental and other ancillary data to improve the estimation of optimal N rates.

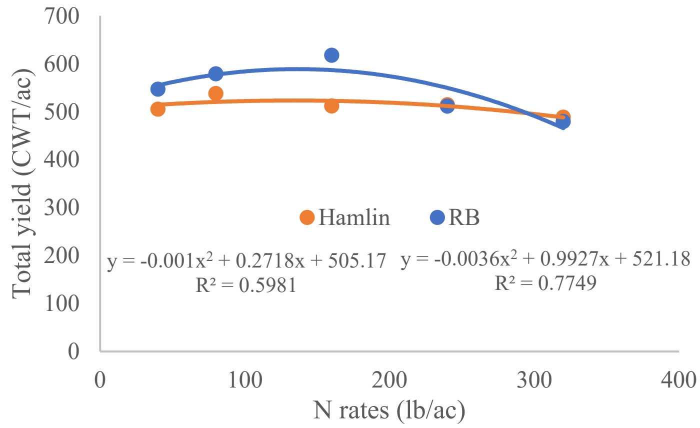

Fig. 3. Total potato tuber yield responses to N rates for Russet Burbank (RB) and Hamlin cultivars.

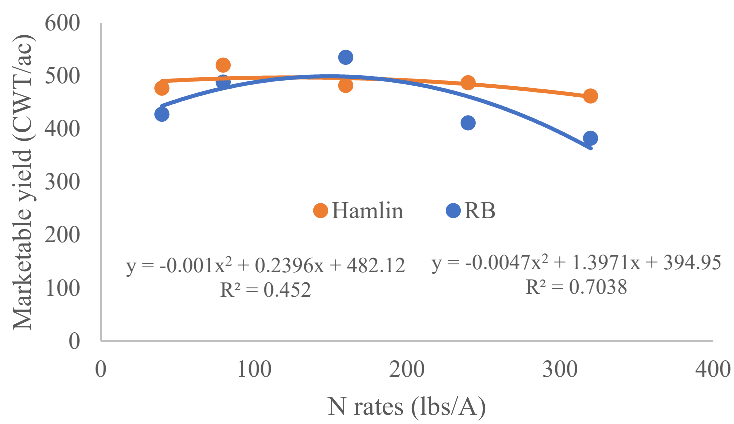

Fig. 4. Marketable yield responses to N rates for Russet Burbank and Hamlin Russet cultivars.

Tuber size and specific gravity for both cultivars are shown in Figures 5 and 6, respectively. Across all N rates, Hamlin Russet produced larger tubers than Russet Burbank. The large Hamlin Russet tubers were produced more frequently even at lower N rates (40 and 80 lb/ac). Russet Burbank produced smaller tubers across all N rates. Additionally, Hamlin Russet had higher specific gravity than Russet Burbank across all N rates.

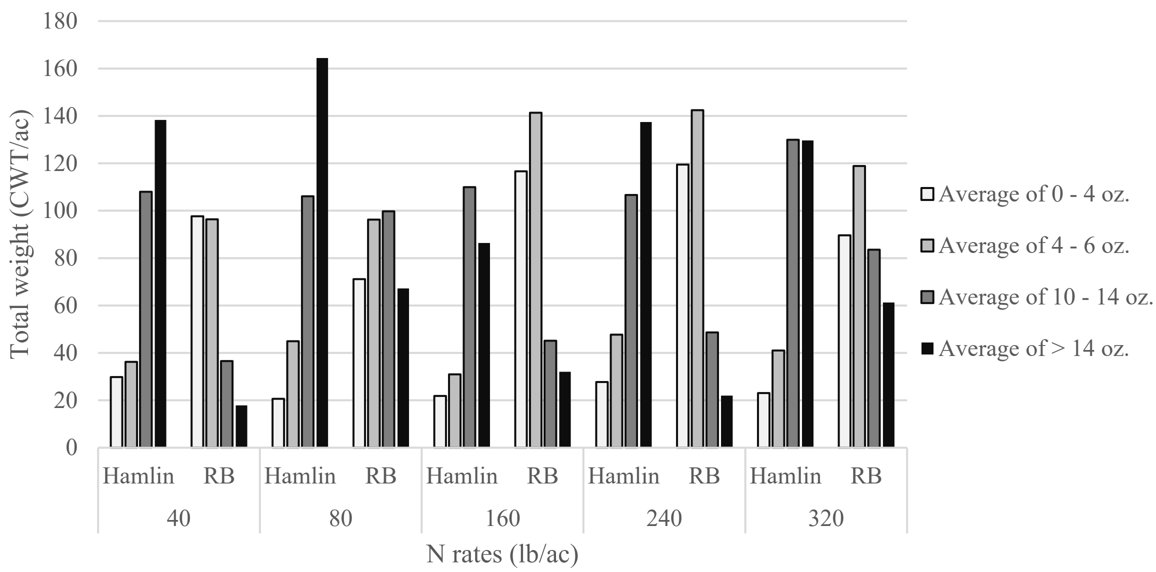

Fig. 5. Total weight (CWT/ac) of Hamlin Russet and Russet Burbank tubers in four size categories at the five N rates.

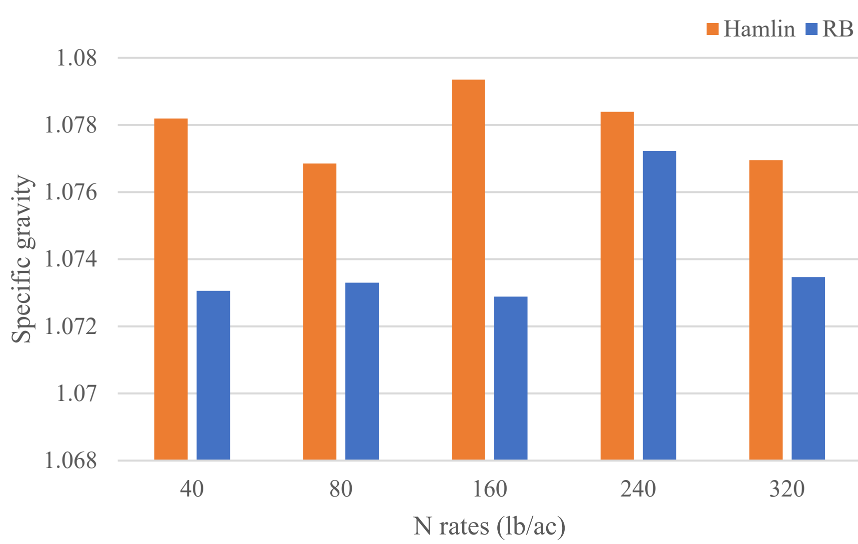

Fig. 6. Specific gravity of Hamlin Russet and Russet Burbank at the five N rates.

Leaf sensor data response to N rates at different growth stages

Figures 7, 8, and 9 show the relationships between SPAD, Dualex Chl, or NBI readings and N rates for each cultivar on different measurement dates, respectively. Using SPAD, Dualex Chl, or NBI readings were more responsive than tuber yield and increased with N up to to the highest N rate (320 lb/ac). Aboveground vegetation chlorophyll or N concentration tended to increase with N rates, but tuber yields did not necessarily increase correspondingly. More research is needed to determine how these sensor data can be used to estimate the optimal N rates.

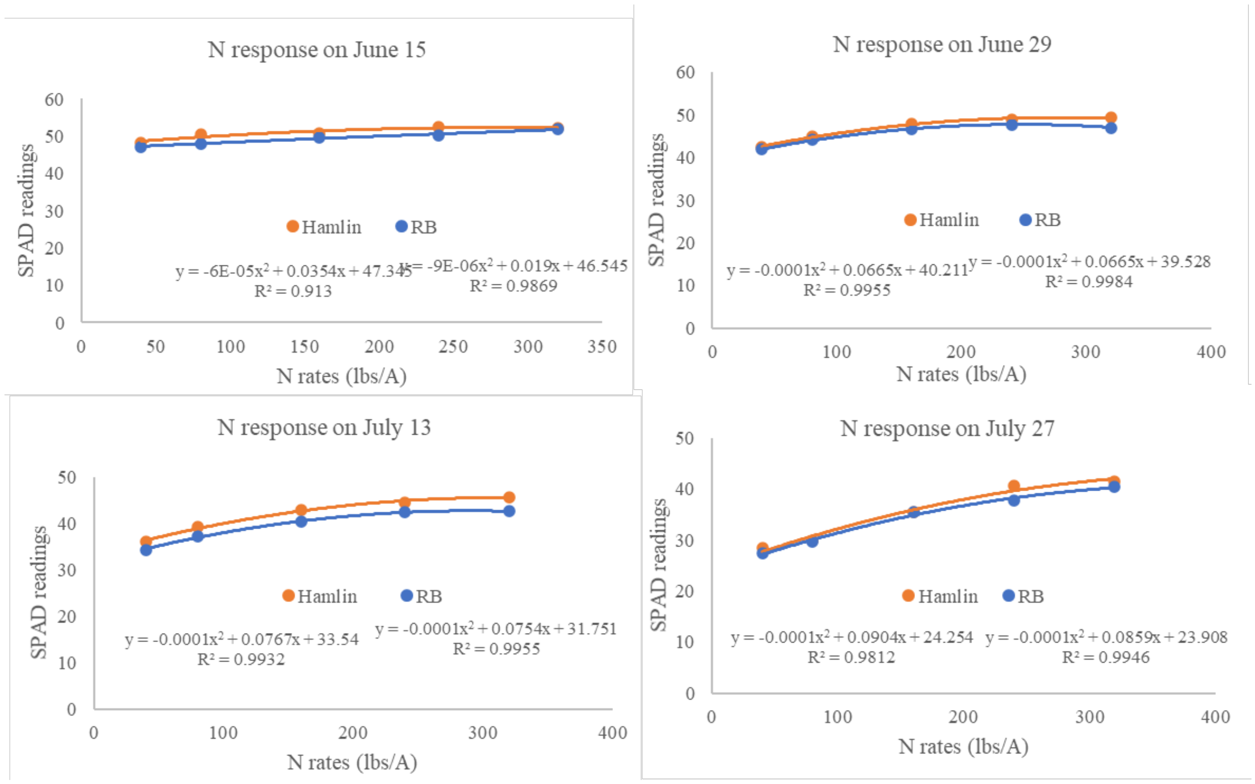

Fig. 7. Relationships between N rates and SPAD readings on four measurement dates for Hamlin and Russet Burbank.

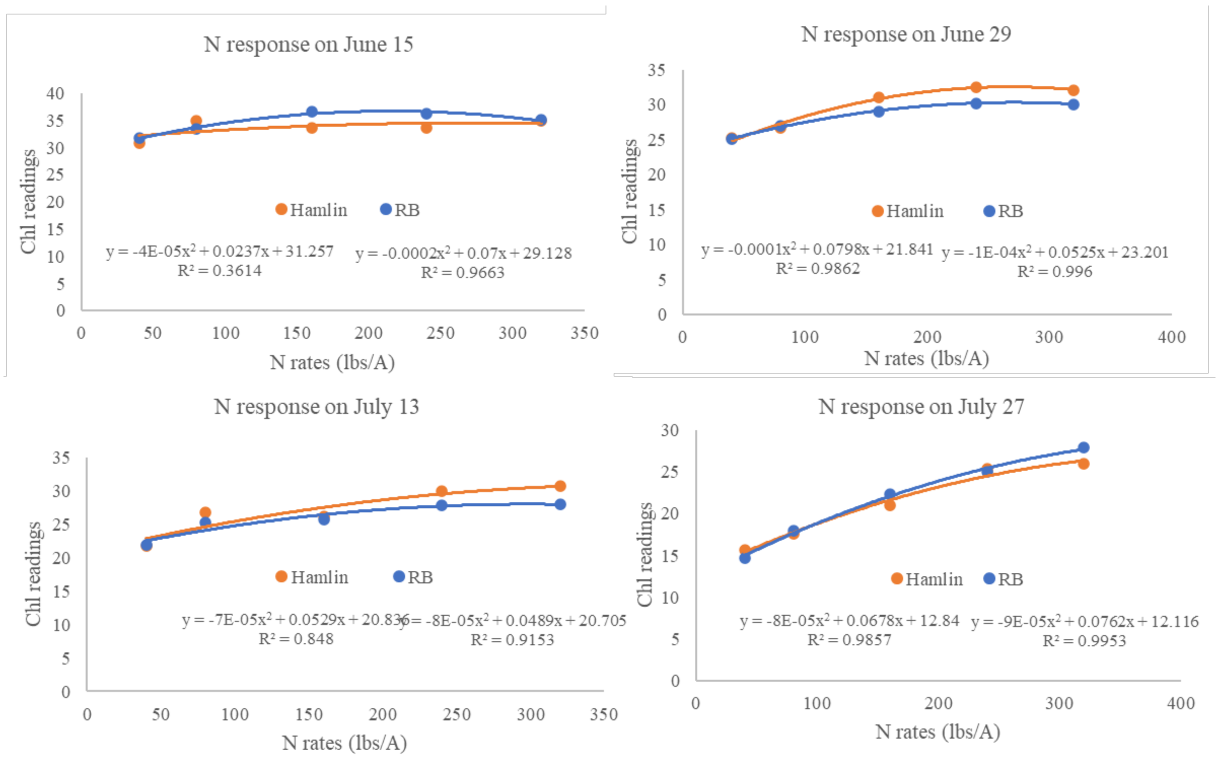

Fig. 8. Relationships between N rates and Dualex Chl readings on four measurement dates for Hamlin and Russet Burbank.

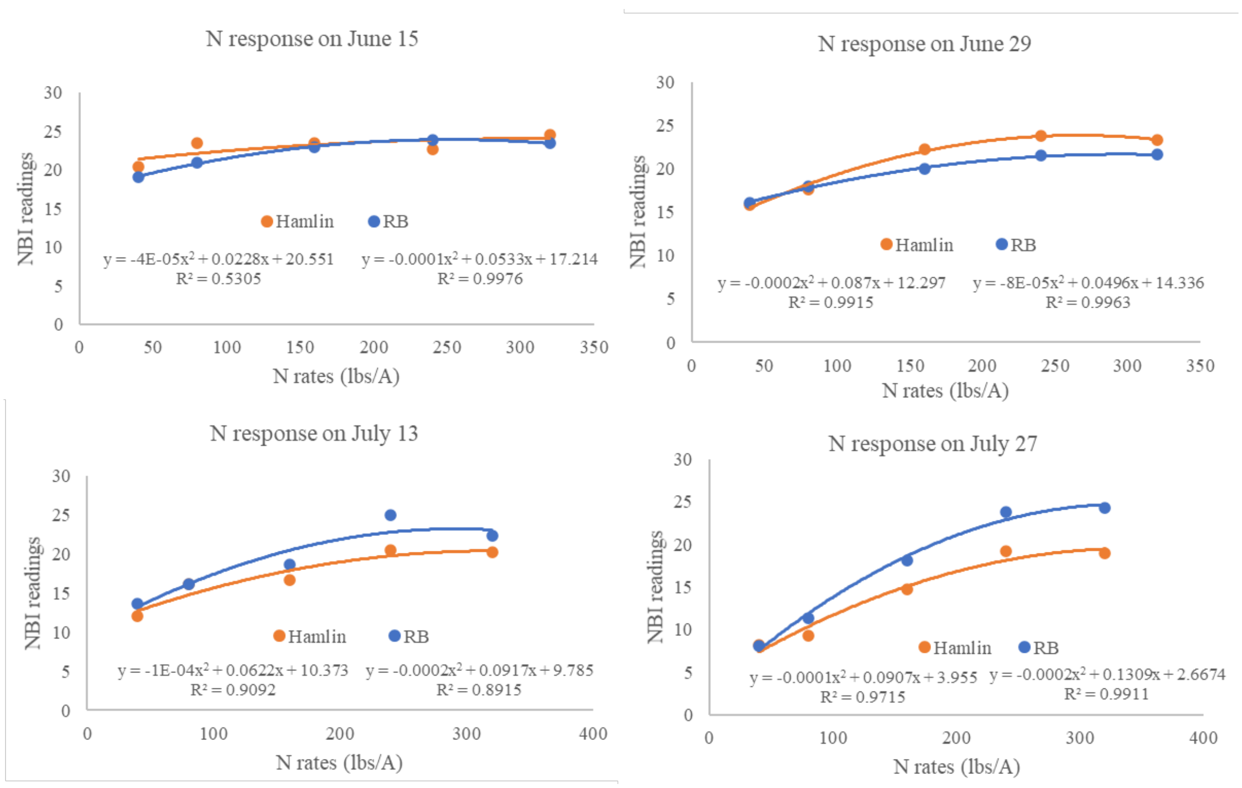

Fig. 9. Relationships between N rates and Dualex NBI readings on four measurement dates for Hamlin and Russet Burbank.

Active Canopy Sensor data response to N rates at different growth stages

Figures 10 and 11 show the relationships between CCP sensor-based normalized difference vegetation index (NDVI) or normalized difference red edge (NDRE) and N rates for each cultivar, respectively. Each figure consists of four sub-figures corresponding to each measurement day. On June 15, 2021, the NDVI

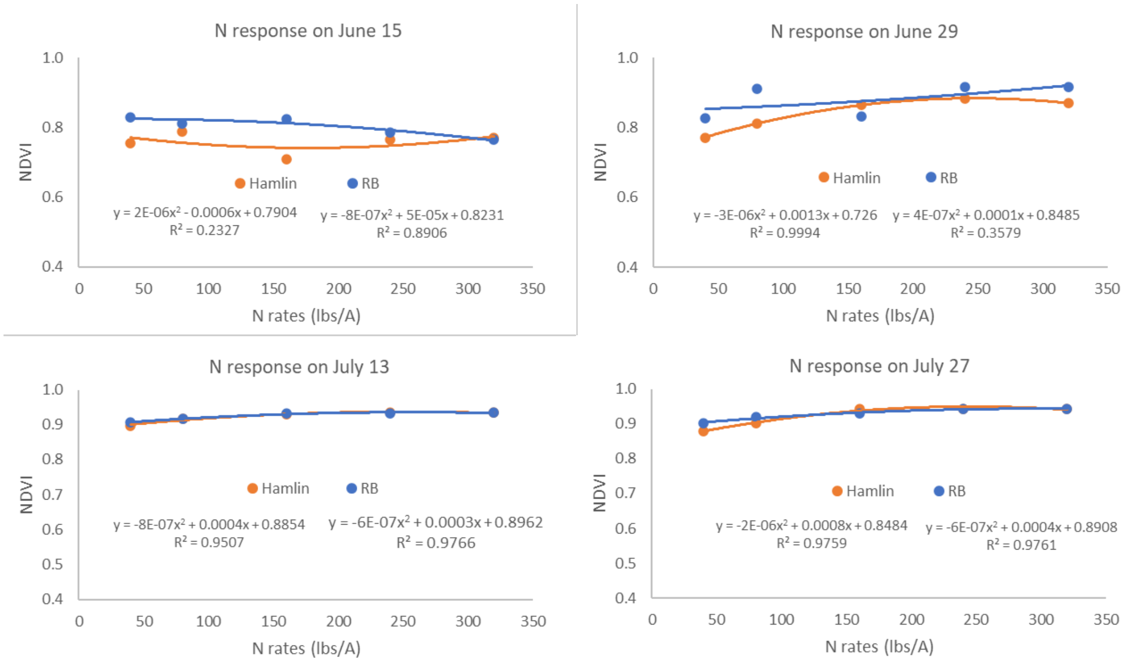

Fig. 10. Relationships between CCP NDVI and N rates and on four measurement dates for Hamlin and Russet Burbank.

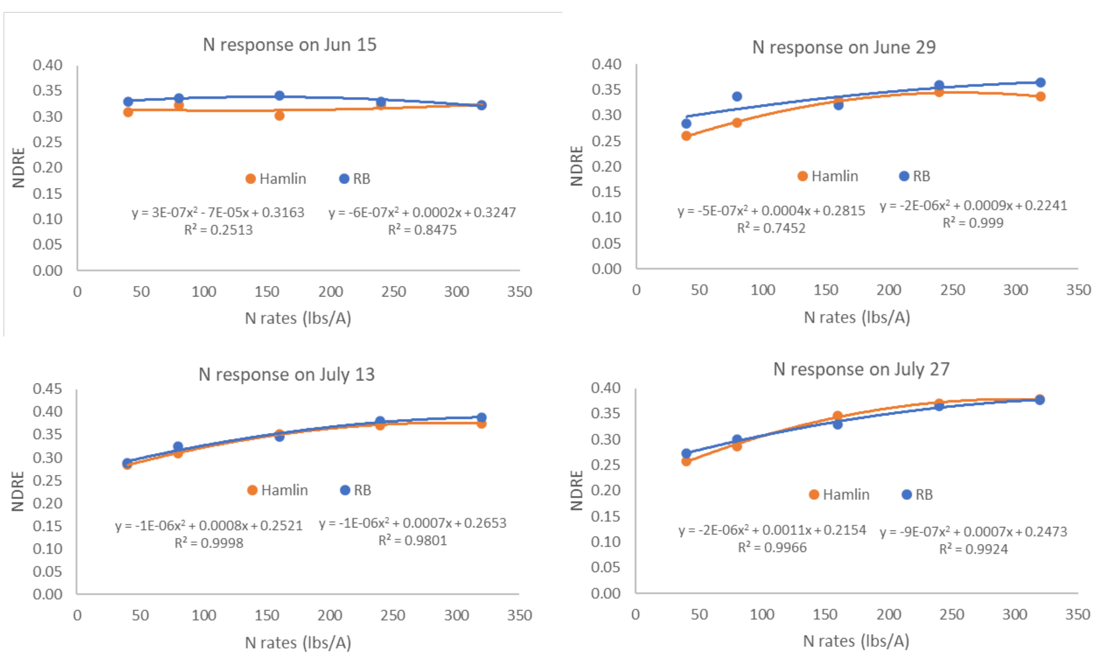

Fig. 11. Relationships between CCP NDRE and N rates on four measurement dates for Hamlin and Russet Burbank.

and NDRE were not significantly affected by N rates, and no N stress was detected. In July, the two cultivars had similar NDVI and NDRE values and responses to N. Their responses to N may not represent tuber yield response to N very well.

Figure 12 shows the air and canopy temperature differences for both cultivars at each N rate. With sufficient water supply, canopy temperature should be lower than air temperature due to the cooling effect of evapotranspiration. When there is water stress, canopy temperature may be similar to or even higher than the air temperature. It is clear that on June 15, the potato plots were water stressed. This sensor may well be a good indicator of plant water stress and could be used to guide variable rate irrigation.

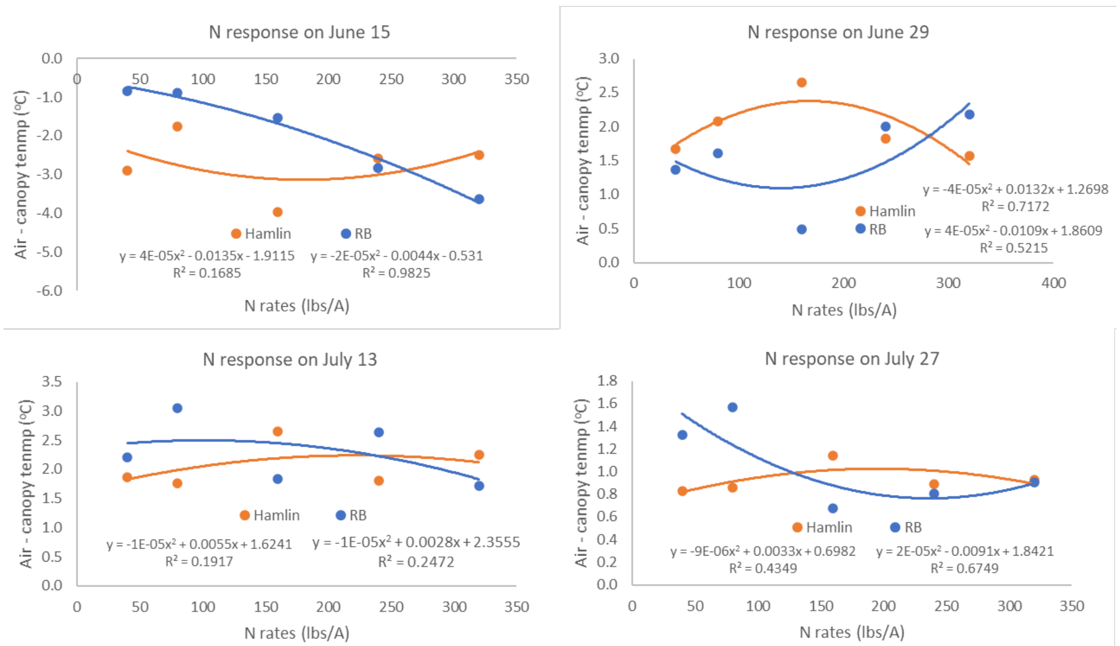

Fig. 12. Air and canopy temperature differences for both cultivars at each N rate.

Using SPAD or Dualex sensor data to predict petiole nitrate N and diagnose N status

The petiole nitrate-N data from this study are still be analzed in the lab, so petiole nitrate-N and SPAD and Dualex sensor data from a N x Cultivar experiment conducred in 2018-2019 were analyzed to determine the potential of using these sensor data to predict petiole nitrate-N concentration. The results SPAD or Dualex sensor data combined with cultivars, accumulated growing degree days, and N rates using random forest regression models could be used to reliably predict petiole nitrate-N concentration across site-years, with similar performance ($R^2 = 0.90$-0.91) (Figure 13).

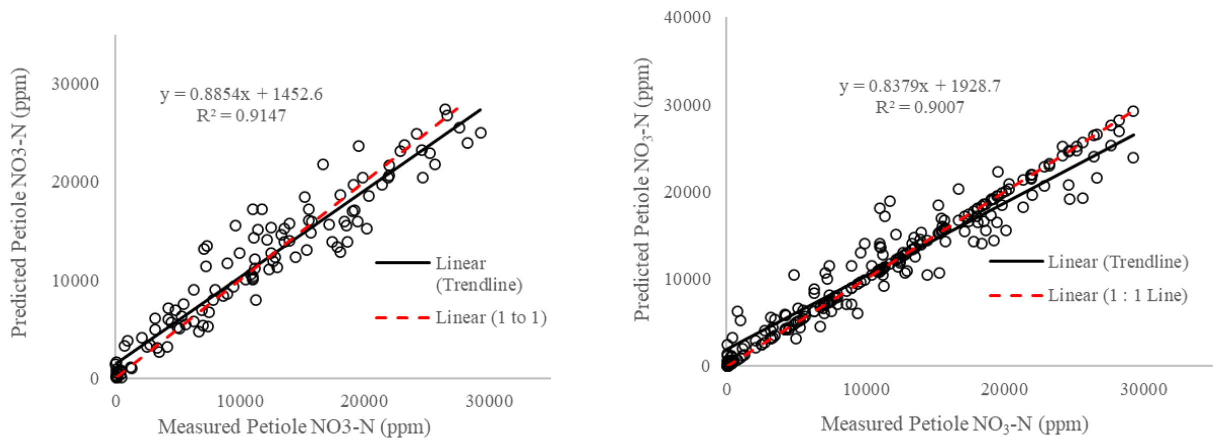

Fig. 13. The correlations between the measured and predicted petiole nitrate N concentrations with random forest regression models using SPAD (left) or Dualex (right) sensor data together with cultivar, accumulated growing degree days and N rates across site-years.

Implications for potato N management

The Hamlin Russet cultivar is more efficient in N use and less responsive to N applications, with a lower optimal N rate than Russet Burbank. This result needs to be confirmed because 2021 was a very dry year. If this is confirmed in further experiments, less N can be applied than Russet Burbank. In 2021 the yield potential of Russet Burbank was higher than Hamlin Russet.

The results based on previous data indicated that petiole nitrate-N could be reliably predicted using machine learning models by combining SPAD meter or Dualex sensor data with cultivar, cumulative growing degree days, and N rate information. This result will be further evaluated when the data from this study are available. If the results can be confirmed, then it means that petiole nitrate-N can be non-destructively estimated nearly real-time during the growing season, without the need to collect petiole samples and send them to the labs for analysis. We can get the results in the field and then make N management decisions right away. More studies are needed to assemble a more representative dataset and develop a machine learning model that can be applied across a large region for practical applications. Studies are also needed to determine the theshold values of petiole nitrate-N for differnet cultivars and growth stages.

Conclusion

The preliminary results of this study indicated that the optimum N rates for total and marketable yield were slightly lower for Hamlin Russet than Russet Burbank. The optimal rates in 2021 for both cultivars were lower than expected, possibly due to high N concentration in the irrigation water, and dry weather conditions. Hamlin Russet produced larger tubers than Russet Burbank regardless of the N rates. Hamlin Russet consistently had higher specific gravity than Russet Burbank. Based on data from previous experiemnts, both SPAD meter and Dualex sensor could be combined together with cultivar, environment, and management information using machine learning to reliably predict petiole nitrate-N well across site-years and cultivars, with similar performance (R2 = 0.90-0.91). The results will be further evaluated when data from this study are avialable. The preliminary result demonstrated the potential of using N efficient cultivars and real-time nondestructive prediction of petiole nitrate-N to improve potato N management. More studies are needed

Acknowledgments

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Evaluation of Sus-Terra as a phosphorus source for Russet Burbank potatoes

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Summary

Phosphorus (P) is important in potato production, and potatoes often show yield responses to P fertilization even when soil-test P is high. Potato growers are increasingly interested in improving soil health in potato cropping systems. The purpose of this study was to evaluate Sus-Terra (Mosaic Co.), which contains 15% organic materials, as a P source for production of Russet Burbank potatoes. The study was conducted at the Sand Plain Research Farm in Becker, MN on a Hubbard loamy sand soil with low soil P (13 ppm). Nine treatments were applied: (1) a zero-P, zero-S control treatment, (2) a treatment receiving 100 lbs/ac P_2O_5 as MAP with no S, (3) a treatment receiving the same P rate as MAP plus S as ammonium sulfate, (4) a treatment receiving the same rate of P plus S as MicroEssentials S10, (5) a treatment receiving the same rate of P plus S as a blend of MicroEssentials S10 and Sus-Terra, with Sus-Terra providing 37% of the P, (6) a treatment receiving 90 lbs/ac P_2O_5 plus S from the same ratio of MicroEssentials S10 and Sus-Terra, (7) a treatment receiving 100 lbs/ac P_2O_5 plus S as a blend of MicroEssentials S10 and Sus-Terra, with Sus-Terra providing 20% of the P, (8) a treatment providing 90 lbs/ac P plus S with the same ratio of MicroEssentials S10 to Sus-Terra, and (9) a treatment receiving 100 lbs/ac P_2O_5 plus S as a blend of Sus-Terra and MAP, with Sus-Terra providing 32% of the P. Every treatment that received P had higher total tuber yield than the zero-P check treatment, and the treatments receiving P taken as a group also had higher U.S. No. 1 yield and total marketable yield and less of their yield represented by tubers over six or ten ounces than the zero-P check treatment. The treatments receiving both P and S, taken as a group, had higher U.S. No. 1 and total marketable yield than the treatment receiving P without S. Among the blends of Sus-Terra and MicroEssentials S10, the application rate of P and the percentage of P provided by Sus-Terra had no significant effect on yield. Tuber specific gravity was higher in the treatments that received P, as a group, than the zero-P control treatment. Tuber dry matter content was not related to treatment, and hollow heart, brown center, and scab were too rare to show a meaningful response to treatment. Overall, Sus-Terra blended with MicroEssentials S10 or MAP appears to be an effective source of P for Russet Burbank potato production but showed no yield differences when compared with conventional sources.

Background

Phosphorus (P) management is important in potato production because P promotes canopy growth, tuber set, and starch production, with positive implications for tuber yield and quality. Potatoes have a high soil P requirement and often show positive yield responses to P fertilization even when initial soil-test P is high (Bray P > 25 ppm).

Managing for increased soil health has become a significant goal in potato production in recent years. Sus-Terra is a newer P product developed to include 15% organic materials and is intended to promote soil microbial activity, support a balanced microbial community, and improve soil health.

The purpose of this study was to evaluate the effectiveness of Sus-Terra fertilizer (Mosaic Co.: 14-24-0-10S) blended with MicroEssentials S10 (Mosaic Co.: 12-40-0-10S) or monoammonium phosphate (MAP: 11-52-0) as a P source relative to MicroEssentials S10 alone or MAP blended with ammonium sulfate (AS: 21-0-0-24S). In previous research, MicroEssentials S10 (Mosaic Co.) has been found to be an effective P source for potato production, comparable to MAP.

Methods

Study design

The study was conducted at the Sand Plain Research Farm in 2021 on a Hubbard loamy sand soil, using a randomized complete block design. The previous crop was soybeans. Each plot received one of nine treatments based on P and S sources received at planting, as summarized in Table 1. The P and S sources applied were MAP (11-52-0), ammonium sulfate (21-0-0-24S), MicroEssentials 10 (12-40-0-10S), and Sus-Terra (14-24-0-10S).

Soil sampling

Soil samples to depths of six inches and two feet were collected throughout the study field on April 5, 2021. The six-inch samples were analyzed for Bray P, acetate-extractable K, Ca, and Mg, DTPA-extractable Fe, Mn, Zn, and Cu, hot-water-soluble B, SO_4^{2-}-S, pH, and loss-on-ignition organic matter content. The two-foot samples were analyzed for NH_4^+-N and NO_3^--N concentrations using a Wescan Nitrogen Analyzer. The results of these analyses are presented in Table 2.

Treatment applications

On April 19, 300 lbs/ac K_2O were broadcast applied MOP (0-0-60). On May 5, the fertilizer treatments were broadcast by hand. Blended with the fertilizer for each treatment were 50 lbs/ac MOP, 160 lbs $MgCl_2$ (25% Mg), 3.1 lbs/ac ZnO (80% Zn), and 6.7 lbs/ac Granubor (15% B), providing 30 lbs/ac K_2O, 40 lbs/ac Mg, 2.5 lbs/ac Zn, as well as enough urea (46-0-0) to bring the total N application rate at planting to 50 lbs/ac. The planting rows were opened mechanically with 36-inch spacing between rows. Two- to three-ounce Russet Burbank seed potatoes were planted by hand with 12-inch spacing, and the rows were closed mechanically. Belay was applied in-furrow for beetle control, along with the systemic fungicide Quadris, and the rows were closed by machine. Weeds, diseases, and insects were controlled using standard practices. Rainfall was supplemented with sprinkler irrigation using the checkbook method of irrigation scheduling.

On May 21, 377 lbs/ac ESN (44-0-0) were sidedressed at hilling, providing 166 lbs/ac N. On June 29 and July 20, 20 lbs/ac N were applied as 28% UAN with irrigation.

Percent stand was assessed for 36 plants in the middle two rows of each plot on June 1 and 7. The number of stems per plant were determined for ten plants in one of the middle two rows on June 14. Petiole samples were collected on June 24 and July 8, 19, and 29. These were dried at 140 °F until their weight was stable and then ground. They will be analyzed for P concentration by the University of Minnesota Research Analytical Laboratory using an ICP spectrometer and for N and S concentrations using an Elementar Vario EL CNS Analyzer.

Vines were chopped with a flail mower on September 15, and tubers were machine-harvested from 36 plants in the middle two rows of each plot on September 23. On October 11, tubers were hand-sorted by size and USDA grade and weighed. A twenty-five-tuber subsample was collected from each plot's harvest sample and assessed for hollow heart, brown center, scab, specific gravity, and dry matter content.

Data analysis

Data were analyzed with SAS 9.4m3® software (copyright 2015, SAS Institute, Inc.) using the GLIMMIX procedure. Data were analyzed as functions of treatment and block. Means for each treatment were calculated and pairwise comparisons between treatments made using the

LSMEANS statement with the DIFF option. Pairwise comparisons were only made when the P-value of the treatment effect in the ANOVA was less than 0.10, and comparisons with P-values less than 0.10 were considered significant. Four CONTRAST statements were used to compare subsets of the treatments, one comparing the zero-P treatment (treatment 1) with treatments 2-9, one comparing the zero-S treatment (treatment 2) with treatments 3-9, one comparing the treatments receiving 90 versus 100 lbs/ac P as a blend of Sus-Terra and MicroEssentials S10 (treatments 6 and 8 versus 5 and 7), and one comparing the treatments receiving 20% of their P as Sus-Terra (treatments 7 and 8) with those receiving 37% of their P as Sus-Terra (treatments 5 and 6).

Results

Tuber yield

Results for tuber yield are presented in Table 3. Total tuber yield was significantly related to treatment, with the zero-P control treatment (treatment 1) having lower yield than any other treatment. Based on the contrast comparing this treatment to the other treatments as a group, the zero-P treatment also had lower U.S. No. 1 yield and marketable yield and a larger percentage of yield represented by tubers over six or ten ounces than the treatments that received P did. Contrasts did not show a significant effect of the ratio of Sus-Terra to MicroEssentials S10 or whether P was applied at 90 or 100 lbs/ac.

Tuber quality

Results for tuber quality are presented in Table 4. Hollow heart, brown center, and scab were all rare, and their prevalence was unrelated to treatment. Based on the contrast comparing the zero-P control treatment (treatment 1) to the treatments receiving P, as a group, the control treatment had a lower specific gravity than the other treatments. Tuber dry matter content was unrelated to treatment.

Conclusions

Our results indicate that blends of MicroEssentals S10 with Sus-Terra perform similarly as P sources to MicroEssentials S10 alone or a conventional blend of MAP with ammonium sulfate. The soil in the study field had a moderate Bray P concentration (15 ppm), and tuber yield and size both responded to fertilization with 90 or 100 lbs/ac P_2O_5, indicating that a response to P source or rate was possible. Based on our results, Sus-Terra blended with MicroEssentials S10 or MAP is an effective P source for potato production but resulted in similar yields when compared with conventional sources.

Table 1. Treatments applied to Russet Burbank potatoes to evaluate Sus-Terra as a source of P.

Treatment		P_2O_5 rate (lbs/ac) from each source:				Other nutrients (lbs/ac)	
Number	Description	MAP[1]	MicroEssentials S10[2]	Sus-Terra[3]	Total	N[5]	S
1	Control	0	0	0	0	0	0
2	MAP	100	0	0	100	21	0
3	MAP/AS[4]	100	0	0	100	21	30
4	MES10	0	100	0	100	30	25
5	63:37 MES10:Sus-Terra, 100 lbs/ac	0	63	37	100	40	31
6	63:37 MES10:Sus-Terra, 90 lbs/ac	0	56	34	90	37	28
7	80:20 MES10:Sus-Terra, 100 lbs/ac	0	80	20	100	36	28
8	80:20 MES10:Sus-Terra, 90 lbs/ac	0	72	18	90	32	26
9	68:32 MAP:Sus-Terra, 100 lbs/ac	68	0	32	100	33	13

[1]Monoammonium phosphate: 11-52-0

[2]MicroEssentials S10: 12-40-0-10S

[3]Sus-Terra: 14-24-0-10S

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

[5]N was supplemented with urea to supply 50 lbs/ac total in every treatment

Table 2. Soil characteristics prior to fertilizer application.

0 - 2 feet	0 - 6 inches				
Primary macronutrients			Secondary macronutrients		
NO_3^--N	Bray P	K	Ca	Mg	SO_4-S
(mg·kg^{-1} soil)					
4.5	15	86	970	204	5.1

0 - 6 inches							
Micronutrients					Other characteristics		Cation exchange capacity
Fe	Mn	Zn	Cu	B	pH	Organic matter (%)	
(mg·kg^{-1} soil)							
32	9.7	2.1	0.60	0.21	6.5	2.0	6.5

Table 3. Effects of P treatments on Russet Burbank tuber yield, size, and grade. Values within a column that have a letter in common are not significantly different from each other based on pairwise comparisons. Pairwise comparisons were only applied when the treatment effect was significant (P <0.10).

Treatment		Yield ($CWT \cdot ac^{-1}$)										% yield in tubers over:	
Number	Description	Culled	0 - 4 oz.	4 - 6 oz.	6 - 10 oz.	10 - 14 oz.	> 14 oz.	Total	US No. 1	US No. 2	Marketable	6 oz.	10 oz
1	Control	13	68	75 c	153	80	43	419 b	332	19	351	65	29
2	MAP	5	115	103 ab	186	63	30	497 a	345	37	382	56	19
3	MAP/AS	4	90	102 b	180	78	54	503 a	381	33	414	62	26
4	MicroEssentials S10	4	104	103 ab	204	70	40	521 a	381	36	417	60	21
5	37% Sus-Terra, 100 lbs/ac	3	116	100 b	208	68	44	537 a	389	31	420	60	21
6	37% Sus-Terra, 90 lbs/ac	10	102	110 ab	168	91	45	515 a	396	17	413	59	26
7	20% Sus-Terra, 100 lbs/ac	3	114	104 ab	195	76	53	541 a	399	29	428	60	24
8	20% Sus-Terra, 90 lbs/ac	0	105	110 ab	184	63	60	522 a	381	35	417	58	23
9	MAP:Sus-Terra	1	102	122 a	179	63	47	513 a	390	21	411	56	21
Effect of treatment (P-value)		0.2223	0.2301	***0.0584***	0.1205	0.6049	0.5832	**0.0081**	0.1535	0.1857	0.1175	0.5833	0.3716
Contrasts	Effect of P (1 vs. 3-9)	**0.0172**	**0.0121**	**0.0014**	**0.0154**	0.5484	0.5897	**<0.0001**	**0.0069**	0.1381	**0.0020**	***0.0878***	0.1122
	P rate (5&7 vs. 6&8)	0.5738	0.3739	0.3674	***0.0580***	0.6423	0.6966	0.2980	0.7675	0.5395	0.6150	0.6986	0.4205
	Effect of S (2 vs. 3-9)	0.7496	0.4385	0.6038	0.8862	0.3957	***0.0720***	0.2373	**0.0309**	0.2309	***0.0731***	0.3208	0.1500
	Sus-Terra ratio (5&6 vs. 7&8)	0.1879	0.9981	0.8035	0.9064	0.3516	0.2266	0.7772	0.0897	0.2066	0.7602	0.9721	0.9961

Table 4. Effects of P treatments on hollow heart, brown center, scab, specific gravity, and dry matter content of Russet Burbank tubers.

Treatment Number	Treatment Description	Hollow heart	Brown center	Scab	Specific gravity	Dry matter content (%)
		------------ Percent of tubers ------------				
1	Control	0	0	0	1.0690	20.6
2	MAP	0	0	0	1.0719	21.0
3	MAP/AS	1	1	1	1.0721	21.2
4	MicroEssentials S10	0	0	0	1.0727	20.7
5	37% Sus-Terra, 100 lbs/ac	0	0	0	1.0732	20.1
6	37% Sus-Terra, 90 lbs/ac	0	0	0	1.0736	21.2
7	20% Sus-Terra, 100 lbs/ac	1	1	0	1.0740	21.4
8	20% Sus-Terra, 90 lbs/ac	0	0	0	1.0722	20.2
9	MAP:Sus-Terra	1	1	0	1.0731	20.5
Effect of treatment (P-value)		0.6761	0.6761	0.4613	0.1568	0.8132
Contrasts	Effect of P (1 vs. 2-9)	0.5212	0.5212	0.6920	**0.0030**	0.8814
	P rate (5&7 vs. 6&8)	0.3523	0.3523	1.0000	0.5439	0.9778
	Effect of S (2 vs. 3-9)	0.5212	0.5212	0.6920	0.3572	0.7525
	Sus-Terra ratio (5&6 vs. 7&8)	0.3523	0.3523	1.0000	0.7975	0.8410

Yield and quality responses of Ivory Russet and Russet Burbank potatoes to P rate, banded P application, soil fumigation, and mycorrhizal inoculation in high-P soils, year two

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Summary

Potato yield often responds positively to phosphorus (P) fertilizer even in soils with high soil-test P, suggesting that potatoes are not efficient at taking up P. This may be attributable to their short root systems or poor formation of mycorrhizal associations, possibly as a side effect of soil fumigation to control soilborne pathogens. Banded placement of P should place more P within reach of plant root systems, while inoculating seed with mycorrhizae may increase the number of mycorrhizae formed. Root system reach, ability to form mycorrhizae, and P use efficiency all potentially vary among cultivars. We conducted an experiment to assess the roles soil fumigation, fertilizer placement, inoculation with mycorrhizal fungi, and potato cultivar play in determining P use efficiency. We used a split-split-plot randomized complete block design with four replicates. Whole plots were defined by fumigation treatment (no fumigant or fall-applied Vapam) and subplots by cultivar (Ivory Russet or Russet Burbank). Sub-subplots were defined by nine P treatments: five in which P was broadcast-applied at different rates (0, 75, 150, 300, or 450 $lbs \cdot ac^{-1}$ P_2O_5), two in which the mycorrhizal product MycoGold Liquid was applied in-furrow at planting and P was broadcast at 0 or 150 $lbs \cdot ac^{-1}$ P_2O_5, and two in which P was banded at 75 or 150 $lbs \cdot ac^{-1}$ P_2O_5. Total and marketable yield were higher in fumigated plots than unfumigated control plots, and this effect was stronger in Russet Burbank than Ivory Russet. Russet Burbank had higher total and marketable yield than Ivory Russet overall. Yield increased linearly with P rate in both cultivars, and the slope of this relationship was not significantly different between the two cultivars. Marketable yield showed a stronger response to P rate in fumigated plots than unfumigated control plots. Banded application resulted in higher yield than broadcast application at the same P rates for both cultivars. The percentage of yield represented by tubers over six ounces was higher in Ivory Russet in fumigated soils than in other combinations of fumigation treatment and cultivar, but it was not related to P treatment. Applying MycoGold at planting resulted in decreased yield of U.S. No. 2 tubers and increased prevalence of common scab. In Russet Burbank, hollow heart and brown center were more prevalent in fumigated plots than unfumigated plots overall. The effect of fumigation on these defects varied among P treatments but was not consistently related to P rate, use of MycoGold, or application method. In Ivory Russet, common scab was more common in unfumigated control plots than Vapam-fumigated plots overall, but the effect of fumigation on scab varied among P treatments in a way that was unrelated to P rate, MycoGold application, or P application method. Tuber specific gravity and dry matter content increased with P rate, and this increase was greater in fumigated plots than unfumigated control plots. In end-of-season soil samples, Mehlich-3 P and the phosphate saturation index (PSI: Mehlich-3 Al/P*100) increased with the application rate of P. Both soil P and PSI were higher in unfumigated control plots than plots fumigated with Vapam and in subplots planted in Ivory Russet than Russet Burbank. It is unclear why the two cultivars showed similar yield responses to P treatment when Ivory Russet has shown the stronger response of the two in the past. The robust yield response of Russet Burbank was not due to a lack of available P in the soil. Neither cultivar reached a point at which additional P fertilizer had diminishing returns in tuber size, yield, or tuber specific gravity. Adding mycorrhizal fungi had no significant effect on total yield, indicating that P acquisition in potato plants was not limited by access to mycorrhizal associates. At equivalent P rates, banded application showed benefits to yield, suggesting that root spread may limit P use efficiency in potatoes. Elevated end-of-season Mehlich-3 P and PSI under high application rates of P suggest that the increase in yield with higher P rate comes at a potential cost in increased P losses to the environment.

Background

Potato yield often responds positively to phosphorus (P) applications, even where soil-test P concentrations are high. Consistent with this observation, University of Minnesota Extension recommends a P fertilization rate of 75 $lbs \cdot ac^{-1}$ P_2O_5 in soils with Bray P concentrations over 50 ppm when a yield of at least 400 $cwt \cdot ac^{-1}$ is desired. Yield responses have been observed at much higher application rates, as well – as high as 150 $lbs \cdot ac^{-1}$ P_2O_5 in acidic, irrigated soils.

The fact that potatoes respond positively to P applications even in soils with high soil-test P concentrations suggests that potato plants are not efficient at taking up soil P. This inefficiency has at least two possible causes. First, potato plant root systems rarely extend much more than two feet into the soil, limiting the amount of soil P they have access to. Second, low availability of mycorrhizal associates or poor ability to form mycorrhizal associations may limit the roots' effectiveness at exploiting the P resources within their reach.

The extensiveness of the plant's root system and its ability to form mycorrhizal associations may be influenced by its genetics, so that different cultivars may show different yield responses to P rate. Our previous research at the Sand Plain Research Farm in Becker, MN, has shown that the cultivars Russet Burbank and Ivory Russet differ in their P responses. In a 2019 P response study, in soils with Bray P concentrations of 64 to 78 ppm, the yield of Ivory Russet plants increased with P rate at application rates from 125 to 250 $lbs \cdot ac^{-1}$ P_2O_5. Meanwhile, in soils with much lower Bray P (28 to 31 ppm), Russet Burbank yield did not respond to P rate at application rates between 0 and 80 $lbs \cdot ac^{-1}$ P_2O_5, a situation where a stronger yield response would be expected. This difference in P response was confirmed in a 2020 study in which Ivory Russet yield increased significantly with P rate at two sites with different soil-test P (126 vs. 95 ppm Bray; 198 vs. 136 ppm Mehlich-3 P), in which Ivory Russet showed a significant positive yield response to P in both sites while Russet Burbank did not, although treatments in Russet Burbank receiving P had significantly higher yield than the zero-P check treatment. As a determinate cultivar, Ivory Russet may have a less extensive root system than indeterminate Russet Burbank. There may also be differences between the two cultivars in terms of their potential to form mycorrhizal associations.

If P use efficiency is limited by the ability of plants to capture P within the range of their root systems, and if mycorrhizal associations enhance this ability, then soil fumigation to control soil-borne pathogens (including fungal pathogens), may be detrimental to P use efficiency. If so, applying mycorrhizal products at planting might fully or partially reverse this effect, increasing P use efficiency in fumigated soils more than unfumigated soils, where native mycorrhizal fungi may be more abundant.

Another factor affecting P uptake is placement. If potato P uptake is limited by the extensiveness of the plant's root network, P uptake efficiency could be improved by placing P closer to the plants through banded application.

Bray P may not be the best indicator of the potential for potatoes to respond to P application in acid soils. Research in Eastern Canada has found that a simple P saturation index (PSI; Mehlich-3 P / Mehlich-3 Al * 100) may work better for this purpose, since it accounts for fixation of available P by soluble Al, which is more abundant at lower soil pH. The researchers suggest two critical PSI values – 19.2% where pH < 5.5 and 14.2% where pH > 5.5 – above which P fertilization should be limited to crop requirements to minimize P losses to leaching.

The objectives of this study were to evaluate how potato yield responses to P rate are affected by (1) cultivar, (2) soil fumigation with Vapam, (3) applying MycoGold Liquid (MycoGold LLC), a mycorrhizal product, in-furrow at planting, and (4) banded versus broadcast application of P fertilizer. These results will be considered in the context of the site's PSI, Bray P, and Mehlich-3 P.

Methods

Study design

The study was conducted at the Sand Plain Research Farm in 2020 on a Hubbard loamy sand soil. The previous crop was soybeans. A split-split-plot randomized complete block design was used. Whole plots were defined by fumigation treatment, each plot either receiving Vapam in the fall before planting or no fumigant. Each plot was divided into two subplots defined by cultivar – either Ivory Russet or Russet Burbank. Each subplot was further divided into nine sub-subplots, each receiving one of nine P application treatments: (1) a check treatment receiving no P; four treatments receiving (2) 75, (3) 130, (4) 300, or (5) 450 $lbs \cdot ac^{-1}$ P_2O_5 as triple super phosphate (TSP; 0-45-0-15Ca) broadcast before planting; two treatments being inoculated in-furrow with the mycorrhizal product MycoGold Liquid at planting and receiving either (6) zero or (7) 150 $lbs \cdot ac^{-1}$ P_2O_5 as TSP broadcast before planting; and two treatments receiving either (8) 75 or (9) 150 $lbs \cdot ac^{-1}$ P_2O_5 as TSP banded at planting. A summary of these treatments is presented in Table 1.

Initial soil characteristics

To measure initial soil characteristics, soil samples to depths of six inches and two feet were collected from both fumigation treatments in each block on April 1, 2021. The six-inch samples were analyzed for Bray P, NH_4-acetate-soluble K, hot-water-soluble B, Ca-phosphate extractable SO_4^{2-}-S, pH, loss-on-ignition organic matter content, and Mehlich-3 P, Al, Mg, Mn, Fe, Zn, and Cu. The two-foot samples were analyzed for NH_4^+-N and NO_3^--N concentrations using a Wescan Nitrogen Analyzer. The results of these analyses are presented in Table 2.

Treatment applications

Vapam was injected at inches at a rate of 50 $gal \cdot ac^{-1}$ to the appropriate plot in each block on October 14, 2020. The field was irrigated immediately after fumigant application. On April 14, 2021, 165 $lbs \cdot ac^{-1}$ K_2O and 22 $lbs \cdot ac^{-1}$ S were broadcast applied as 200 $lbs \cdot ac^{-1}$ MOP (0-0-60) and 200 $lbs \cdot ac^{-1}$ SulPoMag (0-0-22-21S-11Mg). TSP was broadcast in treatments 2-5 and 7 on April 19 (blocks 1 & 2) and 20 (blocks 3 & 4).

The subplots were planted with either Ivory Russet or Russet Burbank on April 28 (blocks 1 & 2) and 29 (blocks 3 & 4). TSP was mechanically banded to either side of each furrow at row opening in treatments 8 and 9. Two- to three-ounce cut seed potatoes were planted by hand in the open furrows, with 12 inches between tubers within the rows and 3-foot spacing between rows. Before row closure on April 29, MycoGold Liquid Inoculant was applied in-furrow with a backpack sprayer at a rate of 2 $oz \cdot ac^{-1}$ to tubers in treatments 6 and 7. At row closure, a blend of 87 $lbs \cdot ac^{-1}$ urea (46-0-0), 233 $lbs \cdot ac^{-1}$ MOP, 191 $lbs \cdot ac^{-1}$ SulPoMag, 2.8 $lbs \cdot ac^{-1}$ $ZnSO_4$ (35.5% Zn, 17.5% S), and 3.3 $lbs \cdot ac^{-1}$ Boron 15 (15% B) was mechanically banded in all treatments, supplying 40 $lbs \cdot ac^{-1}$ N, 180 $lbs \cdot ac^{-1}$ K_2O, 40 $lbs \cdot ac^{-1}$ S, 21 $lbs \cdot ac^{-1}$ Mg, 1 $lb \cdot ac^{-1}$ Zn, and 0.5 $lbs \cdot ac^{-1}$ B. All treatments received 150 $lbs \cdot ac^{-1}$ N as ESN (44-0-0, Nutrien, Ltd.) and 60 $lbs \cdot ac^{-1}$ N as urea mechanically banded at hilling so that 250 $lbs \cdot ac^{-1}$ N were applied in total.

Petiole sampling

Petioles were collected on June 23 and July 7 and 21. The petiole of the fourth mature leaf from the shoot tip was collected from 30 leaves per plot. Petioles were dried at 140°F until their weight was stable and then ground. They will be analyzed for nitrate concentration using a Wescan

Nitrogen Analyzer and for P concentration at the University of Minnesota Research Analytical Laboratory using an ICP spectrometer.

Harvest

Vines were chopped with a flail mower on September 8. Tubers were harvested from the central 18 feet from middle two rows in each sub-subplot in blocks 1-3 on September 22 and block 4 the following day. Most tubers were machine-sorted on September 28-29 and October 1. Due to an equipment failure, the remaining tubers were sorted by hand on October 8. A 25-tuber subsample was collected for each plot and analyzed for hollow heart, brown center, common scab, specific gravity, and dry matter content. End-of-season soil samples to a depth of 6 inches were collected from each sub-subplot on September 30 and analyzed for pH and Mehlich-3 Al and P.

Statistical analyses

Dependent variables were analyzed as functions of fumigation treatment, cultivar, P treatment, their interactions, and block using the GLIMMIX procedure in SAS 9.4. The effects of whole plot (fumigation*block) and subplots (fumigation*cultivar*block) were treated as fixed effects. If the effects of fumigation, cultivar, P treatment, or their interactions were statistically significant at $P \leq 0.10$), pairwise comparisons were evaluated using Fisher's LSD with the DIFF option in the LSMEANS statement of the model. Pairs of values were considered different if the difference was at least marginally significant ($P \leq 0.10$). Five treatment comparisons were made using CONTRAST statements. Treatments 1 – 5 were compared in (1) a check-versus-P comparison and (2) linear and (3) quadratic contrasts on the application rate of P; (4) treatments 1 and 3 were compared with treatments 6 and 7 to evaluate the effect of adding mycorrhizae; and (5) treatments 2 and 3 were compared with treatments 8 and 9 to evaluate the effect of broadcast versus banded P application.

Results

Tuber yield

Results for tuber yield are presented in Table 3. Averaged between cultivars and across P treatments, the plots fumigated with Vapam had higher total, marketable, and U.S. No. 1 yields, but lower U.S. No. 2 yields, than the non-fumigated control plots. Averaged across fumigation treatments and P treatments, Russet Burbank had higher total, marketable, and U.S. No. 1 yields than Ivory Russet. The effect of fumigation on yield was larger in Russet Burbank than Ivory Russet, resulting in a significant effect of the fumigant*cultivar interaction (Figure 1). Total, marketable, and U.S. No.1 yield were also related to P treatment. Yield linearly increased with application rate of P for both cultivars. Additionally, total and marketable yield were higher in the treatments receiving P in a banded application (treatments 8 and 9) than in the corresponding treatments receiving a broadcast application (treatments 2 and 3). The effect of the interaction between fumigation treatment and P treatment on marketable yield was significant, with the linear regression line of the yield response to P rate being steeper in Vapam-treated plots than unfumigated control plots (Figure 2). Based on the equations of these regression lines, the treatments receiving 75 and 150 $lbs \cdot ac^{-1}$ P_2O_5 in banded applications (P treatments 8 and 9, respectively) produced yields equivalent to what would be obtained by broadcasting 76 and 241 $lbs \cdot ac^{-1}$ P_2O_5, respectively, in non-fumigated control plots and 194 and 301 $lbs \cdot ac^{-1}$ P_2O_5, respectively, in Vapam-treated plots. U.S. No. 2 yield was also related to P treatment, with the treatments receiving mycorrhizae (P treatments 6 and 7) having lower U.S. No.2 yields than the corresponding treatments without mycorrhizae (P treatments 1 and 3).

Averaged across P treatments, subplots planted in Ivory Russet and fumigated with Vapam had a larger percentage of their yield in tubers over six ounces than unfumigated control plots with Ivory Russet or Russet Burbank subplots in fumigated or unfumigated plots, all of which had similar percentages of yield in tubers over six ounces to each other. The percentage of yield in tubers over six ounces was not related to P treatment. The effect of the interaction between fumigation treatment and P treatment on the percentage of yield represented by tubers over ten ounces was marginally significant ($P < 0.10$), but there was no clear pattern to which treatments had more yield in tubers over ten ounces with Vapam application (treatments 3, 5, and 9) and which had less (treatment 2).

Tuber quality

Results for tuber quality are presented in Table 4. Hollow heart and brown center in Russet Burbank were less common in Vapam-fumigated plots than unfumigated control plots. The prevalence of either defect in Russet Burbank was more consistent across P treatments in Vapam-treated plots than unfumigated plots, in which some P treatments had hollow heart in up to 15% of tubers. In unfumigated control plots, the prevalence of hollow heart or brown center and the effect of fumigation on prevalence were unrelated to P rate or the use of the mycorrhizal product, but brown center was somewhat more prevalent in sub-subplots that received a banded application of P (treatments 8 and 9) than those where P was broadcast-applied at the same rates (treatments 2 and 3). In contrast, since both defects were rare or absent in Ivory Russet, their prevalence responded to neither fumigation treatment nor P treatment in this cultivar, resulting in significant three-way interaction of cultivar, fumigation treatment, and P treatment.

A three-way interaction effect was also observed in the prevalence of common scab. Russet Burbank had a lower average prevalence of scab than Ivory Russet, and its scab prevalence was therefore less responsive to fumigation treatment and P treatment. Among subplots with Ivory Russet, the prevalence of scab and the effect of fumigation on scab prevalence varied among P treatments, but neither scab prevalence nor the effect of fumigation on scab were related to P rate or banded application of P. However, scab was more prevalent, overall, in the treatments receiving MycoGold Liquid (treatments 6 and 7) than in the matched control treatments (treatments 1 and 3).

Tuber specific gravity and dry matter content were higher in Vapam-fumigated plots than unfumigated control plots and in Ivory Russet tubers than Russet Burbank tubers. Specific gravity and dry matter content increased with increasing P rate but were not significantly affected by the method of P application (banded vs. broadcast) or the addition of mycorrhizal fungi. Specific gravity exhibited a more pronounced response to P rate in plots fumigated with Vapam than unfumigated control plots (Figure 3), resulting in a marginally significant ($P < 0.10$) effect of the interaction between fumigation and P treatment.

End-of-season soil P, PSI, and pH

Results for end-of-season soil Mehlich-3 Al and P concentration, PSI, and pH are presented in Table 5. Mehlich-3 Al concentration was higher in Vapam-fumigated plots than unfumigated control plots. Subplots with Ivory Russet potatoes had higher end-of season soil Al and P concentrations than those with Russet Burbank potatoes, on average. Mehlich-3P concentration was also related to P treatment, increasing linearly with P rate. The use of MycoGold and the method of P application had no significant effect on residual Al and P concentrations.

End-of-season PSI showed very similar responses to treatment as Mehlich-3 P, overall. PSI was higher in unfumigated control plots than Vapam-fumigated plots, and it was higher in subplots planted in Ivory Russet than those in Russet Burbank. PSI increased with P rate and was not significantly influenced by the use of MycoGold or banded P application. The effect of the interaction between cultivar and P treatment was significant. While PSI was higher when Ivory Russet was the cultivar regardless of P treatment (averaged across fumigation treatments), the difference between the two cultivars varied from treatment to treatment. The magnitude of this difference did not appear to be related to P rate, MycoGold, or banded application.

Soil pH was higher in unfumigated control plots than in Vapam-fumigated plots and in subplots with Russet Burbank than those with Ivory Russet. Among the broadcast treatments without MycoGold, pH decreased linearly with increasing P rate. MycoGold and banded application had no significant effect on end-of-season soil pH. The effect of the three-way interaction of fumigation, cultivar, and P treatment on soil pH was significant. The effect of P rate on pH appeared to be stronger in Russet Burbank than Ivory Russet and, among Russet Burbank subplots, it appeared to be stronger in plots fumigated with Vapam than unfumigated control plots. The apparent effects of MycoGold and banded application on soil pH varied with P rate, cultivar, and fumigation treatment.

Conclusions

Contrary to our expectations and prior experience, the two cultivars did not show significantly different yield responses to P rate in this study. It is not clear why the two cultivars responded to P rate similarly when Ivory Russet has shown a stronger response than Russet Burbank in the past, including in two fields in which a similar study was conducted in 2020. The soils in the current study had Bray and Mehlich-3 P concentrations intermediate between those of the two fields used in 2020 (Bray P: 105-115 ppm vs. 95 and 126 ppm; Mehlich-3 P: 162-172 ppm vs. 136 and 198 ppm), but a lower PSI than either of them (18.8-18.9% vs. 21.4% and 23.3%). Perhaps this lower PSI explains why Russet Burbank showed a significant yield response to P rate in 2021 and not 2020. However, given the neutral pH of the site (pH: 6.8 – 6.9) and a previously identified critical threshold PSI of 14.2% in mineral soils with pH over 5.5, this explanation seems unlikely.

Although we applied up to six times the recommended amount of P fertilizer, both cultivars showed linear yield and specific gravity responses to P rate across the range we tested. Since the percentage of yield represented by tubers over either six or ten ounces did not change significantly with P rate based on linear contrasts, the yield response to P rate was probably due less to tuber bulking than tuber set. Previous research has found that high rates of P fertilizer in soils with lower soil-test P concentrations promote tuber set, sometimes at the expense of tuber bulking. In these higher P testing soils, it is not clear why tuber bulking was apparently unaffected by P rate in this study.

Applying a MycoGold Liquid in-furrow decreased the yield of U.S. No. 2 tubers. It also increased the prevalence of common scab when P was applied at 150 $lbs \cdot ac^{-1}$ P_2O_5. However, it had no significant effect on other key yield and quality variables. These results indicate that access to mycorrhizal associates was not a major limitation on P use efficiency in potato, even after fumigation with Vapam.

In contrast to last year's results, banded application of P produced slightly but significantly higher total and marketable yield than broadcast application at the same rates in both cultivars. The effect of banded application on yield suggests that the extensiveness of the plant root system under some conditions may limit the ability of potato plants to take up available soil P.

The positive relationship between P rate and end-of-season Mehlich-3 P concentration and PSI suggests that, while increasing P rate increased tuber yield and, presumably, P uptake, potato plants did not make efficient use of the higher available P. Although high P rates may increase yield significantly, even in soils with high soil-test P, this higher yield comes at a cost in terms of the amount of available P left in the soil at the end of the year, potentially increasing P losses to the environment.

Table 1. Phosphorus fertilization treatments applied to Vapam-fumigated and unfumigated Ivory Russet and Russet Burbank potatoes.

Treatment			
Number	P_2O_5 rate (lbs/ac)	Application	Mycorrhizae?[1]
1	0	NA	No
2	75	Broadcast	No
3	130	Broadcast	No
4	300	Broadcast	No
5	450	Broadcast	No
6	0	NA	Yes
7	150	Broadcast	Yes
8	75	Banded	No
9	150	Banded	No

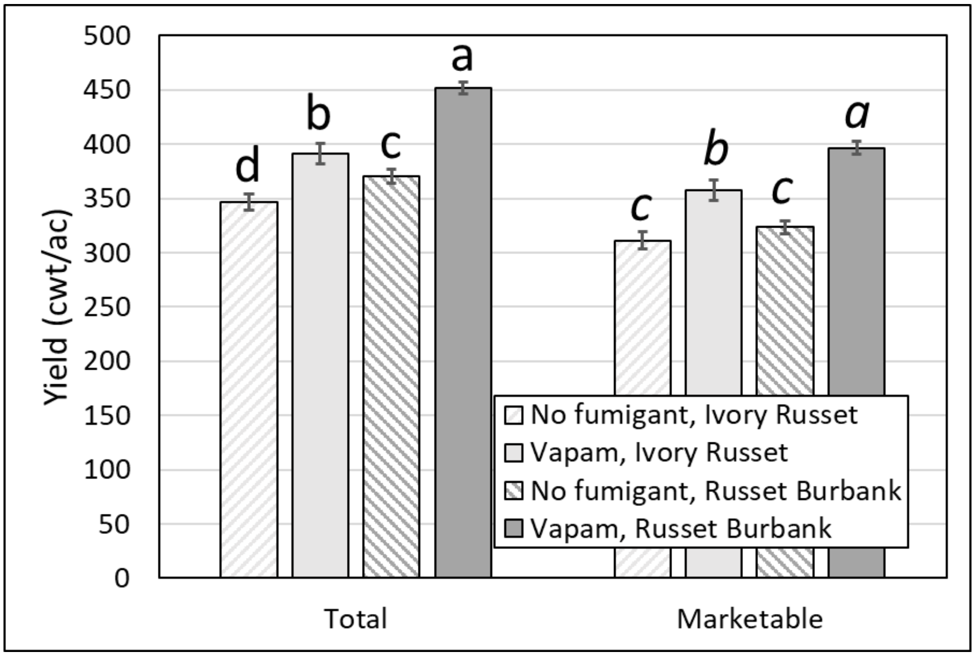
[1]Applied in-furrow at planting with a hand sprayer

Table 2. Soil characteristics before fertilizer application in Vapam-fumigated and unfumigated control plots.

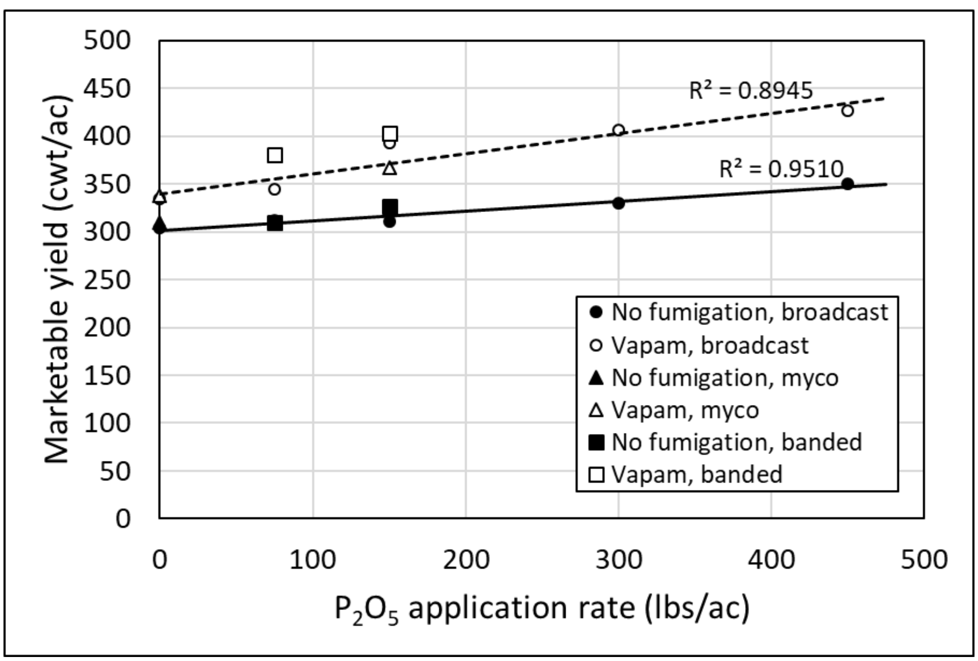
	0 - 6 inches														0 - 2 feet
Fumigation treatment	Bray P (ppm)	Mehlich-3 P (ppm)	Mehlich-3 Al (ppm)	PSI (%)	pH	Organic matter (%)	NH_4OAc-K	Mehlich-3 Ca	Mehlich-3 Mg	Mehlich-3 Mn	Mehlich-3 Fe	Mehlich-3 Zn	Mehlich-3 Cu	Hot water B	SO_4^{2-}-S	NO_3^--N (ppm)
							------- ppm -------									
Control	105	172	913	18.9	6.9	2.4	254	1256	273	35	105	4.9	1.4	0.3	6	6
Vapam	115	162	862	18.8	6.8	2.5	232	1126	241	34	103	4.6	1.3	0.3	6	

Table 3. Effects of fumigation treatment, cultivar, and P treatment on tuber yield, size, and grade. Within each main effect, values within a column that have a letter in common are not significantly different from each other in post-hoc pairwise comparisons. Letters are only presented when the main effect the value pertains to (fumigation treatment, cultivar, or P treatment) is significant (P<0.10).

Treatment description			Yield (CWT·ac^{-1})										% yield in tubers over:	
Fumigant	Cultivar	P treatment	Culled	0 - 4 oz.	4 - 6 oz.	6 - 10 oz.	10 - 14 oz.	> 14 oz.	Total	US No. 1	US No. 2	Marketable	6 oz.	10 oz
None	Average of both	Average of all	4.7	41 b	85 b	118 b	75 b	39 b	358 b	288 b	29 a	317 b	64 b	31
Vapam			4.0	45 a	95 a	141 a	86 a	56 a	422 a	352 a	25 b	377 a	67 a	34
Average of both	Ivory Russet	Average of all	3.5 b	35 b	87 b	128	77 b	43 b	369 b	306 b	29	335 b	67 a	32
	Russet Burbank		5.2 a	51 a	94 a	131	83 a	52 a	411 a	334 a	26	360 a	65 b	33
Average of both	Average of both	1: 0 lbs/ac, myc -	6.1	41	82	114 d	78 bcd	45	360 e	288 d	31	319 f	66	34
		2: 75 lbs/ac broad myc -	3.8	42	91	123 bcd	72 cd	42	370 e	304 cd	24	328 ef	64	31
		3: 150 lbs/ac broad myc -	4.7	40	87	135 ab	86 ab	43	391 cd	322 bc	29	351 bcd	68	33
		4: 300 lbs/ac broad myc -	2.5	48	96	140 a	81 abc	51	416 ab	341 ab	28	368 b	65	32
		5: 450 lbs/ac broad myc -	3.1	41	102	142 a	91 a	54	429 a	359 a	30	388 a	67	34
		6: 0 lbs/ac, myc +	5.5	45	86	116 cd	69 d	40	357 e	291 d	21	312 f	63	31
		7: 150 lbs/ac broad myc +	3.9	41	86	128 abc	79 bcd	55	389 d	323 bc	26	348 cd	67	34
		8: 75 lbs/ac band myc -	6.2	44	91	129 ab	81 abcd	44	389 d	320 bc	25	345 de	65	32
		9: 150 lbs/ac band myc -	3.1	44	91	138 a	83 ab	53	409 bc	334 b	30	365 bc	67	33
ANOVA effects	Fumigant		0.4370	*0.0891*	**0.0058**	**<0.0001**	**0.0008**	**<0.0001**	**<0.0001**	**<0.0001**	*0.0849*	**<0.0001**	**0.0257**	0.1099
	Cultivar		**0.0455**	**<0.0001**	**0.0341**	0.4726	*0.0667*	**0.0047**	**<0.0001**	**<0.0001**	0.1466	**<0.0001**	*0.0754*	0.4543
	P treatment		0.2480	0.7738	0.2896	**0.0016**	*0.0572*	0.2075	**<0.0001**	**<0.0001**	0.5031	**<0.0001**	0.5836	0.8683
	Fumigant*cultivar		0.8741	**0.0163**	**0.0167**	*0.0517*	0.9206	0.3471	**0.0009**	**0.0018**	**0.0092**	**0.0166**	**0.0483**	**0.0332**
	Fumigant*P treatment		0.7392	**0.0322**	0.8571	0.6276	**0.0112**	0.1321	0.2653	0.1196	0.5161	*0.0882*	0.5469	*0.0623*
	Cultivar*P treatment		0.1467	0.2954	0.6023	0.9690	0.2452	0.3062	0.8178	0.9968	0.1873	0.7994	0.2831	0.3891
	Fumigant*cultivar*P treatment		*0.0985*	0.8290	0.9798	0.8334	0.5139	0.7830	0.8581	0.9848	0.2806	0.9296	0.9604	0.8880
Contrasts on P treatment	P addition (1 v 2 - 5)		*0.0577*	0.6290	*0.0506*	**0.0008**	0.4414	0.6072	**<0.0001**	**<0.0001**	0.3600	**<0.0001**	0.9762	0.4012
	Linear P rate (1 - 5)		*0.0694*	0.5391	**0.0091**	**0.0002**	**0.0233**	*0.0560*	**<0.0001**	**<0.0001**	0.8809	**<0.0001**	0.5255	0.8576
	Quadratic P rate (1 - 5)		0.3473	0.3596	0.9569	*0.0805*	0.6875	0.6150	0.2871	0.3709	0.4847	0.4845	0.9852	0.3639
	Mycorrhizae (1&3 v 6&7)		0.5639	0.4549	0.7957	0.7003	*0.0871*	0.4057	0.7398	0.8543	*0.0534*	0.5321	0.3810	0.6146
	Broadcast v band (2&3 v 8&9)		0.7246	0.3056	0.7531	0.4419	0.5605	0.2009	**0.0247**	0.1263	0.7298	*0.0655*	0.8167	0.7221



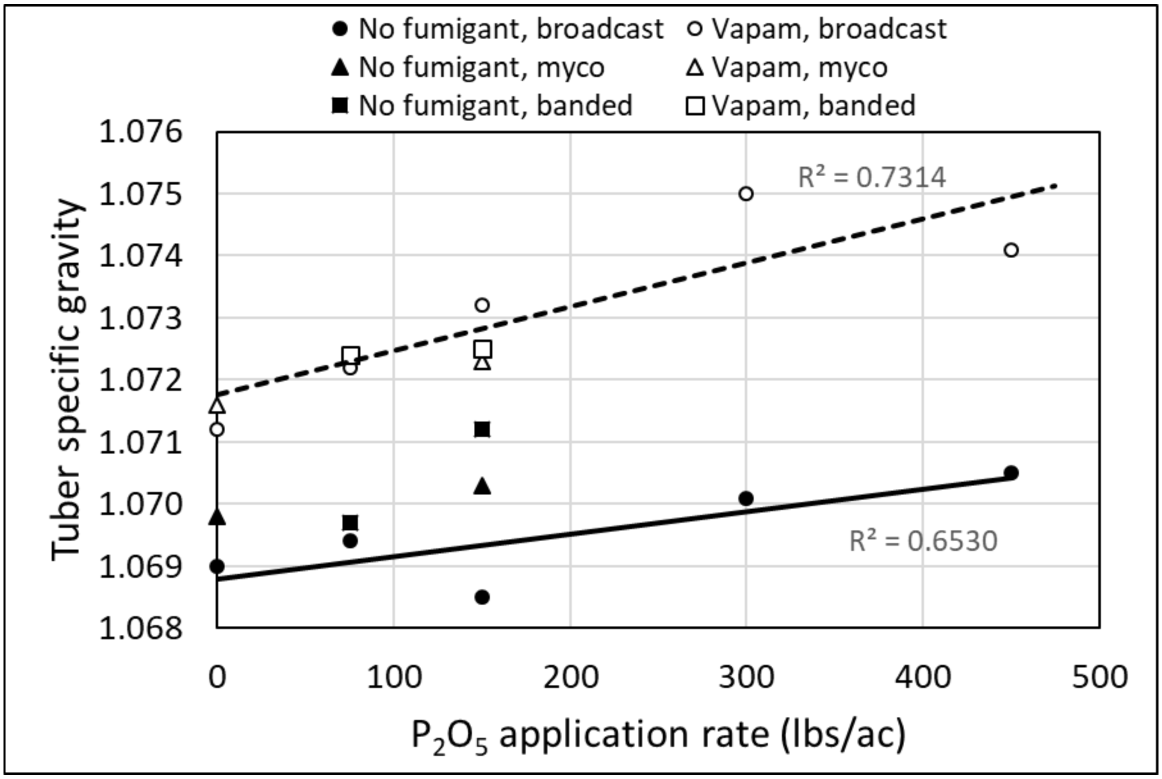
500
450
400
350
300
250
200
150
100
50
0
Yield (cwt/ac)
a
b
c
d
a
b
c
c
No fumigant, Ivory Russet
Vapam, Ivory Russet
No fumigant, Russet Burbank
Vapam, Russet Burbank
Total
Marketable



Marketable yield (cwt/ac)
500
450
400
350
300
250
200
150
100
50
0
R² = 0.8945
R² = 0.9510
No fumigation, broadcast
Vapam, broadcast
No fumigation, myco
Vapam, myco
No fumigation, banded
Vapam, banded
0
100
200
300
400
500
P2O5 application rate (lbs/ac)

Table 4. Effects of fumigation treatment, cultivar, and P treatment on tuber quality. Within each main effect, values within a column that have a letter in common are not significantly different from each other in post-hoc pairwise comparisons. Letters are only presented when the main effect the value pertains to (fumigation treatment, cultivar, or P treatment) is significant (P<0.10).

Treatment description			Hollow heart	Brown center	Scab	Specific gravity	Dry matter (%)
Fumigant	Cultivar	P treatment	Percent of tubers				
None	Average of both	Average of all	4.3 a	3.2 a	6.7 a	1.0698 b	18.6 b
Vapam			1.6 b	0.9 b	2.9 b	1.0727 a	19.2 a
Average of both	Ivory Russet	Average of all	0.1 b	0.0 b	7.4 a	1.0756 a	19.9 a
	Russet Burbank		5.8 a	4.1 a	2.2 b	1.0669 b	17.9 b
Average of both	Average of both	1: 0 lbs/ac, myc -	2.8	1.0 c	3.3 c	1.0701 e	18.3 e
		2: 75 lbs/ac broad myc -	2.8	1.3 bc	4.8 bc	1.0708 cde	18.7 cde
		3: 150 lbs/ac broad myc -	1.5	1.3 bc	3.5 c	1.0708 cde	19.1 abcd
		4: 300 lbs/ac broad myc -	3.5	3.0 ab	3.3 c	1.0726 a	19.3 ab
		5: 450 lbs/ac broad myc -	3.3	1.8 bc	5.5 abc	1.0723 ab	19.5 a
		6: 0 lbs/ac, myc +	3.0	2.0 bc	3.8 c	1.0707 de	18.5 e
		7: 150 lbs/ac broad myc +	3.3	2.8 abc	7.8 a	1.0713 bcd	18.6 de
		8: 75 lbs/ac band myc -	2.0	1.0 d	7.5 ab	1.0710 cde	18.8 bcde
		9: 150 lbs/ac band myc -	4.5	4.5 a	4.0 c	1.0719 abc	19.3 abc
ANOVA effects		Fumigant	**<0.0001**	**<0.0001**	**<0.0001**	**<0.0001**	**0.0019**
		Cultivar	**<0.0001**	**<0.0001**	**<0.0001**	**<0.0001**	**<0.0001**
		P treatment	0.4510	**0.0289**	**0.0487**	**0.0057**	**0.0078**
		Fumigant*cultivar	**<0.0001**	**<0.0001**	***0.0928***	0.8054	0.7199
		Fumigant*P treatment	***0.0815***	**0.0280**	**0.0048**	***0.0819***	0.1761
		Cultivar*P treatment	0.3073	**0.0289**	***0.0596***	0.8109	0.8830
		Fumigant*cultivar*P treatment	***0.0799***	**0.0280**	**0.0003**	0.3758	0.9747
Contrasts on P treatment		P addition (1 v 2 - 5)	0.9936	0.3487	0.4725	**0.0069**	**0.0023**
		Linear P rate (1 - 5)	0.4117	0.2057	0.3929	**<0.0001**	**0.0005**
		Quadratic P rate (1 - 5)	0.5940	0.3436	0.4803	0.2721	0.1762
		Mycorrhizae (1&3 v 6&7)	0.2526	0.1108	***0.0559***	0.2712	0.4725
		Broadcast v band (2&3 v 8&9)	0.2047	***0.0581***	0.1886	0.1784	0.7480



No fumigant, broadcast
Vapam, broadcast
No fumigant, myco
Vapam, myco
No fumigant, banded
Vapam, banded
Tuber specific gravity
1.076
1.075
1.074
1.073
1.072
1.071
1.070
1.069
1.068
R² = 0.7314
R² = 0.6530
0
100
200
300
400
500
P2O5 application rate (lbs/ac)

Table 5. Effects of fumigation treatment, cultivar, and P treatment on end-of-season soil Mehlich-3 Al and P, phosphate saturation index (PSI), and pH. Within each main effect, values within a column that have a letter in common are not significantly different from each other in post-hoc pairwise comparisons. Letters are only presented when the main effect the value pertains to (fumigation treatment, cultivar, or P treatment) is significant (P<0.10).

Treatment description			Mehlich-3 concentration (ppm)		PSI (%)	pH
Fumigant	Cultivar	P treatment	Al	P		
None	Average of both	Average of all	992 b	221	22.2 a	6.63 a
Vapam			1024 a	219	21.4 b	6.57 b
Average of both	Ivory Russet	Average of all	1026 a	236 a	23.0 a	6.58 b
	Russet Burbank		990 b	204 b	20.6 b	6.62 a
Average of both	Average of both	1: 0 lbs/ac, myc -	1001	192 e	19.2 f	6.69 a
		2: 75 lbs/ac broad myc -	992	202 de	20.4 e	6.62 abc
		3: 150 lbs/ac broad myc -	1019	221 c	21.7 cd	6.62 abc
		4: 300 lbs/ac broad myc -	993	241 b	24.2 b	6.60 bc
		5: 450 lbs/ac broad myc -	1004	273 a	27.2 a	6.49 d
		6: 0 lbs/ac, myc +	1018	198 e	19.3 f	6.62 abc
		7: 150 lbs/ac broad myc +	1003	217 c	21.6 cd	6.64 ab
		8: 75 lbs/ac band myc -	1027	213 cd	20.8 de	6.56 cd
		9: 150 lbs/ac band myc -	1013	221 c	21.8 c	6.58 bc
ANOVA effects		Fumigant	**0.0105**	0.6942	**0.0027**	**0.0058**
		Cultivar	**0.0033**	**<0.0001**	**<0.0001**	***0.0629***
		Fumigant*cultivar	0.1260	0.1983	0.8452	0.1795
		P treatment	0.8952	**<0.0001**	**<0.0001**	**0.0118**
		Fumigant*P treatment	0.5122	0.6253	0.2819	0.3723
		Cultivar*P treatment	0.9259	0.4364	**0.0479**	0.5559
		Fumigant*cultivar*P treatment	0.1297	0.1278	0.5569	**0.0360**
Contrasts on P treatment		P addition (1 v 2 - 5)	0.9560	**<0.0001**	**<0.0001**	**0.0055**
		Linear P rate (1 - 5)	0.9893	**<0.0001**	**<0.0001**	**0.0002**
		Quadratic P rate (1 - 5)	0.8786	0.7849	0.5297	0.6762
		Mycorrhizae (1&3 v 6&7)	0.9799	0.8645	0.8957	0.4553
		Broadcast v band (2&3 v 8&9)	0.4352	0.3617	0.5666	0.1489

Interactive effects of biostimulants and nitrogen on potato yield and quality

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Summary

Plant biostimulants are substances, including humic acids and botanicals, or microbes applied to plants to improve crop nutrient use efficiency, stress tolerance, yield, or quality through mechanisms other than simple nutrient input. Their effectiveness in potato production has not been fully explored. The objective of this study was to evaluate the effects of biostimulant products on Russet Burbank tuber yield and quality under different nitrogen (N) regimes. We conducted an experiment with a split-plot randomized complete block design and four replicates. Whole plots were defined by which of four biostimulant treatments and five N treatments were assigned to them, and subplots were defined by whether or not the assigned biostimulant was applied. The four biostimulant treatments were (1) B Sure, (2) B Sure plus iNvigorate, (3) Radiate, and (4) Radiate plus Accomplish. The five N treatments were (1) a check treatment receiving no N beyond 40 $lbs \cdot ac^{-1}$ N applied to the whole field as DAP (18-46-0) at planting, (2 and 3) treatments receiving an additional 126 and 252 $lbs \cdot ac^{-1}$ N, respectively, as ESN at emergence, (4) a treatment receiving an additional 126 $lbs \cdot ac^{-1}$ N as chicken manure before planting, and (5) a treatment receiving the chicken manure plus 166 $lbs \cdot ac^{-1}$ N as ESN at emergence. In plots assigned to B Sure, B Sure plus iNvigorate, or Radiate, averaged across N treatments, marketable yield and the percentage of yield represented by tubers over six ounces were slightly and not significantly greater in subplots where the biostimulant treatment was applied than those where it was not. In plots assigned to Radiate plus Accomplish, however, these metrics were significantly lower in subplots where the biostimulant treatment was applied. The trends were similar for the percentage of tubers that weighed more than six ounces but applying biostimulant significantly increased this percentage in plots assigned to B Sure or B Sure plus Accomplish, while biostimulant application did not significantly affect this percentage in plots assigned to Radiate or Radiate plus Accomplish. Averaging across assigned biostimulants and whether they were applied, total and marketable yield were higher in plots receiving 166 $lbs \cdot ac^{-1}$ N total than those receiving 292 $lbs \cdot ac^{-1}$ N, and at the lower N rate, yield was higher in the plots receiving manure than those receiving ESN. The check treatment had lower marketable yield than the other N treatments taken as a group, but the same was not true of total yield. The percentage of yield in tubers over six ounces was lower in the check treatment than in any of the other N treatments, which did not differ from each other. The check treatment had more tubers per plant than the other treatments as a group, and the treatments receiving 166 $lbs \cdot ac^{-1}$ N total had more tubers per plant than the treatments receiving 292 $lbs \cdot ac^{-1}$ N total. Biostimulant application had no effect on the prevalence of hollow heart, brown center, or scab, nor on tuber specific gravity or dry matter content. Averaged across assigned biostimulant treatments and whether they were applied, hollow heart and brown center were less prevalent in the check treatment than in the treatments receiving supplemental N, as a group, and the treatments receiving 166 $lbs \cdot ac^{-1}$ N total had less hollow heart than those receiving 292 $lbs \cdot ac^{-1}$ N. The prevalence of scab was higher, overall, in the treatments receiving 292 $lbs \cdot ac^{-1}$ N total than those receiving 166 $lbs \cdot ac^{-1}$ N total. Tuber specific gravity and dry matter content were higher in the treatments receiving ESN without manure than it was in the check treatment or the treatments receiving manure before planting. Overall, these results suggest that applying biostimulants can have effects on tuber yield or size, but these effects may be small or even negative. What effect a biostimulant has on yield may be related to its mechanism of action, but this would require further study. How biostimulant application affected tuber yield was not significantly influenced by the N treatment applied.

Background

Plant biostimulants are a broad category of agricultural products intended to improve crop nutrient use efficiency, tolerance to stress, yield, or quality through mechanisms other than simple nutrient input. They include humic acids, proteins, botanicals, and beneficial soil microorganisms. Although the market for biostimulants is growing rapidly, many of these products have not been evaluated in potato growing systems, and their effectiveness in potato agriculture is therefore uncertain. To address this question, we evaluated four biostimulant treatments on Russet Burbank potatoes at the Sand Plain Research Farm in Becker, MN.

B Sure (Agrinos) is a microbial fermentation product intended to promote plant metabolism, health, and root growth, resulting in increased yield and stress tolerance in a variety of different crops. We evaluated B Sure alone and in combination with iNvigorate (Agrinos), another microbial product intended to increase root growth, improving nutrient uptake, stress resistance, and crop quality.

Radiate (Loveland) is also intended to stimulate root growth, leading to increased nutrient use efficiency, stress tolerance, and crop quality. We evaluated this product both alone and in combination with Accomplish LM (Loveland), which contains beneficial bacteria and is intended to increase nutrient availability, stimulate microbial activity, improve root growth, nutrient use efficiency, stress tolerance, and yield.

The effectiveness of biostimulants in promoting yield may depend on the rate and form of N applied. Because biostimulants are intended to promote nutrient use efficiency, they may be more effective at low N rates at which yields are more responsive to differences in N uptake than at high rates. The effectiveness of microbial-based biostimulants may also depend on whether nutrient sources are chemical or organic. Manure, for example, contains a highly diverse suite of microorganisms, some of which may produce products functionally similar to those provided by biostimulants.

The overall objective of this study was to evaluate the effectiveness of biostimulant products under various nitrogen regimes on Russet Burbank potato yield and quality. To accomplish this goal, we conducted an experiment with a split-plot randomized complete block design in which the whole plots were defined by which of four biostimulant treatments (described above) and five nitrogen treatments were assigned to them, and the subplots were defined by whether or not the assigned biostimulant was applied. The five nitrogen treatments were designed to evaluate effects of N rate and source: (1) a control treatment receiving no N beyond 40 lbs/ac applied to the entire field at planting, (2 and 3) treatments receiving 126 or 252 additional lbs/ac N, respectively, as ESN (44-0-0) at emergence, and (4 and 5) treatments receiving additional N at the same rates, but with 126 lbs/ac N supplied as composted chicken manure before planting and, in treatment 5, 126 lbs/ac N provided as ESN at emergence.

Methods

Study design

The study was conducted at the Sand Plain Research Farm in 2021 on a Hubbard loamy sand soil using a split-plot randomized complete block design. The previous crop was rye. Whole plots were defined by N treatment and the biostimulant or biostimulants being evaluated. There were five N treatments: (1) a check treatment that received no N beyond 40 lbs·ac^{-1} applied to the whole field at planting, (2) a treatment receiving 126 lbs·ac^{-1} N as ESN (44-0-0) at emergence (166 lbs·ac^{-1} N total), (3) a treatment receiving 252 lbs·ac^{-1} N as ESN at emergence (292 lbs·ac^{-1} N total), (4) a treatment receiving 126 lbs·ac^{-1} N as poultry manure one week before planting (166 lbs·ac^{-1} N total), and (5) a treatment receiving 126 lbs·ac^{-1} N as poultry manure one week before planting plus 126 lbs·ac^{-1} N as ESN at emergence (292 lbs·ac^{-1} N total). Four biostimulant treatments were applied: B Sure, B Sure plus iNvigorate, Radiate, and Radiate plus Accomplish LM. Subplots were defined by whether or not the biostimulant assigned to the plot was applied. These treatments are summarized in Table 1.

Initial soil characteristics

Soil samples to depths of six inches and two feet were collected from each block on April 5, 2021. The six-inch samples were analyzed for Bray P, NH_4-acetate-extractable K, Ca, and Mg, DTPA-extractable Fe, Mn, Zn, and Cu, hot-water-soluble B, Ca-phosphate SO_4^{2-}-S, pH, and loss-on-ignition organic matter content. The two-foot samples were analyzed for NH_4^+-N and NO_3^--N concentrations using a Wescan Nitrogen Analyzer. The results of these analyses are presented in Table 2.

Treatment applications

Poultry manure was applied at a rate that provided 126 $lbs \cdot ac^{-1}$ N to whole plots receiving N treatments 4 and 5 on April 13 and 14. On April 15, the entire field was fertilized with 400 $lbs \cdot ac^{-1}$ MOP (0-0-60), providing 240 $lbs \cdot ac^{-1}$ K_2O.

Blocks 1 and 2 were planted on April 20, and blocks 3 and 4 were planted the following day. Furrows spaced 36 inches apart were opened by machine, two- to three-ounce Russet Burbank seed potatoes were placed by hand 12 inches apart in each furrow, and the appropriate biostimulant was applied in-furrow with a backpack sprayer to each subplot designated to receive it. Biostimulant was mixed with 19 gal/ac water and applied at the following rates according to treatment: 2 pt/ac B Sure, 4 pt/ac iNvigorate, 4 oz/ac Radiate, and 4 pt/ac Accomplish.

Belay was applied in-furrow at planting for beetle control, along with the systemic fungicide Quadris. At row closure, a planting 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 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.

ESN was applied in the plots designated to receive treatments 2, 3, and 5 at hilling, on May 17, to achieve the designated N rates. Foliar biostimulant applications were made according to treatment at the same rates used at planting with a backpack sprayer on June 23 and a tractor sprayer on July 8. Plant stand was determined in the central 18 feet of the central row of each subplot on May 26 and June 3, and the number of stems per plant was determined for 10 plants in the same row on June 3. Petioles were collected from the fourth mature leaf from the shoot tip from 20 plants per subplot on June 15 and 29 and July 13 and 27. These were dried at 140 °F until their weight was stable and ground. They will be analyzed for NO_3^--N concentration using a Wescan Nitrogen Analyzer. On the same days petioles were collected, terminal leaflet chlorophyll contents were measured on the fourth mature leaf from the shoot tip on 20 plants per subplot using a SPAD-502 Chlorophyll Meter (Konica Minolta).

Canopy cover was evaluated using the Canopeo application on May 26, June 1, 8, 15, 22, and 28, July 7, 13, 20, and 27, August 3, 10, 17, 25, and 31, and September 7.

On September 13, five plants from one of the two central rows of each subplot were hand-dug for tuber counts. On September 15, vines were sampled from the rest of the central row of each subplot to measure N uptake into vines. On September 16, all remaining vines were chopped with a flail mower. The remaining 31 plants from the central two harvest rows of each subplot were machine-harvested on September 24. Tubers from this sample were hand-sorted by size and grade on October 18-19 and 25-29, and the tubers from the five-plant hand-dug samples were sorted and counted by hand on November 1. While only the tubers from the five-plant samples were counted, tubers from both samples in each size/grade category were weighed to estimate yield per acre. A twenty-five-tuber subsample was collected from each plot's harvest sample and assessed for hollow heart, brown center, scab, specific gravity, and dry matter content.

Data analysis

Dependent variables were analyzed as functions of N treatment and the biostimulant used in the plot (whole-plot level), whether the biostimulant was applied (subplot level), and their interactions, using the GLIMMIX procedure in SAS 9.4. Block and the three-way interaction of biostimulant ID with N treatment and block (the whole-plot effect) were treated as fixed effects. If biostimulant use and its interactions were significant at $P \leq 0.10$, pairwise comparisons were evaluated using Fisher's LSD with the DIFF option in the LSMEANS statement of the model. Pairs of values were considered different if the difference was at least marginally significant ($P \leq 0.10$). Pairwise comparisons were not made for effects that did not include biostimulant use (i.e., biostimulant ID, N treatment, and their interaction) because these interactions provide no indication of whether applying biostimulant had any effect. Three treatment comparisons on N treatment were made using CONTRAST statements: (1) a comparison of the treatment receiving 40 $lbs \cdot ac^{-1}$ N total (treatment 1) with the remaining treatments, (2) a comparison of the two treatments receiving 166 $lbs \cdot ac^{-1}$ N total (treatments 2 and 4) with those receiving 292 $lbs \cdot ac^{-1}$ N total (treatments 3 and 5), and (3) a comparison of the two treatments receiving no manure (treatments 2 and 3) with the two treatments receiving manure (treatments 4 and 5).

Results and discussion:

Tuber yield:

ANOVA model results for tuber yield are presented in Table 3. In these results, effects of biostimulant use on yield would be indicated by significant interaction effects between stimulant ID, N treatment, or both, and whether or not biostimulant was applied. For example, a significant effect of the identity of the biostimulant selected with whether it was applied or not on total yield would indicate a difference among the biostimulants in how much (and possibly in which direction) they affected total yield.

Based on this criterion, the four biostimulant treatments differed in their effects on the yields of U.S. No. 1 and 2 tubers, marketable yield, the percentage of yield represented by tubers over six or ten ounces, and the percentage of tubers weighing more than six ounces. In plots assigned to B Sure, B Sure plus iNvigorate, or Radiate, both marketable yield and the percentage of yield in tubers over six ounces were slightly but not significantly higher when biostimulant was applied than when it was not (Figure 1). However, in plots assigned Radiate plus Accomplish, marketable yield and the percentage of yield in tubers over six ounces were significantly lower when biostimulant was applied than when it was not. Accomplish was the only product evaluated that contained beneficial bacteria and claimed to stimulate microbial growth or increase nutrient availability, suggesting that it has a distinct mechanism of action from the others that may have contributed to the difference in yield performance. The percentage of tubers weighing more than six ounces showed similar trends, but the effect of Radiate plus Accomplish was not significant, while the percentage greater than 6 oz. was significantly greater when either B Sure or B Sure plus iNvigorate were applied than when they were not (Figure 2).

The three-way interaction of N treatment with biostimulant identity and whether or not the biostimulant was applied had a marginally significant relationship ($P < 0.10$) with the percentage of yield represented by tubers over 6 ounces (Table 4). Based on pairwise comparisons, among plots assigned no supplemental N (N treatment 1) with B Sure as the biostimulant, the percentage of yield in tubers over 6 ounces was higher when the biostimulant was applied. The same was true of plots assigned 292 lbs·ac^{-1} N total without manure (N treatment 3) with B Sure plus iNvigorate. In contrast, in plots assigned either no supplemental N or 166 lbs·ac^{-1} N total with manure (N treatments 1 and 4) and Radiate plus Accomplish as the biostimulant treatment, the percentage of yield in tubers over 6 ounces was lower when biostimulant was applied than when it was not.

Averaged across stimulant treatments, total and marketable yield responded to N treatment (Figure 3). While the mean total yield of the check treatment (N treatment 1) was about average for the study, this treatment had the lowest mean marketable yield of the five N treatments, with significantly lower marketable yield than either treatment receiving 166 lbs·ac^{-1} N (N treatments 2 and 4). Both total and marketable yield were higher in the treatments receiving 166 lbs·ac^{-1} N total (N treatments 2 and 4) than those receiving 292 lbs·ac^{-1} N total (N treatments 3 and 5), though the difference in marketable yield was significant only when supplemental N was provided by chicken manure (N treatment 4 versus 5). At the 166 lbs·ac^{-1} N application rate, the treatment that received 166 lbs·ac^{-1} N as manure before planting (N treatment 4) had significantly higher total and marketable yield than the treatment that received the same amount as ESN at emergence (N treatment 2).

Tuber number per plant decreased with the application rate of N, averaging across stimulant treatments (Figure 4). N source had no significant effect on tuber set (N treatment 2 vs. 4 and 3 vs. 5).

Averaging across stimulant treatments, the treatment receiving no supplemental N (treatment 1) had less of its yield in tubers over six ounces than any of the other treatments, which did not differ significantly from each other (Figure 5).

Tuber quality:

Overall results for tuber quality are presented in Table 4. As was true with yield, tuber quality showed few significant responses to whether biostimulant was applied.

The prevalence of hollow heart and brown center were related to N treatment averaged across biostimulant treatments (Figure 6). Hollow heart was least prevalent in the low-N control treatment (N treatment 1) and increased in prevalence with N rate regardless of N source. Brown center was also least prevalent in the low-N control, but while its prevalence increased with N rate when ESN was the supplemental N source (N treatments 2 and 3), the same was not true when chicken manure was the source (N treatments 4 and 5).

The prevalence of scab was not significantly related to treatment. However, the linear contrast on N rate was significant because the treatments receiving 292 lbs·ac^{-1} N total (N treatments 3 and 5) had slightly more scab, on average (1.01% ± 1.78% and 1.28% ± 2.81%, respectively), than the treatments receiving 166 lbs·ac^{-1} N total (N treatments 2 and 4; 0.50% ± 1.68% and 0.13% ± 0.71%).

Tuber specific gravity was also not significantly related to treatment. Based on contrast results, the N control treatment (N treatment 1) had lower specific gravity, on average, than the other four N treatments combined (N treatments 2 through 5). In addition, the treatments receiving manure before planting (N treatments 4 and 5) had lower specific gravity, on average (SG = 1.7024 ± 0.0016 and 1.7024 ± 0021, respectively; mean ± standard deviation), than the treatments receiving ESN at emergence (N treatments 2 and 3; SG = 1.7033 ± 0.0021 and 1.7033 ± 0.0026, respectively).

Tuber dry matter content was marginally significantly related to the three-way interaction of biostimulant ID, N treatment, and whether or not the biostimulant was applied. For each biostimulant, the magnitude and direction of the effect that applying the biostimulant had on dry matter content depended on the N treatment. However, the effect of adding biostimulant was not associated with N rate or the use of manure versus ESN as a supplemental N source. Averaged across N treatments and whether or not the assigned biostimulant was applied, the plots receiving B Sure or Radiate alone had higher dry matter content than the plots receiving B Sure plus iNvigorate or Radiate plus Accomplish (Figure 7). However, the effect of the interaction between biostimulant ID and whether or not it was applied was not significant, suggesting that the main effect of biostimulant ID may have occurred by chance and not as an effect of which biostimulant was assigned to each plot.

Conclusions

Overall, these results suggest that biostimulants can have effects on tuber yield or size distribution, but these effects are often small and sometimes negative. The one biostimulant treatment with a significant negative effect on yield included a product, Accomplish LM, that contains beneficial microbes and is intended to stimulate microbial activity and increase nutrient availability, which the other products did not claim to do. This product may have a different mechanism of action that influenced its effect on yield, but further study would be required to test this. Biostimulant application did not have significant effects on tuber quality, and the effect of biostimulant application on tuber yield was not influenced by the N treatment applied.

Table 1. Treatments applied to Russet Burbank potatoes to evaluate the effectiveness of biostimulant products under different N source and rate regimes.

N treatments					Biostimulant treatments[1]
	N (lbs/ac) provided as:				
Number	Manure, preplant	DAP, planting	ESN, emergence	Total	
1	0	40	0	40	B Sure
2	0	40	126	166	B Sure + iNvigorate
3	0	40	252	292	Radiate
4	126	40	0	166	Radiate + Accomplish
5	126	40	126	292	

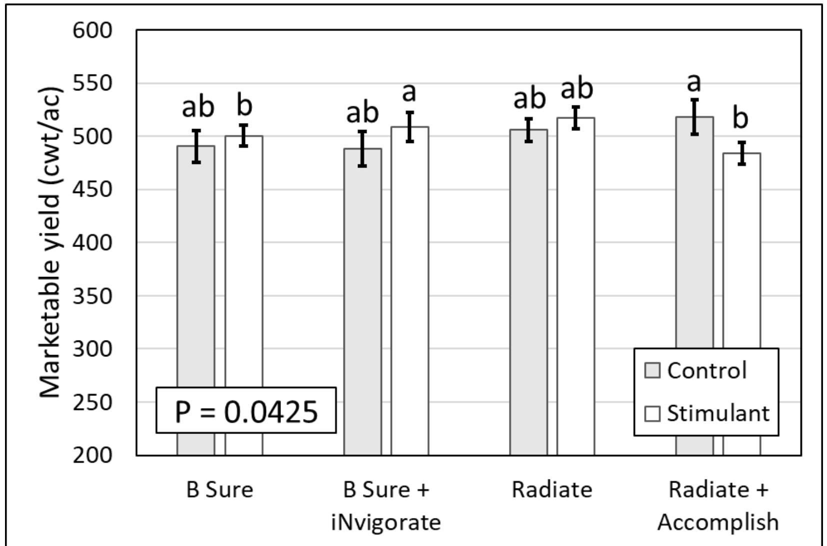
[1]Each plot was split, with half receiving the biostimulant indicated and half receiving none.

Table 2. Soil characteristics at the study site prior to any fertilizer application.

0 - 2 feet	0 - 6 inches				
Primary macronutrients			Secondary macronutrients		
NO_3^--N	Bray P	K	Ca	Mg	SO_4-S
(mg·kg^{-1} soil)					
4.2	51	99	724	159	4.7

0 - 6 inches						
Micronutrients					Other characteristics	
Fe	Mn	Zn	Cu	B	pH	Organic matter (%)
(mg·kg^{-1} soil)						
23	4.7	1.9	0.94	0.13	6.9	1.5

a.



b.

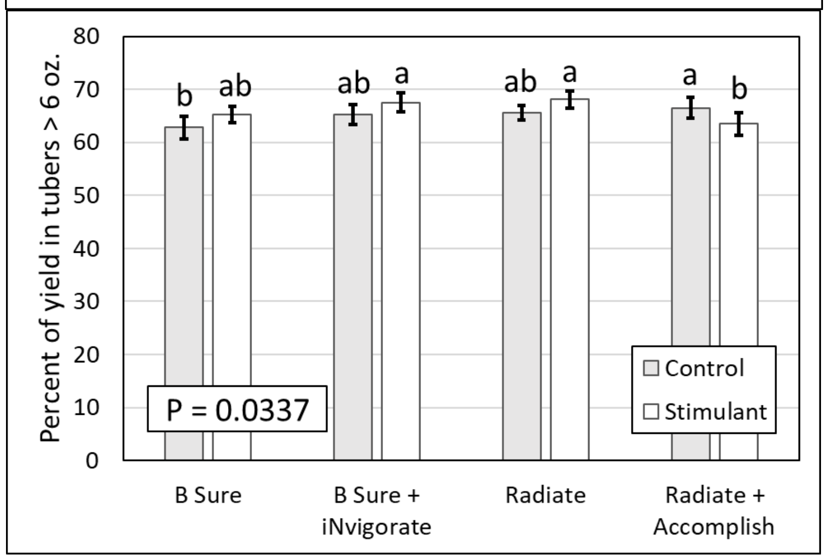


Figure 1. Effects of biostimulant application on (a) marketable yield and (b) the percentage of yield represented by tubers over six ounces for each biostimulant treatment evaluated. Columns that have a letter in common are not significantly different from each other (i.e., $P > 0.10$).

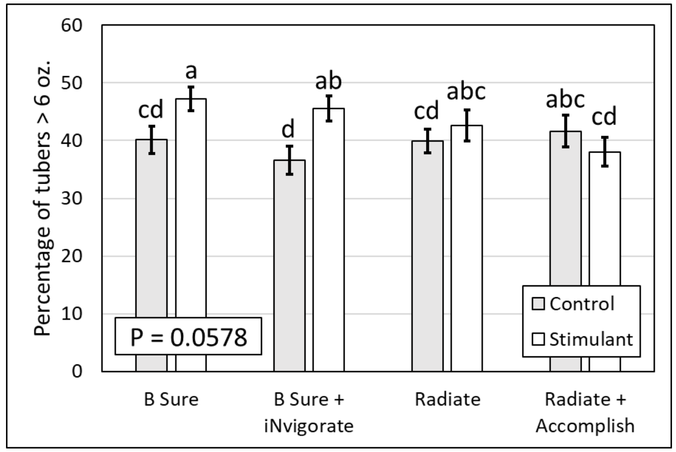


Figure 2. Effect of biostimulant application on percentage of tubers that weigh more than six ounces for each biostimulant treatment evaluated. Columns that have a letter in common are not significantly different from each other (i.e., P > 0.10).

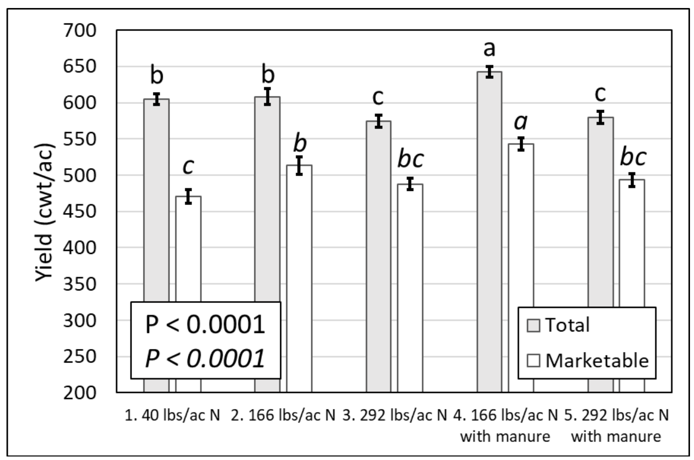


Figure 3. The effect of N treatment (averaged across biostimulant ID and whether biostimulant was applied) on total and marketable yield. Within each yield category, columns that have a letter in common are not significantly different from each other (i.e., P > 0.10).

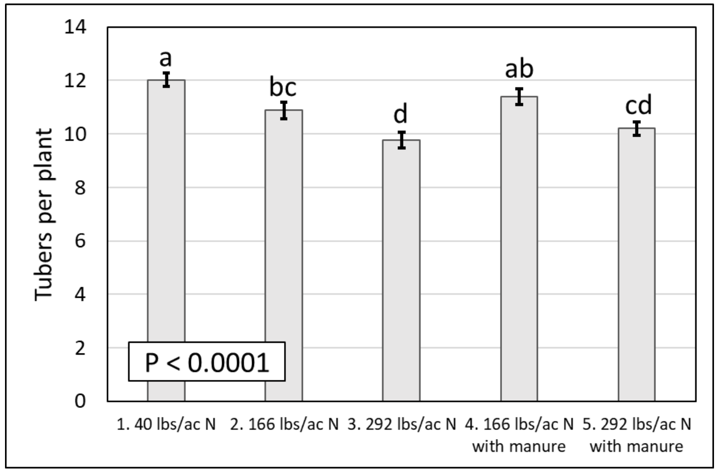


Figure 4. The effect of N treatment (averaged across biostimulant ID and whether biostimulant was applied) on the number of tubers per plant. Columns that have a letter in common are not significantly different from each other (i.e., P > 0.10).

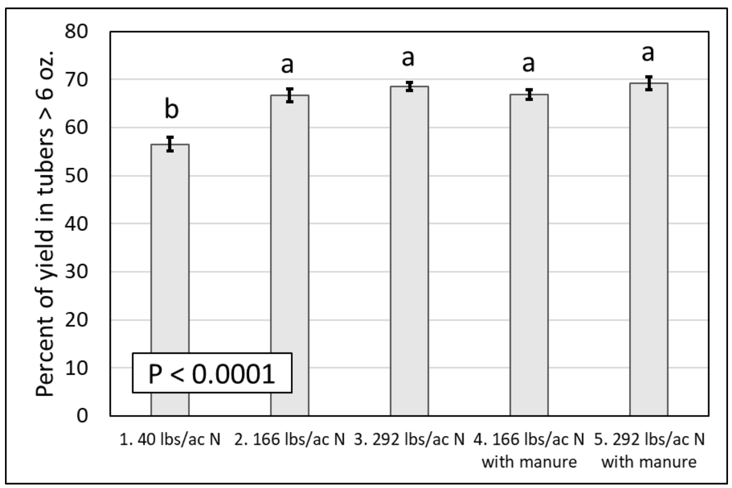


Figure 5. The effect of N treatment (averaged across biostimulant ID and whether biostimulant was applied) on the percentage of yield represented by tubers over six ounces. Columns that have a letter in common are not significantly different from each other (i.e., P > 0.10).

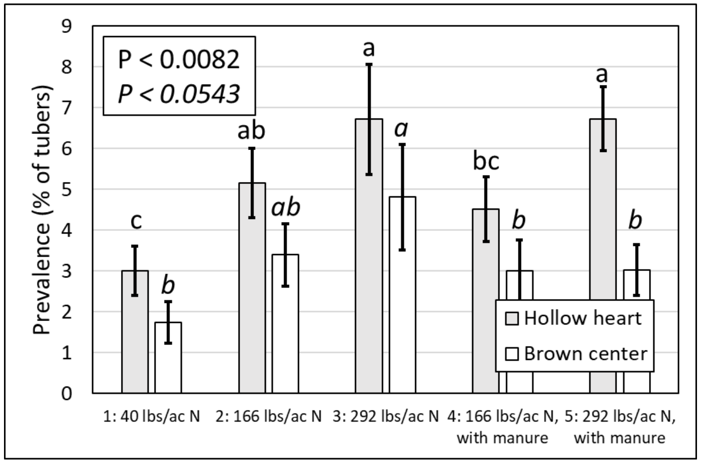


Figure 6. The effect of N treatment (averaged across biostimulant ID and whether biostimulant was applied) on the prevalence of hollow heart and brown center. Within each tuber defect category, columns that have a letter in common are not significantly different from each other (i.e., P > 0.10).

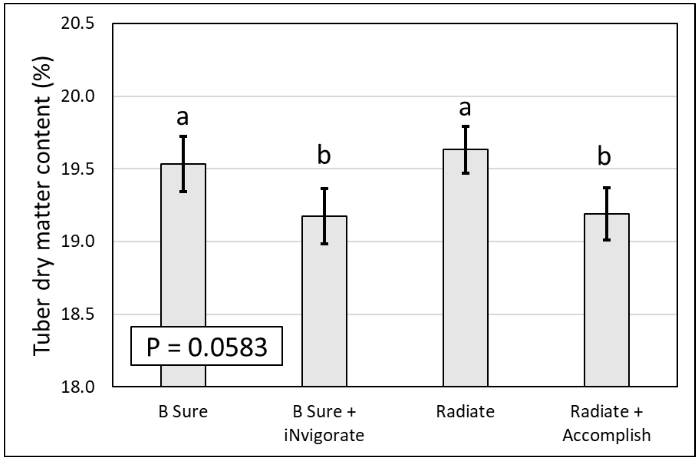


Figure 7. The effect of biostimulant treatment (averaged across N treatment and whether the biostimulant was applied) on tuber dry matter content. Columns that have a letter in common are not significantly different from each other (i.e., P > 0.10).

Table 3. Effects of N treatment, biostimulant treatment, whether or not the biostimulant was applied, and their interactions on Russet Burbank tuber yield, size, and grade. Adjacent values in the same column appear in boldface where the effect of applying biostimulant was statistically significant (P < 0.10).

Treatment			Yield ($CWT \cdot ac^{-1}$)										% yield in tubers over:		Tubers / plant	% tubers over 6 oz.
Biostimulant ID	N treatment	Biostimulant applied?	Culled	0 - 4 oz.	4 - 6 oz.	6 - 10 oz.	10 - 14 oz.	> 14 oz.	Total	US No. 1	US No. 2	Marketable	6 oz.	10 oz.		
B Sure	1: 40 lbs/ac N	No	4	**167**	137	**202**	47	25	578	**386**	25	**410**	**47**	12	12.5	34.6
		Yes	9	**121**	129	**262**	57	27	596	**452**	23	**475**	**58**	14	11.3	43.6
	2: 166 lbs/ac N	No	5	106	114	**249**	74	106	650	512	33	544	66	28	11.6	44.5
		Yes	6	110	124	**216**	90	81	620	478	33	510	62	27	11.4	46.3
	3: 292 lbs/ac N	No	8	96	87	231	91	98	603	473	34	507	69	31	9.4	45.3
		Yes	13	82	87	215	103	95	582	474	26	500	71	34	9.8	53.1
	4: 166 lbs/ac N, with manure	No	6	110	124	262	88	50	632	499	24	523	63	22	12.1	36.1
		Yes	5	113	120	245	73	68	618	475	31	506	62	23	11.7	40.1
	5: 292 lbs/ac N, with manure	No	9	88	86	197	101	**85**	556	**437**	31	468	69	**33**	9.5	**40.2**
		Yes	7	74	84	189	105	**133**	585	**487**	24	511	73	**41**	9.9	**53.1**
B Sure + iNvigorate	1: 40 lbs/ac N	No	**8**	142	112	235	55	42	586	417	**27**	444	56	16	12.3	31.7
		Yes	**16**	142	113	239	80	47	621	431	**47**	479	59	20	11.7	40.7
	2: 166 lbs/ac N	No	**4**	108	102	216	91	**77**	593	**450**	35	485	64	27	11.5	**29.6**
		Yes	**11**	93	103	222	101	**108**	627	**503**	30	534	68	33	12.0	**48.2**
	3: 292 lbs/ac N	No	9	94	94	198	72	**105**	564	442	28	470	**66**	31	10.3	**37.3**
		Yes	8	77	84	213	82	**139**	595	490	28	518	**73**	37	9.4	**50.0**
	4: 166 lbs/ac N, with manure	No	10	89	97	253	**117**	94	650	523	38	560	71	32	12.1	44.4
		Yes	9	90	97	274	**88**	91	641	517	33	551	71	28	11.8	47.4
	5: 292 lbs/ac N, with manure	No	**18**	92	83	212	94	92	574	446	**37**	482	68	31	11.1	40.0
		Yes	**7**	94	85	188	99	92	557	444	**19**	463	67	34	10.2	41.6
Radiate	1: 40 lbs/ac N	No	8	116	135	258	49	60	618	472	30	502	59	17	11.7	44.1
		Yes	4	107	123	246	69	61	606	475	24	499	62	22	12.0	35.0
	2: 166 lbs/ac N	No	9	85	100	220	99	106	610	506	19	525	70	33	10.1	40.1
		Yes	7	82	89	230	98	100	600	490	28	518	72	33	10.9	43.9
	3: 292 lbs/ac N	No	6	83	105	196	80	76	540	437	20	457	65	28	10.1	38.4
		Yes	7	84	97	211	88	81	562	459	19	478	67	30	10.0	46.1
	4: 166 lbs/ac N, with manure	No	6	94	117	257	113	71	653	536	24	559	68	28	10.6	38.8
		Yes	8	83	105	252	110	90	641	520	38	558	71	31	10.0	48.1
	5: 292 lbs/ac N, with manure	No	5	93	103	219	93	70	580	472	14	487	66	28	10.2	38.3
		Yes	6	86	105	245	91	93	619	506	28	534	69	29	10.1	40.1
Radiate + Accomplish	1: 40 lbs/ac N	No	6	**118**	128	**254**	**72**	62	635	**480**	37	**517**	**61**	***21***	12.3	44.3
		Yes	8	**158**	141	**209**	**44**	45	598	**413**	27	**440**	**50**	***15***	12.5	32.8
	2: 166 lbs/ac N	No	10	88	104	203	86	94	575	453	34	487	65	30	10.2	37.8
		Yes	8	89	101	232	86	84	592	482	21	503	68	28	9.5	42.4
	3: 292 lbs/ac N	No	9	85	99	203	88	92	567	459	23	482	67	32	10.2	38.1
		Yes	4	87	90	218	92	92	578	471	21	492	69	31	9.2	41.6
	4: 166 lbs/ac N, with manure	No	8	**97**	120	**292**	**101**	68	**677**	**543**	**37**	**580**	**68**	25	11.8	46.7
		Yes	5	**119**	121	**255**	**72**	58	**624**	**484**	**21**	**505**	**62**	21	11.3	35.5
	5: 292 lbs/ac N, with manure	No	**5**	79	90	207	115	111	601	492	30	522	72	37	10.3	41.3
		Yes	**14**	88	88	199	105	87	567	451	28	479	69	34	10.6	41.0
	Stimulant ID		**0.0307**	**0.0025**	**0.0009**	0.4725	0.5951	0.1399	0.9966	0.1028	***0.0501***	0.4327	***0.0508***	0.1029	0.3408	0.4516
	N treatment		0.6828	**<0.0001**	**<0.0001**	**<0.0001**	**<0.0001**	**<0.0001**	**<0.0001**	**<0.0001**	0.2858	**<0.0001**	**<0.0001**	**<0.0001**	**<0.0001**	0.4311
	Stimulant applied?		0.6400	0.3643	0.2778	0.9479	0.9032	0.2529	0.9348	0.6060	0.4761	0.7813	0.1798	0.1908	0.5960	**0.0291**
	Stim*N		0.3304	**0.0320**	**0.0036**	0.1231	0.1013	**0.0027**	0.1487	0.2265	0.7654	0.1787	**0.0070**	**0.0002**	0.4973	0.7635
	Stim*app		0.7725	**0.0046**	0.5822	0.5132	0.2205	***0.0887***	0.3072	***0.0784***	***0.0764***	**0.0425**	**0.0337**	**0.0287**	0.9093	***0.0578***
	N*app		0.6003	0.8115	0.8988	0.7380	***0.0869***	0.6867	0.5656	0.2315	0.9511	0.3919	0.5679	0.6345	0.9596	0.4990
	Stim*N*app		**0.0075**	0.1182	0.9477	**0.0047**	0.9116	0.2367	0.5700	0.1474	0.1735	0.1993	***0.0654***	0.6906	0.9915	0.7079
Contrasts	N addition (1 vs. 2 - 5)		0.9605	**<0.0001**	**<0.0001**	**0.0148**	**<0.0001**	**<0.0001**	0.6592	**<0.0001**	0.3600	**<0.0001**	**<0.0001**	**<0.0001**	**<0.0001**	***0.0689***
	N rate (2 & 4 vs. 3 & 5)		0.2057	**0.0009**	**<0.0001**	**<0.0001**	0.8352	**0.0056**	**<0.0001**	**0.0008**	***0.0588***	**<0.0001**	**0.0205**	**<0.0001**	**0.0005**	0.6742
	Manure (2 & 3 vs. 4 & 5)		0.6719	0.4380	0.2891	**0.0004**	**0.0257**	**0.0099**	**0.0083**	**0.0348**	0.4489	**0.0331**	0.6478	0.2489	0.1777	0.8230

Table 4. Effects of N treatment, biostimulant treatment, whether or not the biostimulant was applied, and their interactions on Russet Burbank tuber defects, scab, specific gravity, and dry matter content. Adjacent values in the same column appear in boldface where the effect of applying biostimulant was statistically significant (P < 0.10).

Treatment: Biostimulant ID	Treatment: N treatment	Treatment: Biostimulant applied?	Hollow heart (% of tubers)	Brown center (% of tubers)	Scab (% of tubers)	Specific gravity	Dry matter content (%)
B Sure	1: 40 lbs/ac N	No	0	0	2	1.0730	18.9
		Yes	2	1	0	1.0723	19.2
	2: 166 lbs/ac N	No	7	5	0	1.0730	20.3
		Yes	4	2	1	1.0738	19.4
	3: 292 lbs/ac N	No	**12**	**8**	1	1.0725	20.0
		Yes	**6**	**2**	1	1.0716	20.3
	4: 166 lbs/ac N, with manure	No	7	0	0	1.0725	19.7
		Yes	4	4	0	1.0725	19.9
	5: 292 lbs/ac N, with manure	No	10	4	0	1.0733	18.7
		Yes	9	5	2	1.0718	19.1
B Sure + iNvigorate	1: 40 lbs/ac N	No	2	0	0	1.0723	19.0
		Yes	2	2	0	1.0715	18.7
	2: 166 lbs/ac N	No	5	3	0	1.0732	19.5
		Yes	9	7	0	1.0745	19.9
	3: 292 lbs/ac N	No	5	2	1	1.0746	**20.7**
		Yes	8	6	2	1.0727	**19.3**
	4: 166 lbs/ac N, with manure	No	4	4	0	1.0708	19.4
		Yes	4	2	1	1.0733	18.6
	5: 292 lbs/ac N, with manure	No	8	**6**	1	1.0721	18.3
		Yes	5	**0**	1	1.0720	18.5
Radiate	1: 40 lbs/ac N	No	3	2	**3**	1.0712	19.5
		Yes	5	3	**0**	1.0726	18.9
	2: 166 lbs/ac N	No	3	2	0	1.0740	20.7
		Yes	4	4	0	1.0724	20.3
	3: 292 lbs/ac N	No	3	3	1	1.0734	19.3
		Yes	4	4	1	1.0729	19.8
	4: 166 lbs/ac N, with manure	No	4	*2*	0	1.0737	19.5
		Yes	7	*7*	0	1.0726	19.2
	5: 292 lbs/ac N, with manure	No	6	3	**3**	1.0724	19.8
		Yes	8	4	**0**	1.0730	19.3
Radiate + Accomplish	1: 40 lbs/ac N	No	6	3	0	1.0718	18.9
		Yes	4	3	0	1.0715	19.4
	2: 166 lbs/ac N	No	3	2	**3**	1.0732	19.2
		Yes	6	2	**0**	1.0721	20.0
	3: 292 lbs/ac N	No	9	*9*	0	1.0751	**18.5**
		Yes	6	*4*	1	1.0736	**20.3**
	4: 166 lbs/ac N, with manure	No	4	4	0	1.0719	18.9
		Yes	2	1	0	1.0722	18.9
	5: 292 lbs/ac N, with manure	No	5	2	**0**	1.0725	**19.7**
		Yes	2	0	**3**	1.0719	**18.2**
	Stimulant ID		0.4886	0.9787	0.9754	0.9755	*0.0583*
	N treatment		**0.0082**	*0.0543*	0.1625	0.1620	**0.0001**
	Stimulant applied?		0.6991	0.9158	0.7726	0.4660	0.6449
	Stim*N		0.1235	0.4119	0.7286	0.8837	0.3825
	Stim*app		0.1767	0.1411	0.2270	0.8863	0.3291
	N*app		0.7646	0.4711	0.2955	0.7639	0.7097
	Stim*N*app		0.8340	0.1482	0.2070	0.9258	*0.0728*
Contrasts	N addition (1 vs. 2 - 5)		**0.0032**	**0.0238**	0.7900	*0.0963*	**0.0305**
	N rate (2 & 4 vs. 3 & 5)		**0.0230**	0.3104	**0.0189**	0.9658	0.1962
	Manure (2 & 3 vs. 4 & 5)		0.6982	0.1241	0.8748	*0.0520*	**<0.0001**

Evaluation of struvite-MAP blends as phosphate sources for Russet Burbank potatoes

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Summary

Struvite is a phosphate-rich mineral byproduct of municipal wastewater treatment that can be used as a phosphorus (P) source in agriculture. Because struvite has low solubility in water but high solubility in citrate, which is exuded by plant roots, it may preferentially release P where plant roots are present to take it up, increasing P use efficiency and reducing P leaching relative to conventional P sources. Because struvite is more expensive to produce than conventional P sources, an optimal balance between fertilizer cost and improved P use efficiency might be achieved by a blend of struvite with a conventional P source, such as monoammonium phosphate (MAP: 11-50-0). The objective of this study was conducted at the Sand Plain Research Farm on a relatively low P soil (13 ppm Bray P) to evaluate a variety of experimental struvite blends from Ostara as P sources for Russet Burbank potatoes relative to sources currently on the market. Ten treatments were applied in a randomized complete block design: (1) a zero-P check treatment receiving 41 lbs/ac S as Sul-Po-Mag (0-0-22-22S-11Mg), (2) a zero-S check treatment receiving 80 lbs/ac P_2O_5 as MAP, and treatments receiving Sul-Po-Mag as needed to provide 41 lbs/ac S and providing 80 lbs/ac P_2O_5 as (3) MAP, (4) a 15:85 physical blend of struvite and MAP (i.e., 15% of P from struvite, 85% from MAP), (5) a 15:85 cogranulated blend of struvite and MAP, (6) a 25:75 cogranulated blend of struvite and MAP, (7) the 25:75 blend physically blended with polyhalite (0-0-14-19S-15Ca-3Mg), (8) a cogranulated blend of 25:75 struvite and MAP with humate, (9) a cogranulated blend of 25:75 struvite and MAP with polyhalite, and (10) the Mosaic product MicroEssentials S10. The zero-P check treatment had the lowest total tuber yield while the MAP + zero-S treatment had the highest, but not significantly higher than the struvite blends. All struvite:MAP blends produced numerically higher total yields than the treatment receiving MAP + S, but only the treatment receiving 25:75 struvite and MAP physically blended with polyhalite had significantly higher yield. The effect of treatment on marketable yield was not significant. Among the treatments providing struvite, the ones in which struvite provided 15% of the fertilizer P had the highest percentage of yield represented by tubers over ten ounces. Although applying P increased tuber specific gravity and dry matter content relative to the zero-P check treatment, the overall treatment effect was not significant, indicating that the form of P applied had little effect on these variables. Post-harvest soil Bray P concentration was significantly related to treatment. The 25:75 blend of struvite and MAP physically blended with polyhalite had the highest residual Bray P, while the zero-P check had the lowest. The 15:18 physical blend of struvite and MAP had the lowest residual Bray P among the treatments receiving P and S. Overall, blends of struvite with MAP were effective sources of P, producing yields at least as high as MAP alone. The ratio of struvite to MAP may have some effect on tuber size. Post-harvest soil Bray P varied significantly among treatments receiving P and S, but with no clear relationship to yield.

Background

Struvite is a phosphate-rich mineral ($NH_4MgPO_4 \cdot 6H_2O$: 5-28-0-10Mg) that can be precipitated from municipal wastewater and used as a phosphorus (P) source in agriculture. Struvite may have an advantage over conventional P sources such as monoammonium phosphate (MAP: 11-50-0) in that the phosphate in struvite has low solubility in water but high solubility in citrate, which is exuded by plant roots. The P in struvite may therefore be highly available to plants yet less prone to fixation than many other plant-available forms of P, resulting in higher P use efficiency.

A disadvantage of struvite as a P fertilizer is that it is not cost-competitive with conventional P sources. However, a blend of struvite with a conventional P source may provide a balance of low cost and increased P use efficiency that results in a yield boost that more than compensates for the cost of the struvite content.

The objective of this study was to evaluate a variety of struvite blends from Ostara as sources of P for Russet Burbank potatoes relative to MAP and the Mosaic product MicroEssentials S10.

Methods

Study design

The study was conducted at the Sand Plain Research Farm in 2021 on a Hubbard loamy sand soil, using a randomized complete block design. The previous crop was soybeans. Each plot received one of ten treatments to evaluate struvite blends relative to other nutrient sources, as described in Table 1, providing nutrients at the rates indicated in Table 2. Of the novel products being evaluated, 15/85B is a physical blend of MAP and struvite, while 15/85S has the same content co-granulated. 25/75S is similar to 15/85S, but with a higher struvite:MAP ratio. 25/75S + S is a physical blend of 25/75S with polyhalite, while 25/75 StPo has polyhalite co-granulated with 25/75S. 25/75 StHu is 25/75S co-granulated with humic acid.

Initial soil characteristics

Soil samples to depths of six inches and two feet were collected throughout the study field on April 5, 2021. The six-inch samples were analyzed for Bray P, acetate-extractable K, Ca, and Mg, DTPA-extractable Fe, Mn, Zn, and Cu, hot-water-soluble B, SO_4^{2-}-S, pH, and loss-on-ignition organic matter content. The two-foot samples were analyzed for NH_4^+-N and NO_3^--N concentrations using a Wescan Nitrogen Analyzer. The results of these analyses are presented in Table 3.

Treatment applications

On April 19, 300 lbs/ac K_2O were broadcast applied as 500 lbs/ac MOP (0-0-60). On May 6, furrows were opened by machine with 36-inch spacing. The fertilizer treatments were mechanically applied in bands to either side of each furrow in each plot as the rows were opened. Each treatment plot was four rows (12 feet) wide and 20 feet long. Two- to three-ounce Russet Burbank seed potatoes were then planted by hand with 12-inch spacing on May 6. Belay was applied in-furrow for beetle control, along with the systemic fungicide Quadris, and the rows were closed by machine. Weeds, diseases, and insects were controlled using standard practices. Rainfall was supplemented with sprinkler irrigation using the checkbook method of irrigation scheduling.

On May 21, ESN (44-0-0) was applied at 377 $lbs \cdot ac^{-1}$ as the rows were hilled, providing 166 $lbs \cdot ac^{-1}$ N. On June 29 and July 20, 20 $lbs \cdot ac^{-1}$ N were applied as 28% UAN. In total, the field received 236 $lbs \cdot ac^{-1}$ N throughout the season.

Percent stand was assessed for 36 plants per plot (the central 18 feet of the middle two rows) on June 1 and 7. The number of stems per plant was determined for 10 plants on June 14. Petiole samples were collected from the fourth mature leaf from the shoot tip of 20 plants per plot on June 24 and July 8, 19, and 29. These were dried at 140 °F until their weight was stable and then ground. They will be analyzed for P concentration by Agvise Laboratories (Benson, MN) using an ICP spectrometer and for N and S concentrations using an Elementar Vario EL CNS Analyzer.

Vines were chopped with a flail mower on September 15. Tubers were harvested from the central 18 feet of the middle two rows of each plot on September 23. These harvest samples were hand-sorted by size and grade on October 13 and 14. A twenty-five-tuber subsample was collected from each plot's harvest sample and assessed for hollow heart, brown center, scab, specific gravity, and dry matter content. Soil samples to a depth of six inches were collected from each plot on September 30 and analyzed for Bray P and SO_4^{2-}-S concentrations by the University of Minnesota Research Analytical Laboratory (St. Paul, MN). Soil samples to a depth of two feet were collected at the same time, and their NO_3^--N concentrations will be measured with a Wescan Nitrogen Analyzer.

Data analysis

Data were analyzed with SAS 9.4m3® software (copyright 2015, SAS Institute, Inc.) using the GLIMMIX procedure. Data were analyzed as functions of treatment and block. Means for each treatment were calculated and pairwise comparisons between treatments made using the LSMEANS statement with the DIFF option. Pairwise comparisons were only made when the P-value of the treatment effect in the ANOVA was less than 0.10, and comparisons with P-values less than 0.10 were considered significant. Two CONTRAST statements were used to compare subsets of the treatments, on comparing the zero-P treatment (treatment 1) with treatments 3-10 and another comparing the zero-S treatment (treatment 2) with the same treatments.

Results

Tuber yield

Results for tuber yield, size, and grade are presented in Table 3. Treatment had a significant effect ($P < 0.10$) on total tuber yield and the percentage of yield represented by tubers over ten ounces, as well as yields in the 6- to 10-ounce and 10- to 14-ounce size categories. The treatment receiving MAP + zero S (treatment 2) had the highest numerical total yield, but it did not have significantly higher yield than any treatment receiving struvite (treatments 4 through 9). The treatment receiving no P (treatment 1) had a lower total yield than any other treatment. The treatment receiving all nutrients from conventional sources (treatment 3) had the lowest total yield of any treatment receiving P, but of the treatments receiving struvite, only the treatment receiving 25/75S+S (treatment 7) had significantly higher yield.

Treatment was not significantly related to marketable yield, but in the contrast comparison, the zero-P check treatment (treatment 1) had significantly lower marketable yield than the treatments receiving both P and S (treatments 3 through 10). The treatment receiving 25/75S (treatment 6) was the only struvite treatment that did not have numerically higher yield than the conventional fertilizer treatment (treatment 3) or the MicroEssentials S10 treatment (treatment 10).

In contrast to the results for total yield, the treatment receiving MAP + zero S (treatment 2) had the lowest percentage of yield represented by tubers over ten ounces, while the treatment receiving no P (treatment 1) had the highest percentage. Among the treatments receiving struvite (treatments 4 through 9), the highest percentages of yield in tubers over ten ounces were observed in the treatments receiving 15% of their fertilizer P in the form of struvite (treatments 4 and 5). The two struvite treatments with the lowest percentages of yield over ten ounces (treatments 6 and 9) also had the two lowest marketable yields in this group.

Tuber quality

Results for tuber quality are presented in Table 4. Hollow heart, brown center, and scab were rare, and their prevalence was not significantly related to treatment. Common scab was detected in a single tuber in the zero-P check treatment (treatment 1), with the result that the contrast comparing this treatment to the treatments receiving P and S (treatments 3 – 10) was statistically significant but probably not meaningful.

Tuber specific gravity and dry matter content were not significantly related to treatment. However, both measurements were lower in tubers from the zero-P check treatment (treatment 1), and the contrast comparing this treatment to the non-check treatments (treatments 3 – 10) was significant in both cases.

Post-harvest soil P and S

Results for post-harvest soil Bray P and SO_4^{2-}-S concentrations are presented in Table 5. Soil SO_4^{2-}-S concentration was not significantly related to treatment. Bray P concentration was significantly lower in the zero-P check treatment (treatment 1) than in any treatment receiving both P and S (treatments 3 through 10). The MAP + zero-S treatment (treatment 2) had the second-lowest Bray P concentration, and both this treatment and the treatment receiving 15/85B (treatment 4) had significantly lower post-harvest Bray P concentrations than the treatments receiving 25/75S + S (treatment 7) or MicroEssentials S10 (treatment 10). The 25/75S + S treatment also had a higher post-harvest Bray P concentration than the treatments receiving 15/85S (treatment 5) or 25/75S (treatment 6). It is not obvious why post-harvest Bray P varied among the treatments receiving both P and S (treatments 3 through 10). Post-harvest Bray P was not negatively related to total yield among these treatments, so the variation in post-harvest Bray P concentration probably cannot be explained by variations in plant P uptake.

Conclusions

Of the struvite treatments (treatments 4 through 9), only the one receiving 25/75S + S (treatment 6) had significantly higher total yield than the treatment with conventional P and S sources (treatment 3), although all of the struvite treatments had numerically higher total yield than the conventional MAP + S treatment. No treatment receiving struvite had significantly higher total or marketable yield than any other. Addition of S had no effect on marketable yield but did tend to increase tuber size relative to the MAP + zero S treatment.

The two struvite treatments that received 15% of their fertilizer P from struvite (treatments 4 and 5) had the highest percentages of yield in tubers over ten ounces out of the six struvite treatments (treatments 4 through 9). Aside from this possible effect of the struvite:MAP ratio on tuber size distribution, there was no apparent relationship between tuber yield, size, or quality and the formulation of the struvite treatment applied. Post-harvest soil Bray P concentrations varied significantly with treatment with no clear relationship to yield

Overall, the fertilizer blends that included struvite were all effective sources of P and S, producing yields at least as high as MAP alone, and the ratio of struvite to MAP may have some effect on tuber size.

Table 1. Products banded at planting in each treatment. 15/85B is a physical blend of MAP and struvite, while 15/85S has the same content co-granulated. 25/75S is similar to 15/85S, but with a higher struvite:MAP ratio. 25/75S + S is a physical blend of 25/75S with polyhalite, while 25/75 stop has polyhalite co-granulated with 25/75S. 25/75 stop is 25/75S co-granulated with humic acid.

Treatment		Application rate of each product at planting (lbs/ac)											
Number	Description	Urea[1]	MAP[2]	Struvite[3]	15/85S[4]	25/75S[5]	25/75S+S[6]	25/75StrHu[7]	StruPo[8]	MES10[9]	Polyhalite[10]	Sul-Po-Mag[11]	MOP[12]
1	No P	65	0	0	0	0	0	0	0	0	0	186	30
2	No S	28	160	0	0	0	0	0	0	0	0	0	99
3	MAP	28	160	0	0	0	0	0	0	0	0	186	30
4	15/85B	29	136	43	0	0	0	0	0	0	0	185	31
5	15/85S	28	0	0	167	0	0	0	0	0	0	185	31
6	25/75S	25	0	0	0	173	0	0	0	0	0	185	31
7	25/75S + S	28	0	0	0	0	275	0	0	0	218	0	48
8	25/75 StHu	24	0	0	0	0	0	178	0	0	0	185	31
9	25/75 StPo	28	0	0	0	0	0	0	286	0	0	97	39
10	MES10	13	0	0	0	0	0	0	0	200	0	95	64

[1] Urea: 46-0-0
[2] MAP: 11-50-0
[3] Struvite: 5-28-0-10Mg
[4] 15/85S: All-in-1 15% struvite, 85% MAP: 10-48-0-2Mg
[5] 25/75S: All-in-1 25% struvite, 75% MAP: 10-46-0-3Mg
[6] 25/75S+S: 25/75S blended with polyhalite: 6-29-5-7S-6Ca-3Mg
[7] 25/75StHu: All-in-1 25:75S plus humate: 10-45-0-3Mg
[8] StPo: All-in-1 25/75S plus polyhalite: 6-28-5-7S-6Ca-4Mg
[9] MicroEssentials 10: 12-40-0-10
[10] Polyhalite: 0-0-14-19S-15Ca-3Mg
[11] Sul-Po-Mag: 0-0-22-22S-11Mg
[12] MOP: 0-0-60

Table 2. Nutrients supplied by the products banded at planting in each treatment.

Treatment		Application rate of each nutrient at planting (lbs/ac)						
Number	Description	N	P_2O_5	K_2O	S	Mg	Zn	B
1	No P	30	0	59	41	20	1	0.5
2	No S	30	80	59	0	0	1	0.5
3	MAP	30	80	59	41	20	1	0.5
4	15/85B	30	80	59	41	20	1	0.5
5	15/85S	30	80	59	41	20	1	0.5
6	25/75S	29	80	59	41	20	1	0.5
7	25/75S + S	29	80	59	61	15	1	0.5
8	25/75 StHu	29	80	59	41	20	1	0.5
9	25/75 StPo	30	80	59	41	22	1	0.5
10	MES10	30	80	59	41	10	1	0.5

Table 3. Soil characteristics in the study field prior to any fertilizer application.

0 - 2 feet	0 - 6 inches				
Primary macronutrients			Secondary macronutrients		
NO_3^--N	Bray P	K	Ca	Mg	SO_4-S
($mg \cdot kg^{-1}$ soil)					
5.7	13	101	941	191	5.6

0 - 6 inches						
Micronutrients					Other characteristics	
Fe	Mn	Zn	Cu	B	pH	Organic matter (%)
($mg \cdot kg^{-1}$ soil)						
37	11.1	2.3	0.67	0.22	6.4	2.1

Table 4. Effects of P and S fertilizer treatment on Russet Burbank tuber yield, size, and grade. Values within a column that have a letter in common were not significantly different from each other in pairwise comparisons (P > 0.10).

Treatment		Yield (CWT·ac^{-1})										% yield in tubers over:	
Number	Description	Culled	0 - 4 oz.	4 - 6 oz.	6 - 10 oz.	10 - 14 oz.	> 14 oz.	Total	US No. 1	US No. 2	Marketable	6 oz.	10 oz
1	No P	5	74	72	173 e	86 abc	92	498 d	390	35	424	71	36 a
2	No S	3	122	109	239 a	59 d	77	605 a	443	40	483	62	22 e
3	MAP	6	85	94	206 bcde	90 abc	73	548 c	437	26	463	67	30 abcd
4	15/85B	2	79	86	197 cde	92 abc	105	558 abc	430	50	480	70	35 a
5	15/85S	9	89	93	205 bcde	109 a	84	579 abc	447	44	491	68	33 ab
6	25/75S	3	94	91	233 ab	81 bcd	58	557 abc	428	36	463	67	25 cde
7	25/75S + S	0	105	104	220 abcd	74 bcd	90	593 ab	436	52	488	65	28 bcde
8	25/75 StHu	2	84	98	216 abcd	96 ab	86	579 abc	452	43	495	69	31 abc
9	25/75 StPo	4	107	104	225 abc	68 cd	73	578 abc	427	44	470	64	25 de
10	MES10	3	89	98	191 de	74 bcd	100	552 bc	415	49	463	67	32 ab
Effect of treatment (P-value)		0.1837	0.2392	0.1866	***0.0592***	***0.0676***	0.5903	***0.0690***	0.4941	0.6572	0.4909	0.4211	**0.0382**
Contrasts	P effect (1 v 3-10)	0.5968	0.2099	**0.0180**	**0.0202**	0.9637	0.6577	**0.0046**	**0.0409**	0.4451	**0.0345**	0.2319	***0.0971***
	S effect (2 v 3-10)	0.8415	**0.0387**	0.1732	***0.0845***	**0.0332**	0.7050	0.1162	0.6640	0.8207	0.7840	0.1272	**0.0333**

Table 5. Effects of P and S fertilizer treatment on Russet Burbank tuber hollow heart, brown center, scab, specific gravity, and dry matter content.

Treatment		Hollow heart	Brown center	Scab	Specific gravity	Dry matter content (%)
Number	Description		% of tubers			
1	No P	2	2	1	1.0727	18.6
2	No S	0	0	0	1.0766	20.4
3	MAP	0	0	0	1.0751	20.3
4	15/85B	2	2	0	1.0752	20.3
5	15/85S	2	2	0	1.0765	19.3
6	25/75S	1	1	0	1.0743	19.8
7	25/75S + S	1	1	0	1.0782	20.1
8	25/75 StHu	0	0	0	1.0752	19.1
9	25/75 StPo	1	1	0	1.0742	20.7
10	MES10	0	0	0	1.0772	19.9
Effect of treatment (P-value)		0.6229	0.6229	0.2454	0.2832	0.2136
Contrasts	P effect (1 v 3-10)	0.2447	0.2447	**0.0017**	**0.0764**	**0.0444**
	S effect (2 v 3-10)	0.3630	0.3630	1.0000	0.5940	0.4802

Table 6. Effects of P and S fertilizer treatment on post-harvest soil P and S concentrations.

Treatment		Fall soil nutrient concentrations (ppm)	
Number	Description	Bray P	SO_4^{2-}-S
1	No P	13 d	9
2	No S	20 cd	8
3	MAP	28 abc	10
4	15/85B	23 c	11
5	15/85S	26 bc	10
6	25/75S	23 bc	12
7	25/75S + S	40 a	10
8	25/75 StHu	29 abc	10
9	25/75 StPo	30 abc	14
10	MES10	34 ab	12
Effect of treatment (P-value)		**0.0142**	0.6913
Contrasts	P effect (1 v 3-10)	**0.0006**	0.4240
	S effect (2 v 3-10)	***0.0819***	0.1294

Turkey Manure for Potato Nutrition 2021

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Executive summary
Turkey manure is a local source of N that has been used in potato production. With fertilizer prices increasing substantially in 2021 and into 2022, alternative sources of fertilizer will be important. The focus of this study was to evaluate turkey manure and Environmentally Smart Nitrogen (ESN) on Russet Burbank potato production. The overall objective of this project is to increased payable yield for potato growers in Minnesota and North Dakota. The use of 3 ton/a turkey manure with ESN or 5 tons/a turkey manure with or without ESN had the best yields.

Rationale for conducting the research
In 2019 and 2020 we conducted research to compare turkey manure with ESN or urea. At about a third of the total nitrogen, turkey manure had numerically lower yield but not a significantly different yield than ESN and urea in 2019 and in 2020. Describing the benefits of turkey manure as a source of nitrogen is important as the potato industry continues to seek more sustainable sources for plant nutrition. Building upon the previous work, we focused on different rates of turkey manure and the mixture of turkey manure with ESN. The objective of this study was to determine the best nitrogen fertilization option utilizing turkey manure as the major source of nitrogen.

Procedures
A field study was established in near Perham, MN in a commercial potato field. A randomized complete block with a split-plot design and four replications was utilized. Plots were planted on 28 April 2021 with Russet Burbank at 12 inch with-in-row spacing on 36-inch spaced rows. Prior to planting turkey manured was spread over the plot areas. We utilized the planting equipment and hilling (on 10 May) to incorporate the turkey manure. Turkey manure was analyzed and found to have 51 lb N/ton, 49 lb P_20_5/a and 34 lb K_20/a. Environmentally Smart Nitrogen was applied on 9 May and hilled on 10 May. Vines were removed with a vine chopper on 7 September and harvested with a single row plot harvester on 9 September 2021. Following harvest, tubers were graded on 13 September and sized according to USDA standards.

Results
Stand and stem counts were similar between treatments. Differences in total yield, marketable yield, and the percent of tubers >6 oz were found between treatments. The non-treated plot, receiving no additional nitrogen had the lowest yield and fewest tubers >6 oz. The next lowest yielding plot was 3 tons/a turkey manure. All other treatments had similar yield. The numerically highest yield was the treatment with 5 tons/a turkey manure + 100 lb/a N. An economic analysis should be conducted based on current fertilizer prices to determine what combination of turkey manure and ESN would be the best option.

Table 1. Stand, stems per plant, graded yield, and specific gravity of Russet Burbank potato tubers grown in Perham, MN in 2021 treated with turkey manure and ESN.

Treatment	ESN lb N/a	Turkey manure ton/a	Stand %	Stems/plant number	<3 oz	3-6 oz	6-10 oz	10-14 oz	>14 oz	Total	Total marketable	>6 oz	>10 oz	Specific gravity
					cwt/a							%		
1	0	0	90	3.2	53	157	100	14	6	330	277	35	6	1.071
2	250	0	98	2.6	38	183	167	66	5	460	421	51	15	1.070
3	0	3	91	2.9	46	176	112	48	0	382	337	42	13	1.072
4	0	5	90	3.1	45	184	154	52	19	454	409	49	15	1.071
5	50	3	96	3.0	44	182	161	58	20	464	419	50	15	1.072
6	100	3	91	3.1	39	177	171	41	21	448	410	52	14	1.069
7	50	5	91	2.8	35	176	169	64	12	456	421	54	17	1.069
8	100	5	94	2.6	35	146	195	64	37	477	442	61	20	1.069
Mean			93	2.9	42	173	154	51	15	434	392	49	14	1.070
CV			5	17.6	28	12	23	58	122	14	16	19	52	0.369
LSD p=0.05			*ns*	*ns*	*ns*	*ns*	51	*ns*	*ns*	87	94	13	*ns*	*ns*
LSD p=0.1			*ns*	*ns*	*ns*	*ns*	42	*ns*	*ns*	72	78	11	*ns*	*ns*

Table 2. Tuber number by size class of Russet Burbank potato tubers grown in Perham, MN in 2021 treated with turkey manure and ESN.

Treatment	ESN lb N/a	Turkey manure ton/a	<3 oz	3-6 oz	6-10 oz	10-14 oz	>14 oz	Total	Total marketable	>6 oz	>10 oz
			number/a							%	
1	0	0	40,656	60,984	22,869	1,997	545	127,050	86,394	20	2
2	250	0	28,859	65,885	35,756	9,438	545	140,481	111,623	33	7
3	0	3	35,211	69,152	26,318	7,260	0	137,940	102,729	24	5
4	0	5	33,396	69,152	32,307	7,260	1,815	143,930	110,534	29	7
5	50	3	32,489	69,152	36,300	8,349	1,997	148,286	115,797	31	7
6	100	3	30,674	68,789	39,749	6,171	2,178	147,560	116,886	33	6
7	50	5	25,047	63,888	35,937	9,075	1,271	135,218	110,171	34	8
8	100	5	27,044	55,176	42,471	9,257	3,449	137,396	110,352	40	9
Mean			31,672	65,272	33,963	7,351	1,475	139,732	108,061	30	6
CV			26	12	23	57	117	8	11	25	60
LSD p=0.05			*ns*	*ns*	11,391	*ns*	*ns*	*ns*	17,210	11	*ns*
LSD p=0.1			*ns*	*ns*	9,443	*ns*	*ns*	*ns*	14,266	9	*ns*

Seed Lot Trial

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Executive summary
Over the past few years there have been several issues with seed not performing. This is typically expressed as seed not growing or emerging slowly, breaking down, or having a disease or herbicide problem. The amount of PVY and other viruses is constantly a concern of growers. Because of these issues, field have been replanted or had a low stand count causing large economic losses. The purpose of this project was to grow out seed provided by commercial potato farms to identify the field presence of any problems with the seed. The number of seed lots grown in Becker, MN was 32 and at Inkster, ND was 6. Seed lots performed well with minor problems observed.

Introduction
Performing a seed potato grow out provides a variety of benefits. If a seed lot planted in a commercial field is having problems with early growth, the grower and Extension specialist can check the grow out to determine if it appears to be a seed lot issue or an issue with how seed was handled and planted. A seed lot trial allows growers to see which seed growers consistently produce high quality seed. Because seed is vital to a commercial grower's success, purchasing quality seed is a must. The objective for this project was to identify plant stand and any tubers with virus, herbicide or other growth limiting problems.

Procedures
Growers who wanted to participate in this trial submitted 200 seed tubers from each lot they wanted tested. Growers submitting seed lots will provide information about the seed lot, including variety, generation, seed grower, state grown, receiver and date sampled. Locations for sample drop off were provided. Plots were planted in Becker, MN on April 30 and in Inkster, ND on June 4. At Becker, MN Seed tubers were planted in two rows for 75 feet at 9-inch within-row spacing and at 100 feet long rows at Inkster at 12" within-row spacing. Whole seed were utilized and only insecticide was applied to the seed piece to control Colorado Potato Beetles. We did not want any potential problems with emergence that seed cutting, or fungicides may cause to the seed. Once plants reached 12 -16 inches tall, plots were walked to identify plants and mark with a flag those that exhibit symptoms of mosaic, blackleg, chemical damage, phytoplasmas, or calico.

Results
Seed lots all grew well, stands were normal, and the amount of seed rot, herbicide injury, and virus was low. Although three growers submitted samples, they were show the seed lot plots when they desired on a one-on-one basis. Based on the low number of samples submitted, we will not continue this program.

Potato production using narrow row-width under irrigated conditions

Submitted to the Northern Plains Potato Growers Association and MN Area II Potato Growers Council

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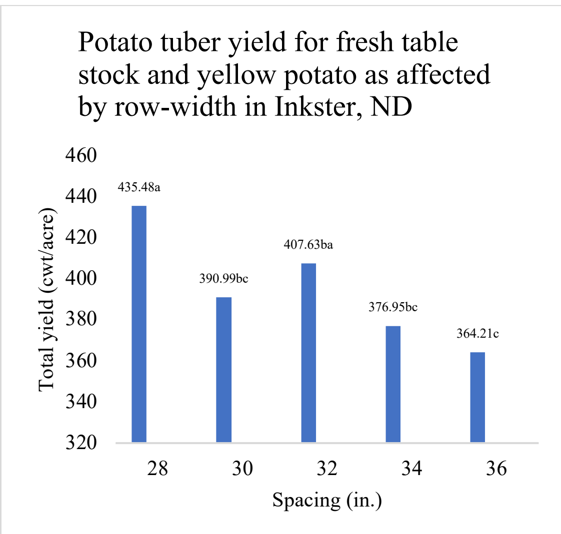
Executive summary
Over time row spacing has narrowed, because it provides improved yield and size of potatoes. With a push for more sustainable agriculture, getting more production per acre with fewer inputs is important. Changing row spacing is one option that would allow growers to maintain similar agronomic practices as they currently have for potatoes and increase marketable yield. Recent work at Washington State University tested different rows spacings found that 32-inch row spacing was ideal for increasing marketable yield and return of six different russet-skinned potatoes and Chieftain, showing increased profits by $380 per acre (Pavek, 2018). The purpose of this project was to evaluate narrower row spacings for chip, red-skinned, and yellow-skinned potatoes. Plots were established in Becker, MN and Inkster, ND in 2021. Great yield was recorded in Inkster, ND with narrower rows for fresh reds and yellows, while there was difference in yield at Becker, MN. Further work will continue to study this topic.

Introduction
The current potato row-width spacing in Minnesota and North Dakota varies from 34 to 38 inches. Narrower potato row-width is feasible especially where irrigation is non-limiting, and this could improve land use efficiency and optimize economic returns. Further, narrower row-width increase yield for russet and some fresh table stock potato cultivars under irrigated conditions. This study investigated yield response of fresh table stock red and yellow cultivars and chip processing cultivars to narrow row-width spacing under irrigated conditions at Becker, MN and Inkster, ND.

Materials and methods
Plots were established in a randomized complete block design with a split plot factorial arrangement at the University of Minnesota Sand Plains Research Farm near Becker, MN and Northern Plains Potato Growers Association Irrigated Research Site near Inkster, ND. The chipping cultivars planted were Dakota Pearl, Lady Liberty, Snowden, and Manistee. Fresh table stock cultivars planted were Red Norland, Musica (only at Inkster), Agata, Modoc, and Columba (only at Becker). Treatments were five row spacings of 28, 30, 32, 34, and 36 inches. Plots were grown under standard grower agronomic practices. Data were analyzed by statistical analysis software and mean separation is reported by least significant difference.

Results

Differences were found in yield at Inkster, ND. However, no differences were found at Becker, MN. Narrow row-width significantly ($p < 0.05$) increased total tuber yield for fresh table stock cultivars in Inkster, ND. Narrow row-width significantly ($p<.05$) increased total and marketable tuber yield for chip processing potato cultivars in Inkster, ND. Narrow row-width spacing shows potential to increase total potato tuber yield. We plan on continuing this work for the next two years to determine if there are consistent effects of narrower row spacing on red, yellow, and chipping potatoes.



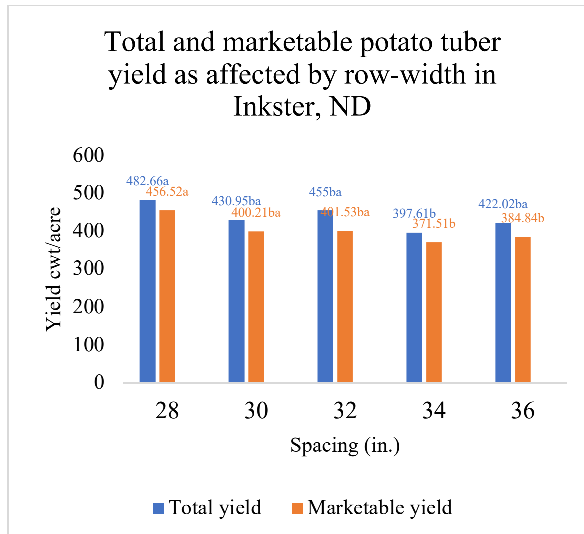


Table 1. Potato tuber yield as affected by row width in Becker, MN in 2021.

Spacing	Tuber yield	
	Chip processing	Fresh table stock and yellows
Inch	cwt/acre	
28	250a	414a
30	308a	409a
32	295a	381a
34	254a	397a

Late Blight Spore Trapping Network for Minnesota and North Dakota

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Executive Summary

Late blight is a community disease that can cause dramatic losses in potato production. As a community disease, early detection of late blight spores is important to enable potato growers to quickly apply premium protectant fungicides. This project was initiated to confirm DNA of late blight spores near potato fields in Minnesota and North Dakota. In 2021, 42-spore traps were setup in North Dakota and Minnesota potato fields region starting the last week in June to early September. There no positives found for late blight between June 28 and September 10, 2021. This coincided with typically no favorable weather conditions for late blight at many times throughout the growing season. Although this monitoring system is costly to operate, it is good insurance for early detection of late blight spores can save millions of dollars in potato losses by allowing growers to adjust fungicide management plans. Weekly reports were emailed out in the Spud Scoop.

Rationale for conducting the research

The threat of late blight is always a concern for potato growers as it has potential to cause severe financial and yield losses. Early detection and protection can help save a potato crop, as it is unknown when late blight spores are present near fields. Currently we do not know if or when late blight spores are present in Minnesota. The focus of this project is to provide real-time data on late blight spores and not just rely on a predictive weather model.

This spore trapping network will enable potato growers to be alerted when late blight spores are found to enable them to know when to apply premium fungicides. Collection traps were placed in cooperating growers' fields and sent to Dr. Pasche's laboratory in a prepaid package. Spores were identified in Dr. Pache's laboratory.

Procedures

Spore traps were distributed to cooperating growers in Minnesota, North Dakota, and Nebraska (Figures 1-5). On a weekly basis, starting between June 28 cassettes were placed in the spore traps. After one week they were shipping in a prepaid envelope to Dr. Pache's laboratory and the DNA was extracted and evaluated for late blight. Sampling continued until September 10, 2021. After data was collected, ArcGIS maps were made and sent to growers by email to let them know all reporting traps and findings. A newsletter was created, call 'Spud Scoop' to put all the week data for potato growers into one update. The Spud Scoop included some observations from Andy Robinson, the Blightline from Gary Secor, the Potato Late Blight Spore Trapping Network data and Andy Robinson and Julie Pasche, and the AphidAlert from Ian MacRae.

Because of this project with cooperating growers, we were able to ensure that late blight spore DNA was not present allowing improved management by reducing fungicide usage. Thank you to all the grower who participated in this project and for the funding and support to make this happen.

Thank you to the cooperating growers who allow traps on their farms and changed them weekly, Northern Plains Potato Growers Association, Minnesota Area II Potato Council, J.R. Simplot Company, Cavendish, R.D. Offutt Farms, Syngenta, Sipcam, Bayer Crop Science, BASF, UPL USA, Corteva, and Nufarm for supporting this effort.

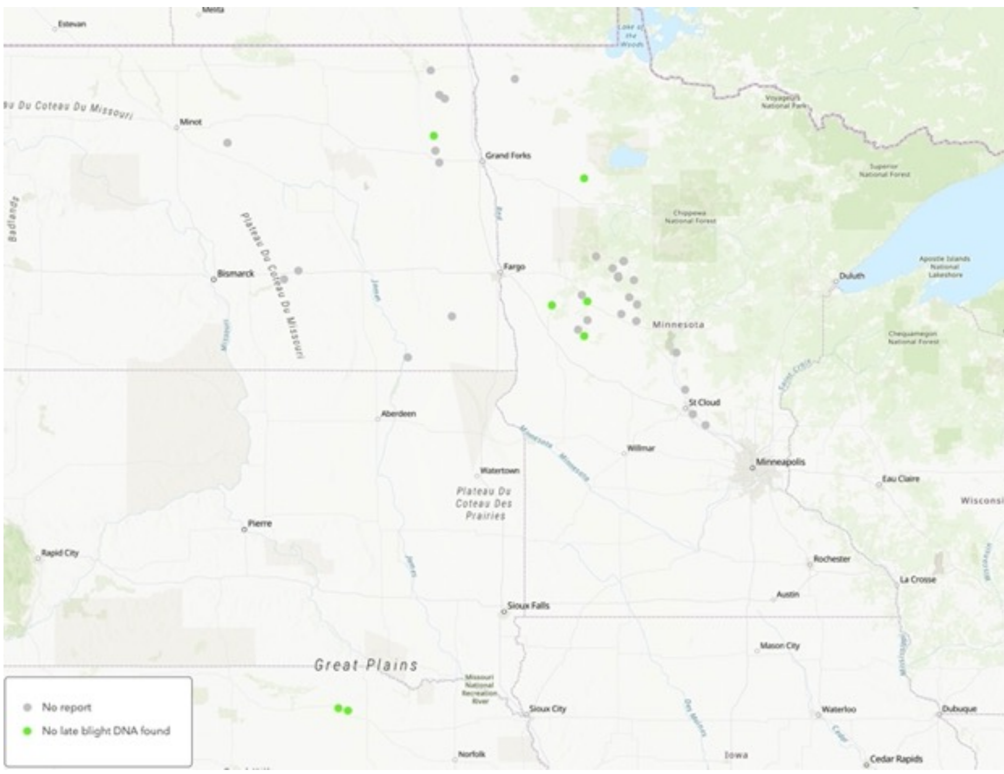

Figure 1. Results of late blight spore traps during the week of July 9 to 16, 2021.

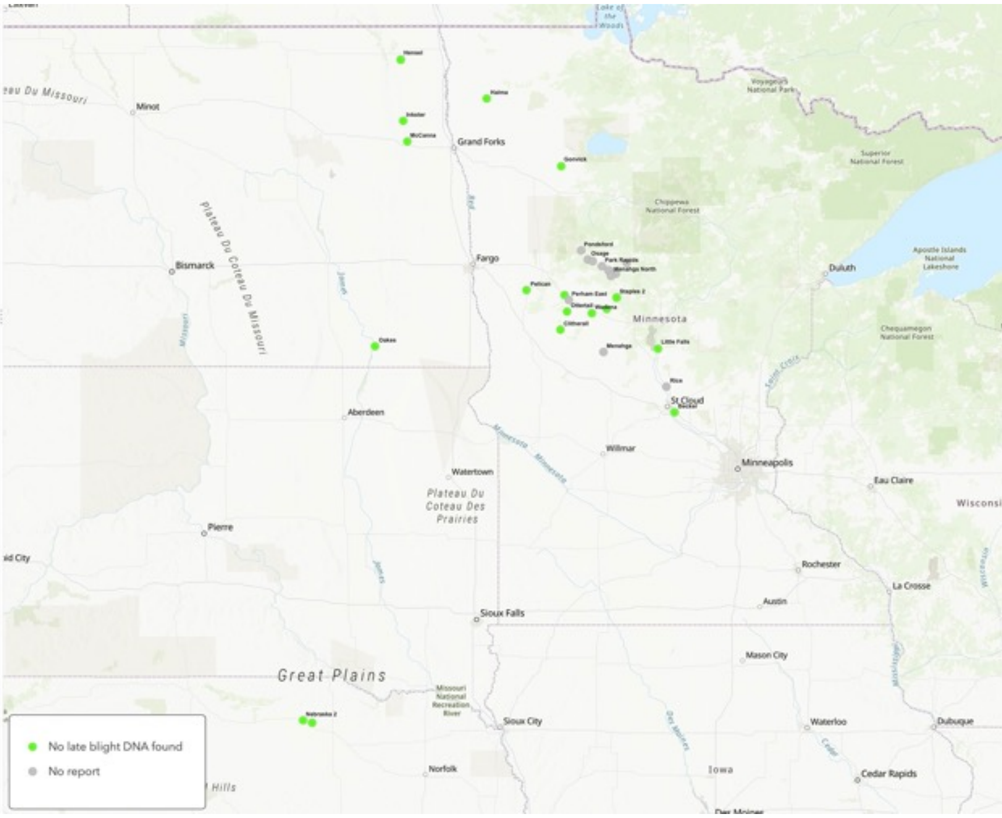

Figure 2. Results of late blight spore traps during the week of July 16 to 23, 2021.

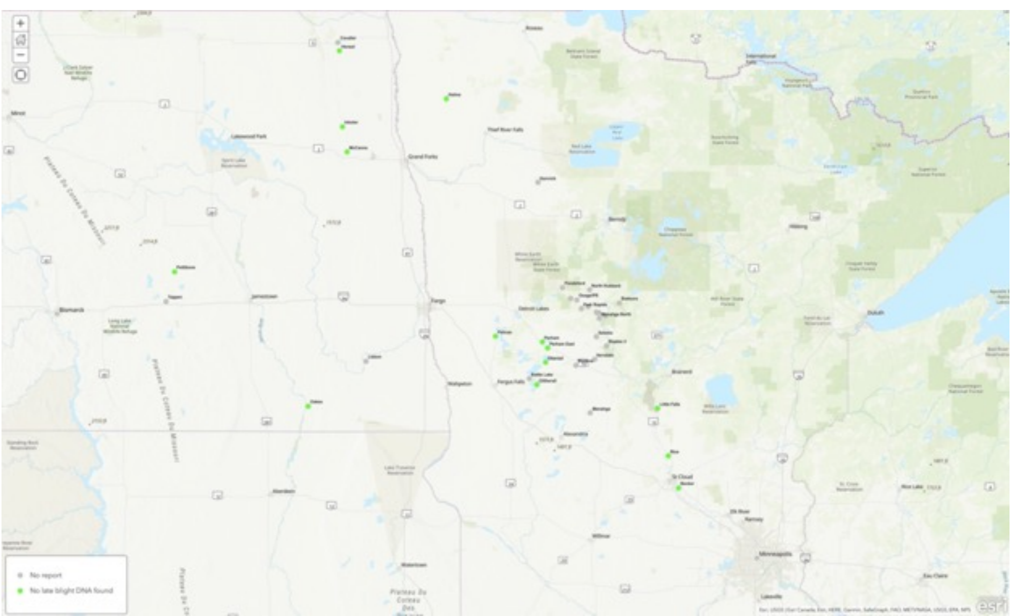
Figure 3. Results of the late blight spore traps from the week of July 26 to August 2, 2021.

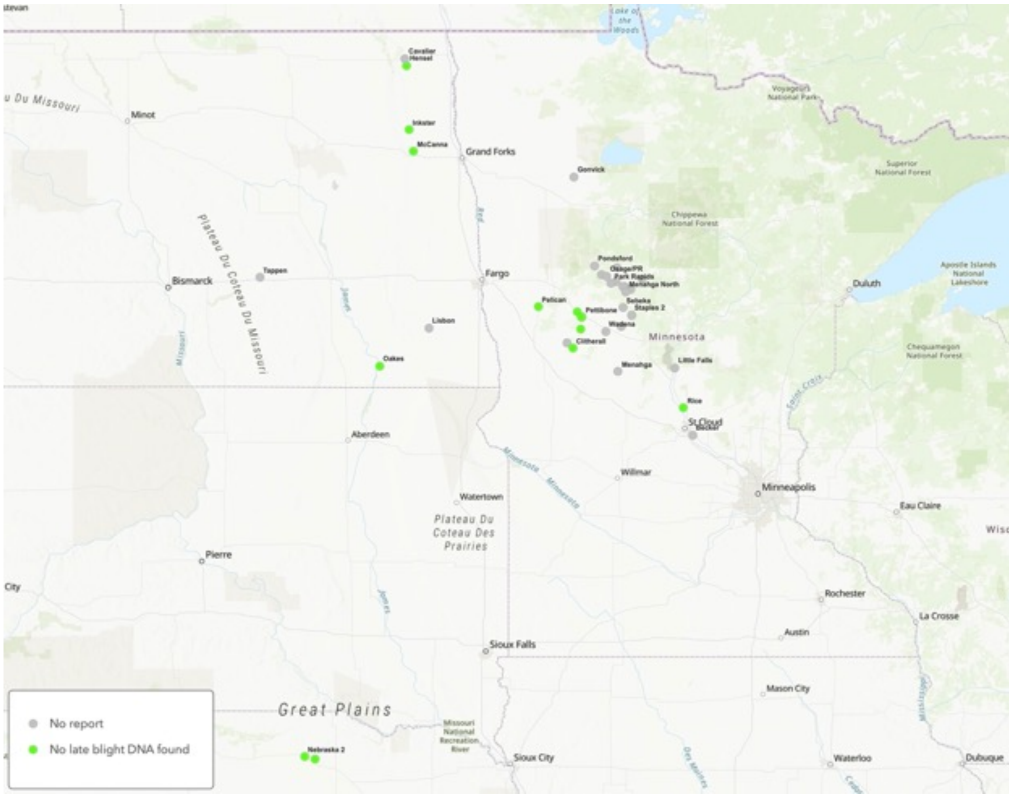

Figure 4. Results of late blight spore traps during the week of August 2 to 9, 2021.

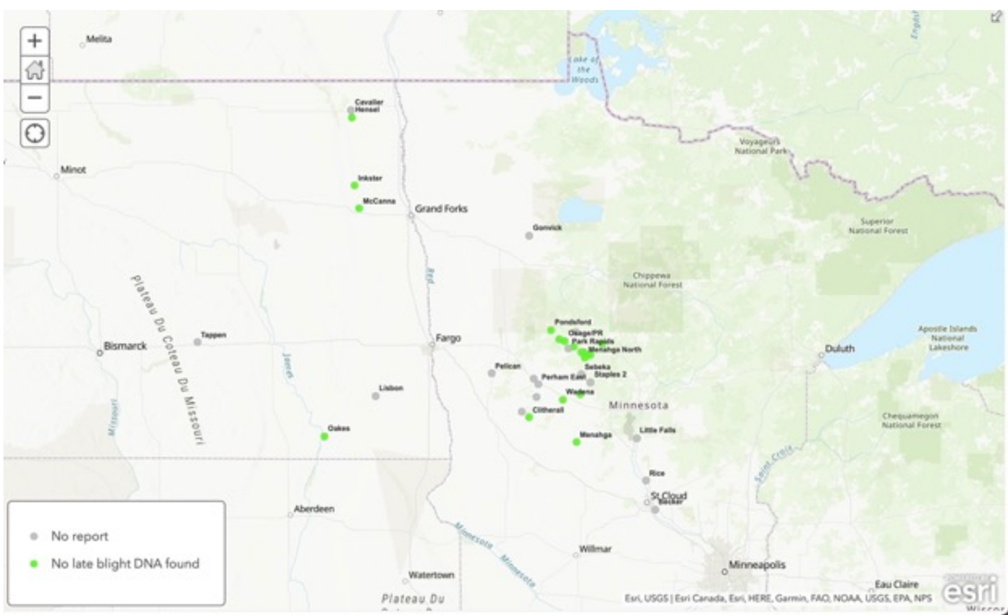

Figure 5. Results of late blight spore traps during the week of August 9 to 16, 2021.

Herbicide efficacy study 2021

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Executive Summary
Weeds are constantly competing with potatoes for water, nutrients, and light. Previous research has reported pests causing up to 40% yield loss in potatoes and weeds can cause 34% loss in yield when weeds are not controlled. Managing hard-to-kill weeds is important for successful potato production. The focus of this project was to evaluate various herbicide combinations on weed control and potato tuber yield. A focus was put on tank mixture that have lower water solubility and have a longer residual. These herbicides included Linex, Zidua, and Matrix.

Materials and Methods
Plots were planted with Russet Burbank near Verndale, MN in a commercial potato field managed by RDO farms on May 7, 2021. Weeds growth was prolific in this field. Preemergent herbicide treatments occurred on May 20, 2021, and postemergence applications were completed on June 17, 2021. Plots were visually evaluated for crop injury at 14 and 28 days after treatment using a scale from 0 to 100, with 0 indicating complete plant death and 100 indicating no injury to the crop. Weed control was rated at 14 and 28 days after treatment using a scale from 0 to 100 with 0 indicating no weed control and 100 representing 100% weed control. Plots were harvested on September 8, 2021, with a single row plot harvest and subsequently graded for size on September 10, 2021. Data were analyzed using Proc Mixed in SAS to account for uneven replicate number in some treatments. Means were separated by Tukey pair-wise comparison at p=0.05.

Results
This field was not fumigated prior to planting potatoes. Weed pressure was high and many species were present. No crop injury was observed (Table 1). Weed control varied by treatment and weed species (Table 1). Preemergent herbicides that were tank mixed with another herbicide tended to perform well. Metribuzin at 0.6 lb/a performed well for a single herbicide. Interestingly, the two postemergence treatments had good weed control at 28 days after treatment. The higher dose of Prowl H2O (3 pt/a) + metribuzin (0.75 lb/a) + Matrix (1.5 oz/a) + K-tone 0.5% v/v had great weed control and the highest yield (Table 2). One explanation for the higher yield may have been that the intense weed pressure (Figure 1) kept the soil cooler and subsequent weed control allowed tubers to bulk more. Weed pressure was much lower on other treated plots (Figure 2). Tuber count was numerically lower compared to all the treated plots causing the percentage of tubers over 6 and 10oz to be the highest from the treatment of Prowl H2O (3 pt/a) + metribuzin (0.75 lb/a) + Matrix (1.5 oz/a) + K-tone 0.5% v/v applied postemergence (Table 3).


Figure 1. Weed pressure in postemergence plots treated 4 days prior to this picture in Verndale, MN.

Table 1. Crop injury and weed control at 14 days after treatment from various preemergent and postemergence herbicides in Verndale, MN, 2021.

	Treatment name	Rate	Timing	Crop injury	Common lambsquarters		Wild buckwheat		Barnyard grass		Redroot pigweed		Eastern black nightshade	
				%	% efficacy									
1	Non-treated check	--	--	100	0	b	0	b	0	c	0	b	0	c
2	Metribuzin	0.6 lb/a	PRE	100	90	a	55	ab	74	ab	99	a	95	a
3	Linex	2 pt/a	PRE	100	81	a	63	ab	70	ab	98	a	100	a
4	Linex	2 pt/a	PRE	100	96	a	70	a	84	ab	98	a	100	a
	Zidua	3 fl oz/a	PRE											
5	Metribuzin	0.6 lb/a	PRE	100	97	a	63	ab	84	ab	98	a	100	a
	Zidua	3 fl oz/a	PRE											
6	Metribuzin	0.6 lb/a	PRE	100	91	a	75	a	81	ab	100	a	100	a
	Linex	2 pt/a	PRE											
7	Metribuzin	0.6 lb/a	PRE	100	93	a	63	ab	78	ab	100	a	100	a
	Linex	2 pt/a	PRE											
	Sulfentrazone	3 oz/a	PRE											
8	Linex	2 pt/a	PRE	100	100	a	74	a	74	ab	99	a	100	a
	Zidua	3 fl oz/a	PRE											
	Sulfentrazone	3 oz/a	PRE											
9	Linex	2 pt/a	PRE	100	89	a	55	ab	83	ab	88	a	100	a
	Zidua	3 fl oz/a	PRE											
	Prowl H2O	1.5 pt/a	PRE											
	Matrix	1.5 oz/a	PRE											
10	Linex	2 pta	PRE	100	86	a	63	ab	84	ab	100	a	100	a
	Zidua	3 fl oz/a	PRE											
	Matrix	1.5 oz/a	PRE											
11	Linex	2 pt/a	PRE	100	94	a	50	ab	79	ab	100	a	100	a
	Dual	1 pt/a	PRE											
12	Zidua	3 fl oz/a	PRE	100	85	a	60	ab	85	ab	100	a	94	a
	Dual	1 pt/a	PRE											
	Metribuzin	0.6 lb/a	PRE											
13	Zidua	3 fl oz/a	PRE	100	92	a	70	a	84	ab	100	a	100	a
	Metribuzin	0.6 lb/a	PRE											
	Matrix	1.5 oz/a	PRE											
14	Linex	2 pt/a	PRE	100	95	a	60	ab	89	a	100	a	100	a
	Zidua	3 fl oz/a	PRE											
	Prowl H2O	3 pt/a	PRE											
15	Linex	2 pt/a	PRE	100	99	a	89	a	88	a	100	a	100	a
	Zidua	3 fl oz/a	PRE											
	Metribuzin	0.6 lb/a	PRE											
16	Linex	2 pt/a	PRE	100	97	a	80	a	89	a	100	a	100	a
	Metribuzin	0.6 lb/a	PRE											
	Matrix	1.5 oz/a	PRE											
	Sulfentrazone	3 oz/a	PRE											
17	Prowl H2O	3 pt/a	POST	100	65	a	67	ab	42	bc	65	a	35	b
	Metribuzin	0.75 lb/a	POST											
	Matrix	1.5 oz/a	POST											
	K-Tone	0.5% v/v	POST											
18	Prowl H2O	1.5 pt/a	POST	100	55	a	75	ab	49	ab	73	a	14	bc
	Metribuzin	0.5 lb/a	POST											
	Matrix	1.25 oz/a	POST											
	K-Tone	0.5% v/v	POST											

Figure 2. June 15, 2021 pictures of each treatment.

Table 2. Crop injury and weed control at 28 days after treatment from various preemergent and postemergence herbicides in Verndale, MN, 2021.

	Treatment name	Rate	Timing	Crop injury %	Common lambsquarters	Wild buckwheat	Barnyard grass	Redroot pigweed	Eastern black nightshade	Hairy nightshade	Common ragweed
					% efficacy						
1	Non-treated check	--	--	100	0 c	0 c	0 b	0 b	0 c	0 b	0 b
2	Metribuzin	0.6 lb/a	PRE	100	75 ab	28 abc	71 a	93 a	35 bc	73 ab	75 a
3	Linex	2 pt/a	PRE	100	48 abc	13 bc	40 ab	80 a	75 ab	40 ab	39 ab
4	Linex	2 pt/a	PRE	100	76 ab	48 abc	70 a	83 a	90 ab	91 a	89 a
	Zidua	3 fl oz/a	PRE								
5	Metribuzin	0.6 lb/a	PRE	100	96 a	70 abc	85 a	100 a	87 ab	92 a	80 a
	Zidua	3 fl oz/a	PRE								
6	Metribuzin	0.6 lb/a	PRE	100	73 ab	64 abc	65 a	74 a	73 ab	60 ab	74 a
	Linex	2 pt/a	PRE								
7	Metribuzin	0.6 lb/a	PRE	100	94 a	40 abc	79 a	73 a	90 ab	44 ab	88 a
	Linex	2 pt/a	PRE								
	Sulfentrazone	3 oz/a	PRE								
8	Linex	2 pt/a	PRE	100	88 a	63 abc	82 a	91 a	98 a	85 a	94 a
	Zidua	3 fl oz/a	PRE								
	Sulfentrazone	3 oz/a	PRE								
9	Linex	2 pt/a	PRE	100	55 ab	13 bc	75 a	90 a	100 a	79 a	81 a
	Zidua	3 fl oz/a	PRE								
	Prowl H2O	1.5 pt/a	PRE								
	Matrix	1.5 oz/a	PRE								
10	Linex	2 pta	PRE	100	36 bc	46 abc	63 a	70 a	73 ab	70 ab	75 a
	Zidua	3 fl oz/a	PRE								
	Matrix	1.5 oz/a	PRE								
11	Linex	2 pt/a	PRE	100	62 ab	0 c	63 a	87 a	100 a	73 ab	100 a
	Dual	1 pt/a	PRE								
12	Zidua	3 fl oz/a	PRE	100	59 ab	41 abc	83 a	98 a	88 ab	85 a	80 a
	Dual	1 pt/a	PRE								
	Metribuzin	0.6 lb/a	PRE								
13	Zidua	3 fl oz/a	PRE	100	77 ab	23 abc	78 a	92 a	90 ab	100 a	83 a
	Metribuzin	0.6 lb/a	PRE								
	Matrix	1.5 oz/a	PRE								
14	Linex	2 pt/a	PRE	100	92 a	13 abc	88 a	100 a	100 a	92 a	83 a
	Zidua	3 fl oz/a	PRE								
	Prowl H2O	3 pt/a	PRE								
15	Linex	2 pt/a	PRE	100	91 a	65 abc	76 a	83 a	100 a	86 a	100 a
	Zidua	3 fl oz/a	PRE								
	Metribuzin	0.6 lb/a	PRE								
16	Linex	2 pt/a	PRE	100	90 a	49 abc	86 a	99 a	93 ab	55 ab	95 a
	Metribuzin	0.6 lb/a	PRE								
	Matrix	1.5 oz/a	PRE								
	Sulfentrazone	3 oz/a	PRE								
17	Prowl H2O	3 pt/a	POST	100	100 a	100 ab	88 a	100 a	100 a	100 a	100 a
	Metribuzin	0.75 lb/a	POST								
	Matrix	1.5 oz/a	POST								
	K-Tone	0.5% v/v	POST								
18	Prowl H2O	1.5 pt/a	POST	100	92 a	100 a	80 a	100 a	95 ab	95 a	100 a
	Metribuzin	0.5 lb/a	POST								
	Matrix	1.25 oz/a	POST								
	K-Tone	0.5% v/v	POST								

Table 3. Graded yield of Russet Burbank potato tubers (cwt/a) following herbicide treatments near Verndale, MN in 2021.

	Treatment name	Rate	Timing	<3 oz	3-6 oz	6-10 oz	10-14 oz	>14 oz	Total yield	Marketable yield	Pct >6oz	Pct >10 oz
					-- cwt/a					--	-------- %	--------
1	Non-treated check	--	--	55	74 b	32 b	3 b	0 b	164 c	109 c	17 c	1 b
2	Metribuzin	0.6 lb/a	PRE	57	162 ab	119 ab	24 b	11 b	373 ab	316 abc	38 bc	9 b
3	Linex	2 pt/a	PRE	48	136 ab	68 ab	16 b	1 b	270 bc	221 bc	31 bc	6 b
4	Linex Zidua	2 pt/a 3 fl oz/a	PRE PRE	38	135 ab	178 ab	52 b	20 b	423 ab	385 ab	57 abc	16 b
5	Metribuzin Zidua	0.6 lb/a 3 fl oz/a	PRE PRE	30	126 ab	177 ab	89 ab	38 ab	461 ab	431 ab	66 ab	28 ab
6	Metribuzin Linex	0.6 lb/a 2 pt/a	PRE PRE	37	143 ab	179 ab	73 ab	21 b	454 ab	417 ab	60 ab	21 ab
7	Metribuzin Linex Sulfentrazone	0.6 lb/a 2 pt/a 3 oz/a	PRE PRE PRE	28	126 ab	157 ab	67 ab	34 ab	412 ab	384 ab	63 ab	25 ab
8	Linex Zidua Sulfentrazone	2 pt/a 3 fl oz/a 3 oz/a	PRE PRE PRE	34	143 ab	159 ab	56 b	23 b	414 ab	380 ab	53 abc	17 b
9	Linex Zidua Prowl H2O Matrix	2 pt/a 3 fl oz/a 1.5 pt/a 1.5 oz/a	PRE PRE PRE PRE	31	145 ab	169 ab	60 b	24 b	429 ab	398 ab	59 ab	19 b
10	Linex Zidua Matrix	2 pta 3 fl oz/a 1.5 oz/a	PRE PRE PRE	48	149 ab	147 ab	22 b	10 b	376 abc	328 abc	42 abc	6 b
11	Linex Dual	2 pt/a 1 pt/a	PRE PRE	41	142 ab	108 ab	28 b	4 b	322 abc	282 abc	42 abc	10 b
12	Zidua Dual Metribuzin	3 fl oz/a 1 pt/a 0.6 lb/a	PRE PRE PRE	49	126 ab	122 ab	47 b	9 b	353 abc	304 abc	49 abc	15 b
13	Zidua Metribuzin Matrix	3 fl oz/a 0.6 lb/a 1.5 oz/a	PRE PRE PRE	23	131 ab	167 ab	81 ab	36 ab	439 ab	416 ab	64 ab	26 ab
14	Linex Zidua Prowl H2O	2 pt/a 3 fl oz/a 3 pt/a	PRE PRE PRE	37	152 ab	138 ab	58 ab	29 b	444 ab	407 ab	56 abc	20 b
15	Linex Zidua Metribuzin	2 pt/a 3 fl oz/a 0.6 lb/a	PRE PRE PRE	37	180 a	176 a	51 b	19 b	463 ab	426 ab	53 abc	15 b
16	Linex Metribuzin Matrix Sulfentrazone	2 pt/a 0.6 lb/a 1.5 oz/a 3 oz/a	PRE PRE PRE PRE	41	158 ab	195 a	83 ab	35 ab	512 a	471 a	60 ab	23 ab
17	Prowl H2O Metribuzin Matrix K-Tone	3 pt/a 0.75 lb/a 1.5 oz/a 0.5% v/v	POST POST POST POST	14	80 b	182 a	144 a	106 a	525 a	511 a	82 a	48 a
18	Prowl H2O Metribuzin Matrix K-Tone	1.5 pt/a 0.5 lb/a 1.25 oz/a 0.5% v/v	POST POST POST POST	29	113 ab	162 ab	78 ab	55 ab	437 ab	408 ab	64 ab	26 ab

Table 4. Graded yield of Russet Burbank potato tuber (tuber number/acre) following herbicide treatments near Verndale, MN in 2021.

	Treatment name	Rate	Timing	<3 oz		3-6 oz		6-10 oz	10-14 oz		>14 oz		Total yield	Marketable yield		Pct >6oz		Pct >10 oz	
								Tuber number/a								%			
1	Non-treated check	--	--	44,286	a	32,912	ab	8,228	484	b	0	b	85,910	41,624	b	9	c	0	b
2	Metribuzin	0.6 lb/a	PRE	44,831	a	63,525	ab	27,407	3,449	b	1,089	b	140,300	95,469	ab	21	bc	3	b
3	Linex	2 pt/a	PRE	40,293	ab	57,536	ab	17,424	2,723	b	182	b	118,157	77,864	ab	17	bc	2	b
4	Linex	2 pt/a	PRE	29,766	ab	51,062	ab	38,962	7,502	b	2,178	b	129,470	99,704	ab	36	abc	7	b
	Zidua	3 fl oz/a	PRE																
5	Metribuzin	0.6 lb/a	PRE	23,958	ab	49,852	ab	40,656	13,068	ab	4,356	ab	131,890	107,932	ab	44	abc	14	ab
	Zidua	3 fl oz/a	PRE																
6	Metribuzin	0.6 lb/a	PRE	33,396	ab	61,710	ab	45,012	12,100	ab	2,662	ab	154,880	121,484	a	38	abc	10	b
	Linex	2 pt/a	PRE																
7	Metribuzin	0.6 lb/a	PRE																
	Linex	2 pt/a	PRE	21,296	ab	48,884	ab	34,848	10,406	ab	3,146	ab	118,580	97,284	ab	41	abc	11	b
	Sulfentrazone	3 oz/a	PRE																
8	Linex	2 pt/a	PRE	29,585	ab	58,806	ab	35,574	8,531	b	2,541	b	135,036	105,452	a	34	abc	8	b
	Zidua	3 fl oz/a	PRE																
	Sulfentrazone	3 oz/a	PRE																
9	Linex	2 pt/a	PRE	26,681	ab	59,351	ab	41,201	9,801	ab	2,723	b	139,755	113,075	a	39	abc	9	b
	Zidua	3 fl oz/a	PRE																
	Prowl H2O	1.5 pt/a	PRE																
	Matrix	1.5 oz/a	PRE																
10	Linex	2 pta	PRE	36,784	ab	58,564	ab	33,638	3,388	b	1,210	b	133,584	96,800	ab	26	bc	3	b
	Zidua	3 fl oz/a	PRE																
	Matrix	1.5 oz/a	PRE																
11	Linex	2 pt/a	PRE	33,880	ab	57,112	ab	25,410	4,356	b	484	b	121,242	87,362	ab	24	bc	4	b
	Dual	1 pt/a	PRE																
12	Zidua	3 fl oz/a	PRE	37,026	ab	51,062	ab	28,556	7,502	b	1,210	b	125,356	88,330	ab	30	abc	7	b
	Dual	1 pt/a	PRE																
	Metribuzin	0.6 lb/a	PRE																
13	Zidua	3 fl oz/a	PRE	17,908	ab	50,820	ab	37,268	12,342	ab	3,872	ab	122,210	104,302	ab	44	abc	13	ab
	Metribuzin	0.6 lb/a	PRE																
	Matrix	1.5 oz/a	PRE																
14	Linex	2 pt/a	PRE	31,702	ab	63,404	ab	40,898	9,196	ab	2,904	ab	147,862	116,402	a	36	abc	9	b
	Zidua	3 fl oz/a	PRE																
	Prowl H2O	3 pt/a	PRE																
15	Linex	2 pt/a	PRE	29,948	ab	72,237	a	42,834	7,805	b	2,178	b	155,001	125,054	a	34	abc	7	b
	Zidua	3 fl oz/a	PRE																
	Metribuzin	0.6 lb/a	PRE																
16	Linex	2 pt/a	PRE	30,129	ab	55,176	ab	41,382	11,798	ab	3,449	ab	141,933	111,804	a	40	abc	11	b
	Metribuzin	0.6 lb/a	PRE																
	Matrix	1.5 oz/a	PRE																
	Sulfentrazone	3 oz/a	PRE																
17	Prowl H2O	3 pt/a	POST	11,616	b	30,492	b	41,140	22,022	a	10,648	a	115,918	104,302	ab	64	a	28	a
	Metribuzin	0.75 lb/a	POST																
	Matrix	1.5 oz/a	POST																
	K-Tone	0.5% v/v	POST																
18	Prowl H2O	1.5 pt/a	POST	21,054	ab	40,414	ab	35,574	11,616	ab	6,050	ab	114,466	93,654	ab	46	ab	15	ab
	Metribuzin	0.5 lb/a	POST																
	Matrix	1.25 oz/a	POST																
	K-Tone	0.5% v/v	POST																

Fungicide Seed Treatment Effects on Emergence and Yield 2021

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Executive summary
Seed treatments on potato tubers has been reported to cause reduced emergence and yield in Wisconsin and Maine. As most potato growers use seed treatment products to protect seed from fungi and insects, this research project was established to determine if any negative effects occur with cut and whole seed with some commonly used seed treatments. Plots were planted in Inkster, ND with the variety Red Norland. There were no differences in stand, stem count, or yield from seed or in-furrow treatments.

Rationale for conducting the research
Grower concern over negative effects of fungicides on seed performance has led to establishing a research project to investigate this question. Reports from Wisconsin and Maine have found that some seed treatments reduced emergence and yield. North Dakota growing conditions are different from those in Wisconsin and Maine, thus it is important that we investigate this topic to determine if negative effects occur from seed treatments or in-furrow treatments. The objective of this project was to determine if common fungicide seed or in-furrow treatments would affect emergence and yield of cut and whole Red Norland potato.

Procedures
A field trials utilizing a randomized complete block design with four replications was established in Inkster, ND on June 4, 2021. The variety Red Norland was the selected seed to represent a commonly grow cultivar and one that has been tested previously in other states. Treatments included a non-treated check, Maxim 4FA at 4 lb/gal, Maxim MZ at 0.5 lb/cwt, Emesto Silver at 0.31 fl oz/cwt, CruiserMaxx Potato at 0.27 fl oz/cwt, and Elatus at 7.26 oz/a. Each treatment was applied to whole and cut seed or applied in-furrow for Elatus. The cut seed were hand cut to 2 to 2.5 oz per seed piece and suberized before planting. Expect from the seed treatment, all other production practices were completed according to recommended practices.

Stand counts were completed on June 30, July 9 and 16 to determine if there were any delays in emergence. Every emerged plant in each plot was counted. Data from June 30 were dropped because of problems with the data. On July 16, stems were counted on 10 consecutive plants in each. The number of stems per plant was averaged from these data to determine the number of stems per plant. Vines were desiccated with diquat on August 31 and September 9. The middle two rows of each plot were harvested with a single row harvester on September 22 and subsequently graded on October 12 with a Kerian Speed Sizer. Specific gravity was measured on October 12. Data were analyzed in SAS to determine if differences existed between treatments.

The agronomic data were analyzed statistically. These analyses allow the reader to ascertain, at a predetermined level of confidence, if the differences observed among treatments are reliable or if they might be due to error inherent in the experimental process.

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 mean a large amount of variation that could not be attributed to differences in the treatments.

Results

Treatments did not affect the emergence on July 9 or 16, stem number, or yield (Table 1). One reason to explain this is the later planting and warm temperatures could have encouraged quick growth of the seed pieces and a higher metabolism of chemistries, reducing the chance of slowed emergence. When contrasting whole seed compared to cut seed, there was a difference in emergence at each date, with cut seed having a 3% greater emergence rate. Additionally, cut seed had an average of 17 cwt/a more A sized tubers than whole seed pieces. The non-treated cut seed had a higher yield of B sized tubers compared to the treated cut seed. In this one-year study there was not enough evidence to suggest that the seed treatments could negatively affect emergence or yield.

Table 1. Response of Red Norland potato seed (whole and cut) to fungicide treatments on stand, stem number, and yield in Inkster, ND 2021.

Treatment	Seed piece	Seed treatment	Stand (7/9/21)	Stand (7/16/21)	Stems/plant number	C	B	A cwt/a	Chef	Total	Specific gravity
1	Whole	Non-treated check	85	81	5.2	2	50	311	44	407	1.064
2	Cut	Non-treated check	87	88	5.7	3	65	309	37	413	1.062
3	Whole	Maxim 4FS 4 lb/gal	80	86	5.6	3	59	302	47	410	1.062
4	Cut	Maxim 4FS 4 lb/gal	90	90	5.3	1	48	326	40	416	1.064
5	Whole	Maxim MZ 0.5 lb/cwt seed	84	92	6.5	2	61	288	48	399	1.063
6	Cut	Maxim MZ 0.5 lb/cwt seed	86	88	5.4	4	54	309	39	406	1.062
7	Whole	Emesto Silver 0.83 lb/gal	83	86	6.0	3	61	284	30	379	1.061
8	Cut	Emesto Silver 0.83 lb/gal	83	88	5.8	1	48	335	21	404	1.062
9	Whole	CruiserMaxx Potato 0.73 lb/gal	82	84	6.0	4	62	309	19	394	1.063
10	Cut	CruiserMaxx Potato 0.73 lb/gal	88	89	5.2	2	55	304	43	403	1.063
11	Whole	Elatus 7.26 oz/a	83	85	5.1	3	58	284	47	392	1.064
12	Cut	Elatus 7.26 oz/a	85	86	5.7	2	55	297	52	407	1.064
Mean			85	87	5.6	2	56	305	39	402	1.063
CV			8	7	17	61	22	9	46	6	0.3
Treatment significance (p-value)			0.7566	0.3754	0.6779	0.1236	0.6506	0.2077	0.1951	0.7553	0.8790
Contrasts	Whole vs cut seed		**0.0824**	**0.0925**	0.4197	**0.0693**	0.2064	**0.0371**	0.9385	0.1346	0.7736
	Non-treated whole vs treated whole		0.5573	**0.0900**	0.2000	0.3303	0.1308	0.2542	0.5384	0.3778	0.1645
	Non-treated cut seed vs treated cut seed		0.8182	0.9998	0.6835	0.4847	**0.0501**	0.7060	0.8623	0.6570	0.2244
	Non-treated vs treated		0.5638	0.2254	0.5305	0.8434	0.7342	0.5850	0.7540	0.3495	0.8976

A1783-21

photo Robinson, NDSU/UMN

North Dakota
Fresh Market Potato
Cultivar/Selection Trial Results for 2021

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Potato cultivars or selections included in this report were selected from recently released cultivars, advancing selections with release potential (numbered lines progressing through the trial process), or cultivars that are new to the U.S. Standard potato cultivars used by growers served as checks. For comparison, studies conducted in 2019 (*https://www.ag.ndsu.edu/publications/crops/north-dakota-fresh-market-potato-cultivar-selection-trial-results-for-2019*) and 2020 (*https://www.ag.ndsu.edu/publications/crops/north-dakota-fresh-market-potato-cultivar-selection-trial-results-for-2020*) evaluated red and yellow-skinned fresh potatoes.

In 2021, two trials were conducted to identify traits of red- and yellow-skinned potato cultivars and advanced selections at Crystal, N.D. Sixteen red-skinned cultivars and 32 yellow-skinned cultivars were evaluated. Plots were established in a commercial, non-irrigated potato field utilizing common potato-production practices. The authors acknowledge J.G. Hall and Sons for hosting these trials.

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. Seed tubers were hand cut to approximately 2-ounce seed pieces prior to planting; an exception was the cultivar Obama, which was planted using whole seed tubers.

Tubers were planted on June 17, 2021, in a single row with 9-inch within-row spacing. Plots were 3 feet wide and 30 feet long.

Stand and stem counts on 10 plants in a row in each plot was taken on July 22. Plant stand was measured on 10 plants on Aug. 9. Vine length was measured on three plants from the base of the plant to the vine tip on Aug. 31. Vigor evaluation was completed on Aug. 31. A rating of 1 indicated least vigor and 5 greatest vigor. Plots were harvested on Sept. 29 and 30 with a single-row plot harvester.

After harvest, potatoes were stored at 55 F until grading. The tuber size profile distribution was determined by sorting all potatoes harvested into C size (less than 1.875 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.

The 2021 agronomic data presented in Tables 1 through 4 were analyzed statistically. Yield data from 2019 and 2020 are presented as averages and were not analyzed statistically. These analyses allow the reader to ascertain, at a predetermined level of confidence, if the differences observed among cultivars/selections are reliable or if

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they might be 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 mean a large amount of variation that could not be attributed to differences in the cultivars/selections.

The data provided does not indicate endorsement or approval by the authors, or 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 the breeding programs at North Dakota State University, University of Minnesota, U.S. Department of Agriculture-Agricultural Research Service, Colorado State University, University of Wisconsin, University of Maine, Michigan State University, EBE Farms, Northern Konstar Potatoes, Parkland Seed, Real Potato, Solanum, Southern Potato and SunRain.

Table 1. Agronomic performance of red-skinned potato cultivars/selections near Crystal, ND, 2021.

Cultivar	Stand[1]	Stem/ plant[2]	Vine length[3]	Vigor[4]	Specific gravity
	%	number	cm		
Autumn Rose	83	3.2	3.5	70	1.081
Cerata	89	3.6	3.8	104	1.065
CO99076-6R	79	3.0	3.8	71	1.076
Dark Red Norland	86	3.4	2.0	66	1.074
Dark Red Norland (Real Potato)	86	4.5	3.0	72	1.072
MSW 343-2R	82	1.4	3.5	61	1.059
ND113207-1R	82	3.8	3.0	68	1.065
ND14113Y-9R	85	4.7	4.0	70	1.070
ND1431Y-2R	85	3.2	3.3	72	1.073
ND1455Y-1R	84	3.8	3.0	59	1.074
NDAF113484B-1	86	1.8	3.0	57	1.072
Red Norland	91	3.8	2.3	70	1.072
Red Pontiac	85	3.3	4.0	80	1.071
Roko	87	3.3	4.3	75	1.078
Sangre	67	1.5	3.5	55	1.071
W8890-1R	88	4.1	4.0	76	1.074
Mean	84	3.3	70	3.4	1.072
CV	8	25	12	14	0.2
LSD p=0.05	10	1.2	12	0.7	0.004
LSD p=0.1	8	1.0	10	0.6	0.003

[1] Stand count was taken on July 22 (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 22 (five weeks after planting) and are shown as the average number of stems per plant.

[3] Vine length was measured on three plants from the base of the plant to the vine tip on August 31.

[4] Vigor evaluation was completed on August 31 (11 weeks after planting). A rating of 1 indicated least vigor and 5 greatest vigor.

Table 2. Graded yield of red-skinned potato cultivars/selections near Crystal, ND, 2021 with total yields compared to previous trial years.

					Total yield			
Cultivar	C[1]	B	A	Chef	2021	2020[2]	2019[3]	3-year average
	cwt/a							
Autumn Rose	6	88	28	0	122	239	196	186
Cerata	10	79	43	0	132	330	126	196
CO99076-6R	2	53	114	2	170	311	118	200
Dark Red Norland	4	78	91	1	174	370	158	234
Dark Red Norland (Real Potato)	6	99	107	0	212	308	176	232
MSW 343-2R	1	46	103	3	153	356	--	--
ND113207-1R	4	67	103	6	180	283	193	219
ND14113Y-9R	8	77	81	0	166	--	--	--
ND1431Y-2R	3	41	105	3	152	336	--	--
ND1455Y-1R	2	62	58	0	122	195	--	--
NDAF113484B-1	1	49	110	0	159	309	--	--
Red Norland	2	51	129	8	190	326	198	238
Red Pontiac	2	50	142	1	195	295	197	229
Roko	3	92	49	2	146	327	148	207
Sangre	2	32	40	1	74	139	89	101
W8890-1R	5	83	89	0	177	299	197	224
Mean	84	3.3	70	3.4	1.072	295	163	206
CV	8	25	12	14	0.2	--	--	--
LSD p=0.05	10	1.2	12	0.7	0.004	--	--	--
LSD p=0.1	8	1.0	10	0.6	0.003	--	--	--

[1] 2001 harvested potatoes 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.

[2] Complete data from the 2020 trial can be found at https://www.ag.ndsu.edu/publications/crops/north-dakota-fresh-market-potato-cultivar-selection-trial-results-for-2020

[3] Complete data from the 2019 trial can be found at https://www.ag.ndsu.edu/publications/crops/north-dakota-fresh-market-potato-cultivar-selection-trial-results-for-2019

Table 3. Agronomic performance of yellow-skinned potato cultivars/selections near Crystal, ND, 2021.

Cultivar	Stand[1]	Stem/plant[2]	Vine length[3]	Vigor[4]	Specific gravity
	%	number	cm		
A00286-3Y	87	3.3	66	4.8	1.078
Actrice	83	3.3	68	2.0	1.064
Agata	81	3.7	62	2.8	1.076
Alegria	81	3.3	75	2.8	1.080
Arizona	84	4.2	63	3.0	1.061
Belmonda	78	3.6	72	4.5	1.084
Cascada	87	4.5	66	4.0	1.072
CO05037-3W/Y	79	5.1	68	2.3	1.082
CO10064-1W/Y	89	4.7	64	3.0	1.088
CO11250-1WY	86	6.4	75	3.8	1.084
CO11266-1W/Y	84	4.3	74	3.3	1.080
Constance	88	4.7	75	3.3	1.081
Crop 56	85	5.0	88	4.0	1.078
Crop 58	81	3.3	74	2.8	1.072
Crop 80	86	4.6	79	4.0	1.076
Dania	80	4.6	76	3.8	1.072
Electra	85	4.8	67	3.3	1.068
Gala	83	4.0	71	3.0	1.075
Jelly	82	3.4	72	4.5	1.074
Lanorma	84	4.0	82	3.3	1.066
Melody	83	2.8	82	3.8	1.067
Montreal	84	3.7	66	2.8	1.074
Musica	81	3.7	76	3.8	1.069
ND1241-1Y	84	2.7	63	3.8	1.091
ND1487-1Y	88	4.9	80	4.0	1.073
NDA081451CB-1CY	88	3.6	72	3.5	1.084
Noelle	90	7.2	68	2.5	1.072
Obama	84	4.6	77	3.3	1.072
Paroli	88	4.4	74	3.0	1.071
W13103-2Y	85	3.4	65	3.3	1.070
W15240-2Y	89	4.3	68	3.0	1.070
W15248-17Y	89	2.4	57	2.3	1.070
Mean	85	4.1	71	3.3	1.075
CV	8	22	12	16	0.6
LSD p=0.05	ns	1.3	12	0.7	0.009
LSD p=0.1	ns	1.1	10	0.6	0.008

[1] Stand count was taken on July 22 (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 22 (five weeks after planting) and are shown as the average number of stems per plant.
[3] Vine length was measured on three plants from the base of the plant to the vine tip on August 31.
[4] Vigor evaluation was completed on August 31 (11 weeks after planting). A rating of 1 indicated least vigor and 5 greatest vigor.

Figure 1. Research plots near Crystal, ND on July 14, 2021.
(Robinson, NDSU/UMN)

Table 4. Graded yield of yellow-skinned potato cultivars/selections near Crystal, ND, 2021 with total yields compared to previous trial years.

					Total yield			
Cultivar	C[1]	B	A	Chef	2021	2020[2]	2019[3]	3-year average
			cwt/a					
A00286-3Y	7	82	42	0	130	391	132	218
Actrice	3	70	126	2	201	533	168	301
Agata	1	75	111	3	189	489	193	290
Alegria	2	68	65	5	141	491	132	255
Arizona	2	81	91	1	175	486	206	289
Belmonda	3	75	50	0	128	463	110	234
Cascada	7	106	16	4	134	--	--	--
CO05037-3W/Y	6	100	37	0	143	372	118	211
CO10064-1W/Y	7	108	24	0	139	360	127	209
CO11250-1WY	20	102	8	0	129	329	--	--
CO11266-1W/Y	10	69	5	0	84	309	--	--
Constance	3	98	65	0	165	--	--	--
Crop 56	12	83	2	0	97	352	122	190
Crop 58	2	73	82	4	161	384	162	236
Crop 80	4	100	55	0	159	384	131	225
Dania	5	124	48	0	177	--	--	--
Electra	5	70	9	0	84	476	149	236
Gala	5	113	54	0	172	--	--	--
Jelly	2	93	49	0	143	317	119	193
Lanorma	3	73	30	0	107	380	157	215
Melody	5	65	51	1	122	--	81	--
Montreal	4	70	116	3	192	468	212	291
Musica	4	127	58	0	190	528	155	291
ND1241-1Y	7	77	38	0	123	323	138	195
ND1487-1Y	11	120	38	0	168	431	--	--
NDA081451CB-1CY	4	101	55	0	159	385	112	219
Noelle	17	114	15	0	146	383	130	220
Obama	2	109	107	0	218	541	185	315
Paroli	5	87	111	3	207	457	--	--
W13103-2Y	6	78	94	1	178	--	--	--
W15240-2Y	5	115	49	1	170	329	--	--
W15248-17Y	1	72	36	0	108	--	--	--
Mean	6	90	54	1	151	414	145	241
CV	50	15	42	371	18	--	--	--
LSD p=0.05	4	19	32	ns	38	--	--	--
LSD p=0.1	3	16	27	ns	32	--	--	--

[1] 2001 harvested Potatoes 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.
[2] Complete data from the 2020 trial can be found at
https://www.ag.ndsu.edu/publications/crops/north-dakota-fresh-market-potato-cultivar-selection-trial-results-for-2020
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Report Title: 2021 Support of Irrigated Potato Research for North Dakota and Minnesota

Submitted to NPPGA & MN Area II

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

Rationale: Irrigated potato production accounts for more than half of the state's total potato production and differs substantially from non-irrigated production. The majority of the irrigated potato production is used in the production of French fries, and as a result the spectrum of cultivars grown under irrigation differs greatly from those produced under non-irrigated conditions. In addition, the pressure of potato diseases, insect and weed pests, cultivar selection and use of fertilizer all differ substantially for irrigated potato production compared to potatoes produced under non-irrigated conditions. To be relevant to the many irrigated potato growers in the region, research must be conducted under irrigated conditions, mimicking as much as possible the grower experience.

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

The total cost of managing irrigated potato research in 2021 at the NPPGA research site near Inkster, ND was nearly $64,000. We continue to make a concerted effort to re-evaluate all operations and to increase efficiencies in management of the Inkster research site. Some notable changes in expenses are attributed to an increase in the total number of trials conducted which subsequently increased labor costs. Fortunately, the one individual per vehicle requirement was lifted for 2021, resulting in reduced costs, compared to 2020. We saved some money in 2020 because field day was cancelled, but it was wonderful to see it back in 2021. 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.

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

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

Preliminary Report Title: Adjusting Planting Date for the Management of Verticillium Wilt Submitted to MN Area II and Northern Plains Potato Growers Associations

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Executive Summary

Verticillium wilt arguably is the most damaging disease of potatoes when considering reduced yield and quality and the increased cost of control, and the industry is looking for sustainability in production. The availability of cultivars with Verticillium wilt resistance has been increasing, with several new options available to growers; however, susceptible cultivars like Russet Burbank and Russet Norkotah are still grown across the majority of US acres. Previous research has supported management practices to reduce the effects of Verticillium wilt, but we feel there may be areas for additional gains in using other management practices. Seed-tubers planted into colder soils emerge more slowly when compared to a later planted crop. Our hypothesis is that a crop planted into colder soils may also suffer increased losses from Verticillium wilt. This hypothesis was tested by planting three cultivars varying in susceptibility to Verticillium wilt into fumigated and non-fumigated soils at three planting dates. The 2021 trial was conducted in a grower field in west-central MN under irrigated conditions. Verticillium wilt incidence, total and marketable yield, tuber grade and grower return estimates were differentially affected by cultivar, planting date and fumigation. No significant difference in Verticillium wilt was observed between fumigated and non-fumigated treatments. Verticillium wilt significantly declined with later planting only in the resistant cultivar Alturas. Stem colonization by the pathogen *V. dahliae* (measured by quantitative PCR) was affected by fumigation, planting date and cultivar. Stem colonization was generally lower when the soil was fumigated and resistant cultivars were planted earlier. We speculate that low level of tissue colonization at the earliest planting date of 2021 trial (April 24) could be due to low soil temperatures. Soil temperatures were consistently below the reported optimal temperatures for *V. dahliae* until about May 15. Further, other factors such as extreme heat and bacterial vine rot could have affected Verticillium wilt severity and colonization in 2021. Total and market yield, USDA grade, and grower returns were not significantly affected by fumigation. Both total and market yield were reduced and the tuber size profile was smaller as planting was delayed, significantly so in some instances. Grower return / acre was reduced significantly across all cultivars and both fumigated and non-fumigated treatments as planting date was delayed. The 2021 trial was severely affected by several environmental factors (e.g. frost damage, extreme heat, and bacterial vine rot). In 2021, planting dates were moved earlier in response to significant reductions in yield observed as planting was delayed, despite reductions in Verticillium wilt damage in the 2020 trial. Results combined over several years will provide a more comprehensive overview on the role of late planting in the management of Verticillium wilt.

Rationale

Verticillium dahliae increases in potato stems as the disease and season progress (Pasche et al. 2013b). Following harvest, the long-lived structures produced by the pathogen are returned to the soil where they can survive for decades. Soil fumigation is effective in reducing *Verticillium* propagules per gram of soil (Vppg) at a rate of about 41 to 78%. Therefore, a pre-fumigation level of 50 Vppg would be reduced to approximately 11 to 30 Vppg, still beyond the level of 8 Vppg suggested for growing susceptible cultivar Russet Burbank (Nicot and Rouse 1987). It is not unusual to find a pre-fumigation levels exceeding 250 Vppg in fields in Minnesota and North Dakota with a history of more than 10 potato crops. The use of susceptible cultivars, relatively short rotations and absence of vine desiccation have contributed to increasing *V. dahliae* in the soil and increasing Verticillium wilt pressure. This has led the NDSU potato pathology research group to investigate alternatives. Preliminary results indicate that vine desiccation may reduce the amount of *V. dahliae* returned to the soil without decreasing total or marketable yield (Gudmestad MN Area II research reports). That research was continued with funding from the ND Dept of Ag Specialty Crop Block Program, contributing to grower recommendations for the use and timing of vine desiccation for Verticillium wilt management.

Research questions have arisen from grower observations that seed planted later, into warmer soils, emerges into more vigorous plants, possibly reducing the damage caused by *V. dahilae*. The Pasche potato pathology research project has substantial expertise in field and laboratory evaluations for Verticillium wilt developed over the past nearly 20 years (Pasche, et al. 2013a; 2013b; 2014; Taylor et al. 2005; Yellareddygari and Gudmestad 2017). We have conducted the first two years of the study in a fumigated/non-fumigated field in an area where successful Verticillium wilt trials have been conducted previously. We have developed and heavily utilized molecular quantification of *V. dahilae* to determine cultivar susceptibility and the efficacy of management strategies (Pasche et al. 2013a). Many of the researchers involved in these previous studies remain in place; therefore, we do not foresee substantial hurdles in performing these studies outside of the typical obstacles of performing field research, most notably Mother Nature. While advances have been made in our understanding of the development and management of Verticillium wilt, additional gains are needed. Therefore, the **objectives of this research** were/are to determine the effect of planting date on the development of Verticillium wilt, the level of *V. dahliae* present in stems at harvest, total and marketable yield, tuber grade and processor returns utilizing three russet-skinned cultivars planted on three dates.

Procedures

In the second year of this experiment in 2021, a field trial was conducted under irrigation near Park Rapids, MN. Similar to 2020, grower practices, including primary tillage, standard fungicide and insecticide regimes were performed by the cooperating grower. Herbicide, side-dress fertilizer applications and cultivation were performed by NDSU. Cultivars Russet Burbank (susceptible (S)), Umatilla Russet (moderately susceptible (MS) and Alturas (resistant (R)) were planted on April 24, May 8, and May 21, 2021 in fumigated and non-fumigated strips (Table 1). Seed for all treatments was obtained in March and held at 45F until one week before the targeted planting date. Seed was warmed to 55F, cut and suberized 3 to 4 days before planting. This procedure was repeated for each planting date to ensure high seed quality at all planting dates. Plots were replicated four times in a randomized complete block design and split-plot arrangement. Fumigation was the main blocking factor. Cultivar and planting date were randomized within fumigated and non-fumigated strips. Four-row plots were seeded at 12 in.

seed spacing and 36 in. row spacing. Soil samples were obtained during the summer of 2020 prior to fumigation in October 2020 and in August 2021 to determine pre- and post-fumigation Verticillium propagules per gram (Vppg) of soil (Table 2). Fumigation reduced Vppg by between 40 and 90% across the four replications; however, Vppg remained over the recommended threshold level of 8 for susceptible cultivars like Russet Burbank after fumigation in all replicates due to high starting levels. Soil temperatures were monitored using HOBO MX data loggers placed in each replicate starting from the first planting date on April 24, 2021.

Table 2. Verticillium propagules per gram (Vppg) of soil sampled pre- and post-fumigation from each replication.

Replication	Fumigation	Vppg	Reduction (%)
1	no	214	89.7
1	yes	22	
2	no	164	91.5
2	yes	14	
3	no	50	48.0
3	yes	26	
4	no	30	40.0
4	yes	18	

Pre-fumigation soil samples taken prior to fumigation in October 2020
Post-fumigation soil samples taken August 19, 2021
Two soil samples were taken at a 0-8” depth from each plot (one hill and one valley) for a total of 18 samples/replication, all samples were thoroughly mixed and dried before shipment to Pest Pros, Plainfield, WI, for analysis.

The number of emerged plants were counted in the center two rows of each plot starting 21 to 33 days after planting and continued until 90% emergence was recorded. Verticillium wilt was visually assessed at weekly basis beginning at mid-potato vegetative growth and flowering stage (from July 29 to September 1, 2021) by counting the number of plants exhibiting symptoms. The trial was affected by

Table 1. Cultivar and planting date evaluated for the effect on Verticillium wilt development in 2021. All cultivars/planting dates were grown in soil treated with metam sodium fumigation and non-fumigated soil.

Cultivar	Planting Date
Russet Burbank	24-Apr
Umatilla Russet	24-Apr
Alturas Russet	24-Apr
Russet Burbank	8-May
Umatilla Russet	8-May
Alturas Russet	8-May
Russet Burbank	21-May
Umatilla Russet	21-May
Alturas Russet	21-May

Figure 1. Bacterial vine rot and extreme heat damage sustained Verticillium wilt planting date trial on September 1, 2021 near Park Rapids, MN.

extreme heat and severe bacterial vine rot starting early September, making further Verticillium wilt evaluations impossible (Fig. 1). Five stems were collected from all 72 plots (2 fumigation, 3 cultivars, 3 planting dates, 4 replicates) on October 4 and returned to the laboratory for *V. dahliae* quantification. Total yield was collected at harvest on October 5. All disease and yield data were collected from the center two rows only. The outside rows were used to buffer the plots from any competitive advantage that can occur during the early season because of staggered planting dates. Data analyses of disease incidence, stem colonization, marketable yield, and USDA grade and grower return were conducted using appropriate statistical procedures.

Results

The mean number (across cultivars and fumigation treatments) of days to reach 90% emergence was reduced by 7 from the first (41 days to 90% emergence) to second (34 days) planting dates, and 13 from the first to third (27 days) planting dates (Figs. 2 and 3). However; the date of emergence was substantially delayed, with 90% emergence recorded on June 4 (April 24 planting), June 11 (May 8 planting) and June 17 (May 21 planting).

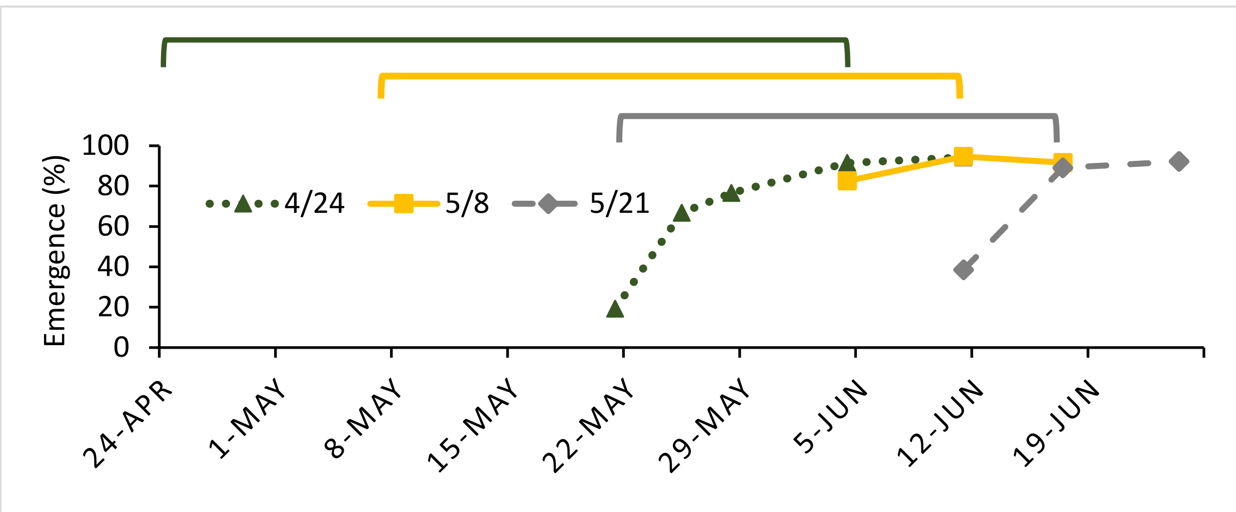

Figure 2. Days to emergence for each planting date. Values represent the means across all three cultivars, fumigated and non-fumigated. Brackets illustrate the time from planting to 90% emergence.

The interaction between planting date and cultivar was significant for Verticillium wilt incidence, based on area under the disease progress curve (AUDPC) (Fig. 4). Fumigation reduced the *Verticillium* propagules in the soil but it did not significantly affect Verticillium wilt incidence across planting dates and cultivars. This may be due to Vppg in the soil remaining above recommend thresholds after fumigation, and the extensive bacterial vine rot and extreme heat affecting the visual rating of Verticillium wilt. Verticillium wilt incidence would likely have been increased had bacterial vein rot damage not limited our ability to rate up until harvest. Vine rot was so severe by September 1 that Verticillium wilt could not be accurately rated visually past that point (Fig. 1). The interaction between planting date and cultivar was significant, indicating that planting date did not equally affect Verticillium wilt in the three cultivars. Wilt in susceptible cultivar Russet Burbank increased with later planting while wilt decreased in the other two cultivars. Within cultivars, wilt was only significantly different with resistant cultivar Alturas at the latest planting data on May 21 compared to the first two planting dates. Differences across cultivars were only significant at the last planting date where Russet Burbank had significantly more wilt than did Umatilla Russet and Alturas.

Figure 3. The plot on the left is the third planting date, May 21 (this plot had just been hilled). The plot in the middle is second planting date, May 8. The plot on the right is the first planting date, April 24. Photos taken by Dean Peterson on June 9, 2021.

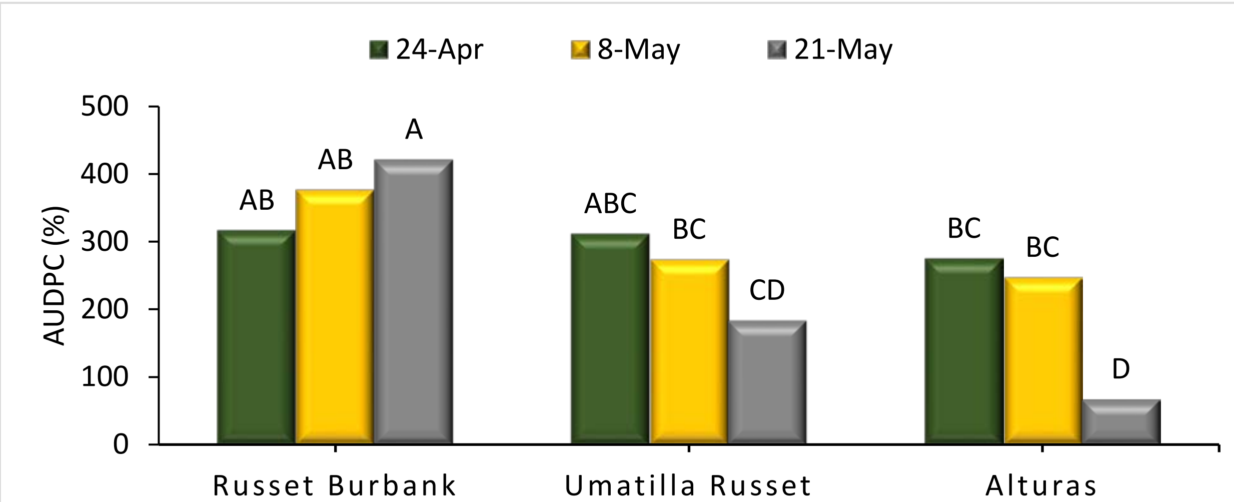

Figure 4. Verticillium wilt incidence as represented by area under the disease progress curve (AUDPC). The interaction between planting date (April 24, May 8, and May 21) and cultivar was significant (*P* <.0001). Bars with the same letters are not significantly different (α = 0.05).

Evaluations of stem colonization by *V. dahliae* using quantitative PCR resulted in a significant interaction among all three variables (cultivar, planting time, and metam sodium application), suggesting that stem colonization was affected by fumigation, planting date and cultivar. In general, stem colonization was lower when soil was fumigated, planting occurred earlier, and cultivar resistance increased (Fig. 5). The lowest stem colonization was measured in moderately susceptible cultivars Umatilla Russet and Alturas planted on April 24 into fumigated soils. Cultivar reaction to *V. dalhiae* stem colonization generally followed the same trend as Verticillium wilt incidence assessed visually in the field. Russet Burbank had significantly higher levels of stem colonization across most fumigation and planting dates than did moderately susceptible Umatilla Russet and resistant Alturas. There were no differences in colonization between Umatilla Russet and Alturas within planting dates and fumigation treatments. Non-fumigated plots of both cultivars planted on May 21 had significantly higher colonization than did fumigated and non-fumigated plots planted on April 24 and fumigated plots planted on May 8. One hypothesis for reduced colonization at the first planting date is low soil temperatures. Optimal temperature for colonization of olive tree roots by *V. dahliae* has been reported to be between 61 and 68F (Calderon et al. 2014). Based on soil monitors placed in this trial at the first planting date, the soil temperature did not consistently reach above 61F until May 15. These low soil temperatures may have inhibited the fungus from breaking dormancy and infecting root tissue. Further evaluations are needed in this area to confirm this hypothesis. The increased ability of stem colonization as measured by qPCR to discern statistical differences across these treatment combinations confirms that visual measurements of Verticillium wilt incidence were likely affected by the severe bacterial vine rot incidence and extreme heat during 2021 growing season and that qPCR remains the most effective way to measure Verticillium wilt under field conditions where environmental factors and cultivar maturity play a large role in symptom development.

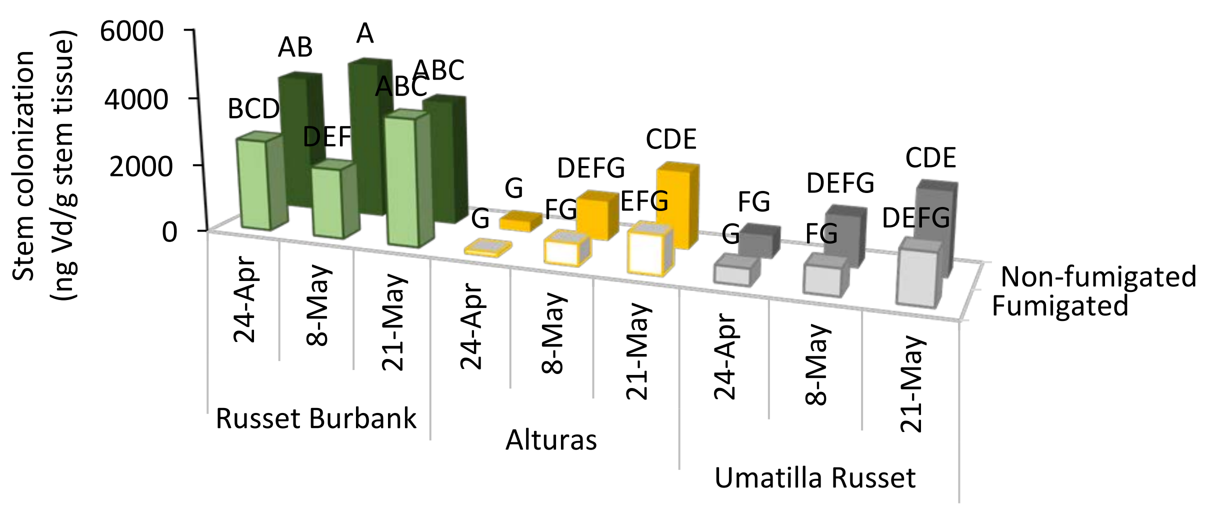

Figure 5. Stem colonization by *Verticillium dahliae* in 2021. A significant interaction between cultivar, fumigation, and planting date was observed ($P = 0.002$).

A significant interaction was observed between fumigation and cultivar in total yield (cwt/acre), meaning that yield of all three cultivars was differentially affected by fumigation. However, fumigation did not significantly increase total yield in any cultivar (Fig. 6 Top). This was likely due to the severe heat stress and bacterial vine rot in these plots. A significant interaction between cultivar and planting date also was observed (Fig. 6 Bottom). Yield of all cultivars was reduced as planting date was delayed. In Alturas and Umatilla Russet, the significant difference occurred between the second and third planting date. Yield of Russet Burbank was significantly reduced from the first to the second planting date and no significant difference observed between the second and the third.

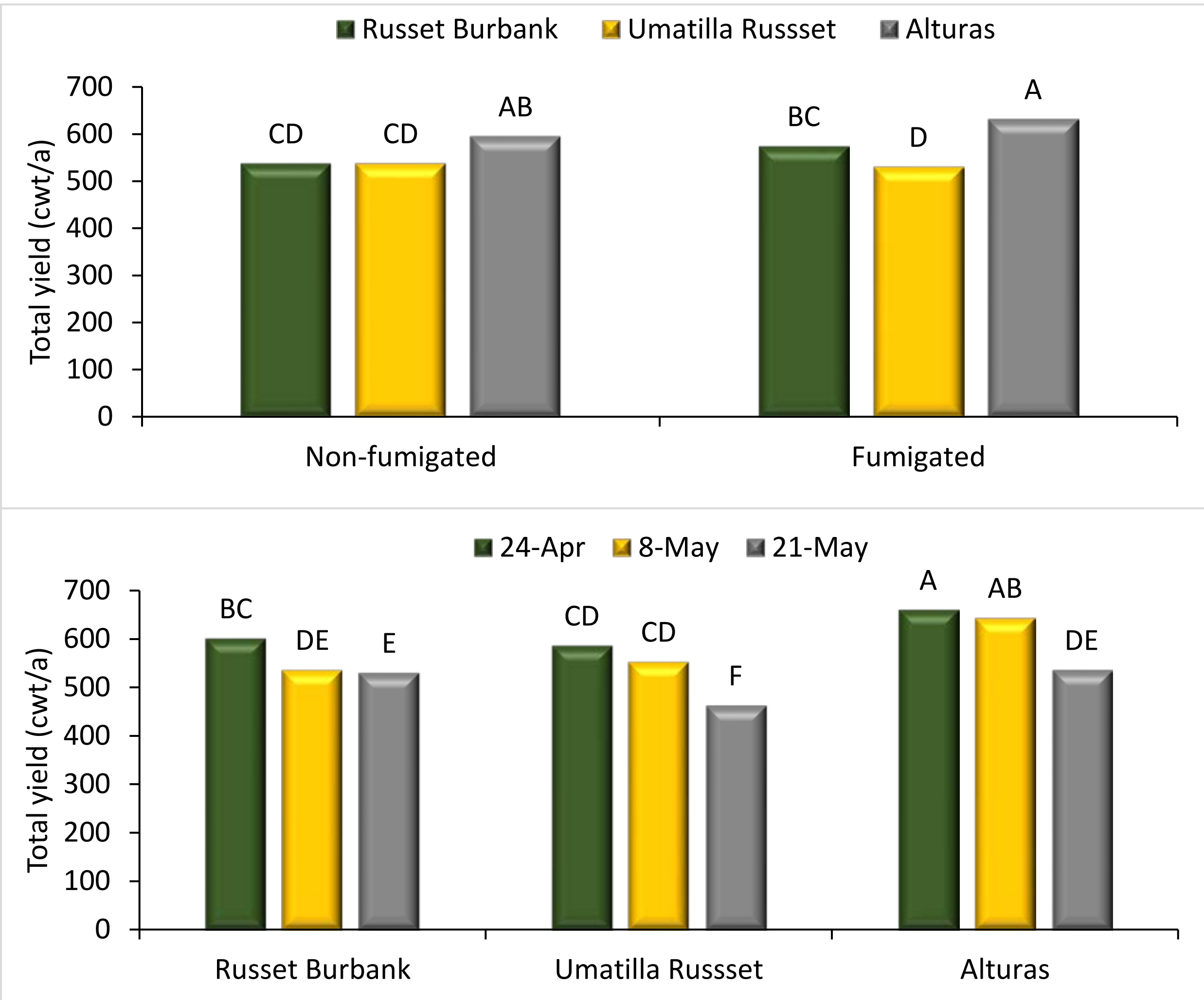

Figure 6. Total yield for the trial conducted at 2021 to evaluate the effect of planting date on the effect of Verticillium wilt in three potato cultivars. (Top) The interaction between fumigation and cultivar measured as total yield (cwt/acre) was significant (*P* = 0.016). (Bottom) The interaction between planting date (April 24, May 8, and May 21) and cultivar measured as total yield (cwt/acre) was significant (*P* = 0.0002). Within each graph, bars with the same letters are not significantly

A USDA grade was conducted on tubers harvested from all plots in this trial. Market yield was calculated by subtracting the weight of 'unusable' tubers (<4 oz and those with major defects) from the total yield. Market yield results generally mirrored results from total yield (Fig. 7).

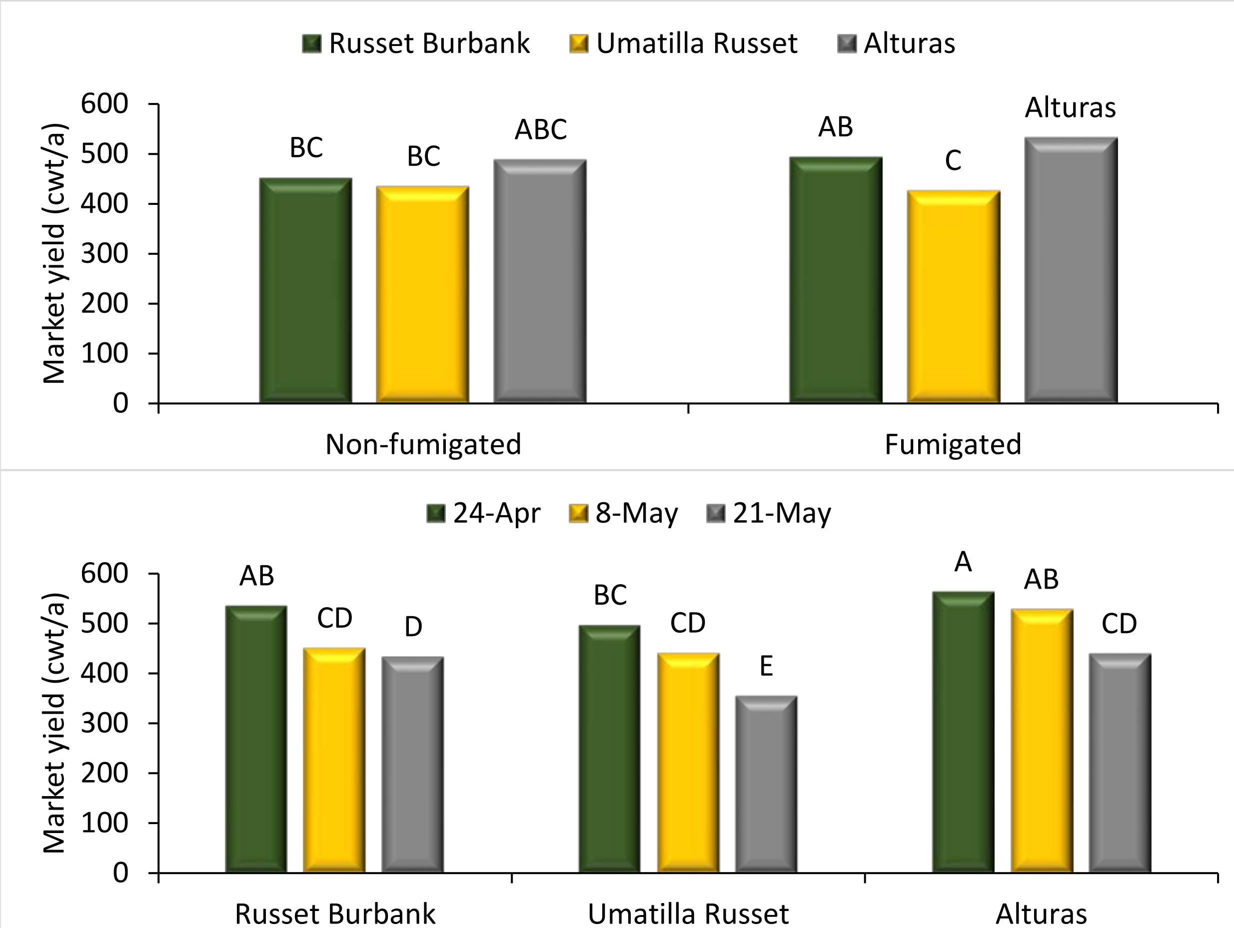

Figure 7. Market yield for the trial conducted at 2021 to evaluate the effect of planting date on the effect of Verticillium wilt in three potato cultivars. (Top) The interaction between fumigation and cultivar for market yield (cwt/acre) was significant ($P = 0.014$). (Bottom) The interaction between planting date (April 24, May 8, and May 21) and cultivar measured for market yield (cwt/acre) was significant at ($P = 0.023$). Bars with the same letters are not significantly different.

Fumigation did not significantly affect any tuber grade categories. A planting date by cultivar interaction was observed for >10 oz tubers (Fig. 8). Following the trend of total and market yield, the percent tubers in the largest class (>10 oz) was lower for all three cultivars as planting date was delayed, significantly so in some instances. Delaying planting also significantly decreased the percentage of >6 oz tubers and significantly increased the percentage 4-6 oz and tubers <4 oz across all cultivars (data not shown). Results indicate that delaying planting date significantly affected grower returns across cultivars and fumigation treatments (Fig. 9). Complete in-season and post-harvest grade results and processor economic analysis are included at the end of the report (Table 3).

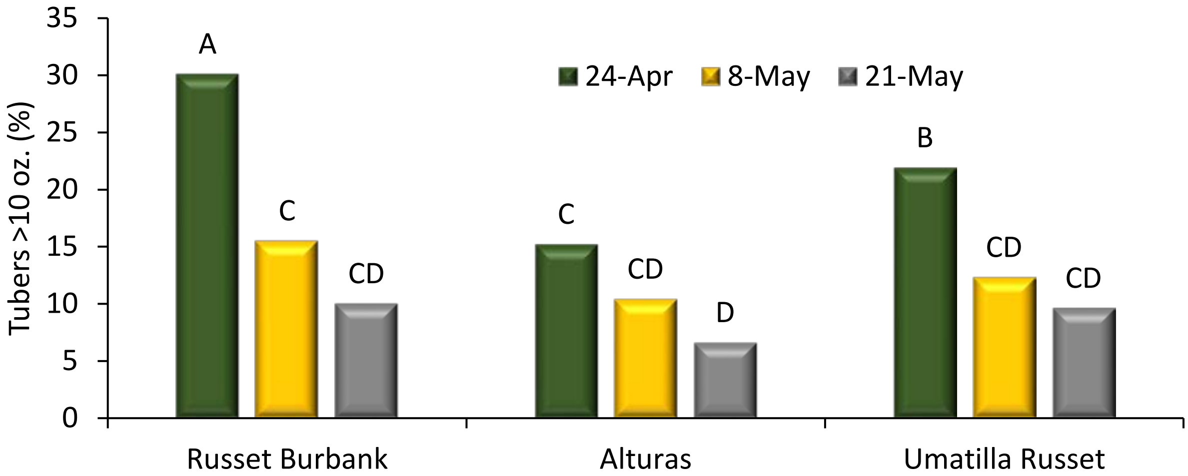

Figure 8. Tubers >10 oz. across fumigated and non-fumigated treatments, where a significant cultivar by planting date interaction was observed. Bars with the same letters are not significantly different.

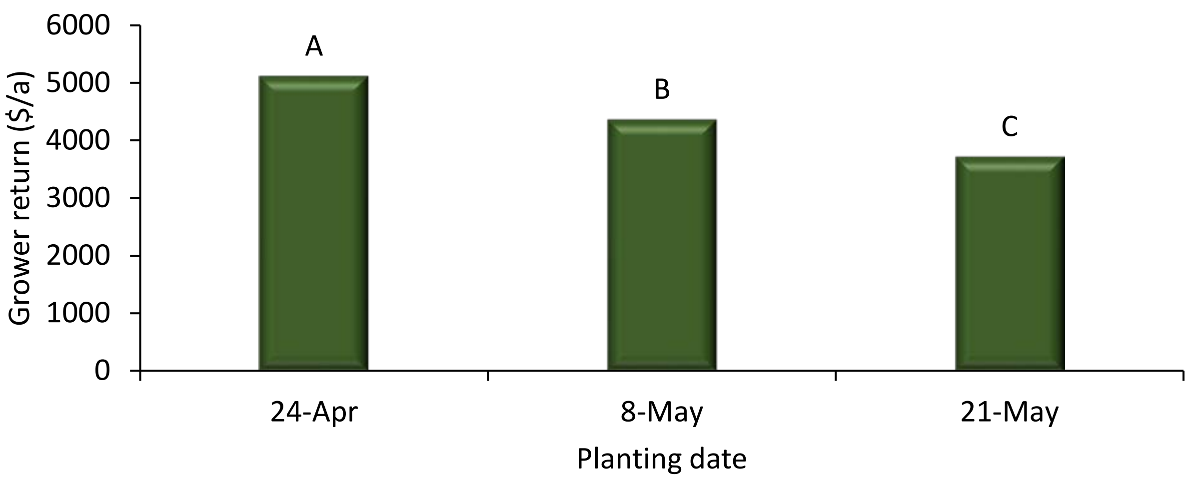

Figure 9. (Top) The effect of planting date on grower return ($/a) was significant across cultivars and fumigation treatments (*P* <.0001). (Bottom) The interaction between fumigation treatment and cultivar measured for grower return ($/acre) was significant at (*P* = 0.023). Bars with the same letters are not significantly different. NOTE: The cost of fumigation was not included in these evaluations.

Preliminary Conclusions

In the first trial conducted in 2020, total and market yield, and tuber size were negatively affected by later planting (June 3); however, Verticillium wilt was lower with that later planting date. In response to those results, planting dates were moved earlier to late April, early May, and late May to determine if there is a point at which yield and Verticillium wilt damage would balance. Preliminary results of the 2021 trial support results from 2020 where yield, tuber size, and grower return were adversely affected by later planting dates. Environmental factors (early severe frost damage (2020), bacterial vine rot, extreme heat (2021) limited our ability to measure

Verticillium wilt development accurately until end of the season; therefore, trends in visual assessment of Verticillium wilt were not consistent between 2020 and 2021. However, in 2021 stem colonization by *V. dahliae* was reduced when planting occurred earlier into colder soils, contradictory to our hypothesis and results observed in 2020.

The location has been selected for this trial in 2022 and will allow for an early start to planting. We propose the first planting date by the end of April, followed by the second and third dates 7-14-days following, with planting concluded by the third week of May, similar to the 2021 trials.

We understand that delaying planting resulted in the yield reductions, which is obviously not an acceptable trade-off for the reductions in Verticillium wilt. However, for growers this could mean adjusting planting date on high risk fields to avoid infection and reduce risks. Combining the results of multiple years could provide clearer conclusions about the relationship between planting (soil temperatures), Verticillium wilt, yield, and grower returns. We believe that this, along with other management practices could help growers reduce reliance on fumigation for the management of Verticillium wilt into the future.

Table 3. Yield, USDA grade and grower return for the 2021 trial conducted near Park Rapids, MN evaluating the effect of planting date, cultivar, and fumigation on the effects of Verticillium wilt caused by *V. dahliae*.

Trt	Cultivar	Planting Date	Treatment	Total Yield (cwt/a)	Market Yield (cwt/a)	10 oz. & over (%)			6 - 9 oz. (%)			>6 oz. (%)	4 - 6 oz (%)			Unusables (%)				Specific Gravity	Adjusted price ($/cwt)	$ / acre
						US No. 1	US No. 2	Total	US No. 1	US No. 2	Total	Total	US No. 1	US No. 2	Total	Total	Under-size	Hollow Heart	Other			
501	Russet Burbank	24-Apr	Vapam	622.6	554.7	29.0	2.0	31.0	31.8	0.9	32.7	63.7	25.6	0.1	25.7	10.7	7.7	2.3	0.8	1.076	9.53	5284.96
502	Umatilla Russet	24-Apr	Vapam	582.6	486.1	18.6	0.7	19.3	35.5	0.7	36.1	55.4	27.7	0.1	27.8	16.8	15.8	0.3	0.7	1.090	9.64	4689.38
503	Alturas Russet	24-Apr	Vapam	679.1	587.3	14.5	1.5	15.9	36.9	1.6	38.5	54.4	31.0	0.8	31.8	13.8	13.0	0.0	0.8	1.089	9.61	5657.23
504	Russet Burbank	8-May	Vapam	544.0	466.3	17.1	0.2	17.4	35.3	0.4	35.7	53.1	32.4	0.2	32.6	14.4	12.7	1.3	0.3	1.075	9.20	4287.26
505	Umatilla Russet	8-May	Vapam	546.7	435.9	11.3	0.7	12.0	31.6	0.6	32.1	44.1	34.6	0.8	35.5	20.4	19.9	0.0	0.5	1.091	9.23	4026.52
506	Alturas Russet	8-May	Vapam	661.3	537.0	9.6	1.0	10.5	30.7	0.9	31.6	42.1	38.7	0.4	39.1	18.9	16.3	2.2	0.4	1.089	9.21	4945.51
507	Russet Burbank	21-May	Vapam	556.0	460.3	9.9	0.0	9.9	36.9	0.1	37.0	46.9	35.9	0.0	35.9	17.3	16.7	0.3	0.3	1.080	9.12	4194.60
508	Umatilla Russet	21-May	Vapam	461.7	357.1	8.5	0.5	9.0	30.5	0.4	30.9	39.9	36.7	0.3	37.0	23.1	23.0	0.0	0.1	1.093	9.11	3256.29
509	Alturas Russet	21-May	Vapam	554.4	472.5	6.3	0.5	6.8	31.9	1.4	33.4	40.1	44.3	0.8	45.1	14.8	13.9	0.0	0.9	1.088	9.28	4382.56
510	Russet Burbank	24-Apr	No Vapam	579.9	515.6	25.8	3.4	29.2	33.8	1.1	34.9	64.1	24.3	0.5	24.8	11.1	9.7	1.2	0.3	1.076	9.59	4941.82
511	Umatilla Russet	24-Apr	No Vapam	590.0	506.9	23.7	0.9	24.6	32.1	1.0	33.1	57.6	27.9	0.4	28.2	14.2	13.2	0.5	0.5	1.089	9.80	4974.03
512	Alturas Russet	24-Apr	No Vapam	641.2	539.4	14.1	0.5	14.5	38.2	0.5	38.6	53.2	30.6	0.4	30.9	15.9	15.2	0.2	0.5	1.088	9.55	5150.10
513	Russet Burbank	8-May	No Vapam	528.3	434.6	12.7	0.9	13.6	37.1	0.5	37.6	51.2	30.6	0.3	30.8	18.0	16.0	1.4	0.7	1.076	9.12	3972.13
514	Umatilla Russet	8-May	No Vapam	559.5	445.5	12.0	0.6	12.6	31.0	0.7	31.7	44.3	34.9	0.4	35.3	20.4	20.0	0.0	0.4	1.091	9.24	4114.05
515	Alturas Russet	8-May	No Vapam	626.1	519.2	9.9	0.4	10.3	34.8	1.1	35.9	46.2	36.0	0.7	36.7	17.1	16.3	0.0	0.9	1.089	9.32	4844.48
516	Russet Burbank	21-May	No Vapam	504.5	405.9	9.5	0.7	10.1	34.1	1.0	35.1	45.2	34.9	0.5	35.4	19.5	17.3	2.0	0.3	1.079	8.94	3627.86
517	Umatilla Russet	21-May	No Vapam	464.2	351.7	9.8	0.5	10.2	30.4	0.5	30.9	41.1	34.4	0.4	34.8	24.2	23.7	0.2	0.3	1.093	9.03	3171.99
518	Alturas Russet	21-May	No Vapam	517.5	405.9	5.6	0.7	6.4	29.6	1.1	30.6	37.0	41.1	0.5	41.6	21.6	21.0	0.0	0.5	1.089	9.05	3671.46
CV				12.3	15.9	53.2	140.8	53.4	12.2	93.5	11.8	18.7	18.6	114.7	18.6	27.8	31.6	250.8	105.3	0.628	3.25	18.22

Note: The early planting date of this trial suffered frost damage on May 28 (treatments 501-503, 510-512).
A temperature of 30F was measured at 5am at the Hubbard Ndawn Station which is located 3.5 miles away.
Frost injury ranged from 8% to 53% of emerged plants/plot damaged.

Stastical notes: Glimmix was run, therefore Lsmeans were used for mean separation, instead of LSD
Since this is a split plot and more than one sources of error could be significant, single P values could not be presented in the table

Acknowledgments

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Managing PVY Vectors, 2021

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Executive Summary – This is a proposal to fund continuing research and outreach that expands and maintains an aphid trapping and monitoring network for aphid vectors of virus disease in potatoes (focusing on PVY) and provides near real-time maps of aphid population distribution in MN and ND.

Rationale – The seed potato production regions of North America, are suffering an epidemic of aphid vectored, virus causing diseases such as Potato Leaf Roll (PLRV) and Potato Virus Y (PVY). PLRV is a non-persistent (circulative) virus; that means after the insect acquires the virus from an infected plant, the virus undergoes a reproductive period inside the insect vector before it can be transmitted to another plant. This is called a *latency period*; and in PLRV it's approximately 72 hours. Consequently, PLRV is often transmitted by aphids that colonize potato - a winged female lands on the plant, decides it's a suitable food species and deposits a daughter aphid, which reproduces, resulting in a new colony of aphids. The 3 day latency means PLRV transmission can be controlled by well-timed applications of traditional insecticides (there's enough time for tan 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 a insect vector from an infected plant and transmitted to an uninfected plant in minutes. Consequently, 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 find. A non-colonizing aphid species will fly into a potato field, probing plants to determine if they're appropriate host plants. If they are not appropriate hosts, the aphid will fly (up to 1-3m) to neighboring plants to assess them as hosts. Consequently, non-colonizing aphid species will move across a potato field, probing plants and transferring any inoculum present. This process results in non-colonizing vector species spending short periods in each field, decreasing the chance of finding them during normal scouting. Not only does this mean that any PVY inoculum will be readily moved from infected to non-infected plants, but the short residence time in the field also means that traditional insecticides will not have sufficient time to prevent the transfer of inoculum by the vector. Traditional insecticides, therefore, will not control the spread of PVY. Rather, the most effective insecticides have been those that cause the insect's feeding behavior to stop.

Currently, the main two insecticides used for this purpose have been Beleaf (FMC Corp., Philadelphia PA) and Fulfill (Syngenta, Crop Protection, Greensboro, NC). Other than these anti-feeding insecticides, the best alternative management product has traditionally been crop oils such as Aphoil. The application of crop oils can reduce the transmission of PVY from between 40%-85% depending on the frequency of application and incorporation of other management tactics.

Some newer products have recently gained registration for use in potatoes that may also have promise in managing the transmission of PVY (e.g. Sefina, BASF Ag Products, Research Triangle Park, NC). Additionally, other research indicates the addition of the synthetic pyrethroid Lambda Cyhalothrin (e.g. Warrior II by Syngenta Crop Protection or Silencer by Adama) increases the length of protection crop oils provide against the transmission of PVY (Singh 2019). Interestingly, Lambda Cyhalothrin was the only insecticide shown to augment efficacy.

There are a number of aphid species that vector virus diseases to seed potatoes, the most efficient being green peach aphid, *Myzus persicae* (Sulzer) but several others are also present. For example, soybean aphids are only 10% as effective in vectoring PVY as is green peach aphid (Davis et al. 2005), but disperses in such high numbers (Ragsdale et al 2004) they can be an important part of seasonal epidemiology. However, potato is not a suitable host for soybean aphid so it will not colonize the crop. The importance of non-colonizing means that scouting for aphids in potatoes, while an excellent management practice, may not provide a complete picture of the amount of vectors present at a given time.

Aphids show a preference for landing on the edge of fields, this is true in for many of the aphids colonizing potato (DiFonzo et al. 1997, Suranyi et al. 2004, Carroll et al. 2004) and for non-colonizing species as well (Hodgson et al 2005). This practice facilitates the use of targeted border applications which can result in significant savings in aphid management (Carroll et al. 2004, Olson et al. 2004). But application timing is critical and treatments must be applied prior to aphid populations dispersing into the field from the margin (this takes about 2 weeks from initial colonization at the border). Consequently, accurate methods of monitoring aphid presence are essential. The regional aphid monitoring network, *Aphid Alert*, provides Minnesota and North Dakota seed potato growers near real-time information on virus vector flight activity.

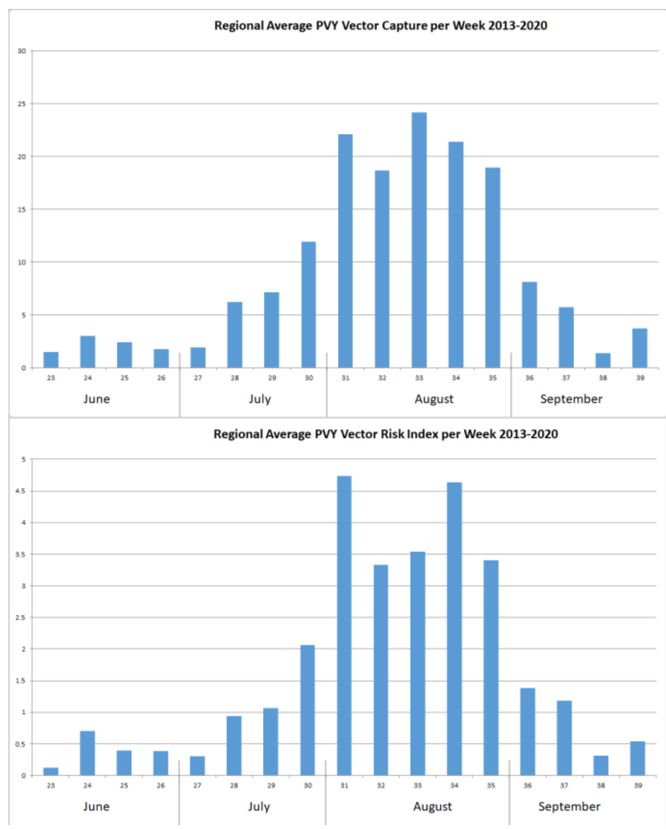

Figure 1. The capture of PVY vectoring aphids in all Aphid Alert traps by week, averaged over 2012-2020 (top graph). And the Regional PVY Risk Index/Week averaged over 2012-2020. The dates were standardized to ISO-8610 week numbers so the data could be compared across years. Note that Vector Risk Index does not precisely mirror the number of Vectors capture, exmeplifying the importance of species efficiency.

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

Our data has allowed to recognize the majority of vector flight occurs starting in late July and through August (Fig 1), 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. Appropriately timed vine-kill could provide an excellent additional tactic to manage PVY spread.

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 1), which uses the number of vector species captured in a trap and their relative efficiency at transmitting PVY to estimate the relative risk of PVY transmission at any given date.

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 do not follow this pattern (Fig 2). 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 their vector Index values peak at specific times with little building (Fig 2).

All of our cooperators have recently received the historical averaged data for their site. Some sites have fewer years trapping data than others but should be able to gain

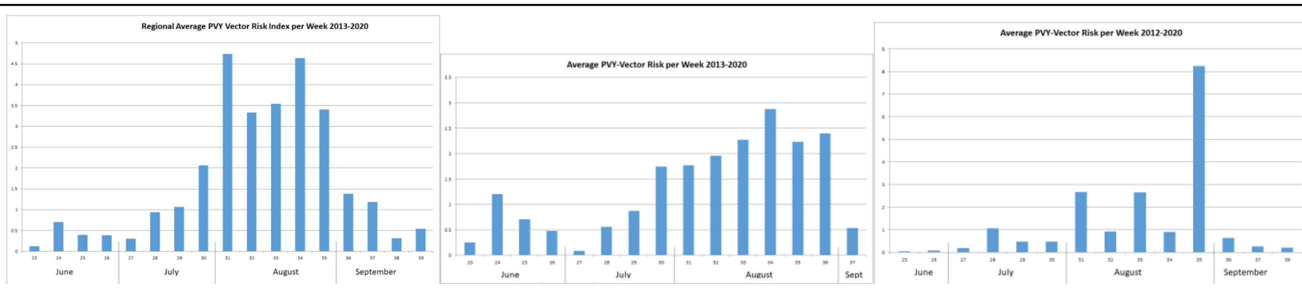

Figure 2. The seasonal PVY Vector Risk Index by week, averaged from 2012-2020 data, for MN & ND (left), Perham (middle) and Lake of the Woods (right). Note the steady ramping of the Index values at Perham vs the concentration of Index values in August at Lake of the Woods.

insights into their vector activity. These local data will be also be used in 2021 to assist in making management decisions.

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.

Objectives:

1. Maintain the Aphid Alert Network, providing potato producers with information on the regional distribution and densities of aphid vectors of virus disease and weekly assessments of PVY risk transmission at each trap location.
2. Compare newer products and additives that may offer additional tactics for managing the transmission of PVY


Figure 3. Suction trap with solar panel.

Procedures: *1) Aphid Alert Trapping Network*. A network of ~20 3m-tall suction traps has been established in the seed potato production areas of Minnesota and North Dakota. These traps consist of a fan, powered by solar panel and deep cell battery, drawing air down in through the trap and trapping the incoming aphids in a sample jar. Traps have a photocell, preventing the fan from running through the night and capturing night flying insects (aphids are day-fliers) reducing the amount of bug stew to be sorted and saving power. The sample jars are changed weekly by grower cooperators and sent to the UMN-NWROC entomology lab. Insects in the jars are sorted, aphids identified to species and aphid population dynamics at sample locations are determined. Maps are prepared weekly showing these dynamics. This information is made available to growers on two websites (aphidalert.blogspot.com and aphidalert.umn.edu), via NPPGA weekly email, linked to on the NDSU Potato Extension webpage (http://www.ag.ndsu.edu/potatoextension), and posted on the AgDakota and Crops Consultants List Serves. Recommendations for beginning oil treatments or targeted edge applications can be made based on the information obtained from the regional monitoring system. Traps are established in early June and maintained until the seed field hosting the trap is vine-killed/harvested. At that point a field is no longer attractive to aphids. We will continue to operate the Aphid Alert suction trap network incorporating the PVY Vector Risk Index maps, developed in last year's funded project, 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. The technique of adding insecticide to Aphoil applications, first researched by Singh (2019), were recommended by the developers to be applied more frequently early in 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 trapping locations can be used to more accurately decide where to apply insecticide with Aphoil to gain the greatest impact on PVY transmission.

Weekly results of the Aphid Alert will be distributed to producers weekly via various electronic media (NPPGA's Potato Bytes, the Aphid Alert blog, Twitter and email

ListServes). The blogsite will be updated and expanded in 2021 to be more interactive with additional data and additional site names will be purchased to simplify access.

2) *Compare products and additives for managing the transmission of PVY* - This trial incorporated two trials, one involving very small caged plots, the second a field trial.

Greenhouse trials used a cage-in-a-cage design. Potted potato plants infected with PVY (Source plants) were placed in small cages, the small cages were then closed and placed into larger cages. Potato Aphids were placed in the small cages and allowed to feed on the PVY infected plants for several days. Additional plants, confirmed via ImmunoStrip to be uninfected with PVY, were treated with an application of the insecticides (Table 1). Insecticides included the anti-feeding products Beleaf (active ingredient = Flonicamid), and Fulfill (ai = Pymetrozine), the relatively new products Transform (ai = Sulfloxaflor), and Sefina (ai = Inscalis), and the paraffinic oil Aphoil, and Aphoil + Lymbda-Cyhalothrin (Synthetic Pyrethroid).

Table 1. Foliar applications to manage transmission of PVY.

Product	Application timing	
Beleaf	1 / wk	
Fulfill	1 / wk	
Transform (Isoclast)	1 / wk	
Sefina (Inscalis)	1/ wk	
Aphoil	1 / wk	
Aphoil & λ-Cyhalothrin	1 / wk with λ-Cyhalothrin tank mixed	

The treated plants (Target plants) were placed the large cages and the smaller cage opened. The now viruliferous aphids from the small cages now had access to feed on the uninfected plants for two days. Aphids were then killed, plants removed and held in cages for 2 weeks before being tested for PVY infection using ImmunoStrips (the 2 weeks was to allow virus titer in the plants to rise to the point where it can be tested). Availability of plants limited trial to 4 replications of each treatment. Transmission success was scored as 0=no transmission, 1=transmission, scores were averaged for graphing and data analyzed with Analysis of Variance (ANOVA), significantly different means were identified using Fisher's Least Significant Difference (Fisher's LSD).

The original proposal called for: a) the use of Green Peach Aphid but we had to use Potato Aphid because of availability, and b) included treatments incorporating insecticide applications at 2 week intervals. The available aphid populations would have made this difficult. In addition, the treatment interval, while perhaps providing information on residual activity, was not realistic. Commercial seed production would never allow a 2 week untreated interval when aphid populations were present.

Due to drought conditions in Crookston, the field trial was moved to the irrigated UMN Sand Plains Research Farm (UMN-SPRF) in Becker, MN. Replicated small plots were established alongside cafes that were scheduled to be used in assessing the potential of Colorado Potato Beetle as a vector of PVY (Fig 4). The trials evaluating foliar applications were scheduled to begin in the third week of August, after CPB trials had been started (to allow for both trials to be completed.

Figure 4. Multiple caged trials established at UMN-SPRF in Becker for PVY vector studies.

Results & Discussion:

1) *Aphid Alert Trapping Network* – As in most years, the trapping network had occasional technical difficulties (equipment replacement, battery failure, etc). The working parts of the traps seem to degrade at different rates. Electric fans and photocells are especially prone to failure, occasionally the voltage regulators for the solar panels will fail, batteries will die, but the solar panels seem to be very reliable over time. As a result, the network was working with anywhere from 16 to 20 twenty traps reporting weekly.

Figure 5. Aphid Alert 2021 blogspot.

Trap catch material shipped to the NWORC Entomology lab by grower cooperators was sorted by undergraduate summer research assistants and identified by either Dr. Ian MacRae or Ayla Morehouse. Identified weekly trap catch reports were prepared and disseminated (e.g. Fig 5).

For the purposes of examining seasonal regional relationships (and for future comparisons across years), reporting dates were transformed to ISO week dates. ISO week dates are part of the ISO 8601 date and time standard. It is basically a leap week calendar system to standardize week numbers and facilitates the comparison of seasonal occurrences across tears.

The average regional PVY Vector numbers peaked earlier in 2021 than the expected average calculated from 2013-2020 data (Fig 6). Given the higher temperatures early in the season, this is not surprising. At the UMN-NWROC, the average daily temperature in June 2021 was 2F higher than in 2020 (meaning we accrued 60 additional Insect

Degree Days in that month. Perhaps more importantly, the average daily highs in 2021 were 10F higher than those in 2020. Aphids, like all insects, are cold and their physiological processes (including growth, maturation and reproduction) are heavily influenced by ambient temperatures, increasing with rising temperatures until an upper threshold is reached. These spiking high temperatures can significantly increase insect growth rates.

As in some years, the PVY Vector Risk Index (Fig 7) did follow a similar pattern as PVY Vector presence. By examining the cumulative seasonal capture of PVY Vectors and the cumulative seasonal accrual of the PVY Vector Risk Index (Fig 8) the close relationship is more evident. The PVY Vector Risk Index, the blue bars in Fig 8, are measured by the left Y-axis, while the cumulative PVY Vector capture is represented by the gold line and measured by the right Y-axis. Please note that the right axis is 10X that of the left. Because the two are closely related, this indicates that the cumulative PVY Vector Risk Index values are close to 1/10th that of the cumulative PVY Vector capture. Which means the vector efficiency of the vectors captured must average close to 0.1 (or 1/10th as efficient as Green Peach Aphid).

This implies that we may have had relatively low vector pressure in 2021. However, the presence and type of management tactics practiced in the field is far more important to outcomes.

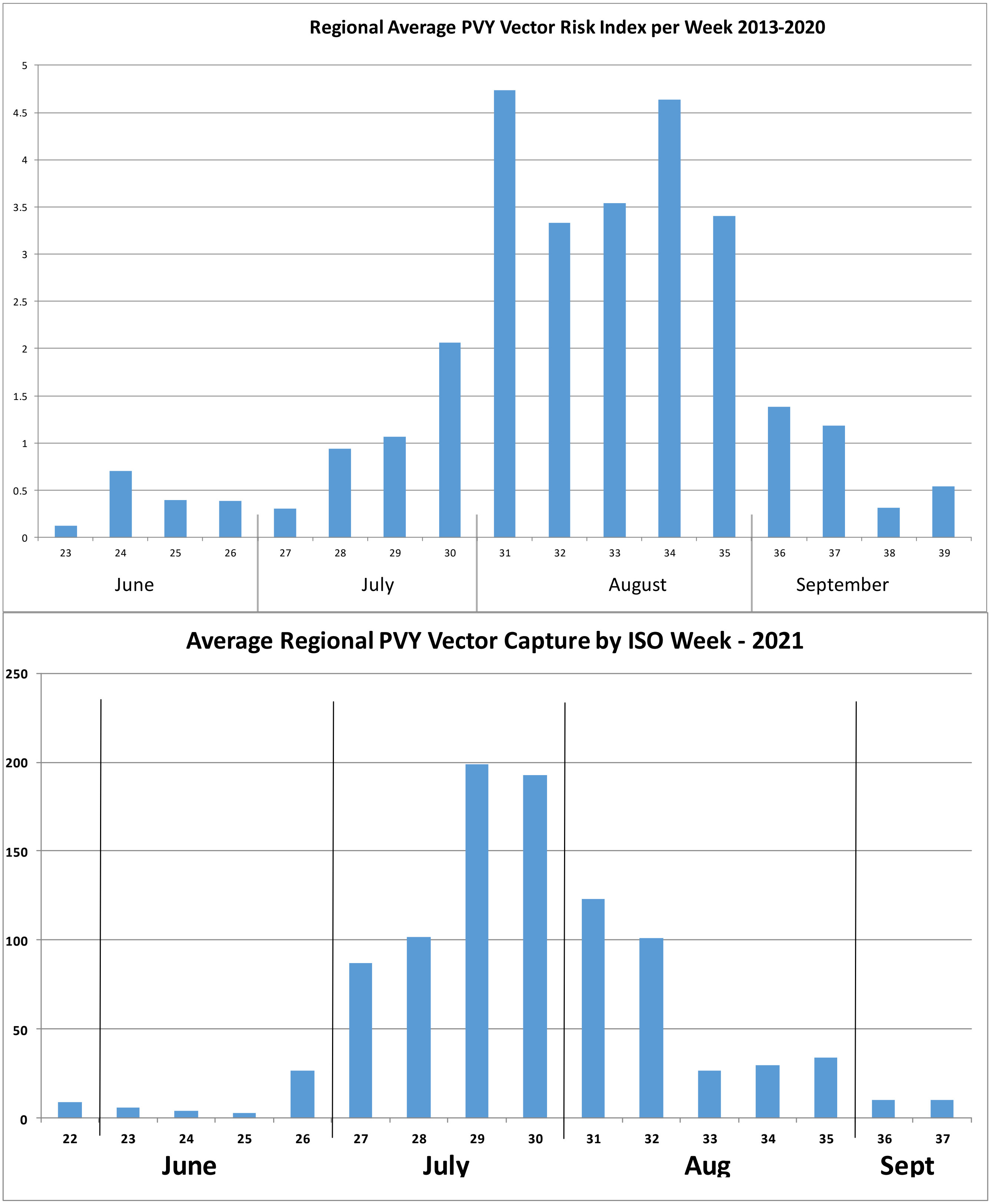

Figure 6. The average capture of PVY vectors combined across all sites across the region by ISO week for the years 2013-2020 (top graph) and for 2021 (bottom graph). It can be seen that 2021 populations peaked somewhat earlier in the season than the 8 year average of 2013-2020 average.

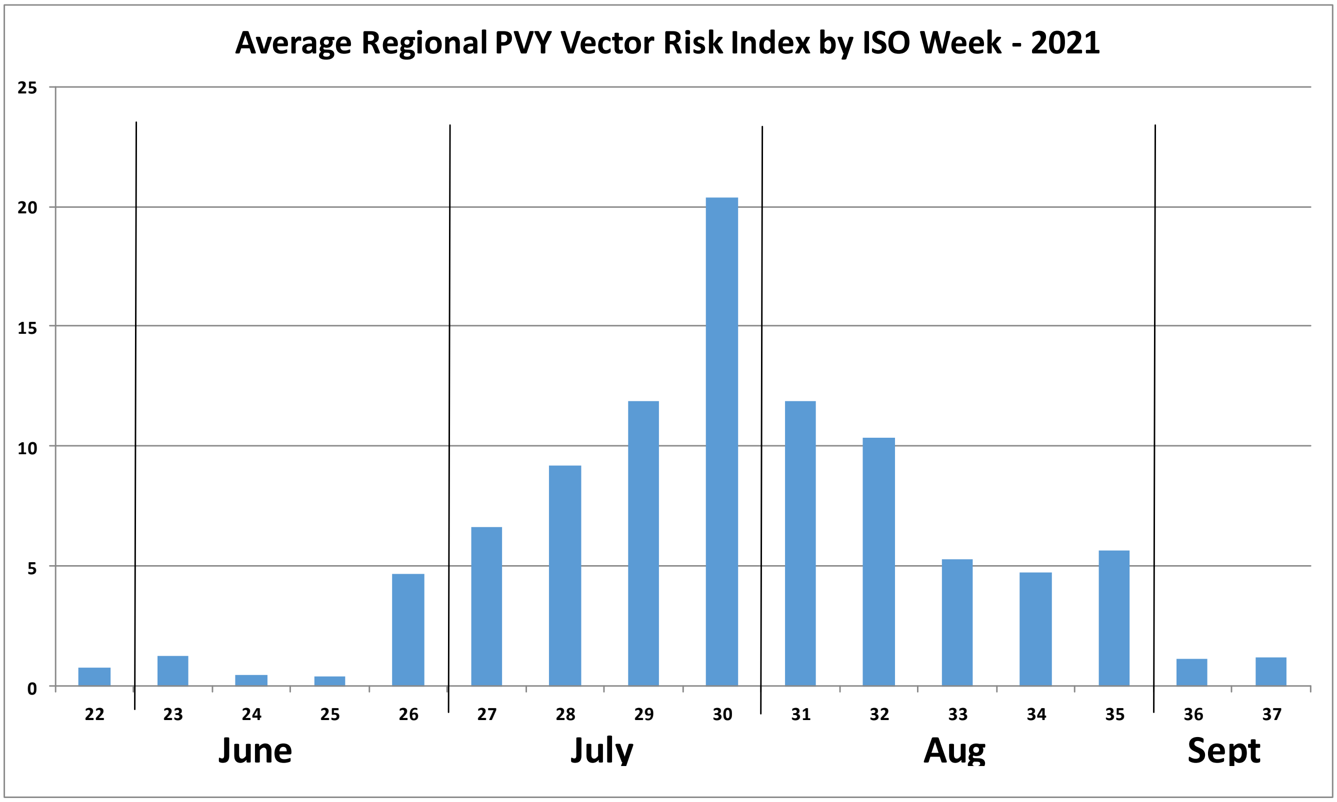

Figure 7. The average PVY Vector Risk Index combined across all sites across the region by ISO week.

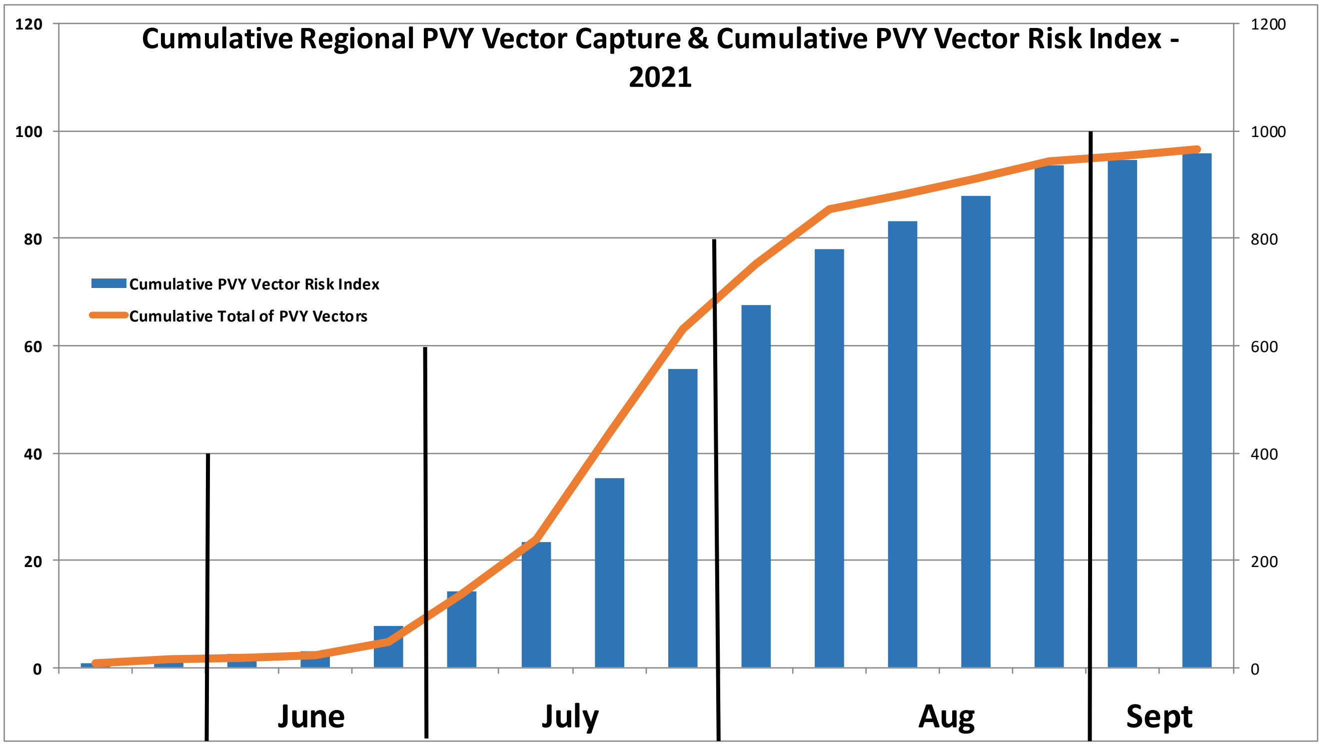

Figure 8. The cumulative total capture of PVY vectors from all sites combined across the region and the cumulative PVY Vector Risk Index. Cumulative PVY Vector Risk Index is represented by the blue bars and measured by the left Y-axis. Cumulative total PVY Vector capture is the gold line and is measured by the right Y-axis. Note the scale of the right axis is 10X that of the left.

2) *Compare products and additives for managing the transmission of PVY* – The original proposal called for this trial to be conducted using the most effective vector of PVY, *Myzus persicae*, commonly called Green Peach Aphid (GPA). The entomology lab had been maintaining colonies of both GPA and *Macrosiphum euphorbiae*, commonly called Potato Aphid. In mid-winter of 2021, a cross-contamination of the colonies resulted in Potato Aphid invading and displacing GPA from the plants in its colony and invading the food source plants being grown in the greenhouse. The result was two colonies of Potato Aphid and mostly leafless plants in the greenhouse (Fig 8). It was not possible to utilize insecticides to clean greenhouse plants as they were food for all of the insect colonies being maintained. A concentrated effort was made to clean plants using pressurized water applications, rearing new food plants in cages in a separate greenhouse bay and tightly monitoring all colonies and plants for the presence of aphids. After a number of weeks, Potato Aphids had been eliminated from the greenhouse but the GPA colony was extinct. Consequently, these trials were conducted with Potato Aphids. While not as effective a vector of PVY as is Green Peach Aphid, Potato Aphid, does, none-the-less, transmit the virus.

Figure 8. Typical aphid damage in greenhouse plants, Feb, 2021. Note the shriveled leaves, leaving no foliage as insect food (it's basically already *been* insect food!)

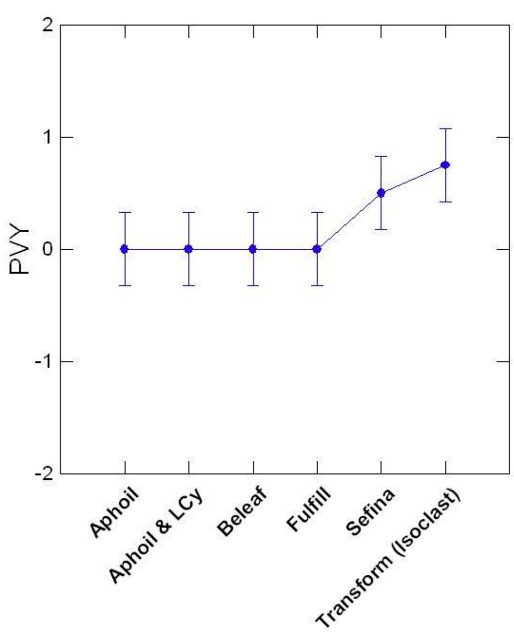

Figure 9. Average transmission success of Potato Aphid vectoring PVY to treated plants.

The only positive PVY transmission was found in Target plants treated with Transform or Sefina. No PVY transmission was recorded in Target plants treated with Aphoil, Aphoil + Lambda Cyhalothrin, Beleaf, or Fulfill (Fig 9). Transmission of PVY to plants treated with Transform or Sefina, however, did occur. ANOVA indicated this was a significant treatment effect (P=0.007, Table 2). Not surprisingly, Fisher's LSD (Table 3) indicated that there was no significant difference in PVY transmission in plants treated with Aphoil, Aphoil + Lambda Cyhalothrin, Beleaf, and Fulfill. There was also no significant difference in transmission rates for plants treated with Transform or Sefina. There was a significant difference between the treatment groups where PVY transmission was seen and those where transmission was not recorded (P=0.036 for non-transmitting vs Sefina, and P=0.003 for non-transmitting vs Transform).

Potato Virus Y can be transmitted by aphids very quickly. Both Beleaf and Fulfill have been established as effective in suppressing the transmission of PVY, consequently their performance was not surprising. Aphoil, with or without the addition of insecticide is also recognized as an effective product to limit, if not stop completely, the transmission of PVY. It may be in this trial, that neither Sefina nor Transform had a rapid enough onset of mortality to prevent PVY transmission. The experimental design - holding aphids back on PVY positive plants and then releasing them when they were likely viruliferous – does not accurately reflect real-life situations. Consequently these results should not be seen as complete without the review of field trials.

Caged trials were established at the UMN-SPRF in Becker, MN (see Fig 4 in Procedures), including the establishment of Target plants and smaller cages with aphids. Unfortunately, a severe wind event occurred prior to treayments being applied and subsequent release of aphids from small cages. This disrupted cages, leaving most of them open to the environment (Fig. 10). The potential presence and subsequent access to the open cages by naturally occurring aphid vectors represented a significant confounding factor. It precluded assuming any subsequent PVY infection found in Target plants was directly due to feeding from the aphids released in the trial.

Figure 10. Cages blown down after severe wind event. This resulted in exposing test plants to the outside environment, where aphid vectors may have been present.

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Management of Colorado Potato Beetle 2021

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Executive Summary – This is a project to develop and refine management tactics for Colorado Potato Beetles in Minnesota and North Dakota. This proposal will include: 1) assessing insecticide resistance of adult Colorado potato beetle in Minnesota and North Dakota to insecticides currently available in management, 2) Continuing to assess the efficacy and economics of foliar applied insecticides and their best fit in insecticide rotations, and 3) Evaluating the efficacy of biopesticides. This information will assist in assessing the need for and developing appropriate foliar management programs in anticipation of decreasing availability and/or efficacy of soil applied insecticides.

Rationale – Colorado Potato Beetle (CPB), *Leptinotarsa decemlineata* Say is the most damaging defoliating insect pest of potatoes in North America (Alyokhin 2009). In the past 25 years, at-plant applications of neonicotinoid insecticides have effectively controlled CPB populations. Unfortunately, this insect has a pronounced ability to develop insecticide resistance (Weisz et al. 1994, Alyokhin et al. 2007, Huseth et al. 2014). Resistance issues have been documented in Central MN for several years, and recent data on CPB populations in the Red River Valley (RRV) also indicate increasing tolerance for neonicotinoid insecticides (see Appendix 1, MacRae, 2018).

Figure 1. The bottle on this quad sprayer contains Imidacloprid and is covered with considerable spray residue. UMN Sand Plains Research Farm, Becker, MN.

Populations of CPB in MN and ND show varying levels of resistance (MacRae, NPPGA & Area II Research reports 2012-14, 2017-19) and control failures and decreased efficacy with at least three neonicotinoid insecticides (imidacloprid, thiomethoxam and clothianidin) have been reported. Data from 2012-14 and 2017-19 indicate that tolerance to neonicotinoids varies by location within the two states but is increasing in both (Fig 1).

Resistance is not the only challenge to the continued use of neonicotinoid insecticides. Issues with pollinators and data linking the leaching of neonicotinoids into ground-water systems (Goulson 2013, Huseth & Groves 2014, Hladik et al. 2014) has precipitated regulatory issues. The Environmental Protection Agency review on Imidacloprid, Clothianidin, Thiamethoxam, Thiacloprid, Dinotefuran, and Acetamiprid are planned to be completed in 2021 and Interim regulatory decisions have been announced (US EPA 2020).

In addition, an extended summer emergence of overwintered adult CPB has stretched the presence of adults later in the summer. This has resulted in an erosion of the typical two seasonal population peaks. The seasonal presence of CPB is now more evenly dispersed across the season and presents a more persistent defoliation problem, requiring additional within season foliar applications of insecticides.

This extended emergence is thought to be a behavioral form of resistance. The late emerging beetles are susceptible to neonicotinoid insecticides and represent that portion of the susceptible population that is genetically programmed to emerge later in the season (Szendrei et al. 2012). If a beetle susceptible to neonicotinoid insecticides emerges early in the season into a field treated at-plant with a neonicotinoid, they will die. However, later in the season, the concentration of insecticide in plants will drop because the insecticide is starting to degrade, and the remaining insecticide is being diluted by continued growth of the plant (Huseth & Groves 2010). Consequently, the use of neonicotinoids applied at-plant has selected against early emerging susceptible CPB. The end result is that the later emerging adults survive, mate and lay eggs later in the season, leading to the extended presence of eggs, larvae and adults into the mid-season.

Data from 2018-19 indicates in some locations, not only is the efficacy of neonicotinoid insecticides decreasing, but efficacy of other modes of action is occurring as well (MacRae 2019). This decreasing sensitivity to other insecticides is especially concerning. Populations of CPB collected from some sites in central MN showed tolerance to Abamectin (e.g. AgriMek) insecticides, CPB from a site in ND showed increased tolerance of the Diamide, Chloratraniliprole (Rynaxypyr = Coragen). Populations from two sites in MN showed significant levels of resistance to Spinosyns (Spinosad = Blackhawk & Spintor). These latter sites, however, were isolated organic production fields which had relied heavily on Spinosad for several years.

If foliar management programs are to remain effective against Minnesota and North Dakota CPB populations, we must manage potential resistance. It is desirable to know prior to application if products are effective. Consequently, information on the relative efficacy of the available insecticides is necessary to develop working insecticide resistance management programs.

An increased reliance on foliar applications to control CPB is going to require research to ensure both product efficacy and their sustainability, from the viewpoint of both resistance and economics. Continued review of insecticide efficacy vs cost and rotation is required to address newer and existing modes of action. In addition, formulations containing new mixes of chemistries should be assessed for fit and function in the mode of action rotations that are vital to keeping as many of our modes of action available for the longest period possible.

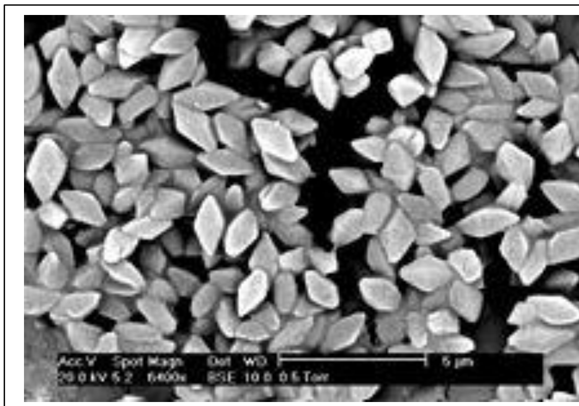

Figure 2. Electronmicrograph of delta endotoxins (Cry proteins) from *Bacillus thuringiensis*. https://en.wikipedia.org/wiki/Bacillus_thuringiensis

There have been recent advances in the use of some biopesticides that may contribute mortality to our CPB management efforts. *Bacillus thuringiensis* (*Bt*), a bacterium found in the soil, produces crystal proteins (called Cry proteins or delta endotoxins) (Fig 2) that have insecticidal action. The insecticidal activity is specific to different insects depending on the strain of *Bt*; *Bt kurstaki* (*Btk*) effects only butterflies and moths, *Bt israeliensis* (*Bti*) affects only true flies, while *Bt tenebrionis* (*Btt*) is effective against only beetles. While foliar applied *Bt* has been commercially available for years, environmental conditions could often impact its efficacy. There are several newer formulations of *Btt* that may provide longer residual activity, and perhaps even establish a multi-year presence of bacterial inoculum that would function as an epizootic (term for an insect epidemic) that may be present in consecutive years.

Another pathogen that is widely available and has shown some activity against CPB is *Beauveria bassiana*. The spores of this commonly occurring pathogenic soil fungus can infect an insect as a disease (think of it as dying of full-body Athlete's Foot). Some research has reported reductions in CPB populations up to 75% (Cantwell et al., 1986). Like *Bt*, there are several commercially available formulations of *B. bassiana* that can be applied using a pesticide sprayer. Also, like *Bt*, *B bassiana* can be negatively impacted by environmental conditions, often providing highly variable results.

Relatively recent data indicated a synergistic action between the two pathogens when applied together (Wraight and Ramos 2017). When applied together, the study found a 20% increase in mortality of either applied alone but no increase in the speed this occurred. As with most pathogen based biopesticides, onset of action is much slower than typical insecticides, often maximum mortality may not be evident for a week. And as soil borne insects pathogens, they'll be most effective when larvae drop to the soil; to pupate into adults. Obviously then, these would not be rescue treatments, but a method of introducing mortality that would impact next-year's populations.

This project proposes to:

1. Continue monitoring for CPB resistance to different insecticide modes of actions, especially foliar applied classes of insecticide.
2. Assess efficacy and economics of rotational foliar applied CPB management tactics.
3. Evaluate the efficacy of biopesticides.

Procedures

1) Monitoring for insecticide resistance in Colorado Potato beetle – The resistance of CPB to selected insecticides was evaluated in several potato production areas within Minnesota and North Dakota. Locations sampled included UMN-NWROC (Crookston, MN), the Forest River Colony experimental plots, and the UMN Sand Plains Research Farm (Becker, MN).

In 2021, drought and heat conditions were rapidly accelerating the physiological processes of in-field populations. Insects are cold blooded, their metabolic rate (including that of metabolically detoxifying pesticides) is controlled by ambient temperature. There were concerns that comparing resistance rates of in-field populations attenuated to the climatic conditions seen this summer to those of a lab colony maintained in a temperature controlled might not be reflective of non-drought years. Instead, dip tests were conducted in the field (Fig 3). A dip test is an in-field test that involves dipping beetles into containers with prepared various concentrations of insecticide. Mortality can then be measured and a response curve to insecticide rate can be calculated. While this technique cannot ascertain if it is genetically controlled resistance, it can indicate if higher than label rates are necessary to cause mortality in an in-field insect population. These trials are conducted in the field and don't require transporting beetles back to the lab, facilitating its use to estimate larval susceptibility to insecticides.

Figure 3. Dip Test Kit, containing all of the equipment to conduct onsite dip tests to assess insecticide resistance.

Sampled beetles were assessed for susceptibility to Abamectin (Agri-Mek) and Spinosyns (Blackhawk). Twenty adult beetles and twenty larvae were collected, placed into a large tea strainer and dipped into 950 ml wide mouthed mason jars containing one of 5 insecticide concentrations; 0, 1, 3, 5, and 10 times the high label rate of the insecticide being tested. Beetles were immersed for 10 sec, then withdrawn and removed from the tea strainer and placed into Petri plates. Plates were stored @~20-22C mortality assessed at 12h and 24h (if there was not sufficient mortality by 12h). Trials were replicated 3 times at each location.

Mortality was determined by probing beetles for movement. Any adults or larva that was drying out, 'deflated' in size or could not be made to move through gentle probing was counted as dead. Adult beetles sometimes 'play dead' during handling, any beetle that elicited no movement but had legs outstretched was counted as dead, if the beetle was unmoving but had legs curled was counted as live. Percent mortality data was used to create dose-response curves to estimate the amount of insecticide relative to the maximum label rate necessary to kill 90% of the sampled population (the high label rate of an insecticide is calculated to provide this level of control).

While not used in the summer of 2021 for direct comparisons, we did continue to maintain our colony of insecticide naïve CPB (Fig 4). This population of insects has never been exposed to insecticides. Consequently, the genetic factors conferring resistance to any insecticide mode of action have never been subject to selection in this population. This colony is a valuable research tool and is used to establish baseline mortality rates for insecticides tested for resistance.

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 2-3 such colonies maintained in the Northern Plains.

2) Assess efficacy and economics of rotational foliar applied CPB management tactics

Site Information – Chemical trials were conducted at both the UMN-NWROC in Crookston and the UMN Sand Plains Research Farm in Becker, MN. Rotational Foliar trials with conventional insecticide were conducted at Crookston. Rotational trials with numbered products and biorational insecticides were conducted in Becker.

Crookston: The trials were conducted at the Northwest Research and Outreach Center located in Crookston, MN (47.813930, -96.616661). The soil type in the trial field is Wheatland Loam and plots were produced under dryland agricultural production, no irrigation regimen was used. These plots represent the only potato production on the research center for research and/or commercial purposes. The field was initially prepped with an appropriate management plan for potatoes.

Plot were 4 rows wide @ 36" row spacing resulting in 12' wide X 25' long plots. Each plot had 12" plant spacing with 10' alleys at each end and 8 ft alleys between plots. All plots were treated weekly with fungicide from emergence through vine kill and had standard weed control. Plots were planted with Red Norland seed potatoes on May 27. Plants began emerging by June 09 and rows were discernible by June 11, adult Colorado Potato Beetle (CPB) had emerged from overwintering and were establishing on plants by this date. Canopies were well established and CPB egg deposition had occurred by June 21. Egg hatch had reached 30-40% by July 07. Insecticides were applied July 07; ambient temperature was ~80F, with 3-5mph NW winds. Adult presence had already begun to drop by the July 07 population count. This was considered a short period of early season adult presence and was probably the result of unseasonably warm temperatures in June. Counts were conducted at 5- & 7-days post-application, and at ~2, 3, and 4 weeks post application (Fig 1).

One of the middle two lots were randomly selected for harvest using a single row custom potato harvester (US Small Farms Equipment Co.). Row yields were transformed to CWT/ac for analysis. The presence of disease symptoms or harvest cuts were noted during harvest.

IN 2021, Colorado Potato Beetle populations entered fields later than usual at the UMN-NWROC. First insecticides applications (Rimon) occurred July 03; ambient temperature at time of application was ~78F, with 3-4mph variable winds from the NE. Other application timings started July 05 and counts were conducted at 7Days After Initial Treatment (DAIT) (July 10), 14DAT (July 17), and 21DAT (July 24). Applications were conducted the same days, after populations and defoliation had been assessed. One of the middle two lots were randomly selected for harvest using a single row harvester. Row yields were transformed to CWT/ac for analysis. The presence of disease symptoms was noted during harvest.

Treatments (Table 1) included AgriMek (Abamectin), Besiege (Synthetic Pyrethroid & Anthranilic Diamide pre-mix), Blackhawk (Spinosyn), Coragen (Anthranilic Diamide), Delegate (Spinosyn), Minecto Pro (Anthranilic Diamide & Abamectin pre-mix), and Rimon (Benzoylureas, insect growth regulators, referred to as IGRs). Untreated Control plots were used to establish baseline damage levels. Application timings included at 1st egg hatch, 50% egg hatch, post-bloom and rotated application timings (through each of these timings). Rotations of the different modes of action were conducted that ensured appropriate application of products at targeted life stages of CPB that would best reflect commercial usage. It should be noted that due to available plot space, not all currently available, or even highly successful, CPB management products could be included in the trial. Inclusion or exclusion or any product in this trial does not infer recommendation or lack thereof.

Table 1. Chemical applications in demo rotation, UMN-NWROC, Crookston, MN. 2021.

Application	Treatment
AgriMek (Abamectin)	Rotated appl. timings
Besiege_50 (Synthetic Pyrethroid & Diamide)	Applied @ 50% egg hatch
Besiege_Post (Synthetic Pyrethroid & Diamide)	Applied post-bloom
Blackhawk (Spinosyn)	Rotated appl. timings
Blackhawk_50 (Spinosyn)	Applied @ 50% egg hatch
Blackhawk_Post (Spinosyn)	Applied post-bloom
Coragen_50 (Diamide)	Applied @ 50% egg hatch
Coragen_Post (Diamide)	Applied post-bloom
Delegate (Spinosyn)	Rotated appl. timings
MinectoPro_50 (Diamide & Abamectin)	Applied @ 50% egg hatch
MinectoPro_Post (Diamide & Abamectin)	Applied post-bloom
Rimon_1st (Benzoylureas, IGRs)	Applied at 1st hatch
UTC	N/A

Inclusion or exclusion of a product from this trial does not represent either recommendation or lack thereof. Rather this trial simply looks at some, but not all, of the available insecticide modes of action for controlling Colorado Potato Beetle.

Plots were sampled at 48h post-application and then every 7d post-application. Four representative plants were randomly selected from the inner two rows of each plot and percent defoliation was assessed visually and CPB numbers counted on each of the four plants. Beetle numbers were recorded for adults, eggs, small larvae and large larvae. All those collecting data ‘calibrated’ their defoliation estimates prior to each data collection to decrease relative differences in estimates. Population data was plotted and analyzed using General Linear Model ANOVA. Any significantly difference means were separated using Fisher's Least Significant Difference analysis.

3) Evaluate the efficacy of biopesticides

Site Information –The trials were conducted at the University of Minnesota Sand Plains Research Farm (UMN-SPRF), Becker MN (45.336469, -93.821006). The SPRF is an irrigated site with a unique coarse textured soil (riverbed sand). Plots were produced under irrigated agricultural production. The SPRF is UMN's principal potato research site, and the trial field was initially prepped with appropriate management plan for commercial potatoes.

Plot were 4 rows wide with 36" row spacing resulting in 12' wide X 25' long plots. Each plot had 12" plant spacing with 10' alleys at each end and 8 ft alleys between plots. All plots were treated weekly with fungicide from emergence through vine kill and had standard weed control. Plots were planted with Russet Burbank single-drop, seed potatoes on May 11.

Plants began emerging by May 20 and rows were discernible by May 28. Adult Colorado Potato Beetle (CPB) had emerged from overwintering and were establishing on plants by this date. Canopies were well established and CPB egg deposition had occurred by June 01. Egg hatch had reached 20-30% by June 03. Adult presence had already begun to drop by the June 10 population count. This was considered a short period of early season adult presence and was probably the result of unseasonably warm temperatures in June.

Commercial formulations of *Bacillus thuringiensis* (*Bt*) and *Beauveria bassiana* were applied for assessment as potential controls for Colorado Potato Beetle. Unfortunately, trial plots were very rapidly defoliated, forcing early termination of this trial.

However, a single trial of a *Bt tenebrionis* strain was tested at the UMN-SPRF in Becker, MN. The same application techniques were used as in as objective #2. Three rates and three separate application timings were tested (Table 2). Data and analyses were similar to those used in objective #2.

Table 1. Application rates and timings used in the *Bacillus thuringiensis tenebrionis* trials at the UMN-SPRF, Becker MN.

Treatment	Product	Rate	Application Timing
***Bt*1**	**Untreated Check**	**N/A**	**N/A**
***Bt*2**	***Bt tenebrionis***	**0.5 lbs/ac**	**3 apps @ 5D intervals**
***Bt*3**	***Bt tenebrionis***	**1.0 lbs/ac**	**3 apps @ 5D intervals**
***Bt*4**	***Bt tenebrionis***	**1.5 lbs/ac**	**3 apps @ 5D intervals**
***Bt*5**	***Bt tenebrionis***	**1.0 lbs/ac**	**2 apps @ 7D intervals**
***Bt*6**	***Bt tenebrionis***	**1.5 lbs/ac**	**2 apps @ 7D intervals**
***Bt*7**	***Bt tenebrionis***	**1.0 lbs/ac**	**2 apps @ 10D intervals**
***Bt*8**	***Bt tenebrionis***	**1.5 lbs/ac**	**2 apps @ 10D intervals**

4) Colorado Potato Beetle as a potential vector of PVY

Site Information – These trials were conducted at the UMN-SPRF in Becker, MN (described above). Plots in this trial were one solid block, 4 rows wide and ~210’ long rather than small plots. Large, medium and small scale cages (Fig 5) were established to assess the ability of CPB to vector PVY from infected plants to uninfected plants.

Figure 5. Multiple caged trials established at UMN-SPRF in Becker for PVY vector studies.

In the cages were established multiple plants that had been confirmed uninfected with PVY via PVY ImmunoStrips (target plants) and several plants already confirmed to be infected with PVY (source plants) that were individually caged (cage within cage design). Cages were treated with an aphicide (Fulfill, Syngenta) to ensure there were no aphid vectors present in the cage. Colorado Potato beetle adults or larvae were then placed into the source plant cages and allowed to feed on source plants for 24-48h. Source plants cages were then removed, allowing CPB that had fed on source plants access to target plants. Access was to be allowed for 7 days and then target plants would be removed and any tubers harvested by hand. The target plants would be tested for PVY infection with enzyme-linked immunosorbent assay (ELISA), and tubers stored and grown out in the greenhouse during the winter months for additional ELISA testing.

Unfortunately, a severe wind event occurred 2 days after the trial had been established disrupting cages, leaving most of them open to the environment (Fig. 6). The potential

Figure 6. Cages blown down after severe wind event. This resulted in exposing test plants to the outside environment, where aphid vectors may have been present.

presence and subsequent access to the open cages by naturally occurring aphid vectors represented a significant confounding factor. It precluded assuming any subsequent PVY infection found in target plants was directly due to CPB feeding. Although the trial design was now incomplete, several cages remained intact and data was obtained but because the experimental design no longer had sufficient replications to be analyzed, these data can only be considered preliminary rather than conclusive.

A trial using fewer plants in smaller cages (some of which can be seen to the left in Fig. 5), however, was not disturbed by the wind. Target plants were tested, and tubers collected for winter grow out and subsequent virus testing via ELISA (this is ongoing).

Results & Discussion

1) Monitoring for insecticide resistance in Colorado Potato beetle – While the climatic conditions in MN and ND through the 2021 growing season significantly affected insect populations, this did not seem to exacerbate resistance issue in the area. Indeed, while neonicotinoid resistance is well-established in Central Minnesota with decreasing efficacy having been reported over the past 10-12 years, growers and agricultural professionals reported better performance of at-plant thiomethoxam and clothianidin (the active ingredients found in Platinum and Belay respectively) than in the past several years. We witnessed this in the UMN-SPRF plots in Becker as well. It may be that the early season drought prevented the leaching of neonicotinoid insecticides experienced in years with more typical moisture. This would have increased levels of neonicotinoid in plants, providing higher levels of active ingredient at target sites in the insect. It may also be that the higher-than-normal early season temperatures increased the digestion rates of CPB. One of the important resistance mechanisms seen in some CPB populations results from rapid digestion, so rapidly passing toxic insecticide through the part if the insect's gut where absorption occurs that insufficient levels of active ingredient enter the insect.

Dip tests at the UMN-NWROC indicated that both Abamectins and Spinosyns are still effective. The 1X high label rate of Abamectin provided >90% mortality, any rate over this was highly effective, killing all of the test beetles within 12h. The spinosyn Blackhawk, while effective, had slightly less efficacy; it required 1.4X of the high label rate to kill 90% of the test insects. However, onset of mortality was still rapid and the variability in the data precludes assuming this product is losing efficacy in this location.

The dip tests conducted at Forest River indicated that both products are still effective. AgriMek was controlling populations with 1.3X the label rate while Blackhawk was providing control at 1.2X high label rates.

The results at the UMN-SPRF in Becker were different, however. It required approximately 2.4X high label rate to obtain 90% mortality in that population. The spinosyn Blackhawk was better but still required ~1.5X the high label rate to obtain 90% mortality. These results are not surprising. It has already been recorded that the population of CPB in the Becker region has developed an increased tolerance of AgriMek. In addition, in 2021 Blackhawk was used in different plot areas at different times to terminate populations in treated p[lots that were at the end of their trial period. There is significant movement of CPB in experimental fields and it is possible that this trial, conducted at the very end of the season, included individuals remaining after previous applications.

As previously noted, the data from dip tests lacks the ability to identify true, genetically based resistance. In addition, the nature of the test and the influence of environment on the results makes the results somewhat imprecise and focused on tested fields. The results can be used as a guide to what may be happening, but I would hesitate to use them to guide regional management decisions.

2) Assess efficacy and economics of rotational foliar applied CPB management tactics – Examining the average & defoliation for each treatment by date (Fig 7) provides some valuable points about the evaluated insecticides. As July progressed, all treatments were suffering less defoliation than were the Untreated Control plots. It should be noted that by Aug 02, treatments had ended, and many plots were seeing increasing defoliation. Much of this was the result of reinfestation by beetles moving in from untreated plots or plots where residual activity from earlier treated insecticides was wearing off.

Some generalities from the defoliation patterns can be made on the insecticides. AgriMek in general rotation was effective in suppressing CPB. As dip tests indicted (Objective 1) there is no efficacy fade with this product in the Red River Valley so far.

Coragen had mixed results, being more effective when applied post-bloom than at 50% egg hatch. The Post-Bloom application seemed to fit better into general rotations as well, providing better suppression of CPB defoliation. Coragen has little ovicidal activity and so applying when half of the population are still eggs is ill-timing for this insecticide.

A similar pattern was seen in Blackhawk applied at 50% egg hatch and Post-Bloom. Not surprisingly, Blackhawk in general rotations did well and was very effective in suppressing CPB defoliation. The difference with the general rotation plots was that insecticide was being applied in response to population rather than waiting for a specific plant stage. Blackhawk is now being shifted to other crops and is being replaced with Delegate (Spinetoram, another Spinosyn). For the most part in these trials, Delegate performed similarly to Blackhawk in general rotation.

Minecto Pro, a mixture of a diamide and an Abamectin, performed similarly to either Coragen (a Diamide) or AgriMek (an Abamectin) at different stages of the trial. It had, as expected, good residual and suppressed CPB defoliation well. It should be noted that if using this product in rotation, it shouldn't be used after either a Diamide or an Abamectin. Neither should either of those individual modes of action be used after a Minecto Pro application.

Rimon, effective only against eggs and early instar larvae, suppressed populations early and demonstrated that getting off to an early start is useful. Without subsequent application, Rimon plots has relatively low defoliation until July 26 when new summer adults had started to appear and were defoliating plots. When well timed, targeting application between 20-50% egg hatch, Rimon can provide valuable early control, decreasing the need for foliar applications later in the season. A worthwhile strategy is to split Rimon applications, applying 2 applications of 10oz each at 7D intervals or 3 applications of 8oz each at 5D-7D intervals.

The performance of the individual insecticides against separate life stages are also presented on the following graphs: efficacy against the average number of: small Larvae on treated plants (Fig 8), large Larvae on treated plants (Fig 9), adult CPB on treated plants (Fig 10), and total feeding forms, that is the average of all Larvae and Adults present on treated plants (Fig 11). Please note that as COB get older, their feeding stimulates the development of Mixed Function Oxidase enzymes, making them ore efficient at detoxifying both the nasty chemicals in potato leaves *and* insecticides. Consequently, controlling older CPB is more difficult.

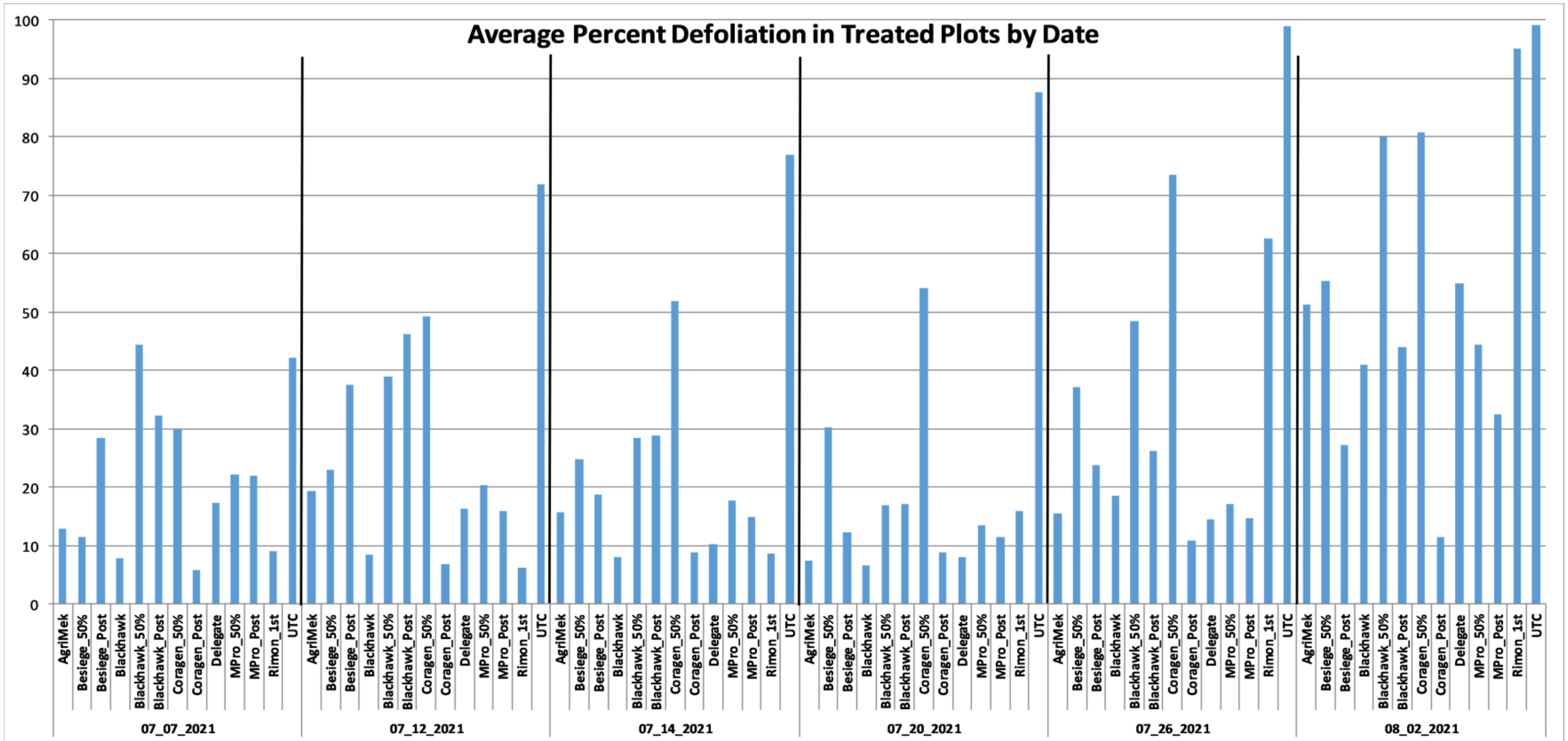

Figure 7. The average % defoliation in plots by treatment and date.

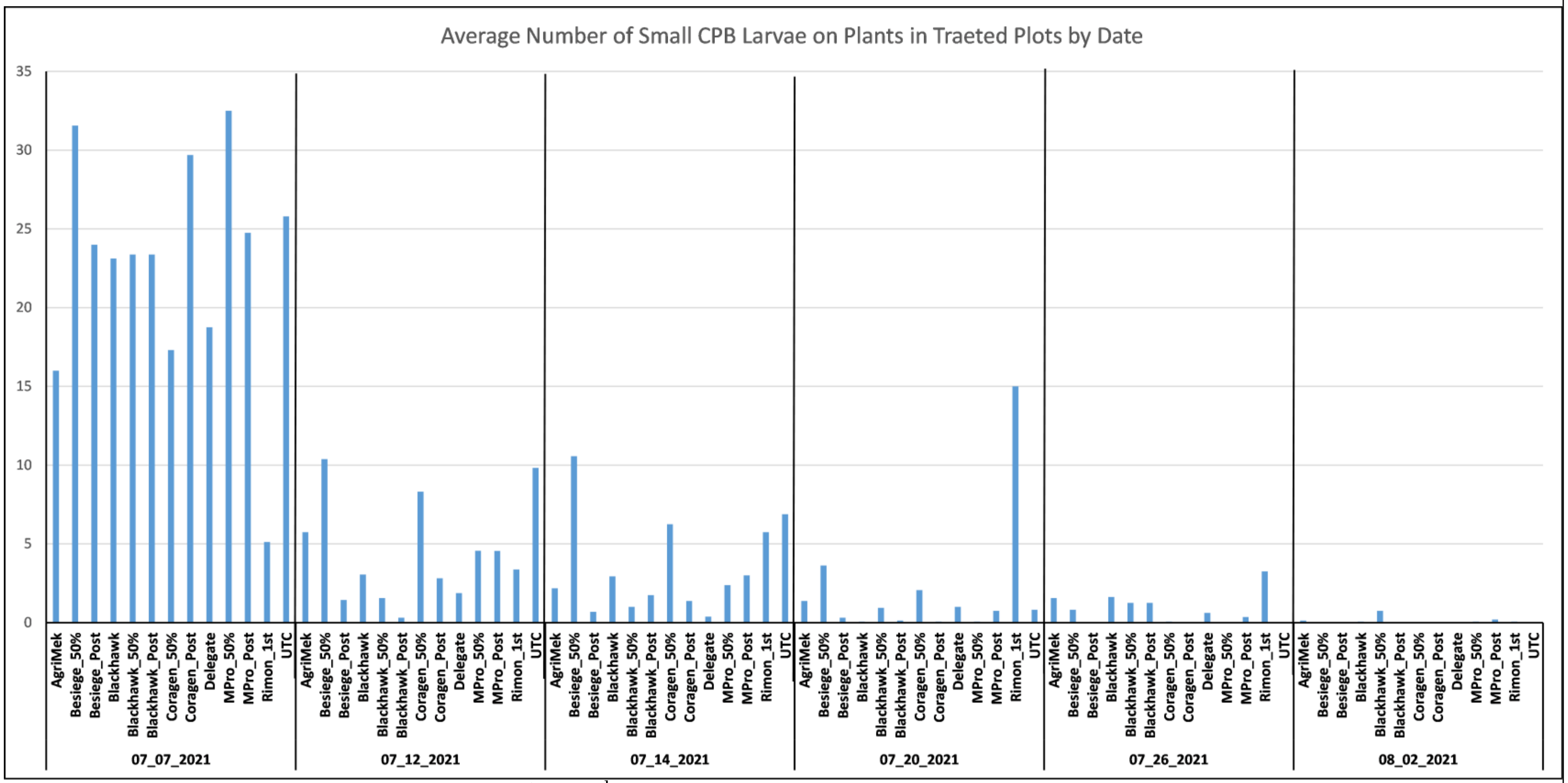

Figure 8. The average number of small (1st & 2nd instar) Colorado Potato Beetle larvae on treated plants by date..

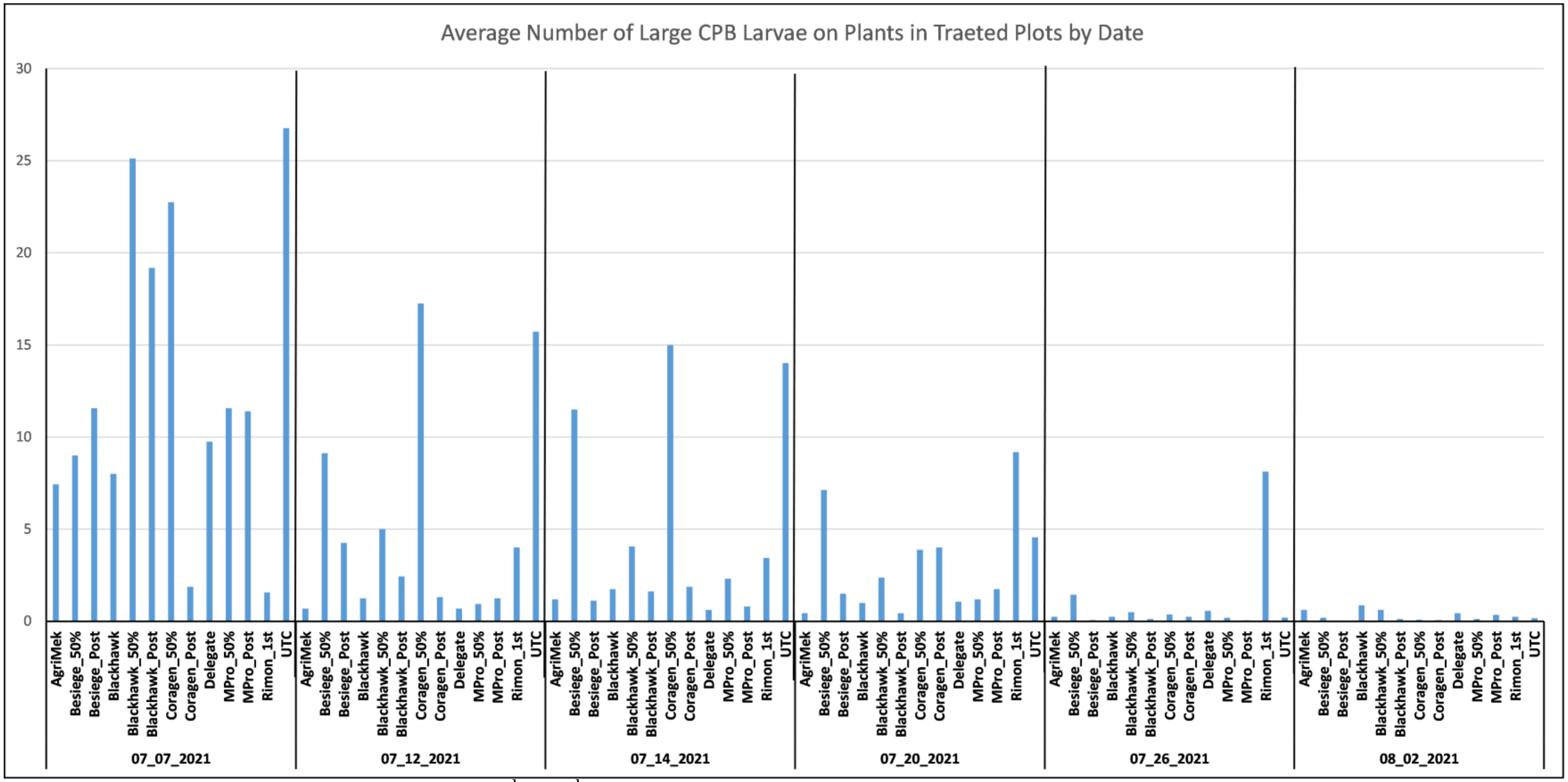

Figure 9. The average number of large (3rd & 4th instar) Colorado Potato Beetle larvae on treated plants by date..

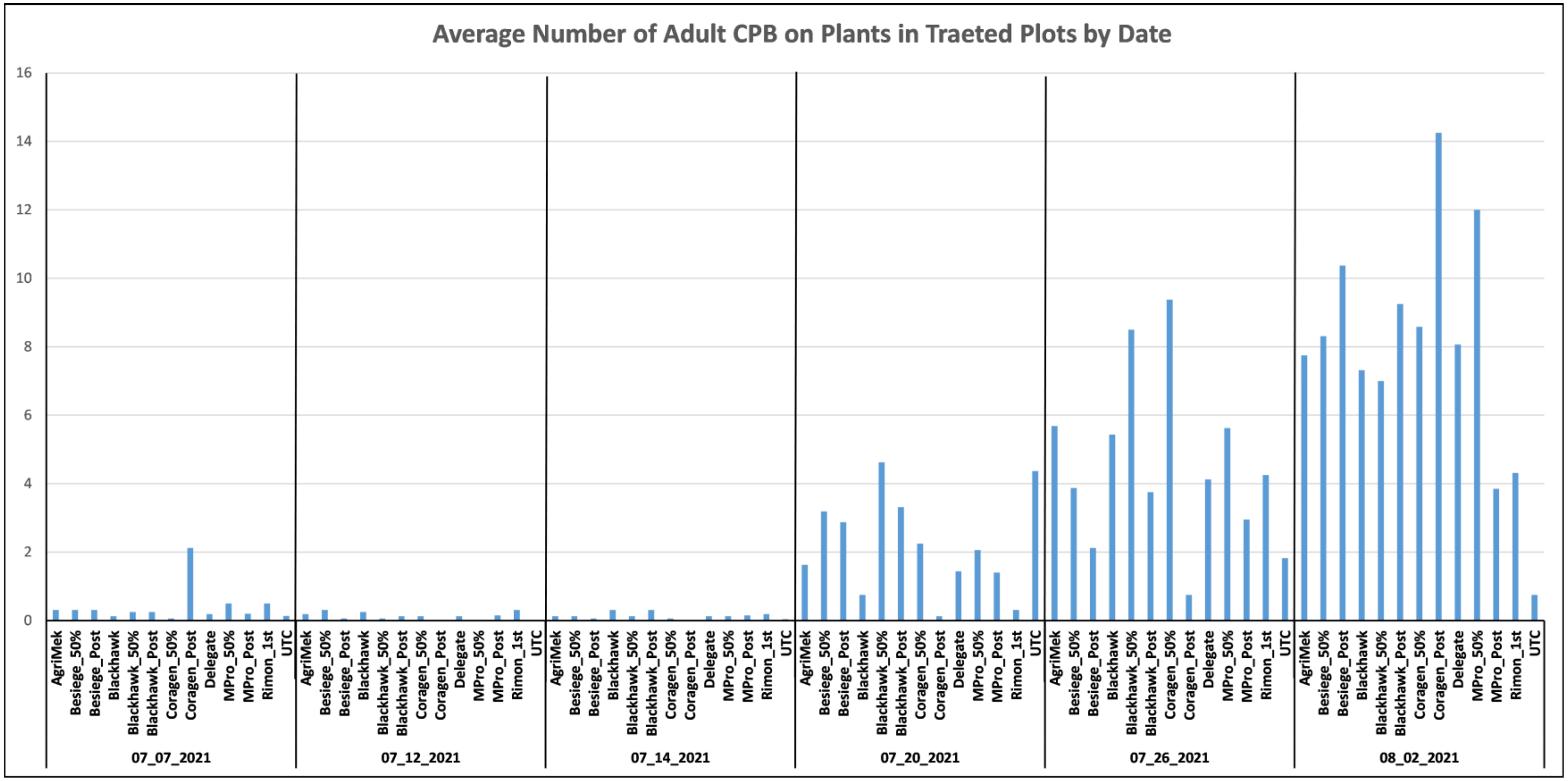

Figure 10 The average number of adult Colorado Potato Beetles on treated plants by date.

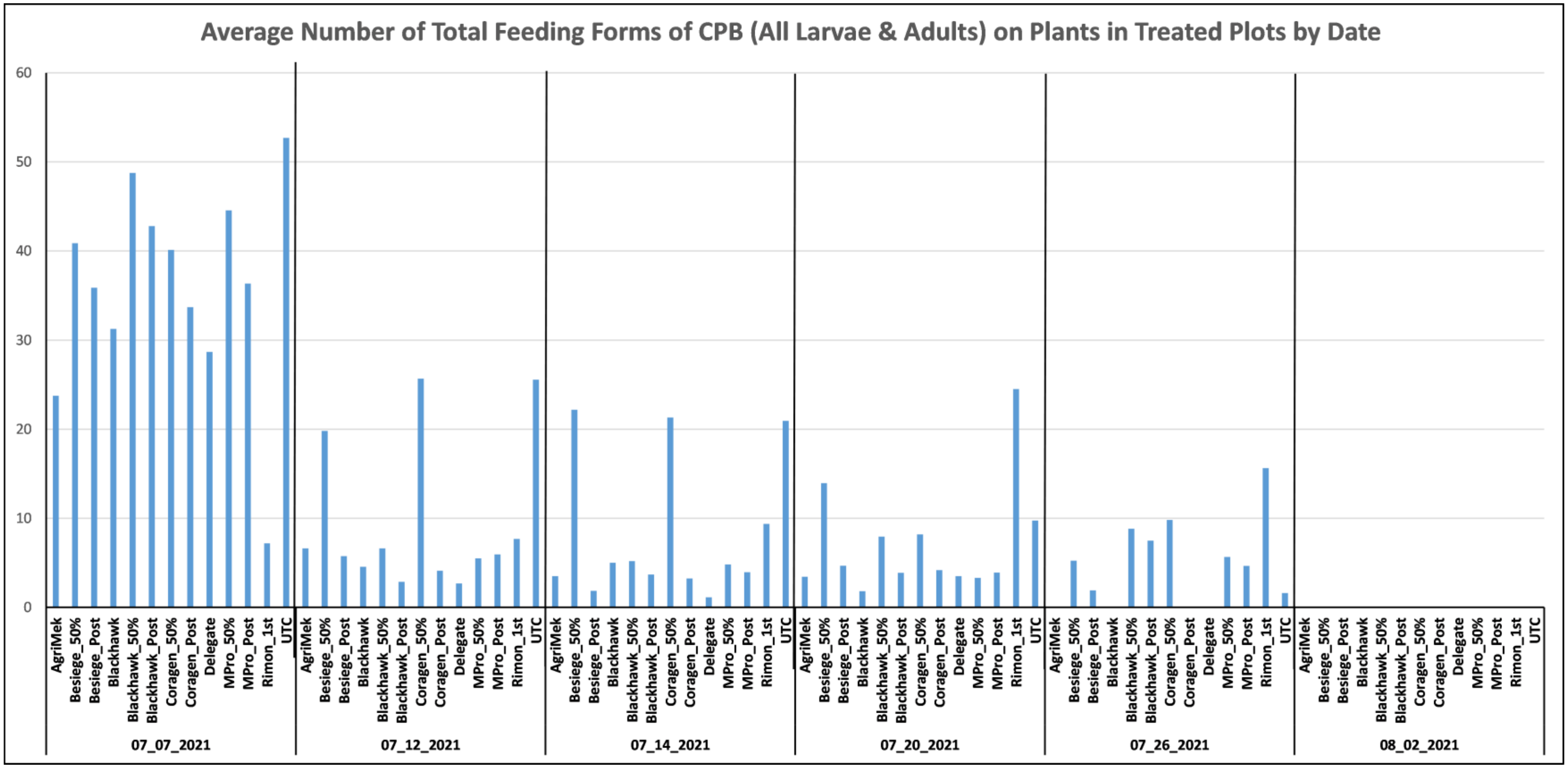

Figure 11. The average number of total feeding forms (all larvae and adults) of Colorado Potato Beetles on treated plants by date.

3) Evaluate the efficacy of biopesticides – Although the Crookston trial comparing the efficacy of *Bt* and *B. bassiana* was prematurely terminated, a trial of a single *Bt*

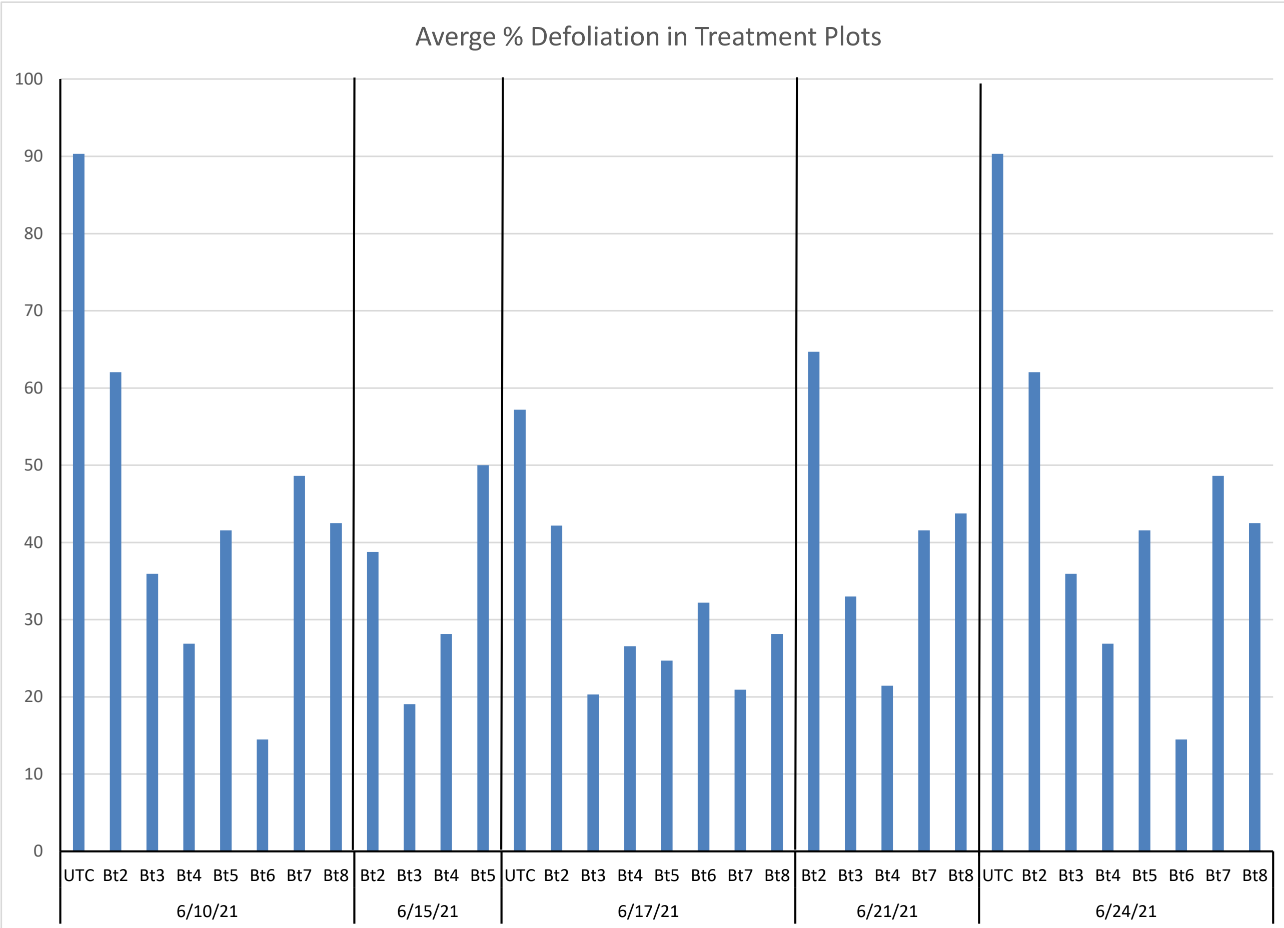

Figure 12. Average defoliation of plots treated with numbered *B thuringiensis* product. Note all *Bt* treatments had less defoliation (and therefore lower CPB numbers) than did the Untreated plots.

product was conducted in Becker and this product demonstrated potential as a management tool for young larvae (Fig 12). Although statistical analyses are ongoing, it can be noted that by the 3rd week (June 21) the heavier rates (1.0 lbs/ac and 1.5 lbs/ac) at 7&10 day intervals (*Bt*5, *Bt*6, 2 apps @7D, and *Bt*7, *Bt*8, 2 apps @10D) are providing significant suppression compared to Untreated plots. The 3 applications @ 5D intervals are now 6 days beyond their last treatment and without additional insect control starting to experience increasing defoliation. Likewise, 1 week beyond the last weekly application, those plots are also seeing increasing defoliation.

It appears that in this trial, residual activity of *Btt* began to decrease sharply 7 days post the previous application. Residual activity is often linked to environmental conditions. The trial site was irrigated and 2021 was a drought year, resulting in more frequent irrigation events. One of the standard factors responsible for decreasing residual activity is precipitation. Further, as the time period of the trial passed, the CPB population was getting older. As CPB mature, their feeding stimulates the development of mixed function oxidase enzyme systems used in the detoxification of insecticides. Basically, the older the beetles get, the harder they tend to be to kill with insecticides.

These data indicate that applications of *Bacilius Thuringiensis tenebrionis* with appropriate rates and timings can suppress CPB numbers, especially at younger stages.

4) Colorado Potato Beetle as potential vector of PVY - This research was funded with a Minnesota Dept. of Agriculture / USDA NIFA grant but preliminary results are presented for general information.

While larger cages in the PVY experiments were disrupted by a high velocity linear wind event (see Fig 6 in Procedures), smaller cages, better protected by soil and the crop canopy, were left undisturbed. At least one of the target plants from those small cages did have a weak PVY response to ImmunoStrip testing at the end of the trial. A weak test response on an ImmunoStrip may represent a false positive. All tubers from all plants in the cages were collected, however, and are currently being prepared for growout in the greenhouse. The resulting plants will be tested for PVY infection using ELISA.

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Northern Plains Potato Growers Association
Minnesota Area II Potato Research and Promotion Council

Title: Impact of Bannock seed age on yield components.

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Executive Summary:
The impact of seed physiological age of ND produced Bannock is being investigated. In 2021, three lots of Bannock tubers were collected from a ND field location. The potato lots were grown under the same field conditions with planting on April 17, 2021 and samples harvested on October 1, 2021. Immediately following harvest, samples were transported to the USDA lab in East Grand Forks. After suberization for three weeks at 95% RH and 12°C, tuber aging treatments were implemented to simulate contrasting storage degree days that will provide diverse physiological seed age. The impact of seed age on Bannock field growth parameters (emergence, stem number, tuber set, and yield) will be examined among a replicated 2022 field trial conducted at the Larimore, ND research field plot.

Rational:
In 2020, several concerns regarding certified Bannock seed produced in ND were observed: including delayed emergence, decreased stem number and decreased tuber set/yield. These field observations may be attributed to delayed physiological age resulting from the shortened growing season typical in ND production.

It is not uncommon to manipulate seed age through storage temperature treatment. Investigators in the Columbia Basin (*1*) reported that emergence, stem number, and tuber set/yield were significantly impacted by storage aging treatment. By manipulating and monitoring storage degree days prior to a 4°C holding temp, this research provided predictive models for both stem number and tuber set that could be incorporated by seed and process growers. The impact of aging treatment on Bannock ND production was initiated in 2021.

1) Knowles NR and Knowles LO. 2006. Manipulating stem number, tuber set, and yield relationships for Northern- and Southern-Grown Potato Seed Lots. Crop Sci. 46: 284-296.

Procedures:
Three bannock seed lots were grown in the same Oakes, ND field location in 2021. Field production followed standard ND commercial practices. For the purpose of this report, the bannock seed lots are identified as Sample A, B, and C. Additional information on seed lot history may be made available upon request. All samples were harvested on October 1st, 2021

and 1000# tote bags were transported immediately to the USDA laboratory in East Grand Forks, MN. Samples were suberized for three weeks at 95% RH, 12°C. After suberization, the samples were separated into duplicate 50 lb storage crates and storage degree day aging treatments (SDD) were implemented through adjustment of storage temperature and duration (Table 1).

Table 1. 2021-22 Storage treatments to create contrasting physiological age.

		Storage Phase					
	Tuber age[1]	Curing		Aging		Holding	
Trt #	(SDD >4°C)	°C	Day	°C	Day	°C	Date[2]
1	168	12	21	-	-	4	Oct-26
2	536	12	21	12	46	4	Dec-10
3	546	12	21	22	21	4	Nov-21
4	532	12	21	32	13	4	Nov-08
5	984	12	21	12	102	4	Feb-05
6	996	12	21	22	46	4	Dec-10
7	952	12	21	32	28	4	Nov-28

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

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

Three ranges in storage degree days were imposed in 2021-22; (168 SDD-seed age control -Trt 1, moderate aged 540 SDD- Trt 2-4, and oldest aged 980 SDD- Trt 5-7). Tubers in treatment 1 were immediately brought to a 4°C holding temperature following suberization. Additional seed aging treatments were imposed through a combination of increased temperature and contrasting storage duration. To provide supplemental heating for Treatments 3, 4, 6, and 7, crates were placed into separate cabinets and temperature set point (22 or 32°C) was maintained with a small room heater (Figure 1).

In the 2022 crop year, a replicated field trial will be conducted at the Hoverson' Farms research irrigation pivot, Larimore, ND. All seed treatments will be uniformly warmed and prepped prior to planting. Emergence notes, stem number, tuber set and yield will be recorded and presented at the NPPGA field day and VPG magazine publication.

Although only at mid-storage, several observations have been recorded and all lots (A, B, and C) are similar. No peeping has been observed in the control (Treatment 1, 168 SDD) and moderately aged samples (Treatment 2-4, 540 SDD). In contrast, the 900+ SDD aged samples had high frequency of peeping and small sprouts were observed (Treatment 5-7; Figure 3); with the largest and highest frequency of sprouting occurring in Treatment 5. The aging phase of treatment 5 was longest duration (102 day/ 12°C), where treatment 6 and 7 had warmer aging temperatures and shortened durations (Table 1). Additional sprouting notes will be collected prior to seed piece preparation.

Figure 1. Inside view of the 22°C incubator used for seed aging treatment #3 and #6. The 22°C temperature set-point was maintained with small room heater placed inside the incubator (top shelf). Similar storage conditions were achieved for a separate 32°C incubator (aging treatment #4 and #7 (not shown).

Figure 2. Bannock 'Lot A' treatments 1, 2, and 5; photo taken January 27th, 2022. The storage degree days (days > 4C) for Treatment 1, 2, and 5, are 168, 536, and 984 SDD, respectively.

Figure 3. Bannock 'Lot A' storage age treatments # 5, 6 and 7; photo taken January 27th, 2022.

Identifying Effective Cover Crops for Management of the Root-lesion Nematode, *Pratylenchus penetrans*

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Summary

Among many nematode pests of potato, root-lesion nematode, *Pratylenchus penetrans*, is one of the most important nematodes that causes significant economic damage. Additionally, expanded severity in tuber yield can be resulted due to the association of this nematode species with secondary pathogens. Nematicides are costly and detrimental to soil organisms and the environment. Cover crops that are non-hosts, poor hosts, or have bio-fumigation properties can be an economically effective and environmentally rational approach for management of *P. penetrans* in potato fields. Greenhouse trials were performed to confirm the host range of nine cover crops with distinct reactions to *P. penetrans* in our previous trials and to evaluate additional nine cover crops for host status and population reduction ability. One trial was conducted to confirm the host range of cover crops from our previous trials and two trials were conducted to evaluate additional cover crops using nematode infested soil. Experiments were arranged in a completely randomized design with five replications for each crop and control. Annual ryegrass (cultivar not stated), white proso millet and winter rye (Dylan) were confirmed as poor host, similar to one of our previous experiments whereas sunn hemp showed excellent hosting ability for *P. penetrans*. All cultivars of oilseed radish (Concorde, Control, and Image), turnip (Pointer), and forage oat showed good hosting ability to the nematode in the current experiment. All the additional cultivars of alfalfa and annual ryegrass reduced the nematode population displaying poor host range for the nematode. Alfalfa (FSG 527) reduced the greatest (average 74%) nematode population from the soil followed by annual ryegrass (Tetilia: 64%) from both trials. However, three cultivars of winter rye (Aroostook, Hazlet, and Rymin) consistently maintained the nematode population throughout the experiments with reproductive factor (Rf) values less than two. Susceptible potato (Red Norland) had good hosting ability to the nematode in all the trials. The tested cover crops with poor hosting ability have a great potential to be integrated into effective management strategies of the nematode in infested potato fields. This research will help potato farmers select better cover crops for managing *P. penetrans* in the fields to minimize the yield loss.

Background

The economic damage on crops caused by root-lesion nematodes (RLN, *Pratylenchus* spp.) ranks third behind root-knot nematode and cyst nematode (Castillo and Vovlas 2007). RLN are migratory endo-parasitic nematodes that are the most common nematode pests of potato (Brown et al. 1980). The infestation of these nematodes results in stress and weakness in potato plants and makes the plants more susceptible to secondary infection from fungal and bacterial pathogens. *Pratylenchus penetrans*, among many species of RLN, causes the greatest damage to potato (Lima et al. 2018, Waeyenberge et al. 2009). Approximately 30-70% potato yield losses occur due to the infestation of this species (Holgado et al. 2009, Philips 1995). Additionally, severe yield losses can be seen on potato when *P. penetrans* interacts synergistically with a fungal pathogen, *Verticillium dahlia* (Bowers et al. 1996, Rotenberg et al. 2004). The interaction causes potato early dying disease complex that results in significant reductions in tuber size and total marketable yield (Mahran et al. 2010). The damage threshold of *P. penetrans* to potato depends on cultivars and environmental factors (Orlando et al. 2020). Holgado et al. (2009) reported a damage threshold of 100 nematodes per 250 grams of soil with a negative correlation between plant growth and nematode population densities.

Different management strategies for controlling *P. penetrans* generally facilitate the reduction of the initial nematode population and the reproduction of the nematode during the growing seasons. Chemical control by using nematicide, despite being the best approach to manage the nematodes from infested fields, is expensive and poses a threat to human health, environment, and other non-target organisms (Haydock et al. 2013). Management of root-lesion nematodes using biological control agents has shown great potential, but their utilization is limited in agriculture (Stirling 2014). Due to the limitation of nematode resistance to very few crops (Davis and MacGuidwin 2014) and lack of recent research, the use of crop resistance for nematode management needs further research to be effectively utilized (Orlando et al. 2020). Similarly, crop rotation is challenging to employ for management because of the wide host range of this nematode.

The use of cover crops can provide an alternative means of nematode management. Many researchers have reported different potential mechanisms for nematode reduction by the cover crops from an infested field. Cover crops in the Brassicaceae family such as rapeseed, mustard, and radishes have been found to release glucosinolates that have biofumigant property and kill nematodes in the soil (Lord et al. 2011). Cover crops that are non-host and poor host reduce the nematode reproduction during the growing seasons. Cover crops that act as trap crops can help manage the nematodes from the infested field by trapping nematodes inside the roots and stimulating the hatching of nematode eggs, without allowing them to reproduce. Pudasaini et al. (2006) reported effective suppression of *P. penetrans* by French marigolds grown for 105 days, and average potato tuber yield significantly increased when followed marigolds (Kimpinski et al. 2000). However, the host range and nematode population reduction ability by cover crops from our region are not well studied.

In 2020, 25 cover crops species and cultivars were tested for their hosting ability and population reduction ability to *P. penetrans* in two greenhouse experiments. Alfalfa (Bullseye) consistently reduced the nematode population in both experiments showing poor hosting ability, but all other cover crops species and cultivars either maintained or increased the nematode population in at least one of the trials. Annual ryegrass (cultivar not stated) and winter rye (Dylan) reduced 60% and 32% of the initial population in one trial, but they maintained the nematode population in another trial. Additionally, seven more cover crop species showed distinct reactions in two trials. All other cover crops tested had similar reactions to *P. penetrans* infection in both trials. The alfalfa cultivar we tested consistently performed best in our trials against RLN. However, the highest number of nematodes per total root mass was observed in alfalfa cultivar Saranac (Miller 1978). Alfalfa cultivar Alpha was found to be a good host in a trial reported by Mbiro and Wesemael (2016). Hence, different cultivars of the same cover crop have shown distinct reactions to the nematode infection.

The objectives of this project were 1) to evaluate cover crop species/cultivars with distinct reactions to *P. penetran*s in our previous trials to confirm their hosting and population reduction abilities and 2) to evaluate additional cover crop species/cultivars to identity effective cover crops to manage *P. penetrans* in potato fields.

Materials and methods

Selection of cover crop species and cultivars

A total of 18 cover crops species and cultivars were selected based on our previous trials to determine their responses to *P. penetrans*. Nine cover crop species/cultivars, with distinct reactions to nematode in previous trials, were tested to ascertain their host range for nematode (Table 1). Nine cultivars of alfalfa, annual ryegrass and winter rye that have not been tested before were included to determine their response to *P. penetrans* infection (Table 2). Faba bean (Petite) showing the highest nematode reproduction and alfalfa (Bullseye) showing the lowest reproduction in our previous trials were included for comparison, and potato (Red Norland) and unplanted infested soil (fallow) were used as a positive and negative control, respectively. The cover crop seeds were acquired from Allied Seed (Nampa, ID), Forage and Biomass Crop Production Program (North Dakota State University, Fargo, ND), Great Northern AG (Plaza, ND), National Small Grains Collection (Aberdeen, ID), and Pulse USA (Bismarck, ND).

Inoculum preparation, soil processing, and nematode extraction

Pratylenchus penetrans was collected from an infested potato field in central Minnesota and the population was increased using a susceptible potato cultivar Red Norland in the greenhouse. Potato tubers were sprouted before planting. For pre-sprouting, tubers were spread in plastic trays with moist paper towels in the bottom and kept at room temperature for about two weeks. Sprouted tubers were cut into 2 to 3 pieces 3-4 days before planting to provide enough time for healing of cut sections.

Potato tubers were planted in plastic pots (20 cm × 15 cm, 1.5 kg soil capacity) and grown under controlled greenhouse conditions (16-hours daylight and an average temperature 22^{o}C) for ten weeks. A single piece of tuber was used per pot with the appropriate amount of soil in it. After harvesting, potato roots were separated from the soil and cleaned with tap water. Cleaned roots were cut into 1-cm pieces and used for nematodes extraction using Whitehead tray method

(Whitehead and Hemming 1965) for population maintenance and increase. Similarly, soil from all pots was mixed thoroughly and three soil samples were taken to extract nematodes using sugar centrifugal floatation method (Jenkins 1964). Nematodes were then identified and quantified under an inverted light microscope (Zeiss Axiovert 25, Carl Zeiss Microscopy, NY, USA). The infested soil was then mixed with pasteurized sandy soil to obtain enough soil for the experiments. Three subsamples were again taken after mixing the infested soil with pasteurized soil to determine the initial nematode population in the final soil mix. The mixed soil was then kept in a cold room at 4^{o}C to avoid changes in the nematode population until planting.

Greenhouse experiments

Two greenhouse trials were conducted to ascertain the host range of cover crops with distinct reactions in our previous trials and to evaluate more cover crops species/cultivars for managing *P. penetrans*. In the first trial, cover crops with distinct reactions in previous two trials were tested along with nine additional cultivars of alfalfa, annual ryegrass, and winter rye. In the second trial, only those nine cultivars of alfalfa, annual ryegrass, and winter rye were evaluated to confirm the host status and population reductions obtained in the first trial. The initial nematode populations were 2,125/kg of soil and 1,670/kg of soil in the first and second trials, respectively. The first and second trials were set up in May and October of 2021, respectively. A slow-release fertilizer (14-14-16 NPK) was mixed with soil before planting at the rate of 5 g per kg of soil. Each pot was filled with 1 kg of the soil before planting and pots were arranged in a completely randomized design (CRD) with five replications for each entry (treatment).

Seeds of cover crops were directly placed into the soil at 1-3 cm depth depending on the seed size, except potato, that was pre-sprouted before planting as described above. Emerged seedlings were then thinned out to an appropriate number per pot for each treatment (Table 1 and Table 2) after their establishment. Both trials were conducted in the Agriculture Experiment Station, NDSU greenhouse in controlled conditions (16-hours daylight and an average 22^{o}C) for 12 weeks. During termination of the trials, plant tops were removed, roots were separated from soil, and they were stored in a cold room at 4^{o}C in separate individual plastic bags until they were processed, and nematodes were extracted within a month.

Processing of soil and root samples, identification, and quantification of nematodes

The collected soil and root samples after the completion of trials were processed separately using different methods; the Whitehead tray method (Whitehead and Hemming 1965) was used for nematode extraction from roots whereas the sugar centrifugal floatation method (Jenkin 1964) was used for nematode extraction from soil samples. Entire available roots were used for Whitehead tray method while a subsample of 200 g soil was taken from the soil sample of each pot for sugar centrifugal floatation method. Extracted nematodes were stored in 50 ml suspension tubes until identification and quantification. After extraction, they were identified and counted using an inverted light microscope (Zeiss Axiovert 25). Nematodes population extracted from 200 g of soil were converted to the total number of *P. penetrans* in 1 kg of soil and nematode numbers obtained from roots of each plant (each pot) were added to the corresponding nematode number from soil to obtain the final nematode population in each pot.

Reproductive factor and host ability ratings

The reproductive factor (Rf) for each treatment was calculated by dividing the final nematode population density on the tested crop (nematodes from soil and roots) by the initial population density. The average Rf of nematodes for each treatment was calculated as a mean of Rf from five replications of the treatment. Five host groups including N = non-host (Rf < 0.15), P = poor host (Rf = 0.15 to 1.0), M = maintenance host (Rf = 1.0 to 2.0), G = good host (Rf = 2.0 to 4.0), and E = excellent host (Rf > 4.0) were designated based on the average Rf to determine the hosting ability of cover crops (Mbiro and Wesemael 2016, Schomaker et al. 2013).

Data analysis

The average final population densities and population reduction percentage (PRP) of nematodes in cover crops were analyzed using the SAS software (SAS 9.4, SAS Institute Inc. Cary, NC). The average final population density was determined by adding the average nematode population from the soil and roots from each pot. PRP was calculated using the formula [(initial nematode population density on a tested crop - mean final nematode population density on the tested crop)/initial nematode population density on the tested crop x 100]. The general linear model (GLM) with Tukey's honestly significant difference (HSD) mean separation at a significance level of 5% was used to determine the significant difference in the values of final nematode population density and PRP for the tested cover crops and controls.

Results and Discussion

As expected, Alfalfa (Bullseye) and faba bean (Petite), used for comparison, served as poor (Rf = 0.16) and excellent host (Rf = 13.40), respectively, in this trial (Table 3). Annual ryegrass (CNS) and winter rye (Dylan) continued to show poor hosting abilities to *P. penetrans* with Rf values smaller than one. The annual ryegrass reduced almost 70% of the initial population density from the soil, which ranked second after alfalfa (Bullseye) with the greatest population reduction (≈ 84%). Sunn hemp, on the other hand, increased the initial population density by almost eight-folds (Rf = 8.96) confirming its excellent hosting ability and its final nematode population (19,040) was significantly higher than the population (7,821) in susceptible check potato (Red Norland) (Table 3). All three cultivars of oilseed radish, turnip (Pointer), and forage oat served as good hosts in this trial despite their distinct reactions in the previous two trials. Oilseed radish cultivar Defender was found to be a good host for *P. penetrans* when it was assessed in the Michigan carrot production system (Grabau et al. 2017). Similarly, past research suggested similar host range of oat cultivars (Forge et al. 2000, Rudolph et al. 2017, Thies et al. 1995, Vrain et al. 1996). White proso millet reduced about 15% of the initial population in this trial suggesting poor host range for the nematode. However, it supported good reproduction of the nematode in one of the previous trials, suggesting that it has the potential to favor nematode reproduction under certain conditions.

None of the additional cultivars of alfalfa, annual ryegrass, and winter rye tested showed good hosting abilities to *P. penetrans* in our experiments (Table 4). All cultivars of alfalfa (FSG 527, Signature, and Vernal) and annual ryegrass (Gulf and Tetilia) reduced the initial nematode population density from the soil in both trials exhibiting poor host range. Alfalfa (FSG 527) had the greatest population reduction (84.94% in the first trial and 62.16% in the second trial) of *P. penetrans* among all the tested cover crops. Among four cultivars of winter rye tested, three cultivars (Aroostook, Hazlet, and Rymin) consistently maintained the initial nematode population (Rf < 2.0) throughout the experiments. Cultivar Wheeler also maintained the nematode population in the second trial, however, it reduced 33.04% of the initial nematode population from the soil in the first trial (Table 4). Alfalfa (FSG 527, Vernal) and annual ryegrass (Gulf, Tetilia) consistently reduced the nematode population greater than the unplanted control (fallow) throughout the experiments. All cultivars of the three cover crops tested had significantly ($P < 0.05$) lower final populations than the susceptible check potato (Red Norland) in both trials (Table 4).

Several previous studies have demonstrated varied responses of different cultivars of cover crops to *P. penetrans*. Alfalfa cultivar Baker was susceptible (Nelson et al. 1985) while cultivar MNGRN-16 was resistant (Peterson et al. 1991, Thies et al. 1995) to *P. penetrans*. All tested cultivars of alfalfa in our trials showed resistance to the nematode. Winter rye is the cover crop that can survive the winters in North Dakota, and it is one of the best soil covers in the spring. All cultivars of winter rye we tested maintained the initial nematode population when all the experiments were combined (Fig. 1). Winter rye is a good host in past studies for *P. penetrans* (Belair et al. 2002, Thies et al. 1995). Florini and Loria (1990) reported a reduction in *P. penetrans* population under field conditions in different winter rye cultivars including Aroostook, despite their good hosting ability in pot studies. Similarly, winter rye cultivar Wheeler supported good reproduction of nematodes in a greenhouse experiment but suppressed the population in field trials. It was also observed that Wheeler cultivar established well in the winter season and reduced the weeds that supported the growth of *P. penetrans* (Forge et al. 2000).

The susceptible check potato (Red Norland) increased the *P. penetrans* initial population by more than 200% in all trials conducted, suggesting conducive greenhouse environment and suitable soil conditions for the nematode reproduction. On the other hand, 37.41% and 28.44% of the initial nematodes were reduced by unplanted infested soil (fallow) at the end of the first and second trials, respectively (Table 4).

Conclusions

Different cover crop species/cultivars have been found to effectively manage root-lesion nematode from infested soil along with improvement of soil health. The management of root-lesion nematodes depends upon the hosting abilities of cover crops to nematode species. Nine cover crops with distinct reactions to *P. penetrans* in our previous experiments were tested to confirm their host status and nine additional cultivars of three cover crops, alfalfa, annual ryegrass, and winter rye, were also evaluated for suppression of the nematode under greenhouse conditions.

Annual ryegrass (CNS), white proso millet (CNS), and winter rye (Dylan) reduced the nematode population density, confirming their poor host range from one of our previous experiments. Sunn hemp supported excellent reproduction of *P. penetrans* while all cultivars of oilseed radish (Concorde, Control, and Image), turnip (Pointer), and forage oat (CNS) showed good hosting ability to the nematode infection in the experiment conducted during this reporting period. In contrast, all cultivars of alfalfa and annual ryegrass we tested showed poor host range and were able to reduce the initial nematode population. Alfalfa (FSG 527) reduced 74%, the highest percentage of nematode population among the cover crops tested from combined experiments. Winter rye cultivars maintained the nematode population with Rf values ranging from 1.0 to 2.0 based on the combined data of all the experiments. The cover crops with poor hosting ability can be potentially utilized in the infested field for managing *P. penetrans*. Furthermore, the cover crops with maintenance host range may be evaluated under field conditions to determine their ability to manage this important root-lesion nematode species.

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Table 1. List of cover crops with distinct reactions in our previous trials and controls to confirm their host status to the root-lesion nematode, *Pratylenchus penetrans* under controlled greenhouse conditions.

Crop (Cultivar or Cultivar Not Stated = CNS)	Scientific Name	Family	No. of Plants Per Pot
Alfalfa (Bullseye)	*Medicago sativa* L.	Fabaceae	4
Annual ryegrass (CNS)	*Lolium multiflorum* L.	Poaceae	2
Faba bean (Petite)	*Vicia faba* Roth	Fabaceae	2
Forage oat (CNS)	*Avena sativa* L.	Poaceae	2
Oilseed radish (Concorde)	*Raphanus sativus* L.	Brassicaceae	1
Oilseed radish (Control)	*Raphanus sativus* L.	Brassicaceae	1
Oilseed radish (Image)	*Raphanus sativus* L.	Brassicaceae	1
Potato (Red Norland)	*Solanum tuberosum*	Solanaceae	1
Sunn hemp (CNS)	*Crotolara juncea* L.	Fabaceae	1
Turnip (Pointer)	*Brassica rapa subsp. rapa* L.	Brassicaceae	1
White proso millet (CNS)	*Panicum miliaceum L*	Poaceae	2
Winter rye (Dylan)	*Secale cereale* L.	Poaceae	2
Unplanted infested soil	-	-	-

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

Crop (Cultivar)	Scientific Name	Family	No. of Plants Per Pot
Alfalfa (FSG 527)	*Medicago sativa* L.	Fabaceae	4
Alfalfa (Signature)	*Medicago sativa* L.	Fabaceae	4
Alfalfa (Vernal)	*Medicago sativa* L.	Fabaceae	4
Annual ryegrass (Gulf)	*Lolium multiflorum* L.	Poaceae	2
Annual ryegrass (Tetilia)	*Lolium multiflorum* L.	Poaceae	2
Potato (Red Norland)	*Solanum tuberosum*	Solanaceae	1
Winter rye (Aroostook)	*Secale cereale* L.	Poaceae	2
Winter rye (Hazlet)	*Secale cereale* L.	Poaceae	2
Winter rye (Rymin)	*Secale cereale* L.	Poaceae	2
Winter rye (Wheeler)	*Secale cereale* L.	Poaceae	2
Unplanted infested soil	-	-	-

Table 3. Mean final nematode population densities, reproductive factor (Rf), population reduction percentage (PRP), and host ranking of cover crops[u] with distinct reactions in previous trials and controls to the root lesion nematode, *P. penatrans* in the greenhouse trial conducted during this reporting period.

Crop (Cultivar or Cultivar Not Stated = CNS)	Rankings from previous trials		Host ranking from current trial (Trial 1)[v]			
	First	Second	Population[w]	Rf[x]	Host ranking[y]	PRP[z]
Alfalfa (Bullseye)	P	P	344 d	0.16	P	83.81 a
Annual ryegrass (CNS)	M	P	646 d	0.30	P	69.6 a
Faba bean (Petite)	E	E	28,468 a	13.40	E	-1239.67 d
Forage oat (CNS)	M	G	7,752 c	3.65	G	-264.80 b
Oilseed radish (Concorde)	G	P	4,611 cd	2.17	G	-116.99 ab
Oilseed radish (Control)	G	M	4,284 cd	2.02	G	-101.60 ab
Oilseed radish (Image)	G	M	6,206 cd	2.90	G	-192.05 ab
Potato (Red Norland)	G	G	7,821 c	3.68	G	-268.05 b
Sunn hemp (CNS)	M	E	19,040 b	8.96	E	-796.00 c
Turnip (Pointer)	G	M	4,526 cd	2.13	G	-112.99 ab
White proso millet (CNS)	P	G	1,832 cd	0.86	P	13.79 ab
Winter rye (Dylan)	M	P	1,809 cd	0.85	P	14.87 ab
Unplanted infested soil	-	-	1,330 cd	0.63	-	37.41 ab
MSD[*]			6,702			315.4
Pr > F			<0.0001			<0.0001

[u] These cover crops were tested to confirm their host range against *P. penetrans*. They had distinct reactions to the nematode in previous trials.

[v] Trial was initiated in May 2021 with the initial nematode population density of 2,125 *P. penetrans*/kg of soil

[w] Mean final population density is the mean of final population densities of nematodes from five replications of each treatment and was obtained by adding total nematode population from roots and total nematode population from 1 kg soil in a single experimental unit (pot). Mean final population densities with same letters are not significantly different ($P < 0.05$).

[x] Rf (Reproductive factor) is the mean reproductive factor of five replications for each treatment and was calculated by dividing the final population density of *P. penetrans* in the tested crop cultivar by the initial population density of the nematode.

[y] Host range was based on the categorization of reproductive factors into five classes: N = non-host (Rf < 0.15), P = poor host (Rf = 0.15 to 1.0), M = maintenance host (Rf = 1.0 to 2.0), G = good host (Rf = 2.0 to 4.0), and E = excellent host (Rf > 4) (Mbiro and Wesemael 2016; Schomaker et al. 2013).

[z] Population reduction percentage (PRP) is the average of % reduction in nematode populations from five replications for each treatment. Nematode population reduction (%) = (initial population density on the tested crop - final population density on the tested crop)/initial population density on the tested crop x 100. PRP with the same letters are not significantly different ($P < 0.05$). Negative (-) PRP indicates nematode population increase in treatments.

[*] MSD= Mean significant difference.

Table 4. Mean final population densities, reproductive factor (Rf), population reduction percentage (PRP), and host ranking of additional cover crops[u] with controls tested against the root lesion nematode, *P. penatrans* in two greenhouse trials.

Crop (Cultivar)	First trial[v]				Second trial[v]			
	Population[w]	Rf[x]	Host ranking[y]	PRP[z]	Population	Rf	Host ranking	PRP
Alfalfa (FSG 527)	320 c	0.15	P	84.94 a	632 d	0.38	P	62.16 a
Alfalfa (Signature)	655 bc	0.31	P	69.18 ab	1,243 cd	0.74	P	25.57 ab
Alfalfa (Vernal)	930 bc	0.44	P	56.54 ab	1,085 cd	0.65	P	35.03 ab
Annual ryegrass (Gulf)	507 c	0.24	P	76.14 a	1,126 cd	0.67	P	32.58 ab
Annual ryegrass (Tetilia)	427 c	0.20	P	79.91 a	881 d	0.53	P	47.25 a
Potato (Red Norland)	7,821 a	3.68	G	-268.05 c	5,759 a	3.45	G	-244.85 d
Winter rye (Aroostook)	3,744 b	1.76	M	-76.19 b	2,770 bc	1.66	M	-65.87 bc
Winter rye (Hazlet)	3,384 bc	1.56	M	-55.91 ab	1,800 bcd	1.08	M	-7.78 abc
Winter rye (Wheeler)	1,423 bc	0.67	P	33.04 ab	2,319 bcd	1.39	M	-38.86 abc
Winter rye (Rymin)	3,384 bc	1.59	M	-59.25 ab	3,220 b	1.93	M	-92.81 c
Unplanted infested soil	1,330 bc	0.63	-	37.41 ab	1,195 cd	0.72	-	28.44 ab
MSD*	3,109			146.29	1,727			103.43
Pr > F	<0.0001			<0.0001	<0.0001			<0.0001

[u] Additional cultivars of cover crops (alfalfa, annual ryegrass and winter rye) were tested to find effective cover crops against *P. penetrans*.

[v] Trial 1 and trial 2 were initiated in May 2021 and October 2021 with the initial nematode population density of 2,125 and 1,670 *P. penetrans*/kg of soil, respectively.

[w] Mean final population density is the mean of final population densities of nematodes from five replications of each treatment and was obtained by adding total nematode population from roots and total nematode population from 1 kg soil in a single experimental unit (pot). Mean final population densities with same letters are not significantly different ($P < 0.05$).

[x] Rf (Reproductive factor) is the mean reproductive factor of five replications for each treatment and was calculated by dividing the final population density of *P. penetrans* in the tested crop cultivar by the initial population density of the nematode.

[y] Host ranking was based on the categorization of reproductive factor values into five classes: N = non-host (Rf < 0.15), P = poor host (Rf = 0.15 to 1.0), M = maintenance host (Rf = 1.0 to 2.0), G = good host (Rf = 2.0 to 4.0), and E = excellent host (Rf > 4) (Mbiro and Wesemael 2016; Schomaker et al. 2013).

[z] Population reduction percentage (PRP) is the average of % reduction in nematode populations from five replications for each treatment. Nematode population reduction (%) = (initial population density on the tested crop - final population density on the tested crop)/initial population density on the tested crop x 100. PRP with the same letters are not significantly different ($P < 0.05$). Negative (-) PRP indicates nematode population increase in treatments.

[*] MSD= Mean significant difference.

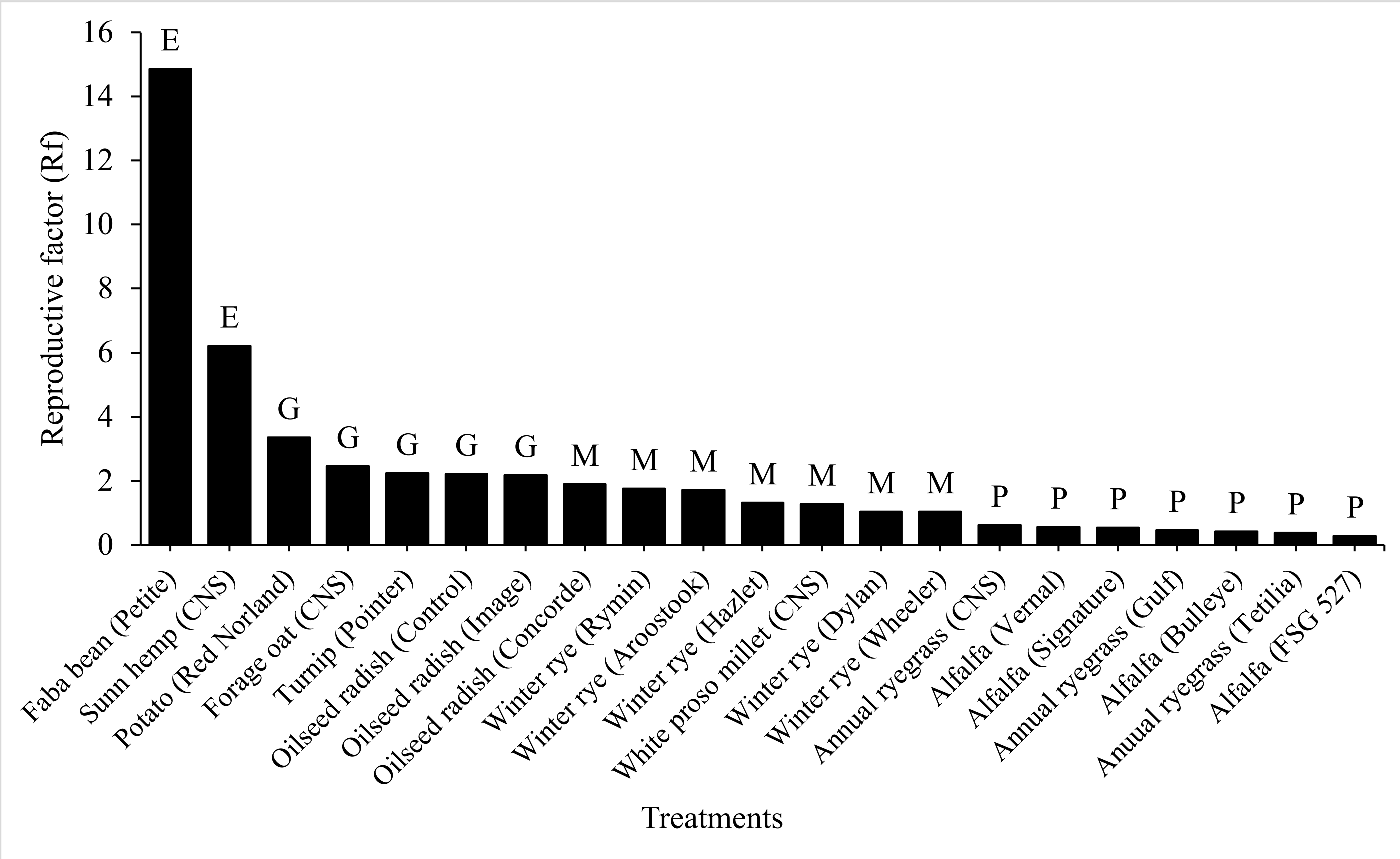

Fig. 1. Host status of all the cover crops included in this report based on the average reproductive factor (Rf) from the entire experiments. Rf is the mean reproductive factor for each crop cultivar from the entire experiments and refers to the final population density of *Pratylenchus penetrans* in the tested cultivar divided by the initial population density of the nematode. CNS = cultivar not stated. Host status was based on the categorization of Rf values into five classes: N = non-host (Rf < 0.15), P = poor host (Rf = 0.15 to 1.0), M = maintenance host (Rf = 1.0 to 2.0), G = good host (Rf = 2.0 to 4.0), and E = excellent host (Rf > 4) (Mbiro and Wesemael 2016; Schomaker et al. 2013).

Data Report for UMN Potato Breeding Program 2021

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Legacy Material

Aim: Although potato breeding has a long history at the University of Minnesota the continuity of the program was interrupted by the unexpected passing of Dr. Christian Thill, the previous breeder, in August of 2014. A team, including Dr. Asunta Thompson, Spencer Barriball, and Peter Imle, stepped in to select clones to be maintained in the program. These approximately 60 clones were maintained by the interim breeder, Dr. Thomas Michaels. Due to limitations in program resources, all clones were grown repeatedly at the Sand Plains Research Farm (SPRF) in Becker MN. In the summer of 2017, when the breeding program came under new management, all of the clones exhibited clear visual indications of multiple diseases. This disease load made evaluation of the clones impossible at that juncture.

Great effort and expertise went into the selection of these legacy clones over the previous 17 years. Presumably, these clones exhibit a range of desirable traits. Examination of four late stage clones from the Thill breeding program which were maintained by collaborators, and therefore had cleaner seed available, demonstrates the potential value of these legacy clones. For example, MN13142, which was maintained by Dr. Sanjay Gupta and Dr. Carl Rosen in the Soil Science department, is a dual purpose russet with impressive dormancy (can be stored at 50°F without CIPC for over 9 months), thick skin and a desirable shape. Peter Imle maintained 3 clones: MN12009PLWR-02R, MN12054PLWR-02R, and MN12054PLWR-03R, at Pine Lake Wild Rice. All of these clones exhibit skin color comparable to Dark Red Norland. We hypothesize that other legacy clones may exhibit similar desirable traits, which should be explored.

Even if none of the legacy clones become varieties, they should be considered as parents. Genotyping studies on the National Fry and Chip Processing Trials (NFPT and NCPT, respectively) suggest that although the US breeding programs work closely together and share material, they still maintain distinct germplasm. Our genotyping efforts confirm that UMN germplasm is distinct. It is probable that UMN clones may contain desirable haplotypes, alleles, and phenotypes, not present in other breeding programs. The pattern of genetic distinctness between programs highlights the importance of evaluating the UMN legacy material.

Between 2017 and 2019 we used anti-viral tissue culture to produce disease free plantlets of legacy clones. We eliminated 25 clones through preliminary phenotyping (pink eyes etc.), genotyping (identified duplicates), and data from regional trials prior to 2014. We genotyped all the remaining legacy material to look for PVY resistance and verticillium wilt resistance genes. In 2020 we produced G1 seed at the North Central Research and Outreach Center (NCROC).

Methods: We harvested G1 seed from Grand Rapids and tested it for PVY using ELISAs in the winter on 2020-2021. That seed was then planted in 15 hill plots with 1 ft spacing at our trial location at the Sand Plains Research Farm (SPRF) in Becker Minnesota. Legacy varieties were split by market class (reds, chips, and russets) so they would receive appropriate amounts of nitrogen. Red Norland, Dark Red Norland, and Red LaSoda were used as checks for the red potatoes. Atlantic, Snowden, and Lamoka were used as checks for the chippers. Russet Norkotah, Russet Burbank, and Goldrush were used as checks for the russets. Vines were desiccated after 114 days for the red potatoes and 127 days for processors. Tubers were harvested 3 weeks after vine desiccation and taken to the Potato Storage Research Facility in East Grand Forks for grading. Specific gravity was taken by weighing a ten tuber sample in air and water. Additionally tubers were planted as part of our seed increase at the North Central Research and Outreach Center (NCROC) in Grand Rapids MN in 20 hill plots with 1 ft spacing. Vines were desiccated after 100 days and tubers were harvested 3 weeks later.

Results: We were able to evaluate 24 of the 35 legacy clones in the field this summer. The 11 we don't have data for we were unable to evaluate due to dormancy or seed loss due to virus. We evaluated 2 chipping clones both of which were round and attractive but one of which was eliminated due to low specific gravity. MN12138WB-01C only yielded 58% of Lamoka but that could in part be due to the difference between G1 seed and certified commercial seed, so we will grow it again with G2 seed in 2022.

We planted 19 red legacy lines. Four did not yield enough for evaluation and will be replanted with G2 tubers next year. Of the lines we evaluated, ten did not make shape and quality standards, and two exhibited very low yield.

Table 1. Red Legacy Selections

Clone	Yield[1]
Red LaSoda	298
MN12028WW-01R	311
MN13007PLWR-02R	399
MN12006WW-01R	424
Red Norland	557
Dark Red Norland	560

[1] oz/15 hills

The legacy russets were the most promising clones. All seven out yielded Russet Norkotah and four out yielded all three checks. Additionally all seven had higher specific gravity than Gold Rush and Russet Norkotah and four had higher specific gravity than all three checks. However, one clone was eliminated due to irregular shape and knobs.

Table2. Russet Legacy Selections

Clone	Yield[1]	Specific Gravity	Resistances
Russet Norkotah	344	1.055	
MN11026WB-07Rus	380	1.064	
MN13101PLWR-02Rus	491	1.056	
MN13072PLWR-01Rus	494	1.068	
Goldrush	621	1.054	
Russet Burbank	636	1.060	
MN12088PLWR-02Rus	686	1.058	
MN13085PLWR-01Rus	749	1.067	
MN14029W-01Rus	1249	1.065	PVY

[1] oz/15 hills

Conclusions: We confirmed our hypothesis that some of the legacy material remaining from Dr. Thill's breeding program would be promising selections. We will be moving forward with one chip, three reds, and six russets. We will also use these clones in our crossing block in the winter of 2022. In 2022 we will perform replicated trials and generate seed for entry into regional and national trials.

Nitrogen Timing

Aim: At the research planning meeting this fall growers identified nitrogen efficiency as a crucial target for our breeding program. We've been working on nitrogen efficiency especially in red potatoes since we restarted the breeding program in 2017. In 2017 and 2018 we grew eleven of the red legacy clones and two checks at two nitrogen (N) levels to assess N use efficiency[1]. Although we did not observe a clone specific response, we did see an effect of N on quality traits including lightness. We also found that selecting for NUE in low N environments may reveal genotypes that had a more static N response in varying N environments. Further, we found that response to selection was possible and breeding for improved NUE in red potatoes is an achievable breeding objective.

We hypothesized that the lack of clone specific response was in part due to the extreme difference in the two N rates. Therefore in 2018 and 2019 we grew a smaller number of red legacy clones at five nitrogen rates[2]. Skin color and yield were affected by N rate in a genotype specific manner. These results were encouraging to us by suggesting we can select for potato breeding lines that yield well with good quality at reduced N levels.

Timing of N application has been shown to effect N efficiency in potatoes[3]. We proposed to test generally if the response to the timing of N application is clone specific in red fresh market potatoes, and specifically identify the ideal N rate and timing for our legacy clones with sufficient seed.

Methods: Three replications of eight clones were planted at the University of Minnesota's Sand Plains Research Farm (SPRF), on May 11, 2021 in three row plots. Each row contained 15 plants with 1 ft spacing. The clones planted were Chieftain, Dark Red Norland, Pontiac, and the five legacy lines MN12006WW-01R, MN13025PLWR-08R, MN13026PLWR-02R, MN14006W-01R, and MN14022W-01R. A starter fertilizer rate of 45 lbs/A was applied to all plots just prior to planting. All plots received a total of 90 lb/A of total N. For 1/3 of the plots N was applied pre-plant and 1 week later. For 1/3 of the plots, N was applied pre-plant, one week later and at emergence, For the remaining plots N was applied pre-plant, one week later, at emergence and at tuber bulking. All N applied after pre-plant was applied over the top of the center row. Plots were vine-killed on August 23, and harvested on September 7. Harvested tubers were then graded by the Agray tuber grader at the USDA potato research facility in East Grand Forks MN providing yield and size distribution data. Finally, Tubers were returned to Saint Paul to be analyzed with our TubAR image analysis protocol, providing skin, color, and shape data[1-2]. Skin color is measured using a Lab color scheme meaning that it can be broken down into redness (red vs. green) and lightness (white vs. black)[4]. Data was analyzed in R using ANOVAs and LSDs.

Results: Clone significantly contributed to all traits but oversized yield (Table 3). Timing of N addition primarily effected yield of smalls, with two post planting N applications boosting yield over both one and three applications. We saw no evidence of significant clone specific response to N application.

Table3. Significance table from ANOVA analysis of N timing experiment.

Phenotype	Clone	N applications	Interaction
Total yield	p<0.05	NS	NS
<4 oz yield	p<0.001	p<0.05	NS
4-6 oz yield	p<0.001	NS	NS
6-10 oz yield	p<0.001	NS	NS
>10 oz yield	NS	NS	NS
Lightness	p<0.001	NS	NS
Redness	p<0.001	NS	NS
Roundness	p<0.001	NS	NS

The highest yielders were Pontiac, MN13025PLWR-08R, MN12006WW-01R, and MN14006W-01R (Figure 1). This pattern was consistent for both mediums and larges suggesting marketable tubers are driving yield. However while Pontiac had the lightest tubers MN13025PLWR-08R, MN12006WW-01R, and MN14006W-01R had the darkest (Figure 2) and all the legacy lines tested were redder than the checks (Figure 3). The vast majority of lines were equally round with MN13025PLWR-08R and MN13026PLWR-02R being less round.

Figure 1. Total yield by genotype N timing experiment

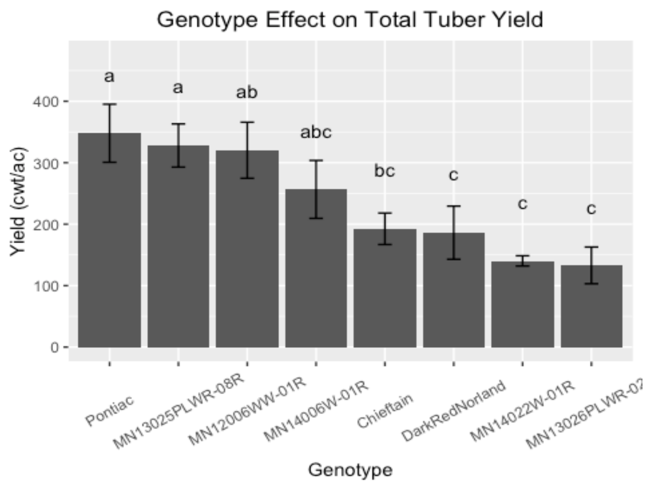


Figure 2. Lightness by genotype N timing experiment

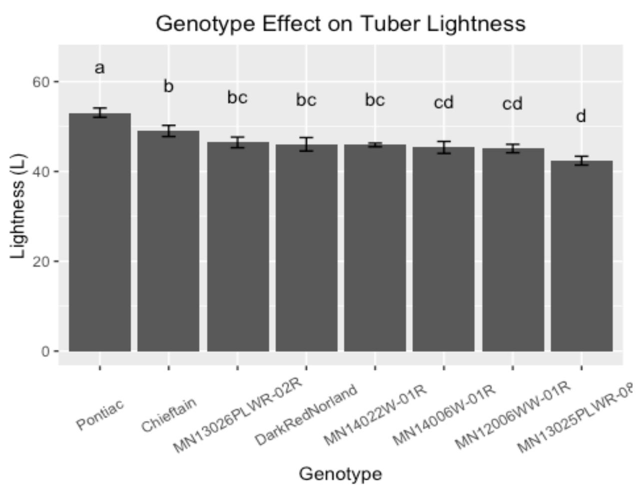
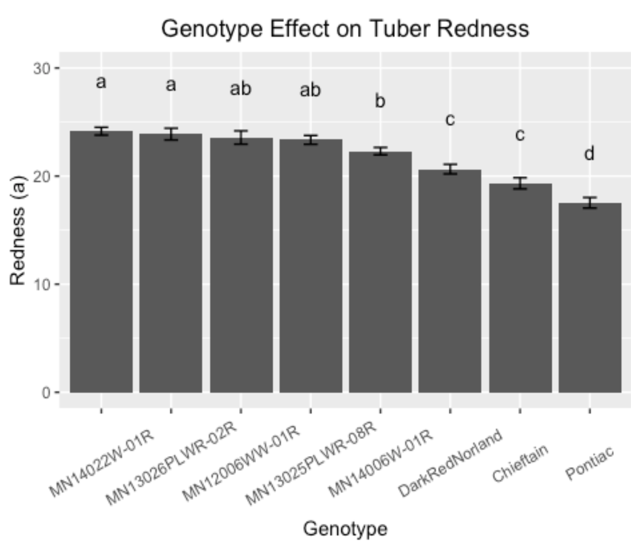


Figure 3. Redness by genotype N timing experiment



Conclusion: While clones differ in their N requirements, our preliminary results suggest that ideal N application timing is consistent across clones. However, we only have data from a single year and other environmental conditions (like a particularly dry summer) could have reduced real effects. Also, one year is a relatively small sample size which reduces our power to detect effects. We plan to repeat the experiment next year to confirm our results.

This experiment also let us collect additional data on some of our red fresh market legacy clones three of which outperformed the checks by most measures.

Generation of Germplasm

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

Potatoes are highly heterozygous, meaning that even a cross between two high performing cultivars largely produces plants with no or low 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. 2021 marks the fourth field season of the re-vamped Minnesota Potato Breeding Program. The fourth field year is the first one in which we have sufficient seed to perform replicated yield trials at our trial site in Becker MN.

Methods:

FY1

We planted 26,000 single hills the majority of which were provided to us by collaborators at University of Maine, North Dakota State University, Texas A&M University, and the University of Colorado. Of the single hills planted, 36% were russets, 34% were reds, 22% were chips, and 8% were specialty. All single hills were planted at the NCROC and selected using visual selection.

FY2

We evaluated 278 FY2 clones this year in 12-hill plots. Of these clones, 51% were chips, 28% were russet, 15% were red, and 6% were specialty. All clones were planted at the NCROC and selected using visual selection. Additionally, post-harvest we collected quantitative measures of: specific gravity, internal defects, chip/fry color, tuber shape, tuber color, and skin set, for each selected clone. This was accomplished at the USDA potato storage research facility in East Grand Forks.

In order to test specific gravity, we took a sample of ten tubers per clone which were weighed on a balance while suspended in the air in a mesh bag. The sample was then weighed while suspended in a sink containing about ten liters of tap water. Specific gravity was calculated as SG = weight in air /(weight in air – weight in water).

Chipping and russet potatoes were analyzed separately for chip/fry color. For the chipping potatoes, each potato in the sample was then 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 three times to provide three 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 pneumatic piston forced the potato into the cutting grid cutting the potatoes into 9.0 x 21.0 mm planks. The planks were notched at the bud end, blotted dry, then fried at 190° C for 3.5 minutes.

Both chip and fry samples were photographed in a light box for visual evaluation. After photographing the chip samples were crushed by hand to a consistency of about 1.0 cm per "crumble". These samples were then assessed in a Hunterlab analyzer which quantifies "darkness".

Additionally a different subset of 10 tubers were arranged 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[4]. Image analysis was performed in-house using the R software with the EBImage[5] package to acquire skinning, shape, and skin color data as described in Jones et al.[1] and Stefaniak et al.[2]. These tubers were cut in half and internal defects were counted.

FY3

Our preliminary yield trials in Becker MN included 182 individuals grown in 15-hill plots. These clones were: 38% russets, 34% chips, 15% reds and 13% yellows. Red Norland, Dark Red Norland, and Red LaSoda were used as checks for the red potatoes. Atlantic, Snowden, and Lamoka were used as checks for the chippers. Russet Norkotah, Russet Burbank, and Goldrush were used as checks for the russets. Vines were desiccated after 114 days for the red potatoes and 127 days for processors. Tubers were harvested 3 weeks after vine desiccation. They were graded to obtain yield and size profile data in addition to repetition of the phenotyping for FY2. They were genotyped using KASP technology from Intertek for two sources of PVY resistance (RYsto and RYadg) and Verticillium wilt resistance (Ve2). These three genes were chosen as targets for selection, due to the availability of low cost genotyping technology. Additionally 57 of the chipping clones were evaluated in 8-hills North Carolina as part of the Early Generation Southern Strategy Trial.

FY4

This was our first year of replicated field trials. They took place in Becker MN and included 84 individuals grown in two 15-hill plots at full N and two 15-hill plots at 45% N. The full N plots were the same as for FY3 so that for each market class FY3, FY4 and the checks were grown in a partially replicated randomized design. The clones were 55% chips, 18% reds, 14% yellows, and 13% russets. They were phenotyped as above. Many of these clones were also grown in North Dakota, Wisconsin, and Michigan as part of the North Central Regional Trial and one was entered into the National Chip Processing Trial.

Results:

FY1

We selected 3.44% of the individuals over all to move forward in the program to year 2, resulting in 894 clones to be evaluated in 12 hills in 2022.

FY2

We selected 39.6% of the clones, resulting in 110 clones to be evaluated in preliminary yield trials in 2022.

FY3

We selected 34% of FY3 based on grading and genotype data to continue in the program, for 50 individuals which will be evaluated as FY4 in summer 2022. We selected eight chipping potatoes (Table 1) which were also evaluated in North Carolina as part of the EGSS. The mean specific gravity from our selections was 1.072, higher than both Lamoka and Snowden. The mean yield for our selections was 110.8% of Atlantic yield.

Table 2. 2021 FY3 Chipping Selections (NAs indicate unmeasured phenotypes)

Clone	Yield MN[1]	SG MN	Yield NC[2]	SG NC	Vert	PVY
MN19TX18093-1	1178.29	1.073	1.21	NA	No	No
MN19AF6866-16	1105.88	1.071	9.10	1.056	No	No
MN19TX18304-1	942.63	1.077	12.13	1.060	No	No
MN19TX18054-2	908.29	1.074	2.26	NA	No	No
MN19TX18120-1	890.46	1.068	1.82	NA	No	No
Atlantic	799.76	1.075	4.74	1.064	NA	NA
Snowden	738.56	1.071	6.71	1.066	NA	NA
MN19AF6866-14	721.74	1.069	0.76	NA	Yes	No
MN19AF6866-12	699.02	1.071	10.44	1.060	No	No
MN19AF6892-9	643.20	1.074	6.13	1.070	No	Yes
Lamoka	616.09	1.068	NA	NA	NA	NA

1 oz/15 hills
2 kg/8 hills

We selected 23 russets (Table 2). All selections out yielded Russet Norkotah and had specific gravity higher than Russet Norkotah and Goldrush. Two selections have the genetic marker for verticillium wilt resistance but none have either known marker for PVY resistance.

Table 3. 2021 FY3 Russet Selections (NAs indicate unmeasured phenotypes)

Clone	Yield[1]	SG	Vert
MN19AOR16065-1	866.31	1.065	No
MN19CO17021-3	830.29	1.061	No
MN19AOR16061-2	806.08	1.061	No

MN19CO17044-2	785.62	1.074	Yes
MN19AOR16059-1	746.07	1.065	No
MN19CO17072-5	740.73	1.068	No
Russet Burbank	636.34	1.060	NA
Goldrush	620.69	1.054	NA
MN19AOR16123-7	587.43	1.070	Yes
MN19CO17074-3	583.91	1.058	No
MN19AOR16091-1	575.34	1.064	No
MN19CO17074-5	536.29	1.058	No
MN19CO17072-4	533.85	1.065	No
MN19AOR16034-2	533.39	1.058	No
MN19AOR16038-2	513.95	1.057	No
MN19AOR16065-9	458.29	1.059	No
MN19AOR16059-2	452.78	1.061	No
MN19CO17066-1	431.66	1.063	No
MN19CO17056-1	427.07	1.065	No
MN19AF7015-2	425.96	1.057	No
MN19CO17074-2	422.49	1.059	No
MN19AOR17031-3	422.31	1.071	No
MN19CO17246-2	416.30	1.061	No
MN19AOR17020-9	410.52	1.066	No
MN19AOR16061-7	401.10	1.056	No
Russet Norkotah	343.99	1.055	NA

1 oz/15 hills

We selected nine red skinned white flesh potatoes (Table 3). All selections were visually attractive with dark red skin, low skinning, and round or oval shape. The average yield was 90.9% of Red Norland but 169.7% of Red LaSoda.

Table 4. 2021 FY3 Red Selections (NAs indicate unmeasured phenotypes)

Clone	Yield[1]	Vert
MN19ND1759-2	698.27	No
MN19TX17731-2	568.38	No
Dark Red Norland	560.40	NA
Red Norland	557.23	NA
MN19ND1759-1	531.16	No
MN19AF6933-4	442.35	No
MN19ND1756-1	409.13	No
MN19AF6933-5	379.99	No
MN19ND14342-3	360.55	Yes
MN19ND14339C-1	312.88	No
MN19AF6933-6	302.99	No

Red LaSoda	298.35	NA
MN19AF6933-9	291.82	No
MN19ND14384-1	260.36	No

1 oz/15 hills

We selected nine yellow skin and yellow flesh clones (Table 4) we grew both types of fresh market potatoes, red and yellow, in a single block and so the checks for the yellow selections were red fresh market potatoes. The mean yield for the selections was 106.7% of Red Norland and all clones were higher yielding than Red LaSoda. The highest yielding clone is PVY resistant and the second highest yielding clone is verticillium wilt resistant.

Table 5. 2021 FY3 Yellow Selections(NAs indicate unmeasured phenotypes)

Clone	Yield	PVY	Vert
MN19AF6945-3	935.04	Yes	No
MN19TX18206-7	902.98	No	Yes
MN19AF6945-5	619.04	No	No
MN19TX17722-3	563.01	No	No
MN19TX18240-1	561.87	No	No
Dark Red Norland	560.40	NA	NA
Red Norland	557.23	NA	NA
MN19TX18336-1	547.15	No	No
MN19AF6945-4	499.98	No	No
MN19TX18240-2	405.64	No	No
MN19TX18195-1	315.94	No	No
Red LaSoda	298.35	NA	NA

FY4

We selected 46% of FY4 based on grading and genotype data to continue in the program, for 26 individuals which will be evaluated as FY5 in summer 2022. We selected ten chipping potatoes (Table 5) which were evaluated at Becker in 2020 and 2021. Selections for which we had sufficient seed were also evaluated in North Carolina in 2020 as part of EGSS and in Wisconsin and Michigan in 2021. It is important to note that plots in different years at different locations are different sizes and measured in different units, it is most informative to look comparatively within year and location rather than at actual numbers. All selections beat at least one check in each location for both yield and specific gravity.

Table 5. 2021 FY4 Chipping Selections (NAs indicate unmeasured phenotypes)

Clone	Yield MN 2021	SG MN 2021	Yield MN 2020	SG MN 2020	Yield NC 2020 (% Atlantic)	SG NC 2020	Yield WI 2021	SG WI 2021	Yield MI 2021	SG MI 2021	PVY	Vert
MN18AF6728-7	1228.50	1.068	14183.86	1.067	NA	NA	NA	NA	NA	NA	No	No
Atlantic	799.76	1.075	20877.9	1.064	100	1.079	510	1.085	461	1.088	NA	NA
MN18W17052-4	783.95	1.082	17052.83	1.063	NA	NA	489	1.098	334	1.098	No	No
MN18W17043-17	761.32	1.069	27820.32	1.067	83	1.077	520	1.085	472	1.084	No	No

MN18W17039-25	755.44	1.069	14567.36	1.060	NA	NA	403	1.087	349	1.088	No	No
MN18W17043-2	745.75	1.072	13200.62	1.067	103	1.079	NA	NA	NA	NA	Yes	No
Snowden	738.56	1.071	NA	NA	NA	NA	528.5	1.081	406.5	1.087	NA	NA
MN18W17065-4	731.52	1.063	19025.25	1.061	NA	NA	NA	NA	NA	NA	Yes	Yes
MN18W17039-5	711.17	1.072	25534.5	1.070	NA	NA	550	1.084	475	1.080	Yes	No
MN18W17037-33	698.46	1.070	18307.29	1.067	94	1.069	NA	NA	NA	NA	Yes	No
MN18W17043-3	694.29	1.065	18788.31	1.068	NA	NA	NA	NA	NA	NA	Yes	No
MN18TX17748-2	617.31	1.068	31447.29	1.068	NA	NA	NA	NA	NA	NA	No	No
Lamoka	616.09	1.068	NA	NA	NA	NA	501	1.084	399	1.081	NA	No

We selected 3 russets (Table 6) which were evaluated at Becker in 2020 and 2021. Two were also evaluated in WI and MI. In general, we required selections to outperform at least one check in each environment. However, although MN18W17091-5 did not perform well in WI it was a standout clone in MN and met requirements in MI and so we are choosing to move it forward.

Table 6. 2021 FY4 Russet Selections (NAs indicate unmeasured phenotypes)

Clone	Yield MN 2021	SG MN 2021	Yield MN 2020	SG MN 2020	Yield WI 2021	SG WI 2021	Yield MI 2021	SG MI 2021
MN18W17091-5	846.84	1.054	24914.56	1.057	476	1.074	380	1.072
Russet Burbank	636.34	1.060	NA	NA	595	1.077	482	1.072
Goldrush	620.69	1.054	NA	NA	530	1.071	366	1.070
MN18W17091-9	584.57	1.062	24914.56	1.054	NA	NA	NA	NA
MN18W17079-11	459.19	1.065	23438.13	1.061	525	1.079	391	1.079
Russet Norkotah	343.99	1.055	12115.16	1.052	546	1.069	350	1.073
Lakeview Russet	NA	NA	NA	NA	561	1.074	NA	NA
Plover Russet	NA	NA	NA	NA	623	1.067	NA	NA
Silverton Russet	NA	NA	NA	NA	597	1.070	NA	NA

We selected four red skinned white flesh potatoes (Table 7). All selected clones are attractive, dark red, with minimal skinning. Although one of the four has PVY resistance none of them have verticillium wilt resistance.

Table 7. 2021 FY4 Red Selections (NAs indicate unmeasured phenotypes)

Clone	Yield MN 2021	Yield MN 2020	Yield WI 2021	Yield MI 2021	PVY
MN18W17026-2	938.04	19804.11	745	540	No
MN18W17026-4	650.94	8356.02	NA	NA	No
MN18CO15083-6	598.70	12688.67	647	605	Yes
Dark Red Norland	560.40	NA	452.5	301.5	NA
Red Norland	557.23	19972.58	540	352.5	NA
MN18CO15117-4	482.14	14732.10	NA	NA	No
Red LaSoda	298.35	NA	478	289	NA

We selected four yellow skin and yellow flesh clones (Table 8) we grew both types of fresh market potatoes, red and yellow, in a single block and so the checks for the yellow selections were red fresh market potatoes.

Table 8. 2021 FY4 Yellow Selections(NAs indicate unmeasured phenotypes)

Clone	Yield MN 2021	Yield MN 2020	Yield WI 2021	Yield MI 2021	Vert
MN18TX17760-4	732.95	38636.2	NA	NA	No
MN18TX17730-8	618.19	8929.47	411	426	No
Dark Red Norland	560.40	NA	452.5	301.5	NA
Red Norland	557.23	19972.58	540	352.5	NA
MN18CO16154-9	519.49	11411.85	450	441	Yes
MN18CO16212-3	344.66	20570.85	NA	NA	No
Red LaSoda	298.35	NA	478	289	NA

Conclusions: We have developed multiple generations of new germplasm that segregate for a variety of traits of interest. This material will continue to be evaluated, in 2022 and beyond, in order to identify promising new clones for Minnesota and North Dakota growers.

Variety Release

Some of the advance material inherited by the breeding program, from Dr. Thill has provided our team with outreach opportunities that we have pursued through Minnesota Department of Agriculture funding. The impetus of these opportunities has arisen from unsolicited feedback our team has received from growers regarding two specialty clones, MN04844-07Y (white skin, yellow flesh), and MN07112 (purple and white skin and flesh). These two clones have found favor with growers and home chefs in northern MN. In fact seed growers in MN and ND have been selling seed of these clones since about 2015. In order for these clones to continue to be sold by seed growers they need to be formally released by the Minnesota Agriculture Experiment Station. In an effort to have these clones formally released, and therefore make it possible for growers to continue to sell their seed, we have attempted to trial them at SPRF and at an organic farm in Hugo, MN.

Another legacy variety we have worked with over the past several years is MN13142, a long dormancy russet with attractive shape, thick skin, and resistance to PVY and *P. nicotianae*. Although results from the National Fry Processing Trial were mixed, reports from organic growers in the South West were promising. Therefore, we included MN13142 in the organic trial as well.

Unfortunately, we were unable to generate enough seed to trial MN04844. However, MN07112 yielded statistically equivalent to Yukon Gold, both in organic production and conventional. MN13142 out yielded Russet Burbank in organic trials but not in conventional trials consistent with observations in industry trials. We have funding and plans to trial all three varieties again at SPRF and also at the farm of Kent Mason in Williams MN in 2022.

In an effort to introduce these clones to the twin cities region we held a tasting event at the Good Acre, in Saint Paul. We invited growers, school nutrition directors, and chefs. Attendance was modest due to the covid pandemic, but feedback for the clones was generally favorable. We will also display these clones at the Minnesota Fruit and Vegetable Marketers Expo, in Roseville, MN in February. We aim to release all three varieties in 2022.

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Simulated Hail Trial. Harlene Hatterman-Valenti and Collin Auwarter, North Dakota State University.

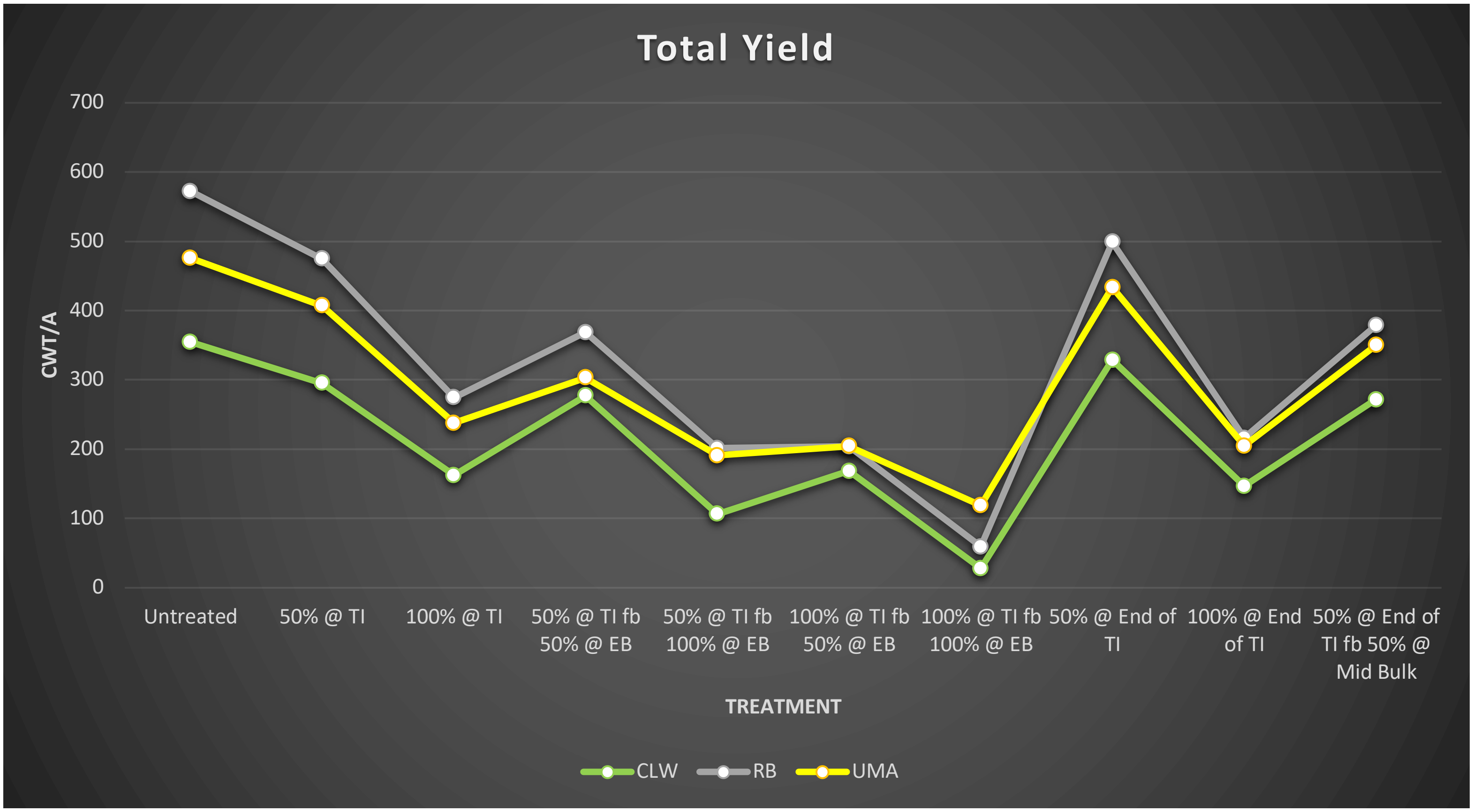
Field research was conducted at the Northern Plains Potato Growers Association irrigated research site near Inkster, ND to evaluate simulated hail damage on Clearwater, Russet Burbank, and Umatilla Russet potatoes. Plots were 4 rows by 20 feet arranged in a randomized complete block design with 4 replicates. Seed pieces (2 oz) were planted on 36-inch rows and 12-inch spacing on June 2, 2021. Extension recommendations were used for cultural practices throughout the year. The hail damage was simulated using a brush cutter with thermoplastic blades during tuber initiation (47 DAP), end of tuber initiation (57 DAP), early tuber bulking (76 DAP) and mid tuber bulking (90 DAP). The trial was desiccated September 21 (111 DAP) and September 30 (120 DAP). Potatoes were harvested October 21.

Our main priority is utilizing the middle 2 (Row 'A' and Row 'B') of the 4 rows while the outside rows we treat as border rows to protect the research conducted. Row 'A' when harvested, is dug and weighed in the field. Row 'B' is dug, bagged and the tubers are brought back to NDSU to be graded. A majority of our yield analysis comes from Row 'B'.

TRT #	TRT NAME	REP 1	REP 2	REP 3	REP 4
1	Untreated	101	202	308	410
2	50% Defoliated @ TI	102	205	303	407
3	100% Defoliated @ TI	103	201	306	409
4	50% Defoliated @ TI + 50% Defoliated @ EB	104	208	309	403
5	50% Defoliated @ TI + 100% Defoliated @ EB	105	210	304	402
6	100% Defoliated @ TI + 50% Defoliated @ EB	106	209	307	408
7	100% Defoliated @ TI + 100% Defoliated @ EB	107	203	305	404
8	50% Defoliated @ End of TI	108	207	301	406
9	100% Defoliated @ End of TI	109	206	310	401
10	50% Defoliated @ End of TI + 50% Defoliated @ Mid Bulk	110	204	302	405

Explanation of column results for Clearwater, Russet Burbank, and Umatilla Russet potato responses to simulated hail treatments.

Column 1 represents % foliage cover utilizing the Canapeo App (www.Canapeo.com).
Column 2 represents the total WEIGHT (pounds) that was harvested in Row 'A'.
Column 3 represents the total WEIGHT (pounds) that was harvested in Row 'B'.
Columns 4-8 represents WEIGHT (pounds) of tubers within respected sizes (0-4 oz, 4-6 oz, 6-8 oz, 8-12 oz, >12 oz) from Row 'B'.
Columns 9-15 represents CWT/A in the respected sizes converting Columns 3-8.
Columns 16-22 represents the COUNTS of tubers in the respected sizes from Row 'B'.



LEARWATER

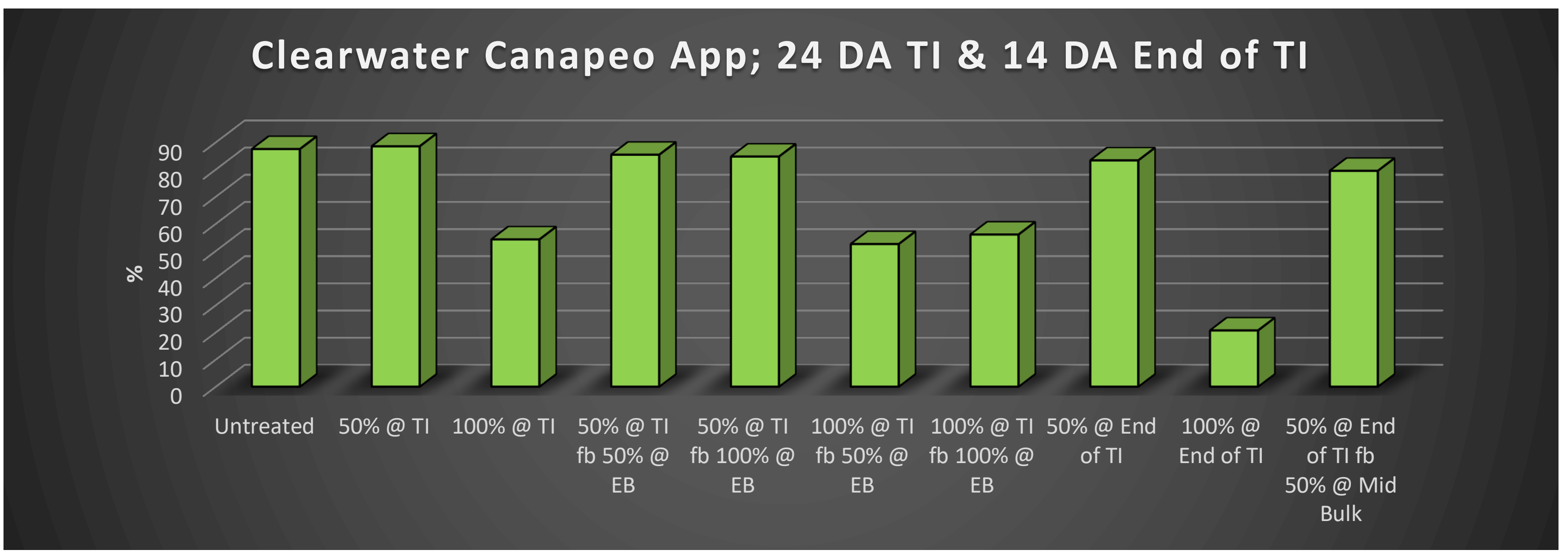
		Canapeo	ROW 'A'	ROW 'B'
		24 DA TI	TOTAL WT	TOTAL WT
		14 DA End of TI	20 FT	20 FT
TRT #	**TRT NAME**	**1**	**2**	**3**
1	Untreated	87.5 a	53.7 a	48.8 a
2	50% @ TI	88.5 a	44.0 b	40.7 bc
3	100% @ TI	54.2 b	29.5 d	22.4 d
4	50% @ TI + 50%@ EB	85.4 a	40.9 bc	38.2 c
5	50% @ TI + 100% @ EB	84.7 a	12.5 f	14.6 e
6	100% @ TI + 50% @ EB	52.5 b	23.1 e	23.2 d
7	100% @ TI + 100% @ EB	56.0 b	4.8 g	3.8 f
8	50% @ End of TI	83.3 a	44.1 b	45.2 ab
9	100% @ End of TI	20.7 c	21.6 e	20.2 d
10	50% @ End of TI + 50% @ Mid Bulk	79.5 a	38.1 c	37.4 c
	LSD (P=.05)	12.26	4.07	5.39

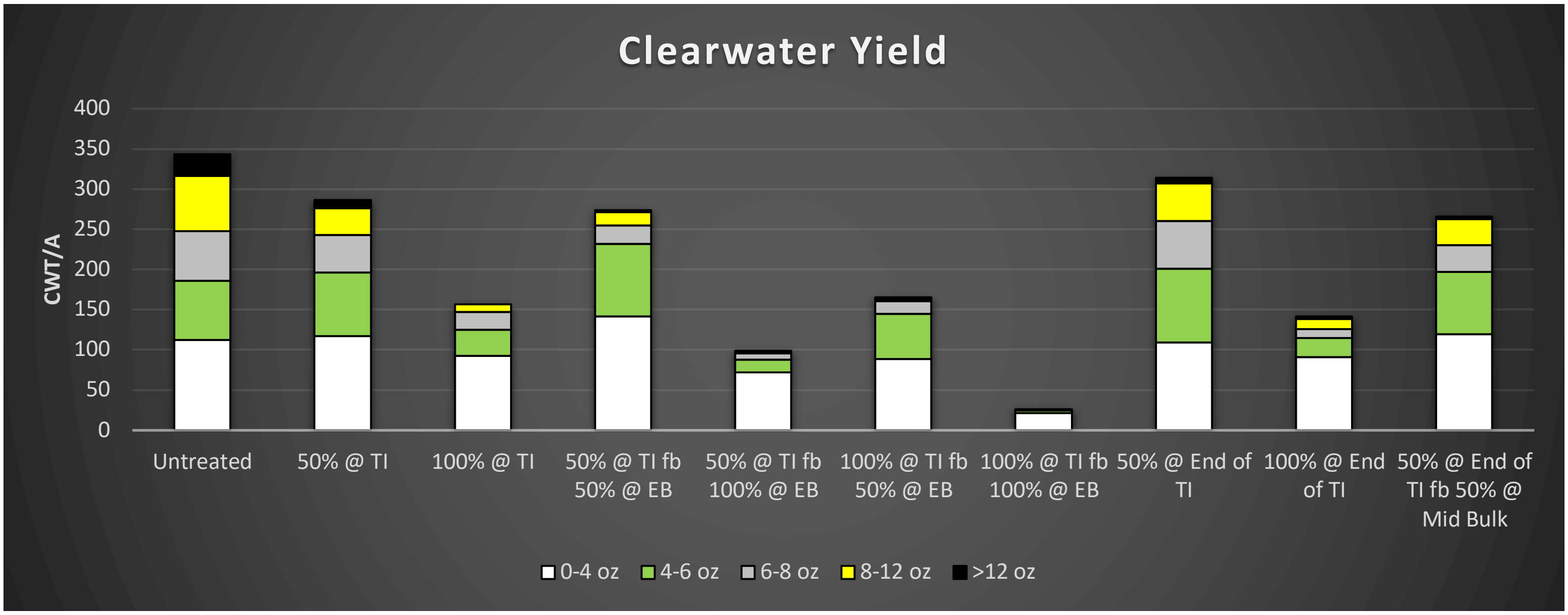
		ROW 'B'	ROW 'B'	ROW 'B'	ROW 'B'	ROW 'B'
		0-4 oz WT	4-6 oz WT	6-8 oz WT	8-12 oz WT	>12 oz WT
		20 FT	20 FT	20 FT	20 FT	20 FT
TRT #	**TRT NAME**	**4**	**5**	**6**	**7**	**8**
1	Untreated	15.5 ab	10.1 a	8.6 a	9.7 a	3.73 a
2	50% @ TI	16.2 ab	10.8 a	6.5 ab	4.8 bc	1.5 b
3	100% @ TI	12.7 ab	4.5 b	3.1 cd	1.5 cd	0.0 b
4	50% @ TI + 50%@ EB	19.5 a	12.5 a	3.1 cd	2.3 cd	0.5 b
5	50% @ TI + 100% @ EB	9.9 b	2.2 c	1.2 de	0.3 de	0.2 b
6	100% @ TI + 50% @ EB	12.2 ab	7.8 a	2.1 cde	0.4 de	0.4 b
7	100% @ TI + 100% @ EB	2.9 c	0.5 d	0.1 e	0.04 e	0.0 b
8	50% @ End of TI	15.0 ab	12.6 a	8.3 a	6.9 ab	1.2 b
9	100% @ End of TI	12.5 ab	3.3 bc	1.5 de	1.9 cd	0.5 b
10	50% @ End of TI + 50% @ Mid Bulk	16.4 ab	10.7 a	4.6 bc	4.6 bc	0.5 b
	LSD (P=.05)	2.94-5.55	0.71-4.34	1.91	0.78-3.81	1.24-1.99

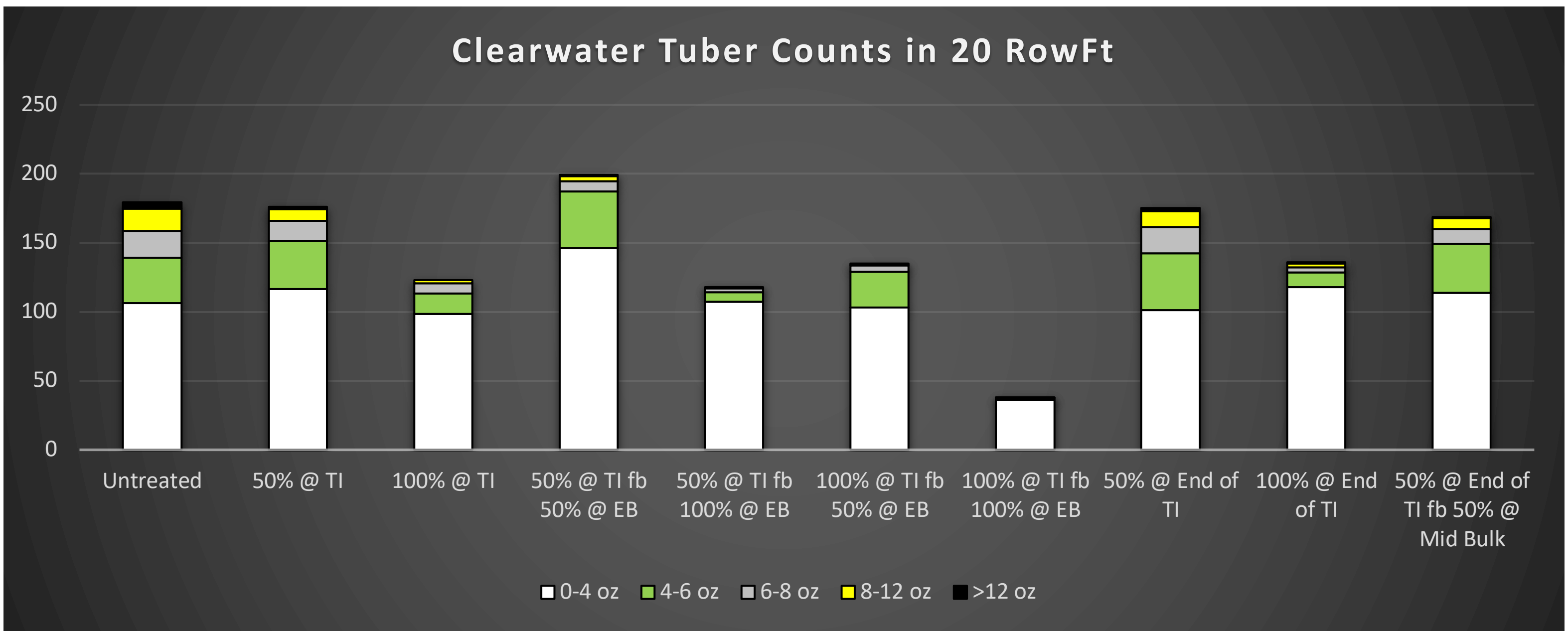
		ROW 'B'	ROW 'B'	ROW 'B'	ROW 'B'	ROW 'B'	ROW 'B'	ROW 'B'
		TOTAL	0-4 oz	4-6 oz	6-8 oz	8-12 oz	>12 oz	>4 oz

		CWT/A	CWT/A	CWT/A	CWT/A	CWT/A	CWT/A	CWT/A
TRT #	**TRT NAME**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
1	Untreated	354.6 a	112.5 ab	73.2 a	62.3 a	68.7 a	27.1 a	237.8 a
2	50% @ TI	295.3 bc	117.4 ab	78.6 a	46.8 ab	33.4 abc	9.8 b	176.1 b
3	100% @ TI	162.3 d	92.4 ab	32.4 bc	22.2 cd	9.3 cd	0.0 b	69.2 cd
4	50% @ TI + 50%@ EB	277.2 c	141.6 a	90.5 a	22.5 cd	16.6 abc	2.8 b	135.5 b
5	50% @ TI + 100% @ EB	106.3 e	72.1 b	15.3 d	8.6 de	1.9 e	0.9 b	33.2 de
6	100% @ TI + 50% @ EB	168.5 d	88.6 ab	56.5 ab	15.1 cde	3.0 de	2.2 b	79.5 c
7	100% @ TI + 100% @ EB	27.8 f	21.3 c	3.0 e	0.9 e	0.5 e	0.0 b	6.0 e
8	50% @ End of TI	328.4 ab	109.0 ab	91.7 a	59.9 a	46.4 ab	7.0 b	217.7 a
9	100% @ End of TI	146.8 d	90.9 ab	23.7 cd	11.1 de	12.9 bc	3.2 b	55.0 cd
10	50% @ End of TI + 50% @ Mid Bulk	271.3 c	119.2 ab	77.4 a	33.5 bc	32.7 abc	3.0 b	149.8 b
	LSD (P=.05)	39.14	20.58-40.48	3.20-41.17	13.85	2.57-43.99	8.54-16.76	34.38

		ROW 'B'	ROW 'B'	ROW 'B'	ROW 'B'	ROW 'B'	ROW 'B'	ROW 'B'
		TOTAL CT	0-4 oz CT	4-6 oz CT	6-8 oz CT	8-12 oz CT	>12 oz CT	>4 oz CT
		20 FT	20 FT	20 FT	20 FT	20 FT	20 FT	20 FT
TRT #	**TRT NAME**	**16**	**17**	**18**	**19**	**20**	**21**	**22**
1	Untreated	189.5 ab	106.3 a	32.9 a	19.5 a	16.2 a	4.3 a	74.3 a
2	50% @ TI	181.8 abc	116.3 a	35.1 a	14.8 ab	8.1 bc	2.0 b	60.8 b
3	100% @ TI	125.8 cd	98.5 a	14.7 b	7.3 cd	2.6 cd	0.0 b	26.0 cd
4	50% @ TI + 50%@ EB	200.3 a	145.9 a	41.6 a	7.3 cd	3.7 cd	0.8 b	54.0 b
5	50% @ TI + 100% @ EB	120.5 d	107.1 a	7.0 a	2.8 de	0.5 de	0.3 b	12.5 ef
6	100% @ TI + 50% @ EB	136.3 bcd	103.1 a	25.7 a	5.0 cde	0.7 de	0.5 b	32.5 c
7	100% @ TI + 100% @ EB	40.8 e	35.9 b	1.4 d	0.3 e	0.1 e	0.0 b	2.3 f
8	50% @ End of TI	179.8 abc	101.4 a	40.8 a	19.0 a	11.9 ab	2.0 b	75.0 a
9	100% @ End of TI	138.8 bcd	117.9 a	10.7 bc	3.5 de	3.1 cd	0.8 b	18.8 de
10	50% @ End of TI + 50% @ Mid Bulk	173.5 a-d	113.9 a	35.3 a	10.8 bc	7.9 bc	0.8 b	55.3 b
	LSD (P=.05)	38.33	18.18-48.48	1.54-16.43	4.5	1.30-6.17	1.71	10.77







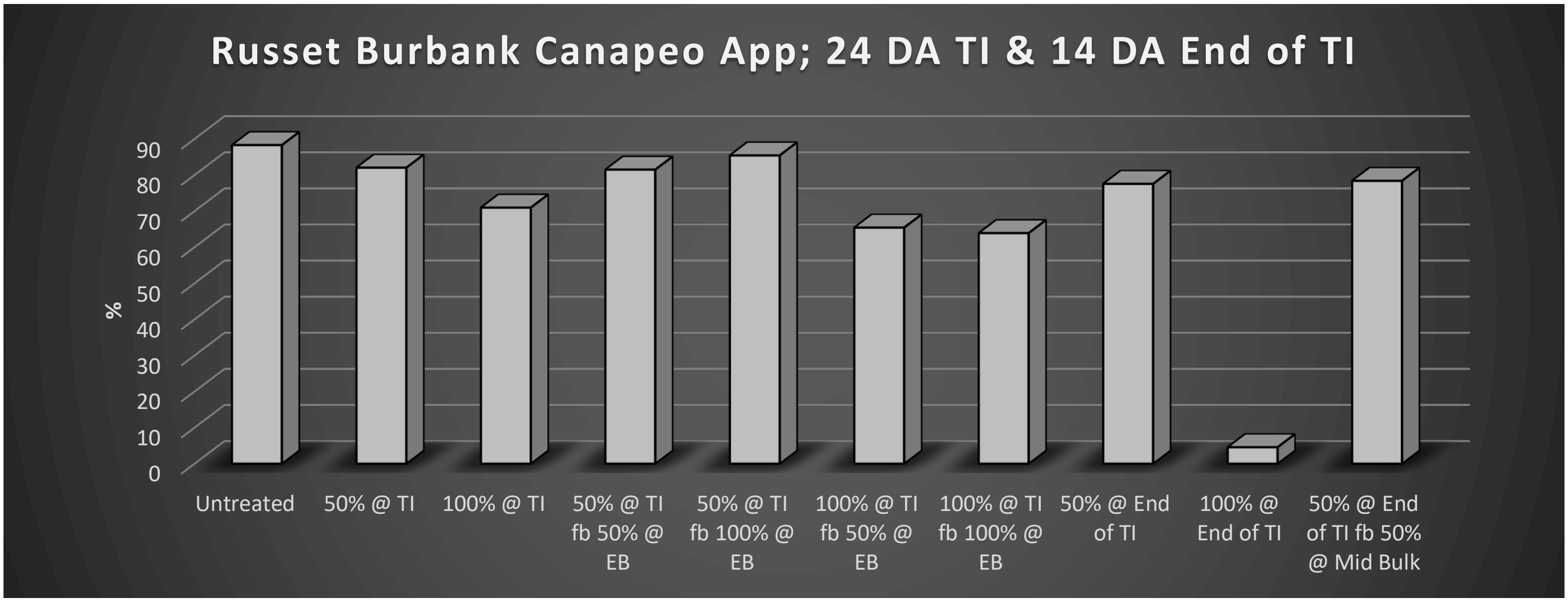
usset Burbank

		Canapeo	ROW 'A'	ROW 'B'
		24 DA TI	TOTAL WT	TOTAL WT
		14 DA End of TI	20 FT	20 FT
TRT #	**TRT NAME**	**1**	**2**	**3**
1	Untreated	88.3 a	78.7 a	78.8 a
2	50% @ TI	82.0 ab	65.7 bc	65.3 b
3	100% @ TI	70.9 bc	37.1 e	37.8 d
4	50% @ TI + 50%@ EB	81.5 ab	53.6 d	50.8 c
5	50% @ TI + 100% @ EB	85.4 a	28.3 ef	27.8 e
6	100% @ TI + 50% @ EB	65.4 c	31.1 ef	28.1 e
7	100% @ TI + 100% @ EB	63.9 c	10.5 g	8.2 f
8	50% @ End of TI	77.5 b	70.3 b	68.7 b
9	100% @ End of TI	4.5 d	26.1 f	29.7 e
10	50% @ End of TI + 50% @ Mid Bulk	78.4 ab	59.7 cd	52.1 c
	LSD (P=.05)	9.10	7.85	7.63

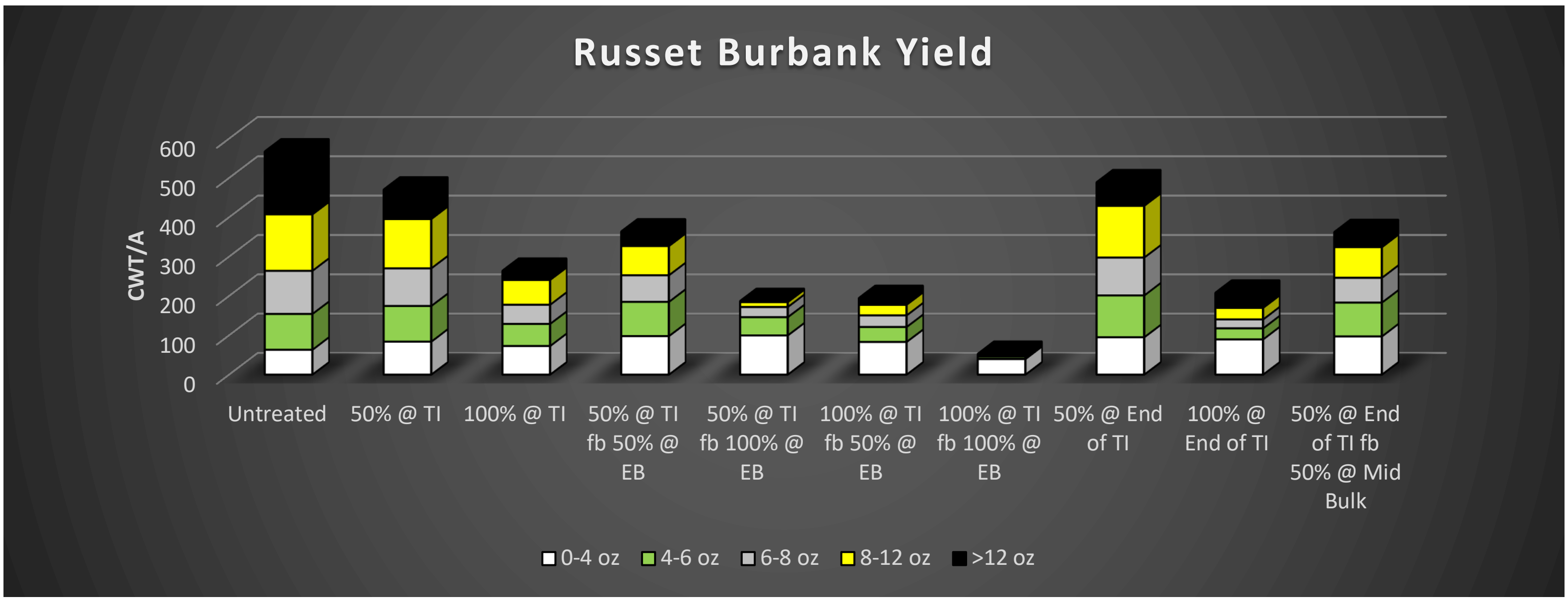
		ROW 'B'	ROW 'B'	ROW 'B'	ROW 'B'	ROW 'B'
		0-4 oz WT	4-6 oz WT	6-8 oz WT	8-12 oz WT	>12 oz WT
		20 FT	20 FT	20 FT	20 FT	20 FT
TRT #	**TRT NAME**	**4**	**5**	**6**	**7**	**8**
1	Untreated	8.7 a	12.6 ab	14.8 a	19.8 a	22.0 a
2	50% @ TI	11.5 a	12.5 ab	12.3 ab	17.4 ab	10.3 b
3	100% @ TI	10.0 a	7.8 bc	6.6 b	8.9 bc	3.4 cd
4	50% @ TI + 50%@ EB	13.5 a	12.0 ab	9.3 ab	10.4 abc	5.1 bcd
5	50% @ TI + 100% @ EB	13.7 a	6.4 c	3.3 c	2.5 de	0.4 ef
6	100% @ TI + 50% @ EB	11.4 a	5.3 cd	3.8 c	4.2 cd	2.3 de
7	100% @ TI + 100% @ EB	5.5 b	0.8 e	0.5 d	0.5 e	0.0 f
8	50% @ End of TI	13.1 a	14.7 a	13.2 ab	18.3 a	8.2 bc
9	100% @ End of TI	12.3 a	4.0 d	2.9 c	4.2 cd	5.3 bcd
10	50% @ End of TI + 50% @ Mid Bulk	13.4 a	11.8 ab	8.6 ab	11.4 ab	5.2 bcd
	LSD (P=.05)	3.17-4.04	0.69-4.28	0.82-5.59	2.18-7.02	2.04-6.66

		ROW 'B'	ROW 'B'	ROW 'B'	ROW 'B'	ROW 'B'	ROW 'B'	ROW 'B'
		TOTAL	0-4 oz	4-6 oz	6-8 oz	8-12 oz	>12 oz	>4 oz
		CWT/A	CWT/A	CWT/A	CWT/A	CWT/A	CWT/A	CWT/A
TRT #	**TRT NAME**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
1	Untreated	572.3 a	63.2 a	91.0 ab	109.8 a	143.5 a	159.5 a	507.7 a
2	50% @ TI	474.5 b	83.8 a	90.6 ab	95.7 4	125.5 a	74.4 b	390.5 b
3	100% @ TI	274.4 d	72.6 a	56.2 bc	48.8 bc	63.1 ab	23.0 cd	200.5 d
4	50% @ TI + 50%@ EB	368.6 c	97.9 a	87.0 ab	67.7 b	74.3 a	36.6 bcd	270.3 c
5	50% @ TI + 100% @ EB	201.4 e	99.6 a	46.4 c	25.9 cd	12.4 b	2.4 e	101.1 e
6	100% @ TI + 50% @ EB	203.9 e	83.0 a	38.1 cd	29.5 cd	26.9 ab	16.9 d	120.5 e
7	100% @ TI + 100% @ EB	59.3 f	39.7 b	5.9 e	4.6 d	2.4 c	0.0 e	18.7 f
8	50% @ End of TI	498.9 b	94.9 a	106.3 a	96.4 a	131.5 a	59.5 bc	401.9 b
9	100% @ End of TI	215.8 e	89.5 a	28.2 d	22.7 cd	29.3 ab	38.2 bcd	125.9 e
10	50% @ End of TI + 50% @ Mid Bulk	378.3 c	97.1 a	85.9 ab	63.2 b	77.9 a	37.9 bcd	276.5 c
	LSD (P=.05)	55.41	22.72-29.33	3.32-34.79	21.18	7.67-99.94	12.87-52.13	54.48

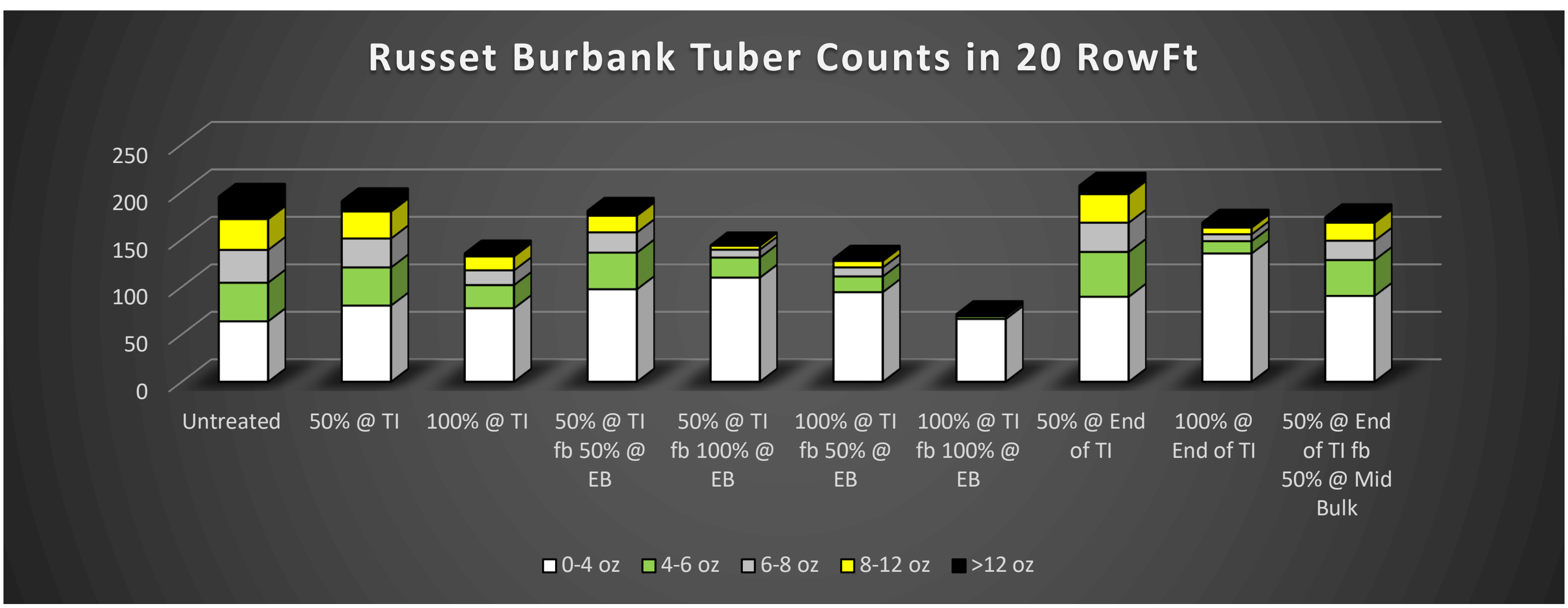
		ROW 'B'	ROW 'B'	ROW 'B'	ROW 'B'	ROW 'B'	ROW 'B'	ROW 'B'
		TOTAL CT	0-4 oz CT	4-6 oz CT	6-8 oz CT	8-12 oz CT	>12 oz CT	>4 oz CT
		20 FT	20 FT	20 FT	20 FT	20 FT	20 FT	20 FT
TRT #	**TRT NAME**	**16**	**17**	**18**	**19**	**20**	**21**	**22**
1	Untreated	198.3 ab	63.6 b	40.7 ab	34.5 a	32.5 a	23.6 a	132.8 a
2	50% @ TI	191.8 ab	80.2 ab	40.2 ab	30.5 a	28.4 a	10.9 b	111.0 b
3	100% @ TI	139 cd	77.4 b	24.4 bc	14.7 bc	14.7 bc	3.1 cd	59.5 d
4	50% @ TI + 50%@ EB	182.3 a-d	97.4 ab	38.6 ab	21.3 b	17.6 ab	5.2 bcd	84.0 c
5	50% @ TI + 100% @ EB	146.8 bcd	109.6 ab	21.2 c	8.3 cd	4.1 de	0.4 e	36.0 e
6	100% @ TI + 50% @ EB	132.3 d	94.3 ab	16.6 cd	9.5 cd	6.8 cd	2.4 d	36.8 e
7	100% @ TI + 100% @ EB	74.3 e	66.1 b	2.8 e	1.5 d	0.8 e	0.0 e	6.3 f
8	50% @ End of TI	214.5 a	89.5 ab	47.2 a	30.8 a	30.1 a	9.0 bc	119.5 ab
9	100% @ End of TI	170.8 a-d	135.1 a	12.9 d	7.3 cd	7.0 cd	5.2 bcd	34.3 e
10	50% @ End of TI + 50% @ Mid Bulk	185 abc	90.4 ab	37.8 ab	20.3 b	19.0 ab	5.8 bcd	84.8 c
	LSD (P=.05)	35.27	26.36-39.46	1.72-14.92	6.59	3.66-11.03	1.36-12.07	15.18



Russet Burbank Canapeo App; 24 DA TI & 14 DA End of TI
%
0
10
20
30
40
50
60
70
80
90
Untreated
50% @ TI
100% @ TI
50% @ TI fb 50% @ EB
50% @ TI fb 100% @ EB
100% @ TI fb 50% @ EB
100% @ TI fb 100% @ EB
50% @ End of TI
100% @ End of TI
50% @ End of TI fb 50% @ Mid Bulk



Russet Burbank Yield
CWT/A
0
100
200
300
400
500
600
Untreated
50% @ TI
100% @ TI
50% @ TI fb 50% @ EB
50% @ TI fb 100% @ EB
100% @ TI fb 50% @ EB
100% @ TI fb 100% @ EB
50% @ End of TI
100% @ End of TI
50% @ End of TI fb 50% @ Mid Bulk
0-4 oz
4-6 oz
6-8 oz
8-12 oz
>12 oz



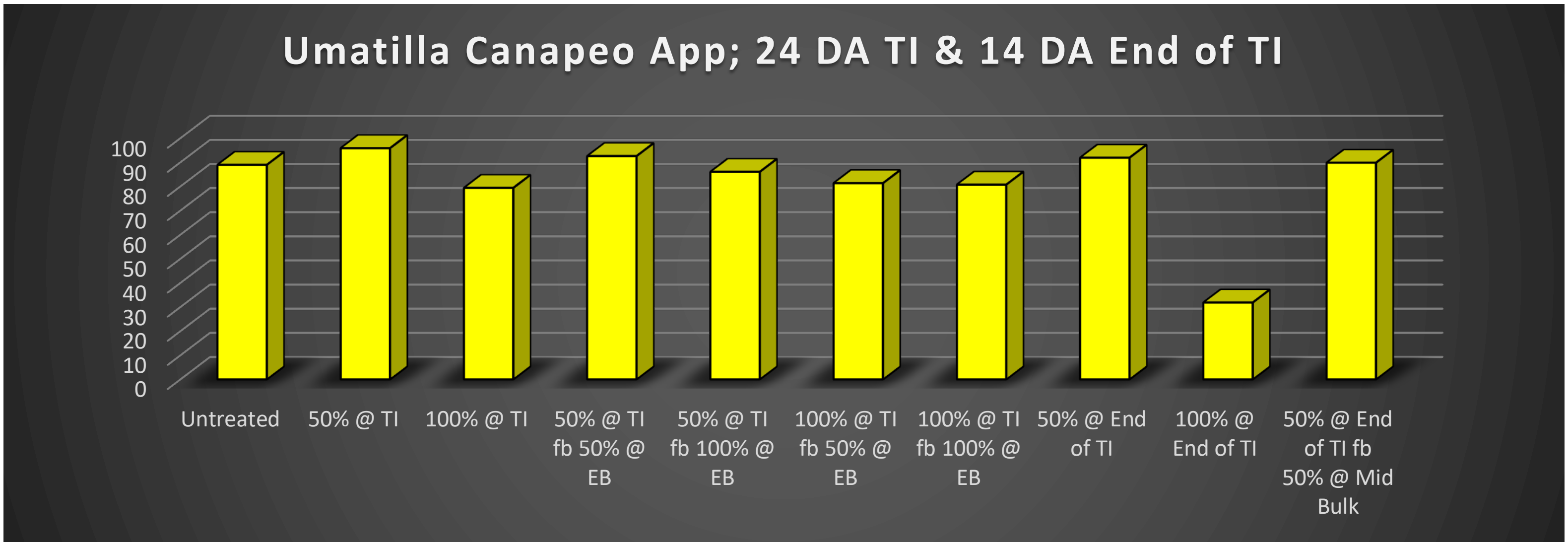
Russet Burbank Tuber Counts in 20 RowFt
0
50
100
150
200
250
Untreated
50% @ TI
100% @ TI
50% @ TI fb 50% @ EB
50% @ TI fb 100% @ EB
100% @ TI fb 50% @ EB
100% @ TI fb 100% @ EB
50% @ End of TI
100% @ End of TI
50% @ End of TI fb 50% @ Mid Bulk
0-4 oz
4-6 oz
6-8 oz
8-12 oz
>12 oz

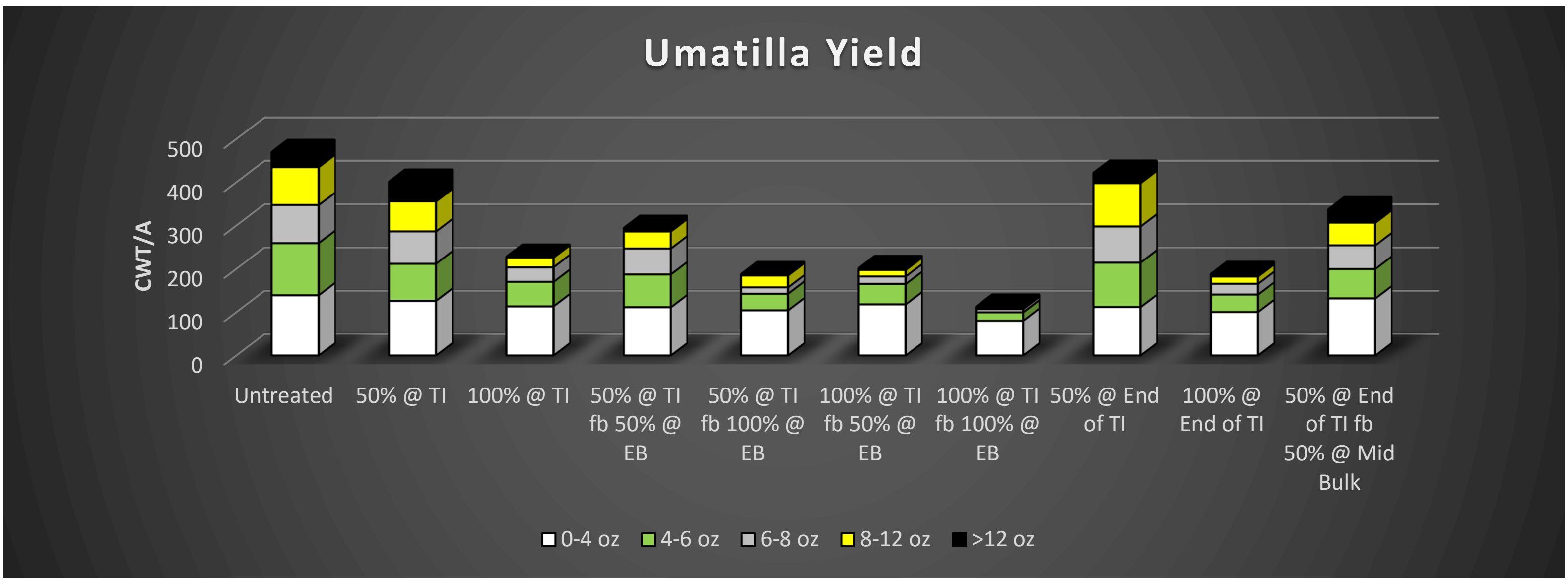
		Canapeo 24 DA TI 14 DA End of TI	ROW 'A' TOTAL WT 20 FT	ROW 'B' TOTAL WT 20 FT
TRT #	**TRT NAME**	**1**	**2**	**3**
1	Untreated	88.9 ab	65.3 a	65.5 a
2	50% @ TI	95.8 a	60.1 ab	56.0 ab
3	100% @ TI	79.4 b	37.4 d	32.71 de
4	50% @ TI + 50%@ EB	92.5 ab	47.5 c	41.74 cd
5	50% @ TI + 100% @ EB	86.0 ab	26.5 ef	26.3 e
6	100% @ TI + 50% @ EB	81.3 b	35.8 d	28.1 de
7	100% @ TI + 100% @ EB	80.7 b	19.6 f	16.3 f
8	50% @ End of TI	91.9 ab	56.5 b	59.7 a
9	100% @ End of TI	31.9 c	30.4 de	28.2 e
10	50% @ End of TI + 50% @ Mid Bulk	89.8 ab	46.8 c	48.2 bc
	LSD (P=.05)	9.11	7.18	9.27

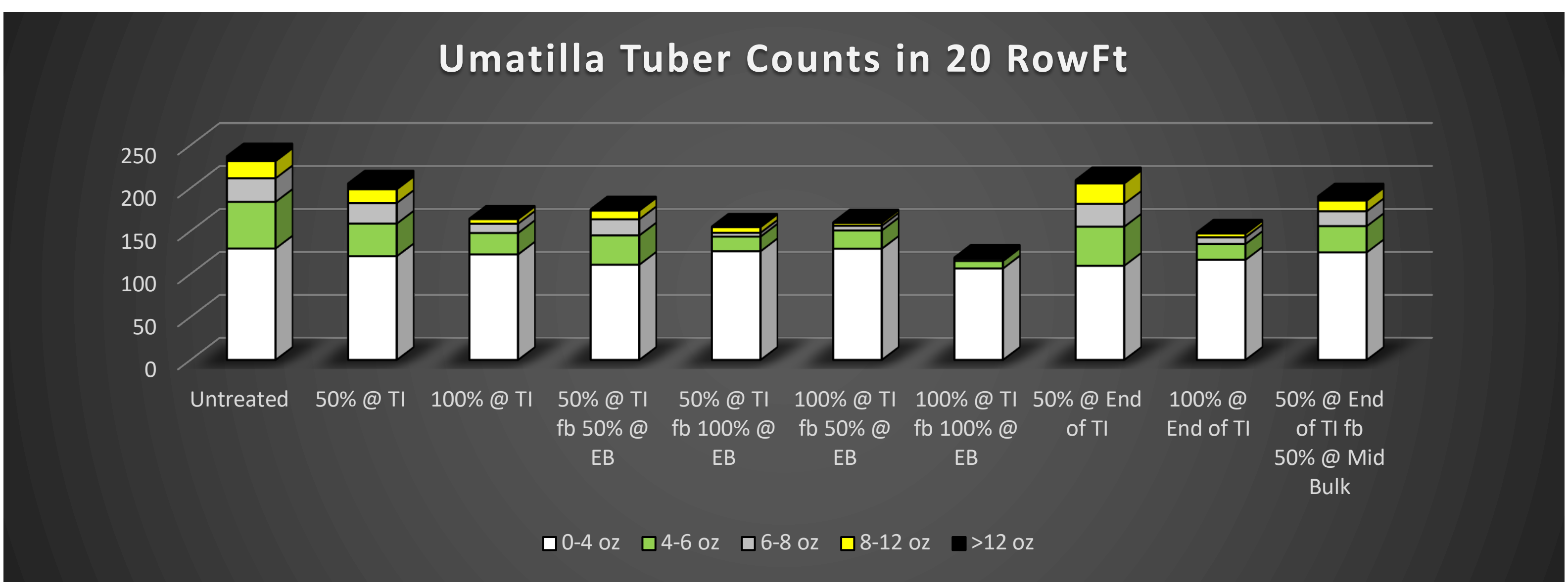
		ROW 'B' 0-4 oz WT 20 FT	ROW 'B' 4-6 oz WT 20 FT	ROW 'B' 6-8 oz WT 20 FT	ROW 'B' 8-12 oz WT 20 FT	ROW 'B' >12 oz WT 20 FT
TRT #	**TRT NAME**	**4**	**5**	**6**	**7**	**8**
1	Untreated	19.2 a	16.6 a	11.7 a	12.1 ab	4.8 a
2	50% @ TI	17.4 a	11.8 abc	10.0 a	9.6 abc	6.3 a
3	100% @ TI	15.6 a	7.8 bcd	4.4 bc	3.2 def	0.3 c
4	50% @ TI + 50%@ EB	15.3 a	10.5 abc	7.6 ab	5.8 cde	1.2 bc
5	50% @ TI + 100% @ EB	14.4 a	5.3 d	1.9 cd	3.9 de	0.5 c
6	100% @ TI + 50% @ EB	16.3 a	6.5 cd	2.0 cd	2.1 ef	0.6 c
7	100% @ TI + 100% @ EB	11.0 a	2.8 e	1.0 d	0.6 f	0.3 c
8	50% @ End of TI	15.4 a	14.2 ab	11.4 a	14.2 a	3.3 abc
9	100% @ End of TI	13.9 a	5.6 d	3.3 c	2.7 def	0.9 c
10	50% @ End of TI + 50% @ Mid Bulk	18.1 a	9.4 a-d	7.1 ab	7.5 bcd	4.3 ab
	LSD (P=.05)	5.72-6.15	1.78-5.66	1.38-5.14	1.89-5.19	1.85-3.28

		ROW 'B' TOTAL CWT/A	ROW 'B' 0-4 oz CWT/A	ROW 'B' 4-6 oz CWT/A	ROW 'B' 6-8 oz CWT/A	ROW 'B' 8-12 oz CWT/A	ROW 'B' >12 oz CWT/A	ROW 'B' >4 oz CWT/A
TRT #	**TRT NAME**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
1	Untreated	475.8 a	139.1 a	120.4 a	87.8 a	87.5 a	35.0 ab	334.6 a
2	50% @ TI	406.9 ab	126.2 a	85.8 abc	74.5 a	69.4 ab	45.2 a	279.5 a
3	100% @ TI	237.5 de	113.3 a	56.5 bcd	34.0 bcd	21.9 bc	1.9 d	122.8 c
4	50% @ TI + 50%@ EB	303.0 cd	111.2 a	76.1 a-d	59.5 ab	39.3 abc	8.0 bcd	191.1 b
5	50% @ TI + 100% @ EB	190.9 e	104.2 a	38.4 d	14.7 d	27.5 abc	3.1 d	86.5 cd
6	100% @ TI + 50% @ EB	204.2 e	118.0 a	47.0 cd	17.6 d	14.9 c	4.0 d	85.8 cd
7	100% @ TI + 100% @ EB	118.6 f	80.1 a	19.4 e	7.6 d	3.9 d	1.5 d	37.9 d
8	50% @ End of TI	433.4 a	111.6 a	102.8 ab	83.4 a	100.0 a	23.9 a-d	321.3 a
9	100% @ End of TI	204.8 e	100.2 a	40.2 d	24.9 cd	16.9 c	6.0 cd	97.8 cd
10	50% @ End of TI + 50% @ Mid Bulk	350.0 bc	131.7 a	68.2 a-d	54.3 abc	52.4 abc	30.9 abc	215.5 b
	LSD (P=.05)	67.30	41.56-44.73	12.05-45.04	25.91	6.90-59.18	11.75-25.82	50.00

		ROW 'B' TOTAL CT 20 FT	ROW 'B' 0-4 oz CT 20 FT	ROW 'B' 4-6 oz CT 20 FT	ROW 'B' 6-8 oz CT 20 FT	ROW 'B' 8-12 oz CT 20 FT	ROW 'B' >12 oz CT 20 FT	ROW 'B' >4 oz CT 20 FT
TRT #	**TRT NAME**	**16**	**17**	**18**	**19**	**20**	**21**	**22**
1	Untreated	241.8 a	129.7 a	54.3 a	27.5 a	20.0 ab	5.5 ab	108.5 a
2	50% @ TI	209.0 ab	120.7 a	38.0 abc	24.0 a	16.0 abc	6.7 a	86.3 b
3	100% @ TI	168.0 bc	122.8 a	24.9 bcd	10.8 bcd	5.4 def	0.4 d	43.8 d
4	50% @ TI + 50%@ EB	177.8 abc	110.8 a	34.1 a-d	18.8 ab	10.1 cde	1.4 bcd	65.8 b
5	50% @ TI + 100% @ EB	155.8 bc	126.5 a	17.0 d	4.5 d	6.6 de	0.6 d	29.0 de
6	100% @ TI + 50% @ EB	161.5 bc	129.4 a	21.3 cd	5.5 d	3.2 ef	0.7 d	31.5 ds
7	100% @ TI + 100% @ EB	121.8 c	106.4 a	8.8 e	2.5 d	1.1 f	0.3 d	14.3 e
8	50% @ End of TI	211.8 ab	109.6 a	45.5 ab	26.5 a	23.9 a	3.7 abc	101.8 a
9	100% @ End of TI	162.5 bc	116.5 a	18.4 d	7.8 cd	4.4 def	1.1 cd	33.5 de
10	50% @ End of TI + 50% @ Mid Bulk	198.5 ab	125.5 a	30.5 a-d	17.3 abc	12.4 bcd	4.9 ab	67.5 c
	LSD (P=.05)	48.52	38.90-45.49	5.58-20.02	8.02	3.19-8.24	1.49-4.09	14.69







he Canapeo App showed all treatments that had 50% defoliation at tuber initiation (treatments 2, 4, 5) and 10 DA (treatments 8, 0) did not differ from the untreated. All treatments that had 100% defoliation at the end of tuber initiation (treatments 3, 6, 7), which occurred ten days later, had significantly less foliage coverage. Finally, treatment 9, which got 100% defoliation at the end of uber initiation had the least foliage coverage among all treatments.

ll varieties showed a similar pattern in yield compared to the treatment; the untreated was the highest yielding, followed by reatment 8, treatment 2, treatment 10, all the way to the lowest yielding treatment, treatment 7. Russet Burbank and Umatilla ad the exact same yield rankings while Clearwater numbers differed from the other two varieties, albeit not significant :reatments 4 and 10, and treatments 3,6 and 8 in Clearwater). All the treatments that received 100% defoliation anytime during ıe season had the lowest yields. Not surprisingly, the only treatment with 100% defoliation twice during the season was the ›west yielder. 50% defoliation at tuber initiation had a lower yield than 50% defoliation at the end of tuber initiation which ccurred 10 days later, but not significant according to ARM.

Starter Fertilizer Trial. Harlene Hatterman-Valenti and Collin Auwarter, North Dakota State University.

Field research was conducted at the Oakes Irrigation Research site near Oakes, ND to evaluate the response of Russet Burbank potatoes when 10-34-0 fertilizer applied in-furrow alone and tank mixed with other fertilizers. Plots were 4 rows by 20 feet arranged in a randomized complete block design with 4 replicates. Seed pieces (2 oz) were planted on 36-inch rows and 12-inch spacing on May 24, 2021. After planting, an additional 195 pounds of nitrogen was applied during the growing season. Extension recommendations were used for cultural practices throughout the year. The trial was harvested September 28.

Soil Test Report

Nitrate (0-6”)	14 lb/ac
Nitrate (6-24”)	12 lb/ac
Phosphorus	25 ppm
Potassium	208 ppm
Sulfur (0-6”)	10 lb/ac
Sulfur (6-24”)	66 lb/ac
Zinc	2.94 ppm
Org. Matter	2.0%
Sol. Salts (0-6”)	0.15 mmho/cm
Sol. Salts (6-24”)	0.19 mmho/cm
Soil pH (0-6”)	7.4
Soil pH (6-24”)	8.0

Additional Nitrogen Applied

Date	LBS N
6/8/21	60
6/28/21	45
7/13/21	45
8/3/21	45
Total	195

Treatment List

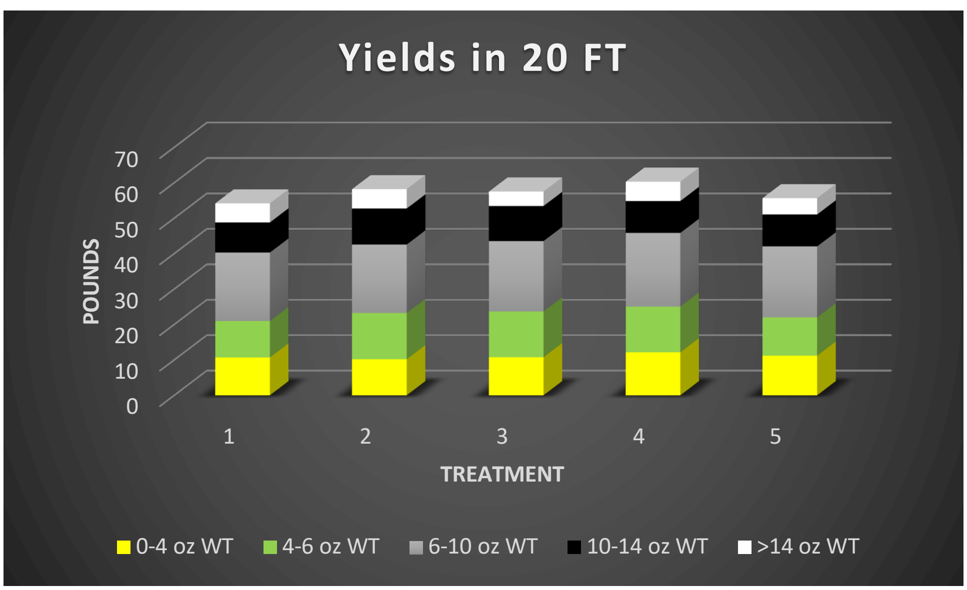
TRT #	TRT NAME	RATE
1	Untreated	
2	10-34-0	25 gal/a
3	10-34-0	22 gal/a
	WC390	3 gal/a
4	10-34-0	22 gal/a
	WC390	3 gal/a
	WC238	2 floz/a
5	10-34-0	22 gal/a
	WC390	3 gal/a
	WC648	2 floz/a

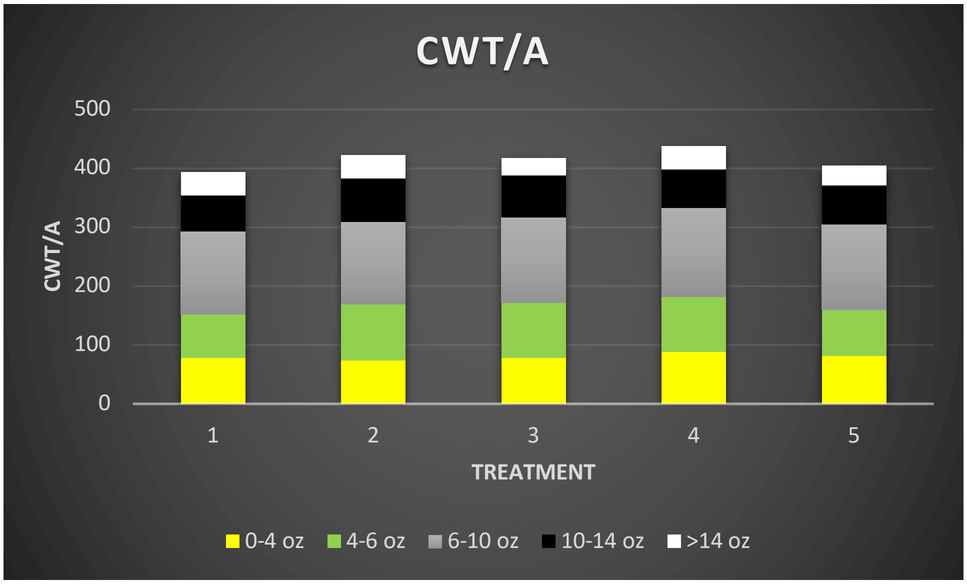
	Canopeo	Total WT	0-4 oz WT	4-6 oz WT	6-10 oz WT	10-14 oz WT	>14 oz WT
	% Canopy Cover	20 FT	20 FT	20 FT	20 FT	20 FT	20 FT
TRT #	64 DAP						
1	86.3	54.4	10.7	10.3	19.3	8.5	5.4
2	83.8	58.3	10.2	13.1*	19.3	10.2	5.5
3	82.9	57.6	10.8	12.9*	19.9	9.9	4.1
4	84.7	60.4	12.2	12.9*	20.8	9.0	5.5
5	83.6	55.7	11.2	10.8	20.0	9.0	4.6
LSD (P=0.05)	4.2	8.3	2.6	1.6	3.1	4.2	3.9

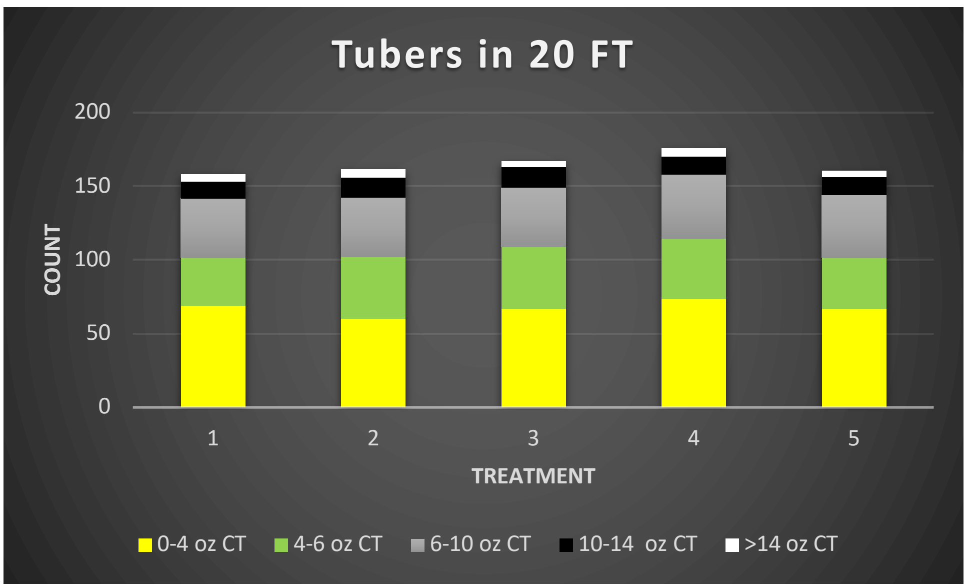
	Total	0-4 oz	4-6 oz	6-10 oz	10-14 oz	>14 oz	>4oz
	CWT/A	CWT/A	CWT/A	CWT/A	CWT/A	CWT/A	CWT/A
TRT #							
1	394.6	77.8	74.6	140.3	61.8	39.1	316.8
2	423.1	74.2	94.7*	140.3	73.8	39.8	348.9
3	418.2	78.2	93.8*	144.2	71.9	29.7	340.0
4	438.3	88.2	93.7*	150.9	65.3	39.5	350.0
5	404.3	81.4	78.6	145.3	65.5	33.4	322.9
LSD (P=0.05)	60.0	18.7	11.5	22.2	30.7	28.3	57.9

	Total CT	0-4 oz CT	4-6 oz CT	6-10 oz CT	10-14 oz CT	>14 oz CT	>4 oz CT	% >4 oz
	20 FT	20 FT	20 FT	20 FT	20 FT	20 FT	20 FT	
TRT #								
1	159.5	68.8	33.0	40.0	11.5	5.0	90.0	56.6
2	162.0	60.4	41.9	40.0	13.8	5.5	101.3	62.2
3	167.3	66.9	42.0	40.3	13.8	4.0	100.3	59.9
4	176.8	73.5	41.3	43.3	12.3	5.5	102.5	58.1
5	162.0	66.8	34.9	42.3	12.3	4.3	93.8	57.9
LSD (P=0.05)	18.7	15.8	5.2	7.0	5.7	3.8	12.9	6.6

- = significant to the untreated at 0.05.







In the first table there is the % Canopy Cover using the Canopeo App (www.Canopeo.com) and weights (lbs) of specific sized tubers in 20 row-ft. The lowest yielding treatment was the untreated, while the highest yielding was treatment 4 with a weight of 60.37 pounds. Treatment 4 also had the greatest amount of unmarketable weight (0-4 oz). The second table converts the 20 row-ft weight into CWT/A. The third table shows number of tubers (CT) in 20 row-ft in specific sized weights. For instance, treatment 5 had a total of 162 tubers and 66.8 tubers weighed between 0-4 ounces. There were 34.9 tubers that weighed between 4-6 ounces. Treatment 2 had the highest percent of tubers that were marketable with 62.2% and the untreated had the lowest amount of total tubers (159.5) and the lowest percent of tubers that are marketable (56.6%). The only significant differences in the study occurred in the 4-6 oz tuber category, with three of the four treatments (2, 3, 4) yielding greater than the untreated. The lack of significance at the 95 percent level of confidence is not surprising given the inherent lack of uniformity between plants regarding yield. With that in mind, all treatments had numerically greater marketable yields compared to the untreated. Treatment 2 had a 10% marketable yield increase, treatment 3 had a 7% marketable yield increase, treatment 4 had a 11% marketable yield increase, and treatment 5 had a 2% marketable yield increase.

Genetic Improvement and Potato Cultivar Development for the Northern Plains
2021 Summary

Susie Thompson, Ph.D.
Department of Plant Sciences
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Potato is an important horticultural crop in North Dakota (ND), Minnesota (MN), and across the Northern Plains. Potato is management, labor, and input intensive compared to agronomic crops. In 2020, the fresh sector dramatically increased as consumers cooked at home; however, in 2021 we saw a rebounding in other marketing sectors as stakeholders tried to return to a level of normalcy. Central to the potato improvement team, the potato breeding program conducts conventional breeding efforts, germplasm enhancement, selection, evaluation, and development of improved cultivars for stakeholder adoption. Emphasis is on incorporating durable, long-term resistance to biotic and abiotic stressors important to our producers and industry, enhancing nutritional and quality attributes, and providing increased opportunities for economic and environmental sustainability via new cultivars possessing early maturity, high yield potential, and/or expanded marketability.

To address the shortcomings of industry standard cultivars and to address the needs of the Minnesota Area II and Northern Plains potato producers and our potato industry, the following research objectives were established for 2021:

1. Develop improved germplasm and potato cultivars adapted to the North Dakota, Minnesota, and beyond.
2. Introgress genes into early maturing genotypes for resistance to abiotic and biotic stressors, and improved sustainability and quality traits, important to the Northern Plains region; conduct screening and evaluation trials.
3. Identify and adopt improved breeding and production methodologies/technologies including marker assisted selection, polyploid genomics tools, rapid phenotyping, data mining, and aerial and ground data collection and diagnostics.

To address these objectives, the potato breeding program conducts potato research and production in the greenhouse, field and laboratory. In 2021, 70 parental genotypes were used to create 321 new families. Parental germplasm included named cultivars and advancing selections from NDSU, USDA-ARS Prosser/Aberdeen, Michigan State University, and University of Maine. In addition to early maturity, emphasis was placed on introgression of resistance to PVY, late blight, Colorado Potato Beetle, Verticillium wilt, and nematodes/Corky Ringspot, and improvement of processing (frozen and chip) and fresh market quality attributes. About 33% of new hybridizations included a PVY resistant parent and about 10% of the new families included a nematode/corky ringspot resistant parent. Seedling tubers were produced in the greenhouse year-round for planting in the single-hill nursery. Unselected seedling tubers were shared with the potato breeding programs in ID, ME, MN, OR and TX. The seedling nursery, clone maintenance and increase lots were grown at Baker, MN. In 2021, 42,544 single hills were grown in the seedling nursery, with 28,943 from NDSU representing 157 families and the remainder received from collaborators in ID, ME and TX. Five hundred thirteen selections were made, with 353 as NDSU seedlings and 160 from out-of-state collaborators. In the maintenance lots, 570 second year selections were grown and 124 retained. One hundred fifty-one third year selections were evaluated and 83 selected to continue in the

program. Three hundred nineteen fourth year and older genotypes were produced, with 188 retained to continue in the breeding pipeline. Specific gravity of all maintenance materials was determined, each selection was photographed using a light box, and russet and chip processing selections were sampled for 0time chip processing evaluation, and following eight weeks storage at 38F (3.3C) and 42F (5.5C) as they were inventoried into our storage facility. Several mapping populations (tetraploid) were also produced, including a number segregating for skin set. Drs. Dogramaci, Haagenson and I, and PhD. student, David Ngure, are evaluating a number of facets related to skin set in order to better understand the processes involved, more quickly identify resistant genotypes, and appreciate environmental/cultural influences impacting periderm development. About a half-acre of increase lots of promising advancing selections was also entered into certification.
In 2021, field research trials were conducted at multiple locations; irrigated sites included Oakes, Larimore and Inkster, ND, and Park Rapids, MN. At the Oakes Research Extension Center (OREC) a processing trial with 13 selections compared to processing industry standards and a fresh market trial evaluating 10 advancing red and yellow skinned selections compared to standards were conducted. Processing genotypes were predominantly second- and third- year materials, so this was our first look at quality and yield performance. A stand out in the fresh market trial was ND1241-1Y, a round yellow which retained its shape unlike many yellows which develop points when exposed to heat stress. Trials at the Larimore site included a processing trial with 16 advancing russet/long white selections compared to industry standards, the National French Fry Processing trial (NFPT), a preliminary processing trial (unreplicated) included 81russet/long white-skinned genotypes and industry standards, the North Central Regional Genomic Selection Trials (Drs. Douches, Endelman and Shannon), a crop oil/vine kill study (in cooperation with Drs. Secor, Robinson, McRae) supported by North Dakota Specialty Crop Block Grant FY19-442, evaluation of Dakota Trailblazer S1 selections (master's student Tannis Anderson), and an agronomic trial. Results for the processing trial are reported in Tables 1 through 3 and in Figure 1. Standouts included ND1412Y-5Russ and ND1413YB-1Russ (both also performed very well in the 2021 NFPT across US sites and will continue evaluation in the 2022 NFPT), in addition to Dakota Russet, Dakota Trailblazer, and Russet Norkotah. A processing trial with 9 entries, including ND12154AB-2Russ, a common scab screening trial with 68 entries across market types, and the replicated *Verticillium* wilt resistance screening trial (25 genotypes across market types conducted in collaboration with Dr. Julie Pasche's program) were conducted at Park Rapids. ND12154AB-2Russ performed very well in processing trials in ND and MN, and combines early bulking with attractive tuber type and good processing qualities.

Non-irrigated research sites were at Crystal, Hoople, and Fargo, ND. All sites suffered from lack of timely rains and heat during the 2021 growing season. The Crystal fresh market trial had 30 entries, including 24 advancing red, yellow and purple skinned selections compared to six fresh market standards (Tables 4 and 5, and Figure 2); standouts included ND081571-2R, ND113207-1R, ND1232-1RY, ND1232-2RY, ND1241-1Y, and ND1243-PY. Yields at Crystal were severely hampered by the environmental conditions this summer, and the small tuber size profile is evidence of the stress. The preliminary fresh market trial (replicated) with 33 entrants, including six Chilean selections compared to standard cultivars; the tuber size profiles of all were small and a few of the selections produced a propensity of heat runners. The chip processing trials were located north of Hoople near the Crystal location; trials included the advanced chip processing trial, the National Chip Processing Trial (NCPT), and preliminary chip processing trial. Yields were slightly better (they were green dug later in September, rather than vine desiccation in early September) than the fresh market trial. Standouts based on yield and quality attributes in the chip processing trial were ND13220C-3, ND7519-1, ND7799c-1, Dakota Pearl and Dakota Crisp (Tables 6-8). The ND13220C-3 is moving to the Mini FastTrack phase of the NCPT/SNAC program. Several selections that did well in the preliminary trial are entered into Tier 1 of the 2022 NCPT. Two trials were grown on the NDSU campus-Fargo Main Station, an herbicide sensitivity trial in collaboration with Drs. Hatterman-Valenti and Flores focused on rapid phenotyping (conducted by Hashim Andidi, MS graduate student), and an organic demonstration trial of 16 specialty selections compared to All Blue, French Fingerling, Red Norland and Yukon Gold. While Colorado Potato Beetles were not an issue in the organic trial in 2021, grasshoppers plagued the plot, defoliating many, providing valuable information in this demonstration.

NDSU has released 27 cultivars; the most recent was Dakota Dawn (ATND99331-2PintoY) in 2021, the first specialty cultivar release from NDSU. ND1241-1Y and ND113207-1R will be presented for pre-release consideration in 2022, and the cold-chipping selection ND7519-1 will be considered for release in 2022. The NDSU potato breeding program is supported by Kelly Peppel (research specialist), Dick (Richard) Nilles (research technician), and undergraduate student Elizabeth Krause. Graduate students include Hashim Andidi, Tannis Anderson, and David Ngure. Additional trial information will be submitted to the Valley Potato Grower magazine, and will be presented at potato industry meetings in 2022.

Heartfelt thanks to the Northern Plains Potato Growers Association, the Minnesota Area II Research and Promotion Council, JR Simplot, Cavendish Farms, Lamb Weston and RDO Frozen, and to our many grower cooperators including Dave and Andy Moquist, Carl, Mike and Casey Hoverson and all at Hoverson Farms, Lloyd, Steve and Jamie Oberg, Nick David, William Mack, Darwin Lake and all at RD Offutt Company, the Forest River Colony, Sandi Aarestad and Alex Bare (Valley Tissue Culture), Mitch Jorde, Black Gold Farms, Justin, Brooks and Sander Dagen, Brad, Keith, Tom and Ryan Nilson, Andy Gullikson/Hoople Farmers Grain Company, John Miller Farms, James F. Thompson, the Forest River Colony, Kelly Cooper, Heidi Eslinger, and Seth Nelson (OREC), and many others, for research funding, hosting trials, supplying certified seed, and all you do supporting potato breeding and potato research efforts.

Table 1. Agronomic evaluations for advanced processing selections and cultivars grown at Larimore, ND, 2021. The processing trial was planted on May 10 and harvested October 18 and 20, 2021, using a single-row Grimme harvester. A randomized complete block design with four replicates was utilized; plots were twenty feet long, with a within-row spacing of 12 inches and 36 inches between rows.

Clone	Stand %	Stems per Plant	Vine Size[1]	Vine Matur-ity[2]	Tubers per plant	General Rating[3]
ND8068-5Russ	99	2.1	1.5	1.0	4.7	3.0
ND050032-4Russ	96	1.4	2.3	1.3	6.0	3.8
ND060735-4Russ	99	1.9	2.8	1.3	8.4	3.3
ND113100-1Russ	93	2.2	3.0	1.6	4.5	3.0
ND12154AB-2Russ	98	2.0	3.0	1.1	5.3	3.3
ND12241YB-2Russ	90	2.0	3.0	1.9	5.4	3.4
ND13100B-1Russ	94	2.3	2.3	1.0	10.3	2.9
ND13245C-4Russ	95	2.7	3.3	1.3	12.5	2.9
ND13288-2Russ	93	2.3	2.8	1.1	10.1	3.1
ND1412Y-1Russ	80	1.9	3.5	2.6	4.6	2.4
ND1412Y-5Russ	99	2.5	3.5	2.4	8.4	3.1
ND1413YB-1Russ	96	2.2	4.0	2.4	7.2	3.5
ND14110B-3Russ	99	2.4	2.8	1.8	8.6	3.2
ND14286BC-2Russ	96	2.0	1.3	1.0	6.7	3.0
ND14286BC-11Russ	95	2.2	3.5	1.3	10.0	3.0
ND14273BC-1Russ	98	2.2	3.0	1.4	7.6	3.1
Bannock Russet	82	3.3	4.8	3.4	7.7	3.0
Dakota Russet	98	1.5	3.5	2.5	4.8	4.1
Dakota Trailblazer	98	1.6	4.6	2.9	5.9	4.0
Ranger Russet	100	2.1	4.0	2.8	7.1	2.9
Russet Burbank	98	2.2	4.3	1.9	7.8	2.8
Russet Norkotah	96	2.2	3.0	1.0	8.2	4.1
Shepody	98	1.6	3.5	1.5	4.7	2.6
Umatilla Russet	94	2.7	3.5	1.8	8.9	2.9
Mean	95	2.1	3.2	1.7	7.3	3.2
LSD ($\propto$=0.05)	12	0.4	0.9	0.9	1.7	0.4

[1] Vine size – scale 1-5, 1 = very small, 5 = very large.
[2] Vine maturity – scale 1-5, 1 = very early, 5 = very late.
[3] General rating based on yield, appearance, tuber size profile, shape, set, defects; scale of 1 to 5; 1 = very poor, 5 = excellent.

Table 2. Yield and grade for advanced processing selections and cultivars grown at Larimore, ND, 2021. The processing trial was planted on May 10 and harvested October 18 and 20, 2021, using a single-row Grimme harvester. A randomized complete block design with four replicates was utilized; plots were twenty feet long, with a within-row spacing of 12 inches and 36 inches between rows.

Clone	Total Yield Cwt./A	US No. 1 Cwt./A	US No. 1 %	0-4 oz. %	4-6 oz. %	6-10 oz. %	>10 oz. %	US 2s & Culls %
ND8068-5Russ	249	184	73	14	35	18	21	12
ND050032-4Russ	372	329	88	8	35	19	33	4
ND060735-4Russ	405	314	77	18	43	20	14	4
ND113100-1Russ	280	238	84	8	30	18	36	8
ND12154AB-2Russ	402	319	80	6	23	14	44	14
ND12241YB-2Russ	329	274	83	9	32	19	31	8
ND13100B-1Russ	280	133	48	52	39	8	1	0
ND13245C-4Russ	319	143	45	54	36	7	1	0
ND13288-2Russ	302	175	58	40	40	11	7	2
ND1412Y-1Russ	231	180	78	14	30	16	31	9
ND1412Y-5Russ	421	339	80	15	48	22	11	5
ND1413YB-1Russ	432	371	86	9	34	19	33	5
ND14110B-3Russ	402	286	71	20	40	17	14	9
ND14286BC-2Russ	396	246	62	11	26	14	22	27
ND14286BC-11Russ	400	265	66	26	42	14	10	7
ND14273BC-1Russ	440	321	73	10	33	16	24	17
Bannock Russet	288	219	75	20	43	18	14	5
Dakota Russet	348	303	87	7	25	15	48	5
Dakota Trailblazer	391	352	90	6	37	23	30	4
Ranger Russet	419	299	71	12	31	15	25	17
Russet Burbank	465	282	61	12	26	13	21	27
Russet Norkotah	460	393	85	11	36	17	32	3
Shepody	344	163	49	7	18	8	23	45
Umatilla Russet	313	184	55	37	37	10	8	8
Mean	362	263	72	18	34	15	22	10
LSD (∝=0.05)	87	71	9	6	11	5	14	8

Table 3. French fry evaluations following grading for advanced processing selections and cultivars grown at Larimore, ND, 2021. The processing trial was planted on May 10 and harvested October 18 and 20, 2021, 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		
Clone	Specific Gravity[1]	Hollow Heart/ Brown Center %	Fry Color[2]	Stem-end Color	% Sugar Ends[3]
ND8068-5Russ	1.1014	0	0.3	1.7	75
ND050032-4Russ	1.0962	13	0.3	1.7	59
ND060735-4Russ	1.1057	9	0.4	0.4	0
ND113100-1Russ	1.0981	1	0.3	3.5	100
ND12154AB-2Russ	1.0902	0	0.9	1.5	59
ND12241YB-2Russ	1.1173	1	0.3	1.7	67
ND13100B-1Russ	1.1073	1	0.8	2.0	92
ND13245C-4Russ	1.1098	11	0.7	1.7	67
ND13288-2Russ	1.1093	13	0.9	1.7	92
ND1412Y-1Russ	1.0982	6	0.3	1.2	59
ND1412Y-5Russ	1.1035	15	0.2	0.5	25
ND1413YB-1Russ	1.1125	20	0.7	2.4	83
ND14110B-3Russ	1.0978	6	0.5	2.9	83
ND14286BC-2Russ	1.0808	0	1.2	1.3	33
ND14286BC-11Russ	1.0912	0	0.4	2.0	67
ND14273BC-1Russ	1.0934	0	0.6	2.7	100
Bannock Russet	1.1050	6	0.6	1.8	67
Dakota Russet	1.1038	19	0.2	0.2	0
Dakota Trailblazer	1.1247	25	0.7	1.4	33
Ranger Russet	1.1102	6	0.5	2.3	92
Russet Burbank	1.0984	1	0.5	3.4	83
Russet Norkotah	1.0892	18	1.5	2.7	50
Shepody	1.0938	4	1.0	1.6	67
Umatilla Russet	1.1062	0	0.6	1.5	58
Mean	1.1018	7	0.6	1.8	62
LSD ($\propto$=0.05)	0.0070	12	0.4	1.2	51

[1] Determined using weight-in-air, weight-in-water method.
[2] Fry color scores: 0.1 corresponds to 000, 0.3 corresponds to 00, 0.5 corresponds to 0, 1.0 equals 1.0; subsequent numbers follow French fry rating scale 000 to 4.0. Scores of 3.0 and above are unacceptable because adequate sugars 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.

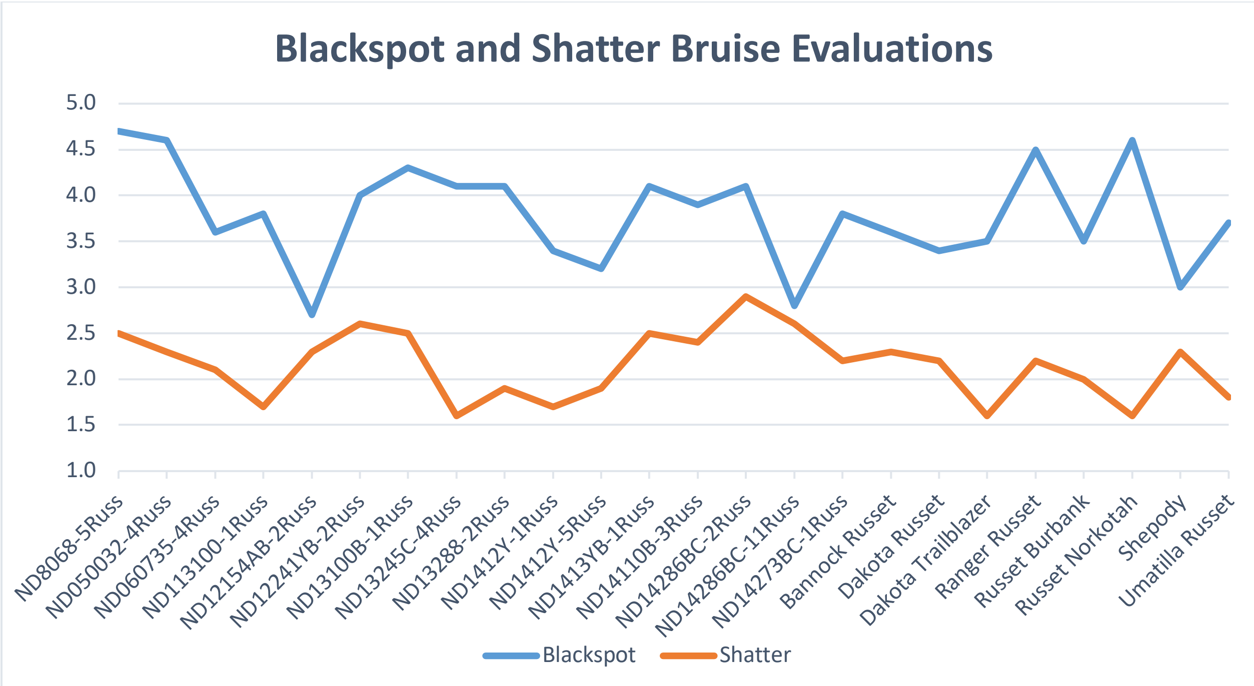

Figure 1. Blackspot and shatter bruise evaluations for advanced processing selections and cultivars grown at Larimore, ND, 2021. The processing trial was planted on May 10 and harvested October 18 and 20, 2021, using a single-row Grimme harvester. A randomized complete block design with four replicates was utilized; plots were twenty feet long, with a within-row spacing of 12 inches and 36 inches between rows. Blackspot bruise determined by the abrasive peel method (Pavek et al. 1985), scale 1-5, 1 = none, 5 = severe. The mean for blackspot was 4.0, and the LSD = 2.1. Shatter bruise is evaluated using a bruising chamber with digger chain link baffles. Tubers are stored at 45F prior bruising. Shatter bruises are rated on a scale of 1-5, with 1 = none and 5 = many and severe. Mean shatter bruise was 2.1, and the LSD = 0.7.

Table 4. Agronomic and quality attributes (skin color, scurf, specific gravity, and general rating (breeder merit score) for advanced fresh market selections and cultivars, Crystal, ND, 2021. The trial was planted May 25, vines shredded on approximately September 8, and harvested on September 18 using a single-row Grimme harvester. A randomized complete block design was utilized with four replicates; plots were 20 feet long, with a 12-inch with-in row spacing, and 36 inches between rows.

Clone	Stand %	Stems per Plant	Vine Size[1]	Vine Maturity[2]	Tubers per Plant	Color[3]	Scurf[4]	Specific Gravity[5]	General Rating
ND081571-2R	100	3.4	3.0	2.3	6.2	4.0	4.4	1.0815	3.7
ND018571-3R	100	3.7	2.5	3.3	6.8	3.5	4.0	1.0870	3.0
ND102663B-3R	94	2.7	1.8	3.5	5.7	4.2	4.8	1.0806	3.5
ND102990B-2R	98	3.3	2.0	3.3	6.9	4.1	4.8	1.0845	3.5
ND102990B-3R	100	3.2	1.3	1.0	5.8	3.5	4.1	1.0903	3.6
ND113207-1R	100	2.7	2.5	2.6	7.1	3.6	3.5	1.0793	3.3
ND113338C-4R	96	3.4	2.3	1.9	6.4	4.0	4.8	1.0778	3.1
ND113461-2P	100	2.8	3.0	3.5	8.3	P	4.0	1.0742	3.7
ND1232-1RY	100	3.2	3.0	3.0	10.8	4.3	4.5	1.0869	3.8
ND1232-2RY	100	3.4	3.0	2.8	8.3	3.9	4.1	1.0832	3.6
ND1240-2R	100	3.6	2.3	1.4	7.1	4.0	4.6	1.0865	3.2
ND1241-1Y	99	2.4	2.3	2.6	6.8	Y	4.3	1.1007	3.7
ND1243-1PY	99	2.8	4.0	4.3	7.2	P	3.9	1.0861	3.6
ND12128B-1R	98	3.5	3.0	3.8	6.0	3.6	3.9	1.0918	3.1
ND1382-2R	99	2.8	3.3	4.0	5.3	3.6	4.3	1.0710	2.4
ND1390-2RY	99	3.0	3.3	3.3	7.7	2.7	4.3	1.0864	3.5
ND1393Y-3R	98	2.4	2.8	3.5	5.0	3.1	3.3	1.0778	2.5
ND13106-1R	99	3.3	3.3	3.8	7.9	4.0	4.3	1.0817	3.3
ND13109-2RY	98	3.0	3.5	3.3	7.7	2.8	4.5	1.0651	3.7
ND13237C-1R	90	2.8	3.5	3.8	9.7	3.4	4.0	1.0855	2.7
ND13241-6R	100	3.1	2.8	3.5	9.9	3.6	4.0	1.0938	2.8
ND14282CB-4R	99	4.4	3.0	3.4	8.0	3.5	3.6	1.0913	2.7
ND14282CB-5R	79	2.2	1.0	3.8	5.3	3.5	4.3	1.0736	3.1
ND14284CB-4R	100	2.2	2.5	3.6	4.2	3.5	3.9	1.0820	3.1
All Blue	100	3.9	4.0	4.0	6.7	P	3.0	1.0788	3.0
Dakota Ruby	99	3.3	2.5	3.0	7.5	4.0	4.6	1.0891	3.8
Gala	98	3.1	2.8	2.5	8.0	Y	4.1	1.0835	3.3
Red LaSoda	88	2.6	2.5	3.8	4.1	2.9	3.9	1.0764	2.9
Red Norland	96	4.1	2.3	1.3	5.5	3.4	2.9	1.0742	3.4
Yukon Gold	99	2.1	3.8	2.0	3.7	Y	4.0	1.0875	3.7
Mean	97	0.8	2.7	3.0	6.8	na	4.1	1.0829	3.3
LSD (∝=0.05)	7	0.5	0.9	0.9	2.1	0.5	0.6	0.0142	0.5

[1] Vine size – scale 1-5, 1 = very small, 5 = very large.
[2] Vine maturity – scale 1-5, 1 = very early, 5 = very late.
[3] Color = 1-5; 1 = white/buff, 2 = pink, 3 = red, 4 = bright red, 5 = dark red, RSY = Red splashed yellow, Y = yellow, P = purple. na = not applicable.
[4] Scurf incidence – scale 1-5, 1 = completely covered, 5 = none (not determined if silver scurf or blackdot sclerotia).
[5] Determined using weight-in-air, weight-in-water method.
[6] General Rating = 1-5; 1 = poor and unacceptable, 3 = fair, 5 = excellent.

Table 5. Yield and grade for advanced fresh market selections and cultivars, Crystal, ND, 2021. The trial was planted on May 25, vines shredded on approximately September 8, and harvested with a single-row Grimme harvester on September 18. A randomized complete block design was utilized with four replicates. The plots were 20 feet long, with a 12-inch with-in row spacing, and 36 inches between rows.

Clone	Total Yield Cwt./A	A Size Tubers Cwt./A	A Size %	0-4 oz. %	4-6 oz. %	6-10 oz. %	>10 oz. %	% Defects
ND081571-2R	78	0	0	100	0	0	0	0
ND018571-3R	98	4	4	96	3	1	0	0
ND102663B-3R	66	1	2	98	1	1	0	0
ND102990B-2R	87	4	3	97	3	0	0	0
ND102990B-3R	77	3	2	98	2	0	0	0
ND113207-1R	118	16	11	87	10	1	0	1
ND113338C-4R	61	1	1	99	1	0	0	0
ND113461-2P	115	0	0	100	0	0	0	0
ND1232-1RY	174	13	6	94	6	0	0	0
ND1232-2RY	126	6	4	96	4	0	0	0
ND1240-2R	69	2	3	97	2	1	0	0
ND1241-1Y	114	13	11	89	11	0	0	0
ND1243-1PY	160	36	23	77	22	0	0	0
ND12128B-1R	80	2	3	96	3	0	0	1
ND1382-2R	51	1	2	98	2	0	0	0
ND1390-2RY	178	63	35	64	31	5	1	0
ND1393Y-3R	93	24	25	74	23	2	0	1
ND13106-1R	163	34	18	82	17	0	0	0
ND13109-2RY	157	39	24	76	22	2	0	0
ND13237C-1R	104	2	2	98	2	0	0	0
ND13241-6R	115	1	0	99	0	0	0	0
ND14282CB-4R	87	0	0	100	0	0	0	0
ND14282CB-5R	70	6	7	93	6	1	0	0
ND14284CB-4R	89	18	21	79	17	4	0	0
All Blue	77	1	1	99	1	0	0	0
Dakota Ruby	122	12	8	92	7	1	0	0
Gala	153	29	16	84	15	1	0	0
Red LaSoda	108	51	39	53	28	10	3	4
Red Norland	95	9	9	91	9	0	0	0
Yukon Gold	108	50	41	57	33	8	2	0
Mean	106	15	11	89	9	1	0	0
LSD (∝=0.05)	48	20	10	11	8	3	1	2

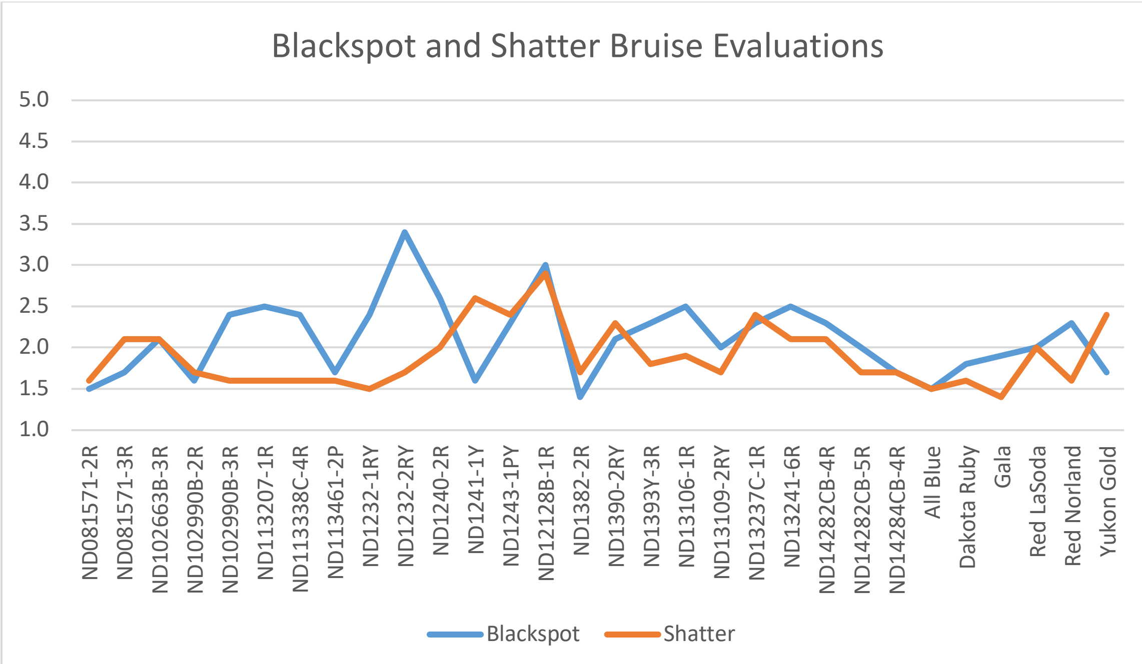

Figure 2. Blackspot and shatter bruise evaluations for advanced fresh market selections and cultivars, Crystal, ND, 2021. The trial was planted on May 25, vines shredded on approximately September 8, and harvested with a single-row Grimme harvester on September 18. A randomized complete block design was utilized with four replicates. The plots were 20 feet long, with a 12-inch with-in row spacing, and 36 inches between rows. Blackspot bruise determined by the abrasive peel method (Pavek et al. 1985) following storage at 45F, using a scale of 1-5, 1 = none, 5 = severe. As an example, Ranger Russet typically rates as a 4.0 or greater. The mean for blackspot was 2.1, with an LSD of 1.1. Shatter bruise is evaluated using a bruising chamber with digger chain link baffles. Tubers are stored at 45F prior bruising. Shatter bruises are rated on a scale of 1-5, with 1 = none and 5 = many and severe. Mean shatter bruise was 1.8, with an LSD equal to 0.6.

Table 6. Agronomic, bruising and merit assessments for advancing chip processing selections and cultivars, Hoople, ND, 2021. The chip processing trial was planted on May 24, 2021, vines were flailed on September 27, and harvested September 28 and 29, using a single-row Grimme harvester. The field design was a randomized complete block, with four replicates; plots were 20 feet long, with a 12-inch with-in row spacing, and 38 inches between rows.

Clone	Vine Size[1]	Vine Maturity[2]	Tubers per plant	Black-spot Rating[3]	Shatter Bruise Rating[4]	General Rating[5]
ND4100C-19	2.0	1.0	8.6	1.7	2.5	3.3
ND7519-1	3.0	1.5	4.5g	2.7	2.5	3.4
ND7799c-1	2.4	1.3	5.3	1.4	2.3	3.4
ND8331Cb-2	3.3	2.5	7.1	1.9	1.7	3.1
ND092018C-2	2.3	1.8	7.2	2.8	2.9	2.0
ND102631AB-1	2.0	1.1	5.9	1.6	2.4	3.4
ND102642C-2	2.0	1.0	5.0	2.4	2.3	2.8
ND102917C-1	1.8	1.0	4.0	3.2	2.5	1.0
ND102921C-3	2.8	1.1	8.7	1.6	2.5	3.1
ND1221-1	2.5	1.3	8.4	2.5	2.2	3.0
ND12180ABC-8	2.5	1.0	6.6	1.5	2.7	3.3
ND1338C-1	3.0	3.0	8.0	2.9	2.3	3.5
ND13219C-3	3.8	1.3	6.7	2.3	2.9	4.0
ND13219C-4	3.6	1.4	11.9	2.2	1.8	3.6
ND13220C-3	4.3	3.5	11.3	2.3	2.8	3.3
ND1462ABC-1a	2.8	1.1	9.6	2.1	2.3	3.4
ND1462ABC-1b	2.0	1.1	8.3	2.3	1.6	3.1
Atlantic	2.0	1.4	4.1	2.4	2.2	3.0
Dakota Crisp	3.0	2.3	6.1	2.6	2.4	3.3
Dakota Pearl	2.5	1.1	6.9	2.2	2.6	3.4
Lamoka	3.3	1.9	4.5	3.7	2.4	2.8
Pike	2.3	1.4	6.3	2.2	1.5	2.7
Snowden	3.0	1.8	5.5	3.5	1.9	3.1
Waneta	2.8	2.0	4.4	2.2	2.5	3.4
Mean	2.7	1.7	6.9	2.3	2.3	3.1
LSD ($\propto$=0.05)	0.8	0.5	1.2	0.8	0.7	0.4

[1] Vine size – scale 1-5, 1 = small, 5 = large.
[2] Vine maturity – scale 1-5, 1 = early, 5 = late.
[3] Blackspot bruise determined by the abrasive peel method (Pavek et al. 1985) following storage at 45F, using a scale of 1-5, 1 = none, 5 = severe. As an example, Ranger Russet typically rates as a 4.0 or greater.
[4] Shatter bruise is evaluated using a bruising chamber with digger chain link baffles; tubers are stored at 45F prior bruising. Shatter bruises are rated on a scale of 1-5, with 1 = none and 5 = many and severe.
[5] General rating based on yield, appearance, tuber size profile, shape, set, defects; scale of 1 to 5; 1 = poor, 5 = excellent.

Table 7. Yield and grade for advancing chip processing selections and cultivars, Hoople, ND, 2021. The chip processing trial was planted on May 24, 2021, vines were flailed on September 27, and harvested September 28 and 29, using a single-row Grimme harvester. The field design was a randomized complete block, with four replicates; plots were 20 feet long, with a 12-inch with-in row spacing, and 38 inches between rows.

Clone	Total Yield cwt./a	Yield A Size cwt/a	A Size %	0-4 oz. %	4-6 oz. %	6-10 oz. %	>10 oz. %	US 2s & Culls %
ND4100C-19	207	67	31	68	27	4	0	0
ND7519-1	213	124	58	23	42	17	12	6
ND7799c-1	239	124	51	27	35	16	19	2
ND8331Cb-2	180	50	27	68	23	4	1	5
ND092018C-2	221	108	48	49	40	8	0	3
ND102631AB-1	183	85	47	47	39	8	3	3
ND102642C-2	242	152	63	18	47	16	10	9
ND102917C-1	138	39	29	31	22	6	6	35
ND102921C-3	175	40	23	76	19	5	1	0
ND1221-1	237	94	40	56	31	9	1	3
ND12180ABC-8	209	104	49	45	39	10	2	3
ND1338C-1	238	110	46	52	37	9	1	1
ND13219C-3	216	105	48	49	39	9	2	1
ND13219C-4	257	63	24	76	20	4	0	0
ND13220C-3	403	239	60	36	46	14	4	0
ND1462ABC-1a	252	108	42	56	34	8	1	1
ND1462ABC-1b	230	94	41	56	34	7	2	1
Atlantic	163	84	51	30	38	13	13	6
Dakota Crisp	307	157	51	19	36	15	20	10
Dakota Pearl	239	124	51	40	41	11	3	5
Lamoka	172	107	60	33	44	16	6	1
Pike	168	59	35	62	27	8	3	0
Snowden	214	122	56	33	41	14	11	0
Waneta	180	109	61	26	46	15	13	1
Mean	221	103	46	45	35	10	6	4
LSD ($\propto$=0.05)	48	36	11	11	8	5	7	5

Table 8. Specific gravity and chip color after grading (USDA chip chart and HunterLab Colorimeter L-value) and following 8-weeks storage at 3.3C (38F) and 5.5C (42F) for advancing chip processing selections and cultivars, Hoople, ND, 2021. The chip processing trial was planted on May 24, 2021, vines were flailed on September 27, and harvested September 28 and 29, using a single-row Grimme harvester. The field design was a randomized complete block, with four replicates; plots were 20 feet long, with a 12-inch with-in row spacing, and 38 inches between rows.

Clone	Specific Gravity[1]	Field Chip		38 F (3.3C) Storage	42F (5.5C) Storage
		Chart[2]	Hunter[3]	Chart[2]	Chart[2]
ND4100C-19	1.0792	2.0	62	8.3	5.8
ND7519-1	1.0896	1.5	61	7.3	4.8
ND7799c-1	1.0815	1.4	64	7.8	6.2
ND8331Cb-2	1.1012	1.5	65	6.3	4.0
ND092018C-2	1.0994	3.8	58	9.1	7.6
ND102631AB-1	1.0894	2.7	63	6.9	4.0
ND102642C-2	1.0845	3.0	62	8.3	6.3
ND102917C-1	1.0792	2.8	56	9.6	8.5
ND102921C-3	1.0876	2.0	64	8.0	6.3
ND1221-1	1.0817	2.8	62	8.8	7.5
ND12180ABC-8	1.0874	2.8	62	7.8	4.6
ND1338C-1	1.0886	2.0	59	8.5	6.3
ND13219C-3	1.1035	3.3	61	9.3	7.5
ND13219C-4	1.1020	1.8	64	7.0	6.3
ND13220C-3	1.1040	2.3	61	8.0	5.3
ND1462ABC-1a	1.0819	2.5	60	7.8	4.8
ND1462ABC-1b	1.0799	1.5	61	8.0	2.8
Atlantic	1.0928	2.3	61	9.0	8.3
Dakota Crisp	1.0818	2.3	59	8.8	7.0
Dakota Pearl	1.0941	2.5	61	7.5	5.3
Lamoka	1.0938	2.5	59	8.8	7.3
Pike	1.0895	3.5	57	9.8	10.0
Snowden	1.0876	2.3	61	9.8	7.8
Waneta	1.0883	2.0	63	8.8	4.3
Mean	1.0894	2.3	61	8.3	6.2
LSD ($\propto$=0.05)	0.0079	1.6	5	2.2	1.2

[1] Determined using weight-in-air, weight-in-water method.
[2] 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.
[3] HunterLab Colorimeter L value: 60 minimum; 70 preferred.