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2018

RESEARCH REPORTS

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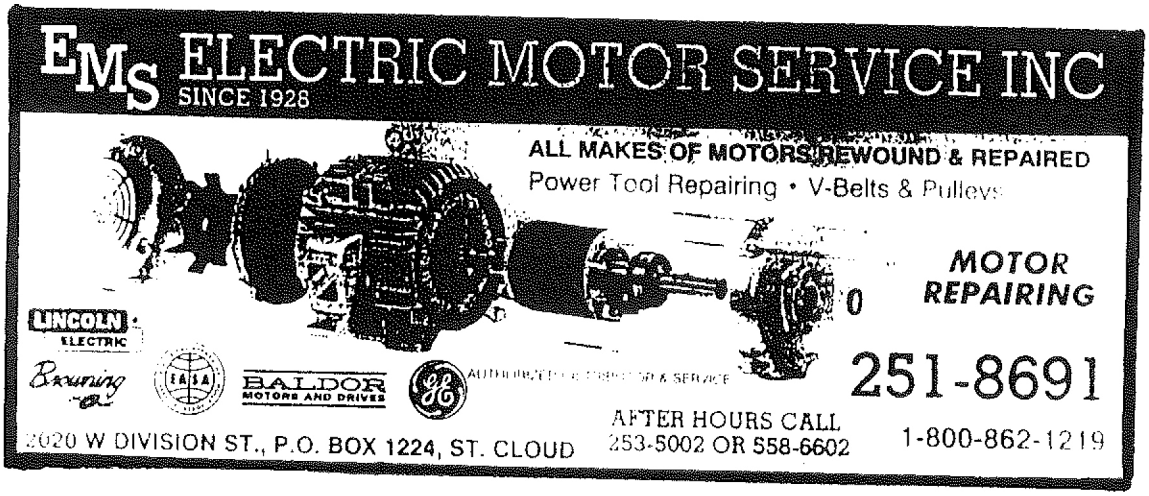

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Vine Desiccation as an Effective Disease Management Strategy to Control Verticillium Wilt of Potato

Submitted to MN Area II

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Executive Summary

Verticillium wilt and the early dying complex are arguably the most economically damaging problem facing the USA potato industry when you consider the losses from the disease itself and the cost of control. Soil fumigation with metam sodium and Verticillum wilt (VW) resistant cultivars are the primary means of disease management. Metam sodium was re-registered by the Environmental Protection Agency (EPA) a number of years ago, but with considerable restrictions placed on its use. All soil fumigants are currently under-going the re-registration process by the EPA and it is very likely that further restrictions on their use will be in place in the near future. Although a number of French fry cultivars have been developed with VW resistance, such as Bannock Russet, Alturas, or Dakota Trailblazer, many of these have only found small niches in production. As a result, Russet Burbank still represents approximately 50% of the French fry production in the USA. Vine desiccation has been largely discontinued as a cultural practice by the French fry potato industry in favor of allowing vines to naturally senesce as a means of increasing yields and decreasing production costs. However, it is very likely that the discontinuation of vine desiccation is negatively impacting the ability to effectively manage Verticillium wilt. Our hypothesis is that there is a production window during harvest, most likely centered around the fall equinox, in which yield increase and inoculum production cross paths. At the fall equinox in the upper Midwest, day length is 3-4 hours shorter than June-mid August and 10-12 F cooler which translates to less light for photosynthesis and temperatures that are generally less than optimal. Simply stated this means that yield increase beyond this point may be insignificant. In contrast, we know from previous studies that inoculum production by *V. dahliae* increases significantly during this period of time which substantially increases disease pressure in future crops (Pasche, et al. 2013b). If our hypothesis is true, this would mean that vine desiccation would have negligible economic impact on the current crop but would significantly improve Verticillium wilt control in later crops.

Current and Previous Research

Our research group has developed considerable expertise on the management of Verticillium wilt using soil fumigation or genetic resistance. In previous studies we have determined that tillage, soil moisture and soil temperature, injection depth, and numbers of *V. dahliae* propagules at the time of metam sodium application all affect the efficacy of soil fumigation (Pasche, et al. 2014; Taylor et al. 2005; Yellareddygari and Gudmestad 2018). During the course of these studies, all performed in potato grower fields utilizing natural inoculum, we have found that it is not unusual in our potato production region to have soil levels of *V. dahliae* >100 verticillium propagules per gram of soil (vppg). These high inoculum levels are likely due to relatively short rotations and the lack of vine desiccation that allows the pathogen to increase its reproduction the longer vines are alive (Pasche, et al. 2013b). Across three separate fumigation studies spanning 16 years we have found metam sodium fumigation reduces *V. dahliae* inoculum over a wide efficacy range, from 41 to 78% efficiency. The economic threshold for *V. dahliae* inoculum in Russet Burbank is 8-10 vppg (Nicot and Rouse, 1987), meaning soil levels above this must be treated with metam sodium to avoid economic loss. This means that the highest efficiency that can be expected from a soil fumigant is 78%, so any soil level above 40 vppg most likely leaves a level of Verticillium above the economic threshold. We hypothesize that the lack of vine desiccation is a contributing factor to the increased importance of Verticillium wilt as a production constraint in the Midwestern USA.

We also have developed a method of quantifying *V. dahliae* colonization in potato stems using PCR techniques (Pasche, et al. 2013a). Using this technology we demonstrated that pathogen levels in potato cultivars develop high levels of inoculum within the vascular tissue of the potato stems late in the season as vines senesce, although less so in cultivars with genetic resistance to *V. dahliae* (Pasche, et al. 2013a, 2013b). This method has proved useful for evaluating the "true" resistance of a potato cultivar to Verticillium wilt (Pasche, et al. 2013b), but also for determining the level of *V. dahliae* that is being returned to the soil from an infected crop (Pasche, et al. 2014). We believe this method will be useful in evaluating the contribution and value of vine desiccation to Verticillium wilt control.

Research Objectives

1. Determine the yield of Russet Burbank under field conditions in experimental plots that are desiccated at six weekly intervals from early September to early October.
2. Determine the level of *V. dahliae* inoculum returned to the soil in the stems of Russet Burbank desiccated at six intervals compared to stems that have senesced naturally.

Research Plan

The field trial was conducted under conditions typical of commercial potato production using overhead sprinkler irrigation near Park Rapids, Minnesota. Grower practices, including cultivation, standard fungicide, insecticide, and herbicide regimes will be performed by the cooperating grower. The field chosen for this trial had an initial *V. dahliae* level prior to fumigation with metam sodium of 20 verticillium propagules per gram (vppg) of soil and a post-fumigation level of 10 vppg.

The experiment was planted on May 10, 2017 to Russet Burbank, moderately susceptible to Verticillium wilt (Pasche et al. 2013b) in a split plot design with four replications planted at 0.3 m seed spacing in four 6.1 m rows, 0.9 m apart. Cultivar was the main plot blocking factor with vine killing date randomized within cultivar. All disease and yield data were collected from the center two rows only. The outside rows are used to buffer the plots from any competitive advantage that can occur during vine desiccation at the end of the growing season.

Disease severity was determined at approximately ten intervals by estimating the percentage of the canopy with wilted / senescent foliage. Wilt severity will be transformed to area under the wilt progress curve (AUWPC). AUWPC values will be normalized by dividing them by the total area of the graph and the resulting relative area under the wilt progress curve (RAUWPC) will used to compare treatments.

Near the end of the growing season, subplots within each replication were desiccated at six weekly intervals from August 29 to September 29 (six desiccation treatments). At each vine desiccation date, two applications of Reglone were applied to each treatment, the second application was made five to seven days after the first application to ensure that potato stems were desiccated. Potato stems were sampled on October 9 within each treatment and will be assayed to determine *V. dahliae* populations using quantitative PCR. Three potato stems per row, per vine kill date, per replication will be assayed for *V. dahliae* in the laboratory. Total yield and marketable yield will be determined at the end of the growing season. Plots were harvested on October 10-12. Total yield was taken at harvest and grade analysis was conducted by AgWorld Support Systems in Grand Forks, ND.

Results

Significant differences in total and marketable yield were observed among vine desiccation dates. The highest total and marketable yield were achieved at the September 17 vine kill date (Table 1). After September 17, total and marketable yield was lower, although not significantly so. Similarly, there were significant differences in the percentage of >10 oz. U.S. number 1 and total >10 oz. tubers among vine desiccation dates. The maximum percentage of >10 oz. tubers was observed also on the September 17 vine desiccation date. However, the percentage of >10 oz. US #1 tubers continued to increase with each later vine desiccation date although not significantly so. There were very few significant differences among other tuber size grades and among unusable tuber percentages (Table 1). Although specific gravity of tubers generally increased with each vine desiccation date, there were no significant differences observed among dates of desiccation.

The grade analysis is being used to generate payable yield (price processor pays per cwt X marketable yield per acre) and first net income per acre return to the grower. That analysis is still being processed and will be available in the future.

The levels of *V. dahliae* present in stems collected from each vine desiccation date are currently being analyzed in the laboratory. These data will be available in the future.

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Table 1. Total and marketable yield and grade characteristics of potato tubers grown and desiccated at six dates in 2017.

Application Dates	Total Yield (cwt/a)	Market Yield (cwt/a)	10 oz. & over (%)			6 - 9 oz. (%)			>6 oz. (%)	2 in/4 oz (%)		Total Smalls (%)	Unusables (%)				Specific Gravity
			US No. 1	US No. 2	Total	US No. 1	US No. 2	Total	Total	US No. 1	US No. 2		Total	Under-size	Hollow Heart	Other	
Aug 29, Sept 4	536.84	471.01	21.15	0.28	21.43	38.53	0.93	39.45	60.88	26.73	0.08	26.80	12.30	10.98	0.68	0.65	1.080
Sept 4, 10	568.24	501.74	28.65	0.75	29.40	36.15	0.35	36.50	65.90	22.23	0.10	22.33	11.75	7.58	2.48	1.70	1.080
Sept 10, 17	595.71	526.01	26.45	0.80	27.25	35.95	0.20	36.15	63.40	24.78	0.05	24.83	11.70	8.73	1.75	1.23	1.084
Sept 17, 22	621.68	563.06	30.68	0.18	30.85	37.05	0.28	37.33	68.18	22.40	0.00	22.40	9.43	7.50	1.20	0.73	1.087
Sept 22, 27	597.53	529.92	31.33	0.30	31.63	34.98	0.18	35.15	66.78	21.93	0.05	21.98	11.25	8.18	1.95	1.13	1.083
Sept 27, Oct 4	608.51	553.34	33.80	0.50	34.30	34.65	0.83	35.48	69.78	20.65	0.45	21.10	9.15	7.38	0.65	1.13	1.086
LSD$_{P = 0.05}$	45.46	44.30	5.17	NS	5.44	NS	NS	NS	NS	NS	0.27	NS	NS	1.35	NS	NS	NS

Title: Nitrogen fertilization rate and cold-induced sweetening in potato tubers during storage.

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Summary: Nitrogen (N) fertilizer is used routinely in potato cultivation to maximize yield. However, it also affects sugar, free amino acid and protein concentrations in potato tubers. The role of N fertilization on potato plant establishment, tuber growth and yield has been extensively studies. However, the reports on potato post-harvest storage and reducing sugar accumulation is limited and inconclusive. Our previous study has shown an increased levels of soluble proteins and expression of key enzyme at harvest, in response to higher N rate. The effects of altered enzyme expression at harvest need to be further explored during storage to understand the effect on processing quality. The aim of the study is to explore the effect of N rate on expression of several enzymes related to reducing sugar accumulation and long term storability of tubers.

Identification of potato varieties with high nitrogen use efficiency (NUE) and low reducing sugar accumulation potential will protect the environment and ground water contamination from N leaching. The information generated through this study could help commercial potato growers to effectively use N fertilization for optimum economic yield and processing quality, as well as potato breeders to develop new environmental friendly potato varieties with improved yield and storability. Savings in fertilizer and improved potato tuber quality will make the potato industry more competitive and sustainable.

Rationale: Potatoes are an important staple food worldwide and Minnesota ranked 7th in U.S. for potato production. In Minnesota nearly 70% of the crop is processed to form French fries and potato chips. Accumulation of high levels of reducing sugars (RS) during cold storage (38-45°F) is a major post-harvest problem for the potato processing industry due to its relationship to processing quality and acrylamide formation during frying. Providing crops with adequate levels of nutrients ensures the best yield possible. Soil-plant atmosphere system inefficiencies prevent complete utilization of the N, leaving residual N in the soil. Farmers apply relatively high rates of N fertilizers as a security. High levels of N fertilization complicate the problem by producing physiologically immature tubers (Shewry et al. 2001). Balancing economic with environmental concerns is often challenging. The consequences of heavy N fertilization that has caused negative impact on environment and have led policy makers and society in search of mitigating options.

Increasing N fertilization and irrigation may lead to increase leaching and ground water contamination. Varieties that are more efficient at capturing soil N during the entire growing season can decrease N leaching and denitrification losses. It is imperative to identify potato varieties with high NUE, which efficiently utilize available N. Increasing plant N use efficiency (NUE) is essential for the development of sustainable agriculture.

N fertilization influence chip color and reducing sugars (RS) concentrations. Several authors have reported a decrease or increase in RS concentrations (Westermann et al. 1994, Kolbe et al. 1995). It has been proposed that N fertilization influences tuber sugar content and chip color at harvest by interfering with tuber chemical maturation (Herman et al. 1996, Iritani and Weller 1997).

The aim of the study is to explore the effect of N fertilization on cellular soluble protein content and concentrations of RS as well as the underlying cellular mechanisms involved. Screening for potato genotypes that can perform well under low N input conditions will be performed.

Material and methods: Four cultivars with known SED problem like, Manistee and Umatilla (SED tolerant); Lamoka (moderately SED tolerant); and Russet Burbank (SED susceptible) were grown in the greenhouse at University of Minnesota, St. Paul campus. Plants were grown in five-gallon pots having 20 kg Hubbard loamy sand soil from the Sand Plain Research Farm, Becker. The cultivars were grown under three different N fertilization regimes (120, 240 and 360 lb/A). Environmentally Smart Nitrogen (ESN) was used as the N source. Plants were grown in four replicates. Pot were planted on July 12, 2017 and harvest on September 21, 2017. At harvest total plant height, weight, tuber number per plant and tuber weight per plant were recorded. Tubers were conditioned at room temperature for two week before storage at 50F cooler.

Results and Discussion:

Providing crops with adequate levels of nutrients ensures the best yield possible. Balancing economic with environmental concerns is often challenging. High N fertilization rate often promotes more vegetative growth of the plant and less partitioning of photo assimilates to developing tubers. High vegetative growth of the plants leads to physiologically immature tubers. Efforts have been made to study the effect of N fertilizer rate on plant growth, development and tuber development. During the growing season, various physiological parameters like plant height, leaf chlorophyll contents, days to first flower etc. were measured. These observations will help us understand the physiology of growth and development. Plant growth has significant effect on tuber growth, development and yield. The results on growth and development are summarized here. After harvesting tubers are stored at 50F cold storage for further biochemical study.

1. Effect of N fertilizer rate on leaf chlorophyll contents. Leaf chlorophyll content has been associated with tuber yield in potato tubers yield and abiotic stress tolerance ((Ramírez et al., 2014). Chlorophyll content measurement through transmittance measurement (SPAD) is frequently monitored to asses delayed senescence. We have used SPAD meter (Model MC-100, Apogee Instruments, Inc, Utah, USA) to monitor chlorophyll contents in four cultivars grown at three different N fertilizer regime. Chlorophyll content assessment during plant growth is in relation to source develop that could influence tuber development.
As the expression of phenotypic traits depend on the developmental stage, we selected three critical stages of potato tuber development (vegetative growth before tuber initiation, tuber bulking and tuber maturation). As shown in Fig 1. higher N fertilizer rate increased chlorophyll contents in Russet Burbank, Umitilla and Lamoka, through the increase may not be significantly higher than optimum N rate of 240 lbs N per acre. The cultivar Manistee showed no response to N rate. Increased chlorophyll contents in the leaves showed source strength and could result in higher dry matter accumulation in the plant.

2. Effect of N fertilizer rate on plant growth. In order to better understand the physiology of growth and development as impacted by fertilizer use, we measured plant height at various developmental stages like tuber initiation to plant maturity stage.
Plant height reflects plant growth. Optimum plant growth before the start of tuber bulking results in better crop yield. Excessive plant growth may reduce translocation of photosynthates to developing tubers and ultimately reduce tuber yield. Table 1 shows average plant height under three N fertilizer regimes. The differences in plant heights were not signification at tuber initiation state. Contrary to leaf chlorophyll contents, the higher N fertilizer rate of 360 lbs per acre resulted in reduction of plant height compared to optimum N fertilizer rate of 240 lbs per acre at 55 days after planting (DAP). However, at maturity Russet Burbank and Lamoka showed a positive response to N rate. Both the cultivars had increase in plant height with increase in N rate. Similar trend in growth was observed by Irungbam et al. (2017). Cultivars Manistee and Umatilla had maximum plant height eight at optimum N rate of 240 lbs per acre. Higher N rate showed inhibitory effect. High N fertilization rate may have caused abiotic stress to the plant.

3. Effect of N fertilizer rate on flowering of the plants. Another parameter that could affect tuber bulking and yield is the time when the plant switches from the vegetative growth phase to the reproductive growth phase. That is phase is generally indicated by the first flower development. Early initiation of flower may have positive influence on tuber yield.
As show in Fig. 2., similar to plant height, plants grown under higher N fertilizer rate started flowering sooner than the plants grown at optimum N rate of 240 lbs/acre for 3 of the 4 cultivars. Early flowering under high N fertilization rate of 360 lbs per acre is possibly due to abiotic stress caused by fertilization. Cultivars Manistee and Lamoka started flowering earlier than cultivar Russet Burbank and Umatilla resulted in higher partitioning of photo assimilates to developing tuber.

4. Effect of N fertilizer rate on dry matter accumulation and partitioning to sink. As the higher N rate positively influenced plant height in cultivars Russet Burbank and Lamoka, similar trend was observed in terms of stem dry weight (Table 1). In cultivars Manistee and Umatilla higher N rate of 360 lbs per acre did increase dry matter accumulation in stem. High dry matter accumulation in stem could increase tuber yield if partitioning of dry matter increase with N rate. To understand the partitioning of dry matter to sink tissue tuber total number of tubers per plant and tuber weight was recorded. As shown in Table 1, number of tubers per plant did not change in response to N rate. In all the cultivars total number of tubers per plants slightly decrease with high N rate of 360 lbs N per acre. Interestingly the tuber weight per plant increased slightly with N rate, except cultivar Lamoka. That means with higher N rate translocation of dry matter to developing tubers increased resulting in larger tubers. We further investigated the partitioning of dry matter from plant to tuber yield. We compared the ratio of tuber weight to total plant weight at harvest. As shown in Fig 3 (lower panel), increase in plant growth was not proportional to tuber weight. Contrary to the plant growth and dry matter accumulation, plants grown under very high N rate of 360 lbs per acre partitioned less dry matter to the developing tubers. Although plants grown under higher N rate had higher dry matter accumulated but they used that dry matter for vegetative growth rather and tuber growth. This has been reported in several studies.

5. Effect of N fertilizer rate on enzymes related to reducing sugar accumulation and processing quality change during storage. Leaf samples have been collected from the top of the canopy of each plant at the tuber initiation stage. The second leaf sampling was done in the middle of November (tuber maturation stage). After harvesting on September 21, 2017 tubers from each pots were collected and conditioned at 55F for two weeks before storage at 50F cooler. After six months of storage tubers will be analyzed for various biochemical parameters to understand the physiology of reducing sugar development during storage.
The response to N fertilizer for soluble protein content, RS and enzyme activity was cultivar-specific. Muttucumaru et al. (2013) reported substantial increase in asparagine and total free amino acid in response to increasing N fertilization. A high concentration of free amino acids may lead to their incorporation in various cellular proteins including the proteins involved in starch synthesis or degradation. N supply has been reported to affect the sugar concentration and interconversion of simple sugars and complex carbohydrates such as fructans (Halford et al. 2011). However, previous studies have not reported a consistent trend in term of N rate and RS accumulation. Muttucumaru et al. (2013) reported inconsistent increase or decrease in glucose concentration with increase N fertilizer. Amerein et al. (2003) reported no significant effect of N fertilization on RS. Dr. Rosen’s lab recorded decreased RS in response to higher N fertilization in Russet Burbank and Alpine Russet (personal communication). Analysis of tuber tissue after six month storage will show the impact of N fertilizer rate on expression of various enzymes related to reducing sugar accumulation during storage.

Conclusion:

Higher N fertilization rate clearly favored excessive vegetative growth of the plants. Cultivars Russet Burbank and Umatilla both have low cold sweetening resistance were more responsive to N rate and had higher biomass production. Whereas, cultivars Manistee and Lamoka with high cold sweetening resistance were less responsive to higher N fertilization rate and less biomass production. But both these cultivars had higher partitioning of dry matter to developing tubers. Data clearly demonstrate that cold sweetening resistant (Manistee and Lamoka) cultivars have different physiological response to N fertilization rate and higher N fertilization rate may have caused abiotic stress in these cultivars. Further analysis of tuber after cold storage will reveal the tuber physiology of reducing sugar accumulation. Management practices for N fertilizer use have been developed to maximize economic yield. There is a need to evaluate commercial cultivars for both optimum yield and best storage quality for process. Cultivars with high N utilization efficiency may reduce fertilizer cost and nitrate leaching to ground water.

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APPENDIX I

Figure 1: Effect of N rate on leaf chlorophyll contents. Data represents 4 replicates ±SE.

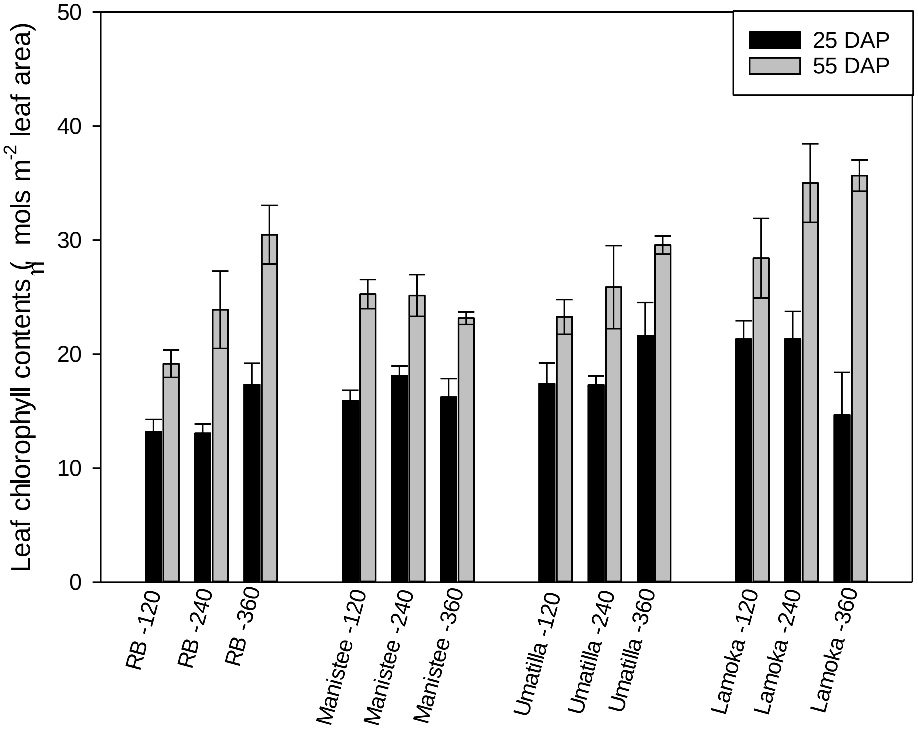

Figure 2: Effect of N rate on days to first flower. Data represents 4 replicates ±SE.

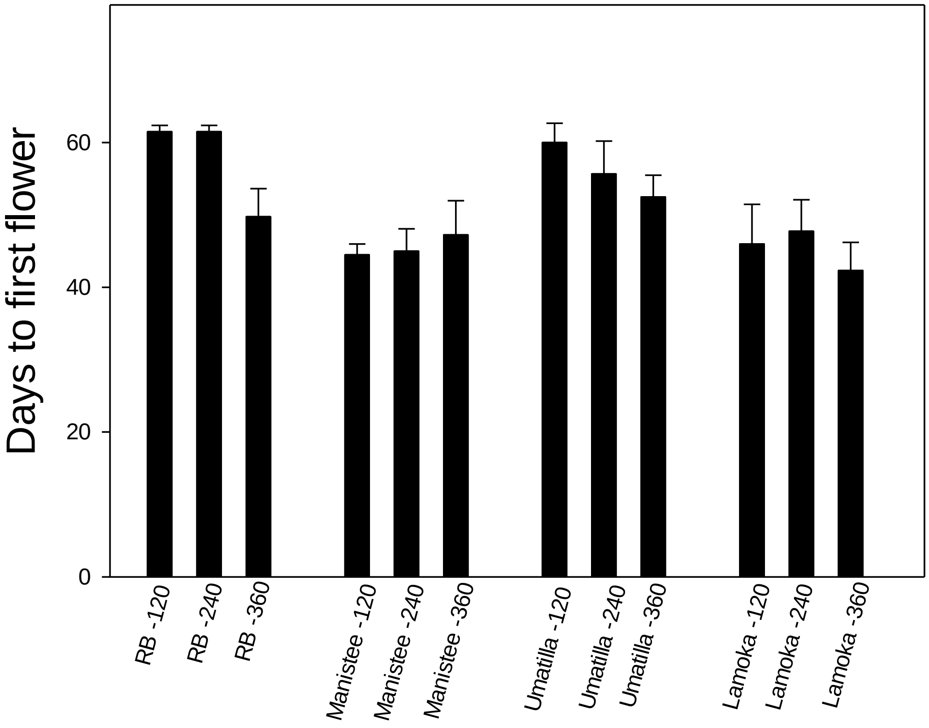

Figure 3: Effect of N rate on dry matter accumulation and partitioning to tubers. Data represents 4 replicates ±SE.

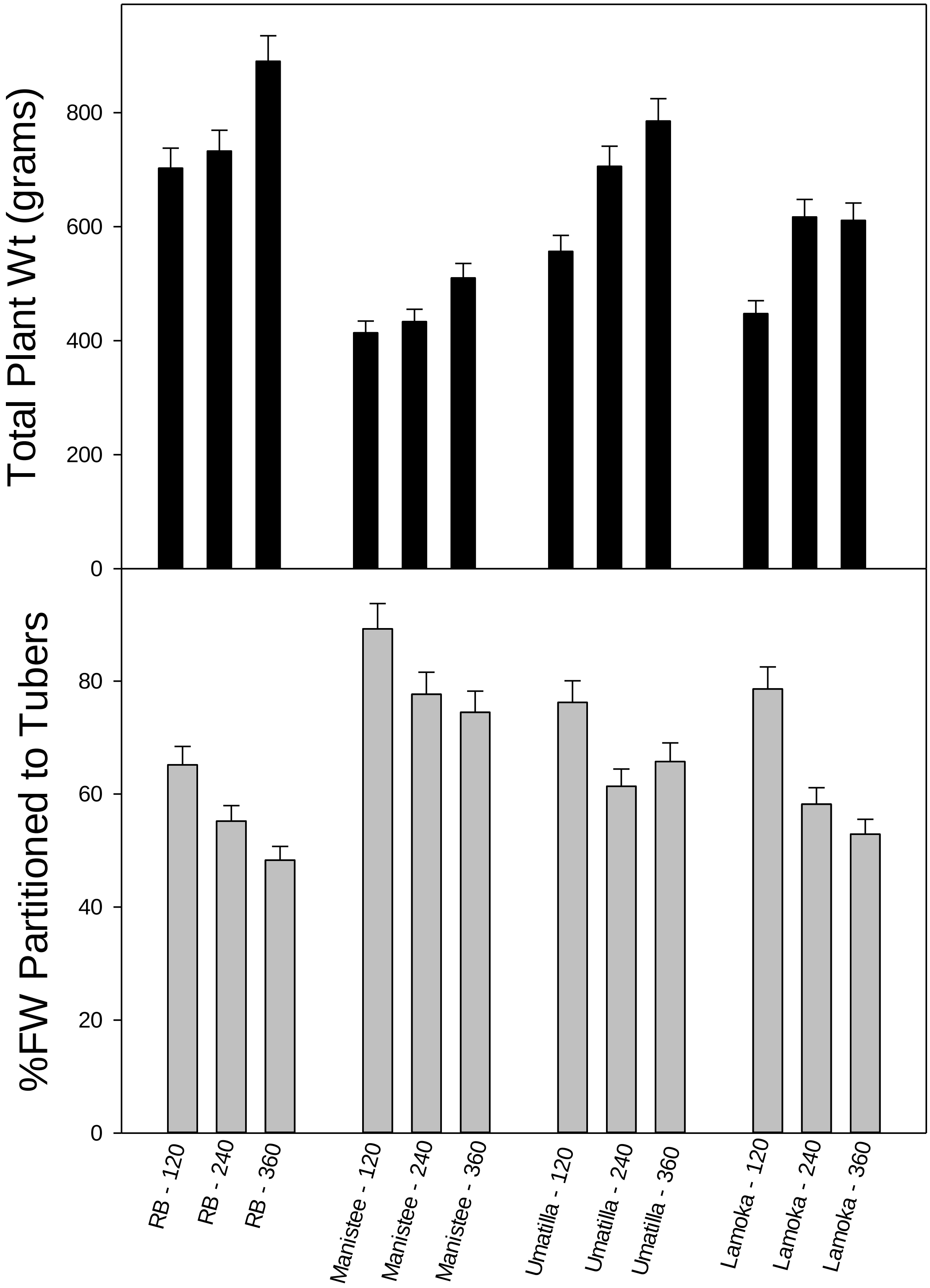

Table 1: Effect of N fertilization rate on agronomic traits at harvest

SN	cultivar	N-Rate lbs/acre	Plant Height (inches)	Plant Wt (grams)	Stem Dry wt. (grams)	No. of Tubers per plant	Tuber wt./p (grams)
1	Russet Burbank	120	74.50 ± 6.34	244.78 ± 52.77	15.59 ± 3.64	10 ± 1.11	457.97 ± 40.87
2	Russet Burbank	240	85.00 ± 5.20	328.18 ± 37.42	22.65 ± 2.81	19 ± 2.80	404.50 ± 46.93
3	Russet Burbank	360	88.25 ± 5.54	460.26 ± 10.72	34.07 ± 0.45	9 ± 0.29	430.13 ± 42.92
4	Manistee	120	44.50 ± 2.25	44.38 ± 8.56	7.96 ± 0.39	7 ± .71	369.46 ± 22.28
5	Manistee	240	52.50 ± 1.32	96.80 ± 20.46	8.57 ± 0.88	6 ± 0.35	336.70 ± 56.01
6	Manistee	360	50.00 ± 3.58	130.11 ± 28.99	11.43 ± 1.32	7 ± 1.00	380.01 ± 33.80
7	Umatilla	120	42.00 ± 0.91	132.38 ± 29.22	9.46 ± 1.08	8 ± 2.02	424.54 ± 49.41
8	Umatilla	240	53.25 ± 2.21	272.71 ± 12.00	17.41 ± 1.38	12 ± 1.47	433.18 ± 95.59
9	Umatilla	360	45.75 ± 4.84	268.96 ± 64.39	15.39 ± 4.43	18 ± 2.78	516.52 ± 106.98
10	Lamoka	120	43.75 ± 2.93	95.90 ± 6.42	8.69 ± 0.68	4 ± 0.50	351.86 ± 18.32
11	Lamoka	240	54.25 ± 4.44	257.78 ± 8.29	13.43 ± 0.93	5 ± 0.63	359.14 ± 42.02
12	Lamoka	360	59.25 ± 3.33	287.87 ± 13.31	16.52 ± 1.65	4 + .48	323.29 ± 29.38

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2017 Storage and Processing Evaluations of NDSU Breeding Lines.

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Summary

Storage and processing quality was assessed among 8 advanced breeding clones from the NDSU potato breeding program. Among the 8 clones, 5 represented advanced chipping clones and 3 represented russet ‘par-fry’ clones. In previous years, all breeding clones, irrespective of market type (fry or chip) were processed into chips using the continuous chip line. Chipping russet clones provided challenges, both physical limitations from the processing line as well as data interpretation. A modified raw fry test was implemented in 2017 and bud and stem end defects of advanced russet clones were quantified using standard reflectance techniques. A main objective of the research was evaluating clone resistance to cold sweetening in storage. Specific gravities, chip Hunter scores, and Photovolt % reflectance at harvest and three months of storage are reported.

Methods

Five chipping and three frozen par-fry market clones were kindly provided by Dr. Asunta Thompson. In addition, 5 commercial chipping varieties and 4 named russet varieties were included as checks. Potatoes were planted on May 25, 2017 and grown under irrigated field conditions at Larimore, ND; potatoes were harvested October 6, 2017. After suberization for two weeks at 55°F, 95% RH, potatoes were stored at 48, 45, 42, and 40°F. Sucrose rating (glucose and sucrose concentrations) was determined with a YSI 2900 biochemical analyzer (Yellow Springs Instruments). Samples for sugar and chip color/Photovolt % reflectance were obtained immediately after suberization (time 0) and after 3, 6, and 7 months. At each time point, specific gravities (weight in air/weight in water) and sucrose rating were measured.

Chip Clones: Chips (thickness of 20 slices/inch or roughly 0.05 inches/slice) were fried in canola oil (365°F) for 90 seconds using the continuous chip line (EGF, MN). Chip photos and HunterLab color scores (HunterLab D25 with DP-9000 processor) were recorded.

Fry Clones: Potato planks (7/8’’W x 5/16’’D) were prepared with a pneumatic knife. Planks were rinsed briefly under cold water, blotted dry, and fried in a batch fryer at 375°F for 3.5 minutes. Immediately after frying, photovolt % reflectance (Photovolt Instruments Inc.) and photos were recorded.

Results

Chip Clones: The specific gravity and HunterLab color scores are presented in Table 1. In this study, the named checks generally had larger size profiles than the numbered lines with Waneta producing the largest chips (Figure 1). ND7519-1 and ND7799C-1 were similar to Lamoka and Ivory Crisp in chip size and had good uniformity. Chips from ND131030C-1 were uniform, but slightly smaller than Lamoka and Waneta, whereas ND124C-1 and ND12209C-3 had a high number of small tubers/chips (Figure 1-4). At harvest, ND124C-1 (1.0815) and ND7799C-1 (1.0788) had the lowest specific gravities of all entries, and ND7519-1 had the highest specific gravity (Table 1).

At harvest, 8 of the 10 clones had acceptable chip color with HunterLab scores exceeding a score of 64 (Table 1). Atlantic produced the poorest quality chips (HunterLab = 50.2) and also had 10% internal defects (hollow heart). ND113030C-1 had an intermediate color score of 62 and possessed vascular discoloration that is often associated with Verticilium infection. Increased glucose concentrations were associated with reduced HunterLab color scores (data not shown). Differences in chemical maturity may have attributed to fluctuations in chip color as clones were green-dug at harvest. Efforts to assess chemical maturity prior to harvest, especially for ND131030C-1, would be beneficial in evaluating the storage potential of new clones. Chemical maturity pre-harvest will be assessed in future research trials.

The resistance to cold sweetening is being examined throughout 7 months of storage. At the time of this report, the three month data has been compiled and is reported in Table 1 and Figures (2-4). With the exception of ND113030C-1 and Atlantic, all remaining clones achieved a Hunterlab score greater than 60 at three months of storage at 48, 45, and 42°F. At the extreme low temperature treatment of 40°F, ND7799C-1 was the only clone to achieve a color score >60 at three months of storage (Table 1). The lower HunterLab scores observed at lower temperature storages were associated with increased glucose concentrations (data not shown).

Fry Clones

In previous years, all breeding clones, irrespective of market type (fry or chip) were processed through the continuous chip line at the USDA-ARS facility in East Grand Forks. Chipping russet clones provided several challenges with both processing and data interpretation. Often, the length of an > 8-oz russet clone exceeds 6 inches, and long chips became entangled within the chip line paddles. More importantly, interpretation of russet 'chip' color data was difficult. Traditional chip scoring methods (Agtron, HunterLab) require a homogenous sample and report a single color score (Figure 5A, B). Capturing a HunterLab score from russet clone chips was problematic as a dark stem end gradient commonly found among russet type clones would impact the mean reflectance data (Figure 5C). Futhermore, color defects of russet fries are routinely measured with a Photovolt reflectance probe. After discussions with breeders and processor stakeholders, a raw fry test was modified for evaluating processing attributes of advanced russet breeding lines in storage (Figure 5D). Using a plank or 'fry', bud and stem end defects of russet clones would be quantified using standard Photovolt % reflectance techniques. Testing the wider (7/8'') plank allows use of the Photovolt probe that has an aperture opening of 0.8 inches.

In 2017, three numbered russet lines were evaluated including: ND050032-4Russ, ND060735-4Russ, and ND8068-5Russ. ND8068-5Russ is marketed as an early maturing clone; maturing approximately a week to 10 days earlier than Russet Norkotah. Both ND050032-4Russ and ND060735-4Russ are also being evaluated in the Potatoes USA sponsored National Fry Processors Trial (NFPT). One goal of the NFPT is identifying clones with processing attributes exceeding that of the industry standard, Russet Burbank. The target specific gravity for NFPT clones is 1.084, and a majority (70%) of the tubers should be greater than 6-oz weight (> 4’’ length). Ideal NFPT tubers should have reducing sugar levels less than Burbank across 9 months of storage and contain minimal or no internal defects. Typical storage temperature for russet clones destined for par-fry production is 48°F, but this study is examining the impact of lower (45 and 42°F) temperature treatment on processing quality (Photovolt % reflectance).

Among the clones tested, ND8068-5Russ had the smallest overall tuber length and Umatilla had the largest and longest tubers. Closely following Umatilla in size was Dakota Russet, and the four remaining clones (Ranger Russet, Russet Burbank, ND050032-4Russ, ND060735-4Russ) were intermediate in size/length. Specific gravity of ND060735-4Russ was similar to Russet Burbank, but both ND8068-5Russ and ND050032-4Russ had lower specific gravities compared to Burbank (Table 2). There was negligible internal defects in any of the numbered lines tested in this study. Processing quality as determined by plank Photovolt % reflectance of the three numbered lines was similar or exceeded that of Burbank at harvest and three months of storage. In general, Russet Burbank, Ranger Russet, and Umatilla were darker (lower reflectance values) than all numbered lines and Dakota Russet at all sample points (Table 2, Figure 6). ND060735-4Russ had the lightest planks (highest Photovolt % reflectance) at all time points/temperatures. Photovolt reflectance corresponds to the USDA color scale (USDA 1 > 44%; USDA 2 = 35 to 44%, USDA 3 = 26 to 35%; USDA 4 < 26 %).

Final sugar and color/reflectance data will be reported after 7 months of storage (June, 2018)

Table 1. Specific gravity and HunterLab color scores of chip clones (2017-18)

		Hunterlab[1] Scores				
	Specific	**Harvest[2]**	**3 months[3]**			
Clones	**Gravity**		**48°F**	**45°F**	**42°F**	**40°F**
ND113030C-1	1.1002	62.0	62.0	61.1	57.8	48.1
ND12209C-3	1.1009	67.3	66.9	62.3	64.9	54.7
ND124c-1	1.0815	65.9	66.1	65.8	63.0	57.2
ND7519-1	1.1050	67.5	65.1	64.7	62.9	58.6
ND7799c-1	1.0788	67.9	63.5	64.5	64.4	61.2
Lamoka	1.0925	66.8	61.5	66.5	63.1	53.2
Ivory Crisp	1.1003	64.1	58.7	64.6	62.2	54.0
Atlantic	1.0996	50.2	61.3	50.6	49.2	44.6
Waneta	1.0929	64.5	65.8	67.4	60.9	58.8
Norvalley	1.0859	64.9	61.5	69.8	64.6	57.3

[1] Lighter chips have higher hunterlab scores (> 64 is a very good chip color)

[2] Harvest date: October 6, 2017. Suberized for two weeks at 55 °F at 95% humidity.

[3] Three month samples were processed at January 23, 2018.

Table 2. Specific gravity and photovolt % reflectance or russet clones (2017-18)

		Photovolt % Reflectance[1]					
		Harvest[2]		3 month[3]			
	Specific			45°F		42°F	
Clones ID	**Gravity**	**Stem**	**Bud**	**Stem**	**Bud**	**Stem**	**Bud**
Umatilla Russet	1.0955	39	44	41	42	35	37
ND050032-4Russ	1.0853	40	46	42	46	38	41
ND060735-4Russ	1.0987	41	50	48	50	45	47
ND8068-5Russ	1.0812	41	46	43	49	36	43
Dakota Russet	1.0901	41	44	44	47	41	41
Ranger Russet	1.1045	39	44	38	42	32	37
Russet Burbank	1.0973	37	43	36	47	30	40

[1] % reflectance (USDA 1 > 44%; USDA 2 = 35 to 44%; USDA 3 = 26 to 35%; USDA 4 < 26%)

[2] Harvest date: October 6, 2017. Suberized for two weeks at 55 °F at 95% humidity.

[3] Three month samples were processed at January 30, 2018.

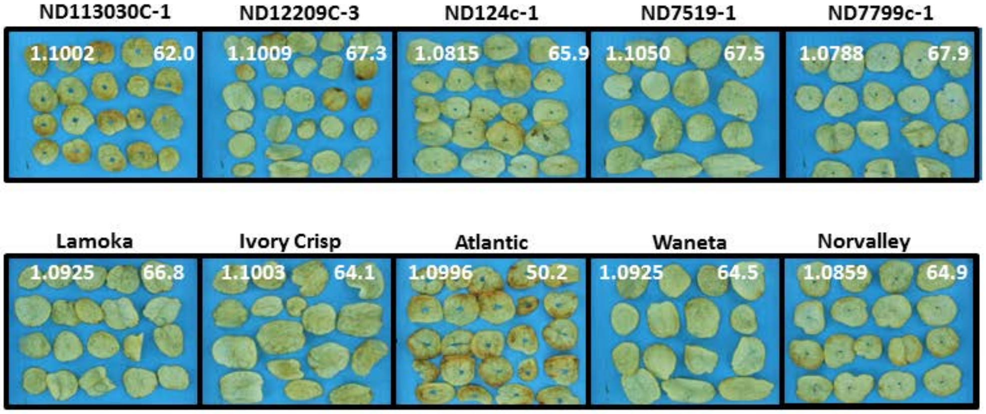

Figure 1. **Harvest** chip color scores (2017 crop). Chips were processed after suberization for 2 wk at 55°F, 95% RH, and chips were fried at 365°F for 90s in EGF continuous chip line. For each clone, Specific Gravity and HunterLab color scores are presented in white typeface.

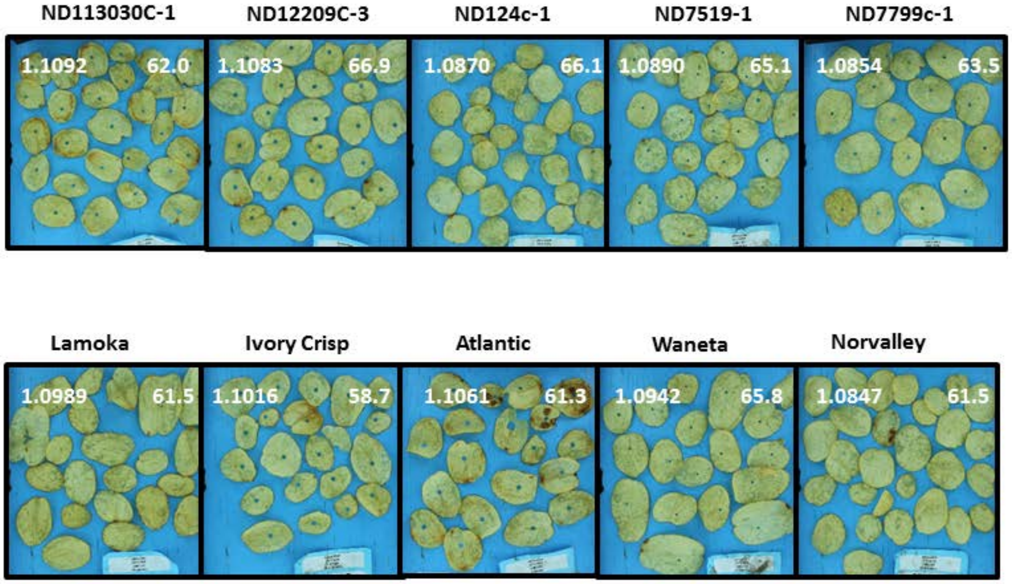

Figure 2. Chip color after 3 months of storage at **48°F** (2017 crop). For each clone, Specific Gravity and HunterLab color scores are presented in white typeface.

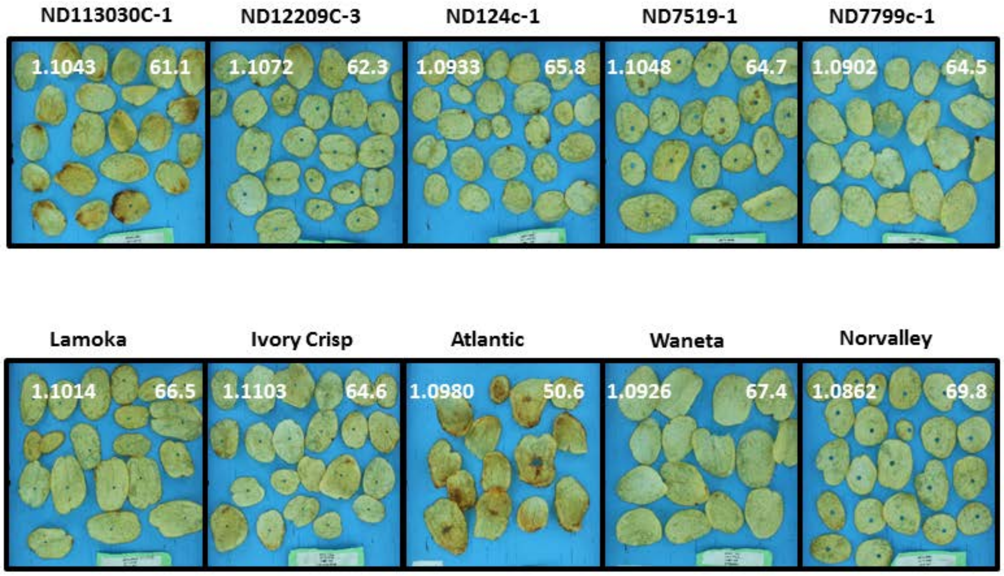

Figure 3. Chip color after 3 months of storage at **45°F** (2017 crop). For each clone, Specific Gravity and HunterLab color scores are presented in white typeface.

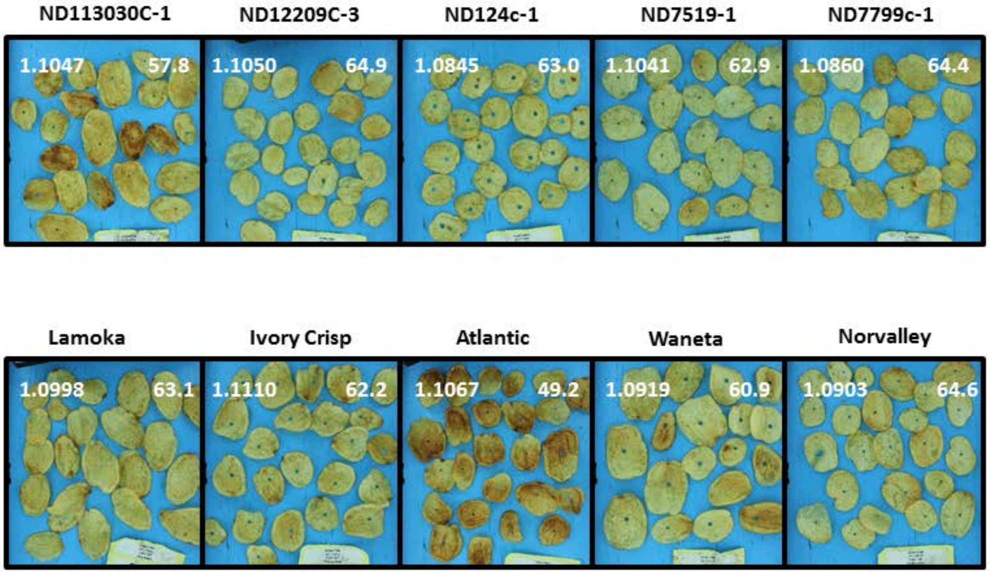

Figure 4. Chip color after 3 months of storage at **42°F** (2017 crop). For each clone, Specific Gravity and HunterLab color scores are presented in white typeface.

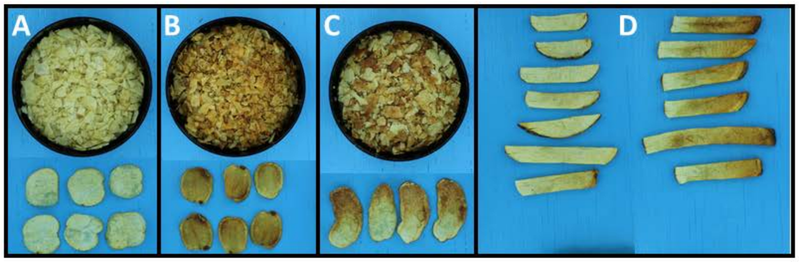

Figure 5. Chip and plank samples used in HunterLab and Photovolt % reflectance measurement. Chip samples of both light (A) and dark (B) colored samples commonly used in HunterLab chip color scoring. In contrast, russet clones chips provide a heterogenous sample (C), and Photovolt measurement of fried planks is now used to monitor processing quality of russet clones (D).

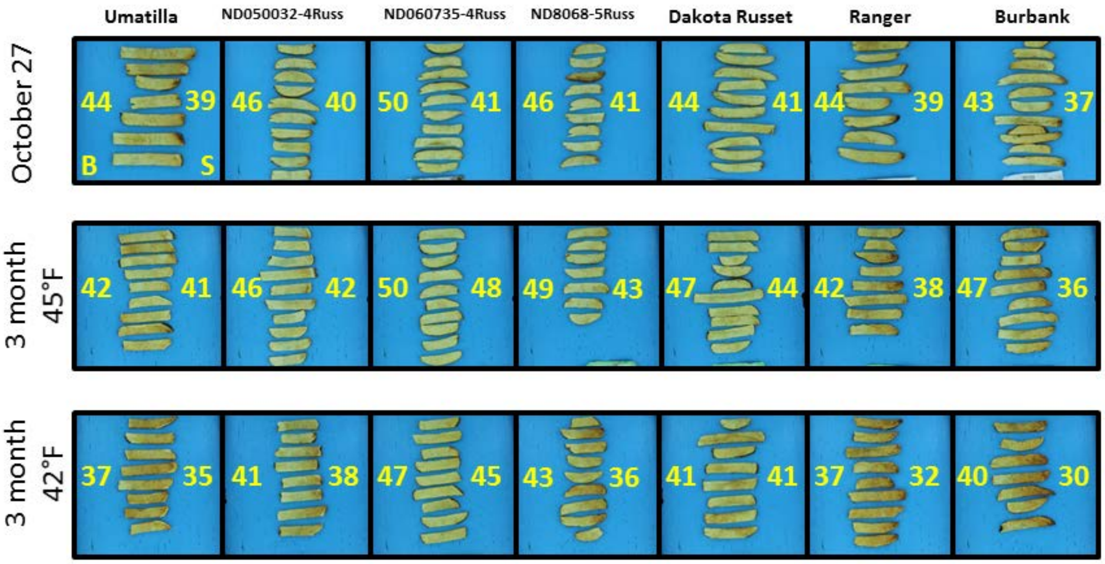

Figure 6. Photovolt % reflectance of bud (B) and stem (S) ends from NDSU breeding lines where Photovolt % reflectance (USDA 1 > 44%; USDA 2 = 35 to 44%, USDA 3 = 26 to 35%; USDA 4 < 26 %). Potato planks represent different potato tubers and planks were fried at 375°F for 3.5 minutes.

Management of Colorado Potato Beetle in Minnesota and North Dakota – Annual Report 2017

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Executive Summary – This is a continuing project designed to management tactics for Colorado Potato Beetles (**CPB**) in Minnesota and North Dakota. This proposal will focus on assessing foliar control methods in anticipation of the potential loss of neonicotinoid insecticides as at-plant treatments, determining changes in the emergence patterns of adult Colorado potato beetle in Minnesota and North Dakota and the influence this plays in resistance management, and the remote sensing of canopy defoliation.

i) CPB Management in a Post-Neonicotinoid World...

Plots were established at the UMN Sand Plains Research Farm in Becker, MN. Plots were 4 rows by 25 ft long and blocked north to south. Insecticides were applied to the center 2 rows with the outer rows left untreated treatments to allow CPB populations to build to ensure feeding pressure. Each treatment was replicated 4 times. Replicated treatments consisted of different rotated, foliar applications of insecticides (different modes of action). Published information and local experience was used to formulate regimes based on expected efficacy and cost. Efficacy was assessed by CPB population suppression and yield. Beetle populations and % defoliation were monitored weekly and applications made when the mean values in a set of treatment plots reached treatment threshold (30% defoliation pre-bloom or 50% egg hatch).

Consequently, not all treatments were sprayed at the same date or as often through the season. Economic analyses of treatment costs (cost of insecticide application over a number of seasonal applications compared to protected yield) is still underway but individual producer results will rely on the various input programs commercially available.

Table 1. Foliar treatments in non-neonicotinoid spray trials, 2017.

Treatment #	1st Foliar Treatment	2nd Foliar Treatment
1	Rimon 0.83EC @ 12oz/ac	Corragen @5oz/ac
2	Rimon 0.83EC @ 12oz/ac	Agri-Mek 0.15EC @ 16oz/ac
3	Rimon 0.83EC @ 12oz/ac	Blackhawk @ 3.3oz/ac
4	Rimon 0.83EC @ 12oz/ac	Hero @ 10.3oz/ac
5	Actara @ 3oz/ac	Corragen @5oz/ac
6	Actara @ 3oz/ac	Agri-Mek 0.15EC @ 16oz/ac
7	Actara @ 3oz/ac	Blackhawk @ 3.3oz/ac
8	Actara @ 3oz/ac	Hero @ 10.3oz/ac
9	Blackhawk @ 3.3oz/ac	Corragen @5oz/ac
10	Blackhawk @ 3.3oz/ac	Agri-Mek 0.15EC @ 16oz/ac
11	Blackhawk @ 3.3oz/ac	Blackhawk @ 3.3oz/ac
12	Blackhawk @ 3.3oz/ac	Hero @ 10.3oz/ac
13	Radiant SC @ 8oz/ac	Corragen @5oz/ac
14	Radiant SC @ 8oz/ac	Agri-Mek 0.15EC @ 16oz/ac
15	Radiant SC @ 8oz/ac	Blackhawk @ 3.3oz/ac
16	Radiant SC @ 8oz/ac	Hero @ 10.3oz/ac
17	UTC	UTC
18	Corragen @5oz/ac	Agri-Mek 0.15EC @ 16oz/ac
19	Corragen @5oz/ac	Blackhawk @ 3.3oz/ac
20	Corragen @5oz/ac	Hero @ 10.3oz/ac
21	Rimon 0.83EC @ 12oz/ac	MinectoPro @ 10oz/ac

Populations were monitored weekly; CPB eggs, small and large larvae and adults counted weekly throughout the season. Little initial defolaition results from overwintering adults aas their populations are significantly lower than later season adults (Fig 1). First insecticide applications were applied according to egg hatch thresholds (~25% egg hatch across the treatment plots). Secondary applications were timed according to defoliation thresholds. Defoliation was calculated by visual estimates of 4 plants per plot. Harvest yields were calculated from the middle 10ft of one treatment row. Seasonal population data do reflect treatment differences (Fig. 2).

Although the data was highly variable, yields also showed significant treatment effects. Not surpirsingly, early season suppression of larvae seemed to be key in maximizing yields.

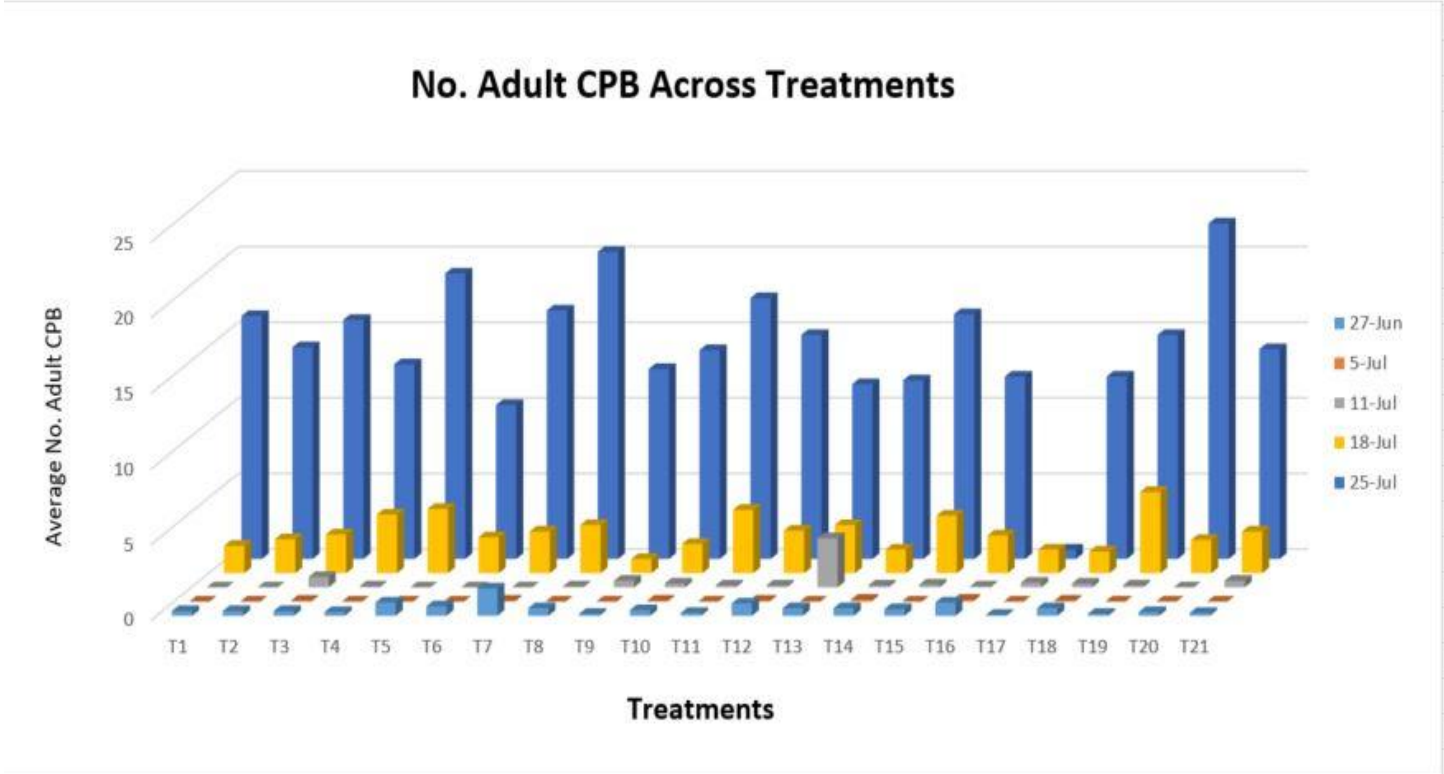

Figure 1. Number of adult CPB across treatments in 2017 foliar trial sat Becker, MN (early season dates are at front of graph with later dates progressing to the back.

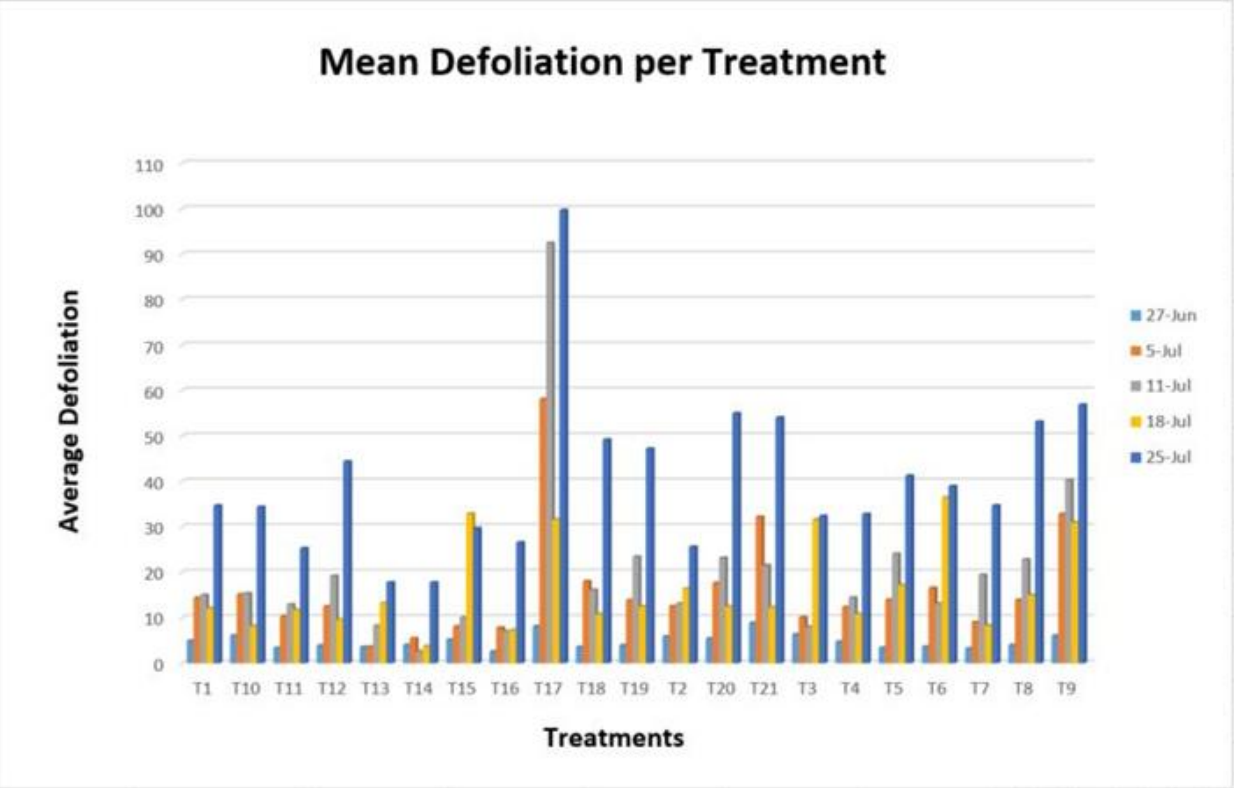

Figure 2. Mean average defoliation in treatment plots at Becker, MN.

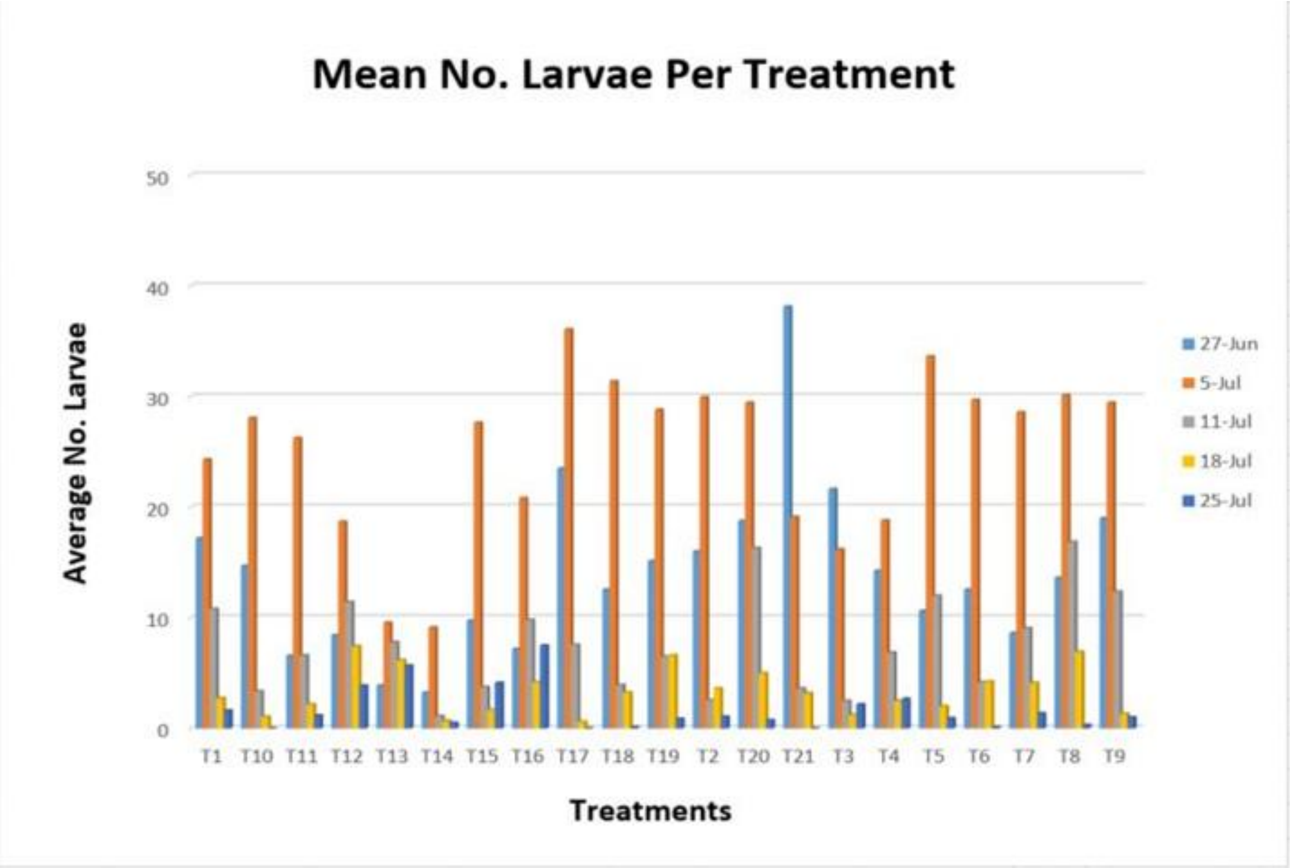

Figure 3. Mean number of larvae per treatment in Becker plots.

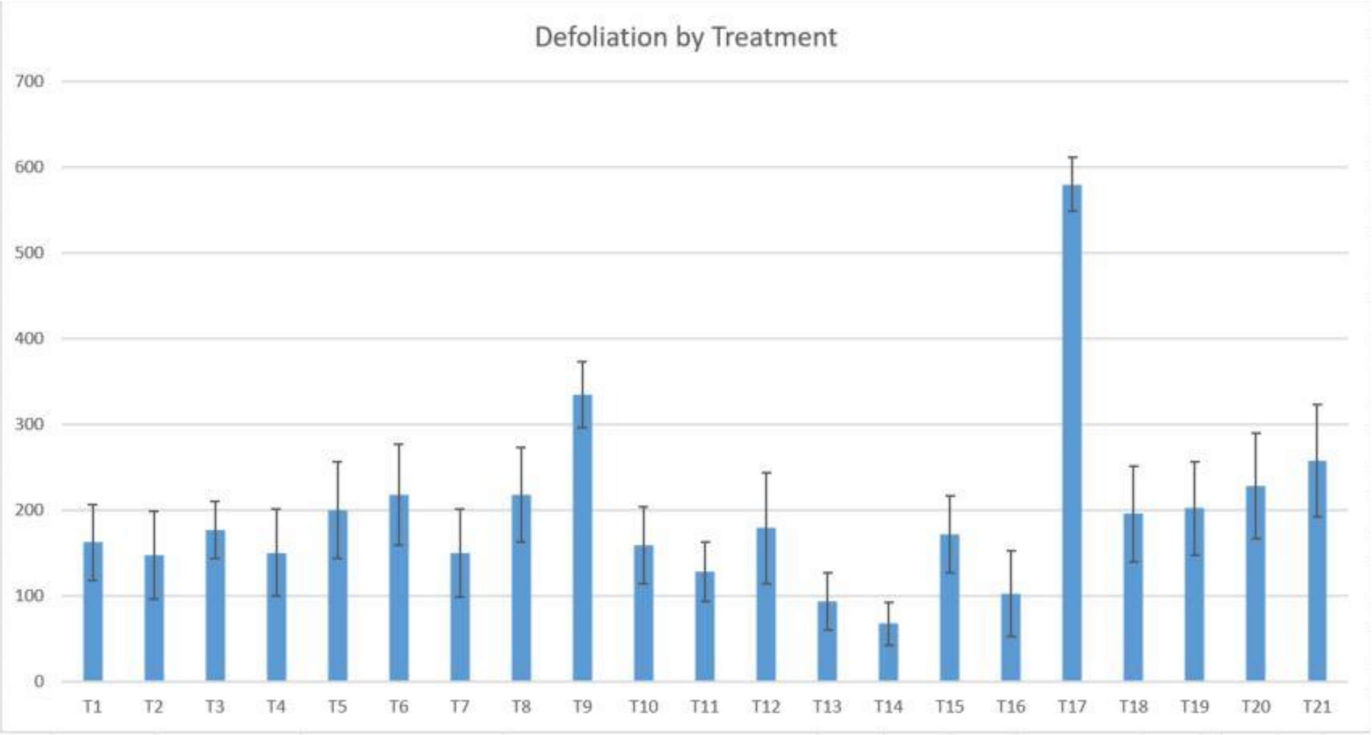

Figure 4. Percent defoliation in Treatment plots at Becker. Vertical bars indicate 95% Confidence Intervals, treatments whose bars do not overlap are significantly different.

ii) Colorado potato beetles were colleced from Becker, Clearwater and Sabin in MN and Forest River and McCanna in ND. We had difficeulty in collecting sufficient beetles to test all chemistries, so instead concentrated on the two common neonicotinoids, Imidacloprid (Admire) and Clothianidin (Belay). Resistance / tolerance of CPB from each area was assessed using a direct exposure bioassay. 600-800 beetles were collected from each location. Once acquired, adult CPB were split up into petri dishes to test different gradient concentrations, or rate, of the ai. Concentrations used were 0x, 1x, 5x, 10x, 20x and 50x (times high labeled field rate). Each rate was replicated 3 times per chemistry, with 10 beetles being tested in each petri dish. Gradient concentrations of active ingredient (ai), the actual toxin in the insecticide, are used in trials to determine how much insecticide is required to kill 50% of the population (i.e.the Lethal Dose 50% or 'LD_{50}'). In the direct exposure trials, 1 microliter drops of insecticide were directly applied to the insect using a microsyringe applicator (Fig 5). Beetles were assessed for mortality at 24, 48, and 168 hrs after application, the 168h rating was used to assess susceptibility to the insecticide (CPB often have an initial moribund reaction after being exposed but may recover in 2-4 days). To assess mortality, beetles were placed onto their backs and evaluated for movement. Any insect not righting itself was considered dead or impacted by the insecticide.

Figure 5. A 10 microliter syringe applicator; it dispenses 1 microliters per button push.

Levels of tolerance seemed elevated over previous years at all locations tested. However, final resistance ratios (the amount of resistance over high labeled field rate) is still being determined. A population of susceptible individuals will be tested with the same batches of insecticide used against sampled individuals and the amont necessary to kill 50% of the population (the LD_{50}) calculated using PROBIT analyses. These ratios will be compared to obtain the final resistance ratio (or how much of the label rate is necessary to kill the sampled population). Susceptible insects are currently being reared for this comparison (the delay in this trial is due to a supplier's colony failure earlier this year).

In the 2018 season, samples will be solicited from 8-10 more locations in both states (especially from producers experiencing a failure). To adequately test each insecticide with adequate replication, approximately 3000 beetles per location will be required in order to test a greater number of ai's. We also intend to add an additional trial; the 'Dip Test" involves 'dipping' multiple individuals into varying rates of material (fig 6). It is far less precise than the 'drop' test and does not provide the data necessary to calculate response rates (i.e. ressiatance ratios) but should provide sufficient data to rapidly determine if the insecticide is effective. This should provide within season indications of effective management chemistries, important in our current situation of increasing reliance on foliar applications.

Figure 6. Dip test to determine insecticide efficacy.

Managing PVY Vectors, Annual Report 2017

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A) A network of 18 - 2m tall suction traps were established in the seed potato production areas of Minnesota and North Dakota. This year, we also incorporated one pan trap at each location, as they have been reported to provide a better representation of species present. 16 of these trap locations were able to consistently provide data through the season.

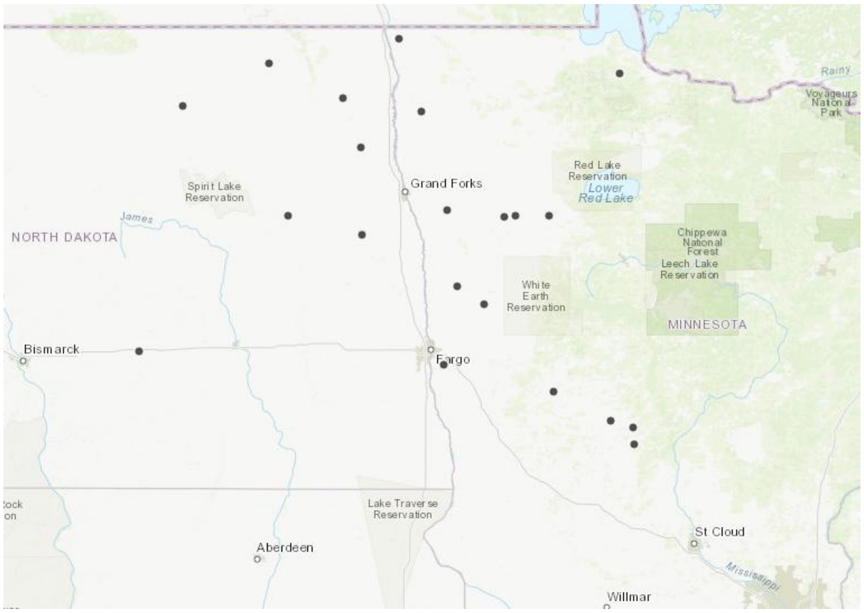


Figure 1. Aphid Alert suction trap locations, 2017.

These suction traps consist of a fan drawing air down in through the trap, sucking the incoming aphids into a sample jar. The pan traps include a modified collection container with a green tile placed at the bottom for aphid attraction. This container was then mounted on a modified tomato cage, and filled with 125ml of fluid. The modified container allowed for easier pouring of collection contents into collection jars for sampling. Each jar is changed out and sent in to be assessed weekly. Sample jars are sorted by undergraduate assistants, then aphids are identified by the lab technician to species. Each week, population dynamics at sample locations are determined and maps are released to reflect where we are seeing higher population numbers.

In 2017, we continued with providing the PVY Risk Index to cooperators and growers. This measurement standardized the amount of vector pressure being encountered at a trap location. Some vectors are more efficient than others at vectoring PVY, therefore the same number of aphids of different species may not cause the same potential of PVY transmission to fields in the area. The relative efficiencies of aphid vectors to transmit PVY have been investigated and published. Green peach aphid is the most efficient vector, therefore vector efficiencies of other aphids are generally compared to it. We used values from the literature to calculate relative cumulative vector pressure at a location based on the relative efficiencies and numbers present (e.g. soybean aphid is 10% as efficient as green peach, so a catch of 5 soybean aphids and 1 green peach at a location would total a PVY Vector Index value of 1.5 for that location). We presented the cumulative yearly PVY Vector Index values and the total PVY Vector Index value from 2016 to provide producers with an insight into what vector pressure they were experiencing compared to last year.

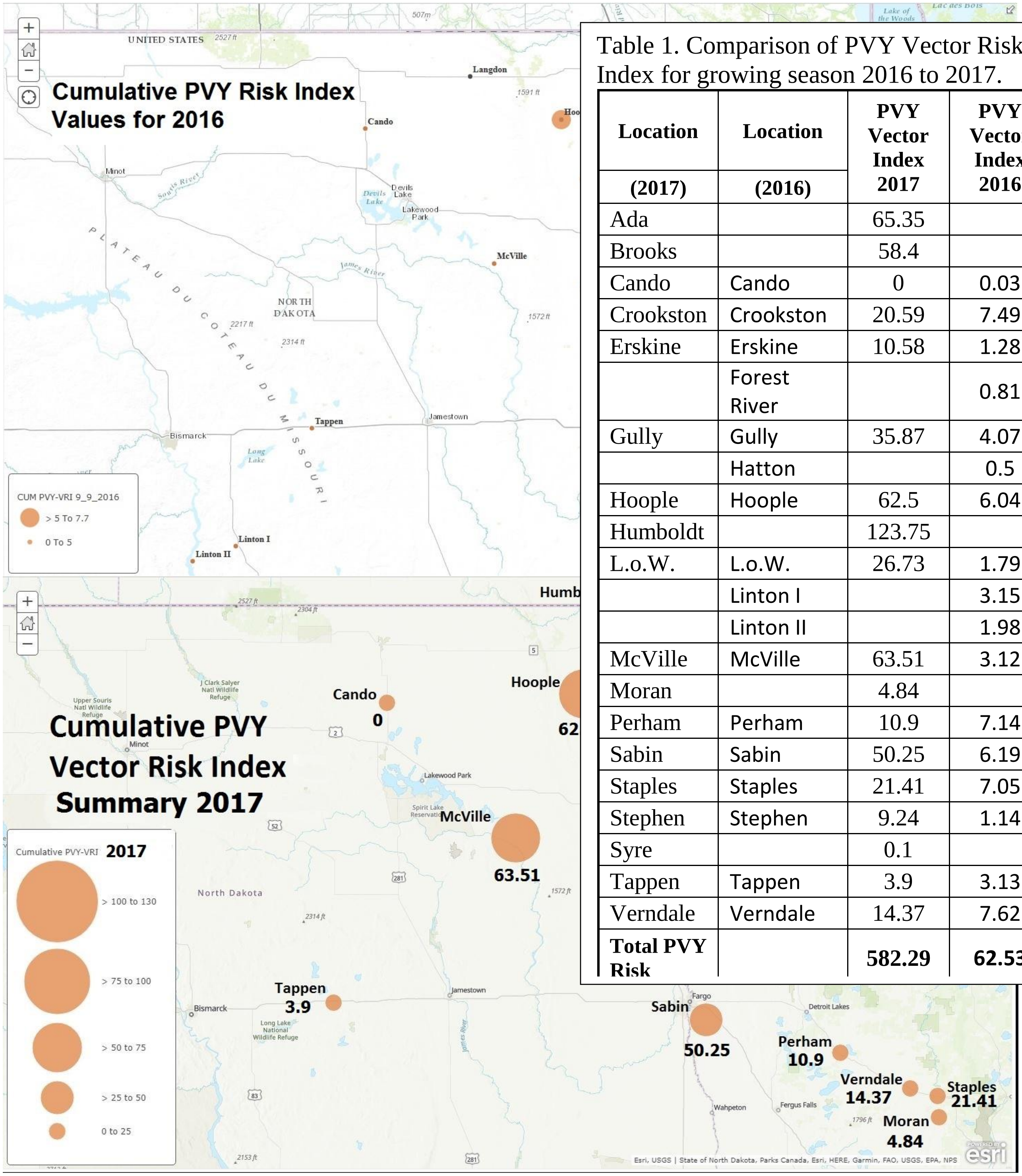


Table 1. Comparison of PVY Vector Risk Index for growing season 2016 to 2017.

Location	**Location**	**PVY Vector Index 2017**	**PVY Vector Index 2016**
(2017)	**(2016)**		
Ada		65.35	
Brooks		58.4	
Cando	Cando	0	0.03
Crookston	Crookston	20.59	7.49
Erskine	Erskine	10.58	1.28
	Forest River		0.81
Gully	Gully	35.87	4.07
	Hatton		0.5
Hoople	Hoople	62.5	6.04
Humboldt		123.75	
L.o.W.	L.o.W.	26.73	1.79
	Linton I		3.15
	Linton II		1.98
McVille	McVille	63.51	3.12
Moran		4.84	
Perham	Perham	10.9	7.14
Sabin	Sabin	50.25	6.19
Staples	Staples	21.41	7.05
Stephen	Stephen	9.24	1.14
Syre		0.1	
Tappen	Tappen	3.9	3.13
Verndale	Verndale	14.37	7.62
Total PVY Risk		**582.29**	**62.53**

Seasonal cumulative PVY Vector Risk Index for 2016 (upper map) and the total cumulative PVY Vector Risk Index for 2017 (bottom map). PVY Vector pressure was higher in 2017 and there were differences in PVY Vector Index values at most locations between the two years. The total cumulative values for the PVY Vector Risk Index in 2017 = 582.29, and in 2016 = 62.53 .

Aphid population information was 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.

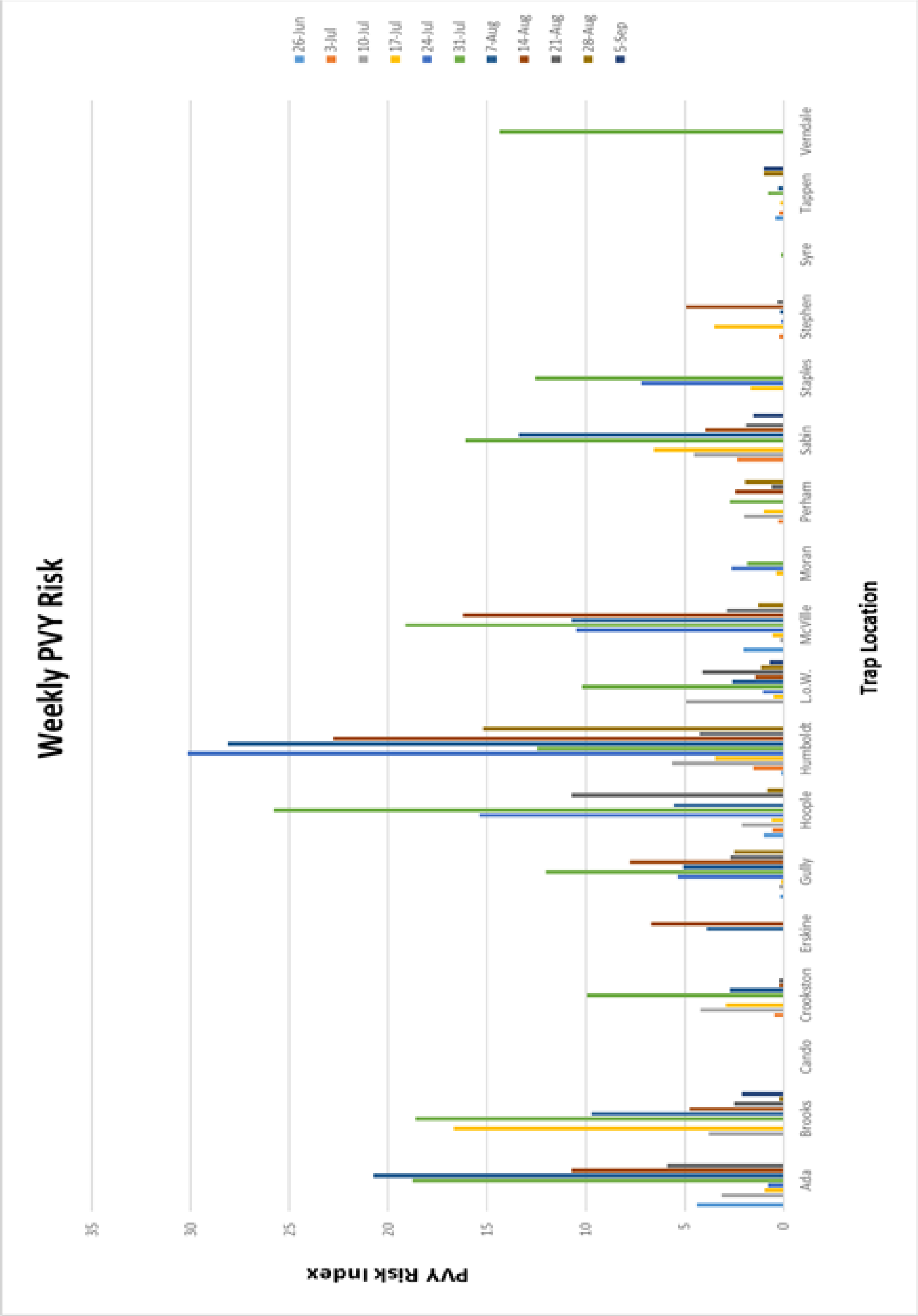
Growers were able to make decisions on beginning oil treatments or targeted edge applications could be made based on the information obtained from the regional monitoring system.

Both traps were established in early June and maintained until the seed field hosting the trap was vine-killed/harvested. At that point a field is no longer attractive to aphids.

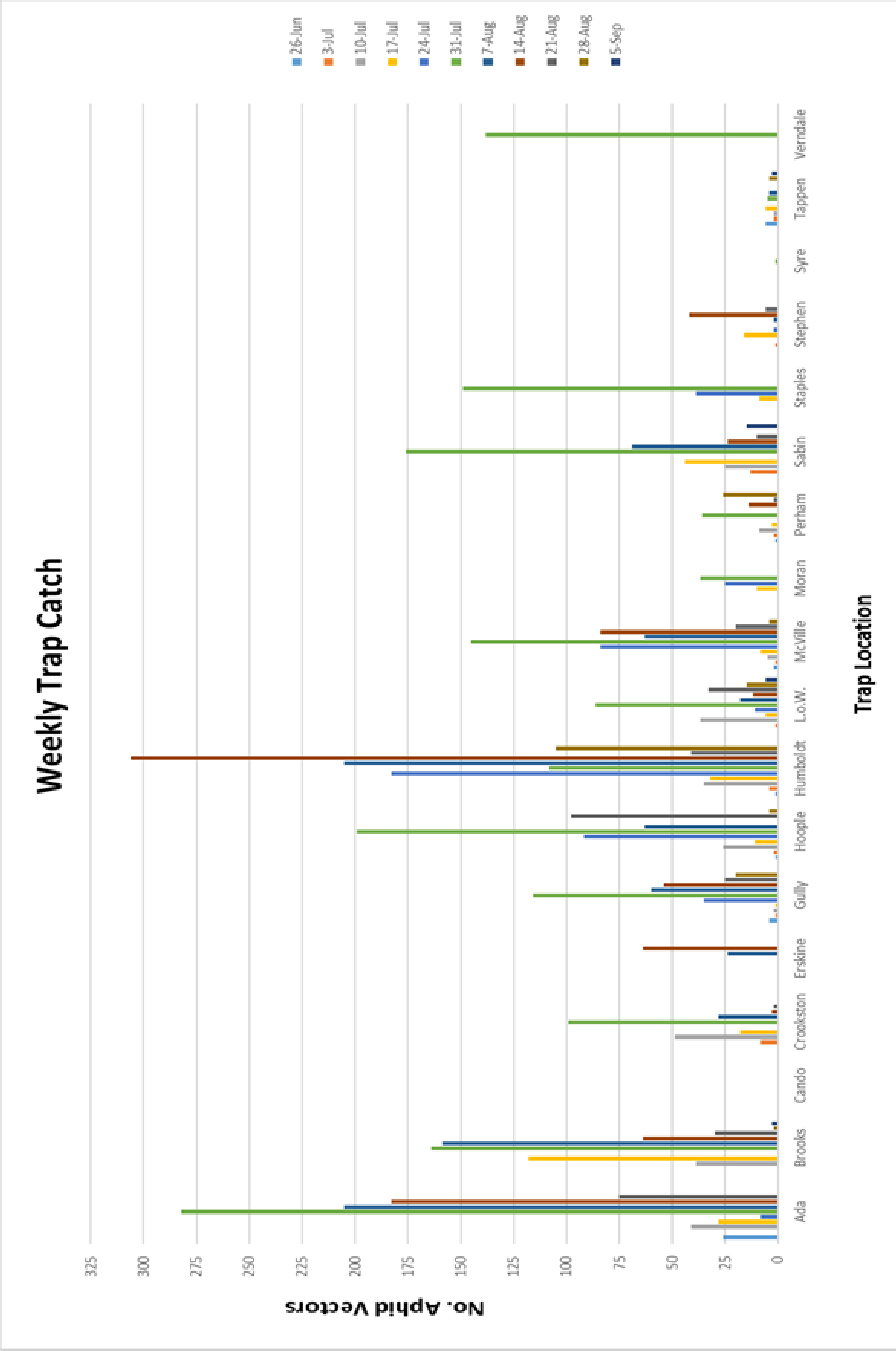
A total of 5,204 vector species aphids, representing 17 potential PVY vector species, were recovered from traps in 2017. This is roughly 10x the number of vectors recovered in 2016. Rather than the raw vector numbers at each location, the comparison of the risk of virus transmission is better represented by the PVY Vector Risk Index maps. The cumulative total values for the PVY Vector Index were much higher in 2017 than in 2016 (584.82 vs 62.53 respectively – again, roughly 10x the PVY Vector Risk Index value) but there were differences at individual sites (see table), with an increase in risk seen at each location.

It was noted, however, that there were no differences in aphid species found between the suction and pan traps. IN addition, numbers recovered from pan traps were significantly lower than those in suction traps, suggesting the pan traps do not as acuurately represent the population density being sampled (which concurs with previous research). Rather than having two traps, which can make it slightly more difficult to maintain for cooperators, it will be more efficient to forgo the pan traps during the 2018 growing season.

In 2017, 4 traps were continually monitored at the MN Dept. of Agriculture winter grow-out site at Waialua HI. These traps are used to survey the presence of aphid virus vectors at the site; the absence of vectors ensures virus is not being transmitted to plants at the grow-out. These traps provide monitoring for the MN, MT, CO and ID programs, but basically provide a good overall representation of the aphid pressure at the grow-out site. A total of 34 vector species were recovered over the 6 week trapping period, including only 1 green peach aphid. Most were low efficiency vectors and the cumulative PVY Vector Risk for all 6 weeks did not exceed 2 for any site; the Minnesota had a PVY Risk Index of 0.06. This is strongly indicative that no transmission of PVY occurred at the growout location.



Seasonal PVY Risk Index by week and location



Seasonal trap catch by week and location

Location	Week of	Green peach aphid	Soybean aphid	Bird cherry oat aphid	Corn leaf aphid	English grain aphid	Green bug	Potato aphid	Sunflower aphid	Thistle aphid	Turnip aphid	Cotton/melon aphid	Pea aphid	Cowpea aphid	Black bean aphid	Foxglove	Buckthorn aphid	Sugarbeet root aphid	Identified non-vector	Total # captured	Total Vectors	PVY Risk Index
1	12/18/2017	1	0	3	2	0	0	0	0	0	0	3	0	7	0	0	0	0	6	22	16	1.54
3	12/18/2017	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	1	3	2	0.06
4	12/18/2017	0	0	0	0	2	0	0	0	0	0	4	0	4	0	0	0	0	0	10	10	0.34
2	12/18/2017	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	1	0.05
1	12/26/2017	0	0	0	0	1	0	0	0	0	0	1	0	2	0	0	0	1	2	7	5	0.32
3	12/26/2017	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0
4	12/26/2017	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	12/26/2017	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	1/2/2018	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0
3	1/2/2018	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0
4	1/2/2018	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	1/2/2018	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	1/10/2018	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	1/10/2018	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	1/10/2018	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	1/10/2018	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	1/24/2018	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	1/24/2018	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	1/24/2018	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	1/24/2018	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Weekly trap catch at winter grow-out location

Baseline Evaluation of Pollinator Landscape Plantings Bordering Commercial Potato

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Executive Summary – ***Potatoes and Pollinators*:** This is a report on continuing research to assess the impact of field border plantings of wild flower and/or native species on the population dynamics of pollinators. In 2017, research was directed at answering 3 questions:

1. How do floral plantings affect floral cover and floral richness in the margins of fields?
2. How do floral plantings affect pollinator communities? Do they impact pollinator abundance and richness, and how pollinators disperse into nearby fields?
3. Do floral planting increase predation on Colorado potato beetle (CPB), the main pest of interest in the potato fields we studied?

<u>Question 1:</u>

How do floral plantings affect floral cover and floral richness in the margins of fields?

<u>Hypothesis:</u> Floral plantings will lead to increase floral cover and increased floral richness. (Margins that are planted with flowers will have more flowers and a greater number of species present). This should influence populations of insect pollinators and natural enemies.

<u>Results</u>

<u>Floral Cover -</u> There was a significant effect of treatment on floral cover (p=0.00027) (fig. 1). The x axis refers to whether or not flowers were planted in the margins. “Control” means no flowers were planted, and the margins were left as they were. “Flowers” means the margin was sown with a flower seed mixture. The y axis quantifies how much area is covered by blooms, and accounts for

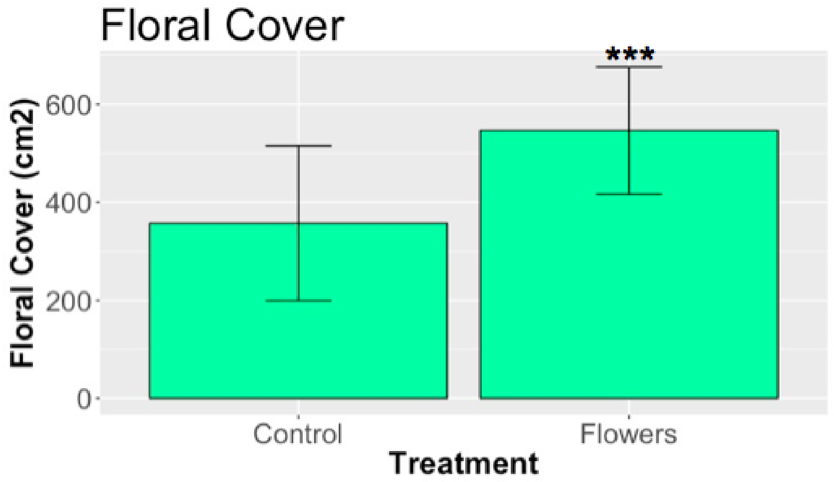

Figure 1. Effect on floral cover of areas planted into pollinator habitat.

both the number of flowers and the size of the flower. It is measured in square centimeters covered by flower blooms. 9
Floral margins had significantly more area covered by blooms throughout the season and across fields.

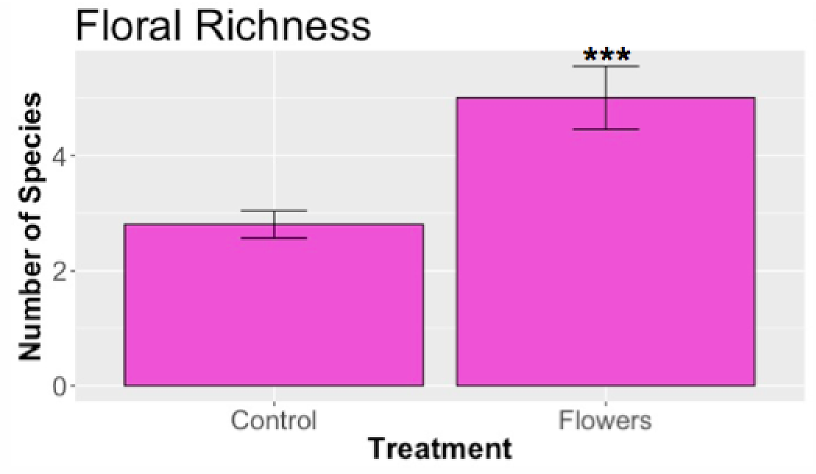

Figure 2. Effect on floral richness of areas planted into pollinator habitat

Floral Richness - There was a significant effect of treatment on floral richness as well ($p=2.2e^{-7}$) (fig. 2). The x axis refers to whether or not flowers were planted in the margins. “Control” means no flowers were planted, and the margins were left as they were. “Flowers” means the margin was sown with a flower seed mixture.
Floral margins had significantly more species of flowers present throughout the season and across fields.

Summary: ***Margins planted with flowers had significantly more area covered by blooms and significantly more species of flowers. This indicates that planting these margins with a floral seed mixture will actually provide a more diverse and dense community of flowers to hopefully benefit pollinators and other beneficial insects.***

Question 2:
How do floral plantings affect pollinator communities? Do they impact pollinator abundance and richness, and how pollinators disperse into nearby fields?

Hypothesis: Floral plantings will lead to increase pollinator abundance and richness. Additionally, they will lead to a greater number of pollinators present in fields adjacent to the margins with floral plantings.

Results

Pollinator Abundance - There was a significant effect of treatment on pollinator abundance (p=0.037) (fig. 3). The x axis refers to whether or not flowers were planted in the margins. “Control” means no flowers were planted, and the margins were left as they were. “Flowers” means the margin was sown with a flower seed mixture.
Floral margins led to significantly higher abundance of pollinators in the margins.

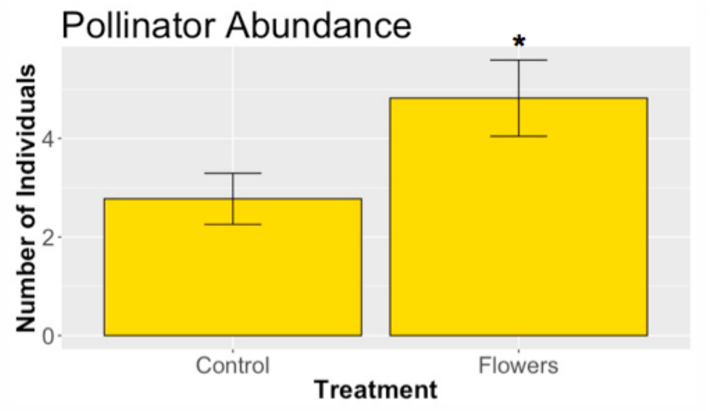

Figure 3. Effect on pollinator abundance of areas planted into pollinator habitat.

<u>Pollinator Richness</u> - There was no effect of treatment on the richness of pollinators in the margins (p=0.63). The x axis refers to whether or not flowers were planted in the margins. “Control” means no flowers were planted, and the margins were left as they were. “Flowers” means the margin was sown with a flower seed mixture. Pollinators were identified to genus, or, in the case of *Apis mellifera*, to species. Hoverflies were also classified as pollinators, but were identified only to family (syrphidae).

Floral margins did not lead to a greater number of pollinator genera present in the margin.

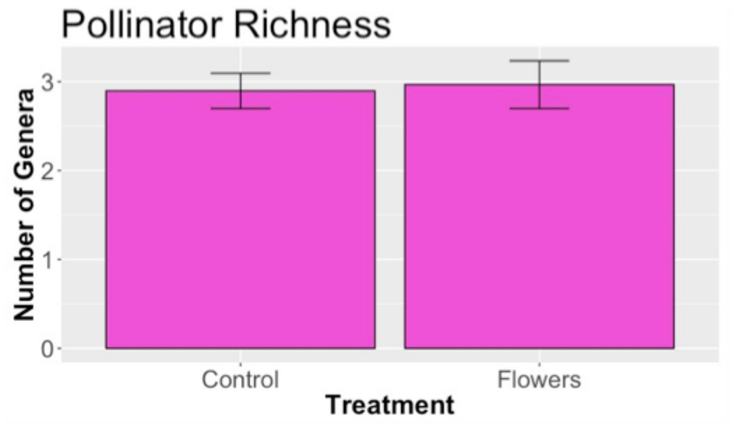

Figure 4. Effect on species richness of pollinators in areas planted into pollinator habitat

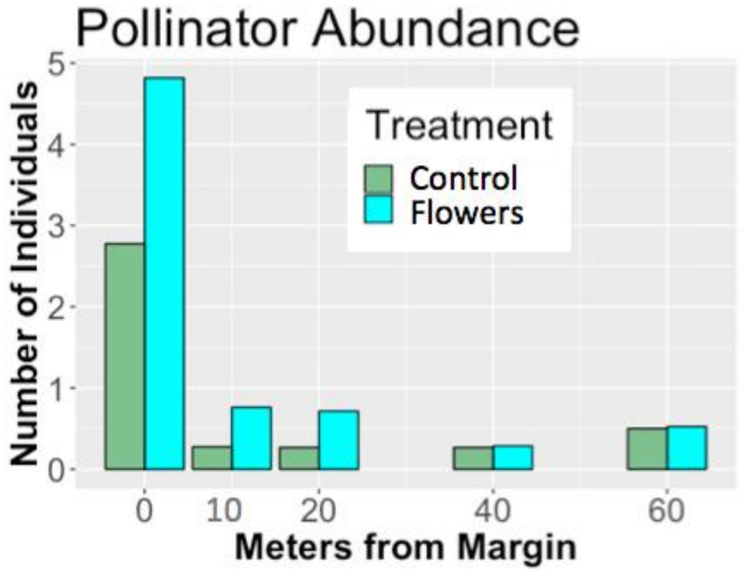

Figure 5. Effect on the abundance of pollinators in areas planted into pollinator habitat.

<u>Pollinator Abundance Moving Into the Field</u> - There was a significant effect of treatment on the number of pollinators present in adjacent fields (p=0.0045), and there was also a significant effect of meters from the margin on the number of pollinators in the field ($p=4.3e^{-5}$) (fig. 5). There was no significant interaction effect between treatment and meters from the margin however (p=0.3035).

The x axis refers to how far into the crop the sampling occurred. 0 meters is the margin of the field, 10 meters is 10 meters into the field, etc. Treatment refers to whether or not flowers were planted in the margins. “Control” means no flowers were planted, and the margins were left as they were. “Flowers” means the margin was sown with a flower seed mixture. “Control” is denoted by the green color, “Flowers” by the teal color.

Flowers led to a greater abundance of pollinators in the margins and in the fields adjacent to floral plantings. Overall, the further into the field we sampled, the fewer pollinators were found. Flowers did not lead to a greater proportional amount of pollinators moving into the field, even though they did lead to a greater overall number of pollinators in the adjacent field.

<u>Summary:</u> ***Floral margins increased the abundance of pollinators both in the margins with flowers and in the fields adjacent t said margins. However, flowers did not attract a more diverse community of pollinators and did not lead to a increase in the rate at which pollinators moved into adjacent crops.***

Question 3:

Do floral planting increase predation on Colorado potato beetle (CPB), the main pest of interest in the potato fields we studied?

Hypothesis: Floral plantings will lead to increased predation of sentinel CPB egg masses in the margins themselves and in the crops adjacent to the floral plantings.

Results

Predation in the Margins - Floral plantings led to significantly more CPB eggs consumed in the margins of fields (p=0.00037) (fig 6). The x axis refers to whether or not flowers were planted in the margins. "Control" means no flowers were planted, and the margins were left as they were. "Flowers" means the margin was sown with a flower seed mixture. The y axis refers to the number of sentinel CPB eggs consumed or found to be missing after 24 hrs. When masses of CPB eggs were placed in the margins, far more were consumed when flowers were present.

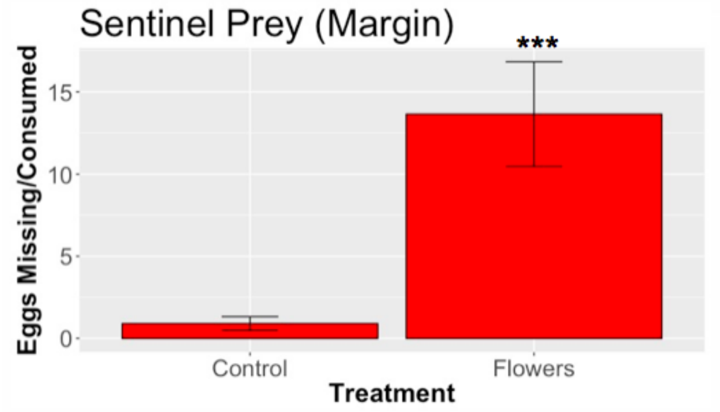

Figure 6. Effect on predation of Colorado Potato Beetle eggs in the margins of fields planted into pollinator habitat.

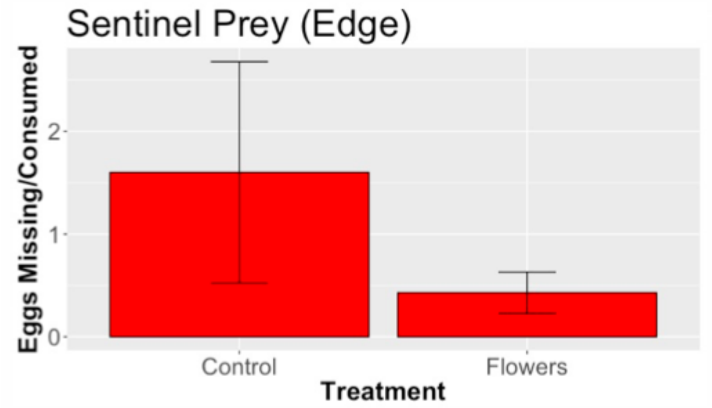

Figure 7. Effect of predation of Colroado Potato Beetle eggs within the crop field whise margin has been planted into pollinator habitat.

Predation in the crop - Floral plantings had no effect on the number of CPB eggs consumed at the edge of the crop (p=0.73) (fig 7). The x axis refers to whether or not flowers were planted in the margins. "Control" means no flowers were planted, and the margins were left as they were. "Flowers" means the margin was sown with a flower seed mixture. The y axis refers to the number of sentinel CPB eggs consumed or found to be missing after 24 hrs. When masses of CPB eggs were placed in at the edge of the crop, almost none were consumed or lost, and their proximity to floral margins had no effect.

Summary

When CPB eggs were placed in the margins themselves, far more the eggs were consumed when flowers were present. However, this effect did not extend into the adjacent crops: few eggs were eaten overall and the present of floral margins did not lead to more eggs being consumed.

Effect of Pyroxasulfone on Potato Cultivars

Submitted to MN Area II Potato Growers and NPPGA

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Seven potato cultivars (Bannock russet, Clearwater Russet, Ivory Russet, Lamoka, Russet Burbank, Russet Norkotah, Shepody, and Umatilla Russet) were planted near Park Rapids, MN on May 8, 2017 in plots measuring 12 ft wide x 25 ft long. Soil characteristics were 69% sand, 22% silt, 9% clay with 1.6% organic matter and a pH of 5.8. Treatments were applied on May 23 as a preemergence treatment with shoots 3 to 4 inches below the top of the hill. All treatments were applied to the center of the plots with a 9-ft-wide boom equipped with XR11002 flat fan nozzles calibrated to deliver 15 gallons per acre. Potatoes emerge on June 1, 2017. Plots were rated for crop injury and weed control at 1, 2 and 4 weeks after emergence. Harvest occurred on September 30, 2017. The experiment was a randomized complete block design with 5 treatments receiving rating during the season and 4 treatments harvested.

Crop injury was not an issue at the 3.5 or 7 oz/a rates of pyroxasulfone. The only cultivar that showed a yield loss was Russet Burbank after being treated with 7 oz/a pyroxasulfone. Potato crop safety to pyroxasulfone was good when treatments were applied with shoots at 3 to 4 inches below the top of the hill. Previous work has found that pyroxasulfone applied to emerged plants can cause significant injury during the growing season.

Table 1. Estimated visual ratings of crop injury and control of common lambsquarters and hairy nightshade in Park Rapids, MN 2017.

			Crop Injury			**Common lambsquaraters**			**Hairy night shade**		
Treatment	**Rate**	**Cultivar**	6/8/17	6/22/17	6/29/17	6/8/17	6/22/17	6/29/17	6/8/17	6/22/17	6/29/17
	oz/a		%								
Non-treated		Bannock	0	0	0	0	0	0	0	0	0
Zidua	3.5	Bannock	0	0	0	100	99	100	100	100	94
Zidua	7	Bannock	0	0	0	100	98	100	100	100	100
Non-treated		Clearwater	0	0	0	0	0	0	0	0	0
Zidua	3.5	Clearwater	0	0	0	100	96	89	100	100	100
Zidua	7	Clearwater	1	0	0	100	76	92	100	100	100
Non-treated		Ivory Russet	0	0	0	0	0	0	0	0	0
Zidua	3.5	Ivory Russet	0	0	0	100	100	100	100	96	100
Zidua	7	Ivory Russet	0	0	0	100	100	100	100	96	100
Non-treated		Lamoka	0	0	0	0	0	0	0	0	0
Zidua	3.5	Lamoka	1	0	0	100	98	100	100	100	100
Zidua	7	Lamoka	0	0	0	100	94	100	100	100	100
Non-treated		Russet Burbank	0	0	0	0	0	0	0	0	0
Zidua	3.5	Russet Burbank	0	0	0	100	96	100	100	96	96
Zidua	7	Russet Burbank	0	0	0	100	100	100	100	87	100
Non-treated		Russet Norkotah	0	0	0	0	0	0	0	0	0
Zidua	3.5	Russet Norkotah	0	0	0	100	98	100	100	100	96
Zidua	7	Russet Norkotah	0	0	0	100	98	94	100	100	100
Non-treated		Shepody	0	0	0	0	0	0	0	0	0
Zidua	3.5	Shepody	0	0	0	100	100	100	100	99	100
Zidua	7	Shepody	0	0	0	100	99	100	100	100	100
Non-treated		Umatilla	0	0	0	0	0	0	0	0	0
Zidua	3.5	Umatilla	0	0	0	97	97	97	97	100	96
Zidua	7	Umatilla	0	0	0	100	94	98	100	100	100
LSD p=0.05			*ns*	*ns*	*ns*	*2*	*13*	*7*	*2*	*5*	*5*

Table 2. Graded yield (cwt/a) of seven cultivars treated with pyroxasulfone in Park Rapids, MN 2017.

Treatment	**Rate**	**Cultivar**	**<4 oz**	**4-6 oz**	**6-10 oz**	**10-14 oz**	**>14 oz**	**Total yield**	**Total Marketable**	**US#1 >4 oz**	**US#2 >4 oz**	**>6 oz**	**>10 oz**
	oz/a		———	———	———	———	———	cwt/a	———	———	———	%	———
Non-treated		Bannock	44	72	131	80	72	398	354	353	1	70	37
Zidua	3.5	Bannock	37	67	147	123	104	477	441	438	3	78	47
Zidua	7	Bannock	33	66	147	106	119	471	438	432	7	79	48
Non-treated		Clearwater	142	145	127	37	7	458	316	313	3	37	10
Zidua	3.5	Clearwater	140	163	141	19	3	467	327	319	8	35	5
Zidua	7	Clearwater	107	152	158	33	11	460	354	347	7	45	10
Non-treated		Ivory Russet	41	89	166	83	60	438	398	391	7	70	31
Zidua	3.5	Ivory Russet	28	58	199	118	77	479	451	439	12	82	41
Zidua	7	Ivory Russet	28	63	181	124	75	471	442	436	6	80	42
Non-treated		Lamoka	54	81	221	128	60	543	490	488	1	75	34
Zidua	3.5	Lamoka	65	101	195	130	63	555	490	489	1	70	35
Zidua	7	Lamoka	42	75	190	144	75	526	484	482	2	78	42
Non-treated		Russet Burbank	72	128	215	105	73	594	522	490	32	66	30
Zidua	3.5	Russet Burbank	63	103	219	129	80	594	531	518	13	72	35
Zidua	7	Russet Burbank	76	113	185	92	51	518	441	421	20	64	28
Non-treated		Russet Norkotah	65	95	219	119	44	542	477	475	2	70	30
Zidua	3.5	Russet Norkotah	59	101	214	149	47	570	511	503	8	72	34
Zidua	7	Russet Norkotah	49	77	209	148	90	573	524	519	5	78	42
Non-treated		Shepody	45	88	163	115	86	497	452	440	12	73	40
Zidua	3.5	Shepody	37	71	168	107	119	502	466	460	6	78	45
Zidua	7	Shepody	44	71	152	140	89	496	452	431	20	77	46
Non-treated		Umatilla	69	111	180	111	63	534	465	455	10	66	33
Zidua	3.5	Umatilla	83	131	204	112	104	633	550	540	11	66	34
Zidua	7	Umatilla	81	115	194	110	77	577	496	489	8	66	32
LSD p=0.05			*27*	*31*	*42*	*35*	*47*	*67*	*68*	*68*	*13*	*10*	*11*

Treatment	Rate	Cultivar	<4 oz	4-6 oz	6-10 oz	10-14 oz	>14 oz	Total yield	Total Marketable	US#1 >4 oz	US#2 >4 oz	>6 oz	>10 oz
	oz/a		-------------------- Tuber number/a --------------------									----- % -----	
Non-treated		Bannock	26,281	23,522	27,443	11,326	6,824	95,396	69,115	68,970	145	48	19
Zidua	3.5	Bannock	19,312	18,876	26,136	14,956	8,422	87,701	68,389	67,808	581	57	27
Zidua	7	Bannock	16,553	18,586	25,991	12,632	9,438	83,200	66,647	65,921	726	58	27
Non-treated		Clearwater	81,748	46,464	26,862	5,082	726	160,882	79,134	78,553	581	21	4
Zidua	3.5	Clearwater	78,989	50,530	29,185	2,759	290	161,753	82,764	81,312	1,452	20	2
Zidua	7	Clearwater	58,370	45,738	32,234	4,356	1,016	141,715	83,345	82,328	1,016	28	4
Non-treated		Ivory Russet	23,377	28,459	33,686	11,326	5,663	102,511	79,134	78,263	871	50	17
Zidua	3.5	Ivory Russet	17,134	19,602	41,818	17,134	7,550	103,237	86,104	85,232	871	65	24
Zidua	7	Ivory Russet	16,117	19,457	35,574	16,553	6,679	94,380	78,263	77,392	871	63	25
Non-treated		Lamoka	30,782	25,410	44,141	17,279	5,808	123,420	92,638	92,492	145	54	19
Zidua	3.5	Lamoka	38,188	32,525	39,930	17,569	6,098	134,310	96,122	95,977	145	47	18
Zidua	7	Lamoka	23,813	24,539	38,333	20,038	7,260	113,982	90,169	89,879	290	58	24
Non-treated		Russet Burbank	41,382	40,366	43,705	14,084	6,824	146,362	104,980	102,076	2,904	44	14
Zidua	3.5	Russet Burbank	37,558	34,074	46,077	17,811	7,550	143,070	105,512	104,350	1,162	50	18
Zidua	7	Russet Burbank	41,092	33,396	35,719	12,052	4,937	127,195	86,104	83,780	2,323	42	14
Non-treated		Russet Norkotah	37,026	29,330	42,544	15,827	4,211	128,938	91,912	91,621	290	49	16
Zidua	3.5	Russet Norkotah	34,993	31,508	42,979	19,602	4,646	133,729	98,736	97,574	1,162	50	18
Zidua	7	Russet Norkotah	28,895	23,813	41,963	20,038	8,422	123,130	94,235	93,509	726	57	23
Non-treated		Shepody	24,974	27,588	31,654	15,101	7,696	107,012	82,038	80,441	1,597	51	21
Zidua	3.5	Shepody	20,183	21,780	33,977	14,665	10,890	101,495	81,312	80,586	726	59	25
Zidua	7	Shepody	25,120	21,635	30,782	18,731	8,131	104,399	79,279	76,230	3,049	55	26
Non-treated		Umatilla	42,253	37,752	38,623	15,827	6,389	140,844	98,591	97,429	1,162	43	16
Zidua	3.5	Umatilla	47,045	41,237	41,382	14,665	9,438	153,767	106,722	104,980	1,742	43	16
Zidua	7	Umatilla	45,012	34,703	38,188	14,230	7,115	139,247	94,235	93,364	871	43	16
LSD p=0.05			15,584	10,019	11,203	5,732	4,480	28,896	20,907	20,933	1,413	15	14

Effect of Pyroxasulfone Tank Mixtures on Russet Burbank and Umatilla Russet

Submitted to MN Area II Potato Growers and NPPGA

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Russet Burbank and Umatilla Russet were planted near Park Rapids, MN on May 5, 2017 in plots measuring 12 ft wide x 25 ft long. Soil characteristics were 76% sand, 18% silt, 8% clay with 1.6% organic matter and a pH of 6.4. Treatments were applied on May 24 as a preemergence treatments with shoots approximately 3 to 4 inches below the top of the hill. All treatments were applied to the center of the plots with a 9-ft-wide boom equipped with XR11002 flat fan nozzles calibrated to deliver 15 gallons per acre. Potatoes emerge on May 30, 2017. Plots were rated for crop injury and weed control at 1, 2 and 4 weeks after emergence. Harvest occurred on September 29, 2017. The experiment was a randomized complete block design with 5 treatments receiving rating during the season and 4 treatments harvested.

Crop injury was the worst when Outlook, Dual or sulfentrazone were included in the treatment. Weed control was relatively good with most treatments. Herbicide control of weeds improved total yield for all treatments compared to the non-treated check. Combining Matrix, Dual or metribuzin seemed to benefit production.

Table 4. Estimated visual ratings of crop injury of Umatilla russet and Russet Burbank. Weed control ratings of common lambsquarters and Eastern black nightshade a 1, 2 and 4 weeks after emergence at Park Rapids, MN 2017.

Treatment		Rate		Umatilla Russet			Russet Burbank			**Common lambsquaraters**			**Eastern black nighshade**		
				Crop Injury			**Crop Injury**			Weed control					
				6/8/17	6/22/17	6/29/17	6/8/17	6/22/17	6/29/17	6/8/17	6/22/17	6/29/17	6/8/17	6/22/17	6/29/17
				%											
1	Non-treated			0	0	0	0	0	0	0	0	0	0	0	0
2	Zidua	3.5	FL OZ/A	0	0	0	0	0	0	96	100	92	100	100	100
3	Zidua	3.5	FL OZ/A	1	2	1	1	2	1	100	98	98	100	100	100
	Matrix	1.5	OZ/A												
4	Zidua	3.5	FL OZ/A	7	0	1	7	0	1	100	95	94	100	100	100
	Outlook	21	OZ/A												
5	Zidua	3.5	FL OZ/A	0	1	2	0	1	2	100	100	100	100	100	100
	Metribuzin	0.5	LB/A												
6	Zidua	3.5	FL OZ/A	0	0	0	0	0	0	100	90	100	100	100	100
	Metribuzin	0.33	LB/A												
7	Zidua	3.5	FL OZ/A	0	1	0	0	1	0	100	100	100	100	100	100
	Metribuzin	0.33	LB/A												
	Prowl H20	2	PT/A												
8	Zidua	3.5	FL OZ/A	7	0	0	7	0	0	100	100	100	100	100	100
	Metribuzin	0.33	LB/A												
	Outlook	16	OZ/A												
9	Zidua	3.5	FL OZ/A	8	0	1	8	0	1	100	97	94	100	100	100
	Dual EC	1	PT/A												
10	Metribuzin	0.5	LB/A	6	0	0	6	0	0	100	97	98	100	100	100
	Dual EC	1	PT/A												
	Reflex	12	OZ/A												
11	Sulfentrazone	2	OZ/A	8	0	2	8	0	2	96	90	85	100	98	97
LSD at p=0.05				*4*	*ns*	*ns*	*4*	*ns*	*ns*	*3*	*9*	*10*	*-*	*2*	*2*

Table 5. Yield of Russet Burbank potato (cwt/a) as affected by various herbicide preemergence treatments in Park Rapids, MN 2017.

Treatment		**Rate**		**<4 oz**	**4-6 oz**	**6-10 oz**	**10-14 oz**	**>14 oz**	**Total yield**	**Total Marketable**	**US#1 >4 oz**	**US#2 >4 oz**	**>6 oz**	**>10 oz**
				cwt/a									%	
1	Non-treated check			142	139	53	13	0	346	205	202	2	18	3
2	Zidua	3.5	FL OZ/A	92	143	212	66	11	523	431	426	6	55	14
3	Zidua	3.5	FL OZ/A	88	152	249	60	32	582	493	490	3	59	16
	Matrix	1.5	OZ/A											
4	Zidua	3.5	FL OZ/A	76	143	191	69	22	501	425	421	4	56	18
	Outlook	21	OZ/A											
5	Zidua	3.5	FL OZ/A	73	138	182	73	24	491	417	413	4	57	19
	Metribuzin	0.5	LB/A											
6	Zidua	3.5	FL OZ/A	76	151	196	54	5	482	405	403	3	53	12
	Metribuzin	0.33	LB/A											
7	Zidua	3.5	FL OZ/A	74	144	204	88	14	524	450	450	0	58	20
	Metribuzin	0.33	LB/A											
	Prowl H20	2	PT/A											
8	Zidua	3.5	FL OZ/A	77	168	203	65	16	528	452	449	3	54	15
	Metribuzin	0.33	LB/A											
	Outlook	16	OZ/A											
9	Zidua	3.5	FL OZ/A	94	180	214	81	16	585	491	482	9	54	17
	Dual EC	1	PT/A											
10	Metribuzin	0.5	LB/A	91	161	213	66	13	543	452	449	3	54	14
	Dual EC	1	PT/A											
	Reflex	12	OZ/A											
11	Sulfentrazone	2	OZ/A	68	137	176	84	18	484	416	408	7	56	20
LSD at p=0.05				*19*	*ns*	*50*	*ns*	*ns*	*ns*	*84*	*83*	*ns*	*8*	*ns*

Table 6. Tuber number per plot of Russet Burbank potato as affected by various herbicide preemergence treatments in Park Rapids, MN 2017.

Treatment		**Rate**		**<4 oz**	**4-6 oz**	**6-10 oz**	**10-14 oz**	**>14 oz**	**Total yield**	**Total Marketable**	**US#1 >4 oz**	**US#2 >4 oz**	**>6 oz**	**>10 oz**
				Tuber number/a									%	
1	Non-treated check			78,989	48,932	22,361	3,340	436	154,057	75,068	74,633	436	11	2
2	Zidua	3.5	FL OZ/A	52,127	46,028	44,141	9,002	1,016	152,315	100,188	99,172	1,016	41	12
3	Zidua	3.5	FL OZ/A	49,949	49,078	52,272	8,422	3,340	163,060	113,111	112,675	436	44	12
	Matrix	1.5	OZ/A											
4	Zidua	3.5	FL OZ/A	42,253	46,028	40,946	9,438	2,323	140,989	98,736	98,155	581	44	15
	Outlook	21	OZ/A											
5	Zidua	3.5	FL OZ/A	42,108	45,012	38,188	9,874	2,468	137,650	95,542	94,961	581	43	16
	Metribuzin	0.5	LB/A											
6	Zidua	3.5	FL OZ/A	44,286	47,916	41,818	7,550	436	142,006	97,720	97,284	436	40	11
	Metribuzin	0.33	LB/A											
7	Zidua	3.5	FL OZ/A	42,398	46,754	42,689	12,342	1,452	145,636	103,237	103,237	0	47	18
	Metribuzin	0.33	LB/A											
	Prowl H20	2	PT/A											
8	Zidua	3.5	FL OZ/A	44,576	54,450	43,270	9,002	1,597	152,896	108,319	107,593	726	41	13
	Metribuzin	0.33	LB/A											
	Outlook	16	OZ/A											
9	Zidua	3.5	FL OZ/A	52,853	58,080	46,174	11,326	1,597	170,029	117,176	116,015	1,162	42	15
	Dual EC	1	PT/A											
10	Metribuzin	0.5	LB/A	50,965	51,836	45,302	9,148	1,307	158,558	107,593	107,158	436	40	12
	Dual EC	1	PT/A											
	Reflex	12	OZ/A											
11	Sulfentrazone	2	OZ/A	42,931	47,045	40,704	11,084	1,791	143,554	100,624	99,656	968	44	17
LSD at p=0.05				*12,428*	*ns*	*14,035*	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*	*8*	*7*

Table 7. Yield of Umatilla russet potato (cwt/a) as affected by various herbicide preemergence treatments in Park Rapids, MN 2017.

Treatment		**Rate**		**<4 oz**	**4-6 oz**	**6-10 oz**	**10-14 oz**	**>14 oz**	**Total yield**	**Total Marketable**	**US#1 >4 oz**	**US#2 >4 oz**	**>6 oz**	**>10 oz**
				cwt/a									%	
1	Non-treated check			114	146	136	36	7	440	326	320	6	40	10
2	Zidua	3.5	FL OZ/A	77	143	217	79	28	543	467	463	3	59	19
3	Zidua	3.5	FL OZ/A	86	156	256	78	33	609	523	512	11	60	18
	Matrix	1.5	OZ/A											
4	Zidua	3.5	FL OZ/A	77	165	246	74	23	585	508	497	11	58	16
	Outlook	21	OZ/A											
5	Zidua	3.5	FL OZ/A	74	149	204	97	56	579	505	502	3	61	26
	Metribuzin	0.5	LB/A											
6	Zidua	3.5	FL OZ/A	83	150	228	116	39	616	533	513	20	62	25
	Metribuzin	0.33	LB/A											
7	Zidua	3.5	FL OZ/A	88	167	243	94	41	633	545	537	8	60	21
	Metribuzin	0.33	LB/A											
	Prowl H20	2	PT/A											
8	Zidua	3.5	FL OZ/A	89	157	241	57	25	568	479	469	10	57	14
	Metribuzin	0.33	LB/A											
	Outlook	16	OZ/A											
9	Zidua	3.5	FL OZ/A	82	165	201	83	44	574	493	484	9	57	22
	Dual EC	1	PT/A											
10	Metribuzin	0.5	LB/A	87	136	234	102	18	577	490	486	4	61	21
	Dual EC	1	PT/A											
	Reflex	12	OZ/A											
11	Sulfentrazone	2	OZ/A	82	141	212	98	64	597	515	507	8	62	27
LSD at p=0.05				*ns*	*ns*	*48*	*ns*	*ns*	*80*	*89*	*86*	*ns*	*12*	*ns*

Table 8. Tuber number per plot of Umatilla russet potato as affected by various herbicide preemergence treatments in Park Rapids, MN 2017.

Treatment		**Rate**		**<4 oz**	**4-6 oz**	**6-10 oz**	**10-14 oz**	**>14 oz**	**Total yield**	**Total Marketable**	**US#1 >4 oz**	**US#2 >4 oz**	**>6 oz**	**>10 oz**
				Tuber number/a									%	
1	Non-treated check			65,630	48,206	29,476	5,082	726	149,120	83,490	82,328	1,162	27	7
2	Zidua	3.5	FL OZ/A	42,979	46,464	46,028	10,745	2,759	148,975	105,996	105,706	290	47	16
3	Zidua	3.5	FL OZ/A	48,642	50,239	53,724	10,745	3,049	166,399	117,757	116,160	1,597	47	15
	Matrix	1.5	OZ/A											
4	Zidua	3.5	FL OZ/A	43,996	54,014	51,546	10,164	2,178	161,898	117,902	116,450	1,452	47	14
	Outlook	21	OZ/A											
5	Zidua	3.5	FL OZ/A	42,253	47,916	42,689	13,504	5,372	151,734	109,481	109,045	436	49	21
	Metribuzin	0.5	LB/A											
6	Zidua	3.5	FL OZ/A	48,061	48,497	48,206	16,117	3,630	164,512	116,450	114,127	2,323	51	22
	Metribuzin	0.33	LB/A											
7	Zidua	3.5	FL OZ/A	48,497	53,579	50,965	12,923	3,920	169,884	121,387	120,516	871	47	17
	Metribuzin	0.33	LB/A											
	Prowl H20	2	PT/A											
8	Zidua	3.5	FL OZ/A	49,949	50,820	51,110	8,131	2,323	162,334	112,385	110,788	1,597	43	12
	Metribuzin	0.33	LB/A											
	Outlook	16	OZ/A											
9	Zidua	3.5	FL OZ/A	45,593	53,143	42,108	11,326	4,211	156,380	110,788	109,336	1,452	44	17
	Dual EC	1	PT/A											
10	Metribuzin	0.5	LB/A	49,368	43,850	49,223	14,230	1,742	158,413	109,045	108,174	871	50	19
	Dual EC	1	PT/A											
	Reflex	12	OZ/A											
11	Sulfentrazone	2	OZ/A	46,464	45,448	44,722	13,794	6,098	156,526	110,062	109,045	1,016	51	22
LSD at p=0.05				*ns*	*ns*	*10,023*	*ns*	*2,725*	*ns*	*16,089*	*16,140*	*ns*	*15*	*11*

Effect of Tank Mixtures with Ethalfluralin on Russet Burbank Potato Production

Submitted to MN Area II Potato Growers and NPPGA

Andrew P. Robinson[1], Eric Brandvik[2] and Peter Ihry[2]

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[2]Department of Plant Sciences, North Dakota State University

Russet Burbank were planted near Park Rapids, MN on May 5, 2017 in plots measuring 12 ft wide x 25 ft long. Soil characteristics were 76% sand, 18% silt, 8% clay with 1.6% organic matter and a pH of 6.4. Treatments were applied on May 24 as a preemergence treatments with shoots approximately 3 to 4 inches below the top of the hill. All treatments were applied to the center of the plots with a 9-ft-wide boom equipped with XR11002 flat fan nozzles calibrated to deliver 15 gallons per acre. Potatoes emerge on May 30, 2017. Plots were rated for crop injury and weed control at 1, 2, 4 and 6 weeks after emergence. Harvest occurred on September 29, 2017. The experiment was a randomized complete block design with 5 treatments receiving rating during the season and 4 treatments harvested.

Crop injury was slight, except for Boundary at 1 week after emergence the metolachlor (Dual) liked caused some injury. Weed control was relatively good with most treatments. Compared to the non-treated check, herbicides improved total yield of all treatments.

Table 9. Visual estimates of crop injury, common lambsquarters and eastern black nightshade weed control following tank mixtures with Sonalan on Russet Burbank potato in Park Rapids, MN 2017.

Treatment		**Crop Injury (%)**				**Common lambsquarters control (%)**				**Eastern Black Nightshade control (%)**			
		8-Jun	**22-Jun**	**29-Jun**	**18-Jul**	**8-Jun**	**22-Jun**	**29-Jun**	**18-Jul**	**8-Jun**	**22-Jun**	**29-Jun**	**18-Jul**
1	Non-treated	0	0	0	0	0	0	0	0	0	0	0	0
2	Eptam 3.5 pt/a + Sonalan 2 pt/a	0	0	0	0	100	95	87	97	84	93	88	100
3	Eptam 4 pt/a + Sonalan 2 pt/a	0	0	0	0	100	100	98	100	88	87	84	100
4	Sonalan 2 pt/a + TriCor 1.5 pt/a	0	0	0	0	100	94	100	100	92	95	98	100
5	Sonalan 2 pt/a + TriCor 1.5 pt/a + Eptam 3.5 pt/a	0	0	4	0	100	100	100	100	93	93	96	100
6	Eptam 3.5 pt/a + TriCor 1.5 pt/a	1	0	0	0	100	100	100	100	100	91	98	100
7	Sonalan 2 pt/a + Linex 1.5 pt/a	0	0	0	0	100	96	98	100	100	100	100	100
8	Sonalan 2 pt/a + Eptam 3.5 pt/a + Linex 1.5 pt/a	2	0	0	0	100	95	98	100	99	95	100	100
9	Boundary 2 pt/a	16	2	0	0	100	100	100	100	98	100	95	100
10	Prowl 2 pt/a	0	1	0	0	82	99	99	100	93	100	100	100
	LSD p=0.05	*2*	*2*	*ns*	-	*10*	*0*	*9*	*3*	*22*	*39*	*11*	-

Table 10. Effects of tank mixtures with Sonalan on Russet Burbank potato yield in Parks Rapids, MN 2017.

Treatment		**<4 oz**	**4-6 oz**	**6-10 oz**	**10-14 oz**	**>14 oz**	**Total yield**	**Total marketable**	**US#1 >4 oz**	**US#2 > 4 oz**	**>6 oz**	**> 10 oz**
		cwt/a									%	
1	Non-treated	108	130	118	36	16	407	299	280	19	42	12
2	Eptam 3.5 pt/a + Sonalan 2 pt/a	79	153	190	65	33	519	440	431	9	55	19
3	Eptam 4 pt/a + Sonalan 2 pt/a	77	145	197	76	27	522	445	435	10	58	20
4	Sonalan 2 pt/a + TriCor 1.5 pt/a	75	146	176	72	28	497	422	412	10	56	20
5	Sonalan 2 pt/a + TriCor 1.5 pt/a + Eptam 3.5 pt/a	80	147	202	77	30	536	456	449	8	58	20
6	Eptam 3.5 pt/a + TriCor 1.5 pt/a	83	158	197	73	8	520	436	430	7	53	16
7	Sonalan 2 pt/a + Linex 1.5 pt/a	69	133	191	64	16	473	404	398	6	58	17
8	Sonalan 2 pt/a + Eptam 3.5 pt/a + Linex 1.5 pt/a	91	161	180	69	29	531	439	423	16	52	18
9	Boundary 2 pt/a	71	148	219	86	37	561	490	480	10	61	22
10	Prowl 2 pt/a	70	138	210	91	22	531	461	444	18	61	21
	LSD p=0.05	*ns*	*ns*	*35*	*ns*	*ns*	*59*	*52*	*55*	*ns*	*9*	*ns*

Table 11. Tuber number per plot of Russet Burbank potato as affected by various herbicide preemergence treatments in Park Rapids, MN 2017.

Treatment		**<4 oz**	**4-6 oz**	**6-10 oz**	**10-14 oz**	**>14 oz**	**Total yield**	**Total marketable**	**US#1 >4 oz**	**US#2 > 4 oz**	**>6 oz**	**> 10 oz**
		Tuber number/a									%	
1	Non-treated	66,792	45,157	27,443	5,227	1,307	145,926	79,134	77,246	1,888	24	5
2	Eptam 3.5 pt/a + Sonalan 2 pt/a	45,738	48,061	39,640	8,567	3,194	145,200	99,462	98,155	1,307	36	8
3	Eptam 4 pt/a + Sonalan 2 pt/a	40,511	42,834	38,768	9,874	2,468	134,455	93,944	92,202	1,742	38	9
4	Sonalan 2 pt/a + TriCor 1.5 pt/a	38,188	39,785	31,799	8,567	2,323	120,661	82,474	81,312	1,162	36	9
5	Sonalan 2 pt/a + TriCor 1.5 pt/a + Eptam 3.5 pt/a	45,157	46,028	41,818	10,309	2,614	145,926	100,769	100,043	726	38	9
6	Eptam 3.5 pt/a + TriCor 1.5 pt/a	42,979	47,190	38,478	9,438	726	138,811	95,832	94,816	1,016	35	7
7	Sonalan 2 pt/a + Linex 1.5 pt/a	36,881	40,075	37,897	8,567	1,452	124,872	87,991	86,830	1,162	39	8
8	Sonalan 2 pt/a + Eptam 3.5 pt/a + Linex 1.5 pt/a	49,804	49,804	36,445	9,293	2,759	148,104	98,300	96,558	1,742	32	8
9	Boundary 2 pt/a	40,220	47,045	45,738	11,471	3,485	147,959	107,738	105,996	1,742	42	11
10	Prowl 2 pt/a	41,237	44,722	45,012	12,632	2,178	145,781	104,544	102,221	2,323	41	10
	LSD p=0.05	*16,013*	*ns*	*9,698*	*ns*	*ns*	*ns*	*17,469*	*ns*	*ns*	*7*	*ns*

Evaluation of Nitrogen Rates on Fumigated and Non-Fumigated Land

Submitted to MN Area II Potato Growers and NPPGA

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Executive Summary

In order to satisfy the demand for quality, the potato industry relies upon the application of soil fumigants to manage soil-borne pathogens commonly affecting the crop. It has been previously determined that fumigation with chloropicrin decreased common scab incidence by 27% and increased marketable yield by 10% relative to non-treated control treatments (Al-Mughrabi et al. 2016). In addition to reduced disease incidence, another consequence of fumigation is that potato plants in fumigated soil have healthier root systems, which may result in a decreased requirement for nutrient inputs. Therefore, the evaluation of nitrogen inputs on fumigated and non-fumigated land in Minnesota is necessary. Although alteration of nitrogen rates may be possible under fumigation, the effects of adjusting nitrogen rate on the skin set of tubers is not well-known. Results from a 2017 field experiment in Big Lake, Minnesota, with Red Norland potatoes suggests that total yield across nitrogen rates was not significantly different. Non-fumigated treatments were determined to have significantly higher yield across nitrogen rates compared to treatments with chloropicrin. However, chloropicrin-treated plots were shown to have significantly lower scab severities. Skin set, measure by resistance to excoriation through a mechanical assay, was also shown to be significantly different among fumigated and non-fumigated plots and among nitrogen rates. Treatments receiving chloropicrin had significantly lower skin set compared to treatments without chloropicrin and skin set was shown to significantly decrease as nitrogen rates increased. These data suggest that additional nitrogen can significantly decrease skin set but may not increase significantly yield.

Research Objectives

1) Determine the effect of nitrogen rate on skin set and tuber quality in Red Norland potatoes.
2) Determine if adjusting the rate of nitrogen on fumigated land results in enhancement of skin set and reduced scab severity.

Current Research

Background

The native periderm covering the surface of potato tubers is composed of phellem, phellogen, and phelloderm cell layers (Lulai, 2007). This periderm is fragile and susceptible to excoriation, or skinning, especially when immature. Skinning injury to the tuber typically occurs during harvesting and handling into storage. The term “skin set” refers to how mature the periderm has become and how resistant it is to skinning injury (Lulai 2007; Lulai and Orr, 1993). As a result of skinning injury, tubers develop wound-related blemishes and defects that significantly reduce quality and can serve as infection courts for pathogens. Blemishes and bruising are particularly problematic for fresh-market potato producers. Therefore, the development of different management approaches to enhance or hasten tuber skin set is important, especially in areas where a large portion of the potato crop is sold fresh, such as in Minnesota. Skinning injuries remain among the most costly and persistent problems of the potato industry (Lulai, 2007). The aim of the current research was to investigate the effect of nitrogen rates on skin set both on fumigated and non-fumigated land and to assess if the adjustment of nitrogen rate could result in improved skin set, reducing skinning injury.

Materials and Methods

The first year of this study was initiated in the fall of 2016. Strike® 100 cp (Chloropicrin) was shank-injected at 100 pounds/acre. Treatments were arranged in a 2x3 factorial in a randomized complete block design with four replications. The experiment was planted into the fumigated area with the variety Red Norland on April 22nd, 2017. A total of 8 treatments were planted (Table 1). Initial nitrogen was applied at planting, and nitrogen applications were also side-dressed at hilling. Later nitrogen applications, depending on the treatment, were applied with overhead irrigation. Two treatments received a baseline nitrogen rate of 185 pounds/acre, one fumigated and one on non-fumigated land (Table 1). Three additional treatments were performed on fumigated and non-fumigated areas each, one with 15 pounds, one with 30 pounds, and one with 45 pounds of additional nitrogen applied per acre over the baseline rate (Table 1). The experiment was vine-killed with desiccant on July 20th, 2017 and plots were harvested on August 14th, 2017. Following the harvesting of this field experiment on August 14th, 2017, tubers were placed in burlap sacks for transport. A total of 25 tubers from each plot were visually evaluated for percentage skinning injury on the tuber surface (0-100%) and percentage scab infection (0-100%).

Skin set assay

Skin set assays were conducted approximately two hours following the harvest of each plot. The assays were performed using a Snap-on Torqometer®, model TQSO50FUA (0-96 oz in/0-678 mNm range). The Torqometer was equipped with a pointer which indicated the maximum torque reading reached in shearing the skin on the tuber surface. A total of 10 tubers were randomly selected from each plot following the two-hour post-harvest interval and three torque readings were recorded for each tuber (Lulai and Orr, 1993). Each of these three readings per tuber were taken from the equatorial region, or middle, of the tuber. The Torqometer testing tip was applied with 17 pounds of contact force normal to the tuber surface during the force measurements (Lulai, 2002). A number one rubber-style stopper with sandpaper adhered to the bottom served as the test tip. Care was exercised to routinely clean and replace the testing tip in order to obtain reproducible measurements (Lulai, 2002). Total force needed to sheer the tuber periderm with the test tip of the Torqometer was indicated by the pointer in inch ounces and was later transformed to milliNewton meters (mNm) (in. oz. = 7.061 mNm).

Statistical Analyses

Percentage Skinning injury and scab severity ratings were analyzed using ANOVA (Proc GLM SAS version 9.3, Cary, NC). Significance among treatments was determined using Fisher's protected LSD test (P = 0.05). Both skin set/excoriation and yield data were analyzed as an RCBD with a 2x3 factorial arrangement using PROC ANOVA in SAS 9.3. There was no significant interaction ($P > 0.05$) between the main effects of fumigation and nitrogen rate.

Results and Discussion

There was no significant interaction between the main effects of fumigation and skin set and main effects are presented individually. Total yield was determined to be significantly higher in non-fumigated treatments compared to treatments receiving chloropicrin (Fig. 1B). Resistance to skinning was also determined to be significantly lower in treatments receiving chloropicrin compared to non-fumigated treatments (Fig. 1A). Data from the first year of this field trail suggest that additional nitrogen on fumigated and non-fumigated land can significantly reduce resistance to excoriation, or skin set (Fig. 2). At a baseline rate of 185 pounds/acre of nitrogen, or zero additional pounds, resistance to excoriation was significantly higher than treatments receiving 15, 30 and 45 additional pounds of nitrogen per acre (Fig. 2A). Treatments which received 15 additional pounds per acre had significantly higher resistance to skinning compared to those with 30 and 45 additional pounds per acre (Fig. 2A). However, yield was not significantly different among nitrogen rates (Fig. 2B).

Similar to excoriation results, treatments receiving additional nitrogen were also determined to have significantly higher percentages skinning injury after harvest (Table 2). Both the chloropicrin-treated and non-treated plots receiving 45 additional pounds of nitrogen, for a total of 230 pounds per acre, had significantly higher skinning injury percentages compared to plots receiving lower nitrogen rates (Table 2). As expected, scab severities were significantly higher in all non-fumigated treatments compared to treatments receiving chloropicrin, regardless of nitrogen rate (Table 2).

Potatoes grown for seed, fresh, and processing are adversely affected by tuber excoriation, or skinning injury. Excoriation is a direct result of inadequate skin set, or periderm maturation, and additional nitrogen may delay tuber maturation. Currently, the sole means of ensuring skin set is vine-killing, which initiates early plant senescence to promote tuber periderm maturation. Results from this study suggest that avoiding excessive nitrogen fertilization may hasten periderm maturation, thus increasing resistance to excoriation and reducing skinning injury on both fumigated and non-fumigated land.

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Table 1. Treatments in a 2017 field trial at Big Lake, MN with Red Norland potatoes to evaluate various nitrogen rates on fumigated and non-fumigated land.

Treatment	Fumigation	Additional Nitrogen / Acre	Total N/acre (lbs.)
1	Chloropicrin	0 lbs Urea/acre	185
2	Chloropicrin	15 lbs Urea/acre	200
3	Chloropicrin	30 lbs Urea/acre	215
4	Chloropicrin	45 lbs Urea/acre	230
5	Non-Fumigated	0 lbs Urea/acre	185
6	Non-Fumigated	15 lbs Urea/acre	200
7	Non-Fumigated	30 lbs Urea/acre	215
8	Non-Fumigated	45 lbs Urea/acre	230

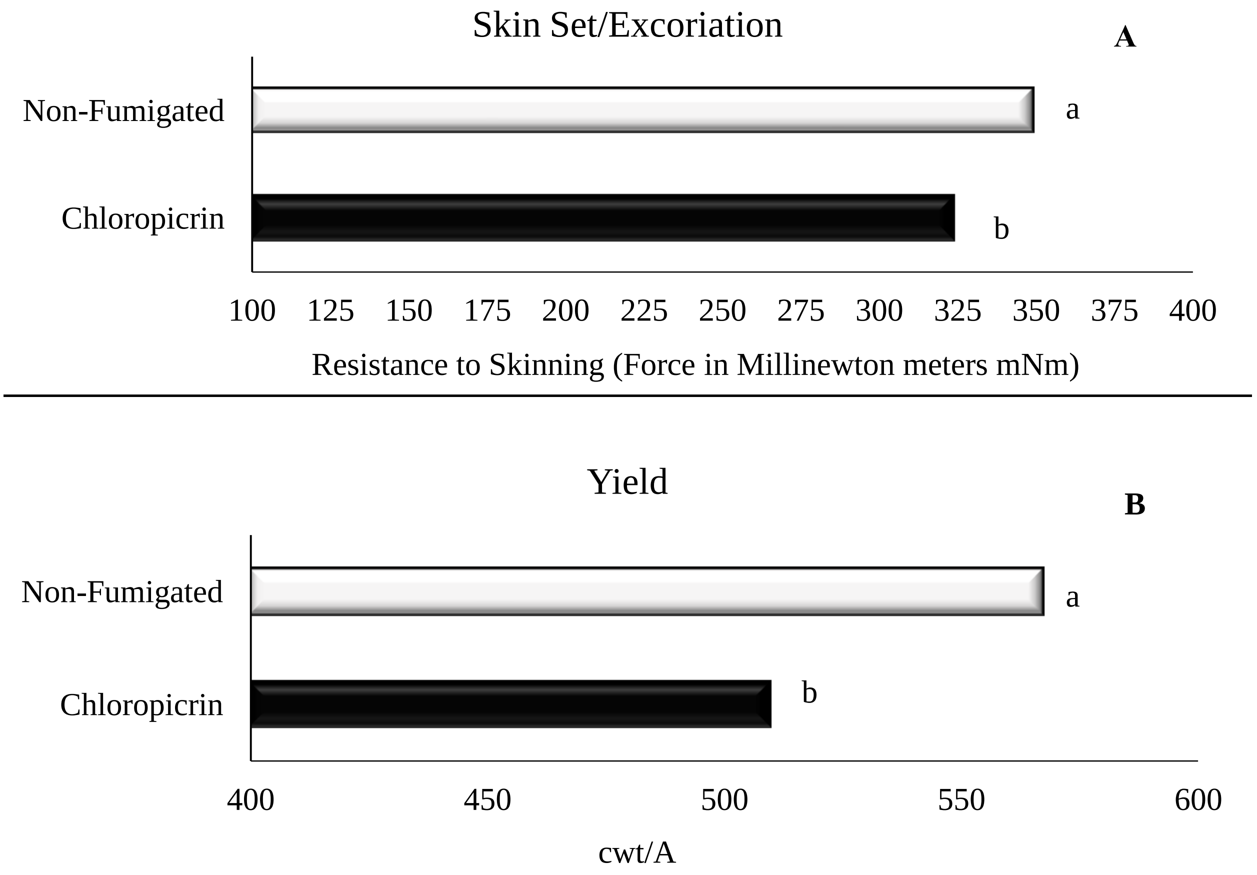

Figure 1. A) Skin set and **B**) yield among fumigated and non-fumigated treatments. Treatments with the same letter are not significantly different according to Fisher’s protected least significant difference test (P=0.05).

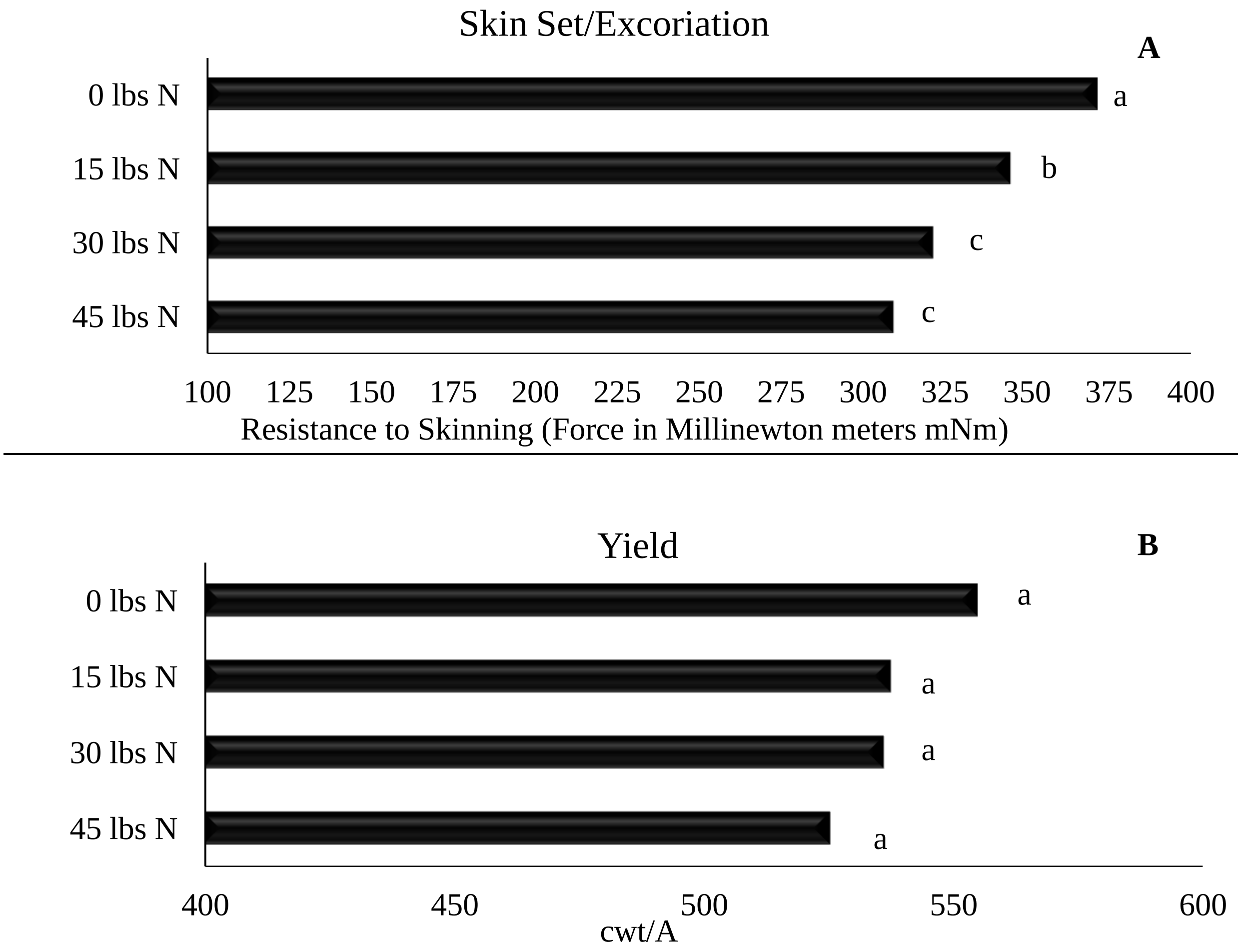

Figure 2. A) Skin set and **B**) yield among treatments with various nitrogen rates. Treatments with the same letter are not significantly different according to Fisher's protected least significant difference test (P=0.05).

Table 2. Percentage skinning and percentage severity of scab (*Streptomyces scabies*) infection across fumigated and non-fumigated treatments with different nitrogen rates.

Treatment[A]	% Skinning	% Scab
Chloropicrin	0.7 bcd	0.7 d
Chloropicrin + Urea 15 lb ai/a	1.1 bcd	0.7 d
Chloropicrin + Urea 30 lb ai/a	1.2 bc	1.0 d
Chloropicrin + Urea 45 lb ai/a	2.4 a	0.6 d
Non-Treated	0.4 d	10.3 a
Urea 15 lb ai/a	0.6 cd	5.6 c
Urea 30 lb ai/a	1.6 b	5.3 c
Urea 45 lb ai/a	2.5 a	8.5 b
LSD (P=0.05)	0.8	1.3

[A] A significant interaction was determined for fumigation x nitrogen rate for both percentage injury and scab severities; Therefore, data for effects are presented together.

Influence of Nitrogen Rate on Early Blight Disease Severity in Potato

Submitted to the MN Area II and NPPGA

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Executive Summary

Resistance to succinate dehydrogenase-inhibiting (SDHI) fungicides, such as boscalid, has developed rapidly in *Alternaria solani*, which causes early blight of potato. This study was initiated to determine the effect of nitrogen rate on early blight severity in a location where boscalid-resistant *A. solani* isolates have been collected at a high frequency and resistance is known to be prevalent. A high, medium, or low rate of nitrogen was applied to four potato varieties which were treated with the fungicides chlorothalonil, mancozeb, or boscalid at weekly intervals for 10 weeks and percentage disease severity was evaluated. Relative area under the disease progress curve (RAUDPC) values were significantly different among nitrogen rates and fungicide regimes. Regardless of variety or fungicide, treatments receiving a low rate of nitrogen had significantly higher RAUDPC values compared to treatments receiving medium or high rates of nitrogen. Although there were no significant differences in total yield, marketable yield also significantly varied among nitrogen rates and fungicide regimes. For example, marketable yield of Ranger Russet potatoes receiving a low rate of nitrogen and treated with boscalid was 262 cwt per acre, which was significantly lower compared to 328 cwt per acre for treatments with a high nitrogen which received boscalid. Preliminary results suggest that higher early blight disease control may be achieved under boscalid application with additional nitrogen fertilization.

Research Objectives

1) Determine the effect of nitrogen rate on early blight disease development in cultivars treated with separate fungicide regimes.
2) Determine if higher levels of early blight control can be achieved with fungicide application under additional nitrogen fertilization.

Current Research

Background

Recent studies have determined that *A. solani* isolates with mutations conferring high levels of resistance to boscalid are prevalent throughout the United States, with greater than 95% of isolates possessing mutations conferring resistance (Bauske et al. 2018). In fact, mutations conferring SDHI resistance were detected in 100% of *A. solani* isolates collected in North Dakota in 2015 (Bauske et al. 2018). Nearly all *A. solani* isolates that possess mutations conferring SDHI resistance also possess resistance to quinone outside-inhibiting (QoI) fungicides by virtue of the substitution of phenylalanine with leucine at position 129 in the *cytb* gene (F129L mutation)(Mallik et al. 2014; Bauske et al. 2018). The aim of this study was to evaluate the effect of nitrogen fertilization on early blight disease severity under different fungicide regimes in an area where SDHI fungicide resistance is known to be prevalent and determine if increased nitrogen can enhance early blight control in addition to fungicides.

Materials and Methods

During the 2017 growing season, a 24-treatment field experiment was conducted at an irrigated research site near Inkster, North Dakota. Four different cultivars including Red Norland, Russet Norkotah, Ranger Russet, and Umatilla Russet were planted on May 31st, 2017. Three different nitrogen rates were evaluated across each cultivar. Nitrogen rates differed among cultivars, with each cultivar receiving the recommended rate, a rate which was 25% lower (75% of recommended rate), and a rate which was 25% higher (125% of recommended rate)(Table 1). All nitrogen applications for each treatment were applied at hilling. Each cultivar receiving one of the three nitrogen rates was also evaluated under two different fungicide regimes (Table 2). Each regime consisted of 10 fungicide applications throughout the growing season, including a protectant schedule consisting of either Dithane® (mancozeb) or Orondis Opti B® (Chlorothalonil) applied at weekly intervals, and a schedule with Endura® (Boscalid) applied at weeks 4 and 7 and a rotation the two protectants (Table 2). The experiment (4 cultivars x 3 nitrogen rates x 2 fungicide regimes = 24 treatments) was arranged as a randomized complete block design with four replications. All foliar fungicides were applied with water volumes of 15 gallons per acre at 55 psi to ensure adequate coverage. Percentage early blight severity was recorded in the center two rows at approximately 7-day intervals beginning in mid-July (about 60-70 days after planting). Early blight disease severity evaluations, taken on a scale of 0-100% diseased leaf tissue, continued for 10 weeks, not surpassing 7 d after the final foliar fungicide application (Pasche and Gudmestad, 2008). All treatments were inoculated twice using four *A. solani* isolates, two possessing the F129L mutation associated with QoI resistance and two wild-type. Isolates were grown under constant fluorescent light for 2 weeks on CV8 medium at room temperature (22 ± 2°C). Distilled water was added to the cultures and conidia were dislodged with a glass rod and diluted in 0.25% gelatin to a concentration of 6.7×10^3 conidia/ml. This suspension was applied to the outside two rows of each four-row treatment at a rate of 104 ml/row on two days, approximately mid-July and early august, using custom ATV application equipment.

Statistical analyses

Percentage early blight severity was used to calculate the area under the disease progress curve (AUDPC) as follows (Shaner and Finney, 1977):

$$\mathrm{AUDPC} = \sum_{\mathrm{i}=1}^{\mathrm{n}} [(\mathrm{W}_{\mathrm{i}+1} + \mathrm{W}_{\mathrm{i}})/2][\mathrm{t}_{\mathrm{i}+1} - \mathrm{t}_{\mathrm{i}}],$$

Where W_{i} is the percentage foliar disease severity at the ith observation, t_{i} the time in days at the ith observation and n the total number of observations. The relative area under the disease progress curve (RAUDPC) was calculated for each treatment of the replicated trials from each year by dividing AUDPC values by the total area of the graph and analyzed using ANOVA (Proc GLM SAS version 9.3, Cary, NC). Fisher's protected LSD test (P = 0.05) was used to differentiate mean RAUDPC values (Pasche and Gudmestad, 2008). Data for graded and total yield were also analyzed using PROC ANOVA and LSDs calculated for total yield, marketable yield, and tubers in various size classes including <4 ounces, 4-6 ounces, 6-10 ounces, 10-14 ounces, and >14-ounce tubers.

Results and Discussion

Percentage foliar early blight severities were significantly different among treatments over the last 9 weeks of evaluation (Table 3). AUDPC values, used as a measure of disease progression over the growing season, were also significantly different among treatments, with the lower rate of nitrogen having significantly higher AUDPC values compared to the higher rate of nitrogen in all of the four cultivars (Table 3). For example, treatments planted to Red Norland receiving 75% of the recommended rate of nitrogen, or 120 pounds/acre, had significantly higher AUDPC values compared to Red Norland treatments receiving 125% of the recommended rate, or 200 pounds/acre. RAUDPC values, which allow comparison of early blight epidemics among treatments, also determined that a higher rate of nitrogen applied in all cultivars resulted in significantly reduced early blight severities compared to the low rate of nitrogen. Furthermore, when comparing severities between the recommended rates of nitrogen in Red Norland and Ranger Russet, 160 and 180 pounds/acre, respectively, to the higher rates in each cultivar, the higher rates were determined to have significantly lower early blight severities even compared to the recommended rates (Table 3).

Significant differences in early blight severities, AUDPC and RAUDPC values were also determined among the two fungicide regimes evaluated. Significantly higher disease severities were observed with the protectant fungicide regime where only Dithane and Orondis Opti B were applied compared to the regime where Endura (Boscalid) was included (Table 3). This was also evident when comparing fungicide regimes among all three rates of nitrogen applied in every cultivar, except Umatilla Russet. For example, at the 75% rate of nitrogen in Red Norland, treatments in which Endura was applied had significantly lower RAUDPC values compared to the same rate of nitrogen in Red Norland treatments which receiving only Dithane and Orondis Opti B (Table 3). Treatments of both Ranger Russet and Russet Norkotah also had significantly lower RAUDPC values when Endura was included in the fungicide regime compared to when only standard protectants were applied (Table 3). For instance, Ranger Russets receiving the recommended nitrogen rate of 180 pounds/acre had an RAUDPC value of 0.085 when only standard protectants were applied, which was significantly higher than an RAUDPC value of 0.068 when Ranger Russets with same nitrogen rate received Endura applications (Table 3). Excluding Umatilla Russet, regardless of cultivar or nitrogen rate, treatments which received Endura applications had significantly lower early blight severity compared to treatments where only the standard protectants were applied (Table 3). Although formulations such as Dithane and Orondis Opti B, which include mancozeb and chlorothalonil, respectively, are the most frequently applied for early blight management, they provide insufficient control under high disease pressure (Gudmestad et al. 2013, Yellareddygari et al. 2016). Therefore, these results are not surprising given that a high level of disease pressure was achieved in this experiment with the combination of natural infection and artificial inoculation. Although resistance to boscalid in *A. solani* is prevalent, its addition to fungicide regimes may be warranted over simply alternating standard protectants. However, it is worth noting that although differences were present, total yield for all treatments in this study were low, regardless of fungicide regime. These uniformly low yields can most likely be attributed to severe early blight infection and suggest that fungicides other than Endura are may be required to achieve sufficient early blight control and minimize losses.

Although significant differences in total yield were observed among cultivars at the end of the growing season, there were no significant difference in total yield determined among nitrogen rates within cultivars (Table 4). Only the Russet Norkotah treatment receiving 125% of the recommended rate of nitrogen and the protectant fungicide regime, which was determined to have a total yield of 400 cwt/acre, was significantly higher than 75% of the recommended rate of nitrogen (Table 4). However, there were significant differences observed in marketable yield among nitrogen rates in treatments of Ranger Russet, with 125% recommended nitrogen and a fungicide regime with Endura having significantly higher marketable yield compared to Ranger Russets with the 75% nitrogen rate (Table 4). Significant differences among size classes in graded yield were also identified in Ranger Russet and Russet Norkotah, with the low nitrogen rate and the protectant fungicide regime resulting in a higher percentage of smaller tubers compared to the same cultivars with the high rate of nitrogen and a fungicide regime including Endura (Table 4).

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Table 1. Nitrogen rates evaluated across each cultivar in 2017.

Cultivar	**Nitrogen Rate (lbs/a)**		
	Low Rate (75 %)	Recommended Rate (100 %)	High Rate (125 %)
Red Norland	120	160	200
Ranger Russet	135	180	225
Russet Norkotah	150	200	250
Umatilla Russet	172.5	230	287.5

Table 2. Fungicide regimes evaluated with each cultivar and nitrogen rate in 2017.

Fungicide Regime		**Active Ingredient (a.i.)**	**Rate**	**Schedule**	**Interval**
Protectant	Dithane M 45	Mancozeb	2 lb/a	1	7 days
	Orondis Opti B	Chlorothalonil	0.75 pt/a	2	
	Dithane M 45	Mancozeb	2 lb/a	3	
	Orondis Opti B	Chlorothalonil	1.5 pt/a	4	
	Dithane M 45	Mancozeb	2 lb/a	5	
	Orondis Opti B	Chlorothalonil	1.5 pt/a	6	
	Dithane M 45	Mancozeb	2 lb/a	7	
	Orondis Opti B	Chlorothalonil	1.5 pt/a	8	
	Dithane M 45	Mancozeb	2 lb/a	9	
	Orondis Opti B	Chlorothalonil	1.5 pt/a	10	
Boscalid	Dithane M 45	Mancozeb	2 lb/a	1	7 days
	Orondis Opti B	Chlorothalonil	0.75 pt/a	2	
	Dithane M 45	Mancozeb	2 lb/a	3	
	Endura	**Boscalid**	4.5 oz/a	4	
	Dithane M 45	Mancozeb	2 lb/a	5	
	Orondis Opti B	Chlorothalonil	1.5 pt/a	6	
	Endura	**Boscalid**	4.5 oz/a	7	
	Orondis Opti B	Chlorothalonil	1.5 pt/a	8	
	Dithane M 45	Mancozeb	2 lb/a	9	
	Orondis Opti B	Chlorothalonil	1.5 pt/a	10	

Table 3. Foliar early blight severity among cultivars, nitrogen rates, and fungicides regimes in 2017.

Cultivar	**Nitrogen (%)**	**Fungicide Regime**	**Foliar Disease (% Severity)**										**AUDPC**	**RAUDPC**
			7/14	7/22	7/28	8/4	8/11	8/18	8/24	9/1	9/8	9/15		
Red Norland	**75**	Protectant	0.00	0.24	0.63	1.28	3.69	8.13	13.44	30.00	52.19	79.38	**1034.14**	**0.148**
Red Norland	**75**	Boscalid	0.00	0.16	0.46	1.16	2.94	7.50	10.63	25.00	44.06	65.00	**861.74**	**0.123**
Red Norland	**100**	Protectant	0.00	0.31	0.54	1.16	3.59	4.75	9.88	26.88	35.00	60.31	**778.46**	**0.111**
Red Norland	**100**	Boscalid	0.00	0.28	0.43	1.13	2.63	4.19	8.31	21.88	29.38	51.25	**650.57**	**0.092**
Red Norland	**125**	Protectant	0.00	0.18	0.32	1.02	2.03	4.38	7.56	13.88	27.50	34.38	**512.36**	**0.073**
Red Norland	**125**	Boscalid	0.00	0.08	0.27	0.91	1.69	3.88	6.81	13.44	23.44	29.38	**450.97**	**0.064**
Ranger Russet	**75**	Protectant	0.00	0.26	0.53	1.02	2.06	6.88	9.94	24.69	46.25	55.94	**828.68**	**0.118**
Ranger Russet	**75**	Boscalid	0.00	0.13	0.41	0.94	1.53	5.13	8.06	21.56	33.44	39.06	**628.53**	**0.090**
Ranger Russet	**100**	Protectant	0.00	0.22	0.50	0.88	1.75	5.63	8.88	14.94	33.13	39.69	**593.00**	**0.085**
Ranger Russet	**100**	Boscalid	0.00	0.21	0.37	0.77	1.34	4.13	8.00	13.38	25.94	29.06	**474.51**	**0.068**
Ranger Russet	**125**	Protectant	0.00	0.14	0.28	0.69	1.00	3.75	6.25	8.19	18.44	20.63	**338.31**	**0.048**
Ranger Russet	**125**	Boscalid	0.00	0.11	0.21	0.50	0.92	3.00	5.00	6.50	14.31	13.44	**256.86**	**0.037**
Russet Norkotah	**75**	Protectant	0.00	0.14	0.41	0.97	2.06	4.69	6.69	15.31	25.31	34.06	**502.56**	**0.072**
Russet Norkotah	**75**	Boscalid	0.00	0.11	0.31	0.77	1.84	3.50	5.50	11.89	15.94	23.44	**356.37**	**0.051**
Russet Norkotah	**100**	Protectant	0.00	0.12	0.36	0.97	1.84	3.31	5.75	10.94	19.06	22.50	**370.71**	**0.053**
Russet Norkotah	**100**	Boscalid	0.00	0.05	0.29	0.77	1.63	3.00	5.13	9.31	11.25	16.88	**274.91**	**0.039**
Russet Norkotah	**125**	Protectant	0.00	0.08	0.17	0.61	0.95	2.44	4.19	6.06	12.56	15.63	**240.81**	**0.034**
Russet Norkotah	**125**	Boscalid	0.00	0.03	0.14	0.47	0.85	1.94	3.19	5.44	10.38	10.56	**191.43**	**0.027**
Umatilla Russet	**75**	Protectant	0.00	0.11	0.25	0.53	0.90	2.06	4.44	6.19	8.56	10.38	**194.34**	**0.028**
Umatilla Russet	**75**	Boscalid	0.00	0.09	0.19	0.39	0.62	1.63	3.75	4.44	5.38	7.38	**138.58**	**0.019**
Umatilla Russet	**100**	Protectant	0.00	0.03	0.22	0.46	0.81	2.06	3.69	5.38	5.63	9.06	**156.70**	**0.022**
Umatilla Russet	**100**	Boscalid	0.00	0.01	0.18	0.37	0.53	1.81	2.94	4.06	4.38	6.25	**119.38**	**0.017**
Umatilla Russet	**125**	Protectant	0.00	0.05	0.13	0.38	0.53	1.63	2.75	2.69	3.19	4.63	**93.36**	**0.013**
Umatilla Russet	**125**	Boscalid	0.00	0.03	0.10	0.24	0.47	1.09	2.00	2.06	2.50	3.44	**69.92**	**0.010**
LSD$_{P = 0.05}$			NS	0.10	0.09	0.15	0.38	0.88	0.95	1.71	1.89	2.02	**25.11**	**0.004**

Table 4. Impact of nitrogen rate and fungicide regime on potato yield and grade in 2017.

Cultivar	Nitrogen (% recommended rate)	Fungicide Regime	Total Yield (cwt/a)	Market Yield (cwt/a)	< 4 oz. (%)	4-6 oz. (%)	6-10 oz. (%)	10-14 oz. (%)	>14 oz. (%)	US No. 1 (cwt/a)	Specific Gravity
Red Norland	**75**	Protectant	304	279	8	17	38	19	18	279	1.0618
Red Norland	**75**	Boscalid	314	279	11	14	39	25	11	279	1.0636
Red Norland	**100**	Protectant	308	273	11	18	42	19	10	273	1.0597
Red Norland	**100**	Boscalid	320	276	13	19	39	17	12	276	1.0596
Red Norland	**125**	Protectant	328	294	10	14	38	25	13	294	1.0608
Red Norland	**125**	Boscalid	326	299	8	11	37	26	18	299	1.0582
Ranger Russet	**75**	Protectant	306	259	15	36	38	8	3	259	1.0948
Ranger Russet	**75**	Boscalid	301	262	13	30	42	13	2	262	1.0917
Ranger Russet	**100**	Protectant	332	296	11	28	35	12	14	296	1.0880
Ranger Russet	**100**	Boscalid	320	286	11	28	40	14	7	286	1.0857
Ranger Russet	**125**	Protectant	360	322	11	21	41	20	7	322	1.0855
Ranger Russet	**125**	Boscalid	359	328	9	23	36	22	10	328	1.0847
Russet Norkotah	**75**	Protectant	314	288	8	12	35	24	21	288	1.0731
Russet Norkotah	**75**	Boscalid	315	294	6	14	36	24	20	294	1.0722
Russet Norkotah	**100**	Protectant	327	303	7	14	37	23	19	303	1.0706
Russet Norkotah	**100**	Boscalid	346	310	10	17	36	22	15	310	1.0707
Russet Norkotah	**125**	Protectant	400	372	7	9	32	26	26	372	1.0635
Russet Norkotah	**125**	Boscalid	365	343	6	14	32	25	23	343	1.0663
Umatilla Russet	**75**	Protectant	284	243	14	22	35	19	10	243	1.0754
Umatilla Russet	**75**	Boscalid	314	266	15	22	36	15	12	266	1.0800
Umatilla Russet	**100**	Protectant	341	284	17	25	32	15	11	284	1.0811
Umatilla Russet	**100**	Boscalid	325	282	13	22	32	21	10	282	1.0756
Umatilla Russet	**125**	Protectant	324	285	12	20	31	20	17	285	1.0778
Umatilla Russet	**125**	Boscalid	308	278	10	12	32	28	18	278	1.0781
LSD$_{P = 0.05}$			63	65	5	8	9	11	12	65	0.0062

Evaluation of a Slow-Release Formulation of Aspire (Mosaic Co.) as a Source of Potassium and Boron for Russet Burbank Potatoes

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Summary

Aspire (Mosaic Co.; 0-0-58-0.5B) is a fertilizer product that resolves the difficulty of uniformly applying small quantities of boron (B) by co-granulating B with potassium (K), which crops require in much larger amounts. In potatoes, an additional challenge with B fertilization is matching the timing of its availability in the soil with crop needs. These are greatest during tuber bulking and maturation, which occur well after most B applied at planting has become unavailable in the soil. One potential solution to this problem is a new, slow-release formulation of Aspire, referred to here as EXPCMT1. To evaluate the effectiveness of EXPCMT1 as a K and B source relative to the original formulation of Aspire, as well as muriate of potash (MOP; 60-0-0) blended with granular B (Granubor; 14.3% B), we applied six treatments at planting in a randomized complete block design. These included: (1) a check treatment receiving no K or B fertilizer; (2) a treatment receiving 300 lbs·ac^{-1} K as MOP (3) a treatment receiving the same rate of K as MOP plus 2.5 lbs·ac^{-1} B as Granubor; (4) a treatment receiving the same rates of K and B as Aspire; (5) a treatment receiving the same rates of K and B as EXPCMT1; and (6) a treatment receiving 40% more K and B (420 lbs·ac^{-1} K and 3.5 lbs·ac^{-1} B) as EXPCMT1. Both K and B fertilization significantly increased tuber yield and size. K fertilization also decreased the prevalence of hollow heart and brown center and decreased tuber dry matter content relative to the check treatment. While both K and B increased yield and tuber size, we found little evidence that the form in which K and B were applied (MOP with Granubor versus Aspire versus EXPCMT1) had any effect on tuber yield, size, or quality. Both Aspire and EXPCMT1 were found to be effective sources of K and B for potato production.

Background

Boron (B) is essential for cell wall integrity and calcium (Ca) absorption, making it important in potato production for tuber internal quality and storability. Our prior research indicates that B also plays a role in increasing tuber size. Because of its high solubility in soil water, B deficiency is relatively common in the sandy, irrigated soils often used for potato production. This deficiency can be corrected with B fertilizers, but because B is required in small quantities, and because there is little margin between B deficiency and B excess, applying B evenly, so that all parts of the field receive it at the correct rate, is challenging.

Potassium (K) is also important in internal tuber quality, storability, and tuber size, as well as tuber yield. Like B, K is often deficient in soils used to grow potatoes, and K fertilization is then needed to maximize tuber yield and quality. Unlike B, K is required in large quantities in potato production, simplifying even application of K. Aspire (Mosaic Co.; 0-0-58-0.5B) is a fertilizer product in which B is co-granulated with K, making it easier to uniformly apply B and avoid pockets of B deficiency or excess in the field.

One disadvantage of many B fertilizers is that they release their B quickly. Because of the high water solubility of B, this means that little residual soil B may be available during tuber bulking and maturation, when plants' B requirements for tuber yield, size, and quality are highest. To address this timing-of-release issue, an experimental slow-release formulation of Aspire, referred to here as EXPCMT1, has been developed.

The objective of this study was to evaluate the effectiveness of the slow-release formulation of Aspire, relative to both the original formulation and traditional blends of granular K with granular B, as a K and B source for Russet Burbank potatoes.

Materials and methods

The study was conducted at the Sand Plain Research Farm in Becker, MN, in 2017, on a Hubbard loamy sand soil. The previous crop was rye. Initial soil characteristics are presented in Table 1. On May 3, six treatments were applied by hand in a randomized complete block design with four replicates: (1) a check treatment receiving no K or B; (2) a treatment receiving 300 lbs·ac^{-1} K as muriate of potash (MOP; 0-0-60); (3) a treatment receiving the same rate of K as MOP plus 2.5 lbs·ac^{-1} B as Granubor granulated B (14.3% B); (4) a treatment receiving the same rates of K and B as Aspire (Mosaic Co.; 0-0-58-0.5B); (5) a treatment receiving the same rates of K and B as the experimental formulation (EXPCMT1, Mosaic Co.; 0-0-58-0.5B); and (6) a treatment receiving 40% more K and B (420 lbs·ac^{-1} K and 3.5 lbs·ac^{-1} B) as EXPCMT1. The treatments are summarized in Table 2.

On May 4, 30 lbs·ac^{-1} N, 140 lbs·ac^{-1} P, 0.5 lbs·ac^{-1} S, and 1 lb·ac^{-1} Zn were broadcast applied as 280 lbs·ac^{-1} monoammonium phosphate (MAP; 11-50-0) and 2.8 lbs·ac^{-1} Blu-Min Zinc-Granular with Sulfur (Kronos Micronutrients; 35.5% Zn, 17.5% S). Planting rows were then opened and planted with Russet Burbank whole "B" seed potatoes, with 36-inch spacing between rows and 12-inch spacing within rows. Each study plot was 12 feet (four rows) wide and 20 feet long, with the central two rows designated as harvest rows. All harvest rows were marked at each end with a single red Chieftain seed potato; the area harvested to determine tuber yield and quality was two rows (six feet) wide by 18 feet long, or 84 square feet. A buffer strip 3 feet wide along the edges of the study field and 5 feet wide along its ends was planted with Russet Burbank potatoes at the same density as the plots.

Belay was applied in-furrow at planting for beetle control, along with the systemic fungicide Quadris. Weeds, diseases, and other insects were controlled using standard practices. Rainfall was supplemented with sprinkler irrigation using the checkbook method of irrigation scheduling. On May 24, 170 lbs·ac^{-1} N and 30 lbs·ac^{-1} S were banded as 327 lbs·ac^{-1} ESN (Environmentally Smart Nitrogen, Agrium, Inc.; 44-0-0) and 125 lbs·ac^{-1} ammonium sulfate (22-0-0-24S) and hilled in. Twenty lbs·ac^{-1} N were applied in each of two post-hilling applications of 28% UAN (urea and ammonium nitrate), on July 6 and 20. In total, 240 lbs·ac^{-1} N were applied to the study field.

Plant stand in the harvest rows was assessed on June 8, and the number of stems per plant was determined for 10 harvest-row plants on June 15. Petioles were samples on June 20 and 29 and July 11 and 25. The petiole of the fourth leaf from the shoot tip was collected from each of 20 shoots per plot. Petiole K and B concentration will be determined on a dry-weight basis by the Research Analytical Laboratory of the University of Minnesota using inductively coupled plasma analysis.

Vines were chopped on September 15, and tubers were harvested on September 27. Total tuber yield and graded yield were measured. Sub-samples of tubers were collected to determine tuber specific gravity and dry matter and the prevalence of hollow heart, brown center, scab, and black scurf.

Results and discussion

Tuber harvest

Tuber harvest results are presented in Table 3. Tuber yield and size both responded significantly to treatments. The check treatment (treatment 1) had significantly lower total and marketable yield, yield in each tuber size category over six ounces, and percentages of yield represented by tubers over six and 10 ounces than any of the remaining treatments, indicating that K fertilization increased both tuber yield and size in this site. The contrast statements found significant positive effects of K fertilization on tuber yield and size.

The treatment receiving MOP without B (treatment 2) had significantly lower total and marketable yield and less of its yield in tubers weighing over six ounces than the treatment receiving 1.4X EXPCMT1 (treatment 6). The remaining treatments, which all received 300 $lbs \cdot ac^{-1}$ K and 2.5 $lbs \cdot ac^{-1}$ B, had values for these variables that were intermediate between these two treatments and not significantly different from either. However, the treatment receiving MOP with Granubor (treatment 3) and the treatment receiving 1.0X EXPCMT1 (treatment 5) had significantly more of their yield in tubers weighing 10 ounces than the treatment receiving MOP alone. The treatment receiving 1.4X EXPCMT1 also had significantly more of its yield in tubers over 10 ounces than the treatment receiving Aspire (treatment 4). The treatment receiving Aspire (treatment 4) had a very similar tuber yield and size distribution to both the treatment receiving MOP with Granubor (treatment 3) and the treatment receiving 1.0X EXPCMT1 (treatment 5). The contrast statements found significant positive effects of B fertilization on tuber yield and size, but also that B fertilization increased the yield of U.S. No. 2 tubers.

Taken together, these results indicate that both K and B fertilization increased tuber yield and size. The plants' K requirements (and possibly their B requirements) were not met by an application rate of 300 $lbs \cdot ac^{-1}$ K (and 2.5 $lbs \cdot ac^{-1}$ B). There was little apparent benefit to co-granulating MOP and B, in terms of tuber production, and the slower-release formulation of EXPCMT1 conferred little benefit over the original formulation of Aspire.

Tuber quality

Tuber quality results are presented in Table 4. Scab was not detected in this study. The prevalence of brown center was significantly greater in the check treatment (treatment 1) than in the plots receiving K, demonstrating a benefit of K fertilization in terms of tuber quality. A similar trend was observed for hollow heart, and the contrast statements found a significant effect of K fertilization on the prevalence of both conditions. The contrast statements also found that K fertilization decreased tuber dry matter content.

Conclusions

Our results demonstrated significant positive effects of fertilization with both K and B on tuber yield and size. In addition, K fertilization decreased the prevalence of hollow heart and brown center, but also decreased tuber dry matter content. Overall, tuber yield and quality with co-granulated MOP and B was similar to a blend of MOP and Granubor. In addition, under the conditions of this study, yield and quality with the slower-release formulation of EXPCMT1 was similar to original formulation of Aspire. Both Aspire and EXPCMT1 were effective sources of K and B for potato production.

Table 1. Soil characteristics of the study site at the Sand Plain Research Farm in Becker, MN, at the beginning of the 2017 season (0 – 6” depth).

Primary macronutrients		Secondary macronutrients			Micronutrients					Other characteristics	
Bray P (ppm)	NH_4OAc-K (ppm)	NH_4OAc-Ca (ppm)	NH_4OAc-Mg (ppm)	SO_4-S (ppm)	DTPA-Fe (ppm)	DTPA-Mn (ppm)	DTPA-Zn (ppm)	DTPA-Cu (ppm)	Hot Water B (ppm)	Water pH	O.M. LOI (%)
17	76	836	146	4	18.6	10.2	1.14	0.36	0.1	5.7	1.6

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

Treatment	K and B sources broadcast before planting[1]	Nutrients applied ($lbs \cdot ac^{-1}$)[2]	
		K_2O	B
1	Check	0	0
2	MOP	300	0
3	MOP + Granubor	300	2.5
4	Aspire	300	2.5
5	EXPCMT1, 1.0X	300	2.5
6	EXPCMT1, 1.4X	420	3.5

[1] MOP (muriate of potash): 0-0-60. Granubor: 14.3% B. Aspire and EXPCMT1: 0-0-58-0.5B.

[2] All treatments received 240 $lbs \cdot ac^{-1}$ N, 140 $lbs \cdot ac^{-1}$ P, 30 $lbs \cdot ac^{-1}$ S and 1 $lb \cdot ac^{-1}$ Zn.

Table 3. Effects of K and B treatments on tuber yield, size, and grade of Russet Burbank tubers at the Sand Plain Research Farm in Becker, MN.

Treatment	K and B sources broadcast before planting[1]	Tuber Yield										
		0-3 oz	3-6 oz	6-10 oz	10-14 oz	>14 oz	Total	#1s > 3 oz.	#2s > 3 oz	Total Marketable	> 6 oz	> 10 oz
		cwt · ac^{-1}									%	
1	Check	30	115	189 b	95 c	30 d	459 c	373 c	86	429 c	68 c	27 d
2	MOP	34	121	231 a	146 b	64 c	596 b	511 ab	85	562 b	74 b	35 c
3	MOP + Granubor	27	108	217 a	153 ab	107 ab	612 ab	497 b	115	585 ab	78 ab	43 ab
4	Aspire	29	102	233 a	161 ab	86 bc	611 ab	511 ab	100	582 ab	79 ab	41 bc
5	EXPCMT1, 1.0X	29	100	237 a	161 ab	93 b	621 ab	510 ab	111	592 ab	79 ab	41 ab
6	EXPCMT1, 1.4X	26	91	228 a	169 a	129 a	642 a	539 a	104	616 a	82 a	46 a
Significance (P-value)		0.8744	0.2881	**0.0249**	**<0.0001**	**0.0003**	**<0.0001**	**<0.0001**	0.1520	**<0.0001**	**0.0033**	**0.0002**
Contrasts	Effect of K	0.6549	0.1361	**0.0024**	**<0.0001**	**<0.0001**	**<0.0001**	**<0.0001**	0.1192	**<0.0001**	**0.0001**	**<0.0001**
	Effect of B	0.2341	**0.0377**	0.8562	**0.0459**	**0.0018**	**0.0352**	0.3649	*0.0733*	**0.0435**	**0.0183**	**0.0036**

[1] MOP: 0-0-60. Granubor: 14.3% B. Aspire and EXPCMT1: 0-0-58-0.5B.

Table 4. Effect of K and B treatments on tuber quality (the prevalence of hollow heart, brown center, and black scurf; tuber dry matter content; and tuber specific gravity) of Russet Burbank tubers at the Sand Plain Research Farm in Becker, MN, in 2017. Scab was not detected in this study.

Treatment	K and B sources broadcast before planting[1]	Hollow heart	Brown Center	Black scurf	Dry matter	Specific gravity
		%				
1	Check	10	13 a	1	24.5	1.0877
2	MOP	1	1 b	1	24.0	1.0869
3	MOP + Granubor	1	1 b	0	23.1	1.0900
4	Aspire	0	0 b	0	23.1	1.0871
5	EXPCMT1, 1.0X	0	0 b	0	23.4	1.0870
6	EXPCMT1, 1.4X	1	1 b	1	23.5	1.0857
Significance (P-value)		0.1568	**0.0195**	0.6813	0.1813	0.6128
Contrasts	Effect of K	**0.0132**	**0.0011**	0.6849	**0.0466**	0.5612
	Effect of B	0.9040	0.8959	0.6248	0.2640	0.9224

[1] MOP: 0-0-60. Granubor: 14.3% B. Aspire and EXPCMT1: 0-0-58-0.5B.

Effects of Foliar Boron Fertilization on Tuber Stolon Retention in Alpine Russet Potatoes

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Summary

Boron (B) plays an important role in plant organ abscission and is therefore expected to be important in the abscission of the stolon from the tuber in potato plants. In addition, B is known to promote potato tuber bulking and decrease tuber reducing sugar concentrations. We hypothesized that heavy foliar applications of B shortly before vine kill would promote stolon abscission in Alpine Russet potatoes (which often retain their stolons after harvest), and that foliar B applied during the growing season would improve tuber bulking and decrease tuber reducing sugar concentrations. To test these possibilities, we planted Alpine Russet potatoes in a site with B-deficient soil (at the Sand Plain Research Farm in Becker, MN) and applied the following six treatments in a randomized complete block design with four replicates: (1) a zero-B check, (2) a treatment receiving 2 lbs·ac^{-1} granular B broadcast at planting, (3) two treatments receiving 2.2 or 4.4 lbs·ac^{-1} foliar B in two applications within 10 days before vine kill, and (4) two treatments receiving 0.8 or 1.2 lbs·ac^{-1} foliar B in six midseason applications plus 2.2 or 4.4 lbs·ac^{-1} foliar B, respectively, within 10 days before vine kill. Tuber size was not significantly affected by treatment, while tuber yield was highest in the zero-B check treatment. The treatment receiving granular B at planting had higher total and marketable yields than those receiving foliar B throughout the growing season, but not those receiving only the heavy applications of foliar B before vine kill. The percentage of tubers retaining their stolons was significantly related to treatment, with the zero-B check treatment retaining a larger percentage of its stolons than four of the five treatments receiving some form of B. However, the treatment receiving1.2 lbs·ac^{-1} foliar B throughout the growing season plus 4.4 lbs·ac^{-1} foliar B shortly before vine kill had an almost identical rate of stolon retention to the check treatment. There were no other significant relationships between the treatment applied and tuber quality variables (including the prevalences of hollow heart, brown center, scab, and black scurf; tuber dry matter content; and tuber specific gravity). These results do not support the hypotheses that B fertilization improves tuber bulking, and they are not entirely consistent with the hypothesis that B fertilization reduces tuber stolon retention. A similar conclusion was obtained when this experiment was conducted at the same research farm in 2016, except that we found no effect of treatment on stolon retention in that year.

Background

Boron (B) is important in the abscission of plant organs from the plant body, as occurs when leaves detach from broadleaf trees in autumn. In particular, B plays a key role in forming a lignified abscission layer, which serves to seal the abscission wound.

Proper abscission of the potato stolon from the tuber improves long-term tuber storage. If an abscission layer does not form, the tuber is more vulnerable to infection if the stolon is broken off. B has been found to be important to successful tuber storage partly because of its role in forming the protective abscission layer.

Alpine Russet potato tubers frequently retain a short length of stolon after harvest. One objective of this study was to evaluate whether the application of a large amount of B within 10 days before vine kill serves to correct this undesirable characteristic of Alpine Russet tubers. To address this question, we compared stolon retention rates in a zero-B check treatment and a treatment receiving the recommended rate of granular B at planting compared with four different treatments receiving 2.2 or 4.4 lbs·ac^{-1} foliar B shortly before vine kill.

B is important to potato plants for many purposes beyond stolon abscission. B-deficient plants produce small tubers with surface cracking and localized browning near the stolon end. B fertilization has been found to enhance tuber bulking in B-deficient soils and to improve tuber storage characteristics by decreasing reducing sugar concentrations. The second objective of this study was to evaluate the effects of light, midseason foliar B applications on tuber size distribution and quality.

Methods

Study design

The study was conducted in 2016 and 2017 at the Sand Plain Research Farm in Becker, MN, on a Hubbard loamy sand soil. Results for 2017 are presented here. In each year, the previous crop was rye. Six treatments were applied in a randomized complete block design with four blocks: (1) a zero-boron check treatment; (2) a treatment receiving 2 lbs·ac^{-1} B as granular Boron 15 broadcast by hand at planting; (3) two treatments receiving a total of either 2.2 or 4.4 lbs·ac^{-1} B as Borosol 10 in two applications in late summer before vine kill; and (4) two treatments receiving 0.8 or 1.2 lbs·ac^{-1} B as Borosol 10 in six light, mid-summer applications plus 2.2 or 4.4 lbs·ac^{-1} B as Borosol 10 in late summer (3.0 or 5.6 lbs·ac^{-1} B as Borosol 10 in total, respectively. These treatments are described in Table 1.

Soil sampling

To measure initial soil characteristics, soil samples to a depth of six inches were collected on April 13. The results of the soil analyses are shown in Table 2.

Planting

On April 22, 24 plots, each 20 feet long and 12 feet wide, were planted with Alpine Russet cut “A” seed with three-foot spacing between rows and one-foot spacing within rows. Plots were arranged three across, with seven, seven-foot-wide alleys running across the rows dividing the plots into eight groups. The field was surrounded by a buffer strip of Alpine Russet potato plants five feet wide on both ends and three feet (one row) wide along each side. Within each plot, the central two rows were designated at harvest rows, and a single Chieftain red potato was planted at each end of each harvest row to mark the harvest rows during the growing season and the boundaries between plots during harvest. SulPoMag (0-0-22-22S-11Mg) was broadcast applied at a rate of 200 lbs·ac^{-1} on April 17, providing 44 lbs·ac^{-1} K, 44 lbs·ac^{-1} S, and 22 lbs·ac^{-1} Mg. At row opening (April 22), 40 lbs·ac^{-1} N, 102 lbs·ac^{-1} P_2O_5, 181 lbs·ac^{-1} K_2O, 40 lbs·ac^{-1} S, 20 lbs·ac^{-1} Mg, and 1 lb·ac^{-1} Zn were banded in as a blend of 222 lbs·ac^{-1} DAP (18-46-0), 180 lbs·ac^{-1} SulPoMag, 235 lbs·ac^{-1} MOP, and 2.8 lbs·ac^{-1} BluMin (17.5% S, 35.5% Zn).

Emergence

The plots were hilled on May 12. During hilling, 200 lbs·ac^{-1} N were banded in as Environmentally Smart Nitrogen (ESN, Agrium, Inc.; 44-0-0) applied at 455 lbs·ac^{-1}. Plant stand was assessed for the harvest rows in each plot on June 1. On June 13, the number of stems per plant was calculated for ten harvest-row plants per plot.

Boron Treatments

One treatment (treatment 2) received 2 lbs·ac^{-1} B as Boron 15, broadcast by hand, on April 21, the day before planting. Two treatments received Borosol 10 in six applications at rates of 1 or 1.5 pints·ac^{-1} per application throughout the growing season (treatments 3 and 4, which received 0.55 and 0.825 lbs·ac^{-1} B, respectively, in these six applications). These applications occurred on June 13, 22, and 29, July 10 and 24, and August 18 (32, 41, 48, 59, 73, and 98 days after hilling, respectively). Four treatments received either 1 gal·ac^{-1} (treatments 3 and 5) or 2 gal·ac^{-1} (treatments 4 and 6) of Borosol 10 in each of two late-summer applications (totaling 2.2 or 4.4 lbs·ac^{-1} B). These heavy applications were made on August 21 and 28 (101 and 108 days after hilling).

Petiole sampling

The petiole of the fourth leaf from the shoot tip was collected from 20 shoots per plot at five times throughout the growing season. Petioles were dried for 24 hours at 140°F, ground, and sent to the Research Analytical Laboratory at the University of Minnesota to be analyzed for B concentration using inductively coupled plasma (ICP) analysis. Petioles were collected on June 14 and 26 and July 5, 18, and 27 (33, 45, 54, 67, and 76 days after hilling, respectively). Petiole B concentration results will be reported when ICP analysis is complete.

Harvest

Vines were chopped on September 5. Tubers were harvested on September 14 (145 days after planting) and sorted by weight and USDA grade. One-hundred 6- to 10-ounce tubers from each plot were examined for stolon remnants. Twenty-five-tuber subsamples were collected for each plot and stored at 45°F for two to three weeks, at which time they were assessed for hollow heart, brown center, scab, and black scurf, and their specific gravity and dry matter content were determined.

Data analysis

Data were analyzed with SAS 9.4m3® software (copyright 2015, SAS Institute, Inc.) using the MIXED procedure. For each dependent variable, treatment and block were used as predictor variables. Means were calculated and post-hoc pairwise comparisons between treatments made using the LSMEANS statement with the DIFF option. Pairwise comparisons were only evaluated where the P-value of the treatment effect in the model was less than 0.10, and pairwise comparisons with P-values less than 0.10 were considered significant.

In each model, four CONTRAST statements were used. The first compared the zero-B check treatment (treatment 1) with the remaining treatments. The second compared the treatment receiving granular B at planting (treatment 2) with the treatments receiving foliar B during the summer (treatments 3 and 4). The third compared the treatments receiving B at planting or during the summer (treatments 2 – 4) with those receiving no treatments prior to 10 days before vine kill (treatments 1, 5, and 6). The fourth contrast compared the treatments receiving one versus two gal·ac^{-1} Borosol 10 within 10 days before vine kill (treatments 3 & 5 vs. treatments 4 & 6).

Results

Tuber yield

Results for tuber yield are presented in Table 3. Total and marketable yields varied significantly among the treatments. The check treatment (treatment 1) and the treatments receiving 2.2 gal·ac^{-1} Borosol 10 without midseason applications (treatment 5) had significantly greater yields than the treatments receiving midseason applications (treatments 3 and 4) or the treatment receiving 4.4 gal·ac^{-1} Borosol 10 with no midseason applications (treatment 6).

Tuber quality

Results for tuber quality are presented in Table 4. The percentage of tubers that retained stolons was related to B treatment ($P = 0.0588$), and the zero-B check treatment (treatment 1) had a greater percentage of tubers with stolons than the other treatments, taken as a group ($P = 0.0346$). However, the treatment receiving summer and pre-vine-kill applications of Borosol 10 at the higher rate (treatment 4) had nearly the same prevalence of stolon retention as the check treatment, and the two treatments were not significantly different in the pairwise comparison ($P = 0.9562$). Scab and black scurf prevalence, tuber dry matter content, and tuber specific gravity were not significantly related to treatment. Hollow heart and brown center were not detected in the tuber quality subsample.

Plant stand and stems per plant

Results for plant stand and the number of stems per plant are presented in Table 5. Plant stand was unrelated to treatment. The number of stems per plant varied significantly at $\alpha = 0.10$ among treatments. Because stem counts were conducted before foliar B treatments were applied, this effect occurred by chance and not as a result of the treatments.

Overall Summary

In this year of this study, we found little evidence for a beneficial effect of B on tuber yield, size, or quality. Tuber size was not related to treatment, nor were most measures of tuber quality. While a larger percentage of tubers retained their stolons in the zero-B check treatment (treatment 1) than in most treatments receiving B, the treatment receiving the largest quantity of B (treatment 4, which received 5.6 lbs·ac^{-1} B in 6 light and 2 heavy applications) had a very similar rate of stolon retention to the check treatment. Boron treatment did have an effect on tuber yield, but it was a negative effect. Total and marketable yields generally decreased as the total amount of B applied increased. In 2016, we found that treatments receiving B had lower tuber specific gravity than those grown in the zero-B check treatment, and that the treatments receiving Borosol 10 in light applications during the summer (treatments 3 and 4) had fewer undersized tubers than those receiving only the heavy applications shortly before vine kill (treatments 5 and 6). No effects of treatment on total or marketable yield, or on tuber stolon retention rates, were observed in that year. In neither year were the results consistent with our predictions. The application of B in this system, regardless of the rate, timing, or form of application (foliar liquid vs. granular soil), had no effect on tuber yield or size. Stolon abscission was not related to treatment in 2016. In 2017, though stolon retention rates were related to treatment, the relationship was not entirely consistent with our hypothesis, because one treatment receiving B had a rate of stolon retention comparable to the zero-B check treatment.

Table 1. B treatments applied to irrigated Alpine Russet potato plants at the Sand Plain Research Farm in Becker, MN, in 2017.

Treatment	B application method[1]	B applied at planting ($lbs·ac^{-1}$)	B applied in summer ($lbs·ac^{-1}$)	B applied before vine kill ($lbs·ac^{-1}$)	Total B applied ($lbs·ac^{-1}$)
1	Zero-B check	0	0	0	0
2	Boron 15 broadcast at planting	2.0	0	0	2.0
3	Borosol 10, 6 X 1 pint/ac summer, 2 X 1 gal/ac before vine kill	0	0.8	2.2	3.0
4	Borosol 10, 6 X 1.5 pint/ac summer, 2 X 2 gal/ac before vine kill	0	1.2	4.4	5.6
5	Borosol 10, 2 X 1 gal/ac before vine kill	0	0	2.2	2.2
6	Borosol 10, 2 X 2 gal/ac before vine kill	0	0	4.4	4.4

[1] Boron 15 is 15% B. Borosol 10 is 10% B and contains 1.1 $lbs·gal^{-1}$ B.

Table 2. Initial soil characteristics in the study site at the Sand Plain Research Farm in Becker, MN, in 2017. Samples were collected to a depth of six inches on April 13.

0 - 6 inches											
Primary macronutrients		Secondary macronutrients			Micronutrients					Other characteristics	
Bray P	K	SO_4-S	Ca	Mg	Zn	Fe	Mn	Cu	B	Organic matter	pH
ppm										%	
27	93	7	547	69	1.575	32.3	22.2	0.60	0.15	1.8	5.2

Table 3. Effect of B treatment on tuber yield, size, and grade for Alpine Russet potato plants grown at the Sand Plain Research Farm in Becker, MN, in 2017. Values within the same column that have a letter in common are not significantly different from each other (i.e. P > 0.10). Letters are only included where the P-value of the effect of B treatment is less than 0.10.

Treatment	**B application method[1]**	**Tuber yield**										
		0-3 oz	**3-6 oz**	**6-10 oz**	**10-14 oz**	**> 14 oz**	**Total yield**	**#1s > 3 oz.**	**#2s > 3 oz**	**Marketable yield**	**> 6 oz**	**> 10 oz**
		cwt·ac^{-1}									**%**	
1	Zero-B check	40	121	253	140	46	600 a	497 ab	103	560 a	73	31
2	2.0 lbs·ac^{-1} as Boron 15 broadcast at planting	39	119	237	142	50	587 ab	498 ab	89	548 ab	73	33
3	3.0 lbs·ac^{-1} in 6 light and 2 heavy Borosol 10 apps	42	136	220	123	42	564 c	471 c	93	522 c	68	29
4	5.6 lbs·ac^{-1} in 6 light and 2 heavy Borosol 10 apps	33	123	237	124	35	552 c	475 bc	78	519 c	72	29
5	2.2 lbs·ac^{-1} in 2 heavy Borosol 10 applications	44	145	229	137	39	595 a	510 a	86	551 a	68	30
6	4.4 lbs·ac^{-1} in 2 heavy Borosol 10 applications	40	138	219	136	33	565 bc	483 bc	82	525 bc	69	30
Treatment significance (P-value)		0.2374	0.2627	0.2865	0.7409	0.4691	**0.0113**	*0.0766*	0.2430	**0.0297**	0.1406	0.9082
Contrasts	Zero-boron check vs. others (1 vs. 2-6)	0.9439	0.2603	*0.0564*	0.5476	0.4129	**0.0169**	0.3621	**0.0457**	**0.0202**	0.1085	0.7228
	Boron preplant vs. foliar (2 vs. 3&4)	0.7614	0.3338	0.5309	0.1940	0.1743	**0.0220**	**0.0477**	0.6850	**0.0305**	0.1532	0.2750
	Effect of early B fertilization (2-4 vs. 1,5&6)	0.2111	0.2642	0.8157	0.3872	0.5717	**0.0243**	*0.0684*	0.5562	*0.0630*	0.4518	0.9970
	Pre-vine-kill application size (3 & 5 vs. 4 & 6)	**0.0406**	0.2765	0.7765	0.9658	0.3497	**0.0376**	0.2519	0.2033	0.1593	0.3091	0.9703

[1] Boron 15 is 15% B. Borosol 10 is 10% B and contains 1.1 lbs·gal^{-1} B.

Table 4. Effect of B treatment on Alpine Russet tuber quality (prevalences of scab, black scurf, and stem retention; tuber try matter content and specific gravity; hollow heart and brown center were absent from the tuber quality subsample) at the Sand Plain Research Farm in Becker, MN, in 2017. Values within the same column that have a letter in common are not significantly different from each other (i.e. P > 0.10). Letters are only included where the P-value of the effect of B treatment is less than 0.10.

Treatment	Boron application method[1]	Tuber quality variables				
		Scab	Black scurf	Tubers with stems	Dry matter (%)	Specific gravity
		% of tubers assessed				
1	Zero-B check	7	8	47.5 a	20.7	1.0831
2	2.0 lbs·ac^{-1} as Boron 15 broadcast at planting	11	9	39.0 b	20.2	1.0952
3	3.0 lbs·ac^{-1} in 6 light and 2 heavy Borosol 10 apps	9	7	35.5 b	20.4	1.0800
4	5.6 lbs·ac^{-1} in 6 light and 2 heavy Borosol 10 apps	3	8	47.3 a	20.2	1.0866
5	2.2 lbs·ac^{-1} in 2 heavy Borosol 10 applications	6	17	38.5 b	21.1	1.0820
6	4.4 lbs·ac^{-1} in 2 heavy Borosol 10 applications	4	10	37.0 b	19.9	1.0797
Treatment significance (P-value)		0.4343	0.7750	*0.0588*	0.3972	0.7494
Contrasts	Zero-boron check vs. others (1 vs. 2-6)	0.8780	0.7306	**0.0346**	0.4241	0.8559
	Boron preplant vs. foliar (2 vs. 3&4)	0.1963	0.8149	0.5489	0.9350	0.2436
	Effect of early B fertilization (2-4 vs. 1,5&6)	0.4232	0.3908	0.8739	0.3436	0.4000
	Pre-vine-kill application size (3 & 5 vs. 4 & 6)	0.1959	0.5628	0.1259	0.1059	0.7910

[1] Boron 15 is 15% B. Borosol 10 is 10% B and contains 1.1 lbs·gal^{-1} B.

Table 5. Mean plant stand and number of stems per plant for each B treatment applied to Alpine Russet potato plants grown at the Sand Plain Research Farm in Becker, MN, in 2017. Values within the same column that have a letter in common are not significantly different from each other (i.e. P > 0.10). Letters are only included where the P-value of the effect of B treatment is less than 0.10.

Treatment	B application method[1]	Plant stand (%)	Stems / plant
1	Zero-B check	99.3	3.15 ab
2	2.0 lbs·ac^{-1} as Boron 15 broadcast at planting	100.0	2.90 bc
3	3.0 lbs·ac^{-1} in 6 light and 2 heavy Borosol 10 apps	97.2	3.40 a
4	5.6 lbs·ac^{-1} in 6 light and 2 heavy Borosol 10 apps	99.3	3.28 ab
5	2.2 lbs·ac^{-1} in 2 heavy Borosol 10 applications	98.6	3.03 abc
6	4.4 lbs·ac^{-1} in 2 heavy Borosol 10 applications	97.9	2.73 c
Treatment significance (P-value)		0.1963	*0.0893*
Contrasts	Zero-boron check vs. others (1 vs. 2-6)	0.4320	0.6364
	Boron preplant vs. foliar (2 vs. 3&4)	*0.0911*	**0.0421**
	Effect of early B fertilization (2-4 vs. 1,5&6)	0.7230	0.1071
	Pre-vine-kill application size (3 & 5 vs. 4 & 6)	0.3903	0.2061

[1] Boron 15 is 15% B. Borosol 10 is 10% B and contains 1.1 lbs·gal^{-1} B.

Effects of Foliar Boron Fertilization on Tuber Skin Set, Color, Yield, and Size in Red Norland Potatoes

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Summary

Boron (B) is important for maintaining the integrity of potato tuber skin and flesh. B deficiency in potatoes has been associated with higher incidence of hollow heart, brown center, and thin, cracked skin with a high susceptibility to skinning during harvest. B has high mobility in the soil, but low mobility in potato tissues once it is removed from the xylem stream; however, based on circumstantial evidence some growers are using multiple foliar B applications to improve tuber quality. The effects of soil and foliar B applications on tuber size and skin integrity of Red Norland potatoes were evaluated in a field study conducted at the Sand Plain Research Farm. The treatments tested were as follows: (1) a zero-B check, (2) a treatment receiving 2 $\text{lbs}\cdot\text{ac}^{-1}$ granular B at planting, (3) two treatments receiving 2.2 or 4.4 $\text{lbs}\cdot\text{ac}^{-1}$ foliar B in two applications within 10 days before vine kill, and (4) two treatments receiving 0.55 or 0.825 $\text{lbs}\cdot\text{ac}^{-1}$ foliar B in four midseason applications plus 2.2 or 4.4 $\text{lbs}\cdot\text{ac}^{-1}$ foliar B, respectively, within 10 days before vine kill. Treatments were replicated four times in a randomized complete block design. B treatments had no significant effect on tuber yield or size, tuber dry matter content, or the prevalences of hollow heart and brown center. The severity of tuber skinning was minimal in all treatments. The treatment receiving granular B at planting had a lower prevalence of severe scab than any other treatment, perhaps indicating that soil B available early in the season plays a role in preventing this condition. Plants receiving the lighter of the two foliar B application rates shortly before vine kill and those receiving granular B at planting produced tubers with deeper-red skin than the zero-B check or the treatments receiving the heavier pre-vine-kill B application. Perhaps the plots receiving the heavier application of foliar B before vine kill had lighter-colored tubers because the plants receiving B at this rate began to die prematurely and were unable to fully mature their tubers, negating the beneficial effects of B on tuber skin color.

Background

Boron (B) plays a role in promoting potato tuber flesh and skin integrity, both through its own role in plant cell wall formation and through its effects on calcium (Ca) absorption and the retention of Ca in cell walls. Potato plants deficient in B produce tubers with symptoms attributable to poor cell wall integrity, such as hollow heart, brown center, and poor skin finishing. Poor skin finishing entails excessive skinning during harvest, thin skin, skin cracking with necrotic flesh beneath the skin, and elevated susceptibility to tuber surface infections such as scab and scurf diseases.

Potatoes have low B requirements, yet B deficiency can occur in sandy soils, which tend to have low B content, or in limed peat soils, which have a high capacity to fix B. To avoid B deficiency symptoms, it is important to correct B deficiencies in such soils with B fertilization.

B may be applied in granular form in the soil or as a foliar spray. B is highly mobile in the soil and in plant xylem, but its mobility in phloem, which varies among plant species, is very poor in potato. Based on circumstantial evidence, some growers are using multiple foliar B applications with the intent of improving tuber quality.

Red Norland is a potato variety that is typically sold as unprocessed tubers direct to consumers. Consumers prefer tubers with unbroken, unblemished skins. Because of its possible role in skin color and integrity, an adequate supply of B is essential to the marketability of Red

Norland potatoes, making this variety useful in evaluating the effects of B fertilization regimes on tuber quality.

The objectives of this study were to evaluate the effect of (1) an in-soil application of granular B (Boron 15; 15% B) at planting relative to light foliar applications of B (Borosol 10; 10% B) later in the season, and (2) an end-of-season heavy foliar B application on tuber yield, size, and quality in Red Norland potatoes.

Methods

Study design

The study was conducted in 2017 at the Sand Plain Research Farm in Becker, MN, on a Hubbard loamy sand soil. The previous crop was rye. Six treatments were applied in a randomized complete block design with four replicates: (1) a zero-B check treatment; (2) a treatment receiving 2 lbs·ac^{-1} B as granular Boron 15 (15% B) hand-broadcast at planting; (3) a treatment receiving 1 pint·ac^{-1} Borosol 10 (10% B) foliar spray in each of four applications during the growing season, plus 1.1 gal·ac^{-1} Borosol 10 in each of two applications approximately two weeks before tuber harvest; (4) a treatment receiving 1.5 pint·ac^{-1} Borosol 10 in each of four applications during the growing season, plus 2.2 gal·ac^{-1} Borosol 10 in each of two applications approximately two weeks before tuber harvest; and (5 and 6) two treatments receiving the same heavy applications of Borosol 10 before tuber harvest as treatments 3 and 4, respectively, but without the light applications during the growing season. These treatments are described in Table 1.

Soil sampling

To measure initial soil characteristics, soil samples to a depth of six inches were collected on April 13. The results of the soil analyses are shown in Table 2.

Planting

On April 22, , 24 plots, each 20 feet long and 12 feet wide, were planted with Red Norland whole “B” seed with three-foot spacing between rows and one-foot spacing within rows. Plots were arranged three across, with seven, seven-foot-wide alleys running across the rows dividing the plots into eight groups. The field was surrounded by a buffer strip of Red Norland potato plants five feet wide on both ends and three feet (one row) wide along each side. Within each plot, the central two rows were designated as harvest rows, and a single Alpine Russet potato was planted at each end of each harvest row to mark the harvest rows during the growing season and the boundaries between plots during harvest. SulPoMag (0-0-22-22S-11Mg) was broadcast applied at a rate of 200 lbs·ac^{-1} on April 17, providing 44 lbs·ac^{-1} K, 44 lbs·ac^{-1} S, and 22 lbs·ac^{-1} Mg. At row opening (April 22), 40 lbs·ac^{-1} N, 102 lbs·ac^{-1} P_2O_5, 181 lbs·ac^{-1} K_2O, 40 lbs·ac^{-1} S, 20 lbs·ac^{-1} Mg, and 1 lb·ac^{-1} Zn were banded in as a blend of 222 lbs·ac^{-1} DAP (18-46-0), 180 lbs·ac^{-1} SulPoMag, 235 lbs·ac^{-1} MOP, and 2.8 lbs·ac^{-1} BluMin (17.5% S, 35.5% Zn).

Emergence

The plots were hilled on May 11. During hilling, 200 lbs·ac^{-1} N were banded in as Environmentally Smart Nitrogen (ESN, Agrium, Inc.; 44-0-0) applied at 455 lbs·ac^{-1}. Plant stand was assessed for the harvest rows in each plot on June 1. On June 13, the number of stems per plant was calculated for ten harvest-row plants per plot.

Boron Treatments

One treatment (treatment 2) received 2 lbs·ac^{-1} B as Boron 15, broadcast by hand, on April 21, the day before planting.

Two treatments received Borosol 10 in four applications at rates of 1 or 1.5 pints·ac^{-1} throughout the growing season (treatments 3 and 4, which received 0.55 and 0.825 lbs·ac^{-1} B, respectively, in these four applications). The applications occurred on June 13, 22, and 29, and July 10 (33, 42, 49, and 60 days after hilling, respectively).

Four treatments (treatments 3 – 6) received either 1 gal·ac^{-1} (treatments 3 and 5) or 2 gal·ac^{-1} (treatments 4 and 6) Borosol 10 in each of two late-summer applications (totaling 2.2 or 4.4 lbs·ac^{-1} B). These heavy applications were made on July 19 and 24 (69 and 74 days after hilling).

Petiole sampling

The petiole of the fourth leaf from the shoot tip was collected from 20 shoots per plot at five times throughout the growing season. Petioles were dried for 24 hours at 140°F, ground, and sent to the Research Analytical Laboratory at the University of Minnesota to be analyzed for B concentration using inductively coupled plasma (ICP) analysis. Petioles were collected on June 14 and 26 and July 5 and 18 (34, 46, 55, and 68 days after hilling, respectively). Petiole B concentration results will be reported when ICP analysis is complete.

Harvest

Vines were chopped on August 1. Tubers were harvested on August 22 (122 days after planting) and sorted by weight and USDA grade. Twenty-tuber subsamples were collected for each plot and stored at 45°F for one month, at which time they were assessed for hollow heart, brown center, scab, and black scurf, and their dry matter content was determined. Tuber skinning severity was assessed on a scale of 1 (< 10% of tuber surface skinned) to 5 (> 80% skinned). Tuber color was visually assessed and scored on a scale of 1 (pale red) to 5 (dark red). In addition, to quantify color, a Minolta CR-200 colorimeter (Konica Minolta, Ramsey, NJ) was used to measure the hue, value (lightness), and chroma (vibrancy) of the skin of each potato in the Munsell color system.

Data analysis

Data were analyzed with SAS 9.4m3® software (copyright 2015, SAS Institute, Inc.) using the MIXED procedure. Treatment and block were treated as fixed effects. For colorimeter readings, which were taken for each individual tuber in the quality samples, plot number was also included as a random effect. Means were calculated and post-hoc pairwise comparisons between treatments made using the LSMEANS statement with the DIFF option. Pairwise comparisons were only evaluated where the P-value of the treatment effect in the model was less than 0.10, and pairwise comparisons with P-values less than 0.10 were considered significant.

In each model, four CONTRAST statements were used. The first compared the zero-B check treatment (treatment 1) with the remaining treatments. The second compared the treatment receiving granular B at planting (treatment 2) with the treatments receiving foliar B during the summer (treatments 3 and 4). The third compared the treatments receiving B at planting or during the growing season (treatments 2 – 4) with those receiving no treatments prior to 10 days before vine kill (treatments 1, 5, and 6). The fourth contrast compared the treatments receiving one versus two gal·ac^{-1} Borosol 10 in each of the two treatments applied within 10 days before vine kill (treatments 3 & 5 vs. treatments 4 & 6).

Results

Tuber yield

Tuber yield results are presented in Table 3. Tuber yield and size did not respond to treatment. Based on contrasts, the treatment receiving granular Boron 15 at planting (treatment 2) had a slightly higher yield of tubers less than 1¾" in diameter than the treatments receiving four light Borsol 10 applications during the summer (treatments 3 and 4).

Tuber quality

Tuber quality results are reported in Table 4. The prevalence of hollow heart and brown center were unrelated to boron treatment, as was tuber dry matter content. The prevalence of scab was related to treatment at $\alpha = 0.1$. The treatment receiving 2 lbs·ac^{-1} B at planting had a lower mean prevalence of scab than the other treatments. Scurf was entirely absent from the tuber quality samples, and all evaluated tubers were less than 10% skinned.

Visual tuber skin color, which ranged from 1 (pale red) to 5 (dark red), was related to treatment at $\alpha = 0.1$. The rate at which Borosol 10 was applied shortly before vine kill was related to tuber skin color, with the treatments receiving the lighter rate (treatments 3 and 5) having darker-red skins than the ones receiving the heavier rate (treatments 4 and 6).

Munsell hue, value, and chroma were not related to treatment, but two of the contrasts were significant at $\alpha = 0.1$. The Borosol 10 application rate shortly before vine kill affected hue scores, with the treatments receiving the lighter rate (treatments 3 and 5) having higher hue scores (colors that were more red and less yellow-red) than those receiving the heavier rate (treatments 4 and 6). The zero-B check treatment also had a lower value score (i.e., darker color) than the other treatments, taken as a group.

The percentage of tubers that were identified by the colorimeter as "red" (as opposed to "yellow-red") was greater in the treatments receiving the lighter application of Borosol 10 before vine kill (treatments 3 and 5) than those receiving the heavier applications (treatments 4 and 6), consistent with the results for visual color and Munsell hue. These results suggest a slight but positive association between B application and red skin color of Red Norland potatoes.

Plant stand and stems per plant

Results for plant stand and the number of stems per plant are presented in Table 5. The number of stems per plant was unrelated to treatment. Plant stand was related to treatment (P = 0.0815), because both plots with less than 100% stand (one with 97.7% stand and one with 95.5% stand) were in treatment 3 (which received 4 applications of 1 pint·ac^{-1} Borosol 10 during the summer and 2 applications of 1 gal·ac^{-1} Borosol 10 shortly before vine kill). Because plant stand was assessed before the first Borosol 10 application, the slight difference in plant stand between treatment 3 and the other treatments was not caused by the treatment applied.

Overall Summary

Treatments receiving less than 3 lbs·ac^{-1} B had slightly darker, redder skins than either the zero-B check treatment or the treatments receiving more than 4 lbs·ac^{-1} B. This suggests that

B fertilization may improve tuber skin color, as expected, but that the effect is negated when very large applications of foliar B are made shortly before vine kill. This result may be attributable to B toxicity resulting from the heavy foliar B applications. It was observed on July 27, eight days after the first heavy B application and 3 days after the second, that the plants in the plots that received these applications had yellower leaves than the plants in the check treatment or the treatment receiving granular B at planting (Figure 1). Plants receiving the heavier of the two application rates of pre-vine-kill foliar B may have been weakened too severely by B toxicity to fully mature their tubers. We found no effect of B treatment on tuber yield or size, nor on the severity of tuber skinning during harvest (which was very low in all treatments). However, the treatment receiving granular B at planting had a lower prevalence of scab than any other treatment. This may indicate that soil B early in the season plays a role in protecting tubers from this condition.

Table 1. B treatments applied to irrigated Red Norland potato plants at the Sand Plain Research Farm in Becker, MN, in 2017.

Treatment	B application method[1]	B applied at planting (lbs·ac^{-1})	B applied in summer (lbs·ac^{-1})	B applied before vine kill (lbs·ac^{-1})	Total B applied (lbs·ac^{-1})
1	Zero-B check	0	0	0	0
2	Boron 15 broadcast at planting	2.0	0	0	2.0
3	Borosol 10, 4 X 1 pint/ac summer, 2 X 1 gal/ac before vine kill	0	0.6	2.2	2.8
4	Borosol 10, 4 X 1.5 pint/ac summer, 2 X 2 gal/ac before vine kill	0	0.8	4.4	5.2
5	Borosol 10, 2 X 1 gal/ac before vine kill	0	0	2.2	2.2
6	Borosol 10, 2 X 2 gal/ac before vine kill	0	0	4.4	4.4

[1] Boron 15 is 15% B. Borosol 10 is 10% B and contains 1.1 lbs·gal^{-1} B.

Table 2. Initial soil characteristics in the study site at the Sand Plain Research Farm in Becker, MN, in 2017. Samples were collected to a depth of six inches on April 13.

0 - 6 inches											
Primary macronutrients		Secondary macronutrients			Micronutrients					Other characteristics	
Bray P	K	SO_4-S	Ca	Mg	Zn	Fe	Mn	Cu	B	Organic matter	pH
ppm										%	
28	101	6	607	75	1.57	32.0	23.1	0.49	0.10	2	5.2

Table 3. Effect of B treatment on tuber yield, size, and grade for Red Norland potato plants grown at the Sand Plain Research Farm in Becker, MN, in 2017. Size categories are delineated by tuber diameter. Values within the same column that have a letter in common are not significantly different from each other (i.e. P > 0.10). Letters are only included where the P-value of the effect of B treatment is less than 0.10.

Treatment	**Boron application method**[1]	**Tuber yield**							
		0" - 1-3/4"	**1-3/4" - 2-1/4"**	**2-1/4" - 2-1/2"**	**2-1/2" - 3"**	**> 3"**	**Total yield**	**#1s**	**#2s**
		cwt·ac^{-1}							
1	Zero-B check	7	17	20	81	421	546	505	41
2	2.0 lbs·ac^{-1} as Boron 15 broadcast at planting	7	13	20	85	427	552	511	41
3	2.8 lbs·ac^{-1} in 4 light and 2 heavy Borosol 10 apps	6	15	19	96	404	540	499	41
4	5.2 lbs·ac^{-1} in 4 light and 2 heavy Borosol 10 apps	5	15	20	83	416	538	496	42
5	2.2 lbs·ac^{-1} in 2 heavy Borosol 10 applications	7	14	19	75	420	535	497	37
6	4.4 lbs·ac^{-1} in 2 heavy Borosol 10 applications	6	14	23	83	423	550	503	47
Treatment significance (P-value)		0.3756	0.7471	0.8609	0.3625	0.8234	0.5819	0.7807	0.9063
Contrasts	Zero-boron check vs. others (1 vs. 2-6)	0.5736	0.1849	0.9437	0.6821	0.8286	0.7195	0.6665	0.8906
	Boron preplant vs. foliar (2 vs. 3&4)	*0.0572*	0.4171	0.9626	0.6137	0.2759	0.1924	0.1898	0.8998
	Effect of early B fertilization (2-4 vs. 1,5&6)	0.4510	0.6014	0.5271	0.1235	0.5607	0.9786	0.9764	0.9352
	Pre-vine-kill application size (3 & 5 vs. 4 & 6)	0.4099	0.9410	0.3783	0.7148	0.5517	0.4100	0.8777	0.3569

[1] Boron 15 is 15% B. Borosol 10 is 10% B and contains 1.1 lbs·gal^{-1} B.

Table 4. Effect of B treatment on Red Norland tuber quality at the Sand Plain Research Farm in Becker, MN, in 2017. Quality variables include the prevalences of hollow heart, brown center and scab; tuber try matter; visual skin color; and Munsell color readings. Visual tuber skinning did not vary within the tuber quality subsample, and scurf was not observed. Values within the same column that have a letter in common are not significantly different from each other (i.e. P > 0.10). Letters are only included where the P-value of the effect of B treatment is less than 0.10.

Treatment	**Boron application method[1]**	**Tuber quality**				**Skin color**	**Munsell color readings**		
		Hollow heart	**Brown center**	**Severe scab**	**Dry matter**	**Visual red (1 = pale, 5 = dark)**	**Hue**	**Value**	**Chroma**
		%							
1	Zero-B check	0	0	74 a	18.3	3.0 bc	5.37	4.30	3.60
2	2.0 lbs·ac^{-1} as Boron 15 broadcast at planting	0	0	45 b	17.7	3.3 abc	5.50	4.39	3.70
3	2.8 lbs·ac^{-1} in 4 light and 2 heavy Borosol 10 apps	0	0	63 a	18.1	3.5 ab	5.96	4.38	3.82
4	5.2 lbs·ac^{-1} in 4 light and 2 heavy Borosol 10 apps	1	1	68 a	18.2	3.0 bc	4.90	4.34	3.55
5	2.2 lbs·ac^{-1} in 2 heavy Borosol 10 applications	0	0	67 a	17.9	4.0 a	5.72	4.37	3.76
6	4.4 lbs·ac^{-1} in 2 heavy Borosol 10 applications	0	1	71 a	18.7	2.5 c	5.37	4.32	3.57
Treatment significance (P-value)		0.4509	0.5987	*0.0648*	0.6572	*0.0571*	0.4934	0.2484	0.8064
Contrasts	Zero-boron check vs. others (1 vs. 2-6)	0.6611	0.5495	0.1223	0.7008	0.4676	0.7635	*0.0646*	0.6654
	Boron preplant vs. foliar (2 vs. 3&4)	0.3332	0.4998	**0.0184**	0.4035	1.0000	0.8882	0.4354	0.9483
	Effect of early B fertilization (2-4 vs. 1,5&6)	0.3332	0.9891	**0.0418**	0.4337	0.7435	0.9242	0.1151	0.7577
	Pre-vine-kill application size (3 & 5 vs. 4 & 6)	0.2396	0.1143	0.4693	0.3176	**0.0052**	*0.0808*	0.1674	0.1794

[1] Boron 15 is 15% B. Borosol 10 is 10% B and contains 1.1 lbs·gal^{-1} B.

Table 5. Mean plant stand and number of stems per plant for each B treatment applied to Red Norland potato plants grown at the Sand Plain Research Farm in Becker, MN, in 2017. Values within the same column that have a letter in common are not significantly different from each other (i.e. P > 0.10). Letters are only included where the P-value of the effect of B treatment is less than 0.10.

Treatment	**B application method**[1]	**Plant stand (%)**	**Stems / plant**
1	Zero-B check	100 a	3.6
2	2.0 lbs·ac^{-1} as Boron 15 broadcast at planting	100 a	3.7
3	2.8 lbs·ac^{-1} in 4 light and 2 heavy Borosol 10 apps	98 b	3.5
4	5.2 lbs·ac^{-1} in 4 light and 2 heavy Borosol 10 apps	100 a	3.8
5	2.2 lbs·ac^{-1} in 2 heavy Borosol 10 applications	100 a	3.4
6	4.4 lbs·ac^{-1} in 2 heavy Borosol 10 applications	100 a	3.7
Treatment significance (P-value)		*0.0815*	0.9545
Contrasts	Zero-boron check vs. others (1 vs. 2-6)	0.4942	0.9443
	Boron preplant vs. foliar (2 vs. 3&4)	0.1380	0.9378
	Effect of early B fertilization (2-4 vs. 1,5&6)	0.1380	0.6970
	Pre-vine-kill application size (3 & 5 vs. 4 & 6)	*0.0742*	0.3703

[1] Boron 15 is 15% B. Borosol 10 is 10% B and contains 1.1 lbs·gal^{-1} B.

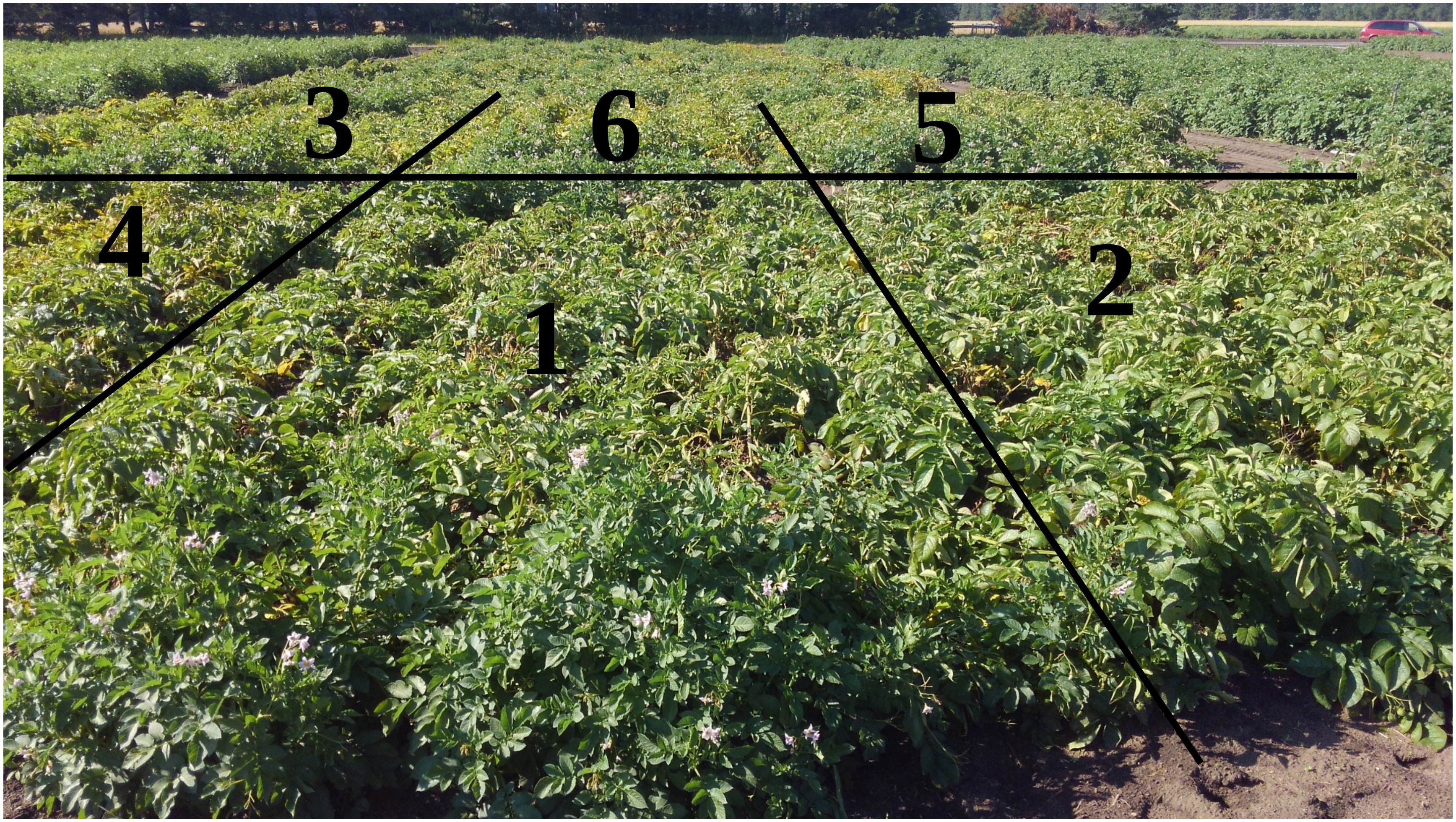

Figure 1. Plots from two adjacent blocks on July 27, 2017 (three days after the final foliar B application), with B treatment numbers indicated. Treatments 3 – 6 received two heavy applications of Borosol 10 (1.1 gal·ac^{-1} per application for treatments 3 and 5; 2.2 gal·ac^{-1} for treatments 4 and 6), while treatments 1 and 2 did not. Treatments 3 – 6 show more advanced yellowing of the leaves than treatments 1 and 2, suggesting B toxicity.

Effects of Fumigation on Nitrogen Response and Soil Microbial Activity in Russet Burbank Potatoes

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Summary

Fumigation is commonly used by potato growers to control soil-borne pathogens. Its short-term benefits include improved disease control and healthier root systems, which may decrease nutrient input requirements. However, fumigation also eliminates beneficial soil organisms, which may depress the soil community's capacity for pathogen control and nutrient cycling. The goal of our research was to determine the effects of fumigation and fumigation source on N response and disease prevalence in Russet Burbank potatoes. We applied treatments in a split-plot randomized complete block design with four blocks. Whole plots received either Chloropicrin, Vapam, or no fumigant, and each whole plot was split into subplots, each receiving N at one of five total rates (including 40 lbs·ac^{-1} N as DAP at planting): (1) 40 lbs·ac^{-1}, 120 lbs·ac^{-1}, 180 lbs·ac^{-1}, 240 lbs·ac^{-1}, and 300 lbs·ac^{-1}. Fumigation treatments were applied in October and November 2016, and N treatments were applied at emergence, on May 11, 2017. Soil 24-hour CO_2 production, NH_4-N, and NO_3-N were determined for six-inch soil samples collected before fumigation in 2016 and before planting, after emergence N application, and after harvest in 2017. Leaflet SPAD readings were taken at five times between hilling and harvest to measure leaf chlorophyll content. The severity of *Verticillium* wilt was assessed from late July until September 12, nine days before harvest. Tuber yield, size, quality (including the prevalence of scab), sugar concentrations, and frying quality were determined after harvest. Soil from the fumigated plots showed low rates of microbial respiration compared to the non-fumigated plots in April and July but converged on non-fumigated levels by harvest. Total and marketable yields were higher in the fumigated plots than in the non-fumigated plots and yields were higher with Vapam than Chloropicrin. Yields tended to increase with N rate regardless of fumigation. The percentage of yield represented by tubers weighing over six or ten ounces was higher and less responsive to N rate in fumigated plots than in non-fumigated plots, suggesting that fumigation may decrease N requirements for both tuber bulking and yield. The fumigated plots, especially those treated with Chloropicrin, had high soil NH_4-N and low NO_3-N relative to the non-fumigated plots, indicating that fumigation may interfere with nitrification. Leaflet SPAD reading increased with N application rate but was slightly higher in the plots receiving either fumigant than in the non-fumigated plots. Plots receiving Chloropicrin had a lower prevalence of scab than those receiving Vapam or no fumigant. Tuber specific gravity was higher in plots receiving Vapam than in non-fumigated plots, with Chloropicrin-treated plots intermediate. Fumigation generally decreased tuber sucrose concentrations at harvest (though Vapam did not decrease stem-end sucrose), but it had no effect on tuber glucose concentrations, which is more relevant to frying quality. Tuber glucose concentrations, as well as stem-end tuber sucrose concentrations, decreased as N application rate increased. Neither fumigation nor N application rate affected French fry quality. Overall, we found that, while fumigation increased marketable yield at all N rates tested and decreased N requirements for tuber bulking and yield, it decreased soil microbial activity during the growing season.

Background

Fumigation of potato fields to control pathogens has well-known short-term benefits. Most directly, fumigation decreases disease incidence. An apparent consequence of this is that potato plants in fumigated soil have healthier root systems, which may result in a decreased requirement for nutrient inputs. However, a major drawback of soil fumigation is that it eliminates beneficial soil organisms in addition to the pathogens. The benefits such organisms provide include pathogen control and nutrient cycling activities. Consequently, once a field is fumigated, additional applications of fumigant are required to control pathogens each time potatoes are planted in the field and nutrient cycling may be disrupted during and beyond the years when fumigant is applied.

The objectives of this study were to: 1) determine the effects of Vapam and Chloropicrin fumigation on potato response to N fertilizer, and 2) characterize the effect of fumigation on soil microbial activity and nitrogen transformations.

Methods

Study design

The study was conducted at the Sand Plain Research Farm in Becker, Minnesota, on a Hubbard loamy sand soil. Initial soil characteristics are presented in Table 1. The previous crop was soybeans. The plots had been cropped to potatoes in a 3 to 4 year rotation for the past 25 years, without fumigation. Fumigation treatments were arranged in a randomized complete block design with four blocks and three fumigation treatments. The fumigation treatments were: no fumigation, with cultivation on October 24, 2016; cultivation on October 18, 2016, followed by fumigation with Chloropicrin on October 19, 2016 at 100 lbs/A applied in strips; and cultivation on October 24, 2016, followed by fumigation with Vapam at 70 gallons/A injected at 6” and 10” on November 10.

Five N fertilization treatments were arranged as randomized subplots within each fumigation plot, as a split-plot randomized complete block design. Each subplot was 20 feet long and 21 feet wide. The subplots within each plot were separated by a 7-foot-wide alley running across the planting rows. All subplots received 40 $lbs \cdot ac^{-1}$ N as DAP at planting, plus 0, 80, 140, 200, or 260 $lbs \cdot ac^{-1}$ N as ESN at emergence, depending on the assigned N treatment.

The subplots were arranged in six columns and ten rows, with the columns running parallel to the planting rows for the length of the field (306 feet) and the rows running across the planting rows for the width of the field (150 feet). Two, 8-foot-wide alleys were placed between every two columns, and irrigation lines were placed along these alleys and the field edges (four lines in total, with 50-foot spacing between lines). A single alley, 30 feet wide, was placed between the fifth and sixth rows of subplots, separating blocks 1 and 2 from blocks 3 and 4. A summary of the treatments is presented in Table 2.

Soil sampling

Soil samples to a depth of 6 inches were collected on October 17, 2016, and April 13, July 5, and October 13, 2017. The samples were dried at 95°C for 48 hours, ground, and subsamples were extracted with 2N KCl. The extracts are being analyzed for NH_4-N and NO_3-N concentrations using a Wescan nitrogen analyzer; results will be presented when this analysis is complete.

The soil microbial respiration rate was determined for a 40-g subsample of each sample using Solvita Soil CO_2 Burst Test kits (Woods End Laboratories), which measure the amount of CO_2 a wetted sample emits in a 24-hour period. The sample was placed a 150-mL plastic beaker inside a glass jar and wetted to achieve 50% water-filled pore space. A CO_2-detecting gel on a plastic paddle was placed inside the jar but outside the beaker, and the jar was sealed with a plastic lid with a CO_2-proof rubber gasket. The jars were incubated at 20°C for exactly 24 hours. The CO_2-detecting gel was immediately analyzed with a Solvita Digital Color Reader to measure the CO_2 concentration in the jar in ppm. A duplicate of one subsample, as well as a standard, were run with each set of Solvita tests to ensure accuracy.

Planting and N treatments

The subplots were planted with Russet Burbank whole "B" seed potatoes on April 25, 2017, with one-foot spacing within rows and three-foot spacing between rows. Each subplot was seven rows wide. In each subplot, the fourth and fifth rows from the irrigation alley were designated as harvest rows. In these two rows, the first and last seed potato in each subplot was replaced with a Chieftain cut "A" seed potato to identify the boundaries between subplots during harvest. Each adjacent pair of whole plots was surrounded by a buffer strip of Russet Burbank potato plants five feet wide on the ends and three feet (one row) wide along the sides. At row opening, 40 lbs·ac^{-1} N, 102 lbs·ac^{-1} P_2O_5, 181 lbs·ac^{-1} K_2O, 40 lbs·ac^{-1} S, 20 lbs·ac^{-1} Mg, 1 lb·ac^{-1} Zn, and 0.6 lbs·ac^{-1} B were banded in as a blend of DAP (18-46-0), MOP (0-0-60), SulPoMag (0-0-22-20S-10Mg), BluMin (0-0-0-0.5S-1Zn), and Boron 15 (0-0-0-15B). Environmentally Smart Nitrogen (ESN; 44-0-0; Agrium, Inc.) was hand-broadcast on subplots per the assigned N treatments shortly after shoot emergence, on May 11, and then hilled in.

Plant stand, leaflet SPAD readings, and petiole NO_3-N

For each plot, plant stand in the harvest rows were recorded on June 8. The number of stems per plant for ten plants in the harvest rows were recorded on June 13. On 5 days throughout the summer, relative greenness in the terminal leaflet of the fourth leaf from the tip of 20 shoots per plot was recorded with a SPAD meter, generating a single average SPAD meter reading for each plot. SPAD readings were taken on June 15 and 27, July 11 and 25, and August 8 (i.e., 35, 47, 61, 75, and 89 days after the emergence fertilizer was applied). On the same days that SPAD readings were collected, the petiole of the fourth leaf from the tip was collected from each of 20 shoots per plot.

Harvest, tuber quality, and tuber sugars and fry color

Tubers were harvested on September 21 (149 days after planting) and sorted by size and USDA grade. Representative 25-tuber samples were evaluated for hollow heart, brown center, dry matter content, and specific gravity. Representative 20-tuber subsamples from each plot were sent to USDA-ARS (East Grand Forks, MN) to determine the sucrose and glucose concentrations of the stem and bud ends of the tubers. Samples from the stem and bud ends were French-fried by USDA on October 10 and 11, and their reflectance was determined using a Photovolt reflectometer.

Data analysis

The data were analyzed with SAS 9.4m3® software (copyright 2015, SAS Institute, Inc.) using the MIXED procedure. For each dependent variable, fumigation treatment, N treatment, their interaction, and block were treated as fixed effects, while the interaction between block and fumigation treatment (the factor differentiating whole plots) was treated as a random effect. Denominator degrees of freedom were estimated using the Kenward-Roger approach (the KENWARDROGER option in SAS). Marginal means for dependent variables were determined using the LSMEANS statement, and post-hoc pairwise comparisons (alpha = 0.10) were conducted using the DIFF option. Pairwise comparisons are only presented where the significance (P-value) of fumigation, N treatment, or their interaction in the model is less than 0.10.

Results and discussion

Tuber yield, size, and grade

Tuber yield, size, and grade results are presented in Table 3. Total and marketable yield were related to both fumigation treatment and nitrogen application rate. The treatments receiving Vapam had higher yields than those receiving Chloropicrin, which had higher yields than the non-fumigated treatments, averaged across N application rates. Yields increased with increasing N application rate, especially between 0 and 140 lbs·ac^{-1} N at emergence (40 and 180 lbs·ac^{-1} N total), averaged across fumigation treatments. The non-fumigated plots showed a stronger response to N rate than the plots receiving either fumigant, but the effect of the interaction between fumigation treatment and N application rate was not quite significant for either total or marketable yield.

The percentage of yield represented by tubers weighing over six ounces was lower in the non-fumigated plots than in those receiving Chloropicrin or Vapam, and a parallel but non-significant difference was observed for the percentage of yield represented by tubers over ten ounces. For both tuber-size thresholds, the percentage of yield in large tubers increased as the application rate of N increased, especially between 0 and 140 lbs·ac^{-1} N applied at emergence. The non-fumigated control plots showed a much stronger response of the percentage of yield in tubers over six or ten ounces to N rate between 0 and 80 lbs·ac^{-1} N applied at emergence than did the plots receiving Chloropicrin or Vapam. As a result, the effect of the interaction between fumigation treatment and N rate was significant for both variables.

Tuber quality

Tuber quality results are presented in Table 4. The prevalence of hollow heart and brown center was higher in the subplots receiving 140 lbs·ac^{-1} N at emergence than those receiving other rates. Each fumigation had one or two plots with high prevalence of these conditions at this N application rate. The significance of this result is unclear.

The prevalence of scab was lower in the plots receiving Chloropicrin than in the non-fumigated plots or the plots receiving Vapam. The effect of the interaction between fumigation treatment and N application rate was significant at $\alpha = 0.10$, but this appears to be a reflection of the sporadic occurrence of scab, which was absent from 22 of 45 subplots, but present in up to 32% of tubers in others. 12 of the 23 subplots with scab were in the non-fumigated plots, versus 5 in Chloropicrin-treated plots and 7 in Vapam-treated plots, suggesting that both fumigants have some suppressive effect on scab.

Fumigation affected tuber specific gravity, with tubers from Vapam-treated plots having higher specific gravity than those from non-fumigated plots. Plots treated with Chloropicrin produced tubers with specific gravity intermediate between the non-fumigated and Vapam plots.

Soil respiration

The results of 24-hour CO_2 burst tests (a measure of soil microbial activity) are presented in Table 5. Fumigation treatment and the fumigation*date interaction were significantly related to soil CO_2 production. The non-fumigated control treatment had a higher rate of soil CO_2 production, averaged across N treatments, than either fumigated treatment in April and July 2017, but not in October 2016 (before the fumigation treatments were applied). The control treatment had a higher rate of soil CO_2 production than the Vapam treatment in October 2017, with the CO_2 production rate of the Chloropicrin treatment intermediate between the two and not significantly different from reduction in CO_2 production in the two fumigated treatments in the April and July samples (and the absence of this reduction in the control treatment).

The effect of the interaction between nitrogen treatment and date on soil CO_2 production was also significant. Three of the five nitrogen treatments showed decreases in CO_2 production between October 2016 and April 2017 and between July and October 2017, with increases in production between April and July 2017. The other two treatments did not follow this pattern. The treatment receiving no N at emergence had a steady decrease in soil CO_2 production across all four sampling times, and the treatment receiving 200 lbs N/ac at emergence had higher soil CO_2 production in October 2017 than in July of that year. It is possible that the treatment receiving no N at emergence showed decreasing respiration throughout the study because N availability limited microbial activity. This would also explain why this treatment had the highest respiration rate in April 2017, but the lowest rate by October 2017. The high average CO_2 production in October 2017 of subplots receiving 200 lbs N/ac at emergence may be attributable to one non-fumigated plot and one plot fumigated with Chloropicrin that both had relatively high CO_2 production rates, although the average soil CO_2 production for plots fertilized at this rate would have increased between July and October 2017 even had these plots been excluded from analysis.

Soil NH_4-N and NO_3-N

Soil NH_4-N and NO_3-N concentration results are presented in Table 6. Soil NH_4-N concentrations did not vary with treatment on October 17, 2016, before treatments were applied, nor on October 13, 2017, after harvest. Plots receiving Chloropicrin had higher soil NH_4-N concentrations than the non-fumigated control plots on both April 13 and July 5, 2017. Plots receiving Vapam had soil NH_4-N concentrations greater than the non-fumigated control plots but less than the plots fumigated with Chloropicrin on April 13, after fumigation but before N treatments applied at hilling. By July 5 (55 days after application of N treatments and hilling), the difference in soil NH_4-N concentration between the Vapam-treated plots and the non-fumigated plots was no longer significant.

Soil NO_3-N concentrations were unrelated to treatment on October 17, 2016, before treatments were applied. In all three samples taken after fumigation treatments were applied, the plots receiving Chloropicrin had lower soil NO_3-N concentrations than the non-fumigated plots. On July 5, 2017, the plots treated with Vapam had soil NO_3-N concentrations higher than the Chloropicrin-treated plots, but lower than the non-fumigated plots.

The high soil NH_4-N concentrations and low NO_3-N concentrations observed in the fumigated plots, particularly the Chloropicrin-treated plots, suggest that fumigation had an inhibitory effect on nitrification. Nitrification is mediated by microbes, and the inhibitory effect of fumigants on this process is presumably a result of the negative effect of fumigants on microbial activity. We observed similar effects on soil NH_4-N, but not NO_3-N, in 2016.

Soil NH_4-N concentration was only related to N application rate on July 5, 2017, after the N treatments were applied but before harvest. The subplots receiving no N at emergence had lower soil NH_4- N concentrations than those receiving between 140 and 260 $lbs \cdot ac^{-1}$ N, with the subplots receiving 80 $lbs \cdot ac^{-1}$ N intermediate. In contrast, soil NO_3-N increased with N application rate in both July and October 2017, though the relationship was stronger in July.

Plant stand and leaflet SPAD

Plant stand and leaflet SPAD results are presented in Table 7. The number of stems per plant 33 days after the emergence fertilizer was applied was unrelated to treatment. However, plant stand was related to both fumigation treatment and the interaction between fumigation treatment and N treatment. The plots receiving Vapam had higher stand than those receiving Chloropicrin or no fumigant. The interaction effect appears to be the result of the plots receiving Chloropicrin having higher stand than the non-fumigated plots among the subplots receiving 140 lbs $N \cdot ac^{-1}$ at emergence; the non-fumigated plots had higher or equal stand to the plots receiving Chloropicrin at all other N application rates.

SPAD readings, which indicate the relative density of chlorophyll per unit area in the measured leaflet, increased with N application rate on all five sampling dates. SPAD generally declined over time, while the response of SPAD to N rate grew stronger over time. The non-fumigated control plots had slightly lower SPAD readings than the plots receiving Chloropicrin or Vapam on each sampling date, resulting in a weak overall effect of fumigation treatment on SPAD. There was a significant effect of the interaction between N treatment and sampling date. SPAD declined more rapidly over time in treatments receiving less N at emergence.

Verticillium wilt development

Results for the development of *Verticillium* wilt between July 31 and September 12 are presented in Table 8. The severity of *Verticillium* wilt increased between late July and mid-September, as expected. The non-fumigated control treatment had greater *Verticillium* wilt severity than either fumigated treatment on all four sampling dates, even though both fumigated treatments had severity close to 90% by September 12. The non-fumigated control treatment therefore had a greater area under the disease progression curve (AUDPC) than either fumigated treatment. The difference in *Verticillium* severity between the two fumigated treatments was less pronounced, but the plots receiving Chloropicrin had greater severity on August 22 and 31, as well as a greater AUDPC, than the plots receiving Vapam.

N application rate also affected *Verticillium* severity, with disease severity declining as N application rate increased. Significant pairwise differences in *Verticillium* severity between N treatments were detected at all sampling times, as well as in the AUDPC.

Tuber sugars and French fry color

Tuber sugar and French fry reflectance results are presented in Table 9. Sucrose concentrations at harvest in both the stem and bud ends of tubers were lower in the Chloropicrin-treated plots than the non-fumigated controls, as were sucrose concentrations in the bud ends of tubers from Vapam-treated plots. Tuber glucose concentration and the reflectance of French fries made from the tubers were not related to fumigation treatment.

Stem-end tuber sucrose and glucose concentrations decreased as N application rate at emergence increased. The same was generally true of bud-end glucose concentration, except that the subplots receiving the highest N application rate had the second-highest mean concentration. Even though bud end glucose increased at this high N rate, the concentration was well below the threshold of 1.5 mg/g for French fry processing.

Conclusions

As expected, fumigation increased tuber yield and size relative to the non-fumigated control plots. While tuber yield and size increased with increasing N rate, fumigation tended to lower the N requirement with Vapam-treated plots showing almost no yield response N above 120 lb N/A. Overall, fumigation treatment appeared to affect soil N cycling processes and overall microbial activity, but fumigated plots had higher tuber yields and larger tubers than non-fumigated plots.

Table 1. Initial soil characteristics in the study site at the Sand Plain Research Farm.

0 - 6 inches											
Primary macronutrients		Secondary macronutrients			Micronutrients					Other characteristics	
Bray P	K	SO4-S	Ca	Mg	Zn	Fe	Mn	Cu	B	Organic matter	pH
ppm										%	
37	118	2.5	940	160	2.1525	37.8	10.2	0.68	0.29	2.25	6.15

Table 2. Fumigation and N treatments applied to irrigated Russet Burbank potatoes at the Sand Plain Research Farm in Becker, MN.

Fumigation treatment (whole plots)	**Nitrogen applicaton rate, lbs·ac^{-1} (subplots)**	
	Emergence (ESN)[1]	**Total[2]**
Control	0	40
	80	120
	140	180
	200	240
	260	300
Chloropicrin	0	40
	80	120
	140	180
	200	240
	260	300
Vapam	0	40
	80	120
	140	180
	200	240
	260	300

[1] ESN = Environmentally Smart Nitrogen (Agrium, Inc., 44-0-0)

[2] Each plot received 40 lbs·ac^{-1} N at planting as DAP (18-46-0)

Table 3. Effects of fumigation and N treatment on tuber yield, grade, and size for Russet Burbank potatoes grown at the Sand Plain Research Farm in Becker, MN, in 2017. Values within the same column that share a letter are not significantly different from each other (i.e. P > 0.10). Letters are only included where the P-value of the effect of fumigation, N treatment, or their interaction is less than 0.10.

Treatment		**Tuber yield**										
		0-3 oz	**3-6 oz**	**6-10 oz**	**10-14 oz**	**> 14 oz**	**Total yield**	**#1s > 3 oz.**	**#2s > 3 oz**	**Marketable yield**	**> 6 oz**	**> 10 oz**
		cwt·ac^{-1}									**%**	
Fumigation treatment	None	16	80	140 b	92 b	56 b	384 c	284 c	84	368 c	73 b	36
	Chloropicrin	13	84	182 a	140 a	94 a	513 b	444 b	56	500 b	81 a	45
	Vapam	14	80	199 a	148 a	107 a	547 a	471 a	62	533 a	83 a	46
Fumigation (P-value)		0.3112	0.9232	**0.0083**	**0.0017**	*0.0521*	**0.0004**	**<0.0001**	0.1450	**0.0003**	**0.0168**	0.1151
Total N applied (lbs/ac)	40	15	117 a	184	73 b	23 d	412 c	350 c	46 d	396 c	65 c	21 d
	120	14	86 b	184	132 a	67 c	482 b	388 b	79 ab	468 b	78 b	40 c
	180	14	72 c	179	144 a	95 b	503 ab	407 ab	83 a	490 ab	83 a	48 b
	240	14	66 c	162	146 a	107 b	495 ab	420 a	61 cd	481 ab	83 a	50 ab
	300	15	67 c	158	139 a	135 a	515 a	433 a	67 bc	500 a	84 a	53 a
Nitrogen (P-value)		0.4286	**<0.0001**	0.1001	**<0.0001**	**<0.0001**	**<0.0001**	**0.0002**	**0.0022**	**<0.0001**	**<0.0001**	**<0.0001**
Control	40	19	121 a	123	15 g	2	281	228	34 f	262	48 e	6 e
	120	16	81 b	159	91 f	34	382	263	103 ab	366	74 d	33 d
	180	14	61 c	139	123 cde	68	406	268	123 a	391	81 abc	47 b
	240	16	70 bc	138	109 ef	68	400	303	81 bcd	384	78 bcd	44 bc
	300	15	68 bc	139	121 cdef	108	451	356	80 bcd	436	81 abc	50 ab
Chloropicrin	40	13	114 a	196	92 f	34	448	394	41 f	435	72 d	28 d
	120	13	105 a	199	125 cde	59	501	437	51 def	488	76 cd	36 cd
	180	13	75 bc	200	168 ab	92	547	465	70 cde	535	84 ab	48 b
	240	13	62 bc	159	165 ab	126	524	451	60 cdef	511	86 a	55 a
	300	15	64 bc	155	152 abc	158	545	473	57 cdef	530	86 a	57 a
Vapam	40	14	115 a	234	111 def	33	506	430	63 cdef	492	74 d	28 d
	120	13	70 bc	192	179 a	107	562	465	84 bc	549	85 a	51 ab
	180	14	78 bc	197	142 bcd	126	557	487	56 def	543	83 ab	48 ab
	240	13	67 bc	190	165 ab	128	562	505	44 ef	549	86 a	52 ab
	300	17	70 bc	179	145 bc	139	550	468	64 cdef	533	84 ab	52 ab
Fumigation*Nitrogen (P-value)		0.4759	*0.0867*	0.2048	**0.0292**	0.1598	0.1735	0.3119	**0.0104**	0.1238	**0.0003**	**0.0020**

Table 4. Effects of fumigation and N treatment on the prevalence of hollow heart, brown center, and scab; tuber dry matter content; and tuber specific gravity for Russet Burbank potatoes grown at the Sand Plain Research Farm in Becker, MN, in 2017. Values within the same column that share a letter are not significantly different from each other (i.e. P > 0.10). Letters are only included where the P-value of the effect of fumigation, N treatment, or their interaction is less than 0.10.

Treatment		**Tuber quality**				
		Hollow heart (%)	**Brown center (%)**	**Scab (%)**	**Dry matter content (%)**	**Specific gravity**
Fumigation treatment	None	4	4	7.2 a	20.6	1.0765 b
	Chloropicrin	3	3	1.6 b	21.2	1.0795 ab
	Vapam	2	2	5.5 a	21.1	1.0813 a
Fumigation (P-value)		0.4303	0.4303	**0.0238**	0.2296	*0.0568*
Total N applied (lbs/ac)	40	1 b	1 b	7.7	20.8	1.0781
	120	1 b	1 b	3.6	21.3	1.0805
	180	8 a	8 a	2.9	21.2	1.0822
	240	2 b	2 b	3.1	20.7	1.0758
	300	2 b	2 b	6.6	20.9	1.0789
Nitrogen (P-value)		**0.0049**	**0.0049**	0.2331	0.4898	0.1319
Control	40	3	3	13.0 ab	19.8	1.0725
	120	0	0	10.7 abc	21.4	1.0800
	180	11	11	1.9 de	21.1	1.0775
	240	6	6	5.8 bcde	20.1	1.0750
	300	0	0	4.6 cde	20.8	1.0775
Chloropicrin	40	1	1	1.4 de	21.4	1.0800
	120	0	0	0.0 e	21.3	1.0800
	180	8	8	1.7 de	21.4	1.0872
	240	1	1	3.6 cde	20.9	1.0708
	300	6	6	1.5 de	21.1	1.0798
Vapam	40	0	0	8.7 abcd	21.2	1.0819
	120	2	2	0.0 e	21.3	1.0815
	180	6	6	5.2 cde	21.3	1.0820
	240	0	0	0.0 e	21.0	1.0816
	300	0	0	13.8 a	20.6	1.0793
Fumigation*Nitrogen (P-value)		0.5176	0.5176	*0.0538*	0.8045	0.2487

Table 5. Effects of fumigation and N treatments on soil microbial respiration, as measured by CO_2 production in a 24-hour period at 70°F using Solvita CO_2 Burst Test kits, at the Sand Plain Research Farm in Becker, MN, in 2017. Values within the same column that share a lowercase letter and values within a row that share an uppercase letter are not significantly different from each other (i.e. $P > 0.10$). Letters are only included where the P-value of the effect of fumigation, N treatment, or their interaction is less than 0.10.

Treatment		**Solvita CO_2 burst test results (ppm increase in CO_2 after 24 hours incubation at 70°F)**				
		October 17, 2016	**April 13, 2017**	**July 5, 2017**	**October 13, 2017**	**Average across dates**
Fumigation treatment	None	50.7 -, AB	44.3 a, C	52.3 a, A	45.4 a, BC	48.2 a
	Chloropicrin	51.2 -, A	34.1 b, C	38.2 b, BC	41.9 ab, B	41.3 b
	Vapam	54.7 -, A	26.5 c, C	37.6 b, B	37.8 b, B	39.2 b
Fumigation (P-value)						**0.0094**
Fumigation*date (P-value)		**0.0009**				
N application rate at emergence (lbs/ac)	0	51.6 ab, A	40.6 a, B	39.7 b, B	34.9 c, B	41.7
	80	50.8 ab, A	38.3 ab, B	51.7 a, A	44.6 ab, AB	46.4
	140	51.3 ab, A	35.0 abc, B	43.8 b, A	43.8 ab, A	43.5
	200	58.6 a, A	31.4 bc, C	36.5 b, C	47.1 a, B	43.4
	260	48.7 b, A	29.7 c, C	41.8 b, AB	38.1 bc, B	39.6
Nitrogen (P-value)						0.1025
Nitrogen*date (P-value)		**0.0253**				
Control	0	50.1	47.5	42.4	35.9	44.0
	80	49.9	55.8	62.5	47.5	53.9
	140	52.8	42.7	50.5	54.7	50.2
	200	49.1	42.2	54.2	52.3	49.5
	260	51.6	33.4	51.9	36.5	43.3
Chloropicrin	0	49.2	37.5	42.7	32.7	40.5
	80	43.6	32.5	52.5	42.7	42.8
	140	48.4	37.9	38.0	36.7	40.2
	200	66.9	29.3	23.1	52.3	42.9
	260	47.8	33.3	34.8	45.2	40.3
Vapam	0	55.4	36.9	33.9	36.0	40.5
	80	59.0	26.6	40.3	43.6	42.4
	140	52.6	24.2	42.9	40.0	39.9
	200	59.7	22.6	32.3	36.8	37.9
	260	46.8	22.3	38.7	32.7	35.1
Fumigation*nitrogen (P-value)						0.7957
Fumigation*nitrogen*date (P-value)		0.2105				
Average across treatments		52 A	35 C	42.7 B	41.7 B	
Date (P-value)		**<0.0001**				

Table 6. Effects of fumigation and N treatments on NH_4-N and NO_3-N concentrations in the top six inches of soil on October 17, 2016, and April 13, July 5, and October 13, 2017, in plots used to grow Russet Burbank potatoes at the Sand Plain Research Farm in Becker, MN. Values within the same column that share a lowercase letter, and values within a row that share an uppercase letter, are not significantly different from each other (i.e. $P > 0.10$). Letters are only included where the P-value of the effect of fumigation, N treatment, or their interaction is less than 0.10.

Treatment		**NH_4-N (mg/kg dry soil)**					**NO_3-N (mg/kg dry soil)**				
		October 17, 2016	**April 13, 2017**	**July 5, 2017**	**October 13, 2017**	**Average across dates**	**October 17, 2016**	**April 13, 2017**	**July 5, 2017**	**October 13, 2017**	**Average across dates**
Fumigation treatment	None	2.6 -, B	1.0 c, B	8.4 b, A	0.8 -, B	3.2 b	1.7 -, D	5.1 a, C	7.4 a, A	6.1 a, B	5.1 a
	Chloropicrin	2.3 -, B	14.1 a, A	17.1 a, A	1.1 -, B	8.7 a	1.7 -, C	3.5 b, B	4.5 c, A	4.8 b, A	3.6 b
	Vapam	2.6 -, BC	5.9 b, AB	9.2 b, A	1.1 -, C	4.7 b	1.9 -, C	4.9 a, B	6.0 b, A	6.1 a, A	4.7 a
Fumigation (P-value)						**0.0338**					**<0.0001**
Fumigation*date (P-value)		**0.0005**					**0.0172**				
Total N applied (lbs/ac)	40	2.6 -, AB	6.3 -, A	0.5 c, B	1.7 -, AB	2.8 c	1.6 -, B	5.0 -, A	2.6 e, B	4.9 c, A	3.5 c
	120	2.6 -, B	8.0 -, A	4.5 c, AB	0.7 -, B	4.0 bc	1.6 -, C	4.1 -, AB	3.8 d, B	5.2 bc, A	3.7 c
	180	2.8 -, BC	6.7 -, B	14.2 b, A	0.9 -, C	6.1 ab	1.7 -, C	4.6 -, B	6.5 c, A	5.4 bc, AB	4.5 b
	240	2.1 -, BC	7.1 -, B	18.4 ab, A	0.8 -, C	7.1 a	2.3 -, D	4.3 -, C	7.7 b, A	6.0 ab, B	5.1 ab
	300	2.5 -, BC	7.1 -, B	20.2 a, A	0.9 -, C	7.7 a	1.6 -, D	4.5 -, C	9.4 a, A	6.9 a, B	5.6 a
Nitrogen (P-value)						**0.0013**					**<0.0001**
Nitrogen*date (P-value)		**<0.0001**					**<0.0001**				
Control	40	2.6	1.0	0.8	1.2	1.4	1.9	5.2	4.2	6.0	4.3
	120	2.3	1.2	1.8	0.3	1.4	1.6	4.4	4.7	6.1	4.2
	180	2.9	1.0	6.6	0.8	2.9	1.8	5.6	7.6	5.9	5.2
	240	1.7	1.2	16.0	0.8	4.9	1.8	4.4	9.0	5.4	5.1
	300	3.3	0.8	16.9	0.8	5.4	1.6	5.8	11.6	7.1	6.6
Chloropicrin	40	2.7	14.3	0.5	2.0	4.9	1.3	3.2	1.9	3.8	2.6
	120	2.1	15.2	8.5	0.7	6.6	2.0	3.6	3.2	3.6	3.1
	180	2.7	13.2	28.2	1.0	11.3	1.5	3.2	5.2	4.3	3.5
	240	2.0	13.8	23.5	0.9	10.1	2.0	4.1	5.8	5.8	4.4
	300	2.2	13.9	24.7	0.8	10.4	1.7	3.4	6.5	6.4	4.5
Vapam	40	2.6	3.4	0.1	1.8	2.0	1.6	6.6	1.6	4.8	3.6
	120	3.4	7.6	3.2	1.1	3.8	1.3	4.4	3.5	5.9	3.8
	180	2.7	6.0	7.7	0.9	4.3	1.9	4.9	6.6	6.0	4.9
	240	2.5	6.1	15.7	0.7	6.3	3.1	4.4	8.2	6.8	5.6
	300	2.1	6.5	19.1	1.2	7.2	1.4	4.2	10.0	7.2	5.7
Fumigation*nitrogen (P-value)						0.9049					0.8061
Fumigation*nitrogen*date (P-value)		0.9942					0.7555				
Average across treatments		2.5 C	7.0 B	11.6 A	1.0 C		1.8 C	4.5 B	6.0 A	5.7 A	
Date (P-value)		**<0.0001**					**<0.0001**				

Table 7. Effects of fumigation and N treatment on plant stand, stems per plant, and leaflet SPAD readings (chlorophyll concentration) on five dates in 2017 for Russet Burbank potatoes at the Sand Plain Research Farm in Becker, MN. Values within the same column that share a lowercase letter and values in the same row that share an uppercase letter are not significantly different from each other (i.e. P > 0.10). Letters are only included where the P-value of the effect of fumigation, N treatment, or their interaction is less than 0.10.

Treatment		**Early-season vigor**		**SPAD readings**					
		June 8 stand (%)	**June 13 stems / plant**	**June 15**	**June 27**	**July 11**	**July 25**	**August 8**	**Average across dates**
Fumigation treatment	None	87 b	2.3	43.9	41.4	37.6	35.6	32.8	38.3 b
	Chloropicrin	85 b	2.5	44.6	43.8	38.4	36.7	34.6	39.6 a
	Vapam	97 a	2.6	44.8	43.2	38.4	36.2	34.5	39.4 a
Fumigation (P-value)		**0.0061**	0.1277						*0.0817*
Fumigation*date (P-value)				0.1833					
Total N applied (lbs/ac)	40	88	2.5	44.0 b, A	40.2 b, B	33.7 d, C	29.3 d, D	23.0 e, E	34.0 e
	120	90	2.5	43.9 b, A	43.1 a, A	36.7 c, B	33.6 c, C	28.8 d, D	37.2 d
	180	90	2.5	44.3 ab, A	43.8 a, A	39.0 b, B	38.1 b, B	35.4 c, C	40.2 c
	240	89	2.4	44.8 ab, A	43.4 a, B	40.0 b, C	39.7 a, C	40.4 b, C	41.6 b
	300	91	2.4	45.1 a, A	43.7 a, B	41.3 a, D	40.2 a, E	42.3 a, C	42.5 a
Nitrogen (P-value)		0.5567	0.6946						**<0.0001**
Nitrogen*date (P-value)				**<0.0001**					
Control	40	86 efgh	2.3	43.2	38.7	33.2	28.7	22.3	33.2
	120	90 cdef	2.3	43.7	42.2	36.8	32.7	27.2	36.5
	180	83 gh	2.4	44.6	41.7	37.8	37.1	33.7	39.0
	240	88 efg	2.4	44.2	42.4	39.4	39.7	38.3	40.8
	300	88 efg	2.3	43.7	42.3	40.7	40.0	42.8	41.9
Chloropicrin	40	81 h	2.6	44.3	41.5	33.7	30.6	23.5	34.7
	120	85 fgh	2.7	43.9	44.1	36.8	33.7	28.9	37.5
	180	91 bcde	2.5	43.6	45.3	39.8	38.6	37.2	40.9
	240	81 h	2.4	44.7	43.9	40.5	40.4	40.9	42.1
	300	90 defg	2.3	46.4	44.2	41.3	40.5	42.6	43.0
Vapam	40	99 a	2.7	44.4	40.3	34.2	28.6	23.1	34.1
	120	96 abc	2.6	44.1	43.0	36.6	34.5	30.4	37.7
	180	97 ab	2.6	44.9	44.6	39.5	38.7	35.5	40.6
	240	97 ab	2.4	45.5	43.8	40.2	39.0	42.0	42.1
	300	95 abcd	2.5	45.2	44.6	41.7	40.2	41.6	42.7
Fumigation*Nitrogen (P-value)		**0.0169**	0.8592						0.9375
Fumigation*Nitrogen*date (P-value)				0.3913					
Average across treatments				44.4 A	42.8 B	38.1 C	36.2 D	34.0 E	
Date (P-value)				**<0.0001**					

Table 8. Severity (prevalence) of *Verticillium* wilt in Russet Burbank potatoes grown at the Sand Plain Research Farm in Becker, MN, 2017 under different fumigation treatments and N application rates. If two values within a column differ by more than the LSD$_{P = 0.05}$ value, they are significantly different from each other ($P < 0.05$).

Treatment		**Wilt (% Severity)**				**AUDPC**	**RAUDPC**
		7/31	**8/22**	**8/31**	**9/12**		
Fumigation treatment	Control	1.6	73.8	93.2	99.1	2733	0.635
	Chloropicrin	0.2	31.9	60.4	92.1	1682	0.391
	Vapam	0.1	21.3	47.0	88.1	1352	0.314
Fumigant LSD$_{P = 0.05}$		0.6	9.5	10.4	5.6	239	0.056
Total N applied (lbs/ac)	40	1.9	67.1	91.4	98.3	2610	0.607
	120	0.6	55.8	84.3	97.8	2343	0.545
	180	0.2	38.8	65.5	96.4	1869	0.435
	240	0.3	33.3	54.9	90.2	1637	0.381
	300	0.1	16.4	38.1	82.7	1151	0.268
Nitrogen LSD$_{P = 0.05}$		0.8	12.3	13.5	7.2	309	0.072
40	Control	5.0	93.8	99.3	100.0	3150	0.733
120	Control	1.4	87.5	97.3	99.3	2988	0.695
180	Control	0.5	76.3	97.8	99.3	2809	0.653
240	Control	0.6	77.5	96.0	100.0	2816	0.655
300	Control	0.3	33.8	75.5	96.8	1899	0.442
40	Chloropicrin	0.4	62.5	91.3	98.5	2522	0.587
120	Chloropicrin	0.4	50.0	83.0	98.0	2239	0.521
180	Chloropicrin	0.1	22.5	61.3	97.0	1575	0.366
240	Chloropicrin	0.1	13.8	45.0	85.5	1200	0.279
300	Chloropicrin	0.0	10.5	21.3	81.3	873	0.203
40	Vapam	0.3	45.0	83.8	96.5	2159	0.502
120	Vapam	0.0	30.0	72.5	96.0	1802	0.419
180	Vapam	0.0	17.5	37.5	93.0	1223	0.284
240	Vapam	0.0	8.8	23.8	85.0	895	0.208
300	Vapam	0.0	5.0	17.5	70.0	681	0.158
LSD$_{P = 0.05}$		1.4	20.0	24.0	12.4	518	0.121

Table 9. Effects of fumigation and N treatment on stem-end and bud-end tuber sucrose and glucose concentrations and the reflectance of French fries made from the stem ends and bud ends of tubers, at harvest, of Russet Burbank potato plants grown at the Sand Plain Research Farm in Becker, MN, in 2017. Values within the same column that share a letter are not significantly different from each other (i.e. P > 0.10). Letters are only included where the P-value of the effect of fumigation, N treatment, or their interaction is less than 0.10.

Treatment		**Sucrose (mg/g)**		**Glucose (mg/g)**		**Reflectance (Photovolt reflectometer)**	
		Stem	**Bud**	**Stem**	**Bud**	**Stem**	**Bud**
Fumigation treatment	None	0.514 a	1.324 a	2.599	0.583	23.7	40.4
	Chloropicrin	0.381 b	1.133 b	2.635	0.546	25.0	40.7
	Vapam	0.476 a	1.096 b	2.422	0.553	24.7	41.6
Fumigation (P-value)		**0.0006**	**0.0002**	0.3842	0.7661	0.2418	0.3062
Total N applied (lbs/ac)	40	0.536 a	1.285	3.664 a	0.661 a	22.8	40.3
	120	0.531 a	1.150	2.618 b	0.602 ab	24.5	40.5
	180	0.456 b	1.208	2.316 bc	0.506 bc	24.9	41.6
	240	0.370 c	1.167	2.046 c	0.410 c	25.3	41.8
	300	0.392 bc	1.111	2.115 c	0.624 a	24.8	40.2
Nitrogen (P-value)		**0.0003**	0.1450	**<0.0001**	**0.0038**	0.1546	0.3351
Control	40	0.600	1.321	3.222 bc	0.639	23.3	40.5
	120	0.650	1.399	2.794 cde	0.506	24.3	40.3
	180	0.463	1.279	2.282 efg	0.619	24.0	39.0
	240	0.406	1.360	2.104 fg	0.538	24.0	40.8
	300	0.451	1.262	2.592 def	0.611	22.8	41.3
Chloropicrin	40	0.443	1.305	3.776 ab	0.647	21.0	40.5
	120	0.418	1.096	3.042 cd	0.611	24.3	39.0
	180	0.382	1.107	2.400 efg	0.400	25.8	43.3
	240	0.311	1.072	2.013 fg	0.336	26.3	41.3
	300	0.353	1.083	1.943 g	0.735	27.6	39.5
Vapam	40	0.565	1.229	3.994 a	0.697	24.0	39.8
	120	0.526	0.956	2.016 fg	0.688	25.0	42.3
	180	0.523	1.239	2.267 efg	0.498	25.0	42.5
	240	0.392	1.069	2.022 fg	0.355	25.5	43.5
	300	0.373	0.988	1.811 g	0.527	24.1	39.8
Fumigation*Nitrogen (P-value)		0.6941	0.3384	*0.0559*	0.1930	0.3436	0.1994

Potato Response to Adaptive Nitrogen and Reduced Irrigation Management in the Minnesota Central Sands

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ABSTRACT: The expansion of fertilizer intensive and irrigated agriculture in Minnesota has led to concerns over the potential cost of these activities to groundwater resources. New regulations from the state government are being developed to address these issues with the goal to improve drinking water quality, which is commonly impaired by nitrate-N, and to manage future groundwater withdrawals in a sustainable manner. Renewed interest has been placed on nitrogen [N] and irrigation [IRR] best management practice to meet these environmental goals, as well as improve input use efficiency and producer profitability. Variable-rate N applications based on multi-spectral remote sensing and reduced IRR rates are two promising management strategy to meet these goals. This study was carried out on Russet Burbank variety potatoes grown on an irrigated, coarse-textured soil in central Minnesota. A total of six N-treatments were imposed including (N1) a 40 lbs. N/acre control treatment, (N2) a split-applied urea treatments of 160 lbs. N/acre, (N4) and of 240 lbs. N/acre, (N3) a controlled-release polymer coated urea [PCU] treatments of 160 lbs. N/acre, (N5) and of 240 lbs. N/acre, and (N6) a variable-rate split-applied urea treatment based on remote sensing observations using the MERIS Terrestrial Chlorophyll Index paired with the Nitrogen Sufficiency Index. IRR treatments included (I1) conventional irrigation rate and (I2) irrigation rate reduced by 15% relative to the conventional treatment. Reduced IRR had a non-significant difference in tuber yield compared to conventional practice while reducing percolation losses by 9 and 15% in 2016 and 2017 respectively. The variable-rate treatment (N6) received 240 and 220 lbs. N/acre in 2016 and 2017 respectively, which is 20 and 40 lbs. N/acre less than the conventional best management practices (N4, N5), and there were no significant differences in yield between these treatments. Nitrate leaching loads were not significantly difference between the variable-rate N treatment and conventional best management practices, or between the reduced and conventional IRR treatments. This study demonstrates that these IRR and N management practices have the potential to improve producer profitability and reduce impacts on water resources.

INTRODUCTION

The environmental impact of irrigated agriculture on groundwater resources in the Upper Midwest states of Minnesota, Wisconsin, North Dakota, and Michigan has been and continues to be a major area of concern. A small, but significant, fraction of total crop acres, 1% (ND) – 8% (MI), in the Upper Midwest are irrigated (NASS, 2012) – when water sensitive crops, such as vegetables, are grown on sandy soils in humid climates, transient water stress can occur between precipitation events and can reduce yield necessitating supplemental irrigation (Shock, et al., 2007). The management of irrigation has important environmental consequences – improperly applied irrigation can drive percolation below the root zone and the leaching of nitrate into groundwater (Hergert, 1986, Martin, et al., 1991, Quemada, et al., 2013). Surficial sandy aquifers are susceptible to nitrate contamination (Adams, 2016, Best, et al., 2015); when contaminated with nitrate above the EPA designated maximum contamination limit [MCL] of 10 mg N/L, drinking water from these aquifers poses a human health risks (US EPA, 2009). The MCL for nitrate is often exceeded in areas with vulnerable soils and intensive agricultural activity (MDA, 2015, MDH, 2017). Removing nitrate from drinking water is expensive for private well owners, $130 – $360 per household per year, and public water suppliers, \$59 – \$2224 per household per year, with a total cost across Minnesota estimated at \$6 million per year (Keeler, et al., 2016, Lewandowski, et al., 2008).

Consumption of groundwater for agricultural irrigation can alter the hydrology of groundwater-surface water systems (Watson, et al., 2014). Seasonal pumping dynamics can temporarily reduce the discharge of groundwater to lakes and streams (Kraft, et al., 2012) – this can adversely impact aquatic life (Poff, et al., 1997) leading to surrounding lakes and streams to be listed as impaired under the Clean Water Act (MN DNR, 2017, MN EQB, 2015). The area of irrigated agriculture in the Upper Midwest has been increasing by 18% (WI) – 45% (MI) over the past two decades (NASS, 2012), increasing in volume by 50% (MN) over the past three decades (MN EQB, 2015), and is expanding into areas not previously under agricultural production (Marcotty, 2016). This has led to novel legal and policy issues in this region over the negative impact of groundwater use for agricultural irrigation on surface water resources (Marcotty, 2017, MN DNR, 2016, Richmond, 2017).

Potato is an important specialty crop grown in the Upper Midwest with a small geographic footprint (Figure 2-1) ranging from 17,800 ha (MI) to 31,600 ha (WI) but a large economic impact with a production value of \$857 million per year (NASS, 2013). However, potato grown in the Upper Midwest has high nitrogen [N] requirements (Rosen and Bierman, 2008), is especially sensitive to water stress (Shock, et al., 2007), and between 36% (ND) and 100% (WI) of potato production uses supplemental irrigation (NASS, 2013). This leads to conditions that are primed for driving nitrate leaching (Kraft and Stites, 2003) and high rate of groundwater use (Nocco, et al., 2017) leading to public concerns about groundwater quality and quantity.

A key strategy to address contamination of groundwater with nitrate and the responsible use of groundwater resources is developing improved irrigation and nitrogen management practices for producers (Alva, 2010, Meisinger and Delgado, 2002, Quemada, et al., 2013, Zebarth and Rosen, 2007). The objectives of this study were to evaluate agronomic and environmental outcomes from adaptive nitrogen management using remote sensing and reduced irrigation for potato production compared to currently recommended best management practices.

MATERIALS & METHODS

A plot-scale field experiment was conducted in 2016-17 on irrigated plots at the Sand Plain Research Farm [SPRF] in Becker, MN (45º 23’ N, 93º 53’ W). Mean temperature at this station is 44.8 ºF and mean annual precipitation is 31.9 mm (Arguez, et al., 2010). The soil at this station was characterized as a Hubbard loamy sand (Sandy, mixed, frigid Entic Hapludolls) and excessively well drained with low available water holding capacity of 0.098 cm cm^{-1} for 0-90 cm depth (Hansen and Giencke, 1988, Natural Resources Conservation Service, 2013). Russet Burbank potato, a processing variety common to the region, was grown each year following a previous crop of rye. Pre-plant soil samples were collected at 0-15 cm and analyzed for standard macro- and micro-nutrient content (Nathan and Gelderman, 2015) and collected at 0-60 cm to be analyzed for inorganic N content using conductimetric analysis (Carlson, et al., 1990) (Table 1). Apart from experimental nitrogen and irrigation treatments, all management and cultural practices were managed by the staff at the SPRF in accordance with common practices for the region (Egel, 2017) and other macro-nutrients were applied based on soil samples and University recommended methods. A weather station (Campbell Scientific, Logan, UT) located at the SPRF recorded measurements of precipitation, maximum and minimum temperature, solar radiation, relative humidity, and wind speed every hour.

Table 1. Soil properties before spring planting

	0–6 in.				0–24 in.
Year	pH	OM	Bray-P	K	NO_3^-–N
		%	mg kg^{-1}		
2016	5.9	1.8	34	136	2.2
2017	6.1	1.9	35	165	2.3

This study was set up as a randomized complete block design with a split-plot restriction on randomization and four replicates. Irrigation rate and timing was the whole plot treatment (with two treatments) and nitrogen rate, source, and timing as the sub-plot treatment (with six treatments). Each replicate was separated by a 50 ft buffer of rye and irrigation blocks within replicates are separated by a 30 ft buffer alley. Experimental plots were 21 ft wide (7 x 3 ft rows) and 20 ft long with an additional 5 ft buffer for plots located at the edge of the irrigation block. A 10 ft buffer separated split-plots within whole plots that were co-located in the same set of 7 rows. Whole “B” seeds were planted on 22 April 2016 and 29 April 2017 with a one-foot spacing between seeds. Vines were killed with a mechanical flail mower on 14 September 2016 and 13 September 2017 and tubers were mechanically harvested from rows 4 and 5 on 30 September 2016 and 27 September 2017.

Irrigation treatments included conventional irrigation rate (I1) based on the checkbook method (Steele, et al., 2010, Wright, 2002) but without using soil moisture measurements as corrections, and reduced irrigation rate (I2) with the rate reduced by 15% relative to the conventional treatment (Table 2). Irrigation was applied on a fixed schedule of every 2-3 days using a solid-set sprinkler system – on a given date of application, irrigation was applied to I1 at a rate determined by the checkbook method to refill the profile completely. Irrigation was managed for an available water holding capacity of 1.8 inches, over a rooting depth of 24 inches and an allowable depletion of 30%.

Table 2. Rate and timing of precipitation and irrigation by treatment

	2016							**2017**					
	May	June	July	Aug.	Sept.	Total		May	June	July	Aug.	Sept.	Total
							in.						
Precipitation	3.74	2.83	7.18	5.72	4.68	24.15		4.89	4.16	1.45	4.68	1.87	17.05
Irrigation													
1 Reduced	–	2.30	2.73	1.92	–	6.95		–	2.13	4.10	1.11	–	7.34
2 Convent.	–	2.70	3.15	2.25	–	8.10		–	2.50	4.80	1.30	–	8.60

Nitrogen treatments included (N1) a 45 kg N/ha control treatment, (N2) a split-applied urea treatments of 180 kg N/ha, (N4) and of 270 kg N/ha, (N3) a controlled-release polymer coated urea [PCU] treatments of 180 kg N/ha, (N5) and of 270 kg N/ha, and (N6) a variable-rate split-applied urea treatment based on remote sensing observations paired with the Nitrogen Sufficiency Index [NSI] (Blackmer and Schepers, 1995) with N5 as the well-fertilized reference (Table 3). Fertilizer at planting was diammonium phosphate applied uniformly to all N-treatments at a rate of 45 kg N/ha. Emergence fertilizer was urea for N2, N4, and N6 and Environmentally Smart Nitrogen (Agrium Inc., Calgary, AB) for N3, and N5 at various rates. Treatments N2 and N4 received four scheduled post-hilling applications of UAN-28 in the form of simulated fertigation on a 1- to 2-week basis.

Table 3. Rate and timing of nitrogen (N) fertilizer treatments

	2016	22 Apr	1 June	23 June	14 July	21 July	27 July	
	2017	29 Apr	30 May	28 June	10 July	20 July	27 July	
		Planting	Emergence	Post-Emergence				Total
Nitrogen		lbs. N acre^{-1}						
1	Control	40 DAP	-	-	-	-	-	40
2	160 Split	40 DAP	60 Urea	15 UAN	15 UAN	15 UAN	15 UAN	160
3	160 CR	40 DAP	120 ESN	-	-	-	-	160
4	240 Split	40 DAP	120 Urea	20 UAN	20 UAN	20 UAN	20 UAN	240
5	240 CR	40 DAP	200 ESN	-	-	-	-	240
6	VR Split	45 DAP	120 Urea	?	?	?	?	?

Weekly measurements of multispectral reflectance (MSR-16R, CROPSCAN, Inc., Rochester, MN) were used to calculate the MERIS Terrestrial Chlorophyll Index [MTCI] (Dash and Curran, 2004), which had previously been identified as best able to detect N-stress in potato (Nigon, et al., 2015), as wells as to calculate Simple Ratio 8 (Datt, 1998) and Green Ratio Vegetation Index (Sripada, et al., 2006). Remote sensing data was collected on a weekly basis on 10 dates between 21 June 2016 and 24 August 2016 and on 11 dates between 1 June 2017 and 23 August 2017. 4 subsamples were collected from each plot at a height of 6 feet, giving a diameter of view of approximately 3 feet. Post-hilling fertilizer applications in the form of 22 kg N/ha of UAN-28 were applied as simulated fertigation to N6 when the NSI value was less than 0.95 prior to the scheduled application date (Table 4). Measurements of petiole nitrate concentration and leaf chlorophyll content using a proximal sensor (SPAD-502, Spectrum Technologies, Aurora, IL) were collected 5 times in 2016 between 16 June and 3 August and 6 times in 2017 between 14 June and 8 August every 1-2 weeks.

Table 4. Nitrogen Sufficiency Indices

Index		Formula[†]	Source
MERIS Terrestrial Chlorophyll Index	MTCI	$\frac{R_{751} - R_{713}}{R_{713} - R_{676}}$	Dash and Curran (2004)
Simple Ratio 8	SR8	$\frac{R_{857}}{R_{554} \times R_{704}}$	Datt (1998)
Green Ratio Vegetation Index	GRVI	$\frac{R_{NIR}}{R_{G}}$	Sripada et al. (2006)
Nitrogen Sufficiency Index	NSI	$\frac{MTCI_{N\ Trt.}}{MTCI_{240\ CR}}$	Peterson *et al.* (1993)

[†] R_n indicate % Reflectance of given wavelength [nm] of light

Nitrate concentration below the root zone at 4-foot depth was monitored with suction-cup lysimeters (Venterea, et al., 2011) and one lysimeter was installed each year in row 3 of each plot. Water samples from lysimeters were collected on a weekly basis with 25 samples collected in 2016 between 18 May and 6 October and 18 samples collected in 2017 between 22 May and 6 October. Samples were analyzed in laboratory setting for inorganic N concentration using conductimetric analysis (Carlson, et al., 1990) and cumulative nitrate leaching was calculated for each plot based on the methods of Errebhi, et al. (1998).

Harvested tubers were mechanically sorted into weight classes (0-3. oz, 3-6 oz., 6-10 oz., 10-14 oz., and >14 oz.) and graded (US No. 1 and No. 2) (USDA, 1997). A subsample of harvested tubers was then evaluated for scab infection, hollow heart internal defects, and specific gravity. Response variables to be assessed include total tuber yield, Grade A tuber yield, ratio of misshapen tubers, ratio of tubers greater than 6 oz., ratio of hollow heart defects, and tuber specific gravity.

Statistical analysis was conducted using SAS PROC GLIMMIX (SAS Institute, 2013) to test the fixed effects of study year, irrigation treatment, nitrogen treatment, and their interactions. The overall significance and a priori non-orthogonal contrast comparisons for nitrogen treatments (Table 5) were conducted for each response variable with significance set at $P \leq 0.10$, and protected multiple comparisons between treatments were conducted with significance set at $P \leq 0.05$ for each response variable with a significant overall effect.

Table 5. Non-orthogonal contrasts used for *a priori* hypothesis testing on main and interaction effects for Nitrogen treatments

Contrast	Control	160 Split	160 CR	240 Split	240 CR	VR Split
Control	-5	+1	+1	+1	+1	+1
Rate	0	-1	-1	+1	+1	0
Source	0	-1	+1	-1	+1	0
Var. Rate	0	0	0	-1	-1	2

RESULTS & DISCUSSION

Remote Sensing and Variable Rate N Treatment

Overall, remote sensing using CROPSCAN could identify significant differences between N-treatments. Remote sensing measurements of VR Split N-treatment taken prior to scheduled post-emergence fertilizer applications were below the 95% NSI threshold using MTCI on 2 dates in 2016 and 2 dates in 2017 (Figure 1). Following these dates, 20 lbs. N/acre were subsequently applied to the VR Split treatment on those applications dates (Table 7). There was one exception – on the fourth application date in 2016, fertilizer was applied to VR Split although the NSI value using MTCI was not less than 95%. This decision was made to apply fertilizer at this time because there would be no subsequent opportunities to apply N-fertilizer and it was expected that the NSI value would drop below 95% within a few days following the scheduled fertilizer application date. In total 3 post-emergence N-fertilizer applications were applied to VR Split in 2016. Relative to the 240 Split treatment, N fertilizer application rate for the VR Split treatment was reduced by 20 and 40 lbs. N/acre in 2016 and 2017, respectively.

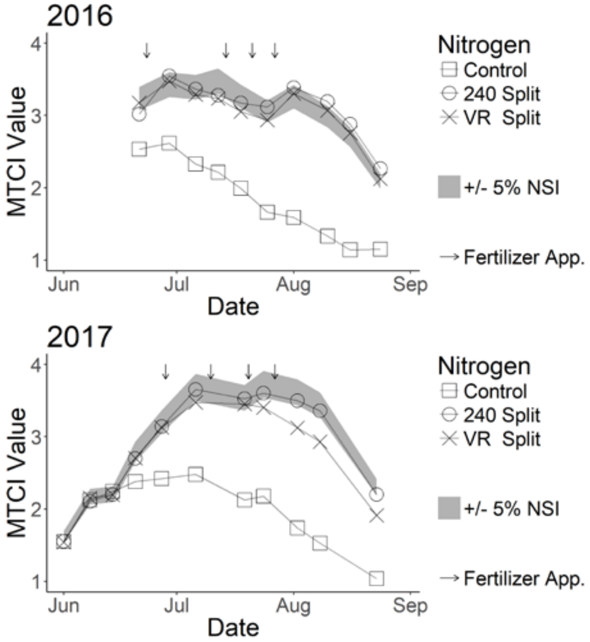

Figure 1. Crop N-status evaluated using the MTCI calculated from the CROPSCAN and NSI

There were differences, however, between the measurements of crop-N status using CROPSCAN, SPAD, and petiole nitrate concentration as well as between MTCI, GRVI and SR8 indices (Table 7). SPAD was insensitive to crop-N deficit using the specified criteria and did measure NSI less than 95%. However, the pattern and trend of SPAD measurements was similar to the CROPSCAN suggesting that this tool could be used with an adjusted threshold NSI value (i.e. 97.5%). The petiole measurements indicated similar patterns of crop-N deficit relative to the CROPSCAN, which is expected – the CROPSCAN indices used in this study were selected based on previous work that showed their correlation with petiole nitrate concentration (Nigon, et al., 2015, Nigon, et al., 2014). However, one notable disagreement between petiole nitrate concentration and CROPSCAN occurred on 27 July 2016 where the petioles indicated crop-N deficit while CROPSCAN indicated crop-N sufficiency. This suggests multiple source of information should be used during critical application periods to determine the need for supplemental N-fertilizer.

Table 7. Monitoring in-season crop N-status for main effect of VR Split N-Treatment

Decision Date	**2016**				**2017**			
	23 June	14 July	21 July	27 July	28 June	10 July	20 July	27 July
Fertilizer Applied to VR Split	lbs. N/acre							
	0	20	20	20	0	20	0	20
CROPSCAN	21 June	12 July	18 July	25 July	27 June	6 July	19 July	24 July
	NSI Value							
MTCI	0.9818[†]	**0.9303**	**0.9359**	0.9602	0.9745	**0.9430**	0.9756	**0.9141**
GRVI	0.9851	**0.9480**	**0.9460**	0.9738	0.9704	0.9641	0.9862	**0.9448**
SR8	0.9704	**0.8846**	**0.8918**	**0.9460**	0.9706	**0.9408**	0.9754	**0.8873**
SPAD-502 Meter	16 June	13 July	–[‡]	25 July	27 June	6 July	18 July	24 July
	NSI Value							
	1.0138	0.9782	–	1.0183	0.9918	0.9597	0.9650	0.9585
Petiole Nitrate	16 June	13 July	–[‡]	25 July	27 June	6 July	18 July	24 July
	ppm NO_3-N							
	23019	**8046**	–	**9726**	17174	**10829**	11798	**2958**

[†]**Bold** values indicate an identified N-deficiency for a given method on a given date. Shaded values indicate that a fertilizer application was made on the corresponding decision date.

[‡]Petiole samples and SPAD Meter Readings were not collected between 14 July and 21 July 2016.

Soil Moisture Content

The irrigation treatments had similar soil moisture deficits except for slight differences observed in June 2016 and July 2017 (Figure 2). The limited magnitude and temporal occurrence of differences in soil moisture deficit between treatments were likely caused by three factors. First, the difference between irrigation application rate for the two treatments of 15% was relatively small. A more substantial reduction (i.e. 30%) in irrigation rate would increase the soil moisture deficit more noticeably. Second, the differences in soil moisture deficit occurred during periods of limited precipitation. Both years of this study had relatively high rates of precipitation, although there were occasional drier periods of 1-2 weeks in which irrigation was the predominant input of water into the soil. Third, irrigation at the SPRF was applied without using soil moisture measurements as a correction to the checkbook which has been previously shown to lead to unintentional over-irrigation (). Frequent exceedance of field capacity occurred in both irrigation treatments because of over-irrigation which further limited the differences in soil moisture deficit between treatments. There were, however, meaningful differences in the calculated volume of percolation between the irrigation treatments (Table 8). The reduced irrigation treatment decreased percolation by 1.18 inches (6%) in 2016 and 1.30 inches (10%) in 2017.

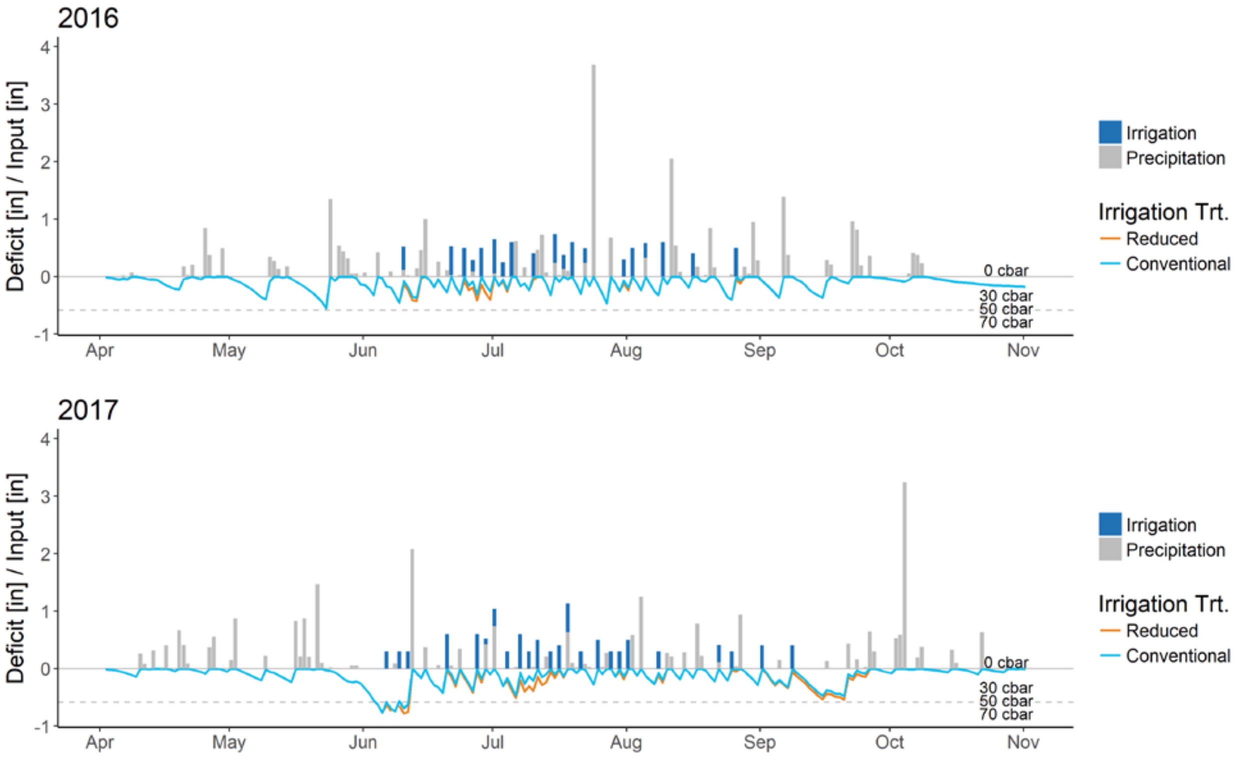

Figure 2. Calculated soil moisture deficit shown by irrigation treatment with precipitation and irrigation input for the Conventional treatment.

Table 8. Rate and timing of percolation by irrigation treatment

	2016							2017					
Irrigation	May	June	July	Aug.	Sept.	Total	in.	May	June	July	Aug.	Sept.	Total
1 Reduced	2.29	1.00	5.99	4.79	3.60	17.67		4.19	2.30	1.05	3.42	0.78	11.74
2 Convent.	2.29	1.40	6.40	5.16	3.60	18.85		4.19	2.66	1.75	3.59	0.85	13.04

Tuber Yield and Quality

Significant differences in total yield and Grade A yield were observed as a response to N treatment (Table 9). As expected, the Control treatment resulted in significantly less tuber yield compared to the 5 fertilized treatments. Treatments with an N rate of 240 lbs. N/acre had significantly greater tuber yield compared to treatments with N rate of 160 lbs. N/acre. The interaction of Year x Nitrogen was significant for both Total and Grade A yield, which is attributable to a greater tuber yield from the Control treatment in 2017 compared to 2016. There was no significant difference in either total or Grade A yield between the controlled-release and split-applied N treatments. The total and Grade A yield of the variable rate N treatment were not significantly different from the conventional best management practice N treatments. Significant differences in the ratio of tubers greater than 6 oz. were observed in response to Nitrogen and Year. Tubers were larger sized in 2017 than 2016; additionally, the Control treatment had significantly smaller tuber size compared to the 5 fertilized treatments and the treatments with N rate of 240 lbs. N/acre had significantly larger tuber size compared to treatments with N rate of 160 lbs. N/acre. There was no significant difference in the ratio of tubers greater than 6 oz. between the controlled-release and split-applied N treatments. The ratio of tubers greater than 6 oz. for the variable rate N treatment was not significantly different from that of the conventional best management practice N treatments. Significant differences in the ratio misshapen tubers were found in response to Nitrogen and Year. The Control treatment had significantly more misshapen tubers than the fertilized treatments and the Source of N fertilizer caused significant differences with the CR treatments having fewer misshapen tubers than the Split treatments. More tubers were misshapen in 2016 than 2017. The interaction of Year x Nitrogen was significant for misshapen tubers which is attributable to a greater ratio of misshapen tubers yield from the control treatment in 2017 compared to 2016. Significant differences in the occurrence of Hollow Heart internal defects were not detected for any of the main effects; however, the Control treatment contrast for Nitrogen was significant with the control treatment having a decreased occurrence of internal defects compared to the fertilized treatments. Significant differences in tuber specific gravity were detected in response to Nitrogen and Year. Specific gravity was significantly higher in 2017 than in 2016. The 160 Split treatment had the highest specific gravity and the 240 CR treatment had the lowest specific gravity. However, differences in specific gravity in response to Nitrogen were not attributable to any of the contrasts tested. For all response variables, Irrigation did not have a significant response.

Nitrate Leaching

Significant differences in nitrate leaching loads were observed in response to Nitrogen and Year (Table 9). Nitrate leaching load was lower in 2016 compared to 2017, which is the result of two combined factors – nitrate concentration and percolation. Because nitrate load is the product of nitrate concentration and percolation, the overall mass of nitrate leached below the root zone depends equally on either of these factors. First, measured nitrate concentrations were much higher in 2017 than in 2016 (Figure 3). Second, although percolation was greater in 2016 than in 2017 (Table 8) it was not greater by a magnitude greater than the difference in nitrate concentration between the two years. By the same reasoning, the differences in nitrate leaching load in response to Nitrogen can be understood. There were no differences in percolation because of Nitrogen treatment, meaning that differences in nitrate leaching were the result of differences in nitrate concentration between treatments (Figure 3); however, the only significant difference in response to Nitrogen was the contrast between the control and fertilized treatments. This resulted in nitrate leaching loads for the control treatment that were significantly lower than the fertilized treatments. Similarly, the non-significant differences in nitrate leaching load to Irrigation treatment can be understood. Between the two irrigation treatments, nitrate concentrations were not significantly different (Figure 3). Relative reductions in percolation between the irrigation treatments were relatively small. This resulted in differences in calculated nitrate leaching that were relatively small, and not significantly different. Overall, there was a trend for more nitrate leaching with the conventional irrigation rate relative to the reduced rate, due to the associated reduction in percolation.

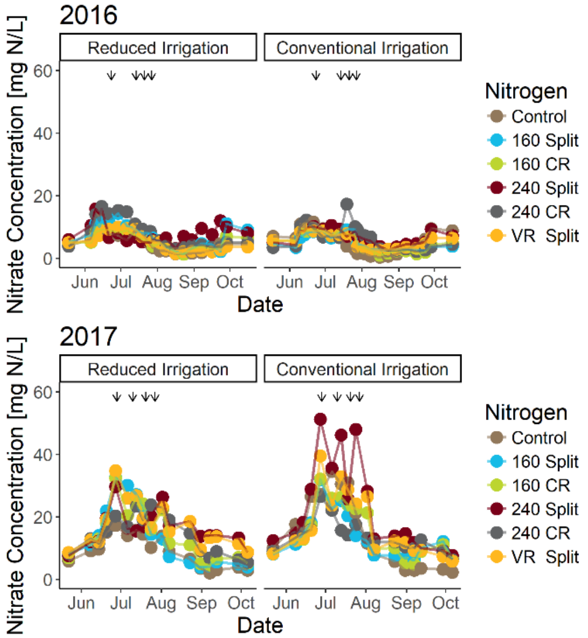

Figure 3. Measured concentration of nitrate-N below the root zone by nitrogen and irrigation treatment

Table 9. Tuber Yield, Quality, and Nitrate Leaching

		Total Yield	Grade A Yield	Tubers > 6 oz	Misshapen Tubers	Hollow Heart	Specific Gravity	Nitrate Leaching
Year		cwt acre^{-1}		%				lbs. N acre^{-1}
2016		613.7	575.5	72.1 B[†]	35.4 A	1.3	1.077 B	26.3 B
2017		607.9	592.6	82.9 A	17.2 B	1.2	1.082 A	50.6 A
Irrigation								
Reduced		609.9	581.7	76.9	25.7	1.3	1.079	35.6
Standard		611.7	586.4	78.1	26.9	1.2	1.080	41.3
Nitrogen								
Control		484.4 D	454.4 C	62.2 C	31.1 A	0.0	1.078 B	28.8 B
160 Split		623.2 BC	594.7 B	77.3 B	27.8 AB	1.9	1.081 A	39.2 AB
160 CR		618.9 C	595.1 B	80.0 AB	23.0 C	2.3	1.080 AB	36.4 AB
240 Split		655.3 A	627.6 A	81.6 A	26.7 BC	0.5	1.080 AB	47.0 A
240 CR		638.4 ABC	611.5 AB	81.6 A	24.0 BC	1.5	1.078 B	39.1 AB
VR Split		644.7 AB	620.8 A	82.3 A	25.3 BC	1.3	1.080 AB	40.1 AB
Main Effect	**Year [Y]**	[‡] –	–	***	***	–	***	***
Main Effect	**Irrigation [I]**	–	–	–	–	–	–	–
Main Effect	**Nitrogen [N]**	***	***	***	**	–	+	+
Contrast[§]	Control	***	***	***	***	*	–	*
Contrast	Rate	**	**	**	–	–	–	–
Contrast	Source	–	–	–	*	–	–	–
Contrast	Var. Rate	–	–	–	–	–	–	–
Interaction	**I x N**	–	–	–	–	–	–	–
Interaction	**Y x I**	–	–	–	–	*	–	–
Interaction	**Y x N**	*	*	–	***	–	+	–
Interaction	**Y x I x N**	–	–	–	–	–	–	–

[†] Means followed by the same letter within a main effect are not significantly different using the Fischer Least Significant Difference procedure for protected *post-hoc* multiple comparison at α=0.05

[‡] ***, **, *, +, and – denote significance for p(>F) of less than 0.001, 0.01, 0.05, 0.10 and greater than 0.10, respectively

[§] Non-orthogonal and *a priori* contrasts, as specified in Table 5

CONCLUSIONS AND FUTURE RESEARCH

Overall, results of this study suggest irrigation and nitrogen have important effects on the agronomic and environmental outcomes of potato production. Reducing irrigation by 15% relative to conventional rates did not have any significant impact on tuber yield or quality parameters measured. This indicates that a reduction in irrigation rates, which has positive environmental impacts by reducing aquifer withdrawals and potentially leaching, can be accomplished without a negative impact on potato production. Although reduced irrigation did not have a significant impact on nitrate leaching load in this study, it is possible in other production years that the reduction in percolation associated with reduced irrigation would in turn produce significant differences in nitrate leaching load.

As for nitrogen, it is clear from this study that rate is an important factor in determining the agronomic outcomes in potato production. However, it is notable that the respective reductions in N rate of 20 and 40 lbs. N/acre in 2016 and 2017 that was associated with the Variable Rate treatment had no significant impacts on agronomic outcomes measured. This suggests that producers should be able to use a NSI approach to determine the timing of post-emergence fertilizer applications for potato, and that this approach may be able to reduce unnecessary fertilizer applications. Before the NSI approach used in this study can be widely adopted, hyperspectral remote sensing needs to become commercially available. Additionally, the NSI approach depends on a well-fertilized reference strip and is unable to directly determine an appropriate N rate which means this approach may still need to be combined with ground truth measurements such as petiole nitrate analysis.

Future work for this study includes an analysis of nitrogen uptake and nitrogen use efficiency, a comparison of methods to make N fertilizer decisions between conventional methods such as petiole nitrate concentration and NSI using the SPAD meter or MTCI, and an economic analysis. Finally, data from this study will be further utilized to calibrate and validate the biophysical simulation model EPIC to explore the agronomic and environmental impacts of alternative management practices.

ACKNOWLEDGEMENTS

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Field Evaluation of Polyhalite as a Potassium, Calcium, Magnesium, and Sulfur Source for Irrigated Russet Burbank Potato Production

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Summary: Polyhalite is a naturally occurring mineral consisting of sulfate forms of potassium, magnesium, and calcium with a chemical formula of $K_2SO_4 \cdot MgSO_4 \cdot 2CaSO_4 \cdot 2H_2O$ and an approximate fertilizer value from one known mineral deposit of 0-0-14-19S-3.6Mg-12.1Ca. Because of relatively large deposits worldwide, there is interest in whether polyhalite can be used as an economical nutrient source for crop production. The overall objective of this study was to determine the effectiveness of polyhalite as a nutrient source for potato production in Minnesota. The study was conducted at the Sand Plain Research Farm in Becker, Minnesota on an acid, low organic matter Hubbard loamy sand soil with low soil test K, Ca, Mg. and S. Nine treatments varying in K fertilizer source and other amendments (lime, $MgSO_4$, and $CaSO_4$) supplying different rates of S, Mg, and Ca were tested: (1) a control treatment with no K, S, Mg, or Ca application; (2) 400 $lbs \cdot ac^{-1}$ K_2O as polyhalite (Sirius Minerals, PLC), which also supplied 543 $lbs \cdot ac^{-1}$ S, 103 $lbs \cdot ac^{-1}$ Mg, and 340 $lbs \cdot ac^{-1}$ Ca; (3) 400 $lbs \cdot ac^{-1}$ K_2O as MOP (muriate of potash); (4) 400 $lbs \cdot ac^{-1}$ K_2O as MOP, plus $CaSO_4$ (gypsum – SuperCal SO4) and $MgSO_4$ (Epsom salts) to provide 410 $lbs \cdot ac^{-1}$ S and the same amounts of Mg and Ca as treatment 2; (5) 300 $lbs \cdot ac^{-1}$ K_2O as polyhalite and 100 $lbs \cdot ac^{-1}$ K_2O as MOP, which also supplied 407 $lbs \cdot ac^{-1}$ S, 77 $lbs \cdot ac^{-1}$ Mg, and 255 $lbs \cdot ac^{-1}$ Ca; (6) 200 $lbs \cdot ac^{-1}$ K_2O as polyhalite and 200 $lbs \cdot ac^{-1}$ K_2O as MOP, which also supplied 272 $lbs \cdot ac^{-1}$ S, 52 $lbs \cdot ac^{-1}$ Mg, and 170 $lbs \cdot ac^{-1}$ Ca; (7) 400 $lbs \cdot ac^{-1}$ K_2O as MOP, plus pelletized lime (SuperCal 98G) and $MgSO_4$ to provide 136 $lbs \cdot ac^{-1}$ S and the same amounts of Mg and Ca as treatments 2 and 4; (8) 400 $lbs \cdot ac^{-1}$ K_2O as MOP, plus $CaSO_4$ which supplied 272 $lbs \cdot ac^{-1}$ S and the same amount of Ca as treatments 2, 4, and 7; and (9) 100 $lbs \cdot ac^{-1}$ K_2O as polyhalite and 300 $lbs \cdot ac^{-1}$ K_2O as MOP, which also supplied 136 $lbs \cdot ac^{-1}$ S, 84 $lbs \cdot ac^{-1}$ Ca, and 26 $lbs \cdot ac^{-1}$ Mg. Russet Burbank was the cultivar tested. At the low soil test K level found at this experimental site, K fertilization was required for optimum yield and tuber size. In contrast to the previous year's results, polyhalite was not found to increase tuber size, but among treatments receiving MOP, polyhalite, or blends of the two with no other amendments, the yield of U.S. No. 2 tubers decreased significantly as the percentage of K provided by polyhalite increased, while the yield of U.S. No. 1 tubers showed a trend in the opposite direction. K fertilization decreased the prevalence of hollow heart and brown center and decreased tuber dry matter content. The chlorophyll content (SPAD readings) of terminal leaflets of the most recently matured leaf collected in June increased as the percentage of K provided by polyhalite increased.

Background

Polyhalite is a naturally occurring mineral consisting of sulfate forms of potassium, magnesium, and calcium with a chemical formula of $K_2SO_4 \cdot MgSO_4 \cdot 2CaSO_4 \cdot 2H_2O$ and an approximate fertilizer value from known deposits of 0-0-14-19S-3.6Mg-12.1Ca. Because of relatively large deposits worldwide, there is interest in whether polyhalite can be used as an economical nutrient source for crop production. Once mined, the mineral is granulated and suitable for spreading with conventional fertilizer spreaders. The lower ratio of K to S content relative to sulfate of potash means that high rates of S would be applied when the product is used to meet the K demands of a crop like potatoes. Among the soils that might benefit from a polyhalite application are low-organic matter, acidic, sandy soils, which are often low in S, Ca, and Mg in addition to K.

The overall objective of this study was to determine the effectiveness of polyhalite as a nutrient source for potato production in Minnesota. This was the 4th year of the study. A treatment with K_2O supplied as a 1:3 blend of polyhalite and MOP was added to those studied in 2016.

Materials and Methods

The study was conducted at the Sand Plain Research Farm in Becker, MN, on a Hubbard loamy sand soil. The previous crop was rye. Thirty-six study plots were arranged in a randomized complete block design with four replicates and nine treatments: (1) a control treatment with no K, S, Mg, or Ca application; (2) 400 lbs·ac^{-1} K_2O as polyhalite (Sirius Minerals, PLC), which also supplied 543 lbs·ac^{-1} S, 103 lbs·ac^{-1} Mg, and 340 lbs·ac^{-1} Ca; (3) 400 lbs·ac^{-1} K_2O as MOP (muriate of potash); (4) 400 lbs·ac^{-1} K_2O as MOP, plus $CaSO_4$ (gypsum – SuperCal SO4) and $MgSO_4$ (Epsom salts) to provide 410 lbs·ac^{-1} S and the same amounts of Mg and Ca as treatment 2; (5) 300 lbs·ac^{-1} K_2O as polyhalite and 100 lbs·ac^{-1} K_2O as MOP, which also supplied 407 lbs·ac^{-1} S, 77 lbs·ac^{-1} Mg, and 255 lbs·ac^{-1} Ca; (6) 200 lbs·ac^{-1} K_2O as polyhalite and 200 lbs·ac^{-1} K_2O as MOP, which also supplied 272 lbs·ac^{-1} S, 52 lbs·ac^{-1} Mg, and 170 lbs·ac^{-1} Ca; (7) 400 lbs·ac^{-1} K_2O as MOP, plus pelletized lime (SuperCal 98G) and $MgSO_4$ to provide 136 lbs·ac^{-1} S and the same amounts of Mg and Ca as treatments 2 and 4; (8) 400 lbs·ac^{-1} K_2O as MOP, plus $CaSO_4$ which supplied 272 lbs·ac^{-1} S and the same amount of Ca as treatments 2, 4, and 7; and (9) 100 lbs·ac^{-1} K_2O as polyhalite and 300 lbs·ac^{-1} K_2O as MOP, which also supplied 136 lbs·ac^{-1} S, 84 lbs·ac^{-1} Ca, and 26 lbs·ac^{-1} Mg. These treatments are summarized in Table 1.

Samples of the top 6” of soil were collected from each block on May 4, 2017. The samples were analyzed for Bray P; NH_4OAc-extractable K, Ca, and Mg; Ca-P -extractable SO_4-S; hot-water-extractable B; DTPA-extractable Cu, Fe, Mn, and Zn; soil water pH; and LOI soil OM content. Initial soil characteristics of the study site are presented in Table 2.

On May 8, before planting, one-half of the amount of each fertilizer treatment was broadcast and incorporated to a depth of about six inches with a field cultivator. Whole “B” seed of Russet Burbank potatoes were then hand-planted in furrows. Four, 20-ft rows were planted for each plot, with the middle two rows used for sampling and harvest. Row spacing was 12 inches within each row and 36 inches between rows.

During row closure, all plots received fertilizer banded three inches to each side and two inches below the seed piece, including 30 lbs·ac^{-1} N, 136 lbs·ac^{-1} P_2O_5, 1.5 lbs·ac^{-1} S, 1.0 lbs·ac^{-1} B, and 2 lbs·ac^{-1} Zn, as a blend of MAP (monoammonium phosphate), EZ20, and Granubor. Belay for beetle control and the systemic fungicide Quadris were also banded at row closure.

After emergence on May 22, the other half of each fertilizer treatment was applied by hand as a sidedress and incorporated during hilling, in addition to 170 lbs·ac^{-1} N as ESN (Environmentally Smart Nitrogen, Agrium, Inc.; 44-0-0). Twenty lbs·ac^{-1} N were applied as 28% UAN (urea-ammonium nitrate) in each of two post-hilling applications, on June 26 and July 13. In total, all treatments received 240 lbs·ac^{-1} N. Weeds, diseases, and other insects were controlled using standard practices. Rainfall was supplemented with sprinkler irrigation using the checkbook method of irrigation scheduling.

Plant stands in the harvest rows were measured on June 8 and the number of stems per plant among ten harvest-row plants on June 15. Petiole samples were collected from the 4th leaf from the terminal from 20 plants per plot on each of four dates: June 19 and 29 and July 11 and 26. Petioles are being analyzed for N, S, K, Mg, and Ca on a dry weight basis using inductively-coupled plasma analysis at the University of Minnesota Research Analytical Laboratory. SPAD readings, which measure the intensity of the green color of plant leaves, and are used as an indirect measurement of leaf N, were recorded on the 4th leaf from the terminal of 20 plants per plot on the same dates.

Vines were killed by chopping on September 15, and tubers were machine-harvested on September 27. Two, 18-ft sections of row were harvested from each plot. Total tuber yield and graded yield were measured. Twenty-five-tuber representative sub-samples were collected to determine tuber specific gravity and dry matter, K, S, Mg and Ca concentrations, and the prevalence of hollow heart, brown center, and scab. In addition, subsamples of tubers were sent to the USDA/ARS, Potato Research Worksite in East Grand Forks for sugar analysis and frying quality.

Results

Tuber yield and size distribution

Results for tuber yield and size distribution are presented in Table 3. The control treatment with no K, S, Mg, or Ca applied had significantly lower total and marketable yields than all other treatments. It also had the smallest percentage of its yield represented by tubers weighing more than six or 10 ounces of any treatment.

Total yield did not vary significantly among the treatments receiving K fertilizer, whether MOP or polyhalite. Marketable yield was significantly greater for the plots receiving MOP, lime, and Epsom salts (treatment 7) than the plots receiving MOP, gypsum, and Epsom salts (treatment 4), but did not otherwise vary significantly among the treatments receiving K fertilizer.

The treatment receiving MOP, lime, and Epsom salts (treatment 7) had a greater percentage of its yield represented by tubers over 10 ounces than any other treatment except for those receiving 100% MOP alone (treatment 3) or MOP with gypsum (treatment 8). The same was true for the percentage of yield represented by tubers over six ounces, except that the treatment receiving 100% polyhalite (treatment 2) was among the treatments that did not have a significantly lower percentage than the treatment receiving MOP, lime, and Epsom salts.

Although there was no overall effect of fertilizer treatment on the yield of U.S. No. 2 tubers over three ounces, the linear contrast of this variable against the proportion of K provided by polyhalite (which included treatments 2, 3, 5, 6, and 9) was significant. The greater the proportion of K provided by polyhalite, the lower the yield of U.S. No. 2 tubers. The yield of U.S. No. 1 tubers showed a trend in the opposite direction. The percentage of marketable yield represented by U.S. No. 2 tubers showed a strong negative relationship to the percentage of K provided by polyhalite (linear regression: $R^2 = 0.9647$).

Tuber quality

Results for tuber quality are presented in Table 4. The control treatment (treatment 1) had a significantly higher prevalence of brown center than any other treatment, and the contrast comparing the prevalence of hollow heart in the control versus the other treatments found a significantly higher prevalence in the control.

The control treatment also had the highest tuber dry matter content. The treatment receiving MOP with gypsum (treatment 8) had a lower tuber dry matter content than the treatment receiving 100% polyhalite (treatment 2), but the treatments receiving K fertilizer did not otherwise differ significantly in dry matter content. Scab was not detected in this study in this year.

Plant stand, stems per plant, and leaflet chlorophyll content

The number of stems per plant and terminal leaflet SPAD readings (a measure of chlorophyll content) are presented in Table 5. Plant stand is not presented because stand was 100% in all plots except one plot with 97.2% stand. The number of stems per plant was unrelated to treatment.

There was a significant effect of the interaction between treatment and sampling date on leaflet chlorophyll content, as measured by SPAD readings. The control treatment (treatment 1) had higher leaflet chlorophyll content than the other treatments on June 29 and July 11 and 26, with the difference increasing over time.

Among the treatments in which blends of MOP and polyhalite were applied (treatments 2, 3, 5, 6, and 9), leaflet chlorophyll content generally increased with the percentage of K provided by polyhalite on June 19 and 29 (R^2 of linear regressions = 0.4949 for June 19; 0.9301 for June 26). This relationship was no longer evident in July (R^2 = 0.1204 for July 11; 0.0684 for July 29).

Similarly, in pairwise comparisons, leaf chlorophyll content was higher in plots fertilized with 100% polyhalite (treatment 2) than in plots fertilized with 100% MOP (treatment 3) in both June samples, but not in either July sample. In contrast, plots fertilized with MOP plus gypsum and Epsom salts to approximate the nutrient composition of polyhalite (treatment 4) had similar leaflet chlorophyll content to the plots fertilized with 100% polyhalite on all four sampling dates. These results suggest that the differences in leaflet SPAD readings in June between polyhalite-fertilized plots and MOP-fertilized plots are due to the S, Ca, or Mg supplied by polyhalite.

Among K-fertilized plots receiving no polyhalite (treatments 3, 4, 7, and 8), SPAD readings in June were more strongly positively related to the application rate of Mg than the application rates of S or Ca (linear regression; results not shown), and this relationship between SPAD readings and Mg application rate broke down in July. This suggests that the positive effect of polyhalite on leaflet chlorophyll content in June may be due to the Mg content of polyhalite. Mg is a component of the chlorophyll molecule and was present in relatively low concentration in the soil of the study site (Table 2).

Conclusions

At the low soil test K level found at this experimental site, K fertilization was required for optimum yield and tuber size. In contrast to last year's results, fertilization with polyhalite did not increase tuber size. However, the use of polyhalite decreased the percentage of U.S. No. 2 tubers. Fertilization with K reduced the prevalence of hollow heart and brown center and decreased tuber dry matter content relative to the zero-K control treatment. Chlorophyll content (as measured by SPAD) of the terminal leaflet of the most recently matured leaf, was highest for the control treatment, as has been observed in previous years. Among K-fertilized treatments, leaflet SPAD readings in June increased with the proportion of K provided by polyhalite.

Table 1. Fertilizer treatments applied to Russet Burbank potatoes.

Treatment	K sources[1]	Nutrients applied (lbs/ac)			
		K_2O	SO_4-S	Ca	Mg
1	None	0	0	0	0
2	Polyhalite	400	543	340	103
3	MOP	400	0	0	0
4	MOP + Gypsum + Epsom salts	400	410	340	103
5	3 Poly : 1 MOP	400	407	254	77
6	1 Poly : 1 MOP	400	272	170	52
7	MOP + Lime + Epsom Salts	400	136	340	103
8	MOP + Gypsum	400	272	340	0
9	1 Poly : 3 MOP	400	136	84	26

[1] Polyhalite: 0-0-14.1-19(S)-3.6(Mg)-12.1(Ca). MOP (muriate of potash): 0-0-60.
Gypsum: 0-0-0-17(S)-21(Ca). Lime: 0-0-0-36(Ca). Epsom salts: 0-0-0-12.9(S)-9.8(Mg)

Table 2. Soil characterstics of the study site used in 2017.

Primary macronutrients		Secondary macronutrients			Micronutrients					Other characteristics	
Bray P (ppm)	NH$_4$OAc-K (ppm)	NH$_4$OAc-Ca (ppm)	NH$_4$OAc-Mg (ppm)	SO$_4$-S (ppm)	DTPA-Fe (ppm)	DTPA-Mn (ppm)	DTPA-Zn (ppm)	DTPA-Cu (ppm)	Hot Water B (ppm)	Water pH	O.M. LOI (%)
17	80	836	146	4	18.6	10.2	1.14	0.36	0.1	5.9	1.6

Table 3. Effects of polyhalite and MOP (with or without gypsum, lime, or Epsom salts) on Russet Burbank tuber yield and size distribution.

Treatment	**K sources**^{1}	**0-3 oz**	**3-6 oz**	**6-10 oz**	**10-14 oz**	**>14 oz**	**Total**	**#1s > 3 oz.**	**#2s > 3 oz**	**Total Marketable**	**> 6 oz**	**> 10 oz**
		cwt · ac^{-1}									**%**	
1	None	50	158 a	153 c	58 c	39 d	458 b	330 c	127	408 c	54 d	21 e
2	Polyhalite	43	118 cd	216 a	121 a	85 bc	583 a	470 ab	113	540 ab	72 ab	35 bcd
3	MOP	45	121 cd	195 ab	120 a	113 ab	593 a	446 ab	148	549 ab	72 ab	39 ab
4	MOP + Gypsum + Epsom salts	52	148 ab	188 b	97 b	88 bc	571 a	465 ab	106	519 b	65 c	32 cd
5	3 Poly : 1 MOP	41	130 bc	196 ab	121 a	90 bc	578 a	460 ab	118	537 ab	70 bc	36 bcd
6	1 Poly : 1 MOP	50	138 abc	199 ab	134 a	67 cd	588 a	462 ab	126	538 ab	68 bc	34 bcd
7	MOP + Lime + Epsom Salts	35	100 d	197 ab	125 a	129 a	587 a	478 a	109	552 a	77 a	43 a
8	MOP + Gypsum	48	118 cd	186 b	115 ab	110 ab	577 a	456 ab	121	529 ab	71 abc	39 abc
9	1 Poly : 3 MOP	42	136 abc	211 ab	119 ab	65 cd	573 a	444 b	129	531 ab	69 bc	32 d
Treatment significance (P-value)		0.3104	**0.0092**	**0.0459**	**0.0006**	**0.0028**	**<0.0001**	**<0.0001**	0.3642	**<0.0001**	**0.0003**	**0.0006**
Contrasts	Control vs. others	0.2823	**0.0041**	**0.0011**	**<0.0001**	**0.0008**	**<0.0001**	**<0.0001**	0.6332	**<0.0001**	**<0.0001**	**<0.0001**
	Linear proportion polyhalite	0.7374	0.7386	0.4573	0.8960	0.4525	0.7118	0.1409	**0.0403**	0.7948	0.8496	0.6353
	Quadratic proportion polyhalite	0.6122	*0.0805*	0.7045	0.5221	**0.0466**	0.6210	0.9593	0.6045	0.4895	0.1797	0.2463

[1] Polyhalite: 0-0-14.1-19(S)-3.6(Mg)-12.1(Ca). MOP (muriate of potash): 0-0-60. Gypsum: 0-0-0-17(S)-21(Ca). Lime: 0-0-0-36(Ca). Epsom salts: 0-0-0-12.9(S)-9.8(Mg)

Table 4. Effects of polyhalite and MOP (with or without gypsum, lime, or Epsom salts) on tuber quality, dry matter percentage, and specific gravity. Scab was not detected.

Treatment	**K sources[1]**	Hollow heart	Brown Center	Dry matter	Specific gravity
		%			
1	None	4	7 a	23.9 a	1.0862
2	Polyhalite	0	0 b	22.6 b	1.0843
3	MOP	0	0 b	22.5 bc	1.0824
4	MOP + Gypsum + Epsom salts	2	2 b	22.3 bc	1.0827
5	3 Poly : 1 MOP	1	1 b	22.2 bc	1.0827
6	1 Poly : 1 MOP	0	0 b	22.3 bc	1.0848
7	MOP + Lime + Epsom Salts	0	0 b	22.6 bc	1.0796
8	MOP + Gypsum	0	0 b	21.6 c	1.0819
9	1 Poly : 3 MOP	0	0 b	22.2 bc	1.0830
Treatment significance (P-value)		0.4865	**0.0120**	*0.0782*	0.6619
Contrasts	Control vs. others	**0.0242**	**<0.0001**	**0.0016**	0.1813
	Linear proportion polyhalite	0.8257	0.8048	0.8034	0.5947
	Quadratic proportion polyhalite	0.8524	0.8345	0.4815	0.8131

[1] Polyhalite: 0-0-14.1-19(S)-3.6(Mg)-12.1(Ca). MOP (muriate of potash): 0-0-60.
Gypsum: 0-0-0-17(S)-21(Ca). Lime: 0-0-0-36(Ca). Epsom salts: 0-0-0-12.9(S)-9.8(Mg)

Table 5. Effects of polyhalite and MOP (with or without Ca, Mg, and S) on the number of stems per plant, and terminal leaflet SPAD readings in Russet Burbank potatoes.

Treatment	**K sources[1]**	**Stems / plant**	**SPAD**				
			June 19	**June 29**	**July 11**	**July 26**	**Average across dates**
1	None	2.8	46.3 abc, BC	45.0 a, C	48.9 a, A	48.0 a, AB	47.0 a
2	Polyhalite	2.8	46.4 ab, A	43.0 bc, BC	43.5 bc, B	41.6 bc, C	43.6 bc
3	MOP	2.7	45.4 bc, A	40.8 d, B	43.5 bc, A	40.0 c, B	42.4 d
4	MOP + Gypsum + Epsom salts	3.0	45.4 bc, A	42.5 bcd, BC	43.4 bc, B	41.1 bc, C	43.1 cd
5	3 Poly : 1 MOP	2.6	47.7 a, A	43.1 b, C	45.1 b, B	40.6 bc, D	44.1 b
6	1 Poly : 1 MOP	3.0	46.1 abc, A	42.2 bcd, BC	43.6 bc, B	41.0 bc, C	43.2 cd
7	MOP + Lime + Epsom Salts	3.0	46.6 ab, A	41.7 bcd, B	42.7 c, B	41.9 b, B	43.2 cd
8	MOP + Gypsum	3.0	44.9 bc, A	41.2 cd, B	42.8 c, B	41.6 bc, B	42.6 d
9	1 Poly : 3 MOP	2.7	44.5 c, A	41.5 bcd, C	43.6 bc, AB	42.3 b, BC	43.0 cd
Average across treatments		NA	45.9 A	42.3 C	44.1 B	42.0 C	
Treatment significance (P-value)		0.7586	**<0.0001**				
Date significance (P-value)		NA	**<0.0001**				
Treatment*date significance (P-value)		NA	**0.0052**				
Contrasts	Control vs. others	0.9091	**<0.0001**				
	Linear proportion polyhalite	0.9389	**0.0041**				
	Quadratic proportion polyhalite	0.7463	0.3033				

[1] Polyhalite: 0-0-14.1-19(S)-3.6(Mg)-12.1(Ca). MOP (muriate of potash): 0-0-60. Gypsum: 0-0-0-17(S)-21(Ca).
Lime: 0-0-0-36(Ca). Epsom salts: 0-0-0-12.9(S)-9.8(Mg)

Evaluation of a Chelated Nutrient Product (Redline) on Yield and Quality of Russet Burbank Potatoes

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Summary

Chelation of plant nutrients is a method of preventing nutrients from forming biologically unavailable precipitates in the soil. One fertilizer product formulated with this approach is Redline (West Central, Inc.), which contains N, P, K, and Fe, Mn, Zn, and Cu chelated with ortho-ortho EDDHA. We evaluated the effect of Redline on tuber yield, size, grade, and quality in Russet Burbank potatoes grown at the Sand Plain Research Farm in Becker, MN. Three treatments were applied at planting: (1) a low-P check treatment receiving 28 lbs·ac^{-1} N in the form of 9.8 gal·ac^{-1} 28% UAN, (2) a treatment receiving 28 lbs·ac^{-1} N and 95 lbs·ac^{-1} P_2O_5 in the form of 25 gal·ac^{-1} ammonium polyphosphate, and (3) a treatment receiving 26 lbs·ac^{-1} N, 87 lbs·ac^{-1} P_2O_5, 0.6 lbs·ac^{-1} K_2O, 0.09 lbs·ac^{-1} Fe, 0.01 lbs·ac^{-1} Mn, 0.29 lbs·ac^{-1} Zn, and 0.01 lbs·ac^{-1} Cu, as 22 gal·ac^{-1} ammonium polyphosphate with 3 gal·ac^{-1} Redline. The treatments receiving P_2O_5 at planting had higher total and marketable yields than the treatment receiving only N, but the treatment receiving polyphosphate with Redline did not have different total or marketable yield than the treatment receiving polyphosphate alone. The treatment receiving Redline had higher yields of 6- to 10-ounce tubers and lower yields of 3- to 6-ounce tubers than the treatment receiving polyphosphate alone, but this did not produce a significant difference in the percentage of yield represented by tubers over 6 ounces. Tubers exhibiting hollow heart, brown center, scab, and scurf were not related to treatment, nor were tuber dry matter content and specific gravity. We did not find evidence that Redline had an effect on total tuber yield or quality, but the tuber size distribution in the treatment receiving Redline shifted from 3-6 ounce tubers toward 6-10 ounce tubers, which is beneficial for processing.

Background

Some plant nutrients chemically interact with each other or with inorganic soil constituents to form biologically unavailable precipitates. Such precipitation reactions can be prevented by applying nutrients in chelates. One fertilizer product developed using this strategy, Redline (West Central, Inc.; 6-12-2-0.3Fe-0.04Mn-1Zn-0.05Cu) contains N, P, and K, plus Fe, Mn, Zn, and Cu chelated with ortho-ortho EDDHA.

The objective of this research was to evaluate Redline as a source of micronutrients for Russet Burbank potato plants. Three treatments were applied at planting: (1) a check treatment providing only N as UAN; (2) a treatment providing N at the same rate plus P_2O_5 as polyphosphate; and (3) a treatment providing N and P_2O_5 at similar rates, plus K, Fe, Mn, Zn, and Cu, as a blend of polyphosphate and Redline.

Methods

The study was conducted in 2017 at the Sand Plain Research Farm in Becker, MN, on a Hubbard loamy sand soil. The previous crop was rye. Twelve study plots were arranged in a randomized complete block design with four replicates and three liquid fertilizer treatments applied at planting: (1) a check treatment receiving 28 lbs·ac^{-1} N as 28% UAN (28-0-0) applied at 9.8 gal·ac^{-1}; (2) a treatment receiving 33.6 lbs·ac^{-1} N and 114.1 lbs·ac^{-1} P_2O_5 as ammonium polyphosphate (10-34-0) applied at 25 gal·ac^{-1}; (3) a treatment receiving 26 lbs·ac^{-1} N, 87 lbs·ac^{-1} P_2O_5, 0.58 lbs·ac^{-1} K_2O, 0.09 lbs·ac^{-1} Fe, 0.01 lbs·ac^{-1} Mn, 0.29 lbs·ac^{-1} N Zn, and 0.01 lbs·ac^{-1}

Cu as a blend of 22 gal·ac^{-1} ammonium polyphosphate and 3 gal·ac^{-1} Redline (6-12-2-0.3Fe-0.04Mn-1Zn-0.05Cu). A summary of the treatments is presented in Table 1.

Samples of the top 6" of soil were collected from each block on April 13, 2017. These samples were analyzed for Bray P; NH_4OAc-extractable K, Ca, and Mg; Ca-P-extractable SO_4-S; hot-water-extractable B; DTPA-extractable Cu, Fe, Mn, and Zn; soil water pH; and LOI soil organic matter content. The initial soil characteristics of the study site are presented in Table 2.

Prior to planting, on April 14, MOP (0-0-60) was broadcast on the 120- by 42-foot field at 200 lbs·ac^{-1}, followed by 200 lbs·ac^{-1} SulPoMag (0-0-21.5-22S-11Mg) on April 17, to provide 163 lbs·ac^{-1} K_2O, 44 lbs·ac^{-1} S, and 22 lbs·ac^{-1} Mg. The twelve, 12- by 20-foot plots were planted on May 8 using Russet Burbank whole "B" seed with three-foot spacing between rows and one-foot spacing within rows. The plots were arranged in four blocks of three plots, separated by seven-foot-wide alleys running perpendicular to the planting rows. The field was surrounded by a buffer strip of Russet Burbank potatoes five feet wide at both ends and three feet (one row) wide along the edges.

The central two rows of each plot were designated as harvest rows. Each end of each harvest row was marked with a Chieftain red potato to produce a visible boundary between the tubers of different plots during harvest, leaving a sampled area of Russet Burbank potatoes six feet wide and 18 feet long in each plot. At row opening, 28% UAN, ammonium polyphosphate, and Redline were applied in-furrow, according to the treatment assigned to each plot (Table 1). The rows were hilled and 200 lbs·ac^{-1} N banded as 455 lbs·ac^{-1} ESN on May 24, 16 days after planting.

In each plot, plant stand in the harvest rows was assessed on June 8, and the number of stems per plant for 10 plants in the harvest rows were determined on June 15. Petioles were sampled June 14 and 26 and July 5 and 18, (i.e., 21. 33, 42, and 55 days after hilling). The petiole of the fourth expanded leaf from the end of the shoot was collected from each of 20 shoots per plot on each date. The petioles were dried for 48 hours at 140°F, ground, and sent to the Research Analytical Laboratory at the University of Minnesota to have their elemental concentrations determined by inductively coupled plasma analysis. Results of petiole analyses are in progress and not available at the time of this report.

Vines were chopped on September 15. The tubers were harvested on September 27 and sorted by size and USDA grade on September 29. Twenty-five representative tubers per plot were separated and stored at 48°F. The prevalence of hollow heart, brown center, scab, and scurf, as well as tuber specific gravity and dry matter content were determined from these samples.

The data were analyzed with SAS 9.4m3® software (copyright 2015, SAS Institute, Inc.), using the MIXED procedure with treatment and block as fixed effects. Post-hoc pairwise comparisons were made using the DIFF option for the LSMEANS procedure, with a threshold of statistical significance $\alpha = 0.10$. Pairwise comparisons were only evaluated where the P-value of the effect of treatment in the model was less than 0.10.

Results and discussion

Results for tuber yield are presented in Table 3. The treatments receiving P fertilizer at planting (treatments 2 and 3) had higher total and marketable yields than the treatment receiving only N (treatment 1). The treatment receiving polyphosphate with Redline (treatment 3) did not have different total or marketable yield than the treatment receiving polyphosphate alone (treatment 2). However, the treatment receiving Redline had higher yields of 6- to 10-ounce tubers and lower yields of 3- to 6-ounce tubers than the treatment receiving polyphosphate alone, which is beneficial for processing. This did not result in a significant difference in the percentage of yield represented by tubers over 6 ounces.

Tuber quality results are presented in Table 4. None of the tuber quality variables measured were significantly related to treatment. Fertilizer treatment was unrelated to either plant stand on June 8 (P = 0.6699) or the number of stems per plant on June 15 (P = 0.3686).

Conclusions

Treatments receiving P fertilizer at planting had higher total and marketable yields than the treatment receiving only N. Redline did not improve tuber quality or total or marketable tuber yield relative to ammonium polyphosphate alone. However, plots receiving Redline had fewer 3- to 6-ounce tubers and more 6- to 10-ounce tubers than plots receiving only ammonium polyphosphate, suggesting an effect on tuber size distribution. The soil in the study site had relatively high concentrations of Fe, Mn, and Zn, indicating that the effect of Redline on tuber size may in part be due to Cu (with a moderately low concentration in this soil), or to some other property of the formulation of this product.

Table 1. Treatments applied to irrigated Russet Burbank potatoes at the Sand Plain Research Farm in Becker, MN.

Treatment	Products applied at planting[1] (gal·ac^{-1})			Nutrients applied[2] (lbs·ac^{-1})						
	UAN	Ammonium polyphosphate	Redline	N	P_2O_5	K_2O	Fe	Mn	Zn	Cu
1	9.8	0	0	28	0	0	0	0	0	0
2	0	25.0	0	28	95	0	0	0	0	0
3	0	22.0	3.0	26	87	0.58	0.09	0.01	0.29	0.01

[1] UAN: 28-0-0. Ammonium polyphosphate: 10-34-0. Redline: 6-12-2-0.3Fe-0.04Mn-1Zn-0.05Cu.

[2] All treatments received 163 lbs·ac^{-1} K_2O, lbs·ac^{-1} S, and 22 lbs·ac^{-1} Mg as a blend of Sul Po Mag (0-0-21.5-22S) and MOP (0-0-60) before planting, plus 200 lbs·ac^{-1} N as ESN (44-0-0) at emergence.

Table 2. Soil characteristics of the study site in the Sand Plain Research Farm in Becker, MN, at the beginning of the 2017 season (0 – 6” depth).

Primary macronutrients		**Secondary macronutrients**			**Micronutrients**					**Other characteristics**	
Bray P (ppm)	NH$_4$OAc-K (ppm)	NH$_4$OAc-Ca (ppm)	NH$_4$OAc-Mg (ppm)	SO$_4$-S (ppm)	DTPA-Fe (ppm)	DTPA-Mn (ppm)	DTPA-Zn (ppm)	DTPA-Cu (ppm)	Hot Water B (ppm)	Water pH	O.M. LOI (%)
17	80	836	146	4	18.6	10.2	1.14	0.36	0.1	5.9	1.6

Table 3. Effect of treatment on tuber yield, size, and grade for Russet Burbank potatoes grown at the Sand Plain Research Farm in Becker, MN.

Treatment	**Products applied at planting[1]**	**0-3 oz**	**3-6 oz**	**6-10 oz**	**10-14 oz**	**>14 oz**	**Total**	**#1s > 3 oz.**	**#2s > 3 oz**	**Total Marketable**	**> 6 oz**	**> 10 oz**
		cwt · ac^{-1}									**%**	
1	UAN	42	138 b	183 b	91	25	479 b	320	159	437 b	62	24
2	Ammonium polyphosphate	51	171 a	190 b	81	28	522 a	347	175	471 a	57	21
3	Ammonium polyphosphate + WC139	48	143 b	225 a	83	30	529 a	350	179	481 a	64	21
Treatment significance (P-value)		0.5153	*0.0973*	**0.0117**	0.8031	0.7060	**0.0071**	0.5769	0.7272	**0.0126**	0.2078	0.6401

[1] UAN: 28-0-0. Ammonium polyphosphate: 10-34-0. Redline: 6-12-2-0.3Fe-0.04Mn-1Zn-0.05Cu.

Table 4. Effect of treatment on tuber quality (the prevalence of hollow heart, brown center, scab, and scurf; dry matter content; and specific gravity) for Russet Burbank potatoes grown at the Sand Plain Research Farm in Becker, MN.

Treatment	**Products applied at planting[1]**	**Hollow heart**	**Brown Center**	**Scab**	**Black scurf**	**Dry matter**	**Specific gravity**
		%					
1	UAN	1	1	0	0	23.3	1.0904
2	Ammonium polyphosphate	1	1	4	1	23.5	1.0912
3	Ammonium polyphosphate + WC139	0	0	0	1	23.1	1.0920
Treatment significance (P-value)		0.6699	0.6699	0.1250	0.6699	0.8577	0.5267

[1] UAN: 28-0-0. Ammonium polyphosphate: 10-34-0. Redline: 6-12-2-0.3Fe-0.04Mn-1Zn-0.05Cu.

Effects of Planting Configuration (Beds versus Hills) and Plant Population Density on Russet Burbank Tuber Yield and Size for Seed Production

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Summary

Planting potatoes in beds instead of conventional hills offers many potential advantages, including increased yields and more efficient water and N use. To date, the effectiveness of bed-planting configurations has not been evaluated extensively in Minnesota, and growers in the state have little basis on which to decide whether the benefits of bed-planting configurations are worth the required investment in planting equipment. To assess the effects of planting in beds compared to a conventional hilled-row configuration, we conducted an experiment with a split-plot randomized complete block design with five replicates, in which whole plots were planted in either hilled rows or a seven-row bed configuration. To determine whether bed planting increased the density at which maximum yield was obtained, the whole plots were split into five subplots with population densities of 17,000, 20,400, 25,500, 34,000, or 51,000 plants·ac^{-1}. Bed plots produced more tubers, more whole seeds, and more total seeds per acre than hilled-row planted plots, but the differences between planting configurations in total yield per acre or per plant and total seeds per plant were not significant. The number of tubers produced per acre increased with planting density, but because mean tuber size decreased with planting density, both total yield per acre and total seed production per acre were unrelated to planting density. Tuber yield and count per acre were higher in beds than in hilled rows on July 28, and tuber count per acre, but not tuber yield per acre, increased with planting density at this time. Hilled-row plots produced more vine fresh mass per acre than bed plots on July 28, while tuber dry matter content was higher in the bed plots. Vine fresh mass also increased with planting density. Overall, the seven-row bed-planting configuration was superior to the conventional hilled-row configuration for seed production. Bed planting did not change the optimal planting density for seed production per acre (which was 20,400 plants·ac^{-1} in both configurations), but it increased per-acre production of whole seeds, with a trend in the same direction for total seeds. Bed planting did not change soil water NO_3-N concentrations, averaged across the season, and these values were not significantly different within rows than they were between them. However, the difference in the dynamics of NO_3-N concentrations in the rows and between rows was much greater in hilled-row plots than in bed plots. Higher spikes of NO_3-N early in the season were found between rows of hilled-row plots than between rows in bed-planted plots.

Background

Potatoes are conventionally grown in hilled rows, which provide furrows for drainage, preventing the tubers from being exposed to excessive moisture. Recently, however, farmers have begun to consider the benefits of a bed-planting configuration, in which multiple rows of potatoes are placed between more widely spaced furrows.

A bed-planting configuration allows less land to be dedicated to furrows and more to plants. It also provides plants with more area for horizontal root growth, which is constrained by furrows on either side in a hilled-row configuration. A bed-planting configuration allows plants to be spaced optimally for both light interception and root growth, which, in turn, can improve water and N use efficiency. In irrigated systems in sandy soils, typical of Minnesota potato farms, water and N are both required in large quantities to optimize yield, making conservation of both resources a priority.

Although some Minnesota growers are already using bed planters for some of their operations, bed-planting configurations have not yet been widely tested in Minnesota. Converting to bed planting requires a significant investment in planting equipment, and more research is needed before growers can determine whether that investment in bed planting is worthwhile.

An experiment was conducted with Russet Burbank potatoes planted in a conventional hilled-row configuration versus a bed configuration at a range of population densities from 17,000 to 51,000 plants$\cdot$ac^{-1}. The specific objectives of this study were to determine the effects of (1) a bed-planting configuration versus a hilled-row configuration and (2) plant population density on potato yield and size and soil water NO_3-N concentration.

Methods

The study was conducted at the Central Lakes College Agricultural and Energy Center in Staples, MN, under a linear irrigation system. The soil at the site is a Verndale sandy loam and the previous crop was corn. Preplant fertilizer was broadcast uniformly and incorporated over the entire plot area within one week before planting. The application was uniform over planting configuration and plant population treatments. Fertilizer application included 432 lbs$\cdot$ac^{-1} ESN, 150 lbs$\cdot$ac^{-1} ammonium sulfate, and 100 lbs$\cdot$ac^{-1} diammonium phosphate, to provide 240 lbs$\cdot$ac^{-1} N, and 300 lbs$\cdot$ac^{-1} 0-0-60. The planting configuration and plant population treatments were arranged in a split-plot randomized complete block design with five blocks. In each 500-foot by 30-foot block, one plot was planted in beds, with 1.7 feet between planting rows within the bed, and the second plot was planted in a hilled-row configuration. The hilled-row plots were six rows (18 feet) wide, and the bed plots were seven rows (12 feet) wide. Adjacent plots were spaced three feet apart.

Each plot was divided into five subplots, each with a different planting density: 17,000, 20,400, 25,500, 34,000, or 51,000 seed pieces per acre. Because the distance between rows was constant within a plot, population density was altered within subplots through seed spacing within rows, as indicated in Table 1. The plots were planted on May 31.

Suction-tube lysimeters were also installed within and between the planting rows of bed plots and within the planting rows (i.e., in the hills) of hilled-row plots on May 31 to sample soil water at a depth of four feet. Additional lysimeters were installed between the planting rows (i.e., in the furrows) of hilled-row plots on June 7, and the lysimeters were flushed. In both bed plots and hilled-row plots, the lysimeters between rows were installed several inches deeper than those within rows. In the hilled-row plots, this arrangement was enforced by the hilled-row topography, and the same vertical positioning was used in the bed plots to keep sampling depths consistent between the two treatments. The lysimeters were installed in subplots with a population density of 25,500 plants$\cdot$ac^{-1}. Soil water samples were collected on 16 dates: June 7, 19, 23, and 29; July 5, 10, 19, and 26; August 4, 9, 17, and 24; September 5, 14, and 20; and October 23. The samples were stored frozen and tested for NO_3-N concentration in January 2018.

Whole-plant samples were collected on July 28. Ten linear feet of row were sampled from each plot, and the number of plants, the number of stems per plant, vine and tuber fresh yields, tuber size, and tuber dry matter were determined for the plants within this sampled area. In the hilled-row plots, the ten linear feet sampled were divided into 5 feet of an edge row and 5 of the adjacent interior row. In the bed plots, 3 feet of an edge row and 7 feet of the adjacent interior row were sampled. Different ratios of edge to interior rows were sampled in hilled-row plots than in bed plots because different proportions of their plants were located on the edge versus the interior.

Vines were killed the first week in September and tubers were harvested on October 23. An area 12 feet wide and seven feet long (84 square feet) was sampled from the center of each plot using a four-row harvester. Tubers were sorted by weight to determine yield and number of tubers per acre by size category. These results were then used to estimate the number of whole and cut seeds that could be produced from that yield. All tubers weighing less than 3 ounces were assumed to produce a single, whole seed. The number of cut seeds produced by each tuber weighing over 3 ounces was estimated as the tuber weight divided by 1.5 ounces, rounded down. Each seed produced by this standard would weigh between 1.5 and 3 ounces.

Data were analyzed using the MIXED procedure with SAS 9.4m3® software (copyright 2015, SAS Institute, Inc.). For data collected in the July 28 and harvest samples, dependent variables were modeled as functions of planting configuration, population density, and their interaction, with block and the interaction between planting configuration and block included as random effects. In each model, CONTRAST statements were used to evaluate each variable as a linear and a quadratic function of population density.

Soil NO_3-N data were modeled as a function of planting configuration, lysimeter location (within row or between row), sampling date, and their interactions as fixed effects. Block and the interaction between block and planting configuration were treated as random effects. Sampling date was treated as the repeated measures variable, and the interaction between plot and lysimeter location (equivalent to individual lysimeter identity) was treated as the individual. The covariance matrix was assigned a spatial power structure because we assumed that soil water NO_3-N values would show temporal autocorrelation.

Denominator degrees of freedom were estimated by the Kenward-Rogers approximation. Pairwise comparisons between treatments were made using the DIFF option in an LSMEANS statement. Comparisons were made when a fixed effect in the model was significant at $\alpha = 0.10$, and they were considered significant when the P-value of the comparison was less than 0.10.

Results and discussion

Tuber size and yield at harvest

Results for tuber yield and size at harvest are presented in Table 2. Tuber counts are presented in Table 3. Yields of whole and cut seeds are presented in Table 4.

Total tuber yield was not significantly related to planting configuration or density. However, tuber size was related to both variables. Bed plots produced more small tubers and fewer large tubers than hilled-row plots. Mean tuber size and per-plant yield were negatively related to population density.

The results for tuber counts reflected those for yields. Bed plots produced more tubers per acre and more tubers per plant, but fewer large tubers per acre, than hilled-row plots. Tuber number per acre increased with planting density, especially between 17,000 and 25,500 plants·ac^{-1}, but per-plant tuber number decreased with planting density, especially above 20,400 plants·ac^{-1}. As planting density increased, the number of tubers per acre in the smallest three size categories (all < 4 oz.) generally increased, while the number of tubers per acre in the largest two size categories (both > 6 oz.) decreased.

Bed plots produced more whole seeds (tubers less than 3 ounces) per acre than hilled-row plots, and whole-seed production increased with planting density. Approximately 1/4 of whole seeds produced weighed less than 1.5 ounces in all treatments (see Table 2). The yield of cut seeds (estimated for each tuber weighing at least 3 ounces as tuber weight in ounces divided by 1.5, rounding down) was unrelated to planting configuration, but decreased with increasing planting density above 20,400 plants·ac^{-1}. Total seed production (assuming large seed would be cut) was not significantly related to planting configuration or population density (Table 4). Yield, tuber count, and seed production per acre all peaked at a population density of 20,400 plants·ac^{-1} in both planting configurations.

Tuber size and yield at midseason

Results for tuber yield in the July 28 whole-plant samples are presented in Table 5. Results for tuber counts are presented in Table 6. Overall tuber yield and number at this time were both higher in the bed plots than in the hilled-row plots. The trade-off between yield of small tubers and yield of large tubers observed at harvest had not yet emerged for planting configuration. In contrast, the impact of planting density on tuber size and yield was already evident in July. Yield and tuber count per acre in small size classes increased with planting density, while the opposite was true in large size classes. The number of tubers produced per acre increased with planting density, especially at densities below 25,500 plants·ac^{-1}.

Other midseason plant characteristics

Results for midseason plant characteristics other than tuber size and yield are presented in Table 7. The number of stems per plant did not differ between bed plots and hilled-row plots, but it generally increased as planting density increased. Vine fresh mass per acre was greater in the hilled-row plots than the bed plots and increased with planting density. Tuber dry matter content was greater in the bed plots than the hilled-row plots. It was not related to planting density.

Soil water NO_3-N

The effects of planting configuration, sampling location (within or between planting rows), sample date, and their interaction on soil water NO_3-N concentration, as well as average NO_3-N concentrations across the season for each planting configuration and sampling location, are presented in Table 8. The dynamics of soil water NO_3-N over the course of the season (from June 7 to October 23) are shown in Figure 1.

Average soil water NO_3-N concentration across the season was not significantly related to planting configuration, sampling location, or the interaction between the two. However, there was a trend toward higher NO_3-N concentrations between rows than within them. As reflected in the low P-values for all interactions involving sampling date (Table 8), the dynamics of soil water NO_3-N concentration varied substantially with planting configuration and sampling location (see Fig. 1). In hilled-row plots, concentrations between rows climbed to over 100 ppm on July 10, declining rapidly after that. In contrast, soil water NO_3-N concentrations within the rows of hilled-row plots rose gradually until August 17 (at 39.0 ppm), peaked sharply on August 24 (at 57.4 ppm), then generally declined for the rest of the year. As a result, while concentrations were much higher between rows than within them in hilled-row plots between June 23 and July 26, between-row concentrations had fallen well below within-row concentrations by August 9, and remained so until at least September 20, possibly due to more leaching in the furrow areas. To evaluate differences in NO_3-N leaching would require data on the percolation of water through the soil profile, which was not collected in this study.

Compared to the hilled-row plots, the bed plots showed relatively little difference in soil water NO_3-N concentration between sampling locations within plots at any time. Concentrations were greater between rows than within them on June 19 and between July 5 and August 17, but this difference was much smaller than that observed in hilled-row plots in July.

Conclusions

Based on these results, planting configuration and population density do not significantly affect total seed production (including both whole and cut seed), though total seed production was higher in beds than in hilled rows and numerically peaked at a planting density of 20,400 plants·ac^{-1}. However, production of whole seeds was higher in beds than in hilled rows, and it increased with planting density across the range of densities tested. Production of cut seed was not related to planting configuration, but decreased with planting density for densities above 20,400 plants·ac^{-1}.

When averaged across the season, bed plots and hill rowed plots had similar soil water NO_3-N concentrations in the row and between the rows. However, the dynamics of NO_3-N concentration within rows differed from those between rows to a much greater extent in the hilled-row plots than the bed plots. Higher spikes of NO_3-N early in the season were found between rows of hilled-row plots than between rows in the bed-planted system. Whether these differences in NO_3-N concentrations across sampling times reflect differences in NO_3-N leaching depends on the rate at which soil water was moving through the soil profile, which was not evaluated in this study.

Table 1. Planting configuration and plant population density treatments applied to Russet Burbank potatoes near Staples, MN.

Planting configuration	Planting density (seed pieces / ac)	Seed spacing within row (inches)
Bed (row spacing 1.7 feet)	17000	18
	20400	15
	25500	12
	34000	9
	51000	6
Hilled row (row spacing 3 feet)	17000	10.25
	20400	8.5
	25500	6.75
	34000	5.1
	51000	3.4

Table 2. Tuber yield per acre at harvest, by size class and in total; total yield per plant; and mean tuber size, as functions of planting configuration, population density, and their interaction, for Russet Burbank potatoes grown near Staples, MN.

Planting configuration	**Planting density (seed pieces / ac)**	**Tuber yield (cwt / ac)**							**Total yield / seed piece (lbs)**	**Mean tuber size (oz.)**
		Tubers < 1.5 oz.	**Tubers 1.5 - 3 oz.**	**Tubers 3 - 4 oz.**	**Tubers 4 - 6 oz.**	**Tubers 6 - 10 oz.**	**Tubers > 10 oz.**	**Total yield**		
Bed	Average of all densities	25 a	95 a	70	101	56	8 b	352	1.39	3.12 b
Hilled row		18 b	73 b	60	91	65	17 a	323	1.29	3.47 a
Planting configuration significance (P-value)		**0.0213**	**0.0093**	0.1126	0.1775	0.2651	**0.0471**	0.1139	0.2593	**0.0118**
Average of bed and hilled row	17000	14 c	56 c	52 c	98 bc	85 a	21 a	325	1.92 a	3.83 a
	20400	15 c	65 c	58 bc	118 a	90 a	22 a	368	1.81 a	3.79 a
	25500	21 b	86 b	72 a	104 ab	57 b	11 b	350	1.37 b	3.27 b
	34000	26 a	102 a	72 a	85 cd	41 c	6 bc	330	0.98 c	2.91 c
	51000	31 a	111 a	68 ab	74 d	30 c	2 c	313	0.62 d	2.66 d
Planting density significance (P-value)		**<0.0001**	**<0.0001**	**0.0422**	**0.0003**	**<0.0001**	**<0.0001**	0.1515	**<0.0001**	**<0.0001**
Bed	17000	17	60	53	98	72	14 b	312	1.85	3.56
	20400	18	75	64	135	80	12 bc	384	1.88	3.54
	25500	24	97	76	114	58	6 bcd	375	1.47	3.14
	34000	30	120	82	84	40	4 cd	354	1.06	2.78
	51000	36	125	73	75	29	2 d	335	0.68	2.57
Hilled row	17000	11	51	52	97	99	28 a	339	1.99	4.11
	20400	13	55	51	101	100	33 a	353	1.73	4.04
	25500	17	75	68	95	56	15 b	326	1.28	3.40
	34000	23	85	63	87	41	8 bcd	305	0.89	3.04
	51000	25	97	62	74	30	2 cd	291	0.57	2.76
Configuration*density significance (P-value)		0.8485	0.4322	0.7951	0.1685	0.1988	*0.0529*	0.4515	0.3281	0.1623
Contrasts on planting density	Linear	**<0.0001**	**<0.0001**	*0.0652*	**0.0001**	**<0.0001**	**<0.0001**	0.1176	**<0.0001**	**<0.0001**
	Quadratic	*0.0915*	**0.0012**	**0.0210**	0.7722	**0.0033**	**0.0274**	0.4650	**0.0002**	**<0.0001**

Table 3. Tuber count at harvest per acre by size class and in total, and tubers produced per plant, as functions of planting configuration, population density, and their interaction, for Russet Burbank potatoes grown near Staples, MN.

Planting configuration	**Planting density (seed pieces / ac)**	**Tuber count (1000s / ac)**							**Total tubers / seed planted**
		Tubers < 1.5 oz.	**Tubers 1.5 - 3 oz.**	**Tubers 3 - 4 oz.**	**Tubers 4 - 6 oz.**	**Tubers 6 - 10 oz.**	**Tubers > 10 oz.**	**Total count**	
Bed	Average of all densities	37 a	69 a	32 a	34	12	1.1 b	184 a	6.9 a
Hilled row		25 b	52 b	27 b	30	14	2.3 a	152 b	5.8 b
Planting configuration significance (P-value)		**0.0168**	**0.0117**	*0.0993*	0.1594	0.2447	**0.0451**	**0.0237**	**0.0346**
Average of bed and hilled row	17000	20 c	40 c	24 c	32 b	18 a	2.8 a	138 c	8.1 a
	20400	22 c	47 c	27 bc	38 a	20 a	3.0 a	156 b	7.7 a
	25500	30 b	62 b	33 a	35 ab	13 b	1.5 b	173 ab	6.8 b
	34000	39 a	74 a	34 a	29 bc	9 c	0.9 bc	184 a	5.4 c
	51000	44 a	81 a	31 ab	25 c	7 c	0.3 c	188 a	3.8 d
Planting density significance (P-value)		**<0.0001**	**<0.0001**	**0.0284**	**0.0009**	**<0.0001**	**<0.0001**	**0.0009**	**<0.0001**
Bed	17000	24	42	24	33	16	2.0	142	8.4
	20400	26	54	30	44	18	1.6	173	8.5
	25500	36	69	35	38	13	0.8	192	7.5
	34000	45	86	38	28	9	0.7	206	6.1
	51000	52	91	34	25	7	0.3	209	4.2
Hilled row	17000	15	37	24	32	21	3.7	133	7.8
	20400	18	40	24	33	22	4.4	140	6.9
	25500	23	54	31	32	13	2.1	155	6.1
	34000	33	61	29	29	9	1.1	163	4.7
	51000	36	71	29	25	7	0.4	167	3.3
Configuration*density significance (P-value)		0.8967	0.3450	0.7680	0.1734	0.2927	*0.0664*	0.5850	0.6151
Contrasts on planting density	Linear	**<0.0001**	**<0.0001**	**0.0467**	**0.0003**	**<0.0001**	**<0.0001**	**0.0002**	**<0.0001**
	Quadratic	*0.0537*	**0.0012**	**0.0149**	0.7125	**0.0042**	**0.0351**	**0.0183**	0.1693

Table 4. Whole, cut, and total seeds produced per acre and per plant as functions of planting configuration, population density, and their interaction, for Russet Burbank potatoes grown near Staples, MN, in 2017. Total seeds produced per acre and acres plantable from those seed pieces share common P-values because acres plantable was calculated as seeds produced divided by a constant (14,520).

Planting configuration	Planting density (seed pieces / ac)	Whole seeds < 3 oz. produced (1000s / ac)	Cut seeds produced (1000s / ac)	Total seeds produced (1000s / ac)	Acres plantable at 14,520 seeds/ac	Whole seeds < 3 oz per seed planted	Cut seeds per seed planted	Seeds produced per seed planted
Bed	Average of all densities	105 a	214	318	22	3.8 a	8.8	12.5
Hilled row		78 b	215	293	20	2.8 b	9.0	11.8
Planting configuration significance (P-value)		**0.0104**	0.9751	0.1176		**0.0104**	0.7913	0.2850
Average of bed and hilled row	17000	59 d	239 ab	298	20	3.5 a	14.0 a	17.6 a
	20400	69 d	266 a	335	23	3.4 a	13.1 a	16.4 a
	25500	91 c	224 b	315	22	3.6 a	8.8 b	12.3 b
	34000	112 b	186 c	297	20	3.3 a	5.5 c	8.8 c
	51000	125 a	159 c	282	19	2.5 b	3.2 d	5.6 d
Planting density significance (P-value)		**<0.0001**	**<0.0001**	0.1349		**0.0022**	**<0.0001**	**<0.0001**
Bed	17000	66	219	284	20	3.9	12.9	16.8
	20400	80	267	347	24	3.9	13.1	17.0
	25500	105	232	337	23	4.1	9.1	13.2
	34000	131	191	319	22	3.9	5.7	9.5
	51000	144	163	303	21	2.9	3.3	6.1
Hilled row	17000	52	258	311	21	3.1	15.2	18.3
	20400	58	266	323	22	2.8	13.0	15.8
	25500	77	216	293	20	3.0	8.5	11.5
	34000	94	180	276	19	2.7	5.3	8.1
	51000	107	155	261	18	2.1	3.0	5.1
Configuration*density significance (P-value)		0.4354	0.5091	0.4133		0.9066	0.2519	0.3078
Contrasts on planting density	Linear	**<0.0001**	**<0.0001**	*0.0800*		**0.0002**	**<0.0001**	**<0.0001**
	Quadratic	**0.0012**	0.4307	0.5676		*0.0956*	**<0.0001**	**0.0001**

Table 5. Tuber yield per acre at midseason (July 28), by size class and in total, as functions of planting configuration, population density, and their interaction, for Russet Burbank potatoes grown near Staples, MN.

Planting configuration	**Planting density (seed pieces / ac)**	**Tuber yield (cwt / ac)**				
		Tubers < 1 oz.	**Tubers 1 - 1.5 oz.**	**Tubers 1.5 - 3 oz.**	**Tubers > 3 oz.**	**Total**
Bed	Average of all densities	47 a	47 a	63 a	8 a	166 a
Hilled row		34 b	28 b	40 b	3 b	104 b
Planting configuration significance (P-value)		**<0.0001**	**0.0001**	**0.0021**	**0.0239**	**<0.0001**
Average of bed and hilled row	17000	31 c	32	69 a	9 a	141
	20400	29 c	34	63 a	9 a	134
	25500	40 b	42	57 ab	5 ab	145
	34000	49 a	42	38 bc	1 b	130
	51000	53 a	37	31 c	2 b	124
Planting density significance (P-value)		**<0.0001**	0.4920	**0.0085**	*0.0918*	0.7721
Bed	17000	33 def	35	85	13	165
	20400	33 def	46	83	15	177
	25500	45 c	54	64	6	169
	34000	57 b	56	45	1	158
	51000	66 a	46	41	5	158
Hilled row	17000	28 ef	30	53	6	117
	20400	25 f	21	43	3	91
	25500	35 de	31	50	4	120
	34000	41 cd	29	32	1	103
	51000	39 cd	28	22	0	89
Configuration*density significance (P-value)		*0.0805*	0.5599	0.6660	0.4503	0.7806
Contrasts on planting density	Linear	**<0.0001**	0.5194	**0.0005**	**0.0240**	0.2855
	Quadratic	**0.0382**	0.1222	0.3054	0.1156	0.8750

Table 6. Tuber count per acre at midseason (July 28), by size class and in total, as functions of planting configuration, population density, and their interaction, for Russet Burbank potatoes grown near Staples, MN.

Planting configuration	**Planting density (seed pieces / ac)**	**Tuber count (1000s / ac)**					**Tubers per plant**
		Tubers < 1 oz.	**Tubers 1 - 1.5 oz.**	**Tubers 1.5 - 3 oz.**	**Tubers > 3 oz.**	**Total**	
Bed	Average of all densities	146	62 a	52 a	3 a	263 a	11.2 a
Hilled row		121	36 b	33 b	1 b	190 b	8.4 b
Planting configuration significance (P-value)		0.1198	**<0.0001**	**0.0011**	**0.0190**	**0.0125**	**0.0092**
Average of bed and hilled row	17000	102 b	42	55 a	4 a	200 c	11.7 a
	20400	107 b	43	50 a	4 a	204 bc	11.7 a
	25500	128 b	55	47 a	3 ab	233 ab	10.3 b
	34000	157 a	56	33 b	0 b	246 a	8.5 c
	51000	174 a	49	26 b	1 b	250 a	6.8 d
Planting density significance (P-value)		**0.0003**	0.4210	**0.0109**	**0.0344**	**0.0382**	**<0.0001**
Bed	17000	108	44	67	5	220	13.7 a
	20400	111	60	66	7	244	13.5 a
	25500	140	69	54	3	267	12.2 a
	34000	171	74	39	0	285	9.2 bc
	51000	201	62	34	1	298	7.3 d
Hilled row	17000	96	39	42	3	180	9.7 b
	20400	103	27	34	1	164	10.0 b
	25500	116	40	41	2	198	8.4 bc
	34000	143	38	26	0	208	7.8 cd
	51000	147	37	19	0	201	6.3 d
Configuration*density significance (P-value)		0.6264	0.5084	0.7167	0.3176	0.6750	*0.0945*
Contrasts on planting density	Linear	**<0.0001**	0.3903	**0.0006**	**0.0061**	**0.0061**	**<0.0001**
	Quadratic	0.1679	0.1035	0.4125	0.1605	0.1296	0.2066

Table 7. Stems per plant, vine fresh mass, and tuber dry matter at midseason (July 28) as functions of planting configuration, population density, and their interaction, for Russet Burbank potatoes grown near Staples, MN.

Planting configuration	**Planting density (seed pieces / ac)**	**Stems per plant**	**Vine fresh mass (T / ac)**	**Tuber dry matter (%)**
Bed	Average of all densities	4.1	21.6 b	21.8 a
Hilled row		4.2	23.3 a	20.9 b
Planting configuration significance (P-value)		0.7888	*0.0922*	**0.0490**
Average of bed and hilled row	17000	4.0 bc	21.1 c	21.0
	20400	3.8 c	20.8 c	21.5
	25500	4.1 abc	21.6 bc	21.9
	34000	4.4 ab	24.1 ab	21.2
	51000	4.5 a	24.8 a	21.2
Planting density significance (P-value)		*0.0831*	**0.0304**	0.3944
Bed	17000	4.1	20.8	21.5
	20400	3.8	20.6	22.3
	25500	4.3	21.6	22.5
	34000	4.2	22.1	21.5
	51000	4.3	23.2	21.2
Hilled row	17000	3.9	21.4	20.6
	20400	3.8	20.9	20.7
	25500	3.9	21.6	21.2
	34000	4.5	26.2	20.8
	51000	4.8	26.4	21.3
Configuration*density significance (P-value)		0.4258	0.5573	0.4785
Contrasts on planting density	Linear	**0.0108**	**0.0026**	0.7675
	Quadratic	0.6446	0.5222	0.4080

Table 8. Whole-season average soil water NO_3-N values at a depth of 4 ft below the soil surface within and between rows in bed plots and hilled-row plots. Samples were collected from subplots planted at 25,500 Russet Burbank potato plants·ac^{-1} near Staples, MN.

Planting configuration	**Sampling location**	**Value of average soil water NO_3-N (ppm) across dates**
Bed	Average of within and between rows	36.6
Hilled row		33.4
Planting configuration significance (P-value)		0.5647
Configuration * date significance (P-value)		**0.0413**
Average of bed and row	Within rows	31.2
	Between rows	38.8
Sample location significance (P-value)		0.1657
Location * date significance (P-value)		**0.0145**
Bed	Within rows	31.5
	Between rows	41.6
Hilled row	Within rows	30.9
	Between rows	36.0
Configuration * location significance (P-value)		0.6496
Configuration * location * date significance (P-value)		**0.0075**
Date significance (P-value)		**<0.0001**

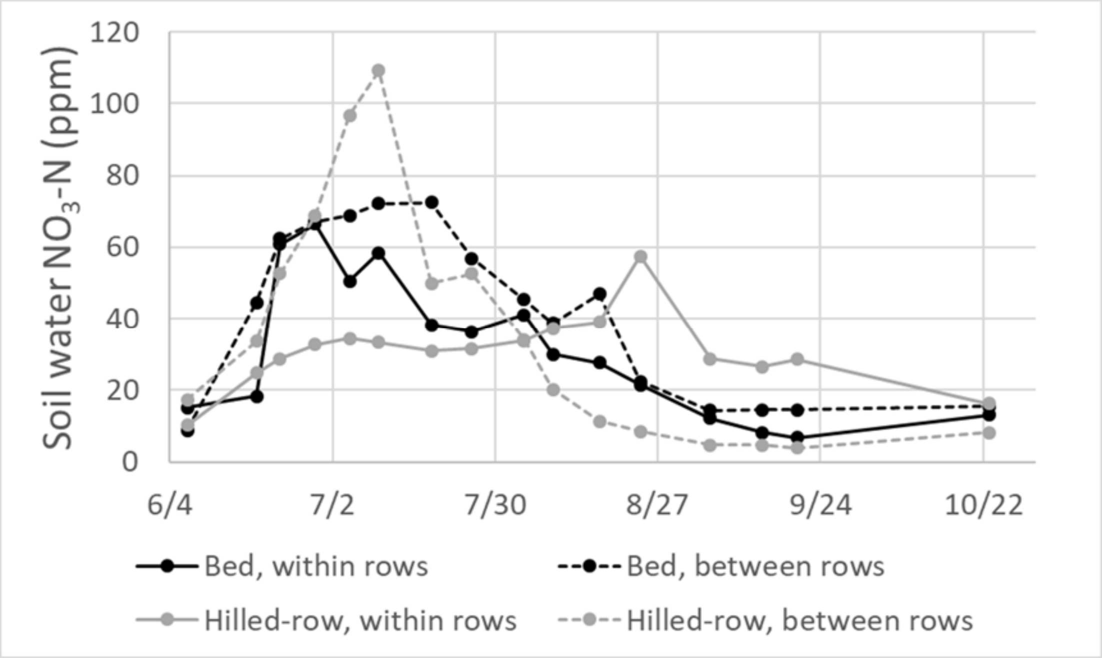

Figure 1. Soil water NO_3-N concentrations at a depth of four below the soil surface within and between rows in bed plots and hilled-row plots planted at a density of 25,500 Russet Burbank potato plants·ac^{-1} near Staples, MN, in 2017.

Genetic Improvement of Potato (*Solanum tuberosum* L.) for the Northern Plains

2017 Summary

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Potato is a significant horticultural crop in North Dakota, Minnesota and the Northern Plains. The North Dakota State University potato improvement team is involved in breeding, germplasm enhancement efforts, selection of improved genotypes, evaluation, and development of superior cultivars for producer and industry adoption in North Dakota, Minnesota, and beyond. Through conventional breeding we emphasize durable and long-term pest and stress resistances, improved nutrient and water-use efficiency, enhanced quality and nutritional attributes, a high yield and marketability potential.

Fall 2017, North Dakota potato production was estimated to be 25.2 million cwt, an increase of 16% over 2016. Yield was estimated at 40 cwt/a more than in 2016, at 340 cwt/a. Similarly, Minnesota production was projected to be 18.9 million cwt, up 12% from 2016, with a yield of 415 cwt/a, a 15 cwt/a increase from 2016. In 2017, more than 17.8% of acreage planted in the major seven states producing fall potatoes (Idaho, Washington, North Dakota, Wisconsin, Oregon, Maine and Minnesota) were planted to cultivars (or selections thereof) developed by the NDSU potato breeding program (Russet Burbank alone accounts for 38%). Dakota Russet, a 2012 multi-purpose russet release from the North Dakota Agricultural Experiment Station and NDSU potato breeding program, ranks twenty-second by acreage planted in the major fall potato producing states at 0.8%. It ranked in the top ten cultivars produced in North Dakota in 2017.

In order to meet the requirements of Northern Plains and Minnesota Area II potato producers and our associated industry, the following research objectives were established for 2017:

1. Develop superior cultivars and improved genotypes of potato adapted to the Northern Plains region via traditional hybridization.
2. Identify and exploit genes of agronomic interest related to resistance to biotic and abiotic stresses and improved quality attributes important to the Northern Plains region.
3. Identify and adopt improved breeding methods.

In 2017, 110 parental genotypes were hybridized; 1,576 flower clusters were pollinated, with 327 families created. At Baker, MN, our seed production location, 22,009 seedlings, representing 180 segregating families, were evaluated; 351 selections across market types were retained. Unselected seedling tubers were shared with cooperating programs in Colorado, Idaho, Maine, Oregon, and Texas. Maintenance and increase lots included 432 second, 71 third year, and 231 fourth year and older selection; 142 second year, 31 third year, and 146 fourth year and older, selections were retained for further evaluation.

Yield and evaluation trials were grown at eight sites in North Dakota and Minnesota, five irrigated (Inkster, Larimore, Oakes, Park Rapids, and Williston) and three non-irrigated locations (Crystal, Grand Forks, and Hoople). The fresh market trials at Crystal (fresh, preliminary fresh, and North Central Regional (NCR) non-irrigated) were excellent. Many of the advancing fresh market clones have high set and excellent red skin color, two important characteristics for the fresh market; additionally, several have good yellow flesh color combined with bright red skin color. The fresh market trial is summarized in Tables 1-3. Standouts included ND081571-2R, ND081571-3R, ND102663B-3R, ND102775C-5RR (a round to oval selection with red flesh), ND113091B-2RY and ND113207-1R. At Hoople, the chip processing trial included 20 entries, nine NDSU advancing selections and 11 standard chipping cultivars (Tables 4-6). ND7519-1 and ND7799c-1 continue to be standouts, high yielding with excellent chip quality. ND102631AB-1 and ND102922C-3 also look promising, but the tuber size profile is smaller, like many potential chip processing selections coming through the national breeding programs. The National Chip Breeders Trial (NCBT), with goals to rapidly identify and develop cultivars to replace Atlantic for southern production areas, and Snowden from storage, initiated by the USPB and regional chip processors, had 115 entries in the unreplicated trial (six from NDSU), and 40 in the replicated trial (two from NDSU). Trials at the NPPGA Research Farm south of Grand Forks included the Colorado Potato Beetle defoliation studies (seedling family evaluation and a single replicate selection study with biweekly defoliation readings). Two trials focusing on nitrogen management and vine kill strategies for Dakota Ruby production were also at the NPPGA Research site. Dakota Ruby is an excellent fresh market cultivar with a small tuber size profile, high yield of uniform round tubers, and bright red skin color. Some producers have had trouble achieving skin set; some may be using excessive nitrogen for the cultivar and/or are applying it later in the growing season than desirable for adequate skin set.

The metribuzin screening trial with 24 entries was conducted at Inkster in collaboration with Dr. Harlene Hatterman-Valenti's program. Razi Ibrahim, a graduate student, is evaluating a model used to determine sensitivity to this widely used herbicide for applicability in ND and the north central region. The Larimore Processing Trial had 32 advancing selections and industry standards (Tables 7-9). Notable entrants included ND8068-5Russ (very early), ND050032-4Russ, Clearwater Russet, and Dakota Russet. The preliminary processing trial had 66 entries and is useful in identifying clones with processing potential and those that should be discarded early in the trialing and evaluation process. The NFPT is an industry driven tiered trial; 58 genotypes were evaluated (12 lines from NDSU. Unselected seedling tubers received from cooperating programs (ID, ME and TX) were grown at Larimore ND; 157 selections were retained. Maintenance plots of second (187), third (15), and fourth (4) year and older clones selected from previous year's out-of-state seedlings were also produced; 21 selections will continue evaluation. The focus of the North Central Regional Potato Variety Trial (NCR) is the fresh market. Thirty-two entries from MI, ND, WI, and NB were included, many with unique skin and tuber flesh colors. NDSU submissions included AND00272-1R, ATND99331-2PintoY, ND113207-1R, ND1232B-2RY, ND1241-1Y, ND1243-1PY. As in 2016, our program participated with a group from the Pacific Northwest led by Dr. Chuck Brown looking at tuber glycoalkaloid stability/variability across northern/western production locals. Twenty-three selections and commercially acceptable cultivars were grown in the Oakes trial that included both processing (16) and fresh market (7) genotypes. The Williston trial was similar, although selections and check cultivars varied between the 2 sites. As in 2016, 10 of the genotypes with high resistant starch levels from our breeding program were produced with the hopes of working with a group focused on improving health attributes of potato. A processing trial with 12 entries, including 3 NDSU advancing selections, was grown at Park Rapids, in collaboration with RDO/LambWeston. A common scab screening trial was conducted; 68 genotypes across market types were evaluated, with clones ranging from highly susceptible to resistant. In the Verticillium screening trial, 25 selections and industry standards were included; DNA from green stems collected prior to vine kill and harvest has been extracted and colony forming units will be determined using qtPCR, in addition to comparison of yield and grade for the two treatments (fumigation, non-fumigation).

ND8068-5Russ (very early dual-purpose russet), ND7799c-1 (high yielding chip processing selection), ND7519-1 (cold chipping selection), ND6002-1R (bright red skinned fresh selection) have been through pre-release. Release determination should occur in upcoming months.

Thank you to our many producer, industry, and research cooperators in North Dakota, Minnesota, the North Central region and beyond. We are very grateful to the Northern Plains Potato Growers Association and the Minnesota Area II Potato Research and Promotion Council for the continued support and cooperation in providing resources of land, certified seed, research funding, and equipment resources.

Table 1. Agronomic evaluations for advanced fresh market selections and cultivars, Crystal, ND, 2017. The fresh market trial was planted on May 12, vinekilled on September 8, and harvested with a single-row Grimme harvester on September 30, 2017. The replicated plots were 20 feet long, with a 12-inch with-in row spacing, and 36 inches between rows.

Clone	% Stand	Vine Size[1]	Vine Maturity[2]	Stems per Plant	Shape[3]	Color[4]	General Rating[5]
1. ND4659-5R	98	4.0	2.4	2.6	1.0	4.1	3.6
2. ND6002-1R	89	3.0	3.5	1.7	3.0	3.9	3.3
3. ND6961B-2PY	100	5.0	4.4	2.5	2.5	P	2.9
4. ND7132-1R	81	4.3	3.8	1.8	3.0	3.4	3.1
5. ND7834-2P	96	3.5	3.1	2.6	3.0	P	2.8
6. ND7982-1R	85	2.3	3.0	3.0	1.0	4.0	3.6
7. ND081557C-1P	98	2.0	2.0	3.2	2.0	P	3.3
8. ND081571-2R	96	3.5	2.4	2.4	1.0	4.0	4.0
9. ND081571-3R	98	3.8	2.5	2.9	1.0	4.0	3.9
10. ND091890-1RR	95	4.3	4.0	2.6	2.3	3.9	3.4
11. ND102663B-3R	98	4.0	3.3	2.6	1.0	4.3	4.1
12. ND102775C-5RR	100	3.5	3.0	2.8	1.5	3.8	4.1
13. ND113089B-2RY	96	3.8	2.9	1.8	2.8	3.8	3.1
14. ND113091B-2RY	94	2.5	2.3	3.0	1.6	3.8	3.6
15. ND113207-1R	94	3.8	3.0	1.9	2.4	4.0	3.8
16. ND1212-1RSY	96	2.8	2.8	2.3	1.0	2.0	3.4
17. ND1232B-1RY	96	4.3	2.9	2.2	1.3	3.9	3.6
18. ND1243-1PY	98	5.0	3.8	2.3	1.0	P	3.6
19. ND12128-1R	95	4.3	3.8	2.2	1.3	4.0	3.6
20. ND12244Y-1R	96	5.0	3.8	2.9	1.6	3.9	3.4
21. All Blue	99	5.0	3.5	2.9	5.0	P	2.6
22. Chieftain	99	5.0	3.5	2.6	3.0	3.0	3.0
23. Dakota Jewel	99	4.0	2.5	2.0	3.0	4.0	3.8
24. Dakota Rose	99	2.3	2.0	2.8	2.8	3.8	3.8
25. Dakota Ruby	99	4.3	3.1	2.5	1.0	4.6	4.8
26. Red LaSoda	100	4.3	3.5	2.3	3.0	3.0	3.0
27. Red Norland	100	2.5	2.0	2.4	3.0	3.0	3.4
28. Red Pontiac	99	4.8	3.5	2.3	2.8	2.9	2.9
29. Sangre	93	4.0	3.5	2.0	3.0	3.1	2.6
30. Yukon Gold	98	4.0	1.9	1.6	3.0	Y	4.1
Mean	97	3.8	3.0	2.4	2.1	na	3.4
LSD (∝=0.05)	23	0.9	0.7	0.8	0.5	na	0.4

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

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

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

[4] Color = 1-5; 1 = white/buff, 2 = pink, 3 = red, 4 = bright red, 5 = dark red, P = purple, Y = yellow. na = not applicable

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

Table 2. Yield and grade for advanced fresh market selections and cultivars, Crystal, ND, 2017. The fresh market trial was planted on May 12, vinekilled on September 8, and harvested with a single-row Grimme harvester on September 30, 2017. The replicated plots were 20 feet long, with a 12-inch with-in row spacing, and 36 inches between rows.

Clone	Total Yield Cwt./A	A Size Tubers Cwt./A	A Size %	0-4 oz. %	4-6 oz. %	6-10 oz. %	>10 oz. %	US No. 2 %	Culls %
1. ND4659-5R	287	167	58	27	42	17	13	0	2
2. ND6002-1R	200	83	42	19	32	11	33	0	6
3. ND6961B-2PY	204	132	65	33	51	14	2	0	0
4. ND7132-1R	182	98	54	14	38	17	30	2	0
5. ND7834-2P	267	159	58	13	40	18	25	1	3
6. ND7982-1R	172	25	14	86	11	2	0	0	1
7. ND081557C-1P	158	6	3	97	2	1	0	0	0
8. ND081571-2R	260	91	34	63	30	5	3	0	0
9. ND081571-3R	224	53	24	74	22	3	1	0	0
10. ND091890-1RR	242	122	51	43	40	10	3	0	3
11. ND102663B-3R	251	56	22	77	19	2	0	0	1
12. ND102775C-5RR	321	143	44	48	36	8	5	0	3
13. ND113089B-2RY	371	177	48	15	33	15	30	1	6
14. ND113091B-2RY	352	116	33	65	27	5	1	1	1
15. ND113207-1R	320	176	56	21	41	14	20	0	3
16. ND1212-1RSY	190	49	26	16	22	4	0	0	0
17. ND1232B-1RY	226	73	33	66	28	5	1	0	0
18. ND1243-1PY	310	168	54	41	41	12	2	0	2
19. ND12128-1R	189	38	20	78	18	2	0	0	2
20. ND12244Y-1R	404	222	55	39	42	13	42	2	0
21. All Blue	207	79	38	56	31	7	2	4	0
22. Chieftain	418	263	63	9	40	23	28	0	0
23. Dakota Jewel	304	197	65	13	41	24	19	2	1
24. Dakota Rose	297	184	66	27	47	19	6	0	1
25. Dakota Ruby	276	123	41	56	35	6	0	1	1
26. Red LaSoda	359	172	49	13	33	16	35	0	3
27. Red Norland	359	252	70	21	49	21	8	0	1
28. Red Pontiac	443	163	36	5	22	15	52	4	2
29. Sangre	338	144	43	8	29	14	45	1	2
30. Yukon Gold	241	134	56	26	40	16	17	0	2
Mean	279	129	44	41	33	11	13	1	1
LSD (∝=0.05)	52	38	10	9	7	4	7	2	3

Table 3. Quality attributes, including specific gravity, internal disorders and bruise potential for advanced fresh market selections and cultivars, Crystal, ND, 2017. The fresh market trial was planted on May 12, vinekilled on September 8, and harvested with a single-row Grimme harvester on September 30, 2017. The replicated plots were 20 feet long, with a 12-inch with-in row spacing, and 36 inches between rows.

Clone	Tubers per Plant	Specific Gravity[1]	% Hollow Heart[2]	Black-spot Bruise[3]	Shatter Bruise[4]
1. ND4659-5R	7.0	1.0890	0	3.1	3.3
2. ND6002-1R	4.4	1.0864	0	2.8	3.3
3. ND6961B-2PY	5.5	1.0925	0	2.0	2.4
4. ND7132-1R	4.1	1.0825	4	2.7	2.7
5. ND7834-2P	4.9	1.0959	0	3.0	2.9
6. ND7982-1R	12.3	1.0990	0	3.4	2.5
7. ND081557C-1P	10.9	1.1212	0	1.9	2.4
8. ND081571-2R	9.9	1.0882	0	2.5	2.1
9. ND081571-3R	10.3	1.1028	0	2.2	2.9
10. ND091890-1RR	8.3	1.0889	0	2.2	3.1
11. ND102663B-3R	12.4	1.0927	0	1.8	3.0
12. ND102775C-5RR	10.1	1.0946	1	2.6	3.0
13. ND113089B-2RY	7.1	1.0853	0	3.1	3.3
14. ND113091B-2RY	15.3	1.0864	0	3.3	2.5
15. ND113207-1R	7.5	1.0760	0	3.2	3.0
16. ND1212-1RSY	8.4	1.0888	0	3.0	2.3
17. ND1232B-1RY	8.4	1.0943	0	2.8	2.3
18. ND1243-1PY	9.4	1.0968	6	2.4	2.7
19. ND12128-1R	9.3	1.1008	0	3.1	2.4
20. ND12244Y-1R	12.0	1.0959	0	2.8	2.8
21. All Blue	8.1	1.0935	0	3.3	2.5
22. Chieftain	6.8	1.0896	0	2.8	2.6
23. Dakota Jewel	5.6	1.0930	0	2.9	4.0
24. Dakota Rose	6.7	1.0797	0	2.7	2.9
25. Dakota Ruby	10.2	1.0970	1	2.1	2.7
26. Red LaSoda	5.3	1.0895	1	2.4	2.9
27. Red Norland	7.0	1.0817	0	2.7	2.6
28. Red Pontiac	5.8	1.0840	3	2.5	3.0
29. Sangre	5.6	1.0869	1	1.3	2.3
30. Yukon Gold	5.6	1.0954	1	2.9	3.5
Mean	8.1	1.0916	1	2.6	2.8
LSD (∝=0.05)	1.9	0.0057	3	0.8	0.7

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

[2] Hollow heart includes brown center.

[3] Blackspot bruise determined by the abrasive peel method, scale 1-5, 1=none, 5=severe.

[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.

Table 4. Agronomic and quality assessments for advancing chip processing selections and cultivars, Hoople, ND, 2017. The chip processing was planted on May 12, 2017, and harvested on September 29 using a single-row Grimme harvester. The replicated plots were 20 feet long, with a 12-inch with-in row spacing, and 36 inches between rows.

Clone	Vine Size[1]	Vine Maturity[2]	Specific Gravity[3]	Shatter Bruise[4]	Black-spot Bruise[5]	General Rating[6]
1. ND7519-1	3.0	1.5	1.1055	2.9	3.2	3.5
2. ND7799c-1	2.3	1.0	1.0883	2.7	2.1	4.3
3. ND8331Cb-2	2.8	1.5	1.1113	2.6	3.1	3.3
4. ND102631AB-1	1.5	1.0	1.0998	3.7	2.3	3.1
5. ND102922C-3	2.3	1.0	1.0936	2.6	1.7	3.8
6. ND113030C-1	2.0	1.0	1.1043	3.1	3.5	3.3
7. ND113386Ab-5	4.0	2.6	1.1014	3.3	2.3	3.4
8. ND113523CB-3	1.0	1.0	1.0882	2.7	3.1	4.1
9. ND1328YABC-1	4.3	2.8	1.1118	1.5	4.0	4.1
10. Atlantic	3.3	1.9	1.1094	3.2	2.5	4.4
11. Dakota Crisp	3.8	2.0	1.0967	2.6	2.4	4.4
12. Dakota Diamond	4.5	2.0	1.1053	3.0	3.3	4.0
13. Dakota Pearl	1.5	1.0	1.0974	3.0	2.1	4.0
14. Ivory Crisp	4.0	2.3	1.1067	2.8	2.1	4.6
15. Lamoka	3.5	1.3	1.0941	2.5	3.2	3.6
16. Norchip	2.5	1.8	1.0960	1.9	2.8	3.1
17. NorValley	2.3	1.3	1.0962	2.3	2.5	3.4
18. Pike	3.5	2.8	1.1044	2.5	2.5	3.9
19. Snowden	3.0	1.3	1.1037	2.5	3.8	3.9
20. Waneta	3.0	1.4	1.0916	2.5	1.8	4.1
Mean	2.9	1.6	1.1003	2.7	2.7	3.8
LSD (∝=0.05)	0.9	0.6	0.0081	0.7	1.0	0.7

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

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

[3] Specific gravity determined by weight-in-air, weight-in-water method.

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

[5] Blackspot bruise determined by the abrasive peel method, scale 1-5, 1=none, 5=severe.

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

Table 5. Yield and grade for advancing chip processing selections and cultivars, Hoople, ND, 2017. The chip processing was planted on May 12, 2017, and harvested on September 29 using a single-row Grimme harvester. The replicated plots were 20 feet long, with a 12-inch with-in row spacing, and 36 inches between rows.

Clone	Total Yield cwt./a	Yield A Size cwt/a	A Size %	0-4 oz. %	4-6 oz. %	6-10 oz. %	>10 oz. %	US 2s & Culls %
1. ND7519-1	194	140	66	26	33	32	4	4
2. ND7799c-1	276	190	69	16	19	50	15	0
3. ND8331Cb-2	229	87	38	61	26	11	0	1
4. ND102631AB-1	220	108	48	46	29	19	0	5
5. ND102922C-3	278	39	15	85	13	2	0	0
6. ND113030C-1	238	97	41	48	26	15	1	10
7. ND113386Ab-5	235	154	65	29	29	36	4	1
8. ND113523CB-3	251	103	41	59	27	15	0	0
9. ND1328YABC-1	368	210	56	43	31	25	1	0
10. Atlantic	293	193	66	30	29	37	4	0
11. Dakota Crisp	338	222	65	32	28	37	2	1
12. Dakota Diamond	361	262	73	20	24	48	5	2
13. Dakota Pearl	254	113	44	55	26	18	0	1
14. Ivory Crisp	311	199	64	28	29	35	7	1
15. Lamoka	252	168	66	30	29	37	4	0
16. Norchip	229	93	40	51	27	12	1	9
17. NorValley	204	125	61	33	24	36	5	1
18. Pike	270	154	57	41	29	28	2	0
19. Snowden	264	109	41	59	30	11	0	0
20. Waneta	264	198	75	18	16	59	7	0
Mean	267	148	54	41	26	28	3	2
LSD (∝=0.05)	66	49	10	12	8	11	10	4

Table 6. Chip color (USDA chip chart and HunterLab L-value) after grading and following 8-weeks storage at 3.3C (38F) and 5.5C (42F) for advancing chip processing selections and cultivars, Hoople, ND, 2017. The chip processing was planted on May 12, 2017, and harvested on September 29 using a single-row Grimme harvester. The replicated plots were 20 feet long, with a 12-inch with-in row spacing, and 36 inches between rows.

	Field Chip		3.3C Storage		5.5C Storage	
Clone	Chart[2]	Hunter[3]	Chart	Hunter	Chart	Hunter
1. ND7519-1	3.0	62	8.0	49	5.2	57
2. ND7799c-1	2.3	65	8.0	41	5.8	53
3. ND8331Cb-2	4.4	59	8.5	40	6.0	55
4. ND102631AB-1	3.8	62	9.0	40	3.8	59
5. ND102922C-3	3.5	62	9.5	32	7.0	51
6. ND113030C-1	6.8	57	9.7	36	7.3	48
7. ND113386Ab-5	4.3	61	7.8	43	6.5	54
8. ND113523CB-3	3.0	62	9.5	32	7.8	49
9. ND1328YABC-1	4.3	58	10.0	29	6.8	51
10. Atlantic	6.5	56	9.8	31	8.3	43
11. Dakota Crisp	4.5	58	9.8	32	8.3	46
12. Dakota Diamond	4.3	60	9.5	34	8.0	48
13. Dakota Pearl	4.0	58	7.8	46	5.0	56
14. Ivory Crisp	2.8	60	9.8	29	7.9	51
15. Lamoka	3.0	62	9.5	36	5.8	54
16. Norchip	6.5	58	9.5	30	9.5	39
17. NorValley	3.8	60	10.0	33	7.2	50
18. Pike	2.5	64	10.0	34	8.3	44
19. Snowden	3.3	61	10.0	31	8,5	44
20. Waneta	2.8	63	10.0	30	5.9	54
Mean	3.9	60	9.2	35	6.9	50
LSD (∝=0.05)	2.1	4	0.8	7	1.5	6

[1] 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.

[2] HunterLab L value – 60 minimum, 70 preferred.

Table 7. Agronomic and quality evaluations for advanced processing selections and cultivars, full season trial, Larimore, ND, 2017. The processing trial was planted on May 24-25, flailed on October 5, and harvested October 5,11 and 13, 2017 using a single-row Grimme harvester. Entries were replicated four times; plots were twenty feet long, with a within-row spacing of 12 inches and 36 inches between rows.

Clone	Vine Size[1]	Vine Maturity[2]	Specific Gravity[3]	% Hollow Heart[4]	Black-spot Bruise[5]	Shatter Bruise[6]
1. AND97279-5Russ	4.5	3.5	1.1050	3	3.0	2.0
2. ND8068-5Russ	3.0	1.3	1.0960	0	3.9	2.8
3. ND050032-4Russ	4.3	3.3	1.0943	6	3.7	1.9
4. ND070927-2Russ	4.3	1.9	1.0963	0	2.2	1.4
5. ND091933ABCR-2Russ	4.5	2.1	1.0861	34	3.4	2.5
6. ND091933ABCR-7Russ	3.8	1.6	1.0921	5	2.7	2.3
7. ND091938BR-2Russ	3.8	3.8	1.0869	10	2.5	2.5
8. ND091997BT-3Russ	4.5	1.4	1.0912	0	2.1	2.3
9. ND092007R-2Russ	4.5	2.5	1.0978	3	3.0	2.7
10. ND092019C-4Russ	3.7	1.6	1.1052	0	2.1	2.7
11. ND092024CR-1Russ	4.0	1.0	1.0882	0	4.1	2.6
12. ND092355CR-2Russ	4.0	1.5	1.0808	1	4.2	2.8
13. ND113096-1Russ	3.3	1.3	1.0873	1	3.7	2.4
14. ND113099-2Russ	3.3	1.5	1.0756	0	2.0	2.1
15. ND113100-1Russ	4.8	1.8	1.0905	1	2.5	2.1
16. ND113174B-2Russ	4.6	3.8	1.1000	5	4.3	1.7
17. ND12162AB-1Russ	4.0	3.8	1.0940	19	3.1	2.3
18. Alpine Russet	5.0	3.3	1.0926	0	3.2	2.2
19. Alturas	5.0	4.3	1.1001	0	1.9	2.4
20. Bannock Russet	5.0	4.8	1.0931	26	2.8	2.4
21. Clearwater Russet	4.5	3.8	1.1079	4	2.5	2.0
22. Dakota Russet	4.3	3.4	1.0859	0	2.5	1.9
23. Pomerelle Russet	4.0	2.3	1.0805	0	1.2	2.0
24. Prospect Russet	4.8	2.5	1.0898	1	2.4	2.3
25. Ranger Russet	4.8	3.0	1.1050	0	3.8	2.3
26. Proprietary Russet	4.3	1.4	1.0871	0	2.8	2.2
27. Russet Burbank	5.0	3.0	1.0838	25	3.8	2.6
28. Russet Burbank	5.0	1.9	1.0950	20	3.3	1.9
29. Russet Norkotah	4.8	1.3	1.0813	19	2.8	1.7
30. Shepody	5.0	1.5	1.0950	6	1.8	2.1
31. Teton Russet	3.8	1.3	1.0825	9	1.7	2.6
32. Umatilla Russet	5.0	2.4	1.0100	3	3.2	2.2
Mean	4.3	2.4	1.0921	6	2.9	2.2
LSD (∝=0.05)	0.8	1.0	0.0089	8	0.8	0.9

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

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

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

[4] Hollow heart includes brown center.

[5] Blackspot bruise determined by the abrasive peel method, scale 1-5, 1=none, 5=severe.

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

Table 8. Yield and grade for advanced processing selections and cultivars, full season, Larimore, ND, 2017. The processing trial was planted on May 24-25, flailed on October 5, and harvested October 5,11 and 13, 2017 using a single-row Grimme harvester. Entries were replicated four times; plots were twenty feet long, with a within-row spacing of 12 inches and 36 inches between rows.

Clone	Total Yield Cwt./A	US No. 1 Cwt./A	US No. 1 %	0-4 oz. %	4-6 oz. %	6-10 oz. %	>10 oz. %	US No. 2 %	Culls %
1. AND97279-5Russ	431	338	78	12	29	13	36	1	8
2. ND8068-5Russ	349	290	83	17	45	20	18	0	0
3. ND050032-4Russ	469	411	87	6	23	15	49	0	7
4. ND070927-2Russ	418	290	69	22	35	14	20	0	9
5. ND091933ABCR-2Russ	332	247	74	10	27	13	34	6	10
6. ND091933ABCR-7Russ	406	296	73	23	38	16	18	1	3
7. ND091938BR-2Russ	238	194	82	6	15	7	60	6	6
8. ND091997BT-3Russ	329	242	74	23	42	17	14	3	0
9. ND092007R-2Russ	294	220	74	15	29	11	34	0	11
10. ND092019C-4Russ	355	248	69	27	43	14	11	1	3
11. ND092024CR-1Russ	329	268	81	18	36	16	28	0	1
12. ND092355CR-2Russ	333	254	76	21	39	17	20	2	1
13. ND113096-1Russ	357	221	62	23	37	13	12	0	15
14. ND113099-2Russ	397	328	81	12	32	13	39	0	7
15. ND113100-1Russ	454	367	81	4	23	11	47	15	0
16. ND113174B-2Russ	327	229	71	8	21	9	40	10	11
17. ND12162AB-1Russ	260	215	82	10	23	13	46	4	4
18. Alpine Russet	514	430	83	6	23	13	49	1	10
19. Alturas	638	421	66	10	26	13	26	0	25
20. Bannock Russet	479	412	85	9	22	13	50	0	6
21. Clearwater Russet	585	513	82	14	36	15	30	2	3
22. Dakota Russet	480	439	91	9	29	16	46	0	0
23. Pomerelle Russet	453	399	88	3	15	11	62	0	8
24. Prospect Russet	499	417	83	8	29	17	38	0	9
25. Ranger Russet	529	430	81	12	28	13	40	4	2
26. Proprietary Russet	591	461	78	17	44	20	15	1	4
27. Russet Burbank	491	311	63	6	17	10	36	0	31
28. Russet Burbank	555	385	70	9	25	12	33	0	22
29. Russet Norkotah	634	504	79	3	10	6	63	0	18
30. Shepody	461	323	70	4	17	9	43	0	26
31. Teton Russet	480	389	81	4	19	12	49	0	15
32. Umatilla Russet	665	548	82	11	32	16	35	0	7
Mean	440	345	77	12	28	14	36	2	9
LSD (∝=0.05)	114	104	8	6	7	4	11	5	9

Table 9. General rating and French fry evaluations following grading and after 8-weeks storage at 7.7C (45F), full season trial, Larimore, ND, 2017. The processing trial was planted on May 24-25, flailed on October 5, and harvested October 5,11 and 13, 2017 using a single-row Grimme harvester. Entries were replicated four times; plots were twenty feet long, with a within-row spacing of 12 inches and 36 inches between rows.

Clone	General Rating[1]	Fry Color[2]	Stem-end Color	% Sugar Ends[3]	Fry Color[2]	Stem-end Color	% Sugar Ends[3]
		Field Fry			Following 8 wks. At 7.7C		
1. AND97279-5Russ	3.3	0.6	0.6	1	1.1	1.6	33
2. ND8068-5Russ	3.6	0.4	0.4	0	0.4	0.9	17
3. ND050032-4Russ	3.5	0.4	0.6	8	0.4	1.4	38
4. ND070927-2Russ	2.6	0.4	0.7	8	0.4	0.7	25
5. ND091933ABCR-2Russ	3.3	0.4	0.4	0	0.3	0.9	17
6. ND091933ABCR-7Russ	3.4	0.4	0.4	0	0.3	0.3	0
7. ND091938BR-2Russ	2.9	0.9	1.1	8	1.6	1.8	17
8. ND091997BT-3Russ	2.8	1.2	1.2	0	1.8	2.1	25
9. ND092007R-2Russ	2.8	0.9	1.0	17	1.7	1.8	8
10. ND092019C-4Russ	3.0	1.3	1.8	25	1.5	2.5	50
11. ND092024CR-1Russ	3.0	0.5	3.4	92	0.5	3.8	100
12. ND092355CR-2Russ	2.4	0.5	3.0	84	1.1	3.3	92
13. ND113096-1Russ	2.1	0.5	3.4	92	0.6	3.7	92
14. ND113099-2Russ	2.4	1.3	2.1	50	2.3	2.5	17
15. ND113100-1Russ	3.1	0.6	1.1	42	0.5	1.5	50
16. ND113174B-2Russ	2.8	0.8	1.9	59	1.3	2.3	59
17. ND12162AB-1Russ	3.3	0.6	0.6	0	0.8	1.3	34
18. Alpine Russet	3.3	0.5	0.7	8	1.3	1.3	0
19. Alturas	2.6	0.8	1.0	33	1.2	1.2	0
20. Bannock Russet	3.5	1.1	1.4	8	1.7	1.8	8
21. Clearwater Russet	3.5	0.4	0.5	8	0.3	0.6	25
22. Dakota Russet	4.5	0.3	0.3	0	0.3	0.4	8
23. Pomerelle Russet	3.1	0.5	1.1	17	0.8	1.3	33
24. Prospect Russet	3.1	0.7	1.5	33	1.6	2.2	33
25. Ranger Russet	2.9	0.9	0.9	0	1.8	2.1	8
26. Proprietary Russet	3.1	0.6	1.3	33	0.9	1.8	33
27. Russet Burbank	2.1	0.8	1.4	67	1.7	2.1	8
28. Russet Burbank	2.3	0.5	2.7	100	1.3	2.2	67
29. Russet Norkotah	2.5	1.9	1.9	0	2.8	3.1	25
30. Shepody	2.4	0.8	1.1	42	0.8	2.0	59
31. Teton Russet	3.1	1.0	1.5	42	1.9	2.6	42
32. Umatilla Russet	3.4	0.8	0.8	0	0.5	0.9	17
Mean	3.0	0.7	1.3	27	1.1	1.8	32
LSD (∝=0.05)	0.6	0.4	0.7	40	0.8	0.9	41

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

[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.

Hosting Ability of Potato and Northern-grown Crops in Rotation with Potato for the Root-lesion Nematode, *Pratylenchus penetrans*

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Summary

Root-lesion nematode, *Pratylenchus penetrans*, is known to cause detrimental effect on growth and yield of potato. Infection by this nematode increases stress in plants making them vulnerable to other plant pathogens. Planting resistant potato cultivars and use of non- or poor hosts in crop rotation plan is an effective, economic and environmentally sound approach to manage this nematode in fields. A total of 14 crop cultivars including six from potatoes and eight from rotational crops (corn, soybean, wheat and barley) were evaluated in the greenhouse to determine their hosting abilities to *P. penetrans*. Two greenhouse experiments were conducted during February and July, 2017 using naturally infested field soil from a potato field in Central Minnesota. In experiment 1, four potato cultivars: Red Norland [reproduction factor (Rf) = 9.8], Shepody (Rf = 7.6), All Blue (5.4), and Atlantic (5.0) were good hosts while the rest of the tested crop cultivars were minor hosts. In experiment 2, potato cultivars: Red Norland (Rf = 12) and Merlot (14) were very good hosts while the rest of the potato cultivars were good hosts. Among the rotational crops, *P. penetrans* reproduced more in soybean and corn cultivars than in barley and wheat cultivars. Average of Rf values across two experiments indicated barley (Genesis: Rf = 2.6; Pinnacle: Rf = 2.9) and wheat cultivars (Glenn: 3.0; Faller: 4.4) as minor hosts while soybean (Barnes: 5.5; Sheyenne: 7.9) as good hosts and corn cultivars as either good host (DK-44-13: 6.8) or very good host (DK-43-48: 10). Moreover, potato cultivar Red Norland (Rf = 10.9) was a very good host, Merlot (Rf = 8.6), All Blue (7.6), Shepody (7.0) and Atlantic (5.0) were good hosts while Lamoka (4.4) was a minor host. Our results indicate high virulence of these *P. penetrans* populations in some potato, corn and soybean cultivars with ability to reproduce quickly. Information on host status of different crop cultivars from this study will help growers to select better crop cultivars to suppress nematode populations and increase potato tuber yield.

Background

Root lesion nematodes, *Pratylenchus* spp. are the most common nematode pests of potato (Florini and Loria 1990; Brown et al. 1980). Six species of this group of nematode, *P. crenatus*, *P. penetrans*, *P. scribneri*, *P. alleni*, *P. thornei* and *P. neglectus* were recovered from potato roots in a survey in Ohio (Brown et al. 1980). Several species of *Pratylenchus* cause negative impact to potato (Mahran et al. 2010). Among the species, *P. penetrans* is the most economically damaging species (Waeyenberge et al. 2009). The yield of potatoes was reduced by 50% in an affected field in Norway, and the economic damage threshold was suggested at 100 nematodes per 250 g of soil (Holgado et al. 2009). In micro-plot studies in Canada, yield loss of 25 to 73% was reported to be caused by *P. penetrans* in different potato cultivars (Olthof 1986).

Host preference study of *P. penetrans* is cruicial to develop effective crop rotational scheme in order to manage this nematode. *P. penetrans* populations were incresed to higher levels in potato and the rotational crops oat and corn than in rye, wheat and sorgho-sudangrass in pot experiments (Florini and Loria 1990). Hosting ability was found to be variable within cultivars of crops (Florini and Loria 1990; Be´lair et al. 2007; Zasada and Moore 2014). Hence, information on hosting suitability of specific cultivars of crops to *P. penetrans* is important for design a successful rotational pattern. However, the resistant or susceptible levels of potato cultivars to *P. penetrans* population in our region and the host status of Northern-grown crops in rotation with potato to *P. penetrans* are unknown.

The objectives of the project were to 1) evaluate six potato varieties used in ND and MN for resistance reactions to the root-lesion nematode *P. penetrans*; and 2) determine the host range of *P. penetrans* for those crops such as corn, soybean, wheat, and barley grown in rotation with potato.

Materials and Methods

Selection of crop cultivars

A total of 14 crop cultivars were selected from potato crop and rotational crops with potato, including corn, soybean, wheat, and barley which are commonly grown in North Dakota-Minnesota region. Six potato cultivars were used in this study which include Red Norland, All Blue, Shepody, Atlantic, Merlot, and Lamoka. Two cultivars were selected for each of the four rotational crops (Table 1). All the seed potatoes were provided by potato research facilities at the North Dakota State University, obtained from seed potato farms. Other crop seeds were taken from seed stocks at Nematology Laboratory, NDSU, obtained from NDSU breeding programs and extention personnel.

Preparation of crop seeds

Seed potatoes and rotational crop seeds were pre-sprouted and pre-germinated, respectivley, before planting. In order to facilate the sprouting, potatoes were spread in plastic trays with moist paper towels in the bottom for 15-20 days at room temperature of 22°C. Sprouted potatoes were cut into 2 to 3 halves each with sprouts. Cutting of potatoes was done 3-4 days before planting in order to provide adequate time for healing of cut sections. Similarly, the seeds of rotational crops were pre-germinated for 4-5 days by placing them in petridishes with wet filter paper. These practices allow quick growth of plant roots which are necessary for nematode feeding after planting in greenhouse conditions.

Collection of P. penetrans-infested soil, soil processing and nematode extraction

Narurally infested soil was collected from a potato field in central Minnesota. This field was identified to be infested with *P. penetrans* during our previous soil surveys. Infested soil was put in plastic bags holding approximately 15 kg of soil. Bags with infested soil were placed in coolers to prevent heat stress to nematodes during transportation. Later, these bags were stored at 4°C in cold room to avoid changes in nematode populations until soils were processed within 2-3 days. Infested soils from plastic bags were spread in a big plastic tray and mixed throughly for hours to ensure uniform nematode distribution. Three sub-samples of 0.2 kg were taken from the bulk of mixed soil. Nematodes were extracted separately from each sub-sample using sugar centrifugal-floatation technique (Jenkins 1964). Root-lesion nemaotdes were identified and counted under an inverted light microscope and recorded as total number of individuals per 0.2 kg of soil. Species identity of root-lesion nematodes in this field was confirmed as *P. penetrans*. Average of nematode populations from three sub-samples was calculated which was used to determine the initial nematode density in the greenhouse trials.

Greenhouse experiments

Two greenhouse trials were conducted to evaluate the hosting ability of different crop cultivars to *P. penetrans*. In the first experiment, the initial population density of *P. penetrans* was 660 per plant per pot during planting. Similarly, in the second experiment the starting density of *P. penetrans* was 450 per plant per pot. Experiments 1 and 2 were performed during February and July of 2017, respectively. Nematode populations used in both trials were obtained from the same field as described above.

Experiments were conducted in the greenhouse with 16 hrs day light at an average temperature of 22°C. For both trials, plastic pots of 20 x 15 cm were used. Each pot was filled with 1.5 kg of soil naturally infested with *P. penetrans*. Each pot with soil was fertilized with one tea spoon of slow release fertilizer (formulation 14-14-16 NPK) and then mixed thoroughly. A single sprouted piece of a potato cultivar was placed in the center of a filled pot at 4-5 cm depth. The potato piece was covered with an appropriate amount of soil with sprouts just visible from soil layer. Similarly, a single pre-germinated seed of a rotational crop cultivar was put in the center of a filled pot at 2-3 cm depth. Each cultivar was replicated five times in both trials. The experiments were completely randomized in blocks and placed in benches in the greenhouse. All plants were allowed to complete one growth cycle and the trials were terminated on 90 days after planting. Plant tops were removed and the soil with roots were placed in plastic bags which were then stored at 4°C until nematode were extracted within a week.

Nematode extraction from soil and roots, and identification and counting

Each soil and root sample collected from a single pot with a plant was placed in a tray (36 cm x 27 cm), and soil was removed from roots to keep the roots separately. After the soil was thoroughly mixed, a sub-sample of 0.2 kg was taken from each sample from which nematodes were extracted using sugar centrifugal-floatation method (Jenkins 1964). During nematode extraction from soil, roots were also rinsed with tap water to get all the nematodes from the soil around the roots. Rinsed roots were cut into 1-inch small pieces and nematodes were extracted from roots using Whitehead tray method (Whitehead and Hemming 1965) after incubation of 48 hrs. Nematodes from soil and roots for a sample were collected separately in 20 to 25 ml tap water in 50 ml tubes. Nematodes from soil and root extractions were identified and counted separately under an inverted light microscope (Zeiss Axiovert 25, Carl Zeiss Microscopy, NY, USA). Numbers of *P. penetrans* from 0.2 kg of soil were converted to total number of *P. penetrans* in 1.5 kg of total soil in a pot. Finally, nematode numbers from roots of each plant in a pot were added to total nematode numbers from soil in the same pot to determine final nematode population in each pot with a single plant.

Reproduction factor and ratings

Nematode reproduction factor (Rf) on each experimental unit (individual pot with a crop plant) was calculated by dividing the final population of nematodes by the initial population. Average reproduction factor of nematodes on a treatment (cultivar) was calculated as an average of reproductive factors from five replications of each cultivar. In order to determine the hosting ability, five groups including non-host (Rf < 0.1), poor host (Rf = 0.1 to 0.9), minor host (Rf = 1.0 to 4.9), good host (Rf = 5.0 to 9.9), and very good host (Rf ≥ 10) were designated based on the reproduction factors (Smiley et al. 2014). Hosting ability ranking was assigned to each cultivar separately from each experiment and also collectively from combination of two experiments. Average of reproduction factors from ten replicates across two trials for each cultivar was used to determine the ranking from combined experiments.

Data analysis

The SAS software (PROC GLM of SAS 9.4; SAS Institute Inc., Cary, NC) was used to analyze the reproduction factors of *P. penetrans* on crop cultivars in two trials. Mean separation was performed using *F*-protected least significant difference (LSD) at $P < 0.05$ to determine the significant differences in reproductive factors of nematodes in the tested crop cultivars.

Results

First experiment

Potato cultivars, Red Norland, Shepody, and All blue favored significanlty higher ($P < 0.05$) reproduction of *P. penetrans* compared to all rotational crop cultivars of corn, soybean, wheat and barley (Fig. 1). There was significant variation in hosting abilities of potato cultivars to *P. penetrans*. Among the potato cultivars, Rf value was significantly lower ($P < 0.05$) in Lamoka compared to other cultivars, except Merlot (Fig. 1). There was no significant difference in Rf values of the tested rotational crop cultivars in experiment 1, except between soybean cultivar, Sheyenne and barley cultivar, Genesis. Population of *P. penetrans* declined by 100% in the non-planted control (Fig. 1). Based on Rf values of potato cultivars, Red Norland, Shepody, All blue, and Atlantic were good hosts (Rf = 5 to 9.8) while Merlot and Lamoka were minor hosts (Rf = 2.6 to 3.2) of *P. penetrans* (Table 1). Similarly, all the rotational crop cultivars were minor hosts in trial 1 (Table 1). Percentage of nematodes recovered from soil and roots were variable between individual cultivars. Overall, 12 to 37% of the total nematodes were recovered from root tissues of the tested cultivars after growth of 90 days while the rest were obtained from soil.

Second experiment

In this trial, significant variation was observed in hosting ability of both potato cultivars and rotational crop cultivars to *P. penetrans*. Compared to experiment 1, Rf values of most crop cultivars were higher in this experiment. Red type potato cultivars, Red Norland and Merlot, had significanlty higher ($P < 0.05$) Rf values than Shepody, Lamoka and Atlantic cultivars of potato (Fig. 2). There was no significant difference in Rf values of barley and wheat cultivars. However, soybean and corn cultivars favored significanlty higher reproduction than the barley cultivar Pinnacle (Fig. 2). Except for corn cultivars, there was no significant difference in Rf values between cultivars within each rotational crop (Fig. 2). *P. penetrans* population was found to be reduced by 60% in the non-planted control. Red Norland and Merlot were very good hosts while the rest of the potato cultivars were good hosts (Table 1). Similarly, two corn cultivars and the soybean cultivar Sheyenne were also very good hosts (Table 1). Barley cultivars were minor hosts similar to trial 1. In general, 13 to 49% of the total nematodes were recovered from root tissues of the tested cultivars and the rest was obtained from soil.

Both experiments combined

Average of Rf values of each crop cultivar across two experiments was used to rank the hosting ability to *P. penetrans*. Barley and wheat cultivars were minor hosts while soybean cultivars were good hosts (Table 2). Corn cultivar, DK-43-48, was a very good host while DK-44-13 was good host (Table 2). Potato cultivars had variations in hosting ability from minor host to very good host. Red Norland was designated as a very good host and Merlot, All Blue, Shepody, and Atlantic were good hosts while Lamoka was minor host (Table 2).

Conclusions

Host preference evaluation of nematodes in different crop cultivars is crucial to develop effective crop roation scheme as a strategy for nematode management in crop fields. In this study, we determined the hosting abilities of crop cultivars including potato and rotational crops (soybean, wheat, and barley) to *P. penetrans* using naturally infested field soil under greenhouse conditions. *P. penetrans* populations used in this study were observed to reproduce well in most of the tested crop cultivars. Most potato cultivars were either good hosts or very good hosts of *P. penetrans*. The combined result of two trials showed barley and wheat cultivars as minor hosts while soybean as good hosts and corn cultivars as either good or very good hosts. *P. penetrans* populations were observed to increase more than 10-fold in a single crop cycle in some potato, soybean, and corn cultivars. Our results indicate high virulence of these *P. penetrans* populations from a potato field in Central Minnesota, with ability to reproduce quickly. It would be wise for farmers to avoid the incorporation of cultivars which are either good hosts or very good hosts of *P. penetrans* in rotational scheme with potato crop in order to manage this nematode. Barley cultivars which were minor hosts in this study have shown potential to be used as comparatively better rotational crop with potato. In future, a wide scale screening of more crop cultivars is required considering the well reproduction of *P. penetrans* in the tested cultivars and some variation in hosting abilities among individual crop cultivars.

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Table 1. Host ranking of potato cultivars and rotational crops to lesion nematode, *Pratylenchus penetrans*, in two greenhouse experiments.

Crop	Cultivar	Experiment 1[a]		Experiment 2	
		Rf[b]	Host ranking[c]	Rf	Host ranking
Barley	Genesis	1.0	M	4.2	M
	Pinnacle	1.6	M	4.2	M
Wheat	Glenn	1.4	M	4.7	M
	Faller	2.6	M	6.2	G
Soybean	Barnes	1.8	M	9.2	G
	Sheyenne	3.2	M	12.6	VG
Corn	DK-43-48	2.0	M	18.0	VG
	DK-44-13	2.4	M	11.2	VG
Potato	Lamoka	2.6	M	6.2	G
	Merlot	3.2	M	14.0	VG
	Atlantic	5.0	G	5.0	G
	All Blue	5.4	G	9.8	G
	Shepody	7.6	G	6.4	G
	Red Norland	9.8	G	12.0	VG
Control	Non-planted	0	-	0.4	-

[a] Experiment 1 was conducted during February 2017 with initial nematode density of 660 *P. penetrans*/pot/plant while experiment 2 was conducted during July 2017 with initial nematode density of 450 *P. pentrans*/pot/plant.

[b] Rf (reproduction factor) is the mean reproduction factor of replications (n = 5) for each crop cultivar, and was calculated by dividing the final population of target nematodes by the initial population of the nematodes.

[c] Host ranking based on the categorization of reproductive factors into five classes: N = non-host (Rf < 0.1), P = poor host (Rf = 0.1 to 0.9), M = minor host (Rf = 1.0 to 4.9), G = good host (Rf = 5.0 to 9.9), and VG = very good host (Rf ≥ 10) as described by Smiley et al. (2014).

Table 2. Host ranking of potato cultivars and rotational crops to lesion nematode, *Pratylenchus penetrans*, based on average of reproduction factors across two greenhouse experiments.

Crop	Cultivar	Average of reproduction factors in two trials	
		Rf[a]	Host ranking[b]
Barley	Genesis	2.6	M
	Pinnacle	2.9	M
Wheat	Glenn	3.0	M
	Faller	4.4	M
Soybean	Barnes	5.5	G
	Sheyenne	7.9	G
Corn	DK-43-48	10.0	VG
	DK-44-13	6.8	G
Potato	Lamoka	4.4	M
	Merlot	8.6	G
	Atlantic	5.0	G
	All Blue	7.6	G
	Shepody	7.0	G
	Red Norland	10.9	VG
Control	Non-planted	0.2	-

[a] Rf (reproduction factor) values are the average of reproduction factors of *P. penetrans* among replications (n=10) for each crop cultivar across two experiments. RF of nematodes was calculated by dividing the final population of target nematodes by the initial population of the nematodes.

[b] Host ranking is based on the categorization of reproduction factor into five classes: N = non-host ($Rf < 0.1$), P = poor host (Rf = 0.1 to 0.9), M = minor host (Rf = 1.0 to 4.9), G = good host (Rf = 5.0 to 9.9), and VG = very good host ($Rf \geq 10$), as described by Smiley et al. (2014).

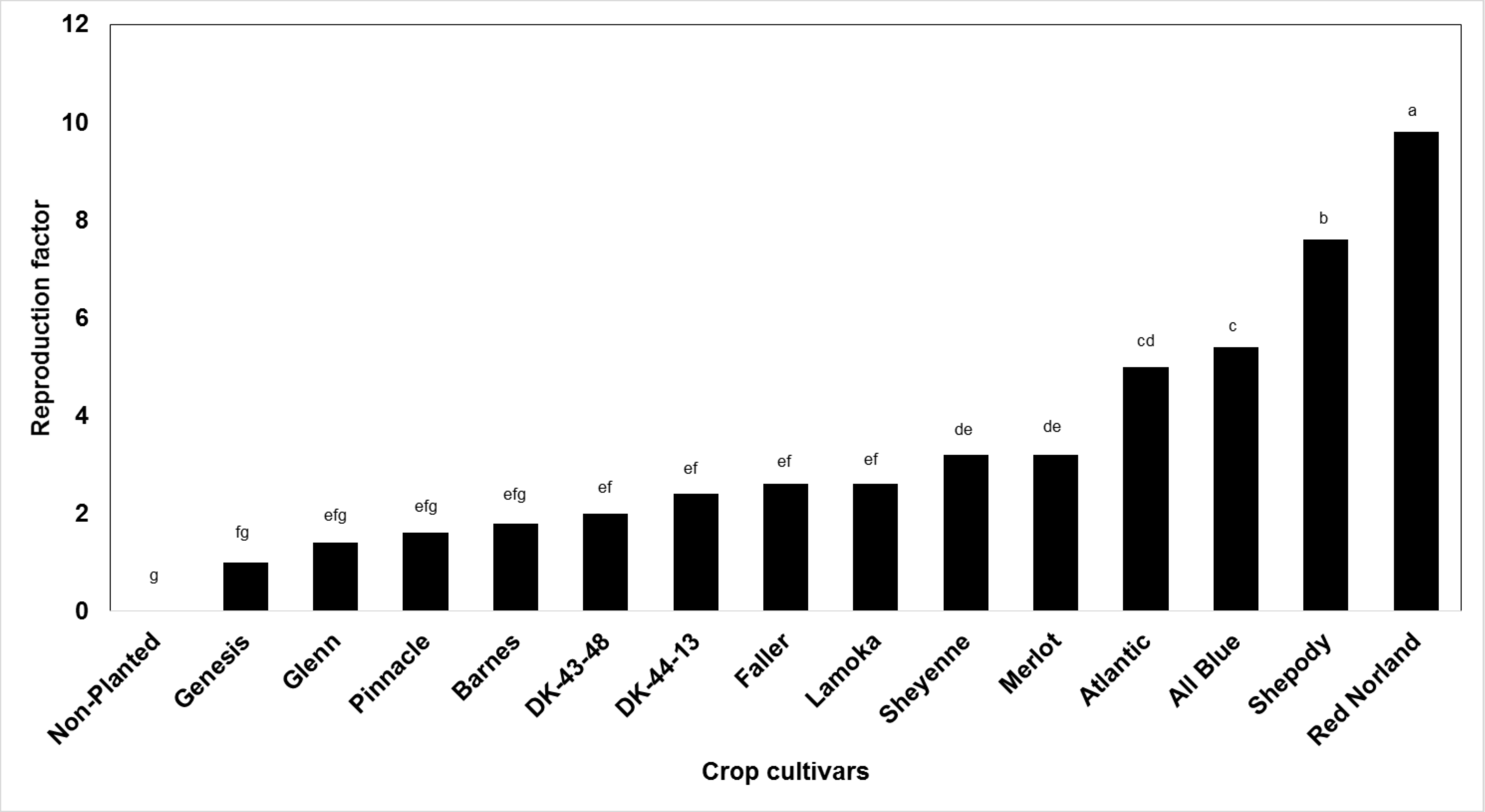

Fig. 1. Reproduction factor (Rf) values (ratio of final nematode population / initial population) of *P. penetrans* on fourteen crop cultivars grown in greenhouse conditions, with an initial density of 660 *P. penetrans*/pot/plant. Rf is the mean of five replications for each cultivar in experiment 1 conducted in February, 2017. Rf values with same letters are not significantly different according to F-protected least significant different test ($P < 0.05$).

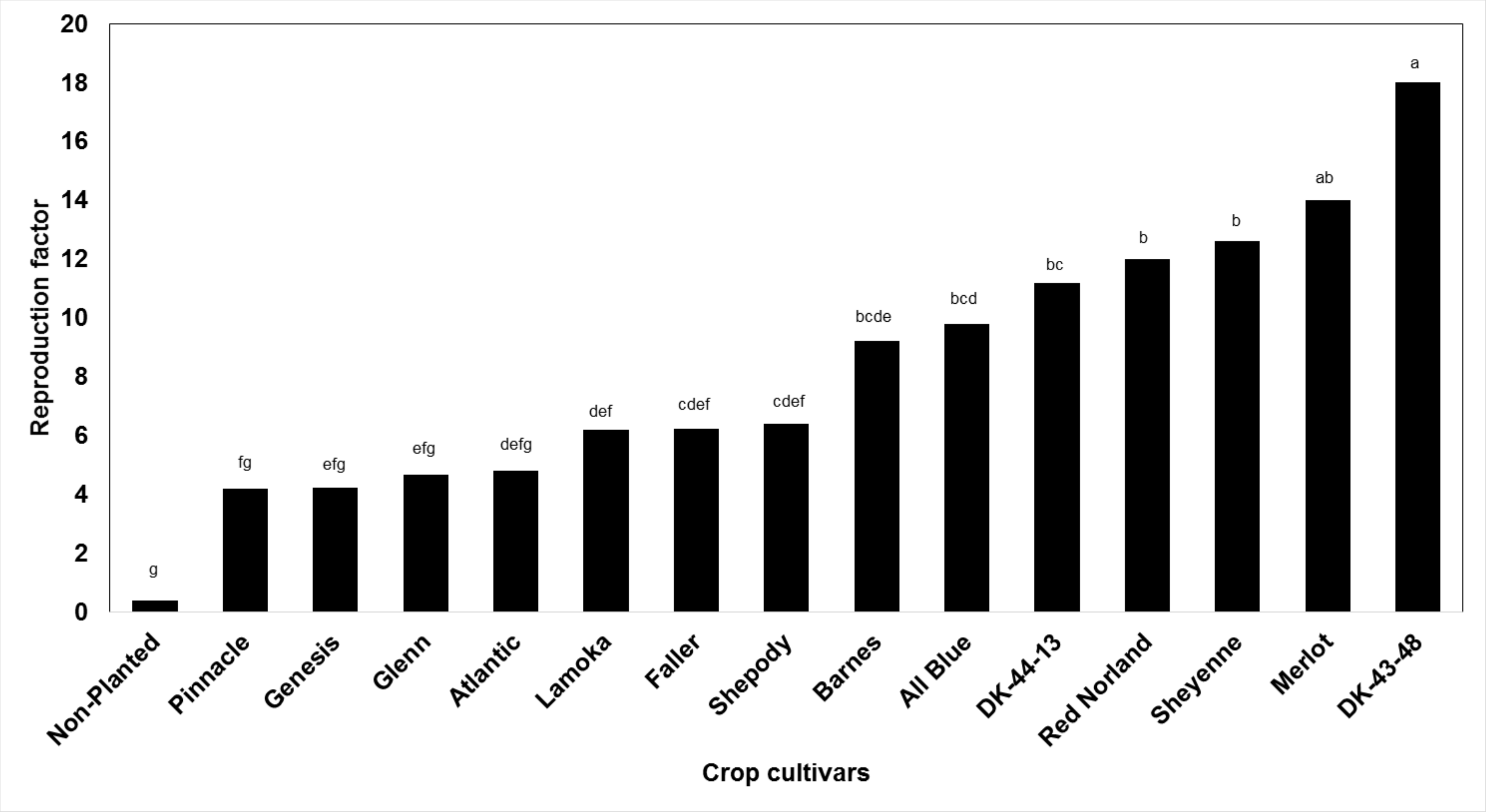

Fig. 2. Reproductive factor (Rf) values (ratio of final nematode population / initial population) of *P. penetrans* on fourteen crop cultivars grown in greenhouse conditions in large plastic pots with an initial density of 450 *P. penetrans*/pot/plant. Rf is the mean of five replications for each cultivar in experiment 2 conducted in July 2017. Rf values with same letters are not significantly different according to F-protected least significant different test ($P < 0.05$).

Effect of adjuvants on 'Red Norland' desiccation. Harlene Hatterman-Valenti and Collin Auwarter.

This study was conducted at the Northern Plains Potato Growers Association dryland research site near Grand Forks, ND to evaluated different adjuvants when added to a common vine desiccant, diquat, on 'Red Norland' potato. 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 14, 2017. Extension recommendations were used for cultural practices throughout the year. Plots were sprayed on September 6 with a CO_2 pressurized sprayer equipped with 8002 XR flat fan nozzles with a spray volume of 20 GPA and a pressure of 40 psi. Plots were rated on September 13 and 19. Harvesting occurred on October 19 and graded a few weeks later.

Date:	9/6
Air Temperature (F):	61
Relative Humidity (%):	58
Wind (MPH):	4
Soil Moisture:	Normal
Cloud Cover (%):	75
Next Rain:	9 DAA

% Necrosis on Leaves and Stems on 'Red Norland' potato.

Trt No.	Treatment Name	Rate	Rate Unit	7 DAA Leaf	7 DAA Stem	13 DAA Leaf	13 DAA Stem
1	Reglone	1	pt/a	70.0 a	60.0 a	88.8 a	77.5 A
2	Reglone Activate Plus	1 0.25	pt/a % v/v	66.3 a	55.0 a	93.8 a	82.5 A
3	Reglone AG17054	1 0.25	pt/a % v/v	75.0 a	62.5 a	95.0 a	85.0 A
4	Reglone AG17055	1 0.25	pt/a % v/v	67.5 a	57.5 a	93.8 a	81.3 A
5	Reglone AG17056	1 0.25	pt/a % v/v	73.8 a	60.0 a	90.0 a	81.3 A
6	Untreated			8.0 b	3.8 b	28.8 b	18.8 B
			LSD (P=.05)	19.13	17.47	8.1	9.62

Yield of 'Red Norland' potato.

Treatment	Rate	---20 Foot Row (lbs)---		-------------------------------------CWT/A-------------------------------------					
		Row B	Row A	0-4 oz	4-6 oz	6-10 oz	>10 oz	Total	>4 oz
1 Reglone	1 pt/a	33.18 a	26.66 a	6.57 a	11.35 a	5.24 a	3.49 b	195.50 a	145.80 a
2 Reglone Activate Plus	1 pt/a 0.25 % v/v	35.33 a	31.14 a	7.08 a	15.45 a	6.00 a	2.62 b	226.05 a	174.63 a
3 Reglone AG17054	1 pt/a 0.25 % v/v	32.40 a	34.87 a	7.28 a	15.64 a	6.85 a	5.10 ab	253.12 a	200.24 a
4 Reglone AG17055	1 pt/a 0.25 % v/v	40.85 a	31.78 a	6.57 a	13.01 a	6.89 a	5.31 ab	230.75 a	183.04 a
5 Reglone AG17056	1 pt/a 0.25 % v/v	38.20 a	33.59 a	5.50 a	15.13 a	6.88 a	6.09 ab	243.85 a	203.91 a
6 Untreated		40.82 a	34.93 a	5.74 a	14.14 a	5.97 a	8.55 a	249.70 a	208.02 a
	LSD (P=.05)	8.27	9.41	2.99	5.28	2.68	2.81	68.33	54.76

Tuber Counts of 'Red Norland' potato.

Treatment	Rate	---------------------------------------20 foot row------------------------------------					
		Row A	0-4 oz	4-6 oz	6-10 oz	>10 oz	>4 oz
1 Reglone	1 pt/a	90.5 a	43.8 a	30.5 a	11.8 a	4.5 B	51.32 a
2 Reglone Activate Plus	1 pt/a 0.25 % v/v	106.5 a	48.5 a	42.0 a	12.5 a	3.5 B	55.18 a
3 Reglone AG17054	1 pt/a 0.25 % v/v	112.3 a	48.5 a	42.8 a	14.5 a	6.5 Ab	56.87 a
4 Reglone AG17055	1 pt/a 0.25 % v/v	103.5 a	47.8 a	34.3 a	14.5 a	7.0 Ab	53.50 a
5 Reglone AG17056	1 pt/a 0.25 % v/v	105.3 a	42.8 a	40.3 a	14.3 a	8.0 Ab	59.65 a
6 Untreated		102.9 a	42.0 a	37.9 a	12.8 a	10.2 A	60.11 a
	LSD (P=.05)	34.28	19.75	13.85	6.10	3.52	9.68

Adding any adjuvant with Reglone did not increase or hasten leaf or stem necrosis. This land had some soil saturation problems from heavy rains early in the season, which may have predisposed plants to be more responsive to desiccants. More statistical separation may have also occurred if the untreated was not included in the necrosis analysis. The grade and yield had little differences among all the treatments. The untreated did have more potatoes larger than 10 oz, an unwanted characteristic for red potatoes. The Reglone alone treatment had the lowest total yield and the fewest amount of total tubers, even though this was not significant, suggesting that this was due to randomization and not the treatment.

Effect of diquat and adjuvants on 'Red Norland' desiccation. Harlene Hatterman-Valenti and Collin Auwarter.

This study was conducted at the Northern Plains Potato Growers Association non-irrigated research site near Grand Forks, ND to evaluated different adjuvants when added to a common vine desiccant, diquat, on 'Red Norland' potato. 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 14, 2017. Extension recommendations were used for cultural practices throughout the year. Plots were sprayed on September 6 with a CO_2 pressurized sprayer equipped with 8002 XR flat fan nozzles with a spray volume of 20 GPA and a pressure of 40 psi. Plots were rated on September 13 and 19. Harvesting occurred on October 19 and graded a few weeks later.

Date:	9/6
Air Temperature (F):	61
Relative Humidity (%):	58
Wind (MPH):	4
Soil Moisture:	Normal
Cloud Cover (%):	75
Next Rain:	9 DAA

% Desiccation on Leaves and Stems on Red Norland potatoes.

Trt No.	Treatment Name	Rate	Rate Unit	7 DAA Leaf	7 DAA Stem	13 DAA Leaf	13 DAA Stem
1	Reglone	1	pt/a	55.3 a	45.0 a	78.8 a	62.5 a
2	Reglone Preference	1 0.25	pt/a % v/v	72.5 a	62.5 a	91.3 a	83.8 a
3	Reglone AG17053	1 0.25	pt/a % v/v	88.3 a	76.3 a	98.8 a	90.0 a
4	Reglone AG13064	1 3	pt/a fl oz/a	72.5 a	61.3 a	97.5 a	86.3 a
5	Reglone Preference Interlock	1 0.25 4	pt/a % v/v fl oz/a	71.3 a	58.8 a	93.8 a	83.8 a
6	Reglone AG8050	1 6.4	pt/a fl oz/a	80.0 a	68.8 a	96.3 a	83.8 a
7	Reglone AG14039	1 6.4	pt/a fl oz/a	81.3 a	70.0 a	97.5 a	86.3 a
8	Untreated			25.0 b	18.8 b	43.8 b	32.5 b
			LSD (P=.05)	28.25	25.25	25.28	22.97

Yield of Red Norland potatoes.

Trt No.	Treatment Name	Rate	Rate Unit	---20 foot row (lbs)---		----------CWT/A----------					
				Row B	Row A	0-4 oz	4-6 oz	6-10 oz	>10 oz	Total	>4 oz
1	Reglone	1	pt/a	36.79 a	31.84 a	45.61 a	106.43 a	51.18 a	27.93 a	231.16 a	185.55 a
2	Reglone Preference	1 0.25	pt/a % v/v	29.2 a	25.83 a	50.24 a	84.69 a	29.79 b	22.84 a	187.56 a	137.32 a
3	Reglone AG17053	1 0.25	pt/a % v/v	30.78 a	24.74 a	51.63 a	69.57 a	29.19 b	29.21 a	179.60 a	127.97 a
4	Reglone AG13064	1 3	pt/a fl oz/a	38.10 a	28.94 a	37.46 a	97.08 a	44.22 ab	31.35 a	210.10 a	172.64 a
5	Reglone Preference Interlock	1 0.25 4	pt/a % v/v fl oz/a	36.75 a	30.72 a	48.73 a	102.89 a	42.44 ab	28.95 a	223.01 a	174.27 a
6	Reglone AG8050	1 6.4	pt/a fl oz/a	35.70 a	31.45 a	52.50 a	103.36 a	40.58 ab	31.88 a	228.31 a	175.81 a
7	Reglone AG14039	1 6.4	pt/a fl oz/a	36.88 a	28.46 a	57.50 a	90.71 a	39.08 ab	19.33 a	206.62 a	149.12 a
8	Untreated			36.90 a	31.28 a	36.95 a	93.97 a	41.57 ab	54.57 a	227.06 a	190.11 a
			LSD (P=.05)	7.53	31.28	15.11	32.85	12.45	20.97	49.74	45.16

Tuber Counts of Red Norland potatoes.

Trt No.	Treatment Name	Rate	Rate Unit	----------20 foot row----------					
				Row A	0-4 oz	4-6 oz	6-10 oz	>10 oz	>4 oz
1	Reglone	1	pt/a	108.1 a	48.4 a	39.6 a	15.0 a	5.1 a	55.28 ab
2	Reglone Preference	1 0.25	pt/a % v/v	95.0 a	49.0 a	33.0 a	9.0 b	4.0 a	47.68 ab
3	Reglone AG17053	1 0.25	pt/a % v/v	90.8 a	51.0 a	26.3 a	8.3 b	5.3 a	43.21 b
4	Reglone AG13064	1 3	pt/a fl oz/a	90.8 a	36.5 a	35.8 a	13.0 ab	5.5 a	58.29 a
5	Reglone Preference Interlock	1 0.25 4	pt/a % v/v fl oz/a	102.0 a	45.3 a	39.3 a	12.3 ab	5.3 a	54.99 ab
6	Reglone AG8050	1 6.4	pt/a fl oz/a	106.3 a	48.8 a	40.3 a	11.8 ab	5.5 a	54.74 ab
7	Reglone AG14039	1 6.4	pt/a fl oz/a	102.0 a	53.5 a	34.0 a	11.0 ab	3.5 a	46.42 ab
8	Untreated			93.5 a	38.0	34.3 a	12.3 ab	9.0 a	59.77 a
			LSD (P=.05)	26.31	15.25	12.99	3.69	3.58	9.09

Potatoes treated with Reglone alone had the lowest leaf and stem necrosis compared to other Reglone treatments with an adjuvant, even though not significant 7 and 13 DAA. Leaf necrosis was >90% 13 DAA when an adjuvant was added. More statistical separation may have also occurred if the untreated was not included in the necrosis analysis. Desiccant treatments did not affect yields, as all had a total yield between 180 and 231 CWT/A. All treatments with Reglone had fewer tubers in the > 10 oz. category resulting in lower yield in that category compared to the untreated. Treatment 7 Reglone + AG14039 had the lowest > 10 oz. yield, a desirable characteristic as these often are unmarketable while tubers < 4 pz. may receive a higher price. Tuber counts were consistent with total yield results, as all had between 91 and 108 tubers in a 20-foot row.

2017 Evaluating Glyphosate and Dicamba on Atlantic Potatoes. Harlene Hatterman-Valenti and Collin Auwarter.

This study was conducted at the Northern Plains Potato Growers Association Irrigated research site near Inkster, ND to evaluate Glyphosate and Dicamba on Atlantic potato. 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 5, 2017. Plots were sprayed on July 18 at the tuber initiation stage with a CO2 pressurized sprayer equipped with 8002 XR flat fan nozzles with a spray volume of 20 GPA and a pressure of 40 psi. Extension recommendations were used for cultural practices throughout the year. Plots were harvested on October 17 and graded into various categories after harvest.

% Injury 10 and 20 DAA from Glyphosate and Dicamba on Atlantic potato.

Treatment		Rate		10 DAA		20 DAA	
				% Injury		% Injury	
1	Untreated Check			0.0	c	0.0	b
2	Glyphosate (PowerMax)	5	fl oz/a	12.5	b	3.8	b
3	Glyphosate (PowerMax)	1	fl oz/a	0.0	c	0.0	b
4	Glyphosate (PowerMax)	0.2	fl oz/a	0.5	c	0.0	b
5	Dicamba (Clarity)	2.825	fl oz/a	16.3	b	11.3	a
6	Dicamba (Clarity)	0.565	fl oz/a	0.0	c	2.5	b
7	Dicamba (Clarity)	0.113	fl oz/a	0.0	c	3.8	b
8	Glyphosate (PowerMax) Dicamba (Clarity)	5 2.825	fl oz/a fl oz/a	36.3	a	15.0	a
9	Glyphosate (PowerMax) Dicamba (Clarity)	1 0.565	fl oz/a fl oz/a	0.0	c	1.3	b
10	Glyphosate (PowerMax) Dicamba (Clarity)	0.2 0.113	fl oz/a fl oz/a	2.5	c	1.3	b
	LSD (P=.05)			7.17		6.13	

Date:	7/18
Air Temperature (F):	65
Relative Humidity (%):	73
Wind (MPH):	3
Soil Moisture:	Normal
Cloud Cover (%):	100
Next Rain:	15 DAA

Yield of Atlantic potato.

Treatment		Rate		-----20 Foot Row-----				-------------------------------------CWT/A-------------------------------------											
				Row B		Row A		0-4 oz		4-6 oz		6-12 oz		>12 oz		Total		>4 oz	
1	Untreated Check			59.08	a	56.60	a	62.223	b	160.56	a	74.41	a	113.76	a	410.96	a	348.74	a
2	Glyphosate (PowerMax)	5	fl oz/a	65.10	a	57.24	a	93.768	ab	178.38	a	77.60	a	65.85	a	415.60	a	321.83	a
3	Glyphosate (PowerMax)	1	fl oz/a	63.88	a	62.45	a	59.033	b	163.75	a	92.74	a	137.89	a	453.43	a	394.40	a
4	Glyphosate (PowerMax)	0.2	fl oz/a	56.63	a	62.46	a	56.140	b	175.29	a	98.54	a	123.47	a	453.46	a	397.31	a
5	Dicamba (Clarity)	2.825	fl oz/a	65.18	a	55.71	a	92.580	ab	170.30	a	69.07	a	72.48	a	404.44	a	311.86	a
6	Dicamba (Clarity)	0.565	fl oz/a	70.15	a	64.53	a	75.595	ab	204.43	a	90.69	a	97.83	a	468.55	a	392.96	a
7	Dicamba (Clarity)	0.113	fl oz/a	77.58	a	55.37	a	63.920	b	157.27	a	72.17	a	108.67	a	402.03	a	338.11	a
8	Glyphosate (PowerMax) Dicamba (Clarity)	5 2.825	fl oz/a fl oz/a	64.30	a	51.79	a	110.705	a	164.60	a	60.01	a	40.69	a	376.00	a	265.30	a
9	Glyphosate (PowerMax) Dicamba (Clarity)	1 0.565	fl oz/a fl oz/a	61.23	a	55.43	a	68.005	ab	172.29	a	85.68	a	76.47	a	402.44	a	334.44	a
10	Glyphosate (PowerMax) Dicamba (Clarity)	0.2 0.113	fl oz/a fl oz/a	64.98	a	50.53	a	71.545	ab	148.56	a	68.39	a	78.38	a	366.88	a	295.33	a
	LSD (P=.05)			22.91		14.06		29.90		46.73		23.79		67.88		102.04		102.18	

Tuber Counts and Sizes in 20' of Row in Atlantic potato.

Treatment		Rate		--20 Foot Row--											
				Total		0-4 oz		4-6 oz		6-12 oz		>12 oz		>4 oz	
1	Untreated Check			154.5	a	54.5	b	59.0	a	20.8	a	20.3	a	64.43	a
2	Glyphosate (PowerMax)	5	fl oz/a	189.8	a	88.8	ab	66.5	a	23.0	a	11.5	a	52.54	ab
3	Glyphosate (PowerMax)	1	fl oz/a	159.0	a	52.5	b	57.8	a	26.0	a	22.8	a	67.20	a
4	Glyphosate (PowerMax)	0.2	fl oz/a	161.5	a	50.0	b	62.0	a	27.5	a	22.0	a	69.61	a
5	Dicamba (Clarity)	2.825	fl oz/a	183.5	a	86.3	ab	64.5	a	19.5	a	13.3	a	53.34	ab
6	Dicamba (Clarity)	0.565	fl oz/a	186.0	a	65.8	b	76.5	a	26.3	a	17.5	a	65.16	a
7	Dicamba (Clarity)	0.113	fl oz/a	151.5	a	55.0	b	57.0	a	20.8	a	18.8	a	63.86	a
8	Glyphosate (PowerMax) Dicamba (Clarity)	5 2.825	fl oz/a fl oz/a	195.5	a	105.5	a	64.5	a	17.5	a	8.0	a	45.64	b
9	Glyphosate (PowerMax) Dicamba (Clarity)	1 0.565	fl oz/a fl oz/a	159.3	a	58.8	b	63.3	a	24.0	a	13.3	a	63.49	a
10	Glyphosate (PowerMax) Dicamba (Clarity)	0.2 0.113	fl oz/a fl oz/a	148.3	a	60.0	b	55.5	a	19.5	a	13.3	a	59.52	ab
	LSD (P=.05)			38.06		24.52		18.78		6.39		11.31		10.99	

10 DAA the combination with the highest rates of Glyphosate plus Dicamba had a significant effect on potato injury 36%). The high rate of Dicamba (16%) and Glyphosate (13%) also showed significant differences compared to all other treatments. The lowest rates of the tank-mix, Glyphosate and Dicamba showed little injury while the mid-rates showed no signs of injury. 20 DAA showed similar trends with injury, however everything with Dicamba showed symptoms. Some symptoms seen with Glyphosate included yellow at growing point, white flowers (instead of pick), flower delay and slight stunting. Symptoms with Dicamba showed leaf curling, less or no flowering, shorter and leaf epinasty. The tank-mix showed all previous signs while more being more definitive. Yields didn't show a lot of differences. The highest rates of the tank-mix, Glyphosate and Dicamba did have the lowest yield, but not at a significant level. Tuber counts and sizes showed the higher the rate, the greater the amount of smaller potatoes (0-4 oz) and less amounts of market-sized potatoes (>4 oz).

2017 UPI Potato Weed Control. Harlene Hatterman-Valenti and Collin Auwarter.

This study was conducted at the Northern Plains Potato Growers Association Irrigated research site near Inkster, ND to evaluate pre-emergence weed control in Russet Burbank potato. 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 5, 2017. Plots were sprayed on June 16 with a CO_2 pressurized sprayer equipped with 8002 XR flat fan nozzles with a spray volume of 20 GPA and a pressure of 40 psi. Extension recommendations were used for cultural practices throughout the year. Plots were harvested on October 17 and graded into various categories after harvest.

Date:	6/16
Air Temperature (F):	68
Relative Humidity (%):	59
Wind (MPH):	8
Soil Temperature @ 4 Inch (F):	62
Soil Moisture:	Normal
Cloud Cover (%):	5
Next Rain:	3 DAA

Common Lambsquarter, Redroot Pigweed, and Yellow Foxtail Control in Russet Burbank 19 & 28 days after application (DAA).

Treatment	Rate	---------------------19 DAA-------------------				------------------------28 DAA-------------------			
		CHEAL	AMARE	PESGL	INJURY	CHEAL	AMARE	PESGL	INJURY
1 Untreated Check		0.0 c	0.0 c	0.0 a	0.0 a	0.0 c	0.0 c	0.0 a	0.0 a
2 Boundary	1.42 lbai/a	97.5 a	97.5 a	100.0 a	0.0 a	96.3 a	96.3 a	100.0 a	0.0 a
3 Boundary	1.83 lbai/a	95.0 a	97.5 a	100.0 a	0.0 a	97.5 a	98.8 a	100.0 a	0.0 a
4 KFD-240-01	1.13 lbai/a	95.0 a	95.0 a	100.0 a	0.0 a	97.5 a	97.5 a	100.0 a	0.0 a
5 KFD-240-01	1.40 lbai/a	96.3 a	97.5 a	100.0 a	0.0 a	98.8 a	97.5 a	100.0 a	0.0 a
6 KFD-240-01	1.69 lbai/a	93.8 a	96.3 a	100.0 a	0.0 a	97.5 a	97.5 a	100.0 a	0.0 a
7 KFD-195-02	1.30 lbai/a	98.8 a	96.3 a	100.0 a	0.0 a	100.0 a	100.0 a	100.0 a	0.0 a
8 Matrix+ Sencor 75DF	1.50 ozwt/a 0.5 lb/a	68.8 b	68.8 b	100.0 a	0.0 a	76.3 b	76.3 b	100.0 a	0.0 a
LSD (P=.05)		7.74	7.34	0.00	0.00	4.37	3.98	0.00	0.00

Yield of Russet Burbank Potatoes.

Treatment	Rate	-----20 Foot Row-----		-------------------------------------CWT/A-------------------------------------					
		Row B	Row A	0-4 oz	4-6 oz	6-12 oz	>12 oz	Total	>4 oz
1 Untreated Check		52.48 a	42.16 a	60.01 a	70.61 a	155.26 a	20.18 a	306.07 a	246.06 a
2 Boundary	1.42 lbai/a	62.53 a	55.52 a	73.57 a	80.57 a	195.52 a	53.46 a	403.13 a	329.56 a
3 Boundary	1.83 lbai/a	54.03 a	56.23 a	67.16 a	86.80 a	194.29 a	60.01 a	408.27 a	341.11 a
4 KFD-240-01	1.13 lbai/a	53.10 a	46.76 a	67.19 a	74.73 a	158.68 a	38.85 a	339.46 a	272.27 a
5 KFD-240-01	1.40 lbai/a	49.80 a	51.75 a	70.95 a	82.77 a	192.48 a	29.50 a	375.72 a	304.76 a
6 KFD-240-01	1.69 lbai/a	49.23 a	48.90 a	59.52 a	76.27 a	175.16 a	44.09 a	355.05 a	295.53 a
7 KFD-195-02	1.30 lbai/a	57.20 a	51.97 a	68.70 a	72.16 a	180.40 a	56.05 a	377.31 a	308.62 a
8 Matrix Sencor 75DF	1.50 ozwt/a 0.5 lb/a	52.40 a	44.71 a	75.10 a	82.60 a	141.49 a	25.43 a	324.64 a	249.53 a
LSD (P=.05)		14.05	10.38	20.21	28.43	57.27	41.41	75.39	80.60

Tuber Counts and Sizes in 20' of Row in Russet Burbank Potatoes.

Treatment	Rate	-----------------------------------20 Foot Row-----------------------------------					
		Total	0-4 oz	4-6 oz	6-12 oz	>12 oz	>4 oz
1 Untreated Check		137.5 a	60.8 a	31.0 a	42.5 a	3.3 a	56.445 a
2 Boundary	1.42 lbai/a	165.3 a	69.0 a	34.8 a	53.3 a	8.3 a	58.048 a
3 Boundary	1.83 lbai/a	168.0 a	68.5 a	38.5 a	52.3 a	8.8 a	59.440 a
4 KFD-240-01	1.13 lbai/a	151.8 a	70.8 a	32.8 a	42.3 a	6.0 a	52.705 a
5 KFD-240-01	1.40 lbai/a	167.3 a	76.0 a	36.0 a	51.0 a	4.3 a	53.770 a
6 KFD-240-01	1.69 lbai/a	148.3 a	60.5 a	33.8 a	47.5 a	6.5 a	58.985 a
7 KFD-195-02	1.30 lbai/a	157.3 a	68.8 a	31.8 a	48.5 a	8.3 a	55.593 a
8 Matrix Sencor 75DF	1.50 ozwt/a 0.5 lb/a	151.8 a	73.0 a	36.5 a	38.3 a	4.0 a	51.645 a
LSD (P=.05)		30.51	21.99	12.60	15.72	5.79	10.97

Regardless of the Boundary or KFD-240-01 rate, Boundary, KFD-240-01 and KFD-195-02 provided excellent weed control throughout the season. Matrix tank-mixed with Sencor provided significantly lower control of common lambsquarter and redroot pigweed. KFD-195-02 provided 100% control of all three weed species by the end of the season, while Boundary and KFD-240-01 had slightly less control, however not significant. There was no significant differences with yield even though Boundary KFD-240-01, or KFD-195-02 treatments had marketable yields approximately 50 cwt/a greater than the untreated or Matrix plus Sencor treatment. Tuber counts were similar for all treatments even though the untreated had lower total tuber counts and fewer tuber counts in 4 out of 5 size categories. The Matrix/Sencor treatment had the fewest tubers in the 6-12 oz category.

2017 Valent Mycoapply Endomaxx. Harlene Hatterman-Valenti and Collin Auwarter.

This study was conducted at the Northern Plains Potato Growers Association Irrigation research site near Inkster, ND to evaluate Mycoapply Endomaxx in-furrow on Red Norland potato. Corn was the previous crop in 2016. 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 12, 2017. While planting, in-furrow, Mycoapply Endomaxx was applied as a spray directly over the seed piece using a CO2 pressurized sprayer equipped with 6501 XR flat fan nozzles with a spray volume of 8 GPA and a pressure of 21 psi. Extension recommendations were used for cultural practices throughout the year. Roots were dug the same day as harvest and sent to the lab for % of mycorrhizal colonization. Plots were harvested on October 17 and graded into various categories after harvest.

Date:	6/12
Air Temperature (F):	68
Relative Humidity (%):	48
Soil Temperature @ 4 Inch (F):	70
Soil Moisture:	Normal
Next Rain:	1 DAA

Red Norland Potato Yield.

Treatment	Rate	---20 Foot Row (lbs)---		--------------------------------------CWT/A--------------------------------------					
		Row B	Row A	0-4 oz	4-6 oz	6-10 oz	>10 oz	Total	>4 oz
1 Untreated Check		56.03 a	47.02 b	52.15 a	111.43 a	58.47 a	119.30 a	341.35 b	289.20 b
2 MA ENDOMAXX	6 g/a	52.70 a	53.51 a	57.50 a	125.23 a	73.34 A	132.45 a	388.52 a	331.01 a
LSD (P=.05)		18.43	2.28	14.25	14.98	23.06	24.40	16.51	25.04

Red Norland Potato Tuber Counts and Sizes in 20’ of Row.

Treatment	Rate	-----------------------------------20 Foot Row-----------------------------------					
		Row A	0-4 oz	4-6 oz	6-10 oz	>10 oz	>4 oz
1 Untreated Check		130.8 a	54.5 a	40.8 a	16.5 a	19.0 a	58.28 a
2 MA ENDOMAXX	6 g/a	144.8 a	58.5 a	44.0 a	20.8 a	21.5 a	59.83 a
LSD (P=.05)		16.69	20.91	6.92	6.01	4.95	10.72

Mycorrhizal Root Colonization Test.

Treatment	Rate	% Root Colonization
1 Untreated Check		2.50 a
2 MA ENDOMAXX	6 g/a	18.75 a
LSD (P=.05)		22.22

Treatment	Rate	% Root Colonization
101 Untreated Check		0
102 MA ENDOMAXX	6 g/a	30
201 MA ENDOMAXX	6 g/a	23.07
202 Untreated Check		0
301 Untreated Check		0
302 MA ENDOMAXX	6 g/a	14.28
401 MA ENDOMAXX	6 g/a	7.66
402 Untreated Check		10

Adding Endomaxx in-furrow to Red Norland potatoes increased the total and marketable (>4oz) yield significantly. By adding the Endomaxx, the marketable yield increased by almost 42 cwt/a. Tuber counts increased with Endomaxx in all categories but this was not significant. The mycorrhizal root colonization test showed all treatments where Endomaxx was applied showed an increase of % root colonization. One of the untreated treatments (402), also showed an increase (10%), while the remaining untreated treatments didn’t have any root colonization.