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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

These field trials were conducted under conditions typical of commercial potato production using overhead sprinkler irrigation near Park Rapids, Minnesota in all three years the experiment has been conducted, 2017-2019. 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 approximately 20 verticillium propagules per gram (vppg) of soil and a post-fumigation level of 10 vppg.

The experiments was planted on May 10, 2017, May 19, 2018 and May 10, 2019 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) in 2017, from August 31 to September 28 in 2018 and from August 30 to October 2, 2019 . It should be noted that a killing frost ended the desiccation intervals on September 28 in 2018. 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 within each treatment and will be assayed to determine *V. dahliae* populations using quantitative PCR and/or direct culture plating. 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 in 2017, October 7, 2018 and October 8, 2019. Total yield was taken at harvest and grade analysis was conducted by AgWorld Support Systems in Grand Forks, ND.

Results

Significant differences in total yield were observed among vine desiccation dates in 2017 (data not shown). The highest total yield was achieved at the September 17 vine desiccation date. Significant differences in marketable yield were observed also among vine desiccation dates. 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. 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 was used to generate payable yield (price processor pays per cwt X marketable yield per acre) and gross income per acre return to the grower. Gross return per acre reached its maximum with the September 17 desiccation date and did not increase thereafter.

In 2018, there were no differences in total yield or marketable yield among any of the desiccation dates (data not shown). The lack of differences among vine desiccation dates is likely due to the lower than normal temperatures throughout much of September and the field frost that occurred on September 28.Total yields varied from 567 cwt/a with the August 31 and September 8 desiccation dates to approximately 605 cwt/a with the September 20 and 27 desiccation dates. During this same timeframe, marketable yield varied from 463 cwt/a to approximately 507 cwt/a. Although there were no significant differences in gross economic return per acre, the economic return/a varied from an average of $3,553/a for the first three vine desiccation dates to $4,136 for the last three desiccation dates. There were significant differences in specific gravity among the vine desiccation dates but these differences were not associated with any obvious trend among the dates.

In 2019, there were no significant differences in total yield among any of the vine desiccation dates (Table 1). Yield varied from 512 cwt/a with the August 31 vine kill date to 550 cwt/a for the September 27 vine kill date, however, this numerical increase in total yield was not significant. Grade analysis was not yet completed at the time this report was written.

Yield data for the three years of this study, 2017-2019 were combined for further analysis (Table 2). Among the six vine kill dates, total yield for the first two vine kill date ranges of August 29-31 and September 4-8 were significantly lower than all other vine kill dates except the third date vine desiccation date range of September 10-14. Across all three years of this field experiment, there was no significant yield increase among any vine desiccation dates that ranged from September 17-September 20 or beyond to the final vine desiccation dates which ranged from September 27-October 2. These data support the original hypothesis that there is no potato yield increase beyond the fall equinox date of September 21. This experiment will be continued in 2020 and 2021 and supported by a specialty crop block grant.

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Table 1. Verticillium disease severity and total yield at six vine kill dates in Park Rapids, MN in 2019

Application Dates	Wilt (% Severity)								AUDPC	RAUDPC	Yield (cwt/a)
	7/31	8/8	8/15	8/23	9/5	9/11	9/18	9/25			
Aug 30, Sept 6	0.03	0.14	0.91	2.50	-	-	-	-	51.700	0.017	512.29
Sept 6, Sept 14	0.00	0.08	0.81	2.25	19.81	-	-	-	519.100	0.102	536.62
Sept 14, Sept 19	0.00	0.08	0.69	2.13	19.69	69.38	-	-	423.200	0.101	542.53
Sept 19, Sept 28	0.00	0.09	0.81	2.19	20.19	70.94	97.63	-	1024.300	0.209	556.54
Sept 28, Oct. 2	0.00	0.09	0.72	2.19	20.13	69.81	97.94	99.88	1315.300	0.239	570.90
Oct. 2	0.01	0.14	0.81	2.63	20.94	71.44	99.13	100.00	1741.900	0.311	550.52
LSD$_{P\ =\ 0.05}$	NS	NS	0.12	0.34	NS	1.37	NS	NS	756.49	0.129	NS

Table 2. Combined total yield data for total yield for six vine kill dates across three years. 2017-2019

Vine Dessication Date Range	Yield (cwt/a)
Aug 29 - Aug 31	538.9a
Sept 4 - Sept 8	557.4ab
Sept 10 - Sept 14	576.2bc
Sept 17 - Sept 20	594.54c
Sept 22 - Sept 28	591.5c
Sept 27 - Oct 2	586.6c
LSD$_{P = 0.05}$	23.6

Evaluation of a promising Minnesota clone for N response, agronomic traits and storage quality

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Summary:

A new promising dual purpose potato clone MN13142 with semi-erect medium vine growth and mid-season maturity was evaluated for its nitrogen management and other agronomic traits associated with growth, yield and long-term storability. MN13142 has very uniform, long attractive tubers with a very heavy russet skin. The heavy russet skin makes it suitable for mechanical harvesting with a low incidence of internal bruising. MN13142 has unusually long dormancy. The clone can be stored for more than 205 days after harvest at 52F storage temperature. A field trial was conducted in 2019 at Becker, MN, with five contrasting cultivars to evaluate effect of N fertilizer levels on tuber physiology, yield attributes and yield. After harvest, tuber yield, size distribution and tuber quality components were evaluated. All the cultivars had a slight decline in total yield at the higher N application of 360 lbs-ac^{-1} except Umatilla Russet. Umatilla Russet did not show such decline in total yield in response to higher N fertilizer rate. Highest total yield was recorded in Russet Burbank at the 240 lbs-ac^{-1} N rate. Irrespective of cultivars, specific gravity declined with increasing N fertilizer rate. Highest specific gravity was recorded in Umatilla Russet followed by Clearwater Russet MN13142 and Lamoka. Lowest specific gravity was recorded in Russet Burbank. Tubers were stored at 40 and 48°F after reconditioning for further physiological and biochemical studies. Storage evaluations are underway.

Background

Providing crops with adequate levels of N fertilizer ensures the best yield possible. However, the soil-plant atmosphere system inefficiencies prevent complete utilization of N, leaving residual N in the soil. Commercial potato production is especially prone to environmental contamination when N fertilizer, irrigation and unpredictable rainfall results in nitrate leaching (Sharifi et al., 2007). The risks of not applying enough N can be substantial. Balancing economic with environmental concerns is often challenging. Farmers usually apply higher levels of nitrogenous fertilizer to ensure profitable potato production as most N in the soil is present in soil organic matter and crop residues, and not readily available for plant uptake. Optimum N fertilizer rates for potato are generally based on the traditional cultivar Russet Burbank. New potato cultivars may not be as responsive to high N fertilizer rates as Russet Burbank. In addition to environmental concerns, excessive available N stimulates top growth and delays tuber formation and maturity. Nitrogen use efficiency has been shown to decrease in a curvilinear manner with increasing crop N supply (Sun et al., 2017; Zebarth et al., 2004).

The role of N fertilization on plant establishment, tuber growth and yield has been extensively studied in traditional commercial cultivars like Russet Burbank. Moreover N fertilization influences tuber sugar content and fry color by interfering with tuber chemical maturation (Belanger et al., 2000; Iritani and Weller, 1977). It has been proposed that higher N fertilization rate influences tuber sugar content and chip color at harvest by interfering with tuber chemical maturation. The reports on potato post-harvest storage and reducing sugar (RS) accumulation in response to N fertilization rates during growth of the plant is limited and inconclusive, especially in new potato cultivars with high resistance to cold induced sweeting (CIS).

Systematic studies are lacking on the effect of N fertilization on expression of various enzymes related to carbohydrate metabolism in potato tubers. Studies have shown a close association of key enzymes with reducing sugar (RS) accumulation. Changes in carbohydrate metabolizing enzyme expression in response to N status may have significant effects on tuber RS accumulation during storage. Management strategies to reduce N losses to the environment from potato production while maintaining profitable yields has been focused on right time, rate, source and place of N application. However, not much effort have been put into the performance of new potato cultivars on N fertilizer requirement, which can increase tuber yield and quality, and avoid N losses. Therefore, the new potato clone MN13142 has been evaluated for N fertilizer rate in relation to total and marketable yield, tuber size distribution and specific gravity. The new clone MN13142 is under evaluation for long term storability, reducing sugar accumulation and processing quality. Various biochemical parameters will be investigated to gain an understanding in physiological response to plant N status.

For decades, the processing industry has had a high demand for potatoes with long dormancy, high solids, low reducing sugar potential and tough skin set, traits important for storability and good processing quality. The sprout inhibitor CIPC is routinely used on potatoes to improve long term storage. However, CIPC is a health concern and European countries have banned the use of CIPC for potatoes, which has increased the demand for potatoes varieties with long dormancy. The new clone MN13142 has several of the needed desirable traits, like long dormancy, no CIPC requirement, high solids, tough skin, low temperature sweetening resistance, postharvest quality retention etc. MN13142 clone could be an attractive alternative for future potato production systems. The overall objective of current study was to evaluate response of new clone MN13142 to nitrogen management and other agronomic traits associated with yield and long term storability.

Methods:

To gain a better understanding of N fertilizer response, five potato cultivars and clone (Russet Burbank, Umatilla Russet, Clearwater Russet , Lamoka and MN13142) having a wide variation in CIS resistance were selected. In 2019, the cultivars were planted on May 06, 2019 at the Sand Plain Research Farm, Becker, MN in a Hubbard loamy sand soil. A randomized complete block design with three replications was used. Each cultivar was subjected to three N rates treatments120, 240, and 360 lbs acre^{-1}. All plots received 40 lbs N acre^{-1} as DAP (18-46-0) at planting (05/06/2019) in a band 8 cm to the side and 5 cm below the seed tuber. At emergence, N was side-dressed at 80, 160 and 240 lbs N acre^{-1} as ESN (Agrium, Inc., Calgary, AB, Canada; 44-0-0) at each specific N rate treatment, respectively, and then hilled in on 22 May 2019. Post-hilling applications split into four applications of 10 and 20 lbs N acre^{-1} as urea and ammonium nitrate – UAN (28-0-0) were applied to supply 40 and 80 lbs N acre^{-1} to achieve 240 and 360 lbs N acres^{-1} rates. All potatoes were harvested on September 27, 2019 and suberized for three weeks at room temperature. At harvest, yield and yield attributes were recorded. Tubers were stored at 40 and 48°F cold storage for evaluations at 3 and 6 months intervals. Baseline sugar, fry color and other biochemical analysis were performed in tubers before cold storage.

For storage evaluations, five tubers from each plot were analyzed for sugars, fry color and other traits at the bud end and the stem end. Soluble protein content was determined using the dye-binding method of Bradford (Bradford, 1976) and expressed as mg per g FW. Sugars, glucose and sucrose were analyzed using a YSI model 2000 Industrial Analyzer (Yellow Springs Instruments Co., Inc., Yellow Springs, OH). The concentration of sugar is expressed in mg g^{-1} FW.

Results and Discussion: To better understand the physiology of N absorption and utilization, various physiological and biochemical parameters like dry matter and plant N content accumulation and partitioning, were recorded during plant growth and development. Mature tubers at harvest were analyzed for tuber N content, free amino acid and soluble protein conc. In this report the effect of N fertilization rate on plant N status, tuber yield and tuber quality is discussed. Mature tubers are currently being evaluated for storability at 40 and 48°F cold storage.

<u>Effect of N fertilizer rate on plant N status:</u> In order to investigate N absorption and utilization by the cultivars in this study, plant N status in terms of petiole nitrate was recorded during four plant growth stages viz 1) Vegetative, 2) tuber initiation, 3) tuber filling and 4) tuber maturation. To gain an understanding of N utilization at harvest, mature tubers were evaluated for total tuber N contents, free amino acid concentration and soluble protein concentrations.

Petiole nitrate showed a clear trend under both the high and low N fertilization rates in all cultivars (Figure 1). Petiole nitrate was highest before tuber initiation, which then declined rapidly in all cultivars as growing season progressed. This trend is consistent with the previously published reports (Love et al., 2005; Zebarth and Rosen, 2007). Regardless of cultivar, petiole nitrate levels were higher when plants were grown at higher N rates. Similar results were reported by Porter and Sisson for Russet Burbank and Shepody potato cultivars (Porter and Sisson, 1991). Among the four cultivars Russet Burbank had the lowest petiole nitrate compared to Clearwater Russet, MN13142 and Umatilla Russet. The utilization of absorbed nitrogen will depend on cultivar and the pathways that are affected by high N rate. Absorbed N could be utilized for excess vegetative growth or translocated to developing tubers. In our study, Russet Burbank and Umatilla Russet absorbed high levels of N and had higher total N content per plant (data not presented). But Clearwater Russet and MN13142 partitioned more N to developing tubers. Possibly Russet Burbank and Umatilla Russet utilized excess absorbed N for vegetative growth as reflected by their higher total biomass production. Even though MN13142 showed lower plant N status, it translocated a much higher percentage of absorbed N to the tubers. Porter and Sisson reported a critical petiole nitrate levels of 1.6% for Russet Burbank at 50 DAP. Petiole nitrate levels above 2.2% at 50 DAP resulted in lower yields of Russet Burbank (Porter and Sisson, 1991). As all the cultivars at higher N rate of 405 kg ha^{-1} had higher petiole nitrate than 2.2%, they may have lower yield.

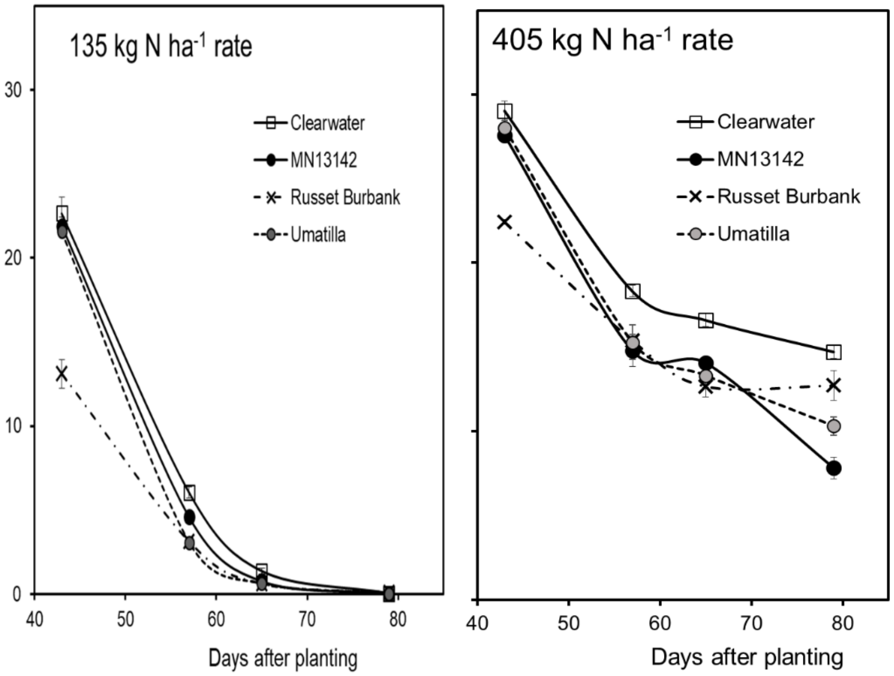

Figure 1: Petiole nitrate (g kg^{-1}) in four cultivars supplied with 135 and 405 kg N ha^{-1} at four growth stages.

Effect of N fertilizer rate on tuber size distribution and yield:

Cultivars showed differential response to N fertilizer rates in terms of tuber size distribution (Table 1). The industry recommendation for tuber size is 68-74% 6oz tubers and 28-40% 10 oz tubers. Russet Burbank had significantly higher 6-10oz tubers than the other cultivars followed by MN13142 and Umatilla Russet. Clearwater Russet had significantly lower 6-10oz tubers compared rest four cultivars in the study. The effect of N rate and N rate * cultivar interaction were found significant for >6 oz tuber size but not for total yield. In the 10-14oz tuber size category there was no significant difference among cultivars MN13142, Russet Burbank and Umatilla. Cultivar Lamoka had significantly higher 10-14 oz tubers and Clearwater Russet had significantly lower 10-14oz tubers. There was a slight increase in >6 oz tubers in response to the higher N rate of 360 lbs-ac^{-1}. Cultivars Russet Burbank, Umatilla Russet and Clearwater Russet were more responsive to N rate for small (0-3 and 3-6 oz size) and more than 6oz tuber size. It is interesting to note that Lamoka had significantly lower small size tuber compared to Russet Burbank, Umatilla Russet or Clearwater. MN13142 was not as responsive to higher N rate possibly due to its mid-season maturity. Compared to Russet Burbank and Umatilla Russet, MN13142 and Clearwater Russet had a very low percentage of large tubers of >14oz size range.

The effect of N rate on total tuber yield was not significant. Highest total yield of 505 cwt-ac^{-1} was recorded in Russet Burbank followed by Umatilla Russet. MN13142 had a total yield of 415 cwt-ac^{-1}. Clearwater Russet had the lowest total yield of 376 cwt-ac^{-1}. The differences among cultivars were found significant. MN13142 had a greater total tuber yield than Clearwater Russet and Lamoka. At higher N rate of 360 lbs-ac^{-1} Umatilla Russet had the highest total tuber yield. Rest of the cultivars had slight decline in total tuber yield at 360 lbs-ac^{-1} N rate. Similar patterns were observed for marketable yield. MN13142 was evaluated at several other locations in MN, ND, OR and NM for its yield potential. The average total yield from other locations in 2019 ranged from 415 (MN) to 618 cwt-ac^{-1} (OR). Therefore, our findings indicate that although MN13142 did not reach the yield potential obtained with Russet Burbank and Umatilla Russet at Becker, this new clone has potential for high yield.

Effect of N fertilizer rate on tuber quality:

Various tuber quality parameters like hollow heart, scab, specific gravity and dry matter content were recorded for all three N rates (Table 2). The effect of N rate was found to be significant for scab, specific gravity and tuber dry matter content.

Low scab incidence was recorded in all the cultivars except Lamoka, which had the highest scbe incidence. Specific gravity (SG) of the tubers is an important trait for the acceptability of new cultivars, with a recommended range of1.082 to 1.088. Umatilla Russet had the highest SG of 1.0924 followed by Clearwater Russet (1.908) and MN13142 (1.0893). The lowest SG of 1.0826 was recorded in Russet Burbank. Clearly all the cultivars tested had acceptable SG. Irrespective of the cultivars there was a decline in specific gravity in response to increasing N fertilizer level. That is often one of the adverse effects of high N fertilization rate. A similar pattern has been reported previously (Sun et al. 2019).

The effect of N rate on tuber dry matter content was significant. The highest dry matter content of 23.7% was recorded in Clearwater Russet followed by Umatilla Russet (22.7%), MN13142 (22.3%) and Russet Burbank.

Conclusion:

The cultivars tested responded differently to N fertilizer rate in terms of small and more than 6 oz tuber size. Overall the differences among cultivars were significant but the effect of N rates and interaction with cultivar was not found significant for total or marketable yield. Even though Russet Burbank and Umatilla Russet had higher N accumulation but that resulted in excessive vegetative growth and biomass production. The observation is based on percentage of total N and dry matter translocated to tubers. MN13142 had lower total plant N content compare to cultivar Russet Burbank and Umatilla Russet, but partitioned higher percentage of total N content to developing tubers. Compared to other cultivars in the study, MN13142 had the best tuber uniformity, and a lower percentage of tubers in more than 14 oz size. MN13142 had high tuber set but due to the wet season and extreme insect pressure, tubers did not achieve full size. In terms of tuber quality, there was no internal defects, scab incidence was low and the clone was resistant to PVY in field evaluations. Field grown MN13142 tubers were tested for Potyvirus group test by Agdia. Tubers were found negative for PVA, PVV and Potato Virus Y (PVY-n, PVY-c, PVY-o+c).

Future success of MN13142 will largely depend on proper seed management and development of a seed warm up protocol. Further studies are needed to determine if alternate N timing or seed spacing are needed to improve total tuber yield of MN13142.

Future research:

MN 13142 is under investigation for long term storability, sugar accumulation potential and fry color change. To gain in-depth understanding of cellular metabolism and investigate all other enzymes affected by high N, total soluble proteins from all cultivars grown at optimum (240 lsb/ac) and high N rate (360 lbs/ac) has being analyzed by MS using TMT labeling.

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Table 1: Tuber yield and yield components in four potato cultivars in response to N fertilizer rates.

Cultivar	**Total N rate (lbs·ac^{-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}									**%**	
MN13142	Average of all	68 c	176 c	145 b	23 b	2 b	415 c	338 b	9 bc	347 c	41 b	6 b
Russet Burbank		80 b	231 a	163 a	25 b	5 b	505 a	415 a	9 bc	424 a	38 bc	6 b
Umatilla		97 a	205 b	143 b	28 b	2 b	474 b	352 b	25 a	377 b	36 c	6 b
Lamoka		56 d	138 d	143 b	47 a	9 a	394 d	334 b	4 c	338 c	51 a	14 a
Clearwater		95 a	180 c	88 c	11 c	1 b	376 d	267 c	14 b	281 d	27 d	3 c
Effect of cultivar (P-value)		**<0.0001**	**<0.0001**	**<0.0001**	**<0.0001**	*0.0960*	**<0.0001**	**<0.0001**	**<0.0001**	**<0.0001**	**<0.0001**	**<0.0001**
Average of all	120	85 a	193 a	131	23	3	435	339	11	350	36 b	6
	240	77 b	192 a	136	27	5	438	349	12	361	38 b	7
	360	76 b	173 b	142	31	3	425	335	13	349	41 a	8
Effect of N rate (P-value)		**0.0299**	**0.0084**	0.2594	0.1539	0.2888	0.2976	0.3633	0.7202	0.4345	**0.0094**	0.2539
MN13142	120	73 cde	170	143 bcd	24	1	412	332	6	338	41 b	6
	240	67 de	185	146 bcd	22	2	423	349	6	355	40 b	6
	360	63 def	173	146 bcd	24	3	410	332	14	347	42 b	7
Russet Burbank	120	96 ab	251	143 bcd	15	5	511	405	9	415	32 c	4
	240	69 de	230	179 a	32	9	519	438	11	449	42 b	8
	360	76 cd	213	167 ab	29	0	484	403	6	409	40 b	6
Umatilla	120	97 ab	210	139 cd	16	0	462	343	22	365	34 c	4
	240	107 a	214	123 de	22	1	468	338	23	361	31 c	5
	360	86 bc	190	166 ab	45	4	491	373	32	405	44 b	10
Lamoka	120	52 f	134	156 abc	55	9	406	350	4	354	54 a	16
	240	53 f	140	146 bcd	48	15	402	344	6	349	52 a	16
	360	62 ef	141	127 de	39	4	372	309	1	310	46 b	11
Clearwater	120	104 a	200	75 g	3	1	383	266	13	279	21 d	1
	240	91 b	194	84 fg	12	0	381	274	16	290	25 d	3
	360	91 b	147	106 ef	19	2	365	260	14	274	34 c	5
Effect of cultivar*N rate (P-value)		**0.0258**	0.1532	**0.0345**	0.1001	0.2291	0.4982	0.2823	0.7041	0.2041	**0.0008**	0.1115

Note: values with same letters indicate no significant difference.

Table 2: Tuber quality in four potato cultivars grown under three N fertilizer rates.

Cultivar	Total N rate ($\text{lbs}\cdot\text{ac}^{-1}$)	Hollow heart	Scab	Specific gravity	Dry matter content (%)
		Percent of tubers			
MN13142	Average of all	0.5	7 b	1.0893 bc	22.3 b
Russet Burbank		0.4	2 b	1.0826 d	20.8 c
Umatilla		0.4	12 b	1.0924 a	22.7 b
Lamoka		0	22 a	1.0874 c	21.2 c
Clearwater		0	6 b	1.0908 ab	23.7 a
Effect of cultivar (P-value)		0.7354	**0.0180**	**<0.0001**	**<0.0001**
Average of all	120	0.3	12	1.0903 a	22.6
	240	0.3	5	1.0897 a	21.8
	360	0.3	12	1.0855 b	22.0
Effect of N rate (P-value)		0.9994	0.2197	**<0.0001**	0.3065
MN13142	120	1.4	11	1.0923	22.5
	240	0	7	1.0885	22.0
	360	0	4	1.0872	22.5
Russet Burbank	120	0	4	1.0827	20.7
	240	1.3	3	1.0858	20.8
	360	0	0	1.0793	20.8
Umatilla	120	0	11	1.0925	23.6
	240	0	5	1.0945	22.0
	360	1.3	19	1.0902	22.5
Lamoka	120	0	32	1.0910	21.8
	240	0	7	1.0872	20.8
	360	0	28	1.0840	20.8
Clearwater	120	0	4	1.0931	24.4
	240	0	5	1.0926	23.4
	360	0	9	1.0867	23.4
Effect of cultivar*N rate (P-value)		0.3077	0.5322	0.2785	0.9512

Note: values with same letters indicate no significant difference.

Measuring bruise susceptibility among new fresh market and processing varieties in storage.

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Summary:

In 2018-19, varietal differences in water loss and pressure bruise susceptibility were assessed after 4 months of storage in simulated pressure towers at the USDA-ARS East Grand Forks Worksite. Storage evaluations are being repeated in the current (2019-20) storage campaign. Bruising will be assessed after six months of storage with evaluations set to occur in March 2020. This report is a summary of the 2019-20 storage experimental approach, and subsequent storage results will be published in a future Valley Potato Grower Magazine article.

Upgrades in 2019-20 include improved temperature set-point control through addition of spray foam and ductwork insulation. In the first year of the study, only one temperature treatment (46°F) was tested due to improper insulation of the storage towers. Foam insulation was added to the storage structure and ventilation ductwork was insulated in Summer 2019 (Figure 1). These improvements have permitted researchers to assess multiple storage temperature treatments (40 and 46°F) for comparing fresh market and processing varieties, respectively. The insulation improvements made in 2019 to the storage structures have enabled our evaluations at 6 months of storage versus 4 months.

Bruising is being characterized across three separate trials: 1) chip, 2) fresh-market reds and yellows, and 3) dual market russets. The evaluation of the fresh-market red and yellow varieties is a collaboration with Dr. Andy Robinson's research variety trials. In this collaboration, the USDA-ARS lab is assessing dormancy, water loss, and pressure bruise rating.

***Chip variety evaluation*.**

After retrieving samples following four months of storage in year one of the study, significant water loss and bruising was observed. However, no tuber flesh discoloration was observed across the bruised areas in all sample treatments (Figure 2). To examine the impact of storage duration on bruise color development we are conducting the evaluation after six months of storage. We are also examining the impact of fluming on tuber discoloration and chip processing quality.

On 09/25/2019 samples from three chip fields were collected from Hoople, ND grower facilities. All samples were harvested that morning and pulp temperature was 54-56°F at the time of sampling. Samples were brought to the EGF lab and immediately sorted into eight replicate mesh bags per field with each bag containing eight tubers. Initial bag weights were recorded and sample bags were positioned inside the macrobin totes in replicated layers. Following six months storage, four bags per field (1/2 of the treatments) will be submerged in water for 15 minutes to examine the impact of fluming on chip processing quality.

Figure 1. Spray foam and ductwork insulation was added to the storage structures in 2019 in effort to improve temperature set point control; extending the storage treatment evaluation from four to six months.

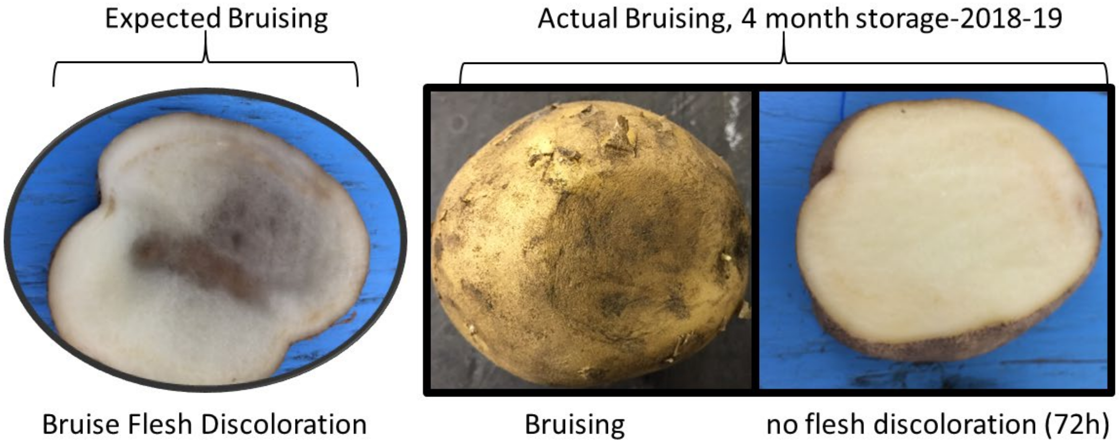

Figure. 2 In 2018-19, no flesh discoloration was observed among the bruised areas. In year 2, storage duration is extended two months and a subsample will be submerged in water in effort to elucidate a discoloration response that often accompanies pressure bruising in storage.

Red and yellow evaluation.

Tubers were collected from a variety trial led by Dr. Andy Robinson. Samples harvested from the Hoople, ND variety trial were brought to the EGF lab and placed into the pressure totes immediately after grading on October 10, 2019. Each variety was evaluated across field replicates and treatment bags consisted of 5 tubers/bag. Tuber water loss, bruise incidence, and bruise area will be assessed after six months of storage (March, 2020).

Russet evaluation.

Seven russet clones were sampled from the USDA-ARS irrigated field trial located at Larimore, ND. The seven clones represent advanced breeding lines from several public breeding programs including the Minnesota clone: MN13142. Sample harvest occurred on October 9th, 2019, and duplicate treatment bags containing 10 tubers/ bag were placed into storage totes within 48 hours of harvest. Tuber water loss, bruise incidence, and bruise area will be assessed after six months of storage (March, 2020).

Pressure adjustment and sampling.

Similar to 2019-20, storage evaluations were conducted in 1000# totes (Macroplastic 32-S Pro-bin; external dimension 48’’l x 44’’w x 30’’h). Totes were stored in one of three storage towers possessing temperature and humidity control. To ensure proper air flow (1.5 cfm/cwt), the tote floor was modified by drilling 5/32’’ holes in a 2’’ grid pattern. Temperature and humidity was controlled and monitored with Techmark Inc. 755 Controller and StorTrac™ software.

Immediately upon placement of tubers (5-10) into mesh sacks, total bag weights were recorded. To ensure treatment bags were not touching the tote surface, a layer of bulk potatoes was placed on the bottom of the tote. Treatment bags were placed in the tote (layered by replicate), and the side and top were filled with additional bulk potatoes. A pressure plate fabricated from ½’’ thick UHMW equipped with a 12 ½ ton bottle jack w/ gauge port (Norco model #76412BG) was placed on the potatoes within the tote. Applied tote pressure equaled 2.1 lb/in^2 and is the estimated force exerted within an 18’ pile height. The desired gauge pressure was achieved by directing the ram into the shelving support structure; pressure was monitored and adjusted as needed. Daily adjustment was required during initial storage, and pressure was routinely monitored every 48hr -72h throughout the entire storage duration.

Humidified air flow through the tote was monitored with a hot-wire anemometer. In the 2019-20 study, reds and yellows were stored at 40°F and processing varieties (russet and chips) were stored at 46°F. Bruise incidence and water loss will be assessed in March, 2020 or after 6 months of storage.

Baseline Evaluation of Pollinator Landscape Plantings Bordering Commercial Potato Report - 2019

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Executive Summary –This proposal assesses the impact of field border plantings of wildflowers on the population dynamics of pollinators and natural enemies (i.e. predators and parasitoids). In the previous two seasons we have determined that floral plantings do increase floral diversity, pollinator numbers and natural enemies that prey on insect pests of potato (but only in the margins of fields). Additionally, we found that predation rates on Colorado potato beetle egg masses were significantly increased in margins planted with flowers. While our previous results show floral plantings provide tangible benefits, it is equally important to determine if these plantings have a negative impact on commercial potato production. To this end, we propose to assess insect pest numbers within plantings and neighboring commercial fields and, more importantly, to determine if pollinator plantings influence Colorado Potato Beetle establishment within commercial fields. We also will attempt to develop techniques whereby predation within floral plantings may contribute to CPB control within commercial fields.

Rationale – Insect pollinators and predators provide important economic and ecological services, contributing some US$3.07B in pollination services and $4.49B in pest control to agriculture each year in the US alone (Losey and Vaughan, 2006). Unfortunately, there is also considerable evidence that populations of these beneficial insects are in decline across the U.S. and Europe, and that the vital services they provide are being severely reduced or lost entirely (Larsen et al. 2005, Biesmeijer et al. 2006, Potts et al. 2010, Ollerton et al. 2011, Lebuhn et al. 2013). While there are many factors affecting this decline, one of the primary drivers is habitat loss due to the expansion of commercial agricultural (Potts et al. 2010). Commercial agriculture usually consists of monocultures that are notably devoid of food resources, shelter, and habitat for pollinators and predators. The few resources that do exist in such landscapes are often ephemeral due to the constant turnover and disruptions caused by planting, harvesting, and managing cropland (Venturini et al. 2017). In order to slow the decline of pollinators and insect predators in the U.S. and across the world, stable sources of forage and habitat need to be incorporated into commercial agricultural landscapes.

To this end, a number of programs recently have attempted to conserve pollinators and other insects within commercial agricultural landscapes by planting perennial wildflowers in the unused margins of crop fields. These floral plantings are designed to provide a constant and stable source of habitat and food in the form of increased vegetation, nectar, and pollen. One such program is Operation Pollinator, which facilitates increasing biodiversity in agricultural habitats. Through this program, R.D. Offutt CO. has established ~1200 acres of flowers adjacent to their commercial potato fields in central

Minnesota. These sites provide an excellent field laboratory to compare the effects of floral plantings with unmanaged field edges.

Our research has demonstrated that these floral plantings, once established, have been successful in significantly increasing the number of both pollinators and insect predators in the margins of fields when compared to neighboring, unmanaged field edges. The notable increase in numbers and diversity of beneficial insects shows that floral plantings can help conserve insect communities that have been in decline. We also found that predation on Colorado potato beetle (CPB), a major pest of potatoes in the area, was increased in the margins with flowers. This indicates that flowers not only attract predators, but that these predators have the potential to reduce the impact of economically important pests. While commercial grown potatoes don't require pollination, increasing numbers of pollinators has clear ecological benefits and may aid other crops in the rotation. Taken together, floral plantings can provide tangible benefits to growers in addition to simply conserving useful insects.

However, it is important to consider if floral plantings have any negative affect on commercial production. One of the primary areas of concern is if plantings promote Colorado potato beetle in any way. CPB generally overwinters outside of production areas, under duff and debris in tree rows and wind breaks, immigrating over-ground (overwintered CPB cannot fly immediately upon emergence) into production fields every spring. Floral plantings may provide overwintering habitat for CPB or may be avenues for immigration. Conversely, they may serve as barriers to immigration, impeding the walking beetles' progress into potato fields, in a similar manner as small grain fields Hoy et al 2000).

Predators and parasitoids can cause a significant increase in pest mortality, and can decrease the need for, or frequency of, insecticide applications (Hare 1990, Houghgoldstein and Whalen 1993, Greenstone et al 2010). Floral plantings often attract multiple predatory taxa (Ramsden et al. 2014), and have been shown to increase predation upon damaging pests when they are placed adjacent to crops (Balzan et al. 2014, Blaauw and Isaacs 2015), including potatoes (Tschumi et al. 2016). We have shown that natural enemies attracted to floral plantings will attack and consume CPB eggs at a high rate. Unfortunately, we have not yet been able to demonstrate that this biological control service extends into the production field. However, there may be techniques whereby predation at the edge of fields can provide a measure of pest control. Adding alternate plant hosts of CPB or early planted potatoes within floral plantings may serve as trap crops. Immigrating beetles will be arrested in the floral plantings and lay eggs in the field margins, thereby decreasing the overall egg load within production fields and becoming more susceptible to predation. Trap crops have been used successfully in other NC potato producing states (Huseth et al. 2014) although there is some concern they may not be appropriate for commercial production on a large scale. However, concentrated habitats of floral plantings provide an excellent location to facilitate this tactic.

We propose to 1). Assess the whether floral plantings provide improved overwintering or immigration opportunities for CPB, and 2). Determine if the use of trap crops within floral plantings is feasible.

Methods

Objective 1) We compared the potential of floral plantings to provide overwintering habitat for CPB with that of unmanaged edges. Sentinel plants (greenhouse reared potato plants and alternate hosts such as tomato and eggplant) will also be established / transplanted in both floral plantings and neighboring unmanaged field edges. These plants will be monitored and beetles counted and counts compared between the two habitats.

In addition, a series of long pitfall traps will be established on the edge of production fields adjacent to both floral plantings and unmanaged field edges. Pitfall traps are holes dug into the earth, and filled with a liquid designed to kill insects (i.e. capture fluid). The captured immigrating CPB in pitfall traps will be assessed and compared between floral plantings and unmanaged edges.

The scheduled population sampling already records and compares CPB populations both in the floral plantings and the within the edge of the adjacent potato field. These data were used to compare the numbers of beetles arriving in a field from unmanaged edges and those with floral plantings.

Emergence cages and ditches traps were not used due to unresolved technical challenges in 2019.

Objective 2) Spraying out CPB on trap plants (the sentinel plants) was not feasible in 2019. The entry period would have required multiple foliar applications. This may be tried again in 2020 by treating the sentinel plants at-plant (effectively IF for the potted plant) with an anthranilic diamide (i.e. Exiril) insecticide. Although not labeled for at-plant application in potato, insecticide trials over the years have indicated that the some Diamides are as effective as neonicotinoids were when they were first introduced. This would negate the necessity of foliar applications.

Results & Discussion

Objective 1) A total of 606 Colorado potato beetle adults and 1,174 larvae were collected between 2016 and 2019. All but 10 CPB adults were found within potato fields, and of those 10, 6 were found in floral margins and 4 were found in control margins. 314 CPB adults and 572 larvae were captured in potato fields adjacent to floral plantings, and 282 CPB adults and 602 larvae were found adjacent to control margins. There was no significant effect of treatment (floral planting or unmanaged edge) on the number of CPB adults (p=0.12), larvae (p=0.49), or the total number of CPB found in the potato crop (p=0.695) (Fig. 1). There was a marginally significant effect of location within the field on CPB numbers (p=0.055), with increasing distance into the field leading to fewer CPB. Colorado potato beetle numbers peaked mid-season, with significantly more CPB present in fields in July compared to late June (p=6.8e-06), or August (p=0.00016). There was no significant effect of treatment on numbers of CPB for different sampling periods. The lack of difference in the numbers of CPB in production fields adjacent to either floral plantings or unmanaged edges would indicate that floral plantings do not provide additional overwintering habitat for CPB or influence their movement into potato fields in the spring.

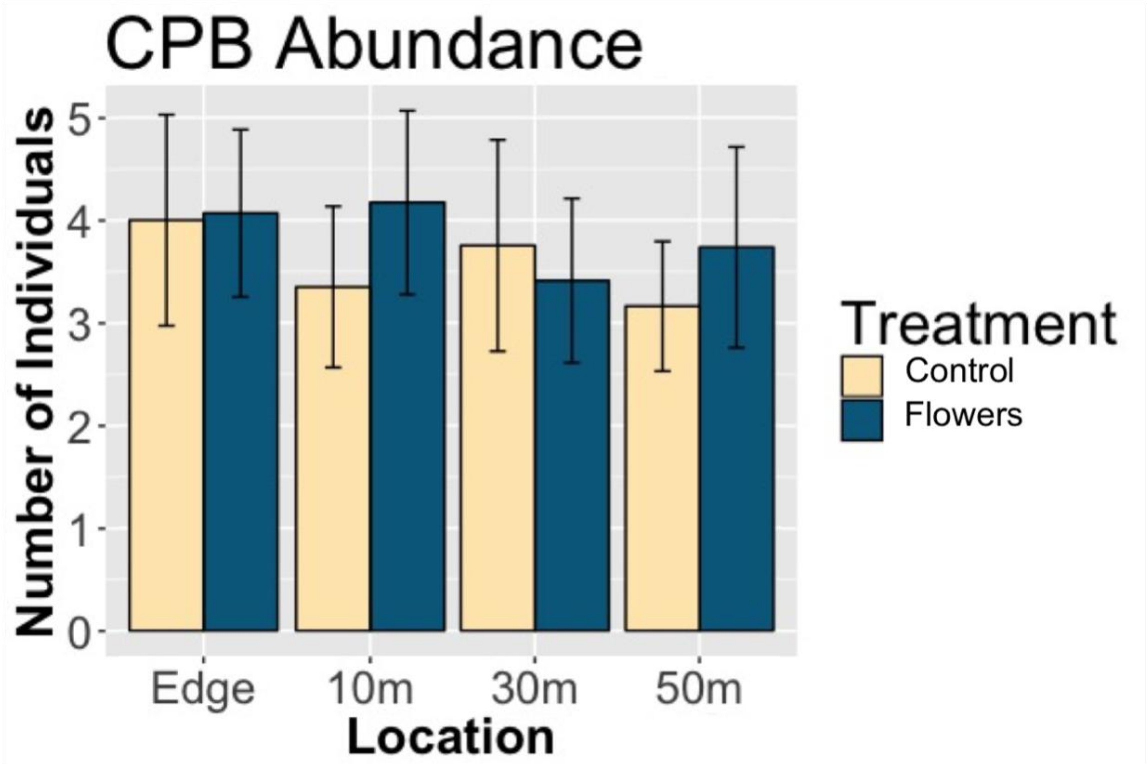

Figure 1. Colorado potato beetle abundance within potato fields by sampling location. Bars are average CPB abundance summed across all sampling dates, with +/- one standard error. No effect of treatment, but there is a marginally significant negative association with CPB abundance and increasing distance into the crop (p=0.055, z=-1.92)

Sentinel potato plants placed in the margins of fields planted with potatoes in 2018 attracted a total of 309 CPB adults across 5 weeks of monitoring. Potato plants in floral margins attracted a greater number of CPB adults on average than control margins (p=0.00039), with a total of 233 adults found in floral margins vs. 76 in control margins. However, this effect was largely due to a single floral margin, where almost half of the total number of CPB adults were found (150 adults). When this field was removed from the analysis, there was no significant effect of treatment (p=0.5962). Further study is needed to determine if this result is an anomaly, or indicative of floral plantings being a favorable overwintering location for CPB.

Objective 2) The response of CPB to the sentinel plants established in fields was extended over a period of time, consequently insecticide control would require multiple applications at trap crop locations to be effective. Given the propensity for this species to develop insecticide resistance, using trap crops to target insecticide application might not be the most beneficial control tactic. If larger establishments of trap crops could arrest beetle migration for a long enough period of time, this technique may work. Use of trap plants at at the edge of production fields is used in locations where length of season is long enough to utilize rapid sprouting varieties as trap plants. Unfortunately, MN potato production areas generally do not provide sufficient time prior to the emergence of the rest of the field (basically, many of the varieties used for 'rapid establishment' are those already in production in MN).

Conclusions

The presence of floral plantings did not result in a greater number of CPB being found in adjacent potato fields. Floral plantings did not change the timing of beele population development. Although one field's populations led to a difference in the number of beetles recovered on sentinel plants in floral plantings vs those in unmanaged margins, this may be an anomaly and simply reflected the number and distribution of overwintering CPB at that location. Further research is necessary to elucidate this factor. However, the lack of any difference in the overall number of adults within the potato fields regardless of margin type, floral or unmanaged, suggests that the presence of floral margins does not provide a benefit to Colorado Potato Beetles.

This, combined with our earlier work on the potential benefits provided by additional natural enemy populations, suggests that floral margins provide either a beneficial or neutral service to potato production fields.

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Management of Colorado Potato Beetle in Minnesota and North Dakota

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Executive Summary – This is a continuing project designed to develop and refine management tactics for Colorado Potato Beetles in Minnesota and North Dakota. This proposal will focus on assessing insecticide resistance of adult Colorado potato beetle in Minnesota and North Dakota to insecticides currently available in management. This information will assist in developing appropriate foliar management programs in anticipation of decreasing availability and/or efficacy of soil applied insecticides.

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

Populations of CPB in MN and ND show varying levels of resistance (MacRae, NPPGA & Area II Research reports 2012-2014, 2019) and reports of control failures and decreased efficacy with at least three neonicotinoid insecticides (imidacloprid, thiomethoxam and clothianidin) have been reported. This building resistance is not the only challenge to continued use of neonicotinoid insecticides. Regulatory issues also threaten their continued use. In 2016, a Governor's directive ordered increased regulation of neonicotinoids in Minnesota. The Environmental Protection Agency has scheduled reviews on the 4 most widely used neonicotinoids for 2018 based on data indicating the insecticide may be prone to leaching into ground-water systems (Goulson 2013, Hladik et al. 2014).

In central MN and in the RRV, we are beginning to see an extended emergence of adult beetles in the early spring. This is thought to be a behavioral form of resistance. The emerging beetles are susceptible to neonicotinoid insecticides and represent that portion of the susceptible population that is genetically programmed to emerge later in the season. If a beetle susceptible to neonicotinoid insecticides emerges early in the season into aq field treated at-plant with a neonic, they will die. However, later in the season, the titer of insecticide in plants will drop because the insecticide is starting to degrade and what is left is being diluted in plant material due to vegetative growth of the plant (Huseth & Groves 2010). Consequently, the use of neonic at-plant has selsected against early emerging susceptible CPB. The end result is that the later emerging adults mate and lay eggs later in the season, leading to the extended presence of eggs, larvae and adults into the mid season. This has changed the seasonal pattern of beetle presence and led to a greater reliance on foliar-applied CPB management later in the season.

Data from 2018 has indicated that in some locations, not only is their increasing tolerance of neonicotinoid insecticides but that tolerance of other modes of action is present at various locations. While CPB populations at many locations show reduced sensitivity to neonicotinoid insecticides, decreasing sensitivity to other insecticide modes of action is especially concerning.

If foliar management programs are to suppress CPB, the active ingredients incorporated in the product rotation must be effective. It is desirable that this is known prior to application. Consequently, information on the relative efficacy of the available insecticides is necessary to develop working insecticide programs. This project proposes to develop this efficacy database.

Methods - Colorado potato beetle adults were sampled from potato production areas within Minnesota and North Dakota. To adequately test each insecticide with adequate replication, approximately 1600-3000 beetles per location were required (unfortunately, this is actually easier than it sounds in most locations suffering insecticide failures…)

Sampled beetles were assessed for susceptibility to a representative registered insecticides; Abamectin, Tolfenpyrad, or Spinosad, depending on local reports of a lack of efficacy. The insecticides to be tested are specific to reports of potential failure received. Only single ai formulations were tested, this can be extrapolated to predict the resistance status of mixed products. Resistance / tolerance of CPB from each sampled area was assessed using direct exposure tests. Gradient concentrations of active ingredient (ai), the actual toxin in the insecticide, were used to determine how much insecticide was required to kill 50% of the population (i.e. the Lethal Dose 50% or 'LD_{50}'). Application involved applying 1 X 10µl (microliter) drop of insecticide directly to the insect using a microsyringe applicator (Fig 1). After the insecticide had dried, beetles were placed onto potato leaves in petrie plates and left to feed for 5-7 days (120h). Beetles were assessed at 24 to determine handling mortality. CPB often appear intoxicated immediately after exposure but recover after several days. Mortality was assessed 5-7 days post application (min. of 120h) to determine insecticide efficacy. Mortality was assessed by placing beetles on their backs and tapped with a small paint brush. Any insect not righting itself was assessed as dead or moribund. While this technique is time consuming and costly, it is the only mechanism whereby an insecticide failure can be attributed to insect tolerance of the chemical.

Figure 2. Microsyringe applicator; dispenses 10 microliters per button push.

Results & Discussion

Increased tolerance of insecticide by populations of Colorado Potato Beetle has been noted in a number of locations in both Minnesota and North Dakota (Table 1). We are starting to see 'rate creep' in a number of insecticide classes (i.e. insecticide classes are defined by their modes of action – the biological mechanism whereby an insecticide kills an insect). 'Rate creep' where it takes higher rates of an insecticide to achieve the same level of control as previous years. It generally happens slowly and is noticed after a couple of years of creep. It does, however, show up fairly clearly when looking at insecticide efficacy data for the same location over several years.

The data in Table 1 show a comparison to the high label rate of insecticide that was necessary to necessary to kill 50% the population of CPB at that location. Keeping in mind that most insecticides registered and labeled for controlling a population of insects is designed to provide 90%+ mortality at the high label rate, we can consider any value below 1X indicates the population of CPB being tested in susceptible to that insecticide. Values above 1X may still be susceptible but may indicate rate creep. Any values over 3X are problematic and indicate that population has developed a significant tolerance to that insecticide. Any values exceeding 10X indicate a well-developed resistance within that population to the insecticide being tested.

Decreased activity seen in western Wisconsin, and east central Minnesota do seem to be the result of developing resistance. High levels of resistance to Spinosad (the active ingredient in Spintor and Blackhawk) were found in two locations in east Minnesota, East Central (2018) and on the MN-WI border (2019). It is important to note that both of these locations were organic production and both had a multi-year of using only the Spinosad product Entrust (Corteva AgroScience, Indianapolis, IN). Control of CPB in organic production is, as can be imagined, very difficult and there are few OMRI registered insecticides that can effectively control CPB. Consequently, spinosyn products are heavily relied on. No other tolerance of Blackhawk or Spintor were noted in any other location in Mn or ND with the expcetion of the research plots at Crookston; this was due to a caged field trial to evaluating the within-field development of Blackhawk resistance, the bioassay results of which were included here.

Currently in Minnesota and North Dakota, not only is tolerance to neonicotinoids occurring in more locations than when we first started sampling 10 years ago, but we starting to see populations demonstrating tolerance to Avermectins (e.g. AgriMek, Reaper), Spinosyns (e.g. Entrust, Blackhawk, Spintor), and Anthranilic Diamides (e.g. Coragen). While neonicotinoids remain the major group showing increased resistance, rate creep is a warning bell that should be considered when making insecticide application decisions. As at-plant applied neonicotinoids become less effective in controlling early season CPB, beetle management will become increasingly reliant on foliar applied insecticide. Given we are witnessing potential development of lowered efficacy n a number of insecticide classes already, it is vitally important to adopt the tactic of rotating modes of action to preserve all the modes of action possible for future insect management.

Insecticide resistance is what is called ‘pre-adaptive’. There are certain individuals in the population that possess a gene that codes for a mechanism that either somehow allows the insect to survive exposure to a particular class of insecticide (Resistant Gene). Resistant Genes are usually not common, and the application of an insecticide starts to immediately kill off all the individuals that don’t possess that Resistant Gene. This leaves the insects that have the Resistant Gene to reproduce and form the future population, eventually all of whom will have that Resistant Gene. The result is that the insecticide will no longer control that population of insects.

Results in Table 1 that are higher than expected may reflect selection / sampling of individuals who have survived an application and therefore skew the sampled population to reflect a higher level of resistance than exists. The presence of tolerant individuals, however, still indicates the frequency of resistant genes are increasing in the population at that location.

Table 1. Resistance rates of Colorado potato beetles to registered insecticides sampled from locations in MN & ND in 2018-19. The resistance rate expressed here is the amount compared to high labeled rate of insecticide required to cause 50% mortality (LD_{50}) of the sampled population. Some locations listed were sampled in both 2018 and 2019. Values <1X indicate susceptibility to that insecticide. Values >1X may indicate developing tolerance. Values >3X indicate low levels of resistance. Values >10X indicate well-developed resistance.

Location	Product	Insecticide Group (grp. No.)	Resistance (X high label rate)	Location	Product	Insecticide Group (grp. No.)	Resistance (X high label rate)
Argyll	Abamectin (AgriMek)	Avermectins (6)	**0.12X**	***Hubbard***	Abamectin (AgriMek)	Avermectins (6)	**8X**
					Clothianidin (Belay)	Neonicotinoids (4A)	**1X**
					Thiomethoxam (Actara)	Neonicotinoids (4A)	**6X**
					Rynaxypyr (Coragen)	Anthranilic Diamides (28)	**2X**
					Spinosad (Blackhawk)	Spinosyns (5)	**1X**
Arvilla	Abamectin (AgriMek)	Avermectins (6)	**1X**	***Larimore***	Clothianidin (Belay)	Neonicotinoids (4A)	**9X**
	clothianidin (Belay)	Neonicotinoids (4A)	**1X**				
	Thiomethoxam (Actara)*	Neonicotinoids (4A)	**19X**				
	Rynaxypyr (Coragen)*	Anthranilic Diamides (28)	**21X**				
	Spinosad (Blackhawk)	Spinosyns (5)	**1X**				
	Tolfenpyrad (Torac)	METIs* (21)	**1.5X**				
Becker	Imidacloprid (Admire Pro)	Neonicotinoids (4A)	**23X**	***McCanna***	Imidacloprid (Admire Pro)	Neonicotinoids (4A)	**9X**
	Clothianidin (Belay)	Neonicotinoids (4A)	**113X**		Clothianidin (Belay)	Neonicotinoids (4A)	**45X**
	Spinosad (Blackhawk)	Spinosyns (5)	**1X**				
Bentru	Abamectin (AgriMek)	Avermectins (6)	**1X**	***Perham***	Abamectin (AgriMek)	Avermectins (6)	**0.3X**
	Spinosad (Blackhawk)	Spinosyns (5)	**1X**				
Big Lake	Abamectin (AgriMek)	Avermectins (6)	**3X**	***Rice***	Abamectin (AgriMek)	Avermectins (6)	**3X**
	Clothianidin (Belay)	Neonicotinoids (4A)	**7X**		Clothianidin (Belay)*	Neonicotinoids (4A)	**49X**
	Thiomethoxam (Actara)	Neonicotinoids (4A)	**6X**		Thiomethoxam (Actara)*	Neonicotinoids (4A)	**10X**
	Spinosad (Blackhawk)	Spinosyns (5)	**4X**		Rynaxypyr (Coragen)*	Anthranilic Diamides (28)	**1X****
					Spinosad (Blackhawk)	Spinosyns (5)	**1.5X**
Clearwater	Imidacloprid (Admire Pro)	Neonicotinoids (4A)	**27X**	***Sabeka***	Abamectin (AgriMek)	Avermectins (6)	**1X**
	Clothianidin (Belay)	Neonicotinoids (4A)	**60X**		Clothianidin (Belay)	Neonicotinoids (4A)	**1X**
	Abamectin (AgriMek)	Avermectins (6)	**1.5X**		Thiomethoxam (Actara)	Neonicotinoids (4A)	**2X**
					Spinosad (Blackhawk)	Spinosyns (5)	**28X**
Crookston	Abamectin (AgriMek)	Avermectins (6)	**1X**	***Sabin***	Imidacloprid (Admire Pro)	Neonicotinoids (4A)	**6X**
	Clothianidin (Belay)	Neonicotinoids (4A)	**1X**				
	Thiomethoxam (Actara)	Neonicotinoids (4A)	**4X**				
	Rynaxapyr (Coragen)	Anthranilic Diamides (28)	**1X**				
	Spinosad (Blackhawk)	Spinosyns (5)	**3X**				
Erskine	Thiomethoxam (Actara)	Neonicotinoids (4A)	**2X**	***Stillwater***	Spinosad (Entrust)	Spinosyns (5)	**10X**
Forest River	Imidacloprid (Admire Pro)	Neonicotinoids (4A)	**10X**	***Western WI***	Abamectin (AgriMek)	Avermectins (6)	**2X**
	Clothianidin (Belay)	Neonicotinoids (4A)	**37X**				

***METI = Mitochondrial Complex I Electron Transport Inhibitors**
****Updated from previous year higher rate of 24X (thought to be a result of handling mortality in 2018)**

Conclusions

Colorado Potato Beetles at several locations in Minnesota and North Dakota are continuing to develop tolerance to at least 3 different insecticide modes of action. Producers not yet rotating insecticides by class (mode of action) are recommended to do so. While we are quickly developing resistance to neonicotinoids in Minnesota and North Dakota, multiple other modes of foliar applied insecticides remain effective but resistance management for these chemistries should be initiated now to prevent their eventual loss.

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Annual Report - Managing PVY Vectors, 2019

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Executive Summary – This is a proposal to fund continuing research and outreach that expands and maintains an aphid trapping and monitoring network for aphid vectors of virus disease in potatoes (focusing on PVY) and provides near real-time maps of aphid population distribution in MN and ND. For 2018, pan traps will be discontinued and reliance solely on solar panels and discontinuation of batteries at several locations will be examined. A subset of this project will continue to maintain traps at the MN winter grow-out location in Waialua, HI and identify weekly samples provided from those traps. These sites will also serve as trial locations to develop and refine remote scouting methods for PVY. A new research project initiated this year will include refining optimum timing for vine-kill to avoid PVY infection which will provide the basis for a Specialty Crop Research Block to be submitted this winter to the Minnesota Dept. of Agriculture.

Rationale – The seed potato production regions of North America, are suffering an epidemic of aphid vectored, virus causing diseases such as Potato Leaf Roll (PLRV) and Potato Virus Y (PVY). PLRV is a non-persistent (circulative) virus, it has a latency period; the time from which the aphid acquires the virus from an infected plant to the time the aphid can then transmit the virus to a non-infected plant is anywhere from 12 to 72 hours. Consequently, PLRV is often transmitted by aphids that colonize potato (colonization by an aphid refers to a winged female depositing a daughter aphid which reproduces, resulting in the plant hosting a resulting population of aphids) and can be controlled by well-timed applications of traditional insecticides. Conversely, PVY is a non-persistent virus; the virus can be acquired by a vector from an infected plant and almost immediately transmitted to an uninfected plant. Consequently, PVY is often vectored by vector species which do not colonize potato. In fact, with regards to PVY transmission, the vector you don't see during scouting is often more important than the ones you find. A non-colonizing aphid species will fly into a potato field, probing plants to determine of they are appropriate host plants. If they are not appropriate hosts, the aphid will immediately probe the next plant. Having very tiny brains and little understanding of modern agriculture practices, aphids are, for the most part, unaware that the next plant in a crop field is the same species as the one they just probed. This process results in non-colonizing vector species spending short periods in each field, probing plants as they move across and eventually leave. Not only does this mean that any PVY inoculum, with its negligible latency period, will be readily moved from infected to non-infected plants, but the short residence time in the field also means that traditional insecticides will not have sufficient time to prevent the transfer of inoculum by the vector. Traditional insecticides, therefore, will not control the spread of PVY.

Certification programs in Minnesota and North Dakota are operationally excellent, but still face the challenge of flushing large amounts of virus-inoculum from the seed production system. This is an increasingly difficult proposition with Potato Virus Y (PVY). New virus strains with variable levels of expression, asymptomatic varieties that show no sign of the virus despite being infected, and a relatively new vector species have all combined to change the epidemiology of this viral disease. The ordinary (common) strain of PVY (PVY^o), present in all potato growing areas, causes mild to severe mosaic, leaf drop and leaf and stem necrosis. Of greater concern are the PVY^N (tobacco veinal necrosis strain, causing typical mosaic symptoms), PVY^{NTN} strains (causing potato tuber necrotic ringspot disease [PTNRD]), and

$PVY^{N\text{-}Wi}$ (the Wilga strain, which presents with mild and difficult to diagnose symptoms). In addition, varietal effects in the visible symptoms of different strains makes within-season diagnosis difficult.

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

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

Over the past several years, the network has provided not only timely information on aphid vector presence, but valuable information on the seasonal patterns of vector dynamics as well. For example, the majority of vector flight occurs starting in late July and through August, reflecting many of the non-colonizing species moving from senescing hosts (e.g. small grains) to seek alternate food sources. This late season flight of aphid vectors confirms what has been held for many years, that the majority of PVY infection occurs late in the growing season. Appropriately timed vine-kill could provide an excellent additional tactic to manage PVY spread. However, to be economically feasible, the timing of vine-kill would have to be optimized to balance any yield loss and disease management.

Over the past several years, the Aphid Alert Network has grown to provide region-wide coverage, estimating the aphid vector populations. The network relies on grower cooperators to maintain and change traps throughout the growing season and send weekly trap catches to the entomology lab at the University of Minnesota's Northwest Research & Outreach Center (NWROC). There the trap contents are sorted and aphid vector species identified and PVY Vector Risk Index values calculated. Results are distributed to seed producers weekly via various electronic media (NPPGA's Potato Bytes, the Aphid Alert blog, Twitter and email lists).

Objective 1) We propose to continue the Aphid Alert Network, providing potato producers with information on the regional distribution and densities of aphid vectors of virus disease and weekly assessments of PVY risk transmission at each trap location. Since 2014, the Aphid Alert network has provided excellent regional coverage of the Red River Valley seed producing area.

Objective 2) We will also develop best recommendations for the timing of vine-kill to minimize any yield loss while providing additional disease management.

Methods

Objective 1) Aphid Alert Trapping Network. A network of ~20 3m-tall suction traps was been established in the seed potato production areas of Minnesota and North Dakota. These traps consist of a fan drawing air down in through the trap and trapping the incoming aphids in a sample jar which is changed weekly by grower cooperators and sent to the UMN-NWROC entomology lab. Insects in the jars are sorted, aphids identified to species and aphid population dynamics at sample locations are determined. Maps are prepared weekly showing these dynamics. This information is made available to growers on two websites (aphidalert.blogspot.com and aphidalert.umn.edu), via NPPGA weekly email, linked to on the NDSU Potato Extension webpage (http://www.ag.ndsu.edu/potatoextension), and posted on the

AgDakota and Crops Consultants List Serves. Recommendations for beginning oil treatments or targeted edge applications can be made based on the information obtained from the regional monitoring system. Traps are established in early June and maintained until the seed field hosting the trap is vine-killed/harvested. At that point a field is no longer attractive to aphids. We will continue to operate the Aphid Alert suction trap network incorporating the PVY Vector Risk Index maps, developed in last year's funded project, into weekly reporting. Aphid species have differing levels of efficiency in their ability to transmit PVY. The PVY Vector Risk Index uses relative transmission efficacies of different aphid vector species to present the relative risk of disease transmission at each location.

Objective 2) Field and laboratory trials will be used to determine the optimal timing of vine-kill. Laboratory colonies of Green peach aphid will be established at the UMN-NWROC and greenhouse trials will be conducted to assess if there is an age effect on the susceptibility.

Prior to the growing season, potatoes will be raised in the greenhouse. Green peach aphids, as the most efficient vector of PVY, will be used to ensure the best chance of infection. Aphids will be fed first on PVY infected plants and then placed on replicated, non-infected potato plants of various ages. Infection of plants will be confirmed with either enzyme-linked immunosorbent assay (ELISA) or ELISA sticks. Rates of infection will be compared across plant age.

Field plots will established at the UMN-NWROC. At specific periods through the summer, multiple, replicated groups of potato plants will be caged and viruliferous aphids (i.e. carrying virus) from lab colonies will be introduced to each cage. After 3 days, cages will be treated with insecticides to kill all aphids and the cages removed to prevent differential growing conditions within the experiment. Equal replications of a subset of infected plants from cages and non-infected plants will be vine-killed after aphid kill. All plants will be tested for PVY infection and harvested at the end of the season and yield components assessed. The economics and timing of vine-killed will be assessed to derive an optimal balance between economic return and disease management.

Appropriate steps will be taken to limit any potential escape and spread in the region of green peach aphids. All lab colonies and trials will be maintained in double containment (i.e. in cages within growth chambers and greenhouse). Winged aphids within source colonies will be destroyed as they develop. Only wingless aphids will be used in all trials and field cages treated 3 days post aphid introduction with insecticides known to be effective against aphids.

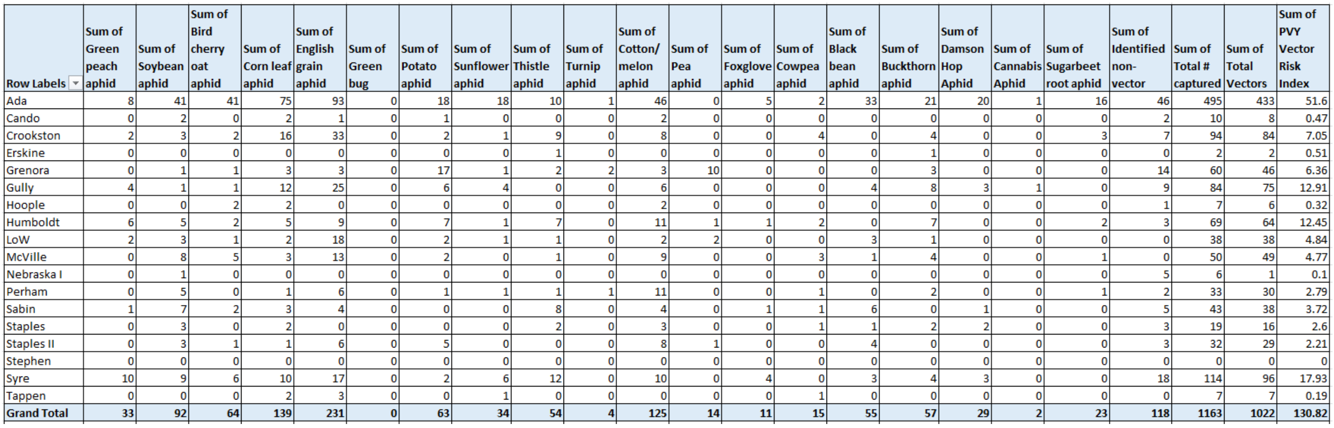
Results

Objective 1) The 2019 growing season had what would be considered moderate aphid vector populations (Table 1). To put it in perspective to the last two years, 2019 trap catches exceeding those of 2018 but still well under the vector levels seen in 2017 (Table 2). These population numbers were reflected by the increased PVY Vector Risk Index of 2019 compared to that of 2018. This would indicate there is potential for levels of PVY to be higher in 2019 than they were in 2018 (Figs 1 & 2).

Seasonal presence of aphid vectors was slower to develop than most years, populations began to rise quickly in mid-August and then dropped quickly (Fig 3). This is not surprising; wheat maturation and harvest was late in 2019 and a significant portion of the mid-August trap catches were cereal aphids. Small grains mature, dry and become less desirable as a host, aphid populations will develop a winged generation and disperse to whatever green, potential hosts are still available (e.g. potatoes). A total of 1022 aphid vectors were recovered from the traps in 2019, some of which serious PVY vectors; E.G. 33 Green peach aphids (the most efficient vector of PVY), 139 corn leaf aphids, 231 English grain aphids and a 125 cotton/melon aphids. All of this influenced the higher PVY Vector Risk Index of 2019 over that of 2018.

Detailed weekly results were distributed in 2019 via the Aphid Alert blog (aphidalert.blogspot.com) (Fig 4), with weekly summaries being disseminated via ListServe emails and Twitter (#MNSpudBug).

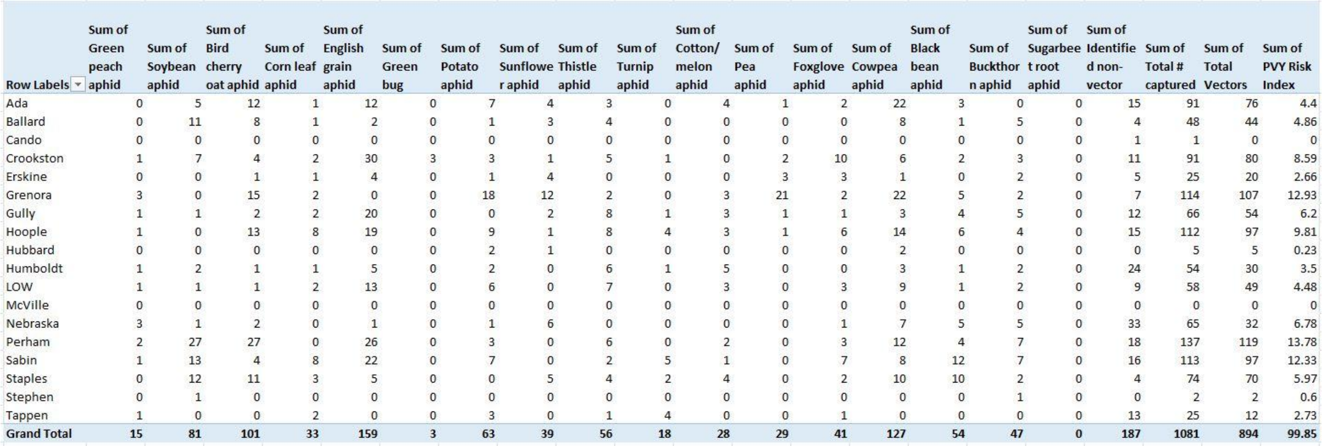
Table 1. Cumulative Seasonal Aphid Species Capture and PVY Vector Risk Index for each trap location in 2019.



Row Labels	Sum of Green peach aphid	Sum of Soybean aphid	Sum of Bird cherry oat aphid	Sum of Corn leaf aphid	Sum of English grain aphid	Sum of Green bug	Sum of Potato aphid	Sum of Sunflower aphid	Sum of Thistle aphid	Sum of Turnip aphid	Sum of Cotton/ melon aphid	Sum of Pea aphid	Sum of Foxglove aphid	Sum of Cowpea aphid	Sum of Black bean aphid	Sum of Buckthorn aphid	Sum of Damson Hop Aphid	Sum of Cannabis Aphid	Sum of Sugarbeet root aphid	Sum of Identified non-vector	Sum of Total # captured	Sum of Total Vectors	Sum of PVY Vector Risk Index
Ada	8	41	41	75	93	0	18	18	10	1	46	0	5	2	33	21	20	1	16	46	495	433	51.6
Cando	0	2	0	2	1	0	1	0	0	0	2	0	0	0	0	0	0	0	0	2	10	8	0.47
Crookston	2	3	2	16	33	0	2	1	9	0	8	0	0	4	0	4	0	0	3	7	94	84	7.05
Erskine	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	2	2	0.51
Grenora	0	1	1	3	3	0	17	1	2	2	3	10	0	0	0	3	0	0	0	14	60	46	6.36
Gully	4	1	1	12	25	0	6	4	0	0	6	0	0	0	4	8	3	1	0	9	84	75	12.91
Hoople	0	0	2	2	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	1	7	6	0.32
Humboldt	6	5	2	5	9	0	7	1	7	0	11	1	1	2	0	7	0	0	2	3	69	64	12.45
LoW	2	3	1	2	18	0	2	1	1	0	2	2	0	0	3	1	0	0	0	0	38	38	4.84
McVille	0	8	5	3	13	0	2	0	1	0	9	0	0	3	1	4	0	0	1	0	50	49	4.77
Nebraska I	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	6	1	0.1
Perham	0	5	0	1	6	0	1	1	1	1	11	0	0	1	0	2	0	0	1	2	33	30	2.79
Sabin	1	7	2	3	4	0	0	0	8	0	4	0	1	1	6	0	1	0	0	5	43	38	3.72
Staples	0	3	0	2	0	0	0	0	2	0	3	0	0	1	1	2	2	0	0	3	19	16	2.6
Staples II	0	3	1	1	6	0	5	0	0	0	8	1	0	0	4	0	0	0	0	3	32	29	2.21
Stephen	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Syre	10	9	6	10	17	0	2	6	12	0	10	0	4	0	3	4	3	0	0	18	114	96	17.93
Tappen	0	0	0	2	3	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	7	7	0.19
Grand Total	**33**	**92**	**64**	**139**	**231**	**0**	**63**	**34**	**54**	**4**	**125**	**14**	**11**	**15**	**55**	**57**	**29**	**2**	**23**	**118**	**1163**	**1022**	**130.82**

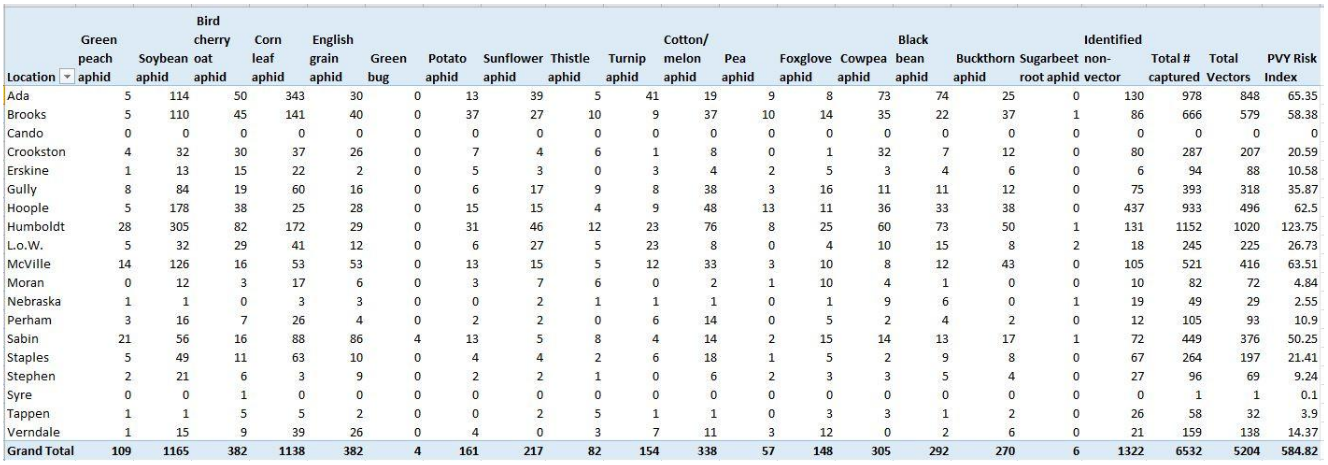
Table 2 Cumulative Seasonal Aphid Species Capture and PVY Risk Index for each trap location in 2018 (A) and 2017 (B).

A - 2018



Row Labels	Sum of Green peach aphid	Sum of Soybean aphid	Sum of Bird cherry oat aphid	Sum of Corn leaf aphid	Sum of English grain aphid	Sum of Green bug	Sum of Potato aphid	Sum of Sunflower aphid	Sum of Thistle aphid	Sum of Turnip aphid	Sum of Cotton/ melon aphid	Sum of Pea aphid	Sum of Foxglove aphid	Sum of Cowpea aphid	Sum of Black bean aphid	Sum of Buckthorn aphid	Sum of Sugarbeet root aphid	Sum of Identified non-vector	Sum of Total # captured	Sum of Total Vectors	Sum of PVY Risk Index
Ada	0	5	12	1	12	0	7	4	3	0	4	1	2	22	3	0	0	15	91	76	4.4
Ballard	0	11	8	1	2	0	1	3	4	0	0	0	0	8	1	5	0	4	48	44	4.86
Cando	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0
Crookston	1	7	4	2	30	3	3	1	5	1	0	2	10	6	2	3	0	11	91	80	8.59
Erskine	0	0	1	1	4	0	1	4	0	0	0	3	3	1	0	2	0	5	25	20	2.66
Grenora	3	0	15	2	0	0	18	12	2	0	3	21	2	22	5	2	0	7	114	107	12.93
Gully	1	1	2	2	20	0	0	2	8	1	3	1	1	3	4	5	0	12	66	54	6.2
Hoople	1	0	13	8	19	0	9	1	8	4	3	1	6	14	6	4	0	15	112	97	9.81
Hubbard	0	0	0	0	0	0	2	1	0	0	0	0	0	2	0	0	0	0	5	5	0.23
Humboldt	1	2	1	1	5	0	2	0	6	1	5	0	0	3	1	2	0	24	54	30	3.5
LOW	1	1	1	2	13	0	6	0	7	0	3	0	3	9	1	2	0	9	58	49	4.48
McVille	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nebraska	3	1	2	0	1	0	1	6	0	0	0	0	1	7	5	5	0	33	65	32	6.78
Perham	2	27	27	0	26	0	3	0	6	0	2	0	3	12	4	7	0	18	137	119	13.78
Sabin	1	13	4	8	22	0	7	0	2	5	1	0	7	8	12	7	0	16	113	97	12.33
Staples	0	12	11	3	5	0	0	5	4	2	4	0	2	10	10	2	0	4	74	70	5.97
Stephen	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	2	2	0.6
Tappen	1	0	0	2	0	0	3	0	1	4	0	0	1	0	0	0	0	13	25	12	2.73
Grand Total	**15**	**81**	**101**	**33**	**159**	**3**	**63**	**39**	**56**	**18**	**28**	**29**	**41**	**127**	**54**	**47**	**0**	**187**	**1081**	**894**	**99.85**

B - 2017



Location	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	Foxglove aphid	Cowpea aphid	Black bean aphid	Buckthorn aphid	Sugarbeet root aphid	Identified non-vector	Total # captured	Total Vectors	PVY Risk Index
Ada	5	114	50	343	30	0	13	39	5	41	19	9	8	73	74	25	0	130	978	848	65.35
Brooks	5	110	45	141	40	0	37	27	10	9	37	10	14	35	22	37	1	86	666	579	58.38
Cando	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Crookston	4	32	30	37	26	0	7	4	6	1	8	0	1	32	7	12	0	80	287	207	20.59
Erskine	1	13	15	22	2	0	5	3	0	3	4	2	5	3	4	6	0	6	94	88	10.58
Gully	8	84	19	60	16	0	6	17	9	8	38	3	16	11	11	12	0	75	393	318	35.87
Hoople	5	178	38	25	28	0	15	15	4	9	48	13	11	36	33	38	0	437	933	496	62.5
Humboldt	28	305	82	172	29	0	31	46	12	23	76	8	25	60	73	50	1	131	1152	1020	123.75
L.o.W.	5	32	29	41	12	0	6	27	5	23	8	0	4	10	15	8	2	18	245	225	26.73
McVille	14	126	16	53	53	0	13	15	5	12	33	3	10	8	12	43	0	105	521	416	63.51
Moran	0	12	3	17	6	0	3	7	6	0	2	1	10	4	1	0	0	10	82	72	4.84
Nebraska	1	1	0	3	3	0	0	2	1	1	1	0	1	9	6	0	1	19	49	29	2.55
Perham	3	16	7	26	4	0	2	2	0	6	14	0	5	2	4	2	0	12	105	93	10.9
Sabin	21	56	16	88	86	4	13	5	8	4	14	2	15	14	13	17	1	72	449	376	50.25
Staples	5	49	11	63	10	0	4	4	2	6	18	1	5	2	9	8	0	67	264	197	21.41
Stephen	2	21	6	3	9	0	2	2	1	0	6	2	3	3	5	4	0	27	96	69	9.24
Syre	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0.1
Tappen	1	1	5	5	2	0	0	2	5	1	1	0	3	3	1	2	0	26	58	32	3.9
Verndale	1	15	9	39	26	0	4	0	3	7	11	3	12	0	2	6	0	21	159	138	14.37
Grand Total	**109**	**1165**	**382**	**1138**	**382**	**4**	**161**	**217**	**82**	**154**	**338**	**57**	**148**	**305**	**292**	**270**	**6**	**1322**	**6532**	**5204**	**584.82**

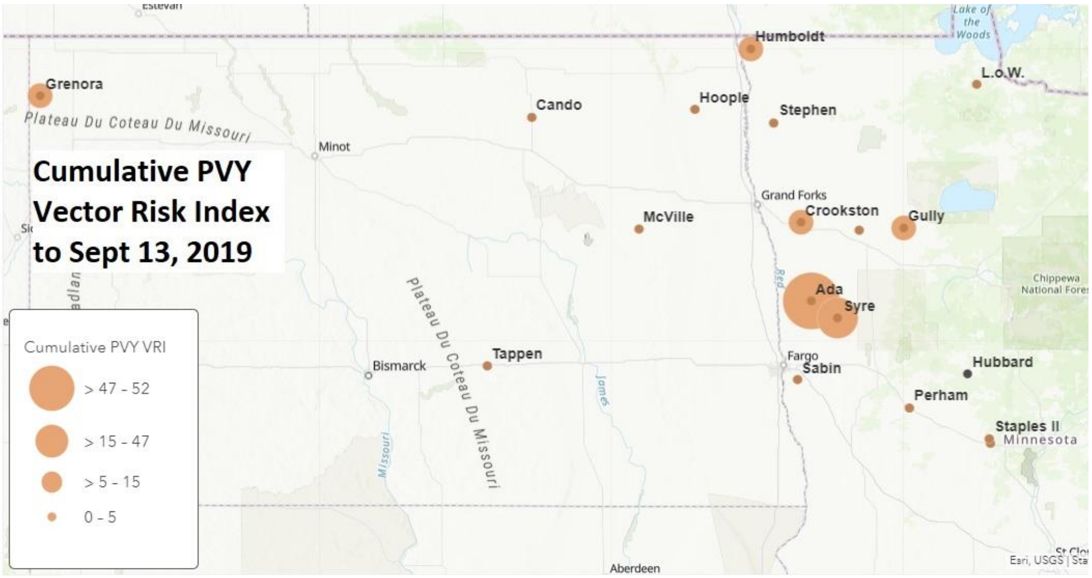


Figure 1. Cumulative PVY Vector Risk Index to September 13, 2019 (end of the monitoring season for 2019). Relative size of the circle indicates the cumulative seasonal PVY Risk Index at that location.

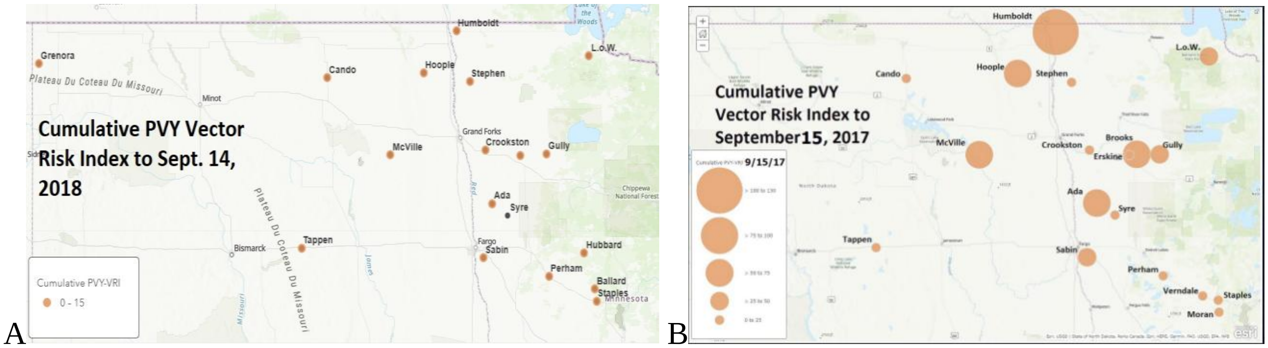


Figure 2. Cumulative Seasonal PVY Vector Risk Index for 2018 (A) and 2017 (B). Relative size of the circle indicates the cumulative seasonal PVY Risk Index at that location.

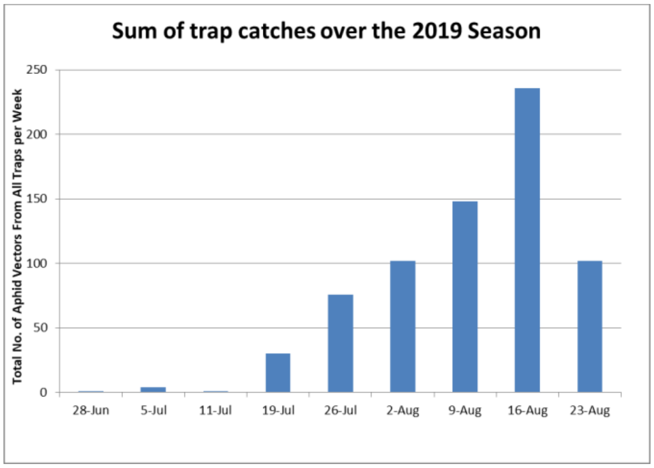
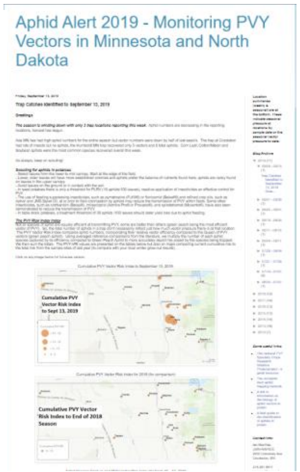


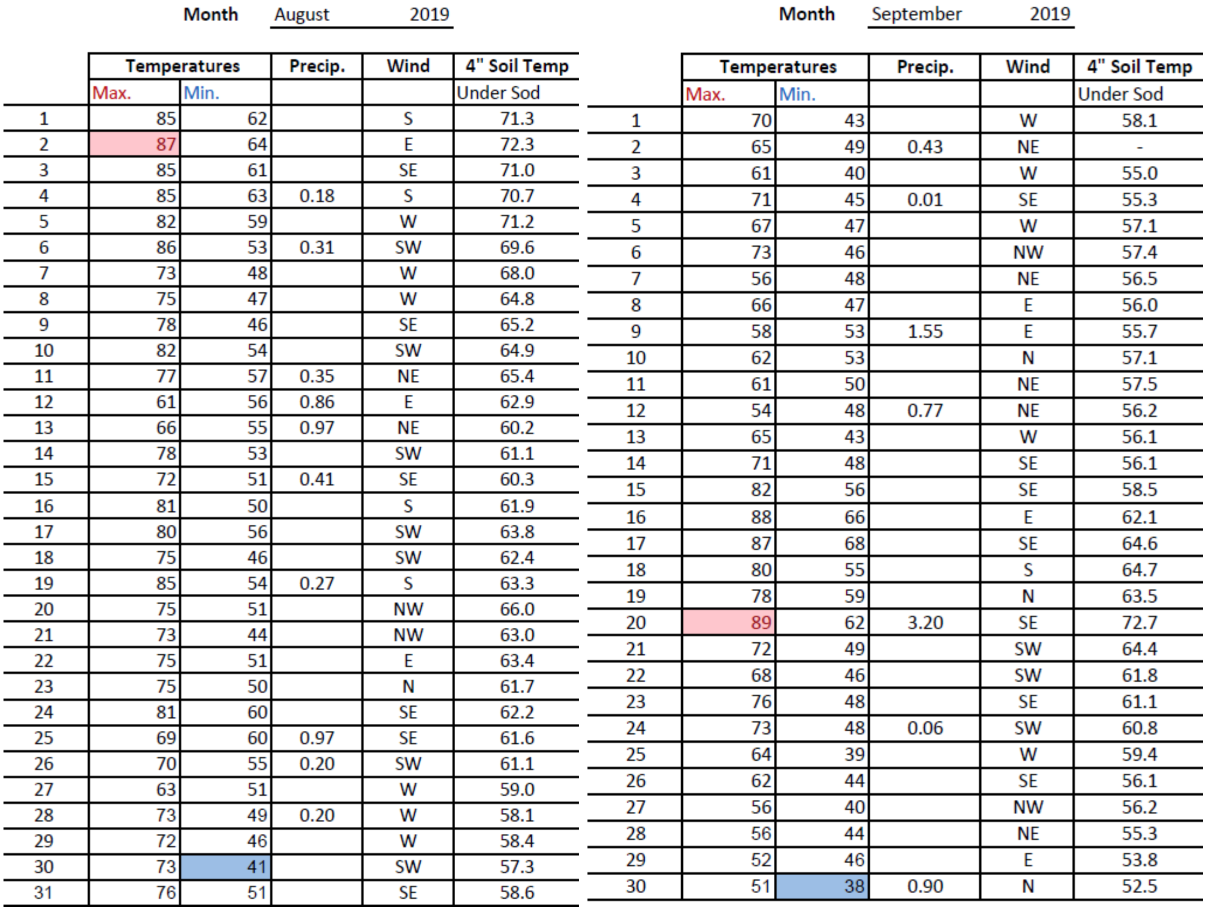
Figure 3. Weekly sum of trap catches across all locations, 2019.

Figure 4. The Aphid Alert Blog, available at aphidalert.blogspot.com, is maintained to deliver seasonal vector population data via the Internet. Weekly summaries were also delivered via List Serve emails and via Twitter (#MNSpudBug)also made available via the NDSU potato List Serve and via Twitter (#MNSpudBug)


Aphid Alert 2019 - Monitoring PVY Vectors in Minnesota and North Dakota

Objective 2) Attempts to establish a laboratory colony of Green peach aphid were frustrated by a slow start to population growth and an accidental exposure to an insecticide application in a neighboring greenhouse bay. Additional aphids were obtained in August from another source.

Field plots were established at the NWROC in Crookston, cages were placed in to plots and seeded with aphids green peach obtained late in the summer. Initial vine kill was delayed in the last week of August due to weather (Fig 5). The second vine kill date (the following week) was also delayed due to rain (Fig 5). Successive rainfall continued to prevent the application of dessicant. Continuous rain through September and October, and eventual development of cold weather in October resulted in the experiment having to be abandoned.



Month August 2019

	Temperatures		Precip.	Wind	4" Soil Temp
	Max.	Min.			Under Sod
1	85	62		S	71.3
2	87	64		E	72.3
3	85	61		SE	71.0
4	85	63	0.18	S	70.7
5	82	59		W	71.2
6	86	53	0.31	SW	69.6
7	73	48		W	68.0
8	75	47		W	64.8
9	78	46		SE	65.2
10	82	54		SW	64.9
11	77	57	0.35	NE	65.4
12	61	56	0.86	E	62.9
13	66	55	0.97	NE	60.2
14	78	53		SW	61.1
15	72	51	0.41	SE	60.3
16	81	50		S	61.9
17	80	56		SW	63.8
18	75	46		SW	62.4
19	85	54	0.27	S	63.3
20	75	51		NW	66.0
21	73	44		NW	63.0
22	75	51		E	63.4
23	75	50		N	61.7
24	81	60		SE	62.2
25	69	60	0.97	SE	61.6
26	70	55	0.20	SW	61.1
27	63	51		W	59.0
28	73	49	0.20	W	58.1
29	72	46		W	58.4
30	73	41		SW	57.3
31	76	51		SE	58.6

Month September 2019

	Temperatures		Precip.	Wind	4" Soil Temp
	Max.	Min.			Under Sod
1	70	43		W	58.1
2	65	49	0.43	NE	-
3	61	40		W	55.0
4	71	45	0.01	SE	55.3
5	67	47		W	57.1
6	73	46		NW	57.4
7	56	48		NE	56.5
8	66	47		E	56.0
9	58	53	1.55	E	55.7
10	62	53		N	57.1
11	61	50		NE	57.5
12	54	48	0.77	NE	56.2
13	65	43		W	56.1
14	71	48		SE	56.1
15	82	56		SE	58.5
16	88	66		E	62.1
17	87	68		SE	64.6
18	80	55		S	64.7
19	78	59		N	63.5
20	89	62	3.20	SE	72.7
21	72	49		SW	64.4
22	68	46		SW	61.8
23	76	48		SE	61.1
24	73	48	0.06	SW	60.8
25	64	39		W	59.4
26	62	44		SE	56.1
27	56	40		NW	56.2
28	56	44		NE	55.3
29	52	46		E	53.8
30	51	38	0.90	N	52.5

Figure 5. Weather data for the NWROC, Crookston, MN for August and September, 2019.

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Carryover of imazamox in soil of potato fields

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Executive Summary

Herbicide injury to potato plants is a common concern in potato production because of the high value of potatoes and the sensitivity of potatoes other herbicides. Herbicide injury commonly occurs from soil carryover, drift from nearby herbicide treatment and from residues carried over in seed. One of the common herbicides that is used in dry bean production prior to potato is imazamox. The purpose of this project is to evaluate the effects of imazamox carryover in soil on potato growth, development and tuber yield.

Rationale for conducting the research

Recently, potato growers have concerns that imazamox carryover in soil is affecting potato plant growth and production, even when following current herbicide labelled directions for plant back. Evidence of this comes from visual and aerial images showing plants taking longer to close rows, and reduced yields. However, the Raptor (imazamox) label states that the minimum interval before planting potatoes is 9 months if there was >18 inches of rain plus irrigation and the soil pH is >6.2. However, if there was <18 inches of rain plus irrigation or the soil pH is <6.2 then an 18-month interval between imazamox application and plant potatoes must occur.

Imidazolinone herbicides are broken in the soil by microbes. Warm, moist soils increase microbial activity, that in turn increases herbicide degradation. Degradation of imidazolinone herbicides will increase in soils with pH higher than 6.5. When soil pH is less than 6.5 or in dry soil, herbicide molecules are strongly bound to OM and become available to plants at a later time (even years later). At soil pH values higher than 6.5, the herbicide molecules are available for plants uptake, thus they do not persist in the soil.

The effects of soil carryover of imazamox on potato has varied in published reports. In one study, Russet Burbank potato following imazamox treatments or 4, 8 or 16 oz/a did not have any injury or yield loss (Greenland 2003). The best explanation of why no injury or yield loss was observed was because the soil pH was 7.7, promoting the rapid dissipation of imazamox. However, this study was not repeated. In another study that planted the cultivar Norchip, O’Sullivan et al. (1998) estimated 5% visual injury at 6 weeks after planting and an 8 to 23% yield loss compared to the non-treated check. The imazamox was applied the previous year at 4 oz/a and the soil pH was 7.0. Although the soil pH at 7.0 should have promoted the dissipation of imazamox, the amount of rainfall and irrigation is unknown. It is unknown if potato cultivars vary in their susceptibility to imazamox. From current grower experiences and because of contradicting results in potato, the need for further work in potato and in various potato cultivars must be conducted. The objective of this study is to determine the effect of soil carryover imazamox on plant growth and reproduction of various potato cultivars. We hope to determine if there are some cultivars that are less susceptible to low amounts of imazamox soil residual.

Procedures

A study was conducted near Menahga, Minnesota in 2018-2019 to determine the carryover potential of imazamox in the soil. A randomized complete block design with four replicates was utilized. Plots measured 30 x 70 feet with a 5-foot border between plots. On September 5, 2018 imazamox treatments were applied with a 30-foot boom attached to an all-terrain vehicle setup for plot spraying. Imazamox was applied at 0, 1, 2, 4 and 8 oz/a. Following herbicide application, the north half of each plot received a metam-sodium treatment in October 2018. The plots were tilled that fall and the following spring. Russet Burbank and Umatilla Russet whole seed (2-3 oz) were planted on May 10, 2019 and harvested on September 20, 2019. Seed pieces were planted in 36 in wide rows with 12 inch within-row spacing. Growth and management were done according to recommend university practices. Measurements included plant stand, plant height (from the soil surface to tallest leaf), stem count, pre-harvest and 20 ft of row were harvested and graded.

Results

Vapam (metam sodium) treatments did not influence any post-harvest yield parameters. Although, we noticed plant growth differences in late June and early July, with plants not closing raw as fast as non-Vapam treated soil (Figures 1 and 2). It seemed that the fumigation likely helped the plants later in the season over the effects of early die. If this study were repeated again, it would be better to test this in a virgin potato field.

Because no differences were found between fumigated and non-fumigated, these plots were combined. Differences from the imazamox treatments were found (Tables 1 to 4). In Russet Burbank yields were lowest from the 4 oz/a imazamox treatment, while the highest yields were from the 8 oz/a imazamox treatment (Tables 1 and 2). Differences in tuber number show that the 4 and 8 oz/a imazamox treatments resulted in a reduced number of tubers for total yield, resulting in a higher percentage of tubers >6 and >10 oz for the 8 oz/a imazamox treatment. For Umatilla Russet differences from imazamox treatment were observed (Tables 3 and 4). The 8 oz/a imazamox treatment caused the most differences in yield, with a shift of lower cwt and tuber number for tubers <4 oz and a numerically higher number of tubers >10 oz. Total yield was the lowest from the 8 oz/a imazamox treatment as was tuber number. The 4 and 8 oz/a imazamox treatment had some effects on Russet Burbank and Umatilla russet yield parameters. It seems that tuber set was more limiting, resulting in fewer smaller tubers and more larger tubers that resulted in a higher percentage of tubers >6 oz.

Figure 1. Row closure was normal following 1 oz/a imazamox treatment the previous year on June 28, 2019 near Menahga, MN.

Figure 2. Row closure delay following soil carryover of 8 oz/a imazamox treatment. The back half of the plot was treated with metam-sodium. Picture taken on June 28, 2019 near Menahga, MN.

Table 1. Effects of soil carryover imazamox on Russet Burbank graded yield near Park Rapids, MN.

Cultivar	**Imazamox**	**<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**
	fl oz/a	cwt/a									%	
Russet Burbank	0	106 ab	150 ab	187 ab	84 ab	21 b	548 ab	442 ab	428 ab	14	53 b	19 b
Russet Burbank	1	130 a	172 a	178 b	46 c	19 b	545 ab	415 b	397 ab	18	44 b	12 b
Russet Burbank	2	125 a	151 a	199 ab	68 bc	33 ab	576 ab	451 ab	428 ab	23	52 b	17 b
Russet Burbank	4	98 ab	134 ab	176 b	58 bc	23 b	488 b	391 b	378 b	13	54 b	18 b
Russet Burbank	8	72 b	111 b	215 a	111 a	53 a	562 a	490 a	461 a	29	68 a	29 a

Table 2. Effects of soil carryover imazamox on Russet Burbank tuber number near Park Rapids, MN.

Cultivar	**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**
	fl oz/a	tuber number/a									%	
Russet Burbank	0	63,616 a	48,642 a	39,023 ab	11,616 ab	2,178 b	165,074 ab	101,459	98,918	2,541 b	33	9 b
Russet Burbank	1	76,049 a	55,902 a	38,297 ab	6,534 c	1,815 b	178,596 a	102,548	98,464	4,084 b	26	5 b
Russet Burbank	2	73,780 a	49,187 a	41,927 ab	9,347 bc	3,267 ab	177,507 a	103,727	99,644	4,084 b	32	7 b
Russet Burbank	4	57,173 ab	43,560 ab	37,208 b	7,805 c	2,360 b	148,104 b	90,932	88,754	2,178 b	35	8 b
Russet Burbank	8	42,380 b	35,483 b	44,921 a	15,337 a	4,810 a	142,931 b	100,551	96,195	4,356 a	46	14 a

Table 3. Effects of soil carryover imazamox on Umatilla Russet graded yield near Park Rapids, MN.

Cultivar	**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**
	fl oz/a	cwt/a									%	
Umatilla Russet	0	177 a	178 a	156	52 ab	14	577 a	400	393	6 b	38 c	11 b
Umatilla Russet	1	157 ab	172 ab	159	40 b	11	538 ab	381	370	12 b	39 c	9 b
Umatilla Russet	2	167 a	169 ab	167	48 ab	17	568 ab	400	389	11 b	41 bc	12 b
Umatilla Russet	4	128 bc	142 b	163	66 a	23	521 ab	394	381	12 ab	49 a	17 a
Umatilla Russet	8	113 c	149 ab	166	49 ab	17	493 b	380	361	20 a	47 ab	13 ab

Table 4. Effects of soil carryover imazamox on Umatilla Russet tuber number near Park Rapids, MN.

Cultivar	**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**
	fl oz/a	tuber number/a									%	
Umatilla Russet	0	107,448 a	58,897 a	33,850	7,260 b	1,452	208,907 a	101,459	100,097	1,361 b	21 b	4 b
Umatilla Russet	1	96,014 ab	56,356 ab	34,576	5,536 ab	998	193,479 ab	97,466	95,106	2,360 b	22 b	3 b
Umatilla Russet	2	104,000 a	54,995 ab	35,846	6,716 ab	1,634	203,189 a	99,190	97,103	2,087 b	22 b	4 b
Umatilla Russet	4	77,954 bc	46,192 b	34,485	8,984 a	2,178	169,793 bc	91,839	89,570	2,269 b	28 a	7 a
Umatilla Russet	8	70,150 c	48,551 ab	35,302	6,806 ab	1,634	162,443 c	92,293	88,028	4,265 a	27 a	5 ab

Evaluation of Fresh Potato Cultivars in the Field and Storage

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Executive summary

A continual demand for yellow-skinned fresh potatoes has caused most fresh growers and pack sheds to include yellow potatoes in their production. However, skin quality and storability of yellow-skinned potatoes has been poor and there is exists the need for specific information on field and storage performance of yellow cultivars. In 2019 we planted 30 yellow-skinned cultivars. 2019 was a good year to test the durability of these potato cultivars or advanced selections in a dry summer. Total yield varied greatly from 81 to over 200 cwt/a. There are some promising cultivars that we are still evaluating for pressure bruise and sprouting.

Rationale for conducting the research

As consumption of yellow-skinned potato cultivars continues to increase, so has the demand for high-quality yellow potatoes enlarged. The challenge has been that most yellow-skinned cultivars come from out-of-state locations and were not bred for a North Dakota/Minnesota environment. An example is some European cultivars tend to express heat-stress in tubers by chaining tubers or causing dumbbell or pointed tubers when they are grown in our environment (the European environment is typically cooler). Additionally, storing and handling potatoes is may be different than red-skinned cultivars.

A number of potato growers and pack sheds have expressed to The Extension Potato Agronomist the need for more research on yellow potatoes. Problems they encounter are skin-blemishes, such as lenticel spot, bruising or malformed tubers. Storage of yellow potatoes also is difficult as many cultivars have a short dormancy increasing pressure bruising and causing the need for sprout control. What is needed is information on what yellow-skinned cultivars store well and have a high pack out percentage as US #1 tubers.

Procedures

In 2019, a trial was conducted to identify traits of yellow-skinned potato cultivars and advanced selections at Hoople, N.D. Thirty yellow-skinned cultivars were evaluated. Plots were established in a commercial, non-irrigated potato field utilizing common potato-production practices. Prior to planting, urea at 120 pounds of nitrogen (N) per acre was broadcast and incorporated. A randomized complete block design was utilized. Seed tubers were hand cut to approximately 2-ounce seed pieces prior to planting. Tubers were planted on May 31, 2019, in rows that were spaced 38 inches apart. Plots were 6.3 feet wide and 20 feet long. Vines were desiccated on September 8 and 13 with diquat. About two-thirds of the yellow-skinned potatoes were harvested on Oct. 8 and the remainder were harvested on Oct. 25. Because of the challenges with harvesting the yellow-skinned tubers, specific gravity average is shown only for plots harvested on Oct. 8 and is not analyzed statistically. After harvest, potatoes were stored at 55 °F until grading. The tuber size profile distribution was determined by sorting potatoes into C size (less than 1.875 inches), B size (1.875 to 2.25 inches), A size (2.25 to 3.5 inches), and Chef size (greater than 3.5 inches). Total yield is a summation of C + B + A + Chef.

Results

The yield response of the cultivars varied greatly. Some had higher percentages of small tubers while others had higher percentages of larger tubers. Some of the lower yielding cultivars tended to have sticky stolons as they were not matured at harvest time. This may have been a result of the dry summer and plants not wanting to produce tubers until the late summertime. There were many statistical differences found amongst the cultivars tested (Table 1). For a more information on this and a red-skinned trial please see "North Dakota Fresh Market Potato Cultivar/Selection Trial Results for 2019" at https://www.ag.ndsu.edu/publications/crops/north-dakota-fresh-market-potato-cultivar-selection-trial-results-for-2019/a7183.pdf

Table 2. Agronomic performance and graded yield of yellow-skinned potato cultivars/selections, Hoople, ND, 2019.

Cultivar/Selection	**Stand**[1]	**Stems/plant**[2]	**Vine length**[3]	**Vigor**[4]	**C**[5]	**B**	**A**	**Chef**	**Total yield**	**Specific gravity**[6]
	plants/a	**number**	**cm**		**cwt/a**					
A00286-3Y	11,921	3.9	77	5	5	77	50	0	132	1.063
A06336-2Y	9,514	4.2	67	4	13	81	22	0	116	1.077
A06336-5Y	10,775	4.7	61	3	8	72	17	0	98	1.071
AC10376-1W/Y	10,546	3.1	57	4	5	70	36	0	110	1.074
Actrice	12,495	4	68	3	3	37	124	4	168	1.074
Agata	12,265	5.5	70	3	4	76	111	2	193	1.072
Alegria	11,692	4.2	71	4	3	51	73	4	132	1.072
Arizona	11,807	6.1	69	4	5	68	125	9	206	1.067
Belmonda	7,565	3.4	69	4	7	71	32	0	110	1.064
CO05037-3W/Y	9,858	4	62	2	6	70	43	0	118	1.077
CO10064-1W/Y	12,495	4.5	65	5	6	78	43	0	127	1.080
Crop 49	9,743	4.4	72	3	4	45	35	0	84	1.071
Crop 56	11,348	5.4	85	5	10	100	12	0	122	1.078
Crop 58	11,463	4.3	68	4	3	62	94	2	162	1.076
Crop 80	9,514	4.8	87	4	13	75	43	0	131	1.073
Electra	11,348	4.9	83	5	5	94	50	0	149	1.062
Fioretta	11,921	5.2	71	4	3	124	68	0	196	1.065
Jelly	13,870	4.4	80	5	3	61	55	0	119	1.070
Lanorma	11,807	3.6	86	5	1	55	100	1	157	1.062
Mariola	10,431	4.5	75	3	2	41	82	4	128	1.060
Melody	11,692	3.1	89	4	4	44	33	0	81	1.060
Milva	11,348	3.7	72	4	4	72	114	4	193	1.073
Montreal	13,297	4.8	63	4	3	97	112	0	212	1.066
MST252-1Y	10,317	3	54	2	2	29	59	2	92	1.075
Musica	11,119	4.6	78	4	4	55	91	5	155	1.066
ND1241-1Y	10,317	3.7	71	5	3	43	85	6	138	1.085
NDA081451CB-1CY	11,807	5	75	5	9	64	33	5	112	1.075
Nicola	12,151	5.3	79	4	22	77	26	0	125	1.069
Noelle	11,692	4.5	62	2	15	86	29	0	130	1.072
Obama	9,629	4.7	75	4	5	65	113	3	185	1.061
Column mean	11,192	4.4	72	3.8	6.0	68	64	2	139	1.070
CV %	17	21	9	11	81	29	58	167	31	-
LSD 0.05	*ns*[7]	1.5	11	0.7	8	32	61	5	71	-
LSD 0.10	*ns*	1.3	9	0.6	7	27	51	4	59	-

Late Blight Spore Trapping Network for Minnesota

Investigators contact:

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Executive Summary

Late blight is a community disease that can cause dramatic losses in potato production. As a community disease, early detection of late blight spores is important to enable potato growers to quickly apply premium protectant fungicides. The potato Blightline, utilizes a weather model to indicate when conditions are most favorable for late blight, but this is primarily available in North Dakota. This project was initiated to provide confirmed DNA data on the presence of late blight spores in or near potato fields in Minnesota. In 2019, 22-spore traps were setup in the North Dakota and Minnesota potato growing region. No positive late blight spores were identified between July 1 through September 9, 2019. This coincided with no findings of late blight in Minnesota or North Dakota potato fields. Although this sentinel monitoring system is costly to operate, early detection of late blight spores can save millions of dollars in potato losses.

Rationale for conducting the research

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

Because Minnesota does not have many weather stations that utilize the Blightline predictive model, this spore trapping network will enable potato growers to be alerted when late blight spores are found to enable them to know when to apply premium fungicides. Collection traps will be placed in cooperating growers' fields and sent to Dr. Gudmestad's laboratory in a prepaid package. Spores were identified in Dr. Neil Gudmestad's laboratory.

Procedures

Spore traps were distributed to cooperating growers in Oakes, Inkster and Cavalier, ND and in East Grand Forks, Gulley, Pondsford Praire, Park Rapids, Hubbard, Menahga, Perham, north of Perham, Ottertail, Wadena, Verdale, Badoura, Stapes, Ripley, Rice, Clearlake, Becker, Big Lake and Hastings, Minnesota (Figures 1-10). On a weekly basis, starting July 1 or 8, cassettes were placed in the spore traps. After one week they were shipping in a prepaid envelope to Dr. Gudmestad's laboratory and the DNA was extracted and evaluated for late blight. Sampling continued until September 9, 2019. After data was collected, ArcGIS maps were made and sent to growers by email and put on the NDSU/UMN Potato Extension webpage to let them know all reporting traps and findings. No late blight DNA was found in 2019 from the trapping network.

What was learned? Every sampling cassette bag needs to have a location name and a date for sampling. We need to work more closely with growers to get samples sent in a timely manner for this to work efficiently.

The good news is no late blight was identified in 2019 in the spore traps or in potato fields. However, it was not tested in a year where late blight was present to see if it could help potato growers have an early warning system for late blight.

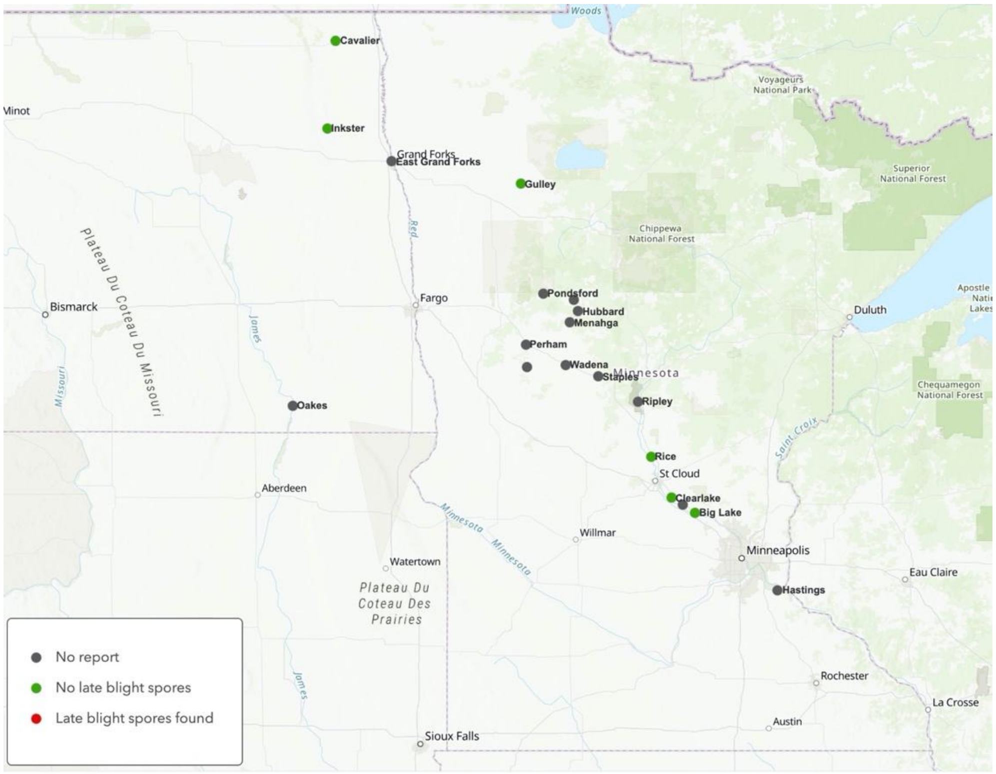


Figure 1. July 8, 2019 late blight spore trapping network report.

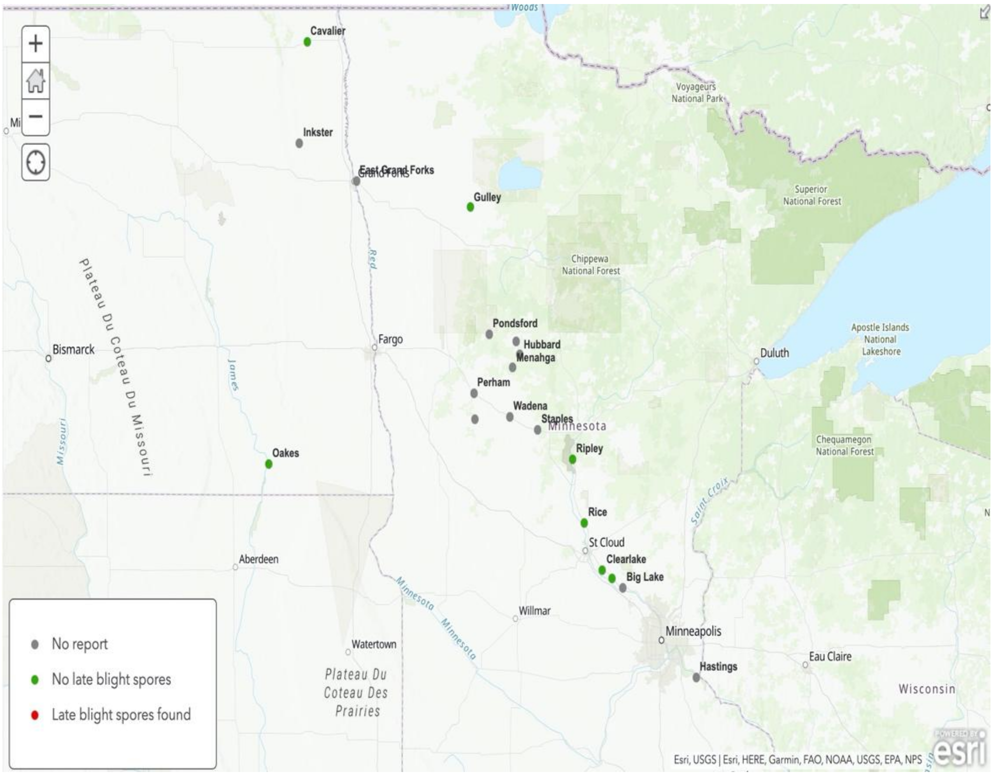


Figure 2. July 15, 2019 late blight spore trapping network report. 2

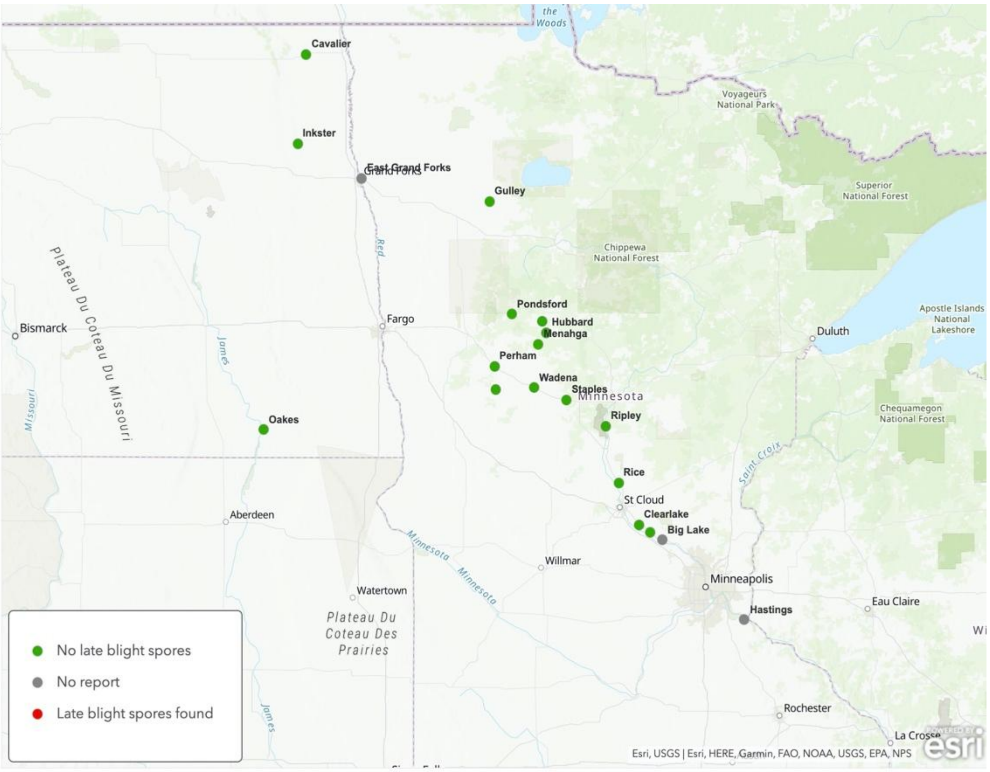


Figure 3. July 29, 2019 late blight spore trapping network report.

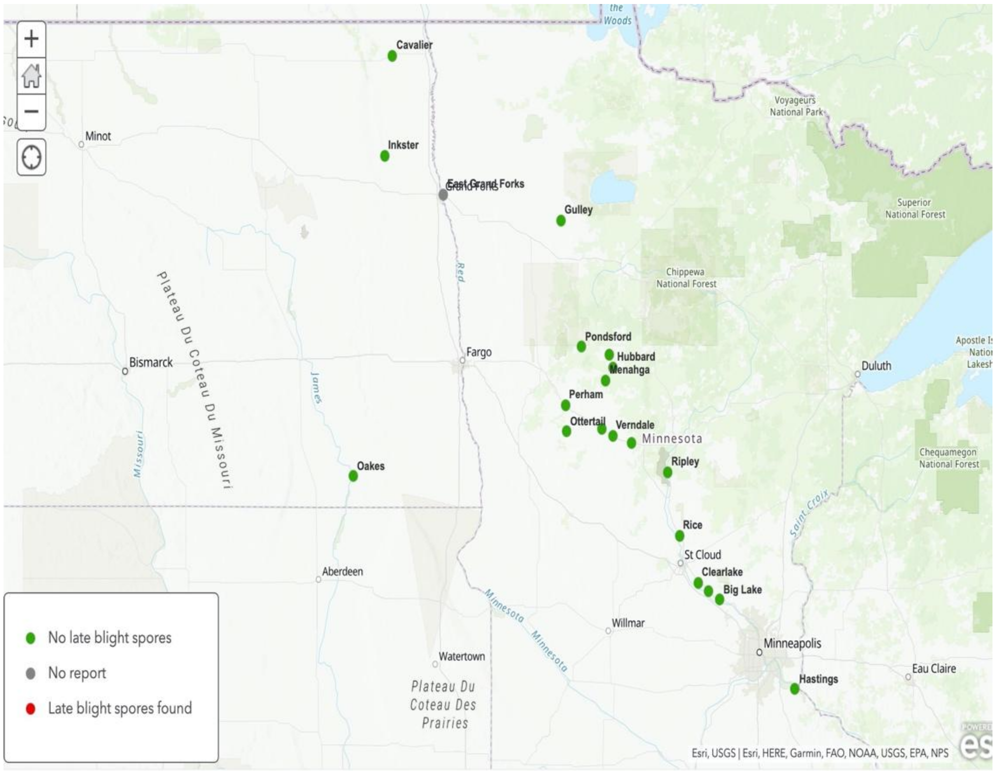


Figure 4. August 5, 2019 late blight spore trapping network report.

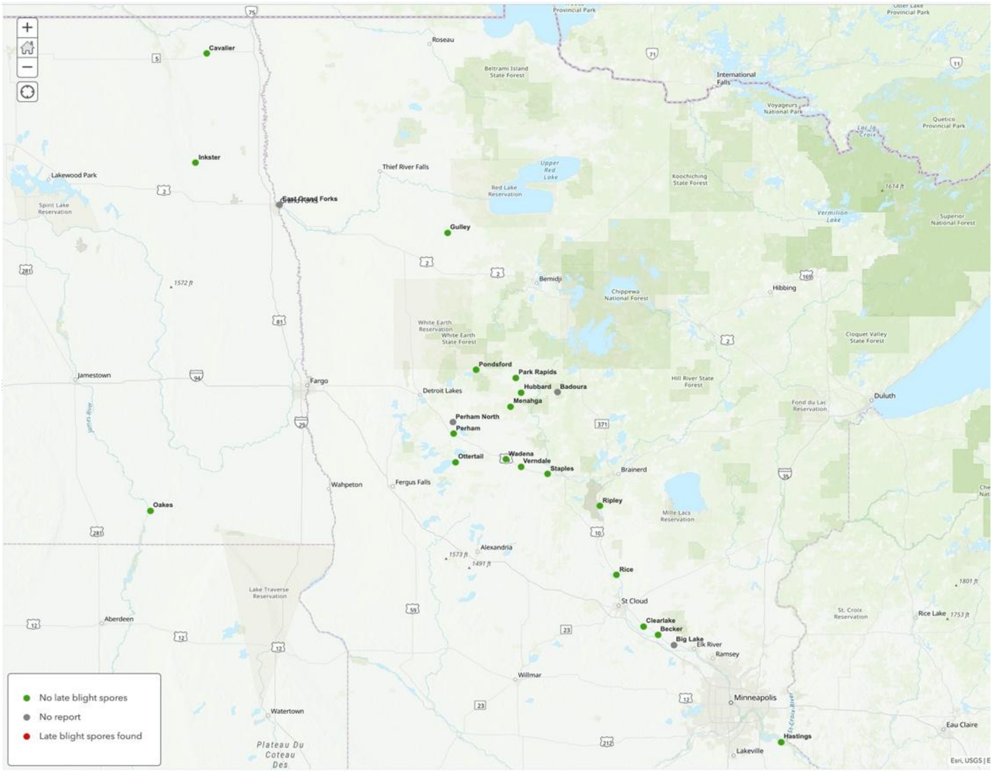


Figure 5. August 12, 2019 late blight spore trapping network report.

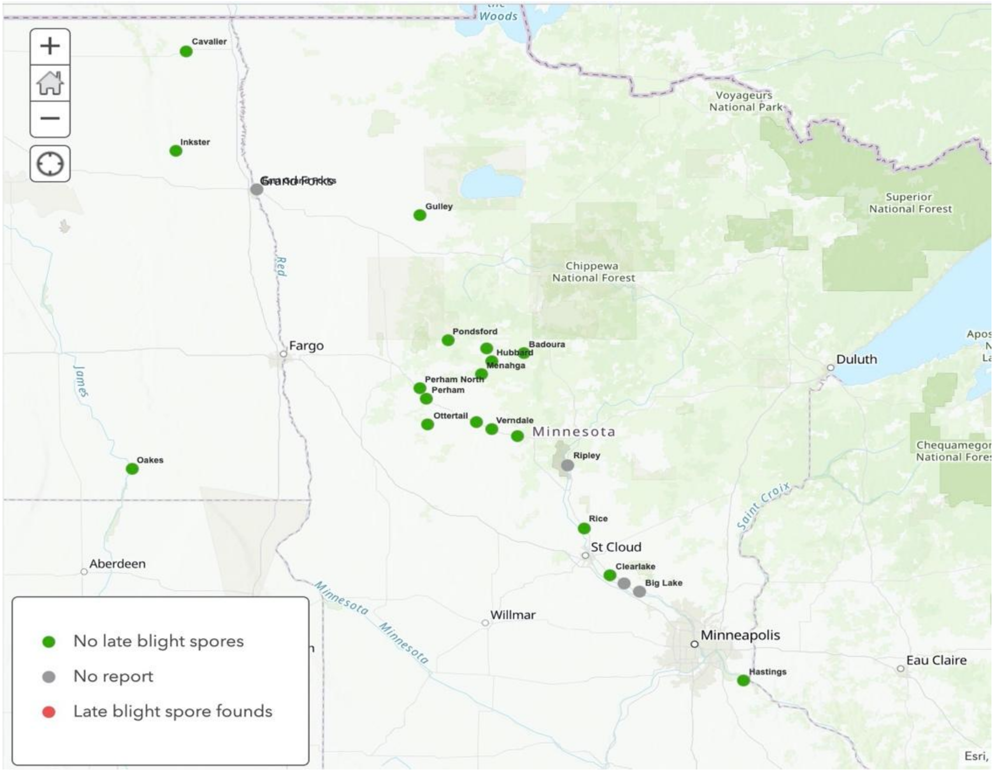


Figure 6. August 19, 2019 late blight spore trapping network report.

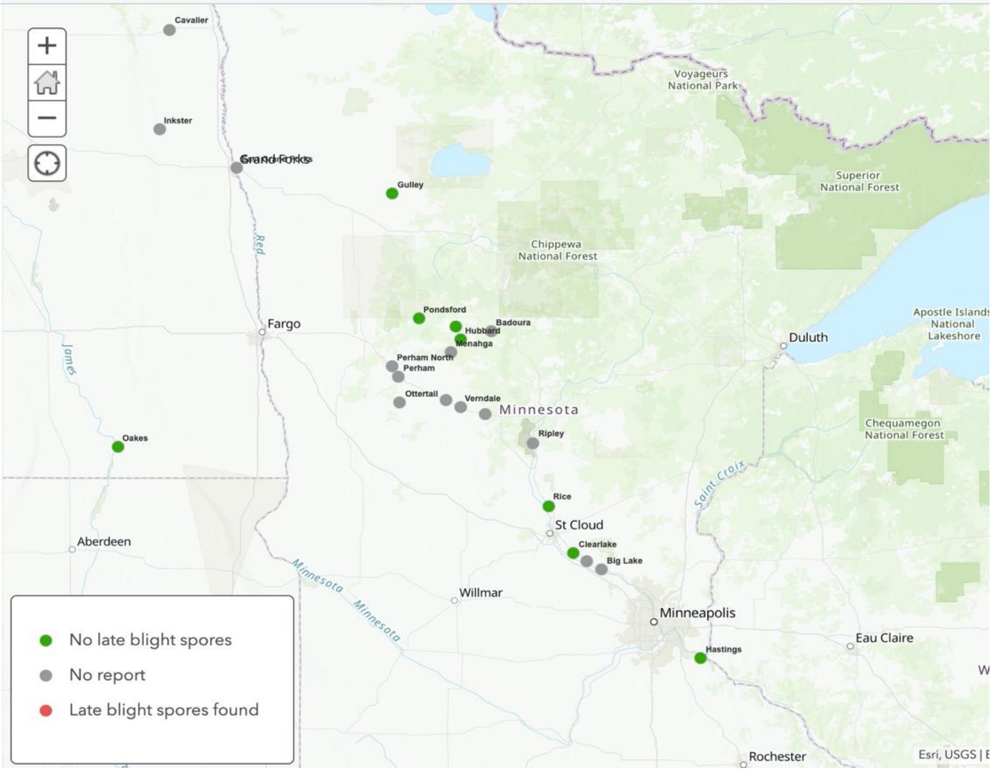
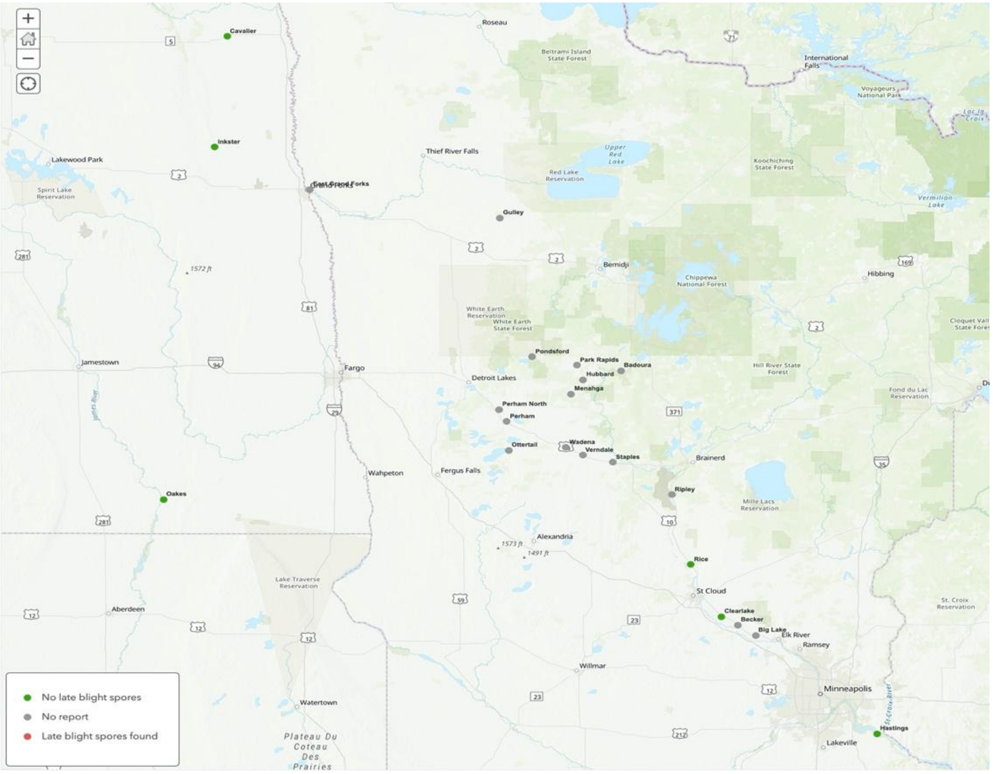


Figure 7. August 26, 2019 late blight spore trapping network report.



Figurer 8. September 9, 2019 late blight spore trapping network report.

A1783-19

North Dakota
Fresh Market Potato
Cultivar/Selection Trial Results for 2019

Robinson photo, NDSU

Andy Robinson
Extension Potato Agronomist,
NDSU/University of Minnesota

Eric Brandvik
Research Specalist, NDSU

Peter Ihry
Agriculture Technician, NDSU

Potato cultivars or selections included in this report were selected from recently released cultivars or from advancing selections with release potential (numbered lines progressing through the trial process), or cultivars that are new to the US. Standard potato cultivars used by growers served as checks.

NDSU | EXTENSION

North Dakota State University
Fargo, North Dakota

December 2019

In 2019, two trials were conducted to identify traits of red-skinned and yellow-skinned potato cultivars and advanced selections at Hoople, N.D. Seventeen red-skinned cultivars and 30 yellow-skinned cultivars were evaluated. Plots were established in a commercial, nonirrigated potato field utilizing common potato-production practices.

Prior to planting, urea at 120 pounds of nitrogen (N) per acre was broadcast and incorporated. A randomized complete block design was utilized.

Seed tubers were hand cut to approximatley 2-ounce seed pieces prior to planting. Tubers were planted on May 31, 2019, in rows that were spaced 38 inches apart. Plots were 6.3 feet wide and 20 feet long.

Vines were desiccated on Sept. 8 and 13 with diquat. Red-skinned potato plots were harvested on Oct. 7. About two-thirds of the yellow-skinned potatoes were harvested on Oct. 8 and the remainder were harvested on Oct. 25. Because of the challenges with harvesting the yellow-skinned tubers, specific gravity average is shown only for plots harvested on Oct. 8 and is not analyzed statistically.

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

The agronomic data presented in **Tables 1 and 2 (Pages 3 and 4)** were analyzed statistically. These analyses allow the reader to ascertain, at a predetermined level of confidence, if the differences observed among cultivars/selections are reliable, or if they might be due to error inherent in the experimental process.

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

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

The data provided does not indicate endorsement or approval by the authors, or NDSU Extension or University of Minnesota Extension.

Reproduction of the tables is permissible if presented with all the same information found in this publication (meaning no portion is deleted and the order of the data is not rearranged).

The authors acknowledge the contribution of cultivars and advanced selections for this work from the breeding programs at North Dakota State University, the Univerity of Minnesota, the U.S. Department of Agriculture-Agricultural Research Service, Colorado State Univertity, the Universiy of Wisconsin, Michigan State University, EBE Farms, Northern Konstar Potatoes, Parkland Seed, Real Potato and SunRain.

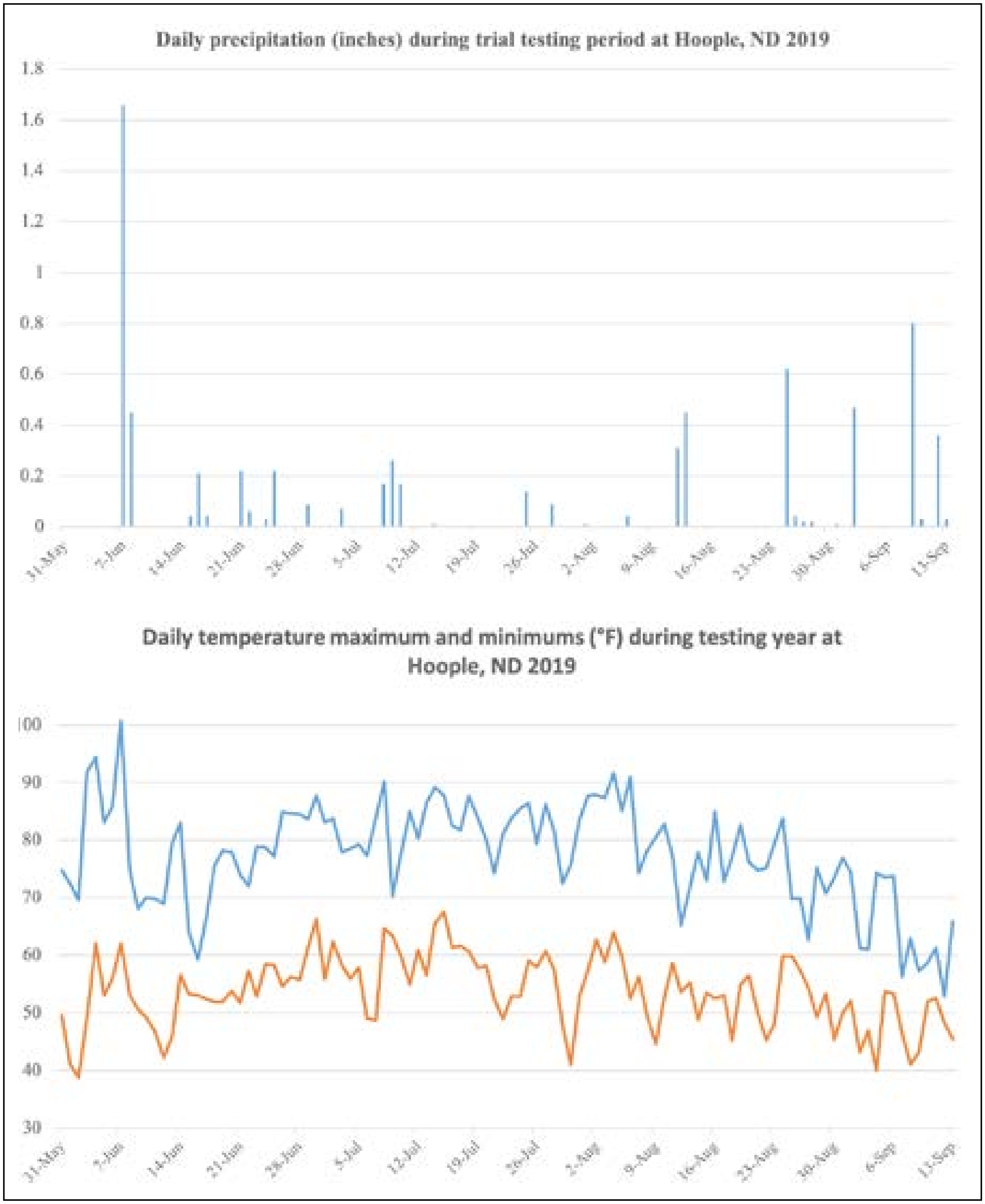


Figure 1.

Weather data from May 31 to Sept. 13, 2019, from the North Dakota Agricultural Weather Network weather station in Crystal, N.D.

Table 1. Agronomic performance and graded yield of red-skinned potato cultivars/selections, Hoople, N.D., 2019.

Cultivar/Selection	**Stand**[1]	**Stems/plant**[2]	**Vine length**[3]	**Vigor**[4]	**C**[5]	**B**	**A**	**Chef**	**Total yield**	**Specific gravity**
	plants/a	**number**	**cm**		**——— cwt/a ———**					
Autumn Rose	11,807	4.7	61	3	11	129	56	0	196	1.083
C099076-6R	11,348	3.7	54	3	0	28	83	6	118	1.078
Cerata	11,921	3.6	88	5	2	47	77	0	126	1.076
Dark Red Norland	12,150	4	55	3	1	37	113	7	158	1.081
Dark Red Norland (Real Potato)	13,297	4.4	55	3	0	49	125	2	176	1.079
ND081571-2R	13,411	2.9	44	3	1	57	46	1	105	1.079
ND102990B-3R	11,807	3.5	40	2	6	56	33	0	94	1.079
ND113207-1R	13,182	3.1	52	3	8	86	98	0	193	1.076
ND13241C-6R	12,380	4.4	53	4	19	109	16	1	144	1.083
ND13282C-1R	11,921	4.1	42	2	4	61	17	0	82	1.083
Red Norland	12,838	3.8	55	3	1	32	158	7	198	1.074
Red Pontiac	12,265	3.9	65	4	1	45	148	3	197	1.075
Red Prairie	12,265	4.2	66	3	4	89	61	0	154	1.077
Roko	12,609	4.8	69	5	2	76	69	1	148	1.087
Sangre	12,609	3.6	53	4	1	44	45	0	89	1.068
W8890-1R	12,036	4.7	56	3	4	89	103	0	197	1.072
W8893-1R	12,495	4.2	42	2	3	70	74	0	147	1.079
Column mean	12,488	4.0	56	3	4	67	78	2	150	1.078
CV %	12	27	9	13	71	27	34	165	23	0.675
LSD 0.05	*ns*[6]	*ns*	9	1	5	30	44	4	58	*ns*
LSD 0.10	*ns*	*ns*	7	1	4	25	36	4	48	*ns*

[1] Stand count was taken on July 11 (six weeks after planting) by counting every emerged plant.

[2] Stems per plant were counted on 10 plants on July 11 (six weeks after planting) and are shown as the average number of stems per plant.

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

[4] Vigor evaluation was completed on Sept. 3 (14 weeks after planting). A rating of 1 indicated least vigor and 5 greatest vigor.

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

[6] *ns* indicates data were not statistically signficiant.

Table 2. Agronomic performance and graded yield of yellow-skinned potato cultivars/selections, Hoople, N.D., 2019.

Cultivar/Selection	Stand[1]	Stems/plant[2]	Vine length[3]	Vigor[4]	C[5]	B	A	Chef	Total yield	Specific gravity[6]
	plants/a	number	cm		cwt/a					
A00286-3Y	11,921	3.9	77	5	5	77	50	0	132	1.063
A06336-2Y	9,514	4.2	67	4	13	81	22	0	116	1.077
A06336-5Y	10,775	4.7	61	3	8	72	17	0	98	1.071
AC10376-1W/Y	10,546	3.1	57	4	5	70	36	0	110	1.074
Actrice	12,495	4	68	3	3	37	124	4	168	1.074
Agata	12,265	5.5	70	3	4	76	111	2	193	1.072
Alegria	11,692	4.2	71	4	3	51	73	4	132	1.072
Arizona	11,807	6.1	69	4	5	68	125	9	206	1.067
Belmonda	7,565	3.4	69	4	7	71	32	0	110	1.064
CO05037-3W/Y	9,858	4	62	2	6	70	43	0	118	1.077
CO10064-1W/Y	12,495	4.5	65	5	6	78	43	0	127	1.08
Crop 49	9,743	4.4	72	3	4	45	35	0	84	1.071
Crop 56	11,348	5.4	85	5	10	100	12	0	122	1.078
Crop 58	11,463	4.3	68	4	3	62	94	2	162	1.076
Crop 80	9,514	4.8	87	4	13	75	43	0	131	1.073
Electra	11,348	4.9	83	5	5	94	50	0	149	1.062
Fioretta	11,921	5.2	71	4	3	124	68	0	196	1.065
Jelly	13,870	4.4	80	5	3	61	55	0	119	1.07
Lanorma	11,807	3.6	86	5	1	55	100	1	157	1.062
Mariola	10,431	4.5	75	3	2	41	82	4	128	1.06
Melody	11,692	3.1	89	4	4	44	33	0	81	1.06
Milva	11,348	3.7	72	4	4	72	114	4	193	1.073
Montreal	13,297	4.8	63	4	3	97	112	0	212	1.066
MST252-1Y	10,317	3	54	2	2	29	59	2	92	1.075
Musica	11,119	4.6	78	4	4	55	91	5	155	1.066
ND1241-1Y	10,317	3.7	71	5	3	43	85	6	138	1.085
NDA081451CB-1CY	11,807	5	75	5	9	64	33	5	112	1.075
Nicola	12,151	5.3	79	4	22	77	26	0	125	1.069
Noelle	11,692	4.5	62	2	15	86	29	0	130	1.072
Obama	9,629	4.7	75	4	5	65	113	3	185	1.061
Column mean	11,192	4.4	72	3.8	6.0	68	64	2	139	1.070
CV %	17	21	9	11	81	29	58	167	31	-
LSD 0.05	*ns*[7]	1.5	11	0.7	8	32	61	5	71	-
LSD 0.10	*ns*	1.3	9	0.6	7	27	51	4	59	-

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[1] Stand count was taken on July 11 (six weeks after planting) by counting every emerged plant.

[2] Stems per plant were counted on 10 plants on July 11 (six weeks after planting) and are shown as the average number of stems per plant.

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

[4] Vigor evaluation was completed on Sept. 3 (14 weeks after planting). Rating compared with Red Norland being a 5. A rating of 1 indicated least vigor and 5 greatest vigor.

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

[6] Specific gravity was not analyzed because of the different harvest date. The mean data for each treatment is presented.

[7] *ns* indicates data were not statistically signficiant.

100-12-19

A Novel Approach to Manage Nitrogen Fertilizer for Potato Production using Remote Sensing

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Summary

This project is part of a broader effort to develop and validate a novel approach to determine the optimum rate of in-season nitrogen fertilizer applications for potato production based on remote sensing. Nitrogen fertilizer applications are one of the most important management practices that affect potato yield. There are limitations to the existing plant tissue sampling methods currently used for in-season nitrogen management, and remote sensing based methods have been suggested as a promising new method to determine the optimal rate of in-season nitrogen applications. Remote sensing enables potato producers to apply the optimal rate of in-season nitrogen fertilizer across the spatial variability found within their fields. This ensures maximum profitability and reduces the risk of environmental pollution. We evaluated a series of nitrogen rate and timing treatments, including in-season nitrogen management as determined by petiole nitrate measurements, to determine their effect on tuber yield and quality. The eight N treatments evaluated included: a check treatment receiving 40 lbs N acre^{-1} as banded diammonium phosphate at planting (Control), a series of treatments receiving urea at a emergence and split-applied UAN applications at total rates of 140 lbs N acre^{-1} (Split Low), 220 lbs N acre^{-1} (Split Med), and 300 lbs N acre^{-1} (Split High), a series of treatments receiving 100 lbs N acre^{-1} urea at emergence with delayed "rescue" applications of split-applied UAN applications at total rates of 140 lbs N acre^{-1} (Rescue Low), 220 lbs N acre^{-1} (Rescue Med), and 300 lbs N acre^{-1} (Rescue High), and finally a treatment with 100 lbs N acre^{-1} urea applied at emergence with in-season UAN applications determined from petiole nitrate measurements (Petiole). Overall, there was a significant quadratic response to N Rate in this study where both Total and US No. 1 yields were highest at a N rate of 220 lbs N acre^{-1} (525 and 400 cwt acre^{-1}, respectively) than both 140 lbs N acre^{-1} (492 and 360 cwt acre^{-1}, respectively) and 300 lbs N acre^{-1} (503 and 376 cwt acre^{-1}, respectively). Averaged across rates, the Split N treatments had significantly greater Total (522 cwt acre^{-1}) and US No. 1 (397 cwt acre^{-1}) yields compared to the Rescue N treatments (490 and 360 cwt acre^{-1}, respectively). The Petiole N treatment was not significantly different in either Total or US No. 1 yield compared to the Split Med treatment. Additionally, we collected in-season measurements of whole plant biomass, nitrogen content, and petiole nitrate with simultaneous measurements using multiple remote sensing tools to gather reflectance measurements. These data will be used in future analyses to relate remote sensing measurements to biophysical parameters such as petiole nitrate, plant N uptake, and percent canopy cover which can be used to direct in-season nitrogen management.

Background

Improving in-season nitrogen management is a key research objective for potato production. Remote sensing based tools have shown promise in previous research studies and have led to the development of new methods to determine in-season crop nitrogen status and determine the optimal rate and timing on nitrogen fertilizer applications. Prior to being used in production systems, this new methods needs to be calibrated with additional experimental data, validated for agronomic effectiveness compared to conventional nitrogen management practices, and be adapted to be used with remote sensing platforms which are commercially scalable (e.g., satellite and UAV sensors). Additionally, these methods need to account for yearly variability in crop growth dynamics caused by climatic conditions and nitrogen management practices. Historically, measurements of petiole nitrate have been used as key indicators of crop nitrogen status to determine the optimal rate and timing of in-season N applications. In order to be widely adopted, remote sensing based nitrogen management needs to perform as well as or better than nitrogen management based on petiole nitrate measurements.

The objectives of this study were to collect additional calibration data necessary to improve remote sensing based nitrogen management for potato and evaluate the performance of N management based on petiole nitrate measurements against conventional split-applied urea/UAN at various rates. This study also evaluated the effectiveness of late-season UAN applications to determine the ability to "rescue" a crop from low N conditions.

Methods

Study design

The study was conducted at the Sand Plain Research Farm in Becker, MN, in 2019, on a Hubbard loamy sand soil. Eight treatments were applied in a randomized complete block design with four replicates. All treatments received 40 lbs·N acre^{-1} as DAP (18-46-0) at planting, with various rates of granular urea (46-0-0) applied and incorporated by hilling at emergence and of post-emergence applications of 28% urea/ammonium nitrate (28-0-0) applied using simulated fertigation. Treatments included a check treatment with no N applications in addition to DAP applied at planting (Control), a series of treatments receiving urea at a emergence and split-applied UAN applications at total rates of 140 lbs N acre^{-1} (Split Low), 220 lbs N acre^{-1} (Split Med), and 300 lbs N acre^{-1} (Split High), a series of treatments receiving 100 lbs N acre^{-1} urea at emergence with delayed "rescue" applications of split-applied UAN applications at total rates of 140 lbs N acre^{-1} (Rescue Low), 220 lbs N acre^{-1} (Rescue Med), and 300 lbs N acre^{-1} (Rescue High), and a treatment with 100 lbs N acre^{-1} urea applied at emergence with in-season UAN applications determined from petiole nitrate measurements (Petiole). Nitrogen treatments are summarized in Table 1. The Rescue N treatments were initially designed to have their in-season N applications managed based on remote sensing measurements; however, technical difficulties prevented these designed treatments from being successfully imposed resulting in the re-design of the study to investigate late-season N applications.

Cultural practices

Pre-treatment soil samples to a depth of six inches were collected on April 10, 2019, and sent to the University of Minnesota Research Analytical Laboratory (St. Paul, MN) to be analyzed for Bray P; NH_4OAc-extractable K, Ca, and Mg; $Ca(H_2PO_2)_2$ / Ba-extractable SO_4-S; hot-water-extractable B; DTPA-extractable Cu, Fe, Mn, and Zn; soil water pH; and LOI soil organic matter content. NO_3-N concentrations in two-foot soil samples collected on the same date were measured using a Wescan Nitrogen Analyzer. Results are presented in Table 2.

Whole "B" Russet Burbank seed was planted in all plots on May 5, with 12" spacing within rows and 36" spacing between rows. Plots were 30 feet long and 21 feet wide. Prior to planting, DAP was banded below the seed bed opening. The plots were hilled on May 23. Prior to hilling, urea was broadcast by hand in all treatments expect the Control treatment. Additional post-emergence N was applied as 28% liquid UAN to various treatments on July 3, July 15, July 22, July 25, July 30, Aug 1, Aug 5, Aug 7, Aug 12, and Aug 14 in increments of 10 to 30 lbs N acre^{-1} per application.

In-season plant sampling

Intensive plant sampling measurements were collected on five dates: June 25, July 9, July 23, Aug 6 and Aug 21. On each date, three whole plants were destructively sampled from each plot segregating roots, vines, and tubers tissues. Fresh weight of each tissue was measured and a subsample was collected for later laboratory analysis. Dry matter content was determined by oven drying. Nitrogen concentration was determined using combustion analysis with an Elementar CNS Element Analyzer. On the same dates, terminal leaflet chlorophyll contents from the fourth mature leaf from the shoot tip were measured for 20 leaves per plot using a SPAD-502 Chlorophyll Meter (Konica Minolta), and the petiole of the fourth mature leaf from the shoot tip was collected for 20 leaves per plot. Petioles were dried at 140°F for 24 hours, then ground and analyzed for NO_3-N concentration using a Wescan Nitrogen Analyzer. Additional petiole samples were collected from the Petiole N treatment and sent to Agvise Laboratories for rapid analysis and nitrate concentration determination. Necessary rates for subsequent nitrogen fertilizer applications for the Petiole N treatment were determined using the results of this rapid analysis based on University guidelines.

Remote sensing

Spectral reflectance data was collected on a weekly basis from mid-May until late-August with the CROPSCAN MSR-16R. On the five whole plant sampling dates, additional remote sensing imagery was also collected. Multispectral reflectance imagery was collected using the MicaSense RedEdge-MX sensor using a DJI Matrice 100 UAV platform. Hyperspectral reflectance imagery was collected using a Resonon Pika sensor using a DJI Matrice 600 UAV platform. Using the CROPSCAN data, percent canopy cover was calculated by scaling NDVI values between observed values for bare soil and full canopy cover. Crop N status was also assessed using MTCI values which have previously been shown to correlate strongly with crop N status in potato.

Harvest sampling

Vines were harvested and weighed from 10 feet of each of the two central rows of each plot on Sept 16. Fresh weight of each tissue was measured and a subsample was collected for later laboratory analysis. Tubers were harvested on September 23 from the central 28 feet of the central two rows of each plot, and harvested tubers were sorted and graded. Twenty-five-tuber subsamples were collected for each plot, stored at 45°F, and assessed for hollow heart, brown center, and scab, and their specific gravity determined. Tuber and vine dry matter content was determined by oven drying. Tuber and vine N concentration was determined using combustion analysis with an Elementar CNS Element Analyzer.

Statistical analysis

Yield and quality data were analyzed with SAS (copyright 2015, SAS Institute, Inc.) using the GLIMMIX procedure with a threshold of $\alpha = 0.10$ to assess main treatment effect significance with multiple pairwise comparisons between treatments conducted at a threshold of $\alpha = 0.05$. A series of contrast comparisons were also conducted. The Control contrast compared the Control treatment against all other fertilized treatments. The Timing contrast compared the three Split treatments against the three Rescue treatments. The Rate-Linear and Rate-Quad contrasts evaluated the presence of a linear and quadratic effect of increasing N rate, respectively, for the Low, Med, and High treatments.

Results and discussion

Tuber yield and quality

The results for tuber yield, size, and grade are presented in Table 3. Overall, there was a significant quadratic response to N Rate in this study where both Total and US No. 1 yields were highest at a N rate of 220 lbs N acre^{-1} (525 and 400 cwt acre^{-1}, respectively) than both 140 lbs N acre^{-1} (492 and 360 cwt acre^{-1}, respectively) and 300 lbs N acre^{-1} (503 and 376 cwt acre^{-1}, respectively). This suggests that both N limiting conditions and excessive N conditions can be yield limiting for potato, which previous studies have observed. In the case of this particular study year, measurements from similar small-plot studies taking place within the same field at the Sand Plain Research Farm suggest that N leaching was higher than normal. Typically, when nitrate leaching levels are high then yield will increase as N rate increases. However, the timing of applied N in this study may have reduced yield in the High N treatments by delaying tuber bulking and maturity, by temporarily creating conditions of excessive N despite overall conditions of low available soil N due to nitrate leaching. In addition vine dies earlier than expected due to an uncontrollable aphid outbreak.

Averaged across rates, the Split N treatments had significantly greater Total (522 cwt acre^{-1}) and US No. 1 (397 cwt acre^{-1}) yields compared to the Rescue N treatments (490 and 360 cwt acre^{-1}, respectively). This suggests that N stress during early- to mid-July (i.e., tuber initiation and bulking) results in yield loss that cannot be rescued through late season N applications. In other words, these results indicate that once N limiting conditions occur, they may not be able to be corrected for without some negative impact on tuber yield, especially if conditions for late season bulking are not optimum.

The Petiole N treatment was not significantly different in either Total or US No. 1 yield compared to the Split Med treatment. These two treatments had identical N fertilizer applications until the week of July 22. Petiole nitrate levels for the Petiole N treatment were trending lower than expected for both the first (June 25, 12911 ppm NO3) and second (July 9, 7508 ppm NO3) sampling dates (Table 5). Early season nitrate leaching observed in other studies may explain the low levels of petiole nitrate on the first two sampling dates. On the third sampling date (July 23), petiole nitrate was extremely low (2018 ppm NO3), despite the previous applications of UAN (40 lbs N acre^{-1}) scheduled in response to low petiole nitrate. Compared to the Split Med treatment, the Petiole N treatment received an additional 40 lbs N acre^{-1} in the weeks of 22 July and 29 July, which resulted in a large increase (12984 ppm NO3) in petiole nitrate levels on the fourth sampling date (9 Aug). However, these late season applications did not affect tuber yield relative to the comparable Split Med treatment. If additional corrective action had been taken sooner (e.g., an additional 40 lbs N acre^{-1} applied in the weeks of 1 July, 8 July, and 15 July), then perhaps the Petiole N treatment would have had greater tuber yield than the Split Med treatment.

Results for tuber quality are presented in Table 4. There is limited evidence for differences in tuber quality resulting from the N treatments evaluated in this study.

Remote sensing

Remote sensing observations indicate that N rate and timing had an effect on canopy cover (Figure 1) and crop N status (Figure 2). No differences in crop N status or canopy cover between any treatment were detected prior to June 24. At this point, canopy cover and crop N status for the Control N treatment began to increase at a lower rate than fertilized treatments, and both canopy cover and crop N status for this treatment began to decline by early July. Differences in crop N status between the Split Low, Split Med, and Split High treatments were observed around June 24 with lower crop N status values for treatments receiving lower N application rate, while differences in canopy cover between the same three treatments were observed beginning July 7. There were no differences in canopy cover or crop N status for the Rescue Low, Rescue Mid, and Rescue High treatments prior to the applications of the late-season UAN applications. At this point in time, both canopy cover and crop N status were declining. After the rescue applications were made, canopy cover and crop N status began to increase for the Rescue High treatment and slightly increase for the Rescue Mid treatment, while continuing to decline for the Rescue Low treatments. Generally, the Rescue N treatments had lower canopy cover and crop N status compared to the Split N treatments. Trends in crop N status measurements for the Petiole N treatment corresponded with the observed trends in petiole nitrate measurements: Crop N status declined from June 25 to July 23, with a subsequent increase in crop N status between July 23 and 6 Aug. This indicates that remote sensing based observations of crop N status can detect similar trends as petiole nitrate measurements. One key limitation is that there is no established sufficiency limit for crop N status based on remote sensing (i.e., MTCI value) in the same manner that exists for petiole nitrate.

Conclusions

Overall, the results of this study reaffirm the importance of tracking for crop N status in real-time throughout the growing season and present new evidence that yield loss may have already occurred by the time that crop N stress is detected. While petiole nitrate remains a key indicator for crop N status, developments in remote sensing technology may provide new tools for in-season detection of crop N stress. Additional work is still to be performed for this study including analysis of in-season whole plant sample for biomass and crop N uptake, and using this data to improve predictions of crop N status using various remote sensing methods.

Table 1. Initial soil characteristics of the study site.

0 - 2 feet	0 - 6 inches											
(mg·kg-1 soil)											(–)	(%)
Primary macronutrients			Secondary macronutrients			Micronutrients					Other characteristics	
NO_3^--N	Bray P	K	Ca	Mg	SO_4-S	Fe	Mn	Zn	Cu	B	pH	OM
1.8	33	72	832	196	5.5	18	5	3.1	0.87	0.20	7.2	1.3

Table 2. Treatments applied to evaluate the effects of PCU application timing and fertilizer placement on Russet Burbank potatoes grown at the Sand Plains Research Farm in Becker, MN, in 2019.

Treatment #	Description	N Rate	Planting	Emergence	Post-Emergence						
			5 May	23 May	Week of 1 July	Week of 8 July	Week of 15 July	Week of 22 July	Week of 29 July	Week of 5 Aug	Week of 12 Aug
1	Control	40	40 DAP								
2	Split Low	140	40 DAP	40 Urea	10 UAN		20 UAN		20 UAN	10 UAN	
3	Split Med	220	40 DAP	100 Urea	20 UAN		20 UAN		20 UAN	20 UAN	
4	Split High	300	40 DAP	160 Urea	20 UAN		30 UAN		30 UAN	20 UAN	
5	Rescue Low	140	40 DAP	100 Urea							
6	Rescue Med	220	40 DAP	100 Urea				20 UAN	20 UAN	20 UAN	20 UAN
7	Rescue High	300	40 DAP	100 Urea				40 UAN	40 UAN	40 UAN	40 UAN
8	Petiole	260	40 DAP	100 Urea	20 UAN		20 UAN	20 UAN	40 UAN	20 UAN	

Table 3. Effects of N treatment on tuber yield, size distribution, and grade of Russet Burbank potatoes grown at the Sand Plains Research Farm in Becker, MN, in 2019.

Treatment #	Description	N Rate	Yield ($CWT \cdot ac^{-1}$)									% yield in tubers > than:	
			0 - 3 oz.	3 - 6 oz.	6 - 10 oz.	10 - 14 oz.	> 14 oz.	Total	U.S. No. 1	U.S. No. 2	Marketable	6 oz.	10 oz
1	Control	40	146 a	207 c	64 c	5	0 c	422 c	251 d	171 a	276 d	16% d	1% c
2	Split Low	140	112 b	262 a	130 ab	19	2 bc	525 a	381 abc	144 b	413 ab	29% bc	4% abc
3	Split Med	220	90 d	248 ab	158 a	29	7 a	532 a	410 a	122 cd	442 a	36% a	7% a
4	Split High	300	95 cd	254 ab	135 ab	20	6 ab	510 a	400 a	110 d	415 ab	31% abc	5% ab
5	Rescue Low	140	97 bcd	243 ab	104 b	13	1 c	458 bc	338 c	120 cd	361 c	26% c	3% bc
6	Rescue Med	220	91 d	258 a	146 a	19	2 bc	517 a	390 ab	126 cd	426 ab	32% ab	4% abc
7	Rescue High	300	108 bc	235 b	129 ab	21	2 bc	495 ab	353 bc	142 b	387 bc	31% abc	5% ab
8	Petiole	260	89 d	243 ab	150 a	25	7 a	514 a	400 a	114 cd	425 ab	36% a	6% a
Main Effect			**<0.0001**	**0.0017**	**<0.0001**	0.1094	**0.0138**	**0.0006**	**<0.0001**	**<0.0001**	**<0.0001**	**<0.0001**	**0.0211**
Control			**<0.0001**	**<0.0001**	**<0.0001**	**0.0106**	**0.0312**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**0.0036**
Rate - Linear			0.5960	0.2957	0.1774	0.3481	0.1512	0.4813	0.2715	0.2163	0.4085	*0.0732*	0.1707
Rate - Quad.			**0.0139**	0.5381	**0.0066**	0.2013	0.1808	*0.0513*	**0.0192**	0.2232	**0.0108**	**0.0070**	0.1561
Timing			0.9454	0.1491	0.1216	0.2604	**0.0102**	**0.0175**	**0.0065**	0.2899	**0.0264**	0.1372	0.1036

Table 4. Effects of N treatment on tuber quality of Russet Burbank potatoes grown at the Sand Plains Research Farm in Becker, MN, in 2019.

Treatment #	Description	N Rate	% of Tubers			Specific Gravity	% Dry Matter
			Hollow Heart	Brown Center	Scab		
1	Control	40	0.0	0.0	14.6	1.0873	20.7
2	Split Low	140	0.0	0.0	5.1	1.0834	21.0
3	Split Med	220	1.0	1.0	8.3	1.0897	21.0
4	Split High	300	1.0	1.0	4.3	1.0834	21.0
5	Rescue Low	140	0.0	0.0	8.3	1.0833	20.8
6	Rescue Med	220	0.0	0.0	6.2	1.0838	21.4
7	Rescue High	300	0.0	0.0	1.1	1.0793	19.8
8	Petiole	260	0.0	0.0	6.0	1.0820	21.0
Main Effect			0.5827	0.5827	0.6698	0.1914	0.4474
Control			0.6070	0.6070	*0.0865*	0.1829	0.7459
Rate - Linear			0.3495	0.3495	0.4053	0.4393	0.2850
Rate - Quad.			0.5559	0.5559	0.5359	*0.0575*	0.1964
Timing			0.1256	0.1256	0.8573	0.1145	0.3863

Table 5. Petiole nitrate measurements for the Petiole N treatment.

Treatment #	Description	N Rate	Petiole Nitrate-N (ppm)			
			25-Jun	9-Jul	23-Jul	6-Aug
8	Petiole	260	12911	7508	2018	12984

Figure 1. Canopy cover observations for each treatment using CROPSCAN reflectance measurements for Russet Burbank potatoes grown at the Sand Plains Research Farm in Becker, MN, in 2019.

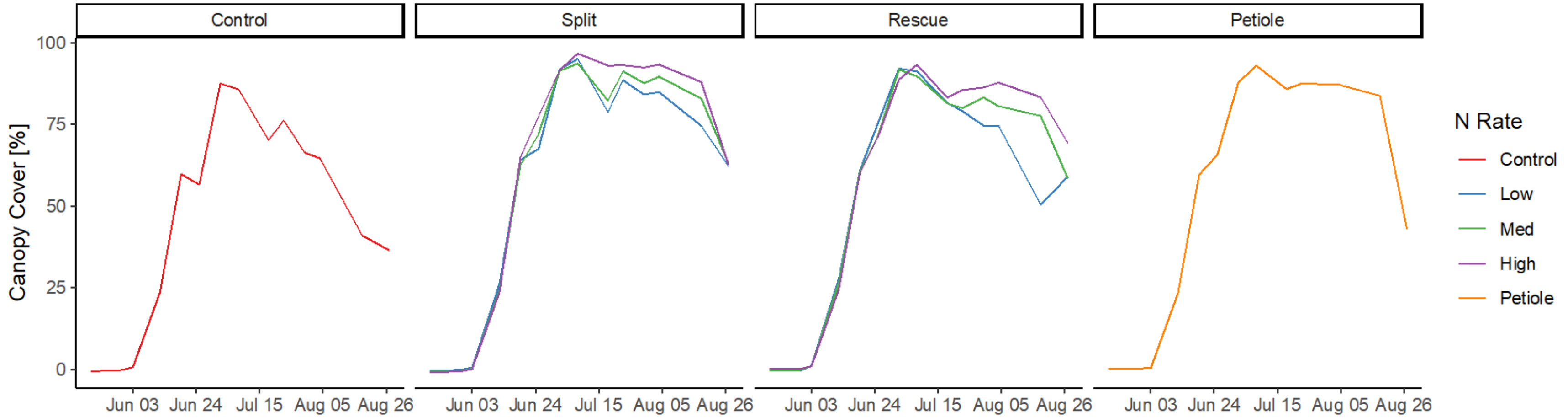

Figure 2. Canopy N status for each treatment using MTCI values from CROPSCAN reflectance measurements for Russet Burbank potatoes grown at the Sand Plains Research Farm in Becker, MN, in 2019.

Effects of application timing and banded versus broadcast application of ESN on Russet Burbank potatoes

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Summary

Applying the polymer-coated urea Environmentally Smart Nitrogen (ESN, Nutrien (formerly Agrium, Inc.), 44-0-0) as a topdress at hilling is considered a best management practice, based on both plant performance in previous studies and the convenience of this method to the grower. However, after a topdress application, many ESN prills may be found on the soil surface in the field furrows, and the N in these prills is unlikely to be accessible to the crop's root systems. This N loss might be minimized by applying ESN in a sidedress (band) instead of a topdress. To evaluate the effects of application timing and fertilizer placement on the effectiveness of ESN as an N source for potatoes, we applied six treatments to Russet Burbank potatoes in a randomized complete block design with four replicates: (1) a zero-N check treatment, (2) a treatment receiving 140 $\text{lbs}\cdot\text{ac}^{-1}$ N as uncoated urea topdressed at hilling, (3) a treatment receiving the same rate of N as ESN broadcast before planting, (4) a treatment receiving the same rate of N as ESN banded at planting, (5) a treatment receiving the same rate of N as ESN topdressed at hilling, and (6) a treatment receiving the same rate of ESN banded at hilling. We analyzed the effects of these treatments on tuber yield, grade, size, and quality, stand, petiole NO_3^--N concentration, leaflet chlorophyll content (SPAD-502 readings), and N uptake into vines and tubers. We also assessed how much N per acre was left on the soil surface in furrows with each method five days after hilling. All treatments receiving ESN had greater marketable yields than the treatment receiving granular urea, but the difference was only significant for the treatment receiving ESN banded at hilling. The overall positive effect of ESN in this study is likely due to early season leaching rainfall. This treatment also had a lower yield of undersized tubers than any other treatment and a higher yield of tubers over 14 ounces than the zero-N check or the treatments receiving either uncoated urea or ESN as a topdress at hilling. Treatments receiving N had higher tuber specific gravity than the zero-N check treatment, but N treatment did not otherwise affect tuber quality. Season-average petiole NO_3^--N concentration was highest in the treatment receiving ESN as a sidedress at hilling. The same was true of season-average SPAD-502 reading, though the average reading for the treatment receiving banded ESN at planting was not significantly lower. Results for vine, tuber, and total N uptake were similar to those for season-average SPAD-502 readings, except that the treatment receiving ESN as a topdress at hilling did not have significantly lower uptake than the treatment receiving ESN as a sidedress at hilling. Application method and timing did not significantly affect the amount of ESN left on the soil surface five days after hilling. Overall, while applying ESN as a sidedress at hilling conferred numerous advantages over the recommended approach of applying it as a topdress at hilling, these benefits were not attributable to the amount of ESN left on the soil surface with each approach. Rather, the benefits of banded application presumably stem from how the prills that are incorporated into the soil are placed relative to the crop's root systems.

Background

Environmentally Smart Nitrogen (ESN, Nutrien, 44-0-0) is a polymer coated urea that releases N over a 60- to 80-day period. This extended release of N is an asset in full season potato cropping systems because less N provided is made available before root systems have developed enough to take it up. Because less N is lost to leaching and volatilization as a result, using ESN is considered a best management practice.

It is recommended that ESN be applied as a topdress at emergence, just before hilling, which incorporates it into the soil. This recommendation was based on observed crop response to this method and its convenience to growers. However, after ESN is applied in this way, apparently significant numbers of prills often end up on the soil surface in the furrows, where the N released may be less accessible to the potato crop's roots. Such loss of N may be minimized by banded application of ESN in place of topdress application.

The objectives of this study were to (1) evaluate the effects of fertilizer placement and application timing on potato yields and N uptake and (2) to quantify the amount of ESN that ends up in the furrow when it is applied as a topdress before hilling.

To evaluate the effects of application timing and fertilizer placement on the effectiveness of a PCU as an N source for potatoes, we applied six treatments to Russet Burbank potatoes in a randomized complete block design with four replicates: (1) a zero-N check treatment, (2) a treatment receiving 140 lbs·ac^{-1} N as uncoated urea broadcast at hilling, (3) a treatment receiving the same rate of N as ESN broadcast at planting, (4) a treatment receiving the same rate of N as ESN banded at planting, (5) a treatment receiving the same rate of N as ESN broadcast at hilling, and (6) a treatment receiving the same rate of N banded at hilling.

Methods

Study design

The study was conducted at the Sand Plain Research Farm in Becker, MN, in 2019, on a Hubbard loamy sand soil. The previous crop was soybeans. Six treatments were applied in a randomized complete block design with four replicates: (1) a check treatment receiving no supplemental N throughout the season, (2) a treatment receiving 140 lbs·ac^{-1} N as uncoated granular urea (46-0-0) broadcast (i.e., top dressed) at hilling, (3) a treatment receiving 140 lbs·ac^{-1} N as Environmentally Smart Nitrogen (ESN; 44-0-0; Nutrien) broadcast three days before planting, (4) a treatment receiving 140 lbs·ac^{-1} N banded as ESN at planting, (5) a treatment receiving 140 lbs·ac^{-1} N as ESN broadcast (i.e., top dressed) at hilling, and (6) a treatment receiving 140 lbs·ac^{-1} N as ESN banded (i.e., side dressed) at hilling. All treatments but the check also received 40 lbs·ac^{-1} N as DAP (18-46-0) at planting and 20 lbs·ac^{-1} N in each of two applications of 28% UAN after hilling. Thus, all treatments receiving N received a total of 220 lbs·ac^{-1} N. The treatments are summarized in Table 1. The study comprised a total of 24 plots, each 12 feet wide by 20 feet long.

Soil sampling

Pre-treatment soil samples to a depth of six inches were collected on April 10, 2019, and sent to the University of Minnesota Research Analytical Laboratory (St. Paul, MN) to be analyzed for Bray P; NH_4OAc-extractable K, Ca, and Mg; $Ca(H_2PO_2)_2$ / Ba-extractable SO_4-S; hot-water-extractable B; DTPA-extractable Cu, Fe, Mn, and Zn; soil water pH; and LOI soil organic matter content. NO_3^--N concentrations in two-foot soil samples collected on the same date were measured using a Wescan Nitrogen Analyzer. Results are presented in Table 2.

Planting

All plots received 200 lbs·ac^{-1} MOP (0-0-60) and 200 lbs·ac^{-1} SulPoMag (0-0-22-22S-11Mg) broadcast on April 24, supplying 164 lbs·ac^{-1} K_2O and 22 lbs·ac^{-1} S. ESN was broadcast at 318 lbs·ac^{-1} in plots receiving treatment 3 on April 30 to provide 140 lbs·ac^{-1} N. Whole "B" Russet Burbank seed was planted in all plots on May 3, with 12" spacing within rows and 36" spacing between rows.

At row closure, planting fertilizer was mechanically banded into each treatment. All treatments received 141 lbs·ac^{-1} SulPoMag, 184 lbs·ac^{-1} MOP, 2 lbs·ac^{-1} $ZnSO_4$ (17.5% S, 35.5% Zn), and 3 lbs·ac^{-1} Boron 15 (15% B), supplying 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. In addition, treatments 2 - 6 received 173 lbs·ac^{-1} DAP (18-46-0), providing 40 lbs·ac^{-1} N and 102 lbs·ac^{-1} P_2O_5. Treatment 1 received 173 lbs·ac^{-1} triple superphosphate (0-46-0), providing 102 lbs·ac^{-1} P_2O_5. Treatment 4 received 318 lbs·ac^{-1} ESN, providing 140 lbs·ac^{-1} N.

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.

Hilling and post-hilling fertilizer applications

The plots were hilled on May 23. Prior to hilling, 304 lbs·ac^{-1} granular urea was broadcast by hand in plots receiving treatment 2; 318 lbs·ac^{-1} ESN was broadcast in plots receiving treatment 5; and lbs·ac^{-1} ESN was sidedressed by hand in plots receiving treatment 6 followed by hilling. Each of these applications supplied 140 lbs·ac^{-1} N. Additional N was applied to all plots not receiving the check treatment (i.e., treatments 2 – 6) as granular UAN followed immediately by irrigation on June 27 and as 28% liquid UAN on July 15, at 20 lbs·ac^{-1} N in each application.

Precipitation and irrigation

Rainfall was monitored by an in-field weather station placed in a nearby field used for another study. Irrigation was supplied using the checkbook method and was recorded by the field station staff.

ESN urea release in situ

Urea release from ESN prills was monitored in each treatment receiving ESN. At the time of ESN application for a given treatment, ten flat mesh packets, each containing three grams of ESN, were buried four inches below the soil surface in the furrow between a buffer row and each of three plots. The packets were installed in the furrow adjacent to the plots to avoid disturbing the fertilizer placement within the plots, and only three plots were used per treatment because only three plots per treatment were adjacent to a buffer row (the others each being adjacent to two other plots). Periodically, a packet was removed from each of the three plots and air-dried, and the ESN prills were separated from soil, roots, and other debris and weighed. Cumulative urea release across the season was estimated as the percent change in prill mass between burial and exhumation, accounting for the mass of the prill coats (taken to be 0.13 g per 3-g sample, based on previous research). Prills were collected from the treatment receiving ESN broadcast at planting (treatment 3) on May 3, 10, 16, and 23, June 3 and 19, July 8, August 1 and 22, and September 13. Prills were collected from the treatment receiving ESN banded at planting (treatment 4) on the same days, except that the first collection date was May 6. Prills were collected from the treatments receiving ESN at hilling (treatments 5 and 6) on May 28, June 3, 10, 19, and 27, July 8 and 22, August 14 and 22, and September 13.

Prill collection from furrows

ESN prills were collected from the soil surface from the same furrows in which prill packets were installed, in the treatment receiving ESN broadcast at planting (treatment 3) and the treatments receiving ESN at hilling (treatments 5 and 6). No prills were observed on the soil surface in the treatment receiving ESN banded at planting (treatment 4). The prills were collected from 15 square feet in a separate part of the furrow from where the prill packets were installed.

Aboveground plant assessments

Plant stand was assessed in the central 18 feet of each of the central two rows of each plot (36 planted tubers in total) on June 5 and 12. The number of stems per plant was determined on June 13 for 10 plants in the same area where stand was assessed. On June 19 and July 2, 18, and 31, terminal leaflet chlorophyll contents from the fourth mature leaf from the shoot tip were measured for 20 leaves per plot using a SPAD-502 Chlorophyll Meter (Konica Minolta). On the same dates, the petiole of the fourth mature leaf from the shoot tip was collected for 20 leaves per plot. Petioles were dried at 140°F until their weight was stable, ground, and analyzed for NO_3^--N concentration using a Wescan Nitrogen Analyzer.

Vines were harvested and weighed from 10 feet of each of the two central rows of each plot on September 13. A subsample from each vine sample was weighed, dried at 140°F until their weight was stable, and re-weighed. The N concentrations of the subsamples were determined using an Elementar CNS Element Analyzer. The data were used to estimate per-acre aboveground N uptake. Vines were chopped in all rows after the vine samples were taken.

Tuber harvest

Tubers were harvested on September 23 from the central 18 feet of the central two rows of each plot. Harvested tubers were sorted and graded on October 4. Twenty-five-tuber subsamples were collected for each plot, stored at 48°F, and assessed for hollow heart, brown center, and scab, and their specific gravity and dry matter content were determined. Tuber N concentrations were determined using an Elementar CNS Element Analyzer and used to estimate N uptake per acre into tubers. On October 7, four plants per plot were dug by hand and their tubers counted to estimate tuber number per plant.

Data analysis

Data were analyzed with SAS 9.4m3® software (copyright 2015, SAS Institute, Inc.) using the MIXED procedure. Two models were applied. In one model, data from all treatments were analyzed as functions of treatment and block. In the second model, data from the treatments receiving ESN (treatments 3 – 6) were analyzed as functions of application timing (planting or hilling), method (broadcast or banded), their interaction, and block. Petiole NO_3^--N and leaflet SPAD-502 data will be analyzed with repeated-measures models that included treatment, sampling date, and their interaction (for all treatments together) or application timing, application method, sampling date, and their interactions (for treatments 3 - 6). In these repeated-measures models, plot will be the subject variable and sampling date the repeated-measures variable. Means for each treatment and each level of application timing, application method, and their interaction, 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 relevant effect in the model was less than 0.10, and pairwise comparisons with P-values less than 0.10 were considered significant.

Results and discussion

Weather

Daily rainfall and irrigation amounts are shown in Figure 1. There were six rainfall events in excess of one inch, on May 8, 18, and 19, June 23, July 15, and September 12. Three of those major events, depositing a total of 5.29 inches, occurred after the planting fertilizer applications (April 30 and May 3) and before the hilling applications (May 23). A month passed between the hilling application and the next rainfall event exceeding one inch (June 23), but relatively little irrigation was required during this time to maintain soil moisture.

Tuber yield, size, and grade

The results for tuber yield, size, and grade are presented in Table 3. The zero-N check treatment (treatment 1) had lower total and marketable yields than any of the treatments receiving N (treatments 2 – 6). The treatment receiving uncoated granular urea at hilling (treatment 2) had a significantly lower total yield than the treatment receiving ESN banded at planting (treatment 4) and a numerically lower total yield than any treatment receiving ESN. The granular urea treatment also had a numerically lower marketable yield than any treatment receiving ESN, with significantly lower marketable yield than the treatment receiving ESN banded at hilling (treatment 6).

The yield of undersized tubers was highest in the treatment where ESN was broadcast at hilling (treatment 5) and lowest in the treatment where it was banded at hilling (treatment 6). While having the highest marketable yield, the treatment receiving ESN banded at hilling (treatment 6) had a significantly lower yield of undersized tubers than any other treatment, while the treatment receiving ESN topdressed at hilling (treatment 5) was the only one that had a significantly greater yield of undersized tubers than the zero-N check (treatment 1). Overall, banded fertilizer application reduced undersized yield compared to broadcast/topdress application, and this effect of fertilizer placement was significant when the fertilizer was applied at hilling but not at planting.

The treatment receiving ESN banded at hilling (treatment 6) also had the highest yield of tubers weighing more than 14 ounces, with significantly greater yield than the zero-N check treatment (treatment 1) or the treatments receiving urea (treatment 2) or ESN (treatment 5) as a topdress at hilling.

The zero-N check (treatment 1) had a significantly lower yield of U.S. No. 1 tubers than any of the N-fertilized treatments (treatments 2 – 6), while the yield of U.S. No. 2 tubers was not significantly related to fertilizer treatment. The treatment receiving uncoated urea at hilling (treatment 2) had a lower yield of U.S. No. 1 tubers than the treatments receiving banded ESN (treatments 4 and 6), and a numerically lower yield than the treatments receiving broadcast/topdressed ESN (treatments 3 and 5).

The zero-N check treatment (treatment 2) had less of its marketable yield represented by tubers over six or ten ounces than any of the N-fertilized treatments (treatments 2 – 6). The treatments receiving either uncoated urea or ESN topdressed at hilling (treatment 2 and 5) had significantly less of their yields in tubers over six ounces than the treatments receiving ESN banded at planting or hilling (treatments 4 and 6). The treatment receiving ESN as a topdress at hilling (treatment 5) had significantly less of its yield in tubers over ten ounces than the treatment receiving ESN banded at hilling (treatment 6).

The number of tubers per plant was not significantly related to treatment, though the zero-N check treatment had numerically fewer tubers than any other treatment.

Tuber quality

Results for tuber quality are presented in Table 4. The prevalence of hollow heart, brown center, and scab were unrelated to fertilizer treatment, as was tuber dry matter content. Tubers from the zero-N check (treatment 1) had significantly lower specific gravity than those from the treatments receiving N (treatments 2 – 6).

Plant stand and stems per plant

Results for plant stand are presented in Table 5. Plant stand was unrelated to treatment on both assessment dates, as was the number of stems per plant.

Fertilizer release from prills in situ

Cumulative fertilizer release from ESN prills installed *in situ* are presented in Figure 2. Prills installed three days before planting (when ESN was applied in treatment 3) and at planting (when ESN was applied in treatment 4) released urea at a relatively slow rate until hilling, releasing approximately 25% of their urea content between installation and hilling. After hilling, prills in all treatments released urea at a fairly rapid rate over the next few weeks, with urea release slowing down somewhat earlier in the season from the prills installed at planting than those installed at hilling. The cumulative urea release from prills applied at hilling never consistently converged with that from the prills installed at planting, with a small difference in cumulative release (roughly 96% for prills installed at planting versus 92% at hilling) present even on September 13, the last day prills packets were collected.

These results indicate that ESN applied and incorporated into the soil at planting released about 25% of its urea content before hilling and 70% between hilling and harvest, while ESN applied and incorporated at hilling released about 90% of its urea content between hilling and harvest. With 140 $\text{lbs}\cdot\text{ac}^{-1}$ N applied as ESN in these treatments, this would indicate that prills applied at hilling released roughly 30 $\text{lbs}\cdot\text{ac}^{-1}$ more N after hilling (and 35 $\text{lbs}\cdot\text{ac}^{-1}$ less N before hilling) than prills applied at planting. However, this estimate ignores whether prills were placed close to plant roots and what percentage of prills were effectively incorporated into the soil.

Fertilizer prills found on the soil surface in furrows

The amount of N found in ESN prills on the soil surface in furrows, on a per-acre basis, is presented in Table 6. The treatment receiving ESN banded at planting (treatment 4) is not represented because virtually none of its prills were found on the soil surface. The prills were collected on May 28, five days after hilling and 25 days after planting. Prills from the treatment in which ESN was broadcast at planting (treatment 3) would have been incorporated at both planting and hilling, and fewer prills were found in furrows in this treatment than in the other two (treatments 5 and 6) as a result. However, no more than 4.2 $\text{lbs}\cdot\text{ac}^{-1}$ N was found on the soil surface in any treatment, and the effect of treatment on the amount of N on the soil surface in furrows was not significant. We expected that ESN applied as a band at hilling would be much less than ESN applied as a topdress; however, the plots were hilled after banding the ESN and some of that ESN in the band was disturbed during the hilling process. Regardless, the amount of ESN in the furrows was not more than 3% of that applied in any of the treatments.

Petiole NO_3^--N concentrations and leaflet SPAD-502 readings

Results for petiole NO_3^--N concentrations are presented in Table 7. Petiole NO_3^--N concentrations generally decreased between each sampling date and the next. This pattern was observed in all of the N-fertilized treatments (treatments 2 – 6), but while the zero-N check treatment showed a similar tendency toward decreasing petiole NO_3^--N concentration over time, the concentration was not significantly greater on the first sampling date (June 19) than on the last (July 31). Among the treatments receiving N (treatments 2 – 6), the treatment receiving ESN banded at hilling (treatment 6) had a significantly greater season-average petiole NO_3^--N concentration than any other treatment, and the treatments receiving ESN as a topdress at hilling (treatment 5) or banded at planting (treatment 4) had significantly higher season-average concentrations than the treatments receiving uncoated urea as a topdress at hilling or ESN broadcast at planting (treatments 2 and 3). These last two treatments also had significantly lower petiole NO_3^--N concentrations than the other N-fertilized treatments (treatments 4 – 6) on each of the last two sample date (July 18 and 31), while the two treatments with the highest season-average concentrations (treatments 5 and 6) had the highest concentrations on each sampling date except for the first one (June 19).

Results for leaflet SPAD-502 readings, which reflect chlorophyll content, are presented in Table 8. Like petiole NO_3^--N concentrations, SPAD-502 readings generally decreased over time, except that, averaged across treatments, SPAD-502 readings did not decrease significantly between the third reading (July 18) and the fourth (July 31). In contrast to petiole NO_3^--N concentrations, however, SPAD-502 readings showed the most pronounced changes over time in the check treatment (treatment 1) and the treatments receiving uncoated urea topdressed at hilling (treatment 2) or ESN broadcast at planting (treatment 3). Season-average SPAD-502 readings showed similar trends to season-average petiole NO_3^--N concentration, except that the difference in season-average SPAD-502 readings between the treatment receiving ESN banded at hilling (treatment 6, which had the highest average) and the treatment receiving ESN banded at planting (treatment 4) was not statistically significant. These results suggest that leaflet chlorophyll content responds to N treatment in a similar way to petiole NO_3^--N concentration, but may take longer to decrease in response to a soil N deficiency.

Nitrogen uptake

Results for N uptake are presented in Table 9. The zero-N check treatment (treatment 1) took up significantly less N into its vines and tubers than any other treatment. The treatments receiving urea as a topdress at hilling (treatment 2) or ESN broadcast before planting (treatment 3) took up less N into their vines than the other three N-fertilized treatments (treatments 4 – 6). The treatment receiving ESN as a sidedress at hilling (treatment 6) had higher tuber N uptake and total N uptake than the treatments receiving urea as a topdress at hilling (treatment 2) or ESN broadcast before planting (treatment 3). The treatments receiving ESN banded at planting (treatment 4) or topdressed at hilling (treatment 5) had higher total N uptake than the treatment receiving urea topdressed at hilling (treatment 2). Applying ESN at hilling as a band (treatment 6) rather than a sidedress did confer a numerical (but not statistically significant) advantage in terms of N uptake over topdress application.

Conclusions

In this leaching year, ESN regardless of timing generally performed better than urea topdressed at hilling. Relative to the recommended approach of applying ESN as a topdress at hilling (treatment 5), applying it as a sidedress band at hilling (treatment 6) resulted in a lower yield of undersized tubers, a higher yield of tubers over 14 ounces, and a larger percentage of yield represented by tubers over six or ten ounces. The sidedressed ESN treatment also had higher season-average petiole NO_3^--N concentration and leaflet chlorophyll content (SPAD-502 reading) than the topdressed ESN treatment. In addition to these statistically significant differences, sidedressing also conferred numerical advantages in terms of marketable yield, specific gravity, and vine, tuber, and total N uptake. Overall, applying ESN as a sidedress at hilling was a markedly superior approach compared to applying it as a topdress at the same time, in this study.

That banded application would be advantageous was predicted based on the observation that topdress application at hilling leaves many prills resting on the soil surface in the furrows. However, this mechanism does not appear to explain the differences we observed between the two treatments (treatments 5 and 6). The amount of N per acre left on the soil surface in the furrows did not differ significantly between the two treatments. It is more likely that the many differences in outcomes between the two treatments were related to the distribution of prills successfully incorporated into the soil. Sidedress application presumably placed a larger percentage of the supplied N within reach of the plant roots than topdress application did.

Whether using a topdress or sidedress approach, applying ESN at hilling (treatments 5 and 6) produced substantially better results than applying ESN at planting (treatments 3 and 4) or uncoated urea at hilling (treatment 2), though the results of banding ESN at planting (treatment 4) were in many ways similar to the results of applying it as a topdress at hilling (treatment 5). Taken together, applying ESN at hilling produced better results than applying it at planting and banded (sidedress) application was superior to broadcast (topdress) application.

Table 1. Treatments applied to evaluate the effects of PCU application timing and fertilizer placement on Russet Burbank potatoes grown at the Sand Plains Research Farm in Becker, MN, in 2019.

Treatment #	Description	N as DAP at planting ($lbs \cdot ac^{-1}$)	Non-DAP granular N applied near planting[2] ($lbs \cdot ac^{-1}$)	Granular N applied at hilling ($lbs \cdot ac^{-1}$)	Form of non-DAP granular N applied	Method of granular N application	N applied post-hilling as UAN ($lbs \cdot ac^{-1}$)[2]	Total N applied ($lbs \cdot ac^{-1}$)
1	Zero N check	0	0	0	NA	NA	0	0
2	Urea[1] topdressed at hilling	40	0	140	Urea	Broadcast	40	220
3	ESN[1] broadcast pre-planting	40	140	0	ESN	Broadcast	40	220
4	ESN[1] banded at planting	40	140	0	ESN	Banded	40	220
5	ESN[1] topdressed at hilling	40	0	140	ESN	Broadcast	40	220
6	ESN[1] banded at hilling	40	0	140	ESN	Banded	40	220

[1] Urea: 46-0-0; ESN (Environmentally Smart Nitrogen, Nutrien): 44-0-0.

[2] Treatment 3 received ESN three days before planting; treatment 4 received ESN at planting.

[3] Granular urea and ammonium nitrate (34-0-0) applied immediately before irrigation on June 27 and liquid 28% UAN on July 15, at 20 $lbs \cdot ac^{-1}$ each time.

Table 2. Initial soil characteristics of the study site.

0 - 2 feet	0 - 6 inches				
Primary macronutrients			Secondary macronutrients		
NO_3^--N	Bray P	K	Ca	Mg	SO_4-S
($mg \cdot kg^{-1}$ soil)					
3.7	27	71	882	209	5

0 - 6 inches						
Micronutrients					Other characteristics	
Fe	Mn	Zn	Cu	B	pH	Organic matter (%)
($mg \cdot kg^{-1}$ soil)						
22	7	5.1	1.01	0.20	7.0	1.6

Table 3. Effects of N treatment on tuber yield, size distribution, grade, and number per plant of Russet Burbank potatoes. Treatments 2 – 6 all received 220 lbs·ac^{-1} N in total.

Treatment #	Description	Yield (CWT·ac^{-1})									% yield in tubers > than:		Tubers per plant
		0 - 4 oz.	4 - 6 oz.	6 - 10 oz.	10 - 14 oz.	> 14 oz.	Total	U.S. No. 1	U.S. No. 2	Marketable	6 oz.	10 oz	
1	Zero N check	125 b	134 b	59 d	5 b	3 bc	326 c	149 c	178	201 c	21 c	2 c	11.3
2	Urea[1] topdressed at hilling	130 ab	211 a	134 c	34 a	4 bc	513 b	356 b	157	384 b	34 b	7 ab	14.2
3	ESN[1] broadcast pre-planting	136 ab	218 a	151 bc	33 a	9 abc	547 ab	391 ab	156	411 ab	35 ab	8 ab	15.1
4	ESN[1] banded at planting	130 ab	204 a	187 a	32 a	10 ab	563 a	405 a	159	433 ab	41 a	7 ab	13.5
5	ESN[1] topdressed at hilling	141 a	217 a	159 abc	26 a	3 c	547 ab	383 ab	164	405 ab	34 b	5 bc	13.1
6	ESN[1] banded at hilling	111 c	219 a	180 ab	35 a	14 a	559 ab	405 a	154	448 a	40 a	9 a	14.1
Effect of treatment (P-value)		**0.0194**	**0.0017**	**<0.0001**	**0.0355**	*0.0525*	**<0.0001**	**<0.0001**	0.5832	**<0.0001**	**0.0001**	**0.0380**	0.1752

[1] Urea: 46-0-0; ESN (Environmentally Smart Nitrogen, Nutrien): 44-0-0.

Table 4. Effects of N treatment on tuber quality of Russet Burbank potatoes. Treatments 2 – 6 all received 220 lbs·ac^{-1} N in total.

Treatment #	Description	Hollow heart	Brown center	Scab	Specific gravity	Dry matter
		% of tubers				% fresh weight
1	Zero N check	3	2	13	1.0789 b	20.1
2	Urea[1] topdressed at hilling	2	2	13	1.0845 a	21.0
3	ESN[1] broadcast pre-planting	3	2	13	1.0848 a	21.4
4	ESN[1] banded at planting	1	0	14	1.0866 a	21.6
5	ESN[1] topdressed at hilling	3	3	13	1.0837 a	21.1
6	ESN[1] banded at hilling	4	3	11	1.0843 a	21.8
Effect of treatment (P-value)		0.7365	0.4884	0.9984	**0.0202**	0.2172

[1] Urea: 46-0-0; ESN (Environmentally Smart Nitrogen, Nutrien): 44-0-0.

Table 5. Plant stand and the number of stems per Russet Burbank plant in each treatment. All ESN and urea treatments were applied 13 days (for hilling applications, treatments 2, 5, and 6), 33 days (for ESN banded at planting, treatment 4), or 36 days (for ESN broadcast at planting, treatment 3) before the first stand assessment. No post-hilling UAN had yet been applied.

Treatment #	Description	Stand (%), June 5	Stand (%), June 12	Stems / plant, June 13
1	Zero N check	99	99	4.7
2	Urea[1] topdressed at hilling	96	100	4.5
3	ESN[1] broadcast pre-planting	99	100	5.2
4	ESN[1] banded at planting	98	99	5.0
5	ESN[1] topdressed at hilling	99	100	4.6
6	ESN[1] banded at hilling	97	100	4.8
	Effect of treatment (P-value)	0.5934	0.4509	0.4922

[1] Urea: 46-0-0; ESN (Environmentally Smart Nitrogen, Nutrien): 44-0-0.

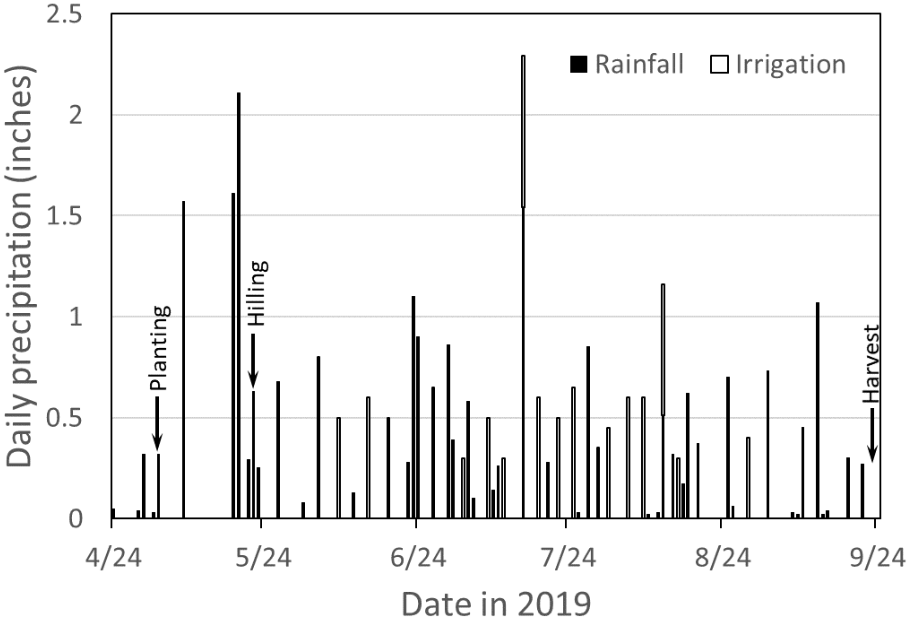

Figure 1. Daily rainfall and irrigation amounts at the Sand Plain Research Farm study location.

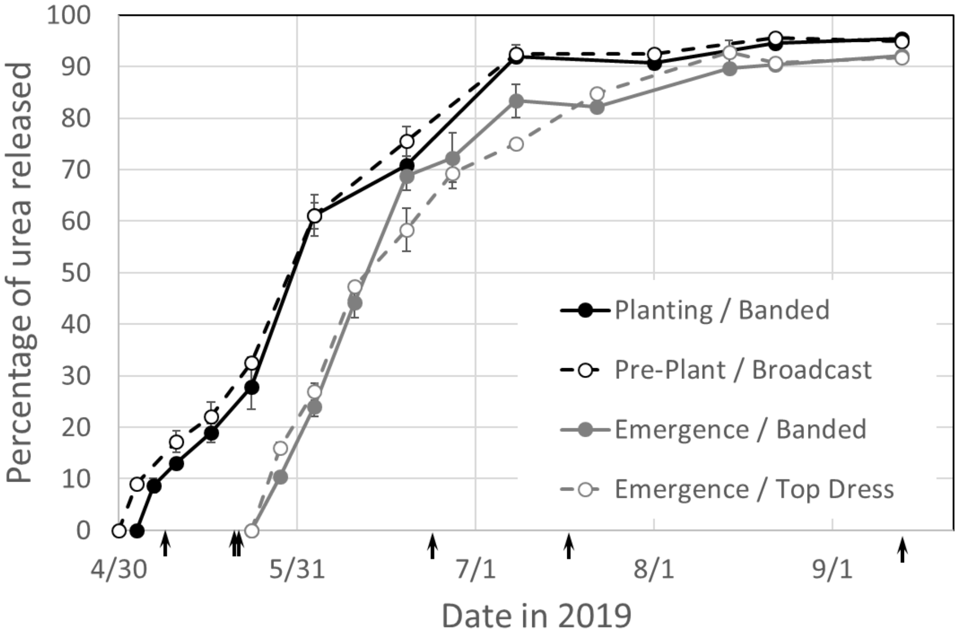

Figure 2. Cumulative urea release from prills installed *in situ* at a depth of four inches below the soil surface in plots receiving ESN (treatments 3 – 6). Prills were installed at the same time ESN was applied to the plot. Arrows indicate days when rainfall exceeded one inch.

Table 6. Amounts of N, on a per-acre basis, in fertilizer prills found on the soil surface in furrows in three of the four treatments receiving ESN (treatments 3, 5, and 6) on May 28, 2019 (5 days after hilling and 25 days after planting). This N may not be accessible to plant roots. Virtually no exposed prills were found in the treatment receiving ESN banded at planting (treatment 4). N was applied as ESN at 140 lbs·ac^{-1} N in these treatments.

Treatment #	Description	Lbs·ac^{-1} N found in furrows
3	ESN[1] broadcast pre-planting	0.7
5	ESN[1] topdressed at hilling	4.0
6	ESN[1] banded at hilling	3.3
	Effect of treatment (P-value)	0.4272

[1] Urea: 46-0-0; ESN (Environmentally Smart Nitrogen, Nutrien): 44-0-0.

Table 7. NO$_3^-$-N concentrations of the petiole of the fourth mature leaf from the shoot tip in 20 plants per plot from each treatment on four dates in June and July. ESN was applied to treatment 3 on April 30 and to treatment 4 on May 3. ESN or urea were applied to treatments 2, 5, and 6 on May 23. UAN applications were made on June 27 and July 15.

Treatment #	Description	Petiole NO$_3^-$-N				
		June 19	July 2	July 18	July 31	Average across dates
1	Zero N check	1281 c, -	342 d, -	351 c, -	27 c, -	500 d
2	Urea[1] topdressed at hilling	18116 ab, A	15140 ab, B	7555 b, C	648 c, D	10365 c
3	ESN[1] broadcast pre-planting	17411 b, A	13664 c, B	7690 b, C	1043 c, D	9952 c
4	ESN[1] banded at planting	18934 a, A	14007 bc, B	10071 a, C	2493 b, D	11376 b
5	ESN[1] topdressed at hilling	16934 b, A	15431 a, B	11094 a, C	2824 b, D	11571 b
6	ESN[1] banded at hilling	17890 ab, A	16380 a, B	10821 a, C	4342 a, D	12358 a
Average across treatments		15094 A	12494 B	7930 C	1896 D	
Effect of treatment (P-value)						**<0.0001**
Effect of date (P-value)		**<0.0001**				
Effect of treatment*date (P-value)		**<0.0001**				

[1] Urea: 46-0-0; ESN (Environmentally Smart Nitrogen, Nutrien): 44-0-0.

Table 8. Chlorophyll content readings taken with a SPAD-502 Chlorophyll Meter (Konica Minolta) from the terminal leaflet of the fourth mature leaf from the shoot tip in 20 plants per plot from each treatment on four dates in June and July. ESN was applied to treatment 3 on April 30 and to treatment 4 on May 3. ESN or urea were applied to treatments 2, 5, and 6 on May 23. UAN applications were made on June 27 and July 15.

Treatment #	Description	Leaflet SPAD-502 readings (chlorophyll content)				
		June 19	July 2	July 18	July 31	Average across dates
1	Zero N check	38.1 b, A	34.1 c, B	31.6 c, C	30.3 d, C	33.5 d
2	Urea[1] topdressed at hilling	44.3 a, A	42.2 b, B	40.1 b, C	37.9 c, D	41.1 c
3	ESN[1] broadcast pre-planting	44.4 a, A	41.7 b, B	40.3 a, C	40.4 b, B	41.7 c
4	ESN[1] banded at planting	44.0 a, A	44.0 a, A	42.1 a, B	42.4 a, B	43.1 ab
5	ESN[1] topdressed at hilling	43.7 a, A	42.0 b, B	42.4 a, AB	43.3 a, AB	42.9 b
6	ESN[1] banded at hilling	44.1 a, -	44.2 a, -	43.0 a, -	43.1 a, -	43.6 a
Average across treatments		43.1 A	41.4 B	39.9 C	39.6 C	
Effect of treatment (P-value)						**<0.0001**
Effect of date (P-value)		**<0.0001**				
Effect of treatment*date (P-value)		**<0.0001**				

[1] Urea: 46-0-0; ESN (Environmentally Smart Nitrogen, Nutrien): 44-0-0.

Table 9. N uptake into vines, tubers, and vines plus tubers (“Total”) in each treatment. Vines were collected on September 13, just before they were killed, and tubers harvested on September 23.

Treatment #	Description	Vine N uptake ($lbs \cdot ac^{-1}$)	Tuber N uptake ($lbs \cdot ac^{-1}$)	Total N uptake ($lbs \cdot ac^{-1}$)
1	Zero N check	7 c	52 c	59 d
2	Urea[1] topdressed at hilling	19 b	107 b	126 c
3	ESN[1] broadcast pre-planting	20 b	110 b	130 bc
4	ESN[1] banded at planting	25 a	125 ab	150 ab
5	ESN[1] topdressed at hilling	25 a	124 ab	149 ab
6	ESN[1] banded at hilling	28 a	139 a	166 a
	Effect of treatment (P-value)	**<0.0001**	**<0.0001**	**<0.0001**

[1] Urea: 46-0-0; ESN (Environmentally Smart Nitrogen, Nutrien): 44-0-0.

Evaluation of Aspire, MicroEssentials S10, and MicroEssentials SZ as Sources of Potassium, Phosphate, Sulfur, Boron, and Zinc for Russet Burbank Potatoes

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Summary

Aspire (0-0-58-0.5B) is a product designed to reduce the challenge of applying the micronutrient boron (B) sufficiently and evenly across a field by co-granulating it with potassium (K). Similarly, a second product, MicroEssentials SZ (MESZ; 12-40-0-10S-1Zn) contains the micronutrient zinc (Zn) co-granulated with nitrogen (N), phosphorus (P), and sulfur (S). MESZ and the related product MicroEssentials S10 (MES10; 12-40-0-10S) are also formulated with both elemental S and SO_4-S to address a challenge with providing plants with adequate S throughout the season. Specifically, elemental S provides very little plant-available S early in the season but is converted to plant-available SO_4-S throughout the season, while SO_4-S is immediately plant-available but can be lost through leaching and therefore may not provide adequate S later in the season. The purpose of this study was to evaluate the effectiveness of Aspire, MESZ, and MES10 as fertilizers for Russet Burbank potatoes in central Minnesota. Twelve treatments were applied in a randomized complete block design with four blocks: (1) a check treatment; (2) a treatment receiving P_2O_5 as MAP (11-52-0); (3) a treatment receiving K_2O as MOP (0-0-60); (4) a treatment receiving P_2O_5 and K_2O as MAP + MOP; (5) a treatment receiving P_2O_5, K_2O, and S as MES10 + MOP; (6) a treatment receiving P_2O_5, K_2O, S, and B as MES10 + Aspire; (7) a treatment receiving P_2O_5, K_2O, S, and Zn as MESZ + MOP; (8) a treatment receiving P_2O_5, K_2O, S, Zn, and B as MESZ + Aspire; (9) a treatment providing P_2O_5, K_2O, S, and Mg as MAP + MOP + K-Mag (0-0-22-21S-11Mg); (10) a treatment providing P_2O_5, K_2O, S, and Mg as MES10 + MOP + K-Mag; (11) a treatment providing P_2O_5, K_2O, S, Zn, and Mg as MESZ + MOP + K-Mag, and (12) a treatment providing P_2O_5, K_2O, and B as MAP + Aspire. Nutrient application rates were 80 $lbs \cdot ac^{-1}$ P_2O_5, 300 $lbs \cdot ac^{-1}$ K_2O, 2.6 $lbs \cdot ac^{-1}$ B, 2 $lbs \cdot ac^{-1}$ Zn, and 15 $lbs \cdot ac^{-1}$ Mg in any treatment to which these nutrients were applied. The application rate for S was 20 $lbs \cdot ac^{-1}$ where MES10 or MESZ was applied, 30 $lbs \cdot ac^{-1}$ where K-Mag was applied, and 50 $lbs \cdot ac^{-1}$ where K-Mag was applied with MES10 or MESZ. Fertilization with K and fertilization with B both increased tuber yield and tuber size, but had no effect on tuber quality. The percentage of yield in tubers over six ounces decreased as the application rate of S increased, but it is not clear whether this is an effect of S fertilization, B deficiency, or the particular fertilizers used in the highest-S treatments (which all received K-Mag and did not receive Aspire). Treatments receiving MESZ had a higher prevalence of scab than similar treatments receiving MES10. Susceptibility to scab is not a known effect of Zn fertilization, and it is not clear why this effect was observed.

Background

Phosphorus (P), potassium (K), sulfur (S), boron (B), and zinc (Zn) are important in potato production, with implications for tuber yield, size, quality, and storability. Potatoes are often grown in sandy, low-organic-matter soils that are prone to deficiencies in all of these nutrients. Micronutrients are applied in very small quantities, and the window between deficiency and excess is often narrow, making uniform application both important and difficult. One way to simplify the uniform application of micronutrients is to co-granulate them with nutrients required in much larger quantity.

Although S is not difficult to apply uniformly across a field, it can be challenging to match S availability to plant need over the course of the season. S supplied as sulfate (SO_4) can leach from the soil, so that even when adequate SO_4-S is provided at planting, its availability may limit plant growth and yield later in the year. In contrast, elemental sulfur is largely inaccessible to plants when first applied, but is converted to usable forms by soil microbes over time. Combining elemental S with SO_4-S is one approach to ensuring that sufficient S will be available to plants throughout the growing season.

The purpose of this study is to evaluate three fertilizer products formulated by Mosaic Co. with these strategies in mind. Aspire (0-0-58-0.5B) contains B co-granulated with K. MicroEssentials S10 (MES10; 12-40-0-10S) contains both SO_4-S and elemental S co-granulated with N and P. MicroEssentials SZ (MESZ; 12-40-0-10S-1Zn) contains SO_4-S, elemental S, and Zn co-granulated with N and P. In a randomized complete block design with four blocks and 12 treatments, the performance of these fertilizers as nutrient sources for Russet Burbank potatoes was compared to that of the conventional fertilizers MOP (0-0-60) and MAP (11-52-0) and K-Mag (0-0-22-21S-11Mg).

Materials and Methods

Study design

The study was conducted in 2019 at the Sand Plain Research Farm in Becker, MN, on a Hubbard loamy sand soil. The previous crop was soybean. Plots were laid out in a randomized complete block design with four replicates and twelve treatments. These included: (1) a treatment receiving no P, K, S, B, Zn, or Mg fertilizer; (2) a receiving 80 $lbs \cdot ac^{-1}$ P_2O_5 as MAP (18-46-0); (3) a treatment receiving 300 $lbs \cdot ac^{-1}$ K_2O as MOP (0-0-60); (4) a treatment receiving both P and K as a blend of MAP and MOP; (5) a treatment receiving P, K, and 20 $lbs \cdot ac^{-1}$ S as a blend of MES10 (12-40-0-10S) and MOP; (6) a treatment receiving P, K, S, and 2.6 $lbs \cdot ac^{-1}$ B and a blend of MES10 and Aspire (0-0-58-0.5B); (7) a treatment receiving P, K. S, and 2 $lbs \cdot ac^{-1}$ Zn as a blend of MESZ (12-40-0-10X-1Zn) and MOP; (8); a treatment receiving P, K, S, B, and Zn as a blend of MESZ and Aspire; (9) a treatment receiving P, K, S, and 15 $lbs \cdot ac^{-1}$ Mg as a blend of MAP, MOP, and K-Mag (0-0-22-21S-11Mg); (10) a treatment receiving the same nutrients as treatment 9, but as a blend of MES10, MOP, and K-Mag; (11) a treatment receiving P, K, S, Zn, and Mg as a blend of MESZ, MOP, and K-Mag; and (12) a treatment receiving P, K, and B as a blend of MAP and Aspire. These treatments are summarized in Table 1. Urea (46-0-0) was applied to all treatments as needed to bring the application rate of N at planting up to 34.4 $lbs \cdot ac^{-1}$. The study comprised a total of 48 plots, each 12 feet wide by 20 feet long.

Soil sampling

To measure initial soil characteristics, soil samples to a depth of six inches were collected on April 10 and sent to the University of Minnesota Research Analytical Laboratory (St. Paul, MN) to be analyzed for Bray P; NH_4OAc-extractable K, Ca, and Mg; $Ca(H_2PO_2)_2$ / Ba-extractable SO_4-S; hot-water-extractable B; DTPA-extractable Cu, Fe, Mn, and Zn; cation exchange capacity; soil water pH; and LOI soil organic matter content. NO_3-N concentrations were measured in two-foot soil samples collected on the same date using a Wescan Nitrogen Analyzer. Results are presented in Table 2.

Planting

Whole ("B") seed of Russet Burbank potatoes were planted by hand on Apirl 29, with three-foot spacing between rows and one-foot spacing within rows.

At emergence (May 21), in all treatments, 166 lbs·ac^{-1} N were banded and hilled in as ESN (Environmentally Safe Nitrogen, 44-0-0, Nutrien). N was applied as 28% UAN in three applications, on July 8, 15, and 25, at rates of 10, 10, and 20 lbs·ac^{-1} N, respectively. In total, 240 lbs·ac^{-1} N were applied to every treatment.

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.

Plant stand and petiole nutrient concentrations

Plant stand in the harvest rows was assessed on June 5 and 12, and the number of stems per plant for 10 harvest-row plants was determined on June 13. Leaf petioles (4th leaf from the terminal) were sampled on June 19, July 2, 13, and 31. Petioles were analyzed for NO_3-N concentrations using a Wescan Nitrogen Analyzer and for N and S concentrations using an Elementar CNS analyzer. Petiole samples were also sent to the Research Analytical Laboratory of the University of Minnesota (St. Paul, MN) to measure nutrient elemental concentrations using inductively coupled plasma analysis.

Tuber harvest

Vines were killed on September 13. Tubers were harvested on September 24. The central 18 feet of the middle two rows were harvested from each plot. The tubers were sorted by size and USDA grade on October 10-11. Subsamples of 25 tubers were collected from each plot, stored at 48°F, and assessed for specific gravity, dry matter content, and the prevalence of hollow heart, brown center, and scab. Samples were analyzed for N and S concentrations using an Elementar CNS analyzer.

Data analysis

Data were analyzed with SAS 9.4m3® software (copyright 2015, SAS Institute, Inc.) using the MIXED procedure. Dependent variables were modeled as functions of treatment and block. Treatment means were determined and pairwise comparisons made using the LSMEANS procedure with the DIFF option. Pairwise comparisons were made only when the effect of treatment was significant at $\alpha = 0.10$, and the same threshold was used to determine the significance of each comparison. Three contrasts were performed for each variable analyzed: (1) a comparison of treatments receiving MOP (4, 5, and 7) with otherwise similar treatments receiving Aspire (12, 6, and 8); (2) a comparison of treatments receiving MES10 (treatments 5, 6, and 10) with those receiving MESZ (treatments 7, 8, and 11); and (3) a linear contrast on the application rate of S among treatments receiving P_2O_5 and K_2O (treatments 4 – 12).

Results

Tuber yield and size

Results for tuber yield and size are presented in Table 3. The check treatment (treatment 1) and the treatment receiving only MAP (treatment 2) had the lowest total and marketable yields and the lowest percentages of yield represented by tubers over six or ten ounces. All other treatments had significantly higher total and marketable yields except for the treatment receiving MAP plus MOP (treatment 4) and the treatment receiving MAP and MOP pus K-Mag (treatment

9). None of the treatments receiving K-Mag (treatments 9 – 11) had significantly more of their yield in tubers over six or ten ounces than the check and the MAP-only treatment (treatments 1 and 2). The treatment receiving MES10 plus Aspire (treatment 6) had significantly higher total and marketable yields than any other treatment except for the one receiving MESZ plus Aspire (treatment 8). The latter treatment, in turn, had more of its yield in tubers over ten ounces than any treatment but the one receiving MES10 plus Aspire (treatment 6), and more of its yield in tubers over six ounces than any treatment except the treatment receiving MES10 plus Aspire (treatment 6) or the one receiving MAP plus Aspire (treatment 12).

Given these results, it is not surprising that the contrast comparing treatments receiving MOP (treatments 4, 5, and 7) with similar treatments receiving Aspire (treatments 12, 6, and 8, respectively) showed a highly significant advantage for Aspire in terms of total and marketable yield and the percentage of yield in tubers over six or ten ounces. This contrast indicated that Aspire also increased the yields of tubers in the 6-10-oz and 10-14-oz size classes, as well as U.S. No. 1 tubers. This suggests that, under the conditions of this study, applying B (in the form of Aspire) improved both yield and tuber size.

The linear contrast on the application rate of S indicated that applying S was detrimental to tuber size, with the yield of undersized tubers increasing with S rate while the yields of 6-10-oz and 10-14-oz tubers, as well as the percentages of tubers over six or ten ounces, decreasing at higher application rates of S. However, the highest-S treatments (treatments 9 – 11) all received K-Mag and did not receive Aspire, and these three treatments largely shaped these relationships with S rate. It is therefore uncertain whether S, K-Mag, or lack of B underlies the apparently detrimental effect of S on tuber size in this study. MESZ and MES10 performed similarly to each other, in terms of tuber yield, grade, and size.

Tuber quality

Results for tuber quality are presented in Table 4. Tuber quality was not significantly related to treatment. Based on the contrast comparing MOP (treatments 4, 5, and 7) to Aspire (treatments 7, 8, and 11), the prevalence of hollow heart was somewhat lower in the treatments receiving Aspire. This is consistent with boron’s role in improving cell wall integrity, but since the prevalence of hollow heart did not exceed 4% in any treatment, it is not certain that this result is meaningful.

The contrast comparing MES10 (treatments 5, 6, and 10) with MESZ (treatments 7, 8, and 11) indicated that fertilization with MESZ decreased the prevalence of brown center, but increased the prevalence of scab, compared to fertilization with MES10. This suggests that Zn fertilization improves the interior integrity of the tuber while making the periderm more vulnerable to scab. These are not generally recognized effects of zinc on potato tubers and further investigation is warranted. Since the prevalence of brown center did not exceed 3% in any treatment, the apparent effect of MESZ on brown center may be less meaningful. The apparent increase in scab in response to MESZ is not as easily dismissed, but not easily explained. Zinc is known to suppress (not promote) powdery scab, but it is not known to promote common scab or scab-like symptoms.

Conclusions

Of the nutrients applied in this study, K and B had the clearest positive effect on tuber yield and size. Because B was supplied as Aspire in each treatment that received it, Aspire demonstrated clear advantages over MOP (without B). Treatments receiving K-Mag had relatively little of their yield in tubers over six or ten ounces. It is not clear whether this is an effect of K-Mag *per se* or the higher rates of S that these treatments received, but potatoes have relatively high S requirements, and S is not known to decrease tuber size, at least at the range of rates tested here. Surprisingly application of P as MAP and K as MOP had minimal effects on tuber yield and quality in this study. Treatments receiving MESZ had a higher prevalence of scab than those receiving MES10. It is not clear whether this was an effect of MESZ *per se* or Zn fertilization, but Zn fertilization has not been demonstrated to promote common scab, to our knowledge.

Table 1. Nutrient sources and application rates from fertilizer treatments applied to Russet Burbank potatoes at the Sand Plain Research Farm in Becker, MN, in 2019.

Treatment	Fertilizers applied[1]	Nutrients broadcast at planting (lbs/ac)[2]						
		N	P_2O_5	K_2O	S	B	Zn	Mg
1	Check	34	0	0	0	0	0	0
2	MAP	34	80	0	0	0	0	0
3	MOP	34	0	300	0	0	0	0
4	MAP + MOP	34	80	300	0	0	0	0
5	MES10 + MOP	34	80	300	20	0	0	0
6	MES10 + Aspire	34	80	300	20	2.6	0	0
7	MESZ + MOP	34	80	300	20	0	2	0
8	MESZ + Aspire	34	80	300	20	2.6	2	0
9	MAP + MOP + K-Mag	34	80	300	30	0	0	15
10	MES10 + MOP + K-Mag	34	80	300	50	0	0	15
11	MESZ + MOP + K-Mag	34	80	300	50	0	2	15
12	MAP + Aspire	34	80	300	0	2.6	0	0

[1] MAP: 11-52-0. MOP: 0-0-60. Aspire: 0-0-58-0.5B. MES10: 12-40-0-10S. MESZ: 12-40-0-10S-1Zn. K-Mag: 0-0-22-21S-11Mg.

[2] All treatments received 166 lbs/ac N as Environmentally Smart Nitrogen (44-0-0) at emergence plus 40 lbs/ac N in three applications of UAN (28-0-0) post-hilling.

Table 2. Soil chemical properties prior to fertilizer treatments in the study site at the Sand Plain Research Farm in Becker, MN, in 2019. Soil was sampled to a depth of two feet for NO_3-N and six inches for all other properties.

0 - 2 feet	0 - 6 inches				
Primary macronutrients			Secondary macronutrients		
NO_3^--N	Bray P	K	Ca	Mg	SO_4-S
($mg \cdot kg^{-1}$ soil)					
1.8	30	91	966	222	7.0

0 - 6 inches							
Micronutrients					Other characteristics		
Fe	Mn	Zn	Cu	B	pH	Organic matter	Cation exchange capacity
($mg \cdot kg^{-1}$ soil)						(%)	($meq \cdot 100g^{-1}$)
21	5	3.0	0.86	0.23	7.1	1.3	7.1

Table 3. Effects of fertilizer treatment on tuber yield and size distribution of Russet Burbank potatoes at the Sand Plain Research Farm in Becker, MN, in 2019.

Treatment	**Fertilizers applied[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}									**% of yield**	
1	Check	71 a	198	154 g	26 f	7	455 g	358 hi	26	384 g	41 f	7 g
2	MAP	65 abc	191	162 fg	26 f	13	457 g	349 i	43	392 g	44 ef	8 g
3	MOP	49 def	191	184 cdef	59 bcd	26	510 cde	429 cde	32	461 cd	52 bcd	16 bcd
4	MAP + MOP	62 abc	183	179 defg	38 ef	13	476 fg	379 ghi	35	414 fg	49 cde	11 efg
5	MES10 + MOP	53 cde	188	194 bcd	65 bc	24	525 bc	433 cd	39	472 c	54 abc	17 bc
6	MES10 + Aspire	47 ef	199	231 a	70 b	22	570 a	477 ab	46	522 a	57 ab	16 bcde
7	MESZ + MOP	53 cde	187	191 bcde	61 bc	14	506 cdef	415 def	38	453 cde	52 bcd	15 bcdef
8	MESZ + Aspire	39 f	174	214 ab	92 a	37	555 ab	482 a	35	517 ab	61 a	23 a
9	MAP + MOP + K-Mag	58 bcde	201	168 efg	40 def	10	478 efg	387 fgh	32	419 efg	46 def	10 fg
10	MES10 + MOP + K-Mag	67 ab	200	187 cdef	41 def	19	514 cd	413 def	34	447 cdef	48 cdef	11 defg
11	MESZ + MOP + K-Mag	60 abcd	208	165 fg	48 cde	11	491 def	398 efg	33	431 def	45 def	12 cdefg
12	MAP + Aspire	49 def	182	207 abc	74 ab	17	530 bc	449 bc	32	481 bc	56 ab	17 b
	Significance of treatment (P-value)	**0.0044**	0.5043	**0.0004**	**<0.0001**	0.1206	**<0.0001**	**<0.0001**	0.7937	**<0.0001**	**0.0007**	**0.0009**
Contrasts	MOP vs. Aspire (4, 5, 7 vs. 12, 6, 8)	**0.0134**	0.9655	**0.0024**	**0.0014**	0.1311	**0.0001**	**<0.0001**	0.9858	**<0.0001**	**0.0122**	**0.0185**
	MES10 vs. MESZ (5, 6, 10 vs. 7, 8, 11)	0.2118	0.4733	0.1128	0.2469	0.8361	0.1047	0.3915	0.4626	0.2958	0.9364	0.3977
	Linear contrast on S application rate	*0.0555*	**0.0226**	**0.0274**	**0.0318**	0.5801	0.3457	0.1109	0.7990	0.1403	**0.0111**	*0.0873*

[1] MAP: 11-52-0. MOP: 0-0-60. Aspire: 0-0-58-0.5B. MES10: 12-40-0-10S. MESZ: 12-40-0-10S-1Zn. K-Mag: 0-0-22-21S-11Mg

Table 4. Effects of fertilizer treatment on tuber quality of Russet Burbank potatoes grown at the Sand Plain Research Farm in Becker, MN, in 2019.

Treatment	Fertilizers applied[1]	Hollow heart	Brown Center	Scab	Dry matter	Specific gravity
		% of tubers			% weight	
1	Check	2	1	4	22.2	1.0835
2	MAP	3	3	12	21.3	1.0827
3	MOP	1	0	2	21.2	1.0828
4	MAP + MOP	4	3	9	21.0	1.0788
5	MES10 + MOP	3	3	8	21.2	1.0821
6	MES10 + Aspire	1	1	3	21.1	1.0824
7	MESZ + MOP	1	0	11	21.0	1.0820
8	MESZ + Aspire	0	0	13	21.1	1.0814
9	MAP + MOP + K-Mag	1	1	10	20.7	1.0814
10	MES10 + MOP + K-Mag	3	3	7	21.0	1.0819
11	MESZ + MOP + K-Mag	1	0	11	20.8	1.0788
12	MAP + Aspire	1	1	2	21.2	1.0813
Significance of treatment (P-value)		0.5958	0.4505	0.1103	0.7782	0.1152
Contrasts	MOP vs. Aspire (4, 5, 7 vs. 12, 6, 8)	*0.0742*	0.2158	0.1920	0.8460	0.4722
	MES10 vs. MESZ (5, 6, 10 vs. 7, 8, 11)	0.1303	**0.0340**	**0.0302**	0.6634	0.1251
	Linear contrast on S application rate	0.7820	0.7771	0.2584	0.5414	0.9997

[1] MAP: 11-52-0. MOP: 0-0-60. Aspire: 0-0-58-0.5B. MES10: 12-40-0-10S. MESZ: 12-40-0-10S-1Zn. K-Mag: 0-0-22-21S-11Mg

Evaluation of a Co-Granulated Formulation of K and B for Russet Burbank Potato Production

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Summary

Potassium (K) and boron (B) are important nutrients for optimizing potato tuber yield, size, quality, and storability, and both are often deficient in potato cropping systems. Crop requirements for B are small, and the window between deficiency and excess is narrow, making it both difficult and important to apply B uniformly to the crop. In contrast, K is required in large quantities, facilitating uniform application. It is also important that these nutrients be available when the crop needs them, and fall application, which may be more convenient for growers than spring application, may imply losing nutrients to leaching and fixation. EXPCMT (Mosaic Co.; 0-0-58-0.5B) is a slow-release formulation of B co-granulated with K. This formulation may both simplify the uniform application of B and preserve more of the B in fall applications from leaching or fixation than quick-release formulations. The purpose of this study was to evaluate the effectiveness of EXPCMT as a source of K and B relative to MOP (muriate of potash; 0-0-60) and granular B (15% B), applied in the fall versus spring before planting. A split spring-hilling application of MOP and granular B was included for comparison with the slow-release formula applied in spring. This is the second year of the study. Based on linear contrasts, applying K increased the yield of U.S. No. 1 tubers and total marketable tubers, as well as the percentage of marketable yield represented by tubers over six or ten ounces. K application also decreased the prevalence of hollow heart, brown center, and scab, though these conditions were not common in any treatment. Applying B increased the yield of six- to ten-ounce tubers and total yield, with marketable yield tending to increase as well, but it decreased the percentage of yield in tubers over ten ounces. B application also decreased tuber specific gravity. These results for K are similar to those obtained in the first year of the study, but in that year, B application increased tuber yield and size. Applying K in the fall resulted in higher tuber specific gravity than applying it in spring, but application timing did not otherwise affect tuber yield or quality. EXPCMT did not produce significantly different results than MOP with granular B, whether applied in fall or spring, but EXPCMT's performance relative to MOP with B was somewhat better with fall application than spring application. This was also observed in the first year of the study. These results suggest that fall K application carries a yield penalty in some years but not in others, and that the slow-release characteristics of EXPCMT may slightly mitigate that penalty, while conferring no advantage in a spring application.

Background

Potassium (K) and boron (B) are both vital in optimizing potato tuber yield, size, quality, and storability, and both are often deficient in the soils in which potatoes are grown. Large quantities of K fertilizer are required to satisfy potato crop requirements, but the sufficiency concentration of B is quite low. Furthermore, the difference between deficient and excess soil B concentrations is narrow, and it is therefore both important and difficult to uniformly supply B at a desirable concentration.

Another challenge with both nutrients is matching the timing of nutrient availability with the timing of plant need. Especially with fall applications, which are more logistically convenient for growers than spring applications, there is a high risk of losing much of the nutrient applied to leaching or immobilization before the crop is present to take it up.

EXPCMT (Mosaic Co.; 0-0-58-0.5B) is a fertilizer product providing B co-granulated in a slow-release formula. Co-granulating the two nutrients makes it easier to uniformly apply B and avoid pockets of B deficiency or excess in the field. The slow-release characteristics may simplify the challenge of matching the timing of nutrient availability with the time when the nutrients are required by the crop.

The purpose of this study was to evaluate the effectiveness of EXPCMT as a source of K and B relative to MOP (0-0-60) and granular B (15% B), applied in the fall versus spring before planting. A split spring-hilling application of MOP and granular B was included for comparison with the slow-release formula applied in spring.

Methods

Study design

The study was conducted at the Sand Plain Research Farm in Becker, MN, in 2019, on a Hubbard loamy sand soil. The previous crop was soybeans. Nine treatments were applied in a randomized complete block design with four replicates. Eight of these treatments are in two groups of four, one receiving fertilizer treatments on December 21, 2018, and one on April 24, 2019. In each of these groups, one treatment received no K or B fertilizer, one received 300 $lbs \cdot ac^{-1}$ K_2O equivalent as MOP (0-0-60) with no B, one received the same rate of K as MOP plus 2.6 $lbs \cdot ac^{-1}$ B as 15% granular B, and one received the same rates of K and B as EXPCMT, a slow-release B version of Aspire (0-0-58-0.5B, Mosaic, Inc.). The ninth treatment received 300 $lbs \cdot ac^{-1}$ K_2O equivalent as MOP plus 2.6 $lbs \cdot ac^{-1}$ B as 15% granular B, split equally between an April 24, 2019, application and a May 23, 2019, application. The fall and spring applications were broadcast by hand, while the hilling application (applied to the ninth treatment in May 2019) was sidedressed by hand. These treatments are summarized in Table 1. In total, there were 36 plots in the study, each 20 feet long and 12 feet (four rows) wide.

Soil sampling

Pre-treatment soil samples to a depth of six inches were collected on April 10, 2019, and sent to the University of Minnesota Research Analytical Laboratory (St. Paul, MN) to be analyzed for Bray P; NH_4OAc-extractable K, Ca, and Mg; $Ca(H_2PO_2)_2$ / Ba-extractable SO_4-S; hot-water-extractable B; DTPA-extractable Cu, Fe, Mn, and Zn; soil water pH; and LOI soil organic matter content. NO_3-N concentrations in two-foot soil samples collected on the same date were measured using a Wescan Nitrogen Analyzer. Results are presented in Table 2.

Planting, fertilizer application, emergence, stand counts

Whole “B” Russet Burbank seed tubers were planted in all plots on April 29, with rows spaced 36 inches apart and seed pieces spaced 12 inches apart within rows. At planting, 30 $lbs \cdot ac^{-1}$ N, 128 $lbs \cdot ac^{-1}$ P_2O_5, 0.5 $lbs \cdot ac^{-1}$ S, and 1 $lb \cdot ac^{-1}$ Zn were banded as a blend of 277 $lbs \cdot ac^{-1}$ MAP (11-50-0) and 2.8 $lbs \cdot ac^{-1}$ Blu-Min (17.5 % S, 35.5% Zn). 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 23, 170 $lbs \cdot ac^{-1}$ N and 30 $lbs \cdot ac^{-1}$ S were banded to all treatments as 327 $lbs \cdot ac^{-1}$ ESN (Environmentally Smart Nitrogen, Nutrien; 44-0-0) and 125 $lbs \cdot ac^{-1}$ ammonium sulfate (22-0-0-24S). The at-hilling K application was applied to the split-application treatment (treatment 9) at the same time. These fertilizers were hilled in at application. Plant stand in the central 18 feet of the middle two rows of each plot was determined on June 5 and 12. The number of stems per plant was determined for ten plants from the stand assessment area on June 13. Supplemental N was applied to all plots on July 8 and 15 at 10 lbs·ac^{-1} per application and on July 25 at 20 lbs·ac^{-1}, all as 28% UAN.

Petiole sampling

On June 19 and July 2, 18, and 31, the petiole of the fourth mature leaf from the shoot tip was collected from 20 leaves per plot. Petioles were dried at 140°F until their weight was stable, ground, and sent to the Research Analytical Laboratory of the University of Minnesota (St. Paul, MN) to determine their K and B concentrations through an inductively coupled plasma spectrometer (ICP).

Tuber harvest

The vines were killed with Reglone and LI 700 on September 13, and tubers were harvested from the central 18 feet of the middle two rows of each plot on September 27. Tubers were sorted by size and grade between October 7 and October 10. Twenty-five-tuber subsamples were collected for each plot, stored at 48°F, and assessed for hollow heart, brown center, and scab, 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 GLIMMIX procedure. Dependent variables were modeled as functions of treatment and block. Treatment means were determined and pairwise comparisons made using the LSMEANS procedure with the DIFF option. Pairwise comparisons were made only when the effect of treatment was significant at $\alpha = 0.10$, and the same threshold was used to determine the significance of each pairwise comparison. Contrasts of the effects of K fertilization (treatments 1 and 5 contrasted with treatments 2 and 6), B fertilization (treatments 2 and 6 contrasted with treatments 3 and 7), spring versus fall K applications (treatments 2 – 4 contrasted with treatments 6 – 8), and B source (treatments 3 and 7 contrasted with treatments 4 and 8) were analyzed using CONTRAST statements.

Results and discussion

Tuber yield, size, and grade

Results for tuber yield, size, and grade are presented in Table 3. Total yield, marketable yield, and the yield of U.S. No. 1 tubers were significantly affected by treatment, while the yield of U.S. No. 2 tubers was not. Based on the contrast comparing the check treatments (treatments 1 and 5) with the treatments receiving MOP without B (treatments 2 and 6), applying K fertilizer significantly increased marketable yield and the yield of U.S. No. 1 tubers. The treatments receiving MOP plus B in fall or spring before planting (treatments 3 and 7) and the treatment receiving EXPCMT in fall (treatment 4) had higher marketable yields than the check treatments (treatments 1 and 5) or the treatment receiving split spring and hilling applications of MOP plus B (treatment 9). The contrast comparing the treatments receiving MOP plus granular B (treatments 3 and 7) to those receiving MOP alone (treatments 2 and 6) indicate that applying B somewhat increased total yield.

The contrast comparing the check treatments (treatments 1 and 5) to those receiving MOP without B (treatments 2 and 6) indicates that applying K fertilizer increased the percentage of yield represented by tubers over six or ten ounces. Based on the contrast comparing the treatments receiving MOP plus granular B (treatments 3 and 7) with those receiving MOP alone (treatments 2 and 6), applying B somewhat decreased the percentage of yield in tubers over ten ounces, but it significantly increased yields of six- to ten-ounce tubers. The treatments receiving K (treatments 2 – 4 and 6 – 9) all had more of their yield in tubers over six ounces than the check treatments (treatments 1 and 5), with the difference being significant for the treatments receiving MOP (without B) or EXPCMT in the fall (treatments 2 and 4) or MOP plus B in the spring (treatment 7). The treatments receiving MOP in fall or spring (treatments 2 and 6) both had more of their yield in tubers over 10 ounces than their counterparts receiving MOP plus B (treatments 3 and 7), but the difference was only significant for treatment 2 versus 3.

Tuber quality

Fertilizer treatment was significantly related to the prevalence of hollow heart and marginally significantly related to the prevalence of brown center. In each case, the treatments receiving K without B (treatments 2 and 6) had a significantly lower prevalence than the zero-K check treatments (treatments 1 and 5). However, neither condition was found in more than 4% of the tubers in any treatment. Based on the contrast estimating the effect of K fertilization, applying K (without B) decreases the prevalence of scab compared to the zero-K checks, which had the highest prevalence of scab in the study.

Tuber specific gravity was higher in the treatment receiving MOP in the fall (treatment 2) than in any other treatment. Specific gravity was lower in the treatments receiving MOP plus B in spring or split application (treatments 7 and 9) and the treatment receiving EXPCMT in spring (treatment 8) than in any other treatment. Based on the contrasts, applying B decreased tuber specific gravity, and the treatments receiving K in the fall had higher tuber specific gravity than those receiving K in spring or split applications. Tuber dry matter content did not respond significantly to fertilizer treatment.

Conclusions

The results of this study indicate that fertilizing Russet Burbank potatoes with K increases tuber size and marketable yield while decreasing the prevalence of hollow heart, brown center, and scab. These results are consistent with previous findings on the effects of K on potato tuber production.

The addition of B increased total yield marginally significantly and slightly, while increasing the yield of six- to ten-ounce tubers substantially. B application tended to decrease tuber size slightly. Applying K plus B also decreased tuber specific gravity compared to applying K alone. Our previous research on co-granulated K and B has found that B fertilization either increases tuber yield and size or has no significant effect on it, while having no effect on tuber specific gravity. Applying K in the fall resulted in higher tuber specific gravity than applying it in the spring or split between spring and hilling. Application timing did not otherwise affect tuber yield or quality.

The EXPCMT formulation of K and B showed no significant advantages over MOP with granular B. Split-applied MOP plus B produced somewhat lower yields than a single application of the same fertilizers or EXPCMT in the spring. This suggests that under the conditions of this study a late (i.e., at hilling) application of K and B is less beneficial than an early application, and that the split application did not mimic the slow-release characteristics of spring-applied EXPCMT very well.

It is worth noting that, in 2018, spring K application produced higher yields and larger tubers than fall K application, while in 2019, there was a weak trend in the opposite direction. In both seasons, EXPCMT's performance relative to that of MOP plus B was slightly better when the fertilizers were fall-applied than spring-applied. These results suggest that fall K application carries a yield penalty in some years but not in others, and that the slow-release characteristics of EXPCMT may slightly mitigate that penalty, while conferring no advantage in a spring application.

Table 1. Treatments applied to Russet Burbank potatoes grown at the Sand Plain Research Farm in Becker, MN, in 2019 to evaluate EXPCMT as a slow-release formulation of K and B.

Treatment	Fertilizer application timing	Fertilzers applied[1]	Nutrients applied (lbs·ac^{-1})[2]	
			K_2O	B
1	Fall *(December 21, 2018)*	Check	0	0
2		MOP	300	0
3		MOP + 15% B	300	2.6
4		EXPCMT	300	2.6
5	Spring *(April 24, 2019)*	Check	0	0
6		MOP	300	0
7		MOP + 15% B	300	2.6
8		EXPCMT	300	2.6
9	Split[3]	MOP + 15% B	300	2.6

[1] MOP (muriate of potash): 0-0-60. EXPCMT: 0-0-58-0.5B.

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

[3] Half applied in spring, half at emergence

Table 2. Initial soil characteristics at the study site in 2019. Soil NO_3-N concentration was determined for samples taken to a depth of two feet. All other characteristics were measured in samples taken to a depth of six inches.

0 - 2 feet	0 - 6 inches				
Primary macronutrients			Secondary macronutrients		
NO_3^--N	Bray P	K	Ca	Mg	SO_4-S
(mg·kg^{-1} soil)					
2.7	28	117	866	195	5.0

0 - 6 inches							
Micronutrients					Other characteristics		
Fe	Mn	Zn	Cu	B	pH	Organic matter	Cation exchange capacity
(mg·kg^{-1} soil)						(%)	(meq·100g^{-1})
19	6	4.0	0.81	0.24	7.0	1.4	6.1

Table 3. Effects of K and B treatments on Russet Burbank tuber yield, grade, and size in 2019.

Treatment	Fertilizer application timing	Fertilzers applied[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	Fall	Check	80	205	193 bc	38	6	522 bcd	402 d	40	442 cd	45 bc	8 d
2		MOP	56	198	198 b	78	23	553 abc	458 abc	39	497 ab	54 a	18 a
3		MOP + 15% B	71	223	212 ab	57	16	580 a	470 abc	38	509 a	49 abc	12 bcd
4		EXPCMT	61	195	214 ab	80	23	574 a	480 a	33	513 a	55 a	18 ab
5	Spring	Check	67	216	160 c	34	11	488 d	398 d	23	421 d	42 c	9 d
6		MOP	58	190	188 bc	61	22	519 cd	423 cd	38	461 abcd	52 ab	16 abc
7		MOP + 15% B	59	195	238 a	64	12	568 ab	471 ab	37	509 a	55 a	13 abcd
8		EXPCMT	65	213	212 ab	57	12	560 abc	466 abc	28	494 abc	50 ab	12 cd
9	Split[2]	MOP + 15% B	65	193	196 b	58	7	520 cd	428 bcd	26	455 bcd	50 ab	13 bcd
Significance (P-value)			0.1678	0.2301	*0.0686*	0.1006	0.3640	**0.0335**	**0.0370**	0.1389	**0.0463**	*0.0789*	*0.0556*
Contrasts	K effect (trts 1 & 5 vs. 2 & 6)		**0.0100**	0.1115	0.2720	**0.0060**	**0.0367**	0.1218	*0.0502*	0.1914	**0.0392**	**0.0061**	**0.0014**
	B effect (trts 2 & 6 vs. 3 & 7)		0.1855	0.1349	**0.0394**	0.4323	0.1801	*0.0652*	0.1433	0.9208	0.1851	0.7825	*0.0864*
	Fall vs. Spring K (trts 2-4 vs. 6-8)		0.6847	0.4122	0.6947	0.2435	0.2866	0.2195	0.3375	0.5826	0.3190	0.9064	0.2225
	B source effect (3 & 7 vs. 4 & 8)		0.7598	0.6030	0.4175	0.4689	0.5272	0.7240	0.9127	0.1322	0.8147	0.9000	0.3451

[1] MOP (muriate of potash): 0-0-60. EXPCMT: 0-0-58-0.5B.

[2] Half applied in spring, half at emergence

Table 4. Effects of K and B treatment on Russet Burbank tuber quality in 2019.

Treatment	Fertilizer application timing	Fertilzers applied[1]	Hollow heart (% of tubers)	Brown center (% of tubers)	Scab (% of tubers)	Specific Gravity	Dry matter (%)
1	Fall	Check	2 ab	3 ab	14	1.0864 b	21.7
2		MOP	1 bc	1 bc	3	1.0887 a	21.4
3		MOP + 15% B	2 ab	2 abc	5	1.0862 b	21.8
4		EXPCMT	1 bc	0 c	8	1.0865 b	21.0
5	Spring	Check	4 a	3 ab	9	1.0863 b	21.5
6		MOP	0 c	0 c	5	1.0856 b	21.4
7		MOP + 15% B	0 c	0 c	7	1.0836 c	21.0
8		EXPCMT	1 bc	1 bc	7	1.0821 c	20.4
9	Split[2]	MOP + 15% B	4 a	4 a	3	1.0816 c	20.9
Significance (P-value)			**0.0378**	*0.0904*	0.1820	**<0.0001**	0.4977

		Hollow heart	Brown center	Scab	Specific Gravity	Dry matter
Contrasts	K effect (trts 1 & 5 vs. 2 & 6)	**0.0094**	**0.0282**	**0.0110**	0.4189	0.6753
	B effect (trts 2 & 6 vs. 3 & 7)	0.4301	0.6446	0.4671	**0.0110**	0.9374
	Fall vs. Spring K (trts 2-4 vs. 6-8)	0.1935	0.4346	0.6639	**<0.0001**	0.2026
	B source effect (3 & 7 vs. 4 & 8)	0.6797	0.6310	0.5949	0.5060	0.1511

[1] MOP (muriate of potash): 0-0-60. EXPCMT: 0-0-58-0.5B.

[2] Half applied in spring, half at emergence

Optimizing planting configuration, planting density, and N rate for Russet Burbank potato production

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Summary

Planting potatoes in a bed configuration, with several rows planted between each pair of furrows, may be expected to confer advantages over the conventional hilled-row configuration. In particular, the more uniform spacing of the bed configuration may allow the crop to more efficiently intercept sunlight, nutrients, and water, which may result in improved yields and reduced nutrient losses. Our research on this approach to date indicates that the bed configuration may be superior to the hilled-row configuration for whole seed tuber production, but perhaps not for processing tuber production. To determine whether these findings on are robust, we planted Russet Burbank potatoes in two configurations (bed and hilled-row) at two densities (13,000 and 34,000 seeds·ac^{-1}), applying N at three rates (150, 200, and 250 lbs·ac^{-1} N). The study had a split-plot randomized complete block design with four replicates, whole plots defined by planting configuration, and subplots defined by planting density and N rate. We analyzed the effects of these treatments on tuber yield, grade, size, and quality. Potatoes grown in the bed configuration produced somewhat more undersized tubers (suitable as whole seed) and fewer marketable tubers, with less marketable yield in tubers over six ounces, than those grown in the hilled-row configuration. Planting density had a stronger effect, with potatoes planted at high density producing substantially more undersized tubers, fewer marketable tubers for processing, and less of their marketable yield in tubers over six or ten ounces than potatoes planted at low density. N rate had little effect on tuber yield, but potatoes grown at the lowest N rate (150 lbs·ac^{-1} N) had less of their yield in tubers over six ounces than those receiving N at higher rates. Both tuber specific gravity and tuber dry matter content were higher in the bed configuration than the hilled-row configuration, higher at high density than low density, and lower in the lowest-N treatments than in treatments receiving higher rates of N. However, the results for tuber dry matter are difficult to interpret due to a significant effect of the interaction among planting configuration, density, and N rate. Petiole NO_3^--N concentrations were higher in hilled-row plots than bed plots, were higher at low density than high density, and increased with the application rate of N. Soil water NO_3^--N concentrations were higher in low-density subplots than high-density subplots. Vine and tuber N concentrations, as well as vine and total (vine plus tuber) N uptake, were lower in subplots receiving 150 lbs·ac^{-1} N than in those receiving the two higher rates. Vine N concentration and vine, tuber, and total N uptake were higher in hilled-row plots than bed plots. End-of-season soil NO_3^-—N concentration was not related to treatment. Based on these results, planting at high density in a bed configuration is superior to planting at low density or in a hilled-row configuration for whole seed tuber production. Conversely, the hilled-row configuration at low density is superior for processing-tuber production. In this particular year, the bed configuration did not confer the benefits in terms of N uptake, yield, and tuber size for processing originally hoped for.

Background

Potatoes for French fry production are grown in hilled rows, which provide furrows for drainage to prevent tubers from being exposed to excessive moisture. However, this may not be the optimal configuration in terms of tuber yield or quality, weed suppression, or the ability of the crop to intercept supplied nutrients, reducing nutrient losses. One planting configuration that has received recent attention is a bed configuration, in which several rows of potatoes are planted between widely-spaced furrows.

Because spacing is more uniform in the bed configuration than the hilled-row configuration, within-row spacing being much more similar to between-row spacing, it is plausible that potatoes grown in a bed configuration would both achieve canopy closure and spread roots throughout the available space (achieve canopy closure underground, so to speak) earlier in the season than those grown in a hilled-row configuration. This, in turn, may be expected to improve the interception of light, nutrients, and water, potentially improving tuber yields while decreasing nutrient losses.

Over the 2017 and 2018 field seasons, we evaluated the bed configuration for both seed and processing tuber production. In 2017, we focused on seed production and found that the bed configuration yielded more whole seed per acre than the hilled-row configuration, though the difference in total (whole plus cut) seed production was not statistically significant. In 2018, we tested whether the bed configuration was suitable for producing processing tubers and found that it had lower marketable yield and less yield in tubers over ten ounces than the hilled-row configuration while generating higher rates of hollow heart and brown center. These results may be due, at least in part, to poor Colorado potato beetle control, which had a stronger impact on the bed plots and would not be likely to occur in commercial production. Overall, the results of our research indicate that the bed configuration may be superior to the hilled-row configuration for producing whole seed, while it is not clear that it offers any benefits for processing tuber production.

In 2019, to determine whether our findings on the suitability of the bed configuration for whole seed production were robust, we evaluated the effects on Russet Burbank potatoes of planting configuration (bed versus hilled-row) at two densities (13,000$\cdot$ac^{-1}, suitable for processing, and 34,000$\cdot$ac^{-1}, suitable for seed) and three N rates (150, 200, and 250 lbs$\cdot$ac^{-1} N in total) in a truncated growing season suitable for seed production (85 days from planting to vine kill). A split-plot randomized complete block design was used, with four replicates, whole plots defined by planting configuration, and subplots defined by planting density and N rate.

Methods

Study design

The study was conducted in 2019 at the Central Lakes College Agricultural and Energy Center near Staples, MN, under a pivot irrigation system. The soil at the site is a Verndale sandy loam, and the previous crop was edible beans. Twelve treatments were applied in a split-plot randomized complete block design with four replicates. Whole plots were defined by planting configuration (bed or hilled-row). Plots were 12 feet wide. Bed plots had seven rows spaced 20.5 inches apart, while hilled-row plots had four rows spaced 36 inches apart. Adjacent plots were separated by three feet. Forty-foot-long subplots were defined by two levels of planting density and three levels of N application rate.

Planting and fertilizer application

Whole "B" Russet Burbank seed pieces were planted in each subplot on June 11, at a density of 13,000 pieces/ac (a within-row spacing of 24 inches in bed plots and 14 inches in hilled-row plots, typical of processing-tuber production) or 34,000 pieces/ac (a within-row of spacing 9 inches in bed plots and 5 inches in hilled-row plots, typical of seed-tuber production). Hilling was carried out immediately after planting.

N was applied to each subplot at 150, 200, or 250 lbs$\cdot$ac^{-1} in total. All treatments received 141 lbs$\cdot$ac^{-1} sulfate of potash (0-0-50-17S) at planting, providing 70 lbs$\cdot$ac^{-1} K and 24 lbs$\cdot$ac^{-1} SO_4-S, and 150 lbs$\cdot$ac^{-1} N as 28% UAN throughout the season. In addition, the lowest-N treatment received 161 lbs$\cdot$ac^{-1} TSP (0-45-0-15Ca) before planting, providing 72 lbs$\cdot$ac^{-1} P_2O_5

and 24 lbs·ac^{-1} Ca). The two higher-N treatments received as DAP applied at 161 lbs·ac^{-1} DAP (18-46-0, providing 29 lbs·ac^{-1} N and 74 lbs·ac^{-1} P_2O_5) before planting plus 48 or 161 lbs·ac^{-1} Environmentally Smart Nitrogen (ESN, 44-0-0, providing 21 or 71 lbs·ac^{-1} N).

Petiole NO_3^--N

Petioles were collected from each subplot on July 12 and 25 and August 14. The petiole of the fourth mature leaf from the shoot tip was collected from 20 shoot per subplot. The samples were dried at 140°F until their weight was stable, ground, and analyzed for NO_3^--N concentrations using a Wescan Nitrogen Analyzer.

Soil water NO_3^--N

To sample soil water at a depth of four feet, a suction-tube lysimeter was installed in each subplot on June 17 for blocks 2 – 4 and June 18 for block 1. Each lysimeter was installed near the center of the subplot and two rows in from the long edge. All lysimeters were flushed and tested on June 18. Water samples were collected on June 24, July 5, 10, 18, and 24, August 1, 9, 16, 21, and 28, and September 5 and 20. Soil water NO_3^--N concentrations were determined using a Wescan Nitrogen Analyzer.

Vine N uptake

Vine samples were collected from 15 feet of row in each subplot on September 3. In bed subplots, 3.2 feet of an edge row and 11.8 feet of the adjacent interior row were sampled. In hilled-row subplots, all 15 feet were taken from an interior row. Different sampling strategies were used because, in a field planted with a bed configuration, the plants at the edges of the beds experience a slightly different environment than those in the middles of the beds, even far from the field borders. This is not the case in the hilled-row configuration, with a single row of plants in each hill. Vine samples were weighed. A subsample was taken from each sample, weighed, dried at 140°F until its weight had stabilized, and re-weighed. The dried tissue was analyzed for total N concentration with an Elementar CNS Element Analyzer in order to estimate above-ground N uptake. The remaining vines in the field were killed with desiccant spray after the samples were taken.

Tuber harvest

Tubers were harvested by hand from the same areas used for vine sampling on September 20, 95 days after planting. The tubers were sorted and graded on October 8. Twenty-five-tuber subsamples were collected for each plot, stored at 48°F, and assessed for hollow heart, brown center, and scab, and their specific gravity and dry matter content were determined. A separate sample was dried and analyzed for total N concentration with an Elementar CNS Element Analyzer in order to estimate tuber N uptake.

End-of-season soil NO_3^--N concentration

Soil samples to a depth of one foot were collected from each plot on September 20, dried at 95°F until their weight was stable, ground, and analyzed for NO_3^--N concentration using a Wescan Nitrogen Analyzer.

Data analysis

Data were analyzed with SAS 9.4m3® software (copyright 2015, SAS Institute, Inc.) using the GLIMMIX procedure. Most variables were modeled as functions of planting configuration, population density, N application rate, and their interactions, with block as a fixed effect and block*configuration as random effect. Petiole NO_3^--N concentration was modeled in a repeated-measures analysis as a function of sampling date, planting configuration, population density, N rate, and their interactions, with block and block*configuration as fixed effects (the model could not execute with block*configuration as a random effect), sampling date as the repeated-measures variable, and plot as the subject variable. A compound symmetrical correlation matrix structure was used.

In all models, a normal data distribution was assumed and the 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 differences were considered significant when the P-value of the comparison was less than 0.10.

Results and discussion

Tuber yield, size, and grade

The results for tuber yield, size, and grade are presented in Table 2. Total tuber yield was not significantly related to treatment. Between 40% and 86% of total yield was represented by tubers under four ounces, depending on the treatment. Marketable yields were higher in subplots with a hilled-row planting configuration than a bed configuration, and substantially higher in low-density subplots than in high-density subplots. Given the lack of treatment effects on total yield, it is not surprising that the results for yield of undersized tubers were the inverse of those for marketable yield, with more undersized yield in the bed configuration and at high density than in the hilled-row configuration or at low density.

The vast majority of tubers of marketable size were U.S. No. 1, and the statistical results for this grade were essentially the same as for marketable yield as a whole. On average, U.S. No. 2 tubers accounted for less than 1% of yield, and statistically significant effects of treatment on U.S. No. 2 yield may not be practically meaningful.

The percentage of marketable yield in tubers over six ounces was higher in subplots with a hilled-row configuration than those with a bed configuration. Subplots receiving 150 $lbs \cdot ac^{-1}$ total N had significantly less of their yield in tubers over six ounces than those receiving 200 or 250 $lbs \cdot ac^{-1}$ N. The percentage of yield represented by tubers over six or ten ounces was higher in low-density than high-density subplots.

Tuber quality

Results for tuber quality are presented in Table 3. The prevalence of hollow heart and brown center was somewhat higher in low-density subplots than high-density subplots, corresponding to the higher yields of large tubers observed at low density. Low-density subplots receiving 150 $lbs \cdot ac^{-1}$ N had an especially high prevalence of hollow heart, resulting in a marginally significant effect of the interaction between planting density and N rate.

The prevalence of scab was universally low, as expected with Russet Burbank, and not significantly related to treatment.

Tuber specific gravity and dry matter content were both significantly higher in subplots planted in beds than those planted in hilled rows, and both variables were higher at the lowest N rate (150 lbs·ac^{-1} N) than in the other two. Subplots at high planting density had higher tuber specific gravity and dry matter content than those planted at low density, but the difference was only marginally significant for specific gravity. The effect of planting density on tuber dry matter content was only evident in subplots with a bed configuration, as indicated by a significant effect of the interaction between configuration and density. In addition, the relationship between N rate and tuber dry matter content depended on both planting configuration and density, resulting in a significant effect of the interaction among configuration, density, and N rate.

Petiole NO_3^--N concentration

Results for petiole NO_3^--N concentration are presented in Table 4. Season-average petiole NO_3^--N concentrations were higher in hilled-row plots than in bed plots. Season-average concentrations were also higher in low-density subplots than high-density subplots. The subplots receiving 250 lbs·ac^{-1} N had higher season-average concentrations than the subplots receiving 200 lbs·ac^{-1} N, which had higher concentrations than the subplots receiving 150 lbs·ac^{-1} N. Averaged across treatments, petiole NO_3^--N concentration decreased between each sampling time and the next. Significant differences in petiole NO_3^--N concentration between bed and hilled-row plots and between low- and high-density subplots did not emerge until the second sampling date (July 20), and the effects of date*configuration and date*density were therefore both significant. The effect of N rate on NO_3^--N concentration were also less apparent on the first sampling date (July 2) than on the last two (July 20 and August 3), but the date*rate interaction was not quite statistically significant. These results are consistent with the results for marketable yield and tuber size, indicating that tuber size was limited by the availability of N to individual plants.

Soil water NO_3^--N

Results for soil water NO_3^--N concentration are presented in Table 5. The season-average soil water NO_3^--N concentration was higher in low-density subplots than in high-density subplots, suggesting that, collectively, the plants in high-density subplots were more efficient at intercepting N in the soil than the plants in low-density subplots. However, neither planting configuration nor the application rate of N were related to the concentration of NO_3^--N in the soil water, averaged across the season.

Due to numerous gaps on the soil water NO_3^--N data, entire treatment groups are absent from 6 of the 13 sampling dates. This both prevents the use of a repeated-measures analysis and makes the statistical results for those dates questionable. Nevertheless, there were two trends in the data that are likely to be meaningful. First, all treatments showed increases in soil water NO_3^--N concentration between the first and third sampling dates (June 24 and July 10). Second, the two treatments that had among the highest soil water NO_3^--N concentrations the most consistently were the treatments planted at low density and receiving the highest rate of N.

Vine and tuber N uptake and end-of-season soil NO_3^--N

Results for vine and tuber N uptake and end-of-season soil NO_3^--N are presented in Table 6. Vine N concentration was somewhat lower in bed plots than hilled-row plots and significantly lower in plots receiving 150 lbs·ac^{-1} N than in subplots receiving 200 or 250 lbs·ac^{-1} N. Tuber N concentration was lower in the subplots receiving 150 lbs·ac^{-1} N than those receiving higher N rates. Tuber N concentration was not otherwise significantly related to treatment.

Vine N uptake was significantly greater in hilled-row plots than bed plots, and it was significantly lower in subplots receiving 150 lbs·ac^{-1} N than subplots receiving higher rates o N. Tuber N uptake was marginally significantly greater in the hilled-row plots than the bed plots, but it was not otherwise related to treatment. Results for total (vine plus tuber) N uptake were substantially similar to results for vine N uptake alone.

In Russet Burbank plants grown for a typical processing season (120 days), vine N uptake is consistently quite small compared to tuber N uptake, representing perhaps 20% of the total. In this truncated season (85 days), vine and tuber N uptake were nearly equal, on average, and vine N uptake was generally greater than tuber N uptake in the hilled-row plots. This suggests that much of the N that would normally be translocated from vines to tubers in a full-length growing season still remained in the vines at vine kill in this study.

End-of-season soil NO_3^--N concentration was not significantly related to treatment.

Conclusions

Overall, planting at high density strongly favored the production of whole-seed-sized tubers at the expense of tubers marketable for processing compared to planting at low density, while the bed planting configuration had a similar, though less pronounced, effect relative to the hilled-row configuration. No treatment produced a commercially viable marketable yield, but this is attributable to the very late planting date (June 11) and short growing season (85 days to vine kill) relative to what Russet Burbank grown for processing requires (120 days). The results for N uptake strongly suggest that the plants had not finished translocating resources from vines to tubers by the time vines were killed.

The effects of the bed planting configuration, planting density, and N rate on tuber specific gravity were consistent with small tubers having higher specific gravity than large tubers. Specific gravity was higher in bed plots than hilled-row plots, higher at high density than low density, and higher at the lowest N rate than at the other two rates. Tuber dry matter content showed similar relationships, but with higher-order interaction effects that are difficult to explain. The weak effects of planting density on the prevalence of hollow heart and brown center may also be attributable to tuber size. Larger Russet Burbank tubers are more prone to these conditions, and both conditions were more prevalent at low planting density.

The results for petiole NO_3^--N indicate that individual plants were better able to acquire N in hilled rows than in beds, at low density than at high density, and at higher N rates than at lower rates. These results generally parallel those for tuber yield and size, indicating that N availability limited the ability of plants to bulk tubers in this study.

While individual plants in low-density subplots had higher petiole NO_3^--N concentrations than those in high-density subplots, the soil water in low-density subplots also had a higher NO_3^--N concentration, averaged across the season, than the soil water in high-density subplots. This indicates that the crop in low-density subplots is not more efficient at intercepting soil N than the crop in high-density subplots. Rather, individual plants at low density face less competition for N and are therefore each able to acquire more than individual plants at high density. However, the higher soil water NO_3^--N concentrations observed at low density did not translate into high end-of-season soil NO_3^--N concentrations, as this variable did not respond significantly to treatment.

There was no effect of planting density on vine or tuber N uptake, indicating that higher N uptake at the level of individual plants at low density roughly counterbalanced the lower number of plants taking up N. Instead, planting configuration and N rate were of much greater importance, with plants in beds taking up less N per acre than those in hilled rows and N uptake increasing with N rate. Notably, the effect of planting configuration was much more pronounced in vines than tubers, which may be a result of incomplete N translocation from vines to tubers in the short growing season.

Based on these results and those of the previous two years' research, the bed planting configuration is superior to the hilled-row configuration for producing whole seed tubers. In 2019, the bed configuration did not promote more efficient interception of soil N, as initially hypothesized, and therefore did not produce higher processing yields or tuber sizes than the traditional hilled-row configuration.

Table 1. Treatments applied to evaluate the effects of planting configuration, planting density, and N rate on whole seed tuber production by Russet Burbank potatoes grown near Staples, MN, in 2019.

Planting configuration	Planting density (seed pieces·ac^{-1})	Seed spacing within row (inches)	Total N application rate (lbs·ac^{-1})[1]
Bed (row spacing 20.5 inches)	13000	24	150
			200
			250
	34000	9	150
			200
			250
Hilled row (row spacing 36.0 inches)	13000	14	150
			200
			250
	34000	5	150
			200
			250

[1] All treatments received 150 lbs·ac^{-1} N as 28% UAN throughout the season. In addition, the medium- and high-N treatments received 161 lbs·ac^{-1} DAP (18-46-0), plus 48 and 161 lbs·ac^{-1} ESN (44-0-0), respectively. The low-N treatment received 161 lbs·ac^{-1} TSP (0-48-0) to provide a similar rate of P_2O_5 to the other treatments.

Table 2. Effects of planting configuration, planting density, and N rate on tuber yield, size distribution, and grade of Russet Burbank potatoes grown near Staples, MN, in 2019.

Planting configuration	Planting density (seed pieces·ac^{-1})	Total N applied[1] (lbs·ac^{-1})	Tuber yield										
			0-4 oz	4-6 oz	6-10 oz	10-14 oz	> 14 oz	Total yield	#1s > 4 oz	#2s > 4 oz	Marketable yield	> 6 oz	> 10 oz
			cwt·ac^{-1}									%	
Bed	13000	150	216	105	32	0	0	356	130	5.1	135	9	0
		200	175	101	59	5	0	339	162	2.6	165	18	1.2
		250	186	113	35	8	0	341	155	0	155	12	2.2
	34000	150	265	41	6	0	0	308	48	0	48	2	0
		200	305	74	9	0	0	388	82	1.1	83	2	0
		250	274	72	5	0	0	351	77	0	77	1	0
Hilled row	13000	150	177	128	48	8	0	360	183	0.8	184	14	1.8
		200	179	109	69	14	2	373	194	0	194	22	4.1
		250	150	130	72	14	2	367	215	2.6	218	22	3.8
	34000	150	284	99	19	0	0	402	117	0.7	118	5	0
		200	233	79	27	3	0	341	107	0.7	108	9	0.8
		250	245	122	41	4	0	413	166	2.2	168	11	0.9
Significance of model effects (P-values)	Planting configuration		*0.0782*	**0.0017**	*0.0755*	0.2400	0.1724	0.1320	*0.0547*	0.6275	*0.0560*	*0.0677*	0.2036
	Planting density		**<0.0001**	**0.0002**	**<0.0001**	**0.0014**	0.1411	0.5669	**<0.0001**	*0.0617*	**<0.0001**	**<0.0001**	**0.0010**
	N rate		0.4444	0.1228	0.1073	0.1346	0.6189	0.8800	0.1048	0.7858	0.1107	**0.0447**	0.1115
	Configuration*density		0.8917	0.1922	0.8948	0.1922	0.2162	0.6976	0.6102	*0.0518*	0.5502	0.9636	0.1696
	Configuration*N rate		0.7418	0.1819	0.2233	0.8783	0.6189	0.4119	0.3248	**0.0094**	0.2787	0.3939	0.7672
	Density*N rate		0.9094	0.4842	0.3827	0.5860	0.7290	0.8004	0.8157	0.1758	0.8086	0.3555	0.4513
	Configuration*density*N rate		0.1591	0.5397	0.9154	0.8268	0.5255	0.1861	0.8430	0.1577	0.8556	0.8298	0.8452

[1] 150 lbs·ac^{-1} N as 28% UAN throughout the season, plus 161 lbs·ac^{-1} DAP (18-46-0) in the two higher-N treatments and 48 and 161 lbs·ac^{-1} ESN (44-0-0) in the medium- and high-N treatments, respectively.

Table 3. Effects of planting configuration, planting density, and N rate on tuber quality of Russet Burbank potatoes grown near Staples, MN, in 2019.

Planting configuration	Planting density (seed pieces·ac^{-1})	Total N applied[1] (lbs·ac^{-1})	Hollow heart	Brown center	Scab	Tuber specific gravity	Tuber dry matter content (%)
			% of tubers				
Bed	13000	150	3.4	1.2	0	1.0856	21.2 bcd
		200	0	0	0	1.0836	20.7 cde
		250	2.0	2.0	0.7	1.0810	20.5 def
	34000	150	0.5	0.8	1.0	1.0897	23.4 a
		200	0	0	0	1.0838	21.0 bcd
		250	0	0	0	1.0843	21.5 bc
Hilled row	13000	150	8.0	3.8	0	1.0843	21.8 b
		200	1.0	1.0	1.0	1.0807	19.6 f
		250	2.0	1.0	0	1.0796	20.0 ef
	34000	150	1.0	0	0	1.0828	20.8 cde
		200	3.0	0	0	1.0804	19.6 f
		250	0	1.0	0	1.0820	20.8 cde
Significance of model effects (P-values)	Planting configuration		0.1347	0.5486	0.7867	**0.0006**	**0.0001**
	Planting density		*0.0557*	*0.0734*	0.6722	*0.0937*	**0.0199**
	N rate		0.1186	0.3171	0.9688	**0.0007**	**<0.0001**
	Configuration*density		0.7158	0.5562	0.3775	0.1619	**0.0101**
	Configuration*N rate		0.5473	0.8526	0.2177	0.5311	0.5052
	Density*N rate		*0.0674*	0.6007	0.2101	0.3038	0.4328
	Configuration*density*N rate		0.4455	0.2637	0.2594	0.3735	**0.0187**

[1] 150 lbs·ac^{-1} N as 28% UAN throughout the season, plus 161 lbs·ac^{-1} DAP (18-46-0) in the two higher-N treatments and 48 and 161 lbs·ac^{-1} ESN (44-0-0) in the medium- and high-N treatments, respectively.

Table 4. Effects of planting configuration, planting density, and N rate on petiole NO_3^--N concentrations of Russet Burbank potato plants grown near Staples, MN, in 2019.

Planting configuration	Planting density (seed pieces·ac^{-1})	Total N applied[1] (lbs·ac^{-1})	Petiole NO_3^--N (mg·kg^{-1})			
			July 2	July 20	August 3	Season average
Bed	13000	150	20532	13545	4248	12775
		200	23197	14674	5527	14466
		250	24119	18088	9192	17133
	34000	150	22407	10604	3912	12308
		200	24596	14412	5049	14686
		250	25542	15353	5779	15558
Hilled row	13000	150	23689	17199	8286	16391
		200	25510	19861	9318	18230
		250	24027	20850	13211	19363
	34000	150	23044	10729	5916	13230
		200	25042	17881	8182	17035
		250	25897	21134	11901	19644
Average across treatments			23967 A	16194 B	7543 C	
Significance of model effects (P-values	Configuration					**<.0001**
	Density					**0.0443**
	N rate					**<.0001**
	Configuration*density					0.4386
	Configuration*N rate					0.7099
	Density*N rate					0.4795
	Configuration*density*N rate					0.1448
	Date		**<.0001**			
	Configuration*date		**0.0464**			
	Density*date		**0.0183**			
	N rate*date		0.1066			
	Configuration*density*date		0.8931			
	Configuration*N rate*date		0.5421			
	Density*N rate*date		0.4808			
	Configuration*density*N rate*date		0.9796			

[1] 150 lbs·ac^{-1} N as 28% UAN throughout the season, plus 161 lbs·ac^{-1} DAP (18-46-0) in the two higher-N treatments and 48 and 161 lbs·ac^{-1} ESN (44-0-0) in the medium- and high-N treatments, respectively.

Table 5. Effects of planting configuration, planting density, and N rate on soil water NO_3^--N concentrations in plots of Russet Burbank potato plants grown near Staples, MN, in 2019.

Planting configuration	Planting density (seed pieces·ac^{-1})	Total N applied[1] (lbs·ac^{-1})	Soil water NO_3^--N (ppm)													
			6/24	7/5	7/10	7/18	7/24	8/1	8/9	8/16	8/21	8/28	9/5	9/16	9/20	Season average
Bed	13000	150	9	23	40	45	31	40	44	35	33	27	54 bc	43	29	40
		200	22	29	40	45	30	26	47	37	39	34	50 bcd	33	45	36
		250	8	13	51	53	56	55	32	55	55	60	59 b	54	-	39
	34000	150	7	22	32	-	18	39	38	34	33	41	40 cde	43	52	35
		200	9	32	40	42	32	40	47	36	42	33	45 bcd	35	50	33
		250	9	18	30	41	28	36	35	37	32	23	32 de	37	-	26
Hilled row	13000	150	11	33	35	48	25	48	39	33	41	39	38 cde	33	63	36
		200	12	19	37	38	37	-	41	33	32	40	22 e	39	31	31
		250	8	-	-	46	35	45	-	56	48	52	61 b	48	75	45
	34000	150	11	30	43	47	32	29	38	43	25	32	37 de	49	45	27
		200	14	17	32	39	27	34	36	32	29	24	80 a	36	47	26
		250	8	20	32	46	35	32	40	30	31	26	24 e	42	62	33
Significance of model effects (P-values)	Planting configuration		0.9239	0.8756	0.8461	0.9189	0.9101	0.5990	0.4071	0.8135	0.3531	0.7914	0.6786	0.9322	0.7940	0.6204
	Planting density		0.4021	0.9315	0.1333	0.6645	0.2990	0.1889	0.6492	0.2590	*0.0663*	**0.0123**	0.2925	0.7884	0.7980	**0.0352**
	N rate		*0.0729*	0.1073	0.9748	0.2341	0.3879	0.3814	0.3576	0.2976	0.3608	0.3299	0.3362	0.3868	0.3293	0.5926
	Configuration*density		0.2646	0.6236	0.4796	0.6731	0.3702	0.5310	0.9902	0.9126	0.6300	0.3928	**0.0206**	0.5397	0.5400	0.7723
	Configuration*N rate		0.6219	**0.0294**	0.6536	0.3349	0.7828	0.8077	0.4402	0.8216	0.7180	0.9112	0.3441	0.9337	0.3059	0.2353
	Density*N rate		0.5268	0.8591	0.3054	0.6047	0.7576	0.1686	0.8097	0.1560	0.2272	**0.0128**	**0.0027**	0.2540	0.8539	0.5206
	Configuration*density*N rate		0.3333	0.8710	0.2197	0.4474	0.4594	0.1713	0.4445	0.7763	0.6298	0.2822	**0.0318**	0.7160	0.2194	0.9485

[1] 150 lbs·ac^{-1} N as 28% UAN throughout the season, plus 161 lbs·ac^{-1} DAP (18-46-0) in the two higher-N treatments and 48 and 161 lbs·ac^{-1} ESN (44-0-0) in the medium- and high-N treatments, respectively.

Table 6. Effects of planting configuration, planting density, and N rate on vine and tuber N concentration, N uptake into vines, tubers, and vines plus tubers, and end-of-season soil NO_3^--N concentrations in plots of Russet Burbank potato plants grown near Staples, MN, in 2019.

Planting configuration	Planting density (seed pieces·ac^{-1})	Total N applied[1] (lbs·ac^{-1})	Vine N (%)	Tuber N (%)	Vine N uptake (lbs·ac^{-1})	Tuber N uptake (lbs·ac^{-1})	Total N uptake (lbs·ac^{-1})	End-of-season soil NO_3^--N
Bed	13000	150	1.54	1.13	44	86	125	15
		200	2.02	1.19	60	84	144	18
		250	2.41	1.20	77	84	161	18
	34000	150	1.68	1.08	43	69	118	16
		200	2.17	1.05	63	86	150	16
		250	2.36	1.18	69	88	156	16
Hilled row	13000	150	2.33	1.08	83	84	167	17
		200	2.88	1.28	112	93	205	24
		250	3.20	1.38	137	100	237	18
	34000	150	2.50	1.04	93	87	180	19
		200	3.09	1.28	127	86	213	20
		250	2.84	1.25	129	107	237	21
Significance of model effects (P-values)	Planting configuration		*0.0891*	0.2943	**0.0502**	*0.0822*	**0.0227**	0.1366
	Planting density		0.8225	0.2319	0.7885	0.8437	0.8188	0.7698
	N rate		**0.0122**	**0.0335**	**0.0003**	0.1639	**0.0019**	0.3140
	Configuration*density		0.8487	0.8631	0.5833	0.6831	0.6927	0.7087
	Configuration*N rate		0.8390	0.2081	0.5785	0.6080	0.5990	0.6222
	Density*N rate		0.6455	0.9678	0.5731	0.6875	0.9373	0.5964
	Configuration*density*N rate		0.3383	0.6282	0.9293	0.5715	0.9275	0.3225

[1] 150 lbs·ac^{-1} N as 28% UAN throughout the season, plus 161 lbs·ac^{-1} DAP (18-46-0) in the two higher-N treatments and 48 and 161 lbs·ac^{-1} ESN (44-0-0) in the medium- and high-N treatments, respectively.

Data Report for UMN Potato Breeding Program 2019

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Disease Elimination

Aim: Potato disease is a major drain on industry resources. Late blight costs the US potato industry over $6.7 billion per year in control measures and lost crops[1] while PVY costs Idaho $34 million annually with similar costs in MN and ND[2]. For this reason, disease resistance must be a major target for selection in our breeding program. Although there are many known disease resistance genes in potatoes with established genetic markers[3-5], genotyping pipelines for these markers are expensive and time consuming. With the development of new technologies for rapidly screening large numbers of samples for multiple genetic markers, it has become possible to start selecting for disease resistance in FY2 of the breeding program. We implemented a program wide screen for known disease resistance genes in FY2 of the breeding program starting in 2019.

Methods: Testing for disease resistance, involved screening our FY2 population. We evaluated 648 FY2 clones in 12-hill plots. All of these had been visually selected out of the 2018 FY1. Visual selection was used again to select 184 clones for FY3.

The Excellence In Breeding Program through the Gates Foundation has entered into a contract with Intertek to use their KASP genotyping technology to screen for up to 10 SNP disease markers for potato. Their price for this including DNA extraction is $2.50/sample which is significantly cheaper than any comparable options. Therefore, we decided against pursuing development of our own panel and instead used this existing one. At the moment the panel includes markers for the known PVY resistance genes, other markers are under development.

This technique was optimized for use with leaf tissue punches. After harvest, tubers were stored until early January at which point one tuber per clone was removed from cold storage to break dormancy. Leaf punches were collected from resulting sprouts. If the process could be adapted for use with tuber tissue, waiting for plants to break dormancy and produce leaves would become un-necessary. We will submit both leaf and tuber tissue from each plant to compare the efficacy of the Intertek protocol across tissue type.

Additionally, we will extract DNA from the collected leaf tissue for genotyping on the SolCAP array.

Results: Due to the time required between harvest and sprouting we do not yet have PVY resistance data on our FY2 clones. We will, however, have the data before planting to facilitate selection next year.

Conclusions: KASP genotyping is a cost-effective way to screen our breeding material for disease resistance genes early in the breeding pipeline. We are experimenting with the use of tuber tissue for genotyping which would vastly accelerate the process.

Generation of Germplasm

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

Potatoes are highly heterozygous, meaning that even a cross between two high performing cultivars largely produces plants with no or low commercial value. Therefore, new cultivars are developed through a process of winnowing from a large number of unselected offspring from a cross, to a small number of promising clones. 2019 marks only the second field season of the re-vamped Minnesota Potato Breeding Program. At this early stage we are focused on generating a large pool of germplasm from which to select.

Methods:

Crossing Block

Our first crossing blocks took place during the winter of 2018-2019. We made 17 unique chipping crosses using 10 parents, 12 unique red crosses using 10 parents, 10 unique russet crosses using 5 parents, and 2 unique yellow crosses using 2 parents. All crosses took place in the Plant Growth Facility Greenhouses (PGF) on the University of Minnesota, St. Paul Campus. The chipping crossing block took place in November 2018 while the red and russet crossing blocks took place in February of 2019.

FY1

In 2019, we planted 29,034 single hills, the majority of which were provided to us by collaborators at North Dakota State University, University of Maine, Colorado State University, and Texas A&M. Of the single hills planted, 55% were russet, 18% were chips, 12% were red, 10% were specialty, and 5% were yellow. All single hills were planted at the NCROC and selected using visual selection.

FY2

We evaluated 648 FY2 clones this year in 12-hill plots. Of these clones, 52% were chips, 17% were russets, 16% were red, 8% were yellow, and 7% were specialty. All clones were planted at the NCROC and selected using visual selection. Additionally, post-harvest we collected quantitative measures of: specific gravity, internal defects, chip/fry color, tuber shape, tuber color, and skin set, for each of the 184 clones. This was accomplished at the USDA potato storage research facility in East Grand Forks.

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

Chipping and russet potatoes were analyzed separately for chip/fry color. For the chipping potatoes, each potato in the sample was then cut transversely, perpendicular to the stem-bud end axis. One cut was first made and discarded to provide a flat surface. Then that half was sliced three times to provide three slices per tuber for frying. The slices were blotted dry to remove surface moisture and then fried at 185° C for 2.0 minutes. For the frying potatoes, each potato was placed in a plank cutter longitudinally along the bud-stem end axis. A pneumatic piston forced the potato into the cutting grid cutting the potatoes into 9.0 x 21.0 mm planks. The planks were notched at the bud end, blotted dry, then fried at 190° C for 3.5 minutes.

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

Additionally a different subset of 10 tubers were arranged in a 3x4 grid in a Photosimile 200 lightbox, and images were taken with a Canon Rebel T6i camera using a 24mm lens, ISO 100, 1/30 sec shutter speed and aperture f/5.6. Following the methods of Caraza-Harter and Endelman[7]. Image analysis was performed in-house using the R software with the EBImage[8] package to acquire skinning, shape, and skin color data. These tubers were cut in half and internal defects were counted.

Legacy Material

When Dr. Thill unexpectedly passed in the middle of the field season, there was a variety of promising material in the breeding pipeline. Dr. Asunta Thompson, Spencer Barriball, Dr. Thomas Michaels, and Peter Imle made selections from this material in order to decide what would stay in the program. The majority of these clones were then grown for five growing seasons in our trial field at the Sand Plains Research Center (SPRF) in Becker, MN. These lines showed visual evidence of multiple virus infections. In order to evaluate these clones for release they had to be put through anti-viral tissue culture.

We selected 37 of the original 60 clones, by selecting individuals which fit market class requirements, were genetically unique, and had not been previously rated poorly in regional trials. Katelyn Filbrandt, our tissue culture specialist, has successfully brought 36 of these 37 varieties through tissue culture.

To accomplish this we first bleached tubers to produce clean sprouts. These sprouts were collected and put into tissue culture. Once established in culture, the sprouts were sub-cultured onto anti-viral media and subjected to heat treatment. Sprouts were removed from heat treatment when they appeared to be close to, but not entirely, dead. Meristem tissue was removed from the heat stressed plants and again placed on anti-viral media. New plants were grown from this meristem tissue and the resulting plants were tested for virus using a combination of Agdia strips and ELISA tests. Clean plantlets were sub-cultured into magentas and then transplanted to the greenhouse, with the goal of generating at least 40 mini-tubers per clone.

Results:

Crossing Block

Potatoes in general are characterized by limited potential for sexual reproduction. Of pollinations in the chipping crossing block 36.3% were successful, with Denali as the most common female parent and DTO02 as the most common male parent (Figure 1). In the red crossing block 36.8% of crosses were successful with Chieftain as the most common male and female parent. Only 13% of the russet crosses were successful with W13008-1Rus as the most common male parent and MN13085 PLWR-01Rus as the most common female parent. None of the yellow crosses were successful.

FY1

We selected 2.1% of the individuals over all to continue on in the program to year 2, resulting in 597 clones to be evaluated in 12 hills in 2020.

FY2

We selected 28.4% of individuals to continue on in the program to year 3, resulting in 184 clones to be evaluated in 20 hills at the Sand Plains Research Farm in 2020. We observed variation in all traits examined. Mean specific gravity for the chips was 1.070 (standard deviation: 0.0070)(figure 2). Mean specific gravity for russets was 1.069 (standard deviation: 0.0074), while it was 1.058 for the reds (standard deviation: 0.0082). Similarly, there was a distribution for chip color scores, as measured by a Hunter Colorimeter (figure 3).

Legacy Material

We have generated PVY negative mini-tubers for 36 of the 37 legacy varieties. Testing to confirm the absence of other viruses is ongoing, with additional rounds of anti-viral culture planned if necessary. All 36 varieties will be grown in preliminary yield trials at the SPRF in 2020.

Conclusions: We have developed multiple generations of new germplasm (crosses, FY1, and FY2) that segregate for a variety of traits of interest. This material will continue to be evaluated, in 2020 and beyond, in order to identify promising new clones for Minnesota and North Dakota growers.

Additionally, we have prepared 37 legacy clones, selected by the previous breeder for evaluation in preliminary yield trials in 2020. This is another source for promising clones.

Nitrogen Efficiency

Aim: Potatoes grown on sandy soils in central Minnesota are typically grown with large amounts of added nitrogen (N). Due in part to the small rooting system[9-12], potato absorbs only 40-60% of available nitrogen[13]. The rest is lost to the environment through volatilization, denitrification and leaching. This is costly to growers and has negative environmental consequences[14-15].

One method to mitigate N loss to the environment is to breed potatoes which require less N. A first step to developing such potatoes is to identify N efficient lines both among commercial cultivars and within our breeding program. In order to identify efficient lines, we grew eight red fresh market cultivars at five nitrogen levels and evaluated yield and quality traits.

Methods: The experiment took place at the University of Minnesota SPRF In 2018 we evaluated Chieftain, Dark Red Norland, Red LaSoda, Red Norland, and 4 advanced breeding lines (MN1209PLWR-02R, MN1254PLWR-02R, MN1254PLWR-03R, and ND6002R). The same clones were planted in 2019 with the exception of ND6002R due to lack of seed.

The plots were planted in an 8 x 5 factorial arrangement in 2018 and a 7 x 5 in 2019. The first factor was the eight and seven potato genotypes in 2018 and 2019 respectively; and the second factor was N application rate. Both years were planted in a randomized complete block design with four replications. Each clone was planted in 15ft rows with 1ft within row spacing. Plots consisted of four adjacent rows, but only the center two rows were harvested.

Plots were amended with side-dressed urea (46-0-0) at hilling (approximately 20-24 days after planting) to establish rates of total applied N: 45, 90, 12, and 180 lb/A. No N fertilizer was applied to the 0.0 N rate treatment. Irrigation was applied throughout the season to maintain the plots at 80% of field capacity.

Plots were desiccated 90 days after planting and then harvested. Tubers were graded by a mechanical grader at the USDA Potato Research Laboratory in East Grand Forks, MN, into USDA small (<6.35 cm), medium (6.35 cm to 8.26 cm), and large (>8.26 cm) diameters (USDA, 2011). Yield was measured in its size component parts, and their sum for total yield.

Tuber quality data was collected from images, as described above (methods FY2). We assessed color, skinning and tuber shape.

Results: Data analysis is ongoing. However, our preliminary results suggest significant difference in how clones respond to decreased added N. Most notably, we see significant interaction between clone and N for yield ($p<2.2x10^{-16}$). For all clones except, Red LaSoda and Red Norland, our highest yield was at 120 lbs/acre N rather than 180 lbs/acre (figure 4). For Red Norland we observed the highest yield at 90 lbs/acre, where as for Red LaSoda the highest yield was at 180 lbs/acre as expected.

Drawing conclusions for our breeding material is more difficult as yield was low overall. This is likely in part due to uneven seed quality. While the commercial cultivars were grown from certified seed, the breeding material was grown from seed grown in the trial field the previous year. Additionally, our results may be confounded by the prevalence of scab and silver scurf in the trial, especially in the second year.

In terms of quality traits, N rate did not affect skinning (p=0.74) and there was no clone by N interaction (p=0.71). Lightness was affected by nitrogen ($p<2.2x10^{-14}$), with tubers grown in low N conditions being lighter in color. Clones did differ in how N effected their redness (p = 0.0016), suggesting that N recommendations for individual clones should take quality traits into account.

Conclusions: Further analysis is required to draw conclusions about this experiment, but we are confident that we are seeing clones differ in their reaction to N limitation and that this affects both skinning and quality traits.

MN13142

Aim: MN13142 is a dual-purpose russet. It is an advanced breeding clone from Dr. Christian Thill's breeding program. We are assessing it in preparation for release in collaboration with Dr. Sanjay Gupta and Dr. Carl Rosen. In small plot evaluations in two commercial field trials it has shown desirable traits including: skin toughness, tuber shape and size, and specific gravity.

This clone is of particular interest because of its long dormancy. Specifically, it can be stored at 50°F without CIPC for over 9 months. This makes the clone of potential interest to the global market, because the practice of applying CIPC to lengthen dormancy is being challenged. The European Union has adopted lower allowable residue tolerances; and consumer pressure in the US also demands reduced CIPC use.

Thus far evaluation of the clone has been limited primarily by the availability of clean seed. In order to generate the data needed for release we needed to generate breeder seed in parallel to the certified seed generation being spearheaded by industry.

Methods: In order to generate breeder seed, we transplanted 80 clones from tissue culture at our seed site, the NCROC. The morphological data for PVP was collected from these plants and others grown at the SPRF.

Concurrently, the clone was in several trials with collaborators. These include: nitrogen trials with Dr. Sanjay Gupta and Dr. Carl Rosen; multi-environment trials with Dr. Asunta Thompson (ND), Dr. Sagar Sathuvalli (OR), and Dr. David Holm (CO); industry trials with Black Gold, McCain and Cavendish; a storage trial with Dr. Darrin Haagenson, an organic trial with Dr. Charlie Higgins, and disease testing with Dr. Neil Gudmestad.

Results: We generated approximately 100lbs of breeder seed which will be used to enter MN13142 in the National Fry Processing Trial to generate further multi-environment data. This will also be used to test the effect of spacing and methods of breaking dormancy on yield for this clone.

We do not yet have data back from all of our collaborators and the North Dakota trial was lost due to flooding. Therefore, we report the results of three trials: Rosen and Gupta's trial at SPRF, Sathuvalli's trial in Oregon, and Haagenson's storage trial (Table 1). In general yield of MN13142 is on the lower side, while still higher than Russet Burbank in Oregon and Clearwater Russet in Minnesota. This may stem from undersized tubers. In the Oregon trial MN13142 produced the highest number of undersized tubers, more than twice that of Ranger Russet or Russet Burbank. This suggests that we may be able to increase yield by increasing spacing, breaking dormancy earlier, or harvesting later, all of which may result in larger tubers.

MN13142 is consistently in the middle of the pack for specific gravity, suggesting suitability for processing. Fries looked dark when fried a month following harvest (figure 5), but that may be influenced by wet and cold harvest conditions.

Dr. Gudmestad reported that MN13142 shows moderate resistance to pink rot after inoculation with *P. erythroseptica*, but susceptibility to leek from inoculation with *P. ultimum*.

Conclusions: MN13142 is a promising dual-purpose russet, with impressive dormancy. In preliminary trials tuber size has been smaller than desired and so in 2020 we will experiment with a variety of methods to increase yield through tuber size. Results from these trials will be included in the paper for this variety when it is named and released. Additionally, evaluation of the clone would benefit from further storage trials after harvest under better conditions. Participation in the National Fry Processing Trial will address this concern.

Table 1. Yield and specific gravity data from three trials. Rosen and Gupta data is averaged over 2018 and 2019 while the rest of the data is from a single year. N/As indicate that a variety was not included in that trial. All OR data is from Dr. Sagar Sathuvalli. All MN data is from Dr. Sanjay Gupta and Dr. Carl Rosen. The GF data is from Dr. Darrin Haagenson in East Grand Forks MN.

Variety	Yield OR	Yield MN	US #1s OR	US #1s MN	Specific Gravity GR	Specific Gravity MN	Specific Gravity OR
Bannock	N/A	N/A	N/A	N/A	1.0778	N/A	N/A
Clearwater Russet	N/A	376	N/A	267	1.0890	1.089	N/A
Dakota Russet	N/A	N/A	N/A	N/A	1.0897	N/A	N/A
Prospect	N/A	N/A	N/A	N/A	1.0647	N/A	N/A
Ranger Russet	828	N/A	635	N/A	1.0827	N/A	1.085
Russet Burbank	475	505	369	415	1.0819	1.080	1.076
Russet Norkotah	658	N/A	494	N/A	N/A	N/A	1.075
Umatilla Russet	N/A	474	N/A	352	N/A	1.090	N/A
MN13142	618	415	426	338	1.0773	1.087	1.082

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Team: Our breeding program logistics were managed at various parts of last year by Dr. Cari Schmitz Carley, Rachel Figueroa, and Dr. Thomas Stefaniak. Disease testing protocols were adapted for our lab and implemented by Katelyn Filbrandt, Rachel Figueroa, and Heather Tuttle. The Intertek KASP array project has been headed by Dr. Jeffrey Endelman at the University of Wisconsin and Dr. Hannele Lindqvist-Kreuze at the International Potato Center. The crossing block was managed by Rachel Figureoa and Sophia Fitzgerald, while Katelyn Filbrandt did all the tissue culture work described. Darrin Haagenson and his team provided space and expertise for grading and post-harvest phenotyping. Data analysis for the nitrogen curve experiment has been carried out by Husain Agha, Sophia Fitzgerald, and Dr. Thomas Stefaniak. MN13142 has been developed in collaboration with Dr. Carl Rosen and Dr. Sanjay Gupta in the soil science department. It was trialed by Bryan Bowen at McCain, Dr. Darrin Haagenson at the USDA Potato Storage Research Facility, Dr. Charlie Higgins, Dr. David Holm at Colorado State University, John Nordgaard at Black Gold, Alan Pranke Cavendish Farms, Dr. Asunta Thompson and Dr. Neil Gudmestad at North Dakota State University, and Dr. Sagar Sathuvalli at Oregon State University. Other members of the lab who assisted in these projects include: Colin Jones, John Larsen, Thomas McGee, Laura Schulz, and Brittany Stokes. Keith Mann and his team took care of our fields at the NCROC while Ron Faber took care of our field at SPRF. Pam Warnke and Tha Cha supported our greenhouse operations. Doug Brinkman supported our growth chamber and cold storage operations.

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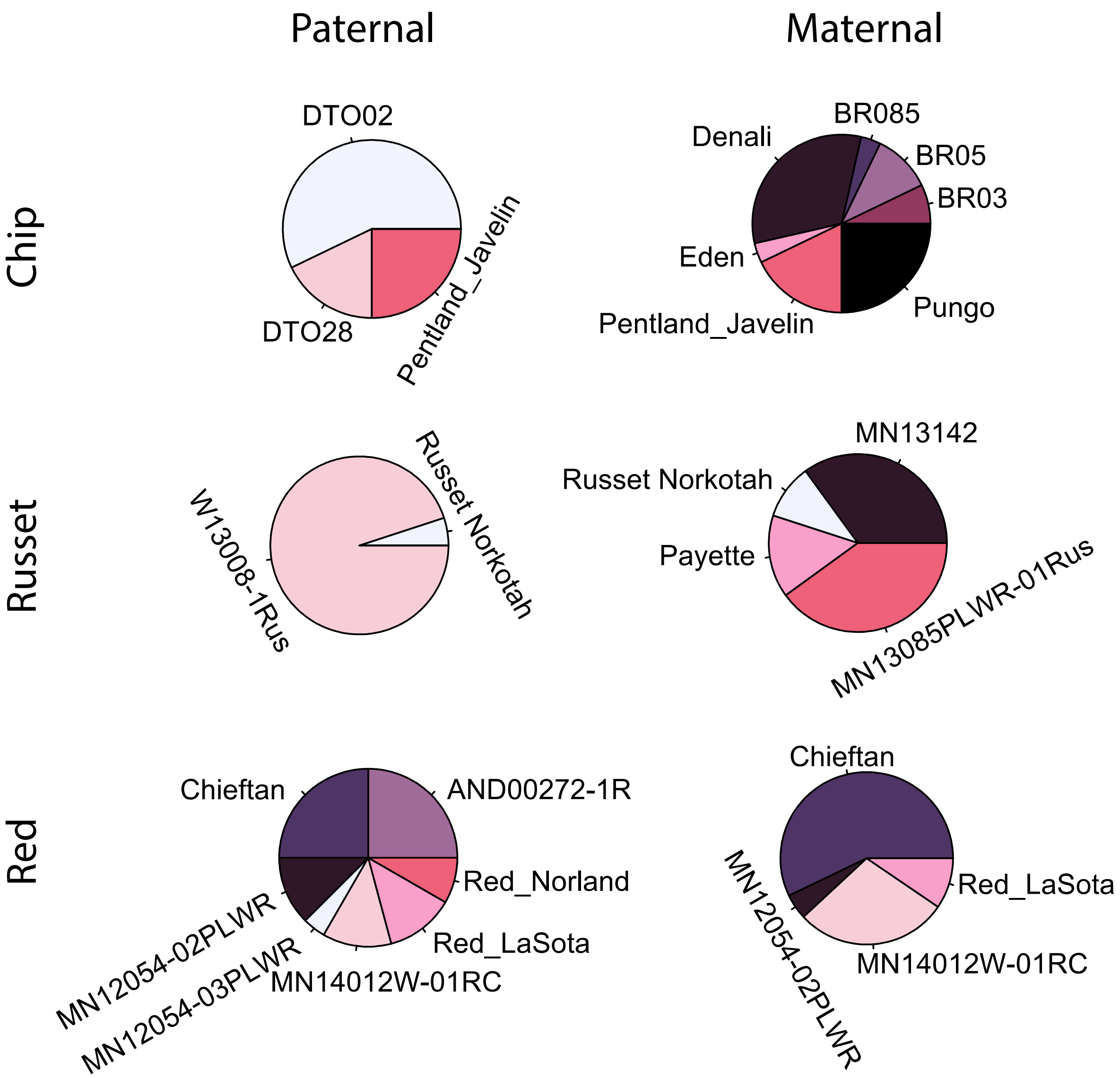

Figure 1. Winter 2018/2019 crossing blocks. Distribution of maternal and paternal parents of successful crosses for each market class.

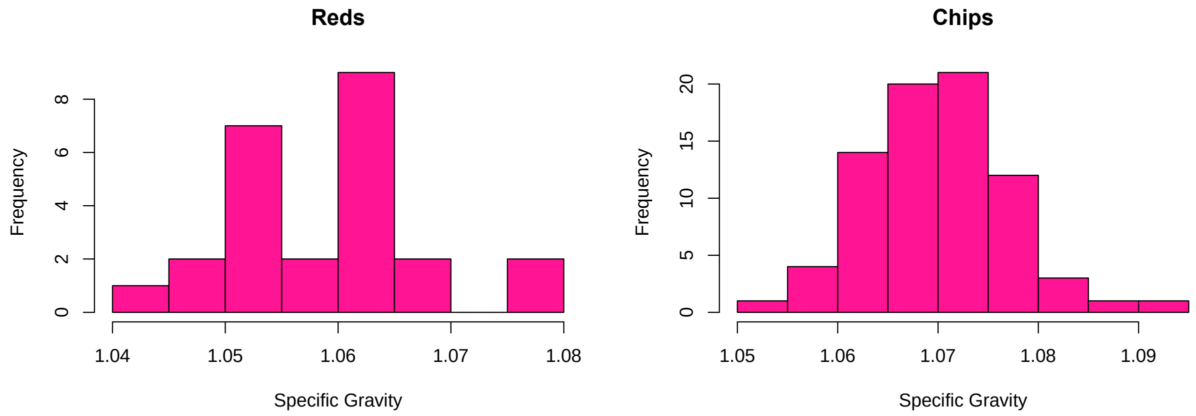

Figure 2. Distribution of specific gravities for the FY2 chips and reds. The number of russets was too low to represent in a histogram.

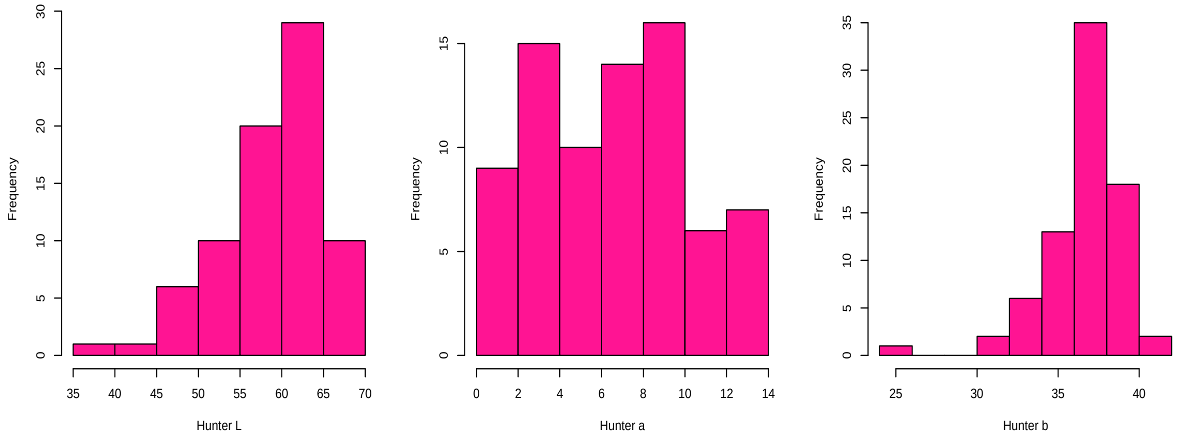

Figure 3. Hunter colorimeter scores for the FY2 chips

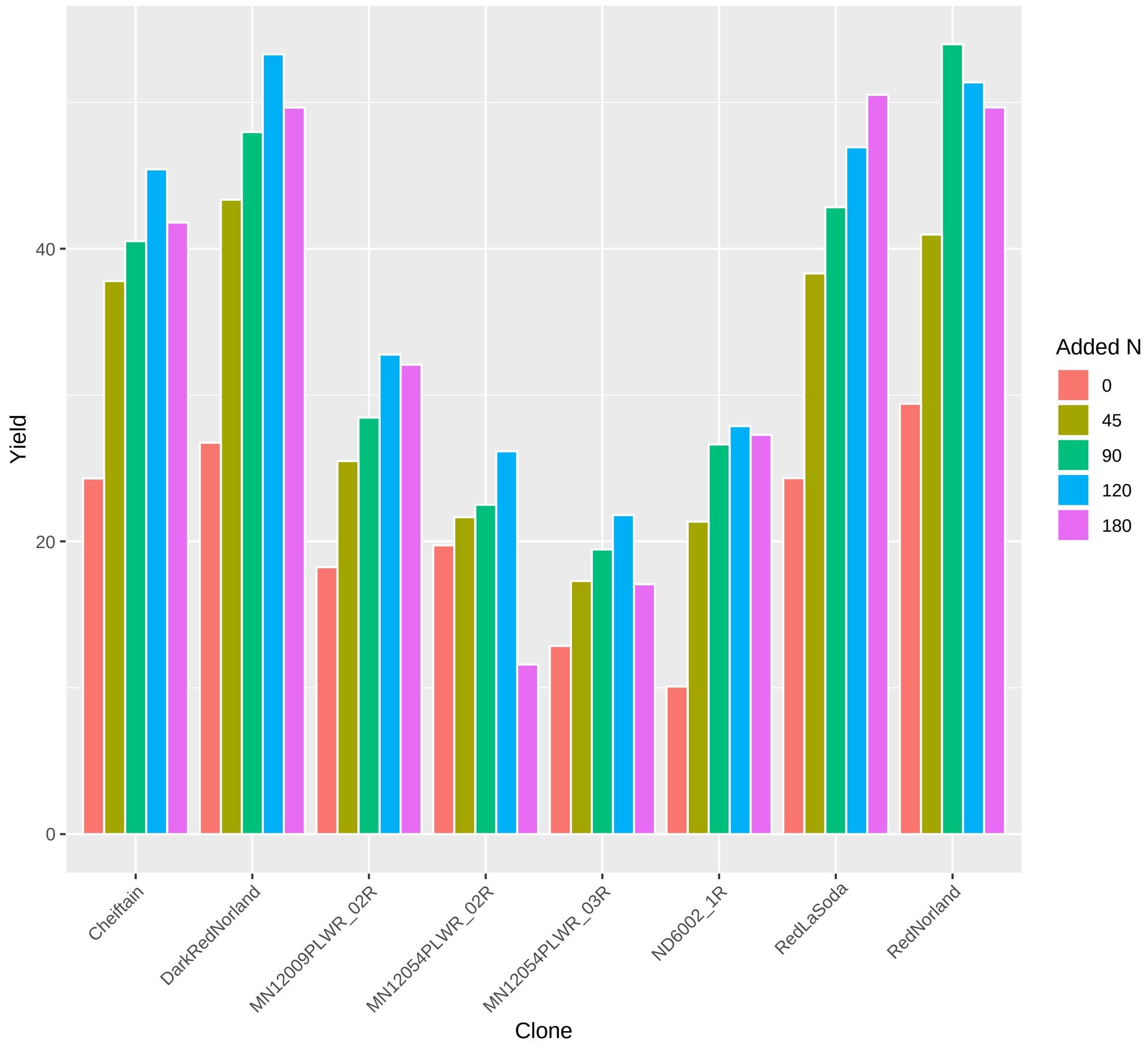

Figure 4. Best Linear Unbiased Estimates (BLUEs) for yield. These estimates are the result of 2 years of data from 8 clones grown under 5 different amounts of added nitrogen.

Planted:
5/31/19

Harvested:
10/9/19

Sugars/ff color:
11/06/19
Raw fry; 375F, 3.5minutes

Photovolt reflectance

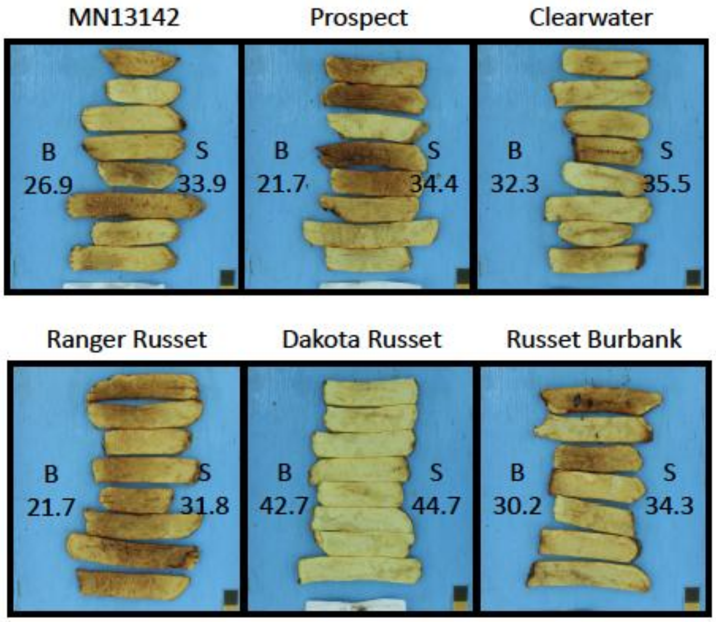

Figure 5. Fry colors after one month in storage. Figure from Dr. Darrin Haagenson.

Potato Improvement and Cultivar Development for the Northern Plains
2019 Summary

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Potato is an important horticultural crop in North Dakota, Minnesota and the Northern Plains. The North Dakota State University potato breeding program is an integral part of the potato improvement team, conducting breeding, germplasm enhancement efforts, selection, evaluation, and development of improved cultivars for stakeholder adoption. Our efforts focus on incorporating durable and long-term resistance to pests and abiotic stresses, enhanced nutrition and quality attributes, improved sustainability, and high yield and marketability.

In order to address the shortcomings of current commercial standard cultivars and the needs of the Northern Plains and Minnesota Area II potato producers and our potato industry, the following research objectives were established for 2019:

1. To develop improved germplasm and superior potato cultivars adapted to the North Dakota, Minnesota and beyond, via traditional hybridization, introgressing resistance genes for biotic pests and abiotic stresses, improved quality attributes, and resource sustainability.
2. Identify and adopt improved and efficient breeding methods including early generation selection technologies, marker assisted selection, extraction of haploids and development of inbred diploid lines, exploitation of SNP genotyping, participatory plant breeding, and others as appropriate in guiding potato breeding efforts.
3. Conduct production related evaluations for promising advancing selections and newly released cultivars, for inclusion in cultivar specific management profiles.

Our field, greenhouse, and laboratory research efforts, addressing these objectives, are summarized here. This concise review of our activities is presented somewhat chronologically for the calendar year/production season.

Seventy-six genotypes were used as parents in hybridizing efforts in 2019; 213 new families were created. Parental germplasm included named cultivars and advancing selections. Traits of focus included processing (chip and frozen) attributes, fresh market quality, PVY, late blight, Colorado Potato Beetle, and Verticillium wilt resistance, in addition to many others. Dihaploid extraction of important NDSU cultivar releases was attempted during crossing in the greenhouse; however, this effort was not successful. Stressed pollen may have been the issue. We will attempt again. Three hundred-one genotypes were submitted for SNP genotyping in 2019. We have only received about one-third of the data back to date, but this information will be utilized in a multitude of ways, including genomic selection, association (linkage) mapping, relating with phenotyping data and identifying individual genes involved in varying traits, refining marker positions, etc.

In 2019, irrigated trial sites were at Inkster, Larimore and Oakes, ND, and at Park Rapids, MN. Three trials were planted at Inkster. The metribuzin sensitivity screening trial was conducted in collaboration with Dr. Harlene Hatterman-Valenti's program. Trial results are being used to validate the model developed by a previous graduate student. The sugar end screening trial was the second year of Felicity Merritt's thesis research. A new trial in 2019 was in response to ND certified seed growers concern about efficient vine kill after repeated use of mineral oils in aphid management, in collaboration with Drs. Gary Secor and Andy Robinson. Eight vine-kill scenarios were evaluated. The Larimore trial site included the Processing Trial (20 selections, cultivars, and industry standards), the National French Fry Processing trial (46 selections compared to Russet Burbank and Ranger Russet; six were NDSU advancing selections), the preliminary processing trial with 58 entries (advancing dual-purpose russet selections compared to industry standards), an irrigated preliminary chip processing trial (106 genotypes), and maintenance of out-of-state selections. We were unable to harvest this site due to heavy rains, snow and freezing temperatures in September and October. Trials at Oakes were focused on fresh market selections and 16 promising dual-purpose russet selections compared to industry standards; common scab was not as prevalent in the fresh market genotypes as in previous years. Results for the Oakes Processing Trial are presented in Tables 7-9. Trials at Park Rapids, MN, included a processing trial with 15 entries, the common scab screening trial with 64 entries across market types, and the replicated screening trial for *Verticillium* wilt resistance (25 genotypes across market types) conducted in collaboration with Dr. Neil Gudmestad's program. Bannock Russet and Dakota Trailblazer continue to be the most resistant genotypes to Verticillium based on colony forming units of stem tissue collected right before vine kill/harvest. Promising advancing processing russet selections include ND12108CAB-3Russ, ND12109CB-2Russ, ND13103B-1Russ, ND13245C-4Russ, ND13252B-6Russ, and ND13252B-12Russ, amongst others.

Non-irrigated research sites included Crystal and Hoople ND. The non-irrigated sites were hampered by a lack of rainfall during summer 2019, with significant rain developing in early September. The Fresh Market trial had 30 entries, while the preliminary fresh market trial included 90 entries. Several fresh market selections look very promising, including ND1232B-2RY, ND1241-1Y, ND102663B-3R, ND081571-2R, ND081571-3R, ND102990B-2R, and ND113091B-2RY. Results of the Fresh Market Trial may be found in Tables 1-3. Yields and the tuber size profile were somewhat reduced, but there are many beauties coming through the pipeline. Chip processing trials were located north of Hoople, and included the Chip Processing Trial included 22 advancing chip selections compared to chip industry standards. Results are summarized in Tables 4-6. The Preliminary chip processing trial evaluated 30 selections and industry standards, and the National Chip Processing Trial (NCPT), included 98 unreplicated selections (Tier 1) and 22 replicated entries (Tier 2) from US potato breeding programs, compared to five industry chip selections. Yields and the tuber size profile were significantly impacted. Specific gravity was reduced dramatically across genotypes as well; this was unexpected as typically drouthy conditions result in abnormally high specific gravity. Outstanding chip selections coming through the program include ND7519-1, ND7799c-1, ND102642C-2, ND102922C-3, ND113307C-3, ND1221-1, ND12180ABC-8, ND13228AB-3, ND14348AB-1, ND14437CAB-1, ND14437CAB-2, and many others. ND7519-1 performed very well in the SNAC trial and will be an entry for a third and final year in 2020. It will be submitted for release consideration. Late blight screening trials at Prosper, ND, conducted in collaboration with Dr. Secor's program, were drown out in early June by excessive rain. Other trial and data summaries will be submitted to the Valley Potato Grower magazine and/or made available on the potato breeding webpage (https://ag.ndsu.edu/plantsciences).

The seedling nursery, seed maintenance plots, and increase lots were planted south of Baker, MN. All lots were entered for certification with the Minnesota Department of Agriculture and passed certification; all were submitted for winter testing. The seedling nursery included single hills from NDSU (115 families) and out-of-state cooperators including the Idaho, Maine, and Texas potato breeding programs; 722 single hills were selected. Of 776 second year selections 235 were retained; 40 of 118 third and 146 of 252 fourth year and older selections were saved. Selection is based on phenotypic recurrent selection, and production from the seed maintenance and increase lots is used as the seed source for our research and collaborative trials at NDSU, and research and industry collaborators in ND, MN, and beyond. As in previous years, several Chilean selections from the INIA program at Osorno, Chile, were evaluated in collaboration with Drs. Gary Secor and Julio Kalazich.

Urban horticulture is receiving a lot of attention in North America and beyond, due to changing demographics, interest by millennials and the Generation Z cohort, and curiosity in knowing where and how one's food is being produced. As such, a part of our efforts in 2019 were geared at sustainability, including a demonstration trial on campus, participation in an on-campus urban field day event, and several participatory opportunities working with upscale, sophisticated restaurants and associated seed companies, all geared toward sustainable food production from field to table, with an emphasis on flavor and experience.

The NDSU potato breeding program is supported by Dick (Richard) Nilles. Graduate students include Felicity Merritt, Edoardo Poletti, Hashim Andidi, James Bjerke, and Stephen Falde.

Our sincere gratitude for the support of the Northern Plains Potato Growers Association, the Minnesota Area II Research and Promotion Council, JR Simplot, our many grower cooperators including Dave and Andy Moquist, Carl, Mike and Casey Hoverson and all at Hoverson Farms, Lloyd, Steve and Jamie Oberg, Keith McGovern, Nick David, Tyler Falk, Clark Camille and all at RD Offutt Company, the Forest River Colony, Darwin Lake and all at Lamb Weston RDO Frozen, Mitch Jorde, Black Gold Farms, James F. Thompson, and so many others, for funding, hosting trials, supplying certified seed, and more…Thank you for all you do.

Table 1. Agronomic evaluations for advanced fresh market selections and cultivars, Crystal, ND, 2019. The trial was planted on May 17, vine killed on approximately September 9, and harvested with a single-row Grimme harvester on October 7. The plots were 20 feet long, with a 12-inch within row spacing, and 36 inches between rows, replicated four times.

Clone	% Stand	Vine Size[1]	Vine Maturity[2]	Stems per Plant	Tubers per Plant
1. AND00272-1R	99	3.5	3.3	3.1	6.4
2. AND07130-2R	98	4.0	4.0	2.9	8.0
3. ND6002-1R	100	3.8	4.0	1.8	3.8
4. ND081571-2R	99	3.3	3.0	2.5	6.4
5. ND102663B-3R	99	3.5	3.6	2.6	12.5
6. ND102990B-2R	100	4.0	3.3	3.4	12.4
7. ND102990B-3R	99	2.3	1.5	2.7	10.5
8. ND113091B-2RY	100	3.8	2.8	2.6	15.0
9. ND1212-1RSY	98	2.8	3.9	2.3	8.0
10. ND1232B-2RY	95	3.8	3.5	2.6	7.7
11. ND1240-2R	95	1.8	2.6	2.6	9.2
12. ND1241-1Y	95	4.0	3.3	2.7	8.5
13. ND12128B-1R	100	3.8	3.1	3.1	8.3
14. ND1382-2R	100	4.3	4.0	3.2	9.1
15. ND1382-3R	88	4.0	3.5	2.1	7.0
16. ND1393Y-3R	98	4.6	3.7	2.3	5.4
17. ND1394B-1RSY	98	4.3	2.8	2.6	6.8
18. ND13140B-3R	99	3.8	2.9	2.4	6.2
19. ND13292B-3R	91	3.3	4.0	2.0	5.4
20. ND13295B-1R	96	3.8	3.5	2.9	9.8
21. Dakota Jewel	98	4.0	3.3	2.1	5.3
22. Dakota Rose	95	3.3	3.3	2.3	5.1
23. Dakota Ruby	99	3.5	3.1	2.5	6.7
24. Gala	100	3.8	2.9	3.1	10.9
25. Red LaSoda	100	4.0	3.0	2.7	5.0
26. Red Norland	100	3.0	2.0	2.6	3.9
27. Red Pontiac	100	4.8	3.5	2.9	4.5
28. Romanze	98	4.8	4.3	2.7	8.1
29. Sangre	95	4.3	4.0	1.8	3.9
30. Yukon Gold	95	4.0	2.4	1.6	4.0
Mean	97	3.7	3.3	2.6	7.5
LSD ($\propto$=0.05)	7	0.7	0.6	0.4	1.7

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

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

Table 2. Yield and grade for advanced fresh market selections and cultivars, Crystal, ND, 2019. The trial was planted on May 17, vine killed on approximately September 9, and harvested with a single-row Grimme harvester on October 7. The plots were 20 feet long, with a 12-inch with-in row spacing, and 36 inches between rows, replicated four times.

Clone	Total Yield Cwt./A	A Size Tubers Cwt./A	A Size %	0-4 oz. %	4-6 oz. %	6-10 oz. %	>10 oz. %	% Defects
1. AND00272-1R	213	108	50	48	42	8	1	1
2. AND07130-2R	165	32	19	61	16	3	0	0
3. ND6002-1R	190	105	55	19	37	18	25	1
4. ND081571-2R	181	68	37	62	30	7	1	0
5. ND102663B-3R	206	14	7	93	6	0	0	0
6. ND102990B-2R	209	12	5	94	5	0	0	0
7. ND102990B-3R	173	10	6	93	5	1	0	0
8. ND113091B-2RY	246	17	7	92	6	1	0	1
9. ND1212-1RSY	175	40	23	75	21	2	0	2
10. ND1232B-2RY	216	91	42	57	36	7	1	1
11. ND1240-2R	106	9	9	91	6	3	0	0
12. ND1241-1Y	208	64	30	69	26	4	1	0
13. ND12128B-1R	189	40	21	78	18	3	0	0
14. ND1382-2R	164	26	16	83	14	3	1	0
15. ND1382-3R	192	80	40	55	32	9	2	2
16. ND1393Y-3R	218	126	58	29	42	15	12	1
17. ND1394B-1RSY	214	106	50	48	42	7	2	0
18. ND13140B-3R	202	62	45	4	34	12	12	0
19. ND13292B-3R	170	63	52	37	36	16	10	0
20. ND13295B-1R	186	33	21	78	17	4	1	0
21. Dakota Jewel	196	109	53	39	41	12	7	1
22. Dakota Rose	222	147	66	21	48	18	13	1
23. Dakota Ruby	216	108	50	44	40	10	4	2
24. Gala	236	43	18	82	16	2	0	0
25. Red LaSoda	260	142	55	17	36	19	27	1
26. Red Norland	229	151	68	9	43	26	22	1
27. Red Pontiac	208	123	59	22	42	17	13	6
28. Romanze	178	63	31	69	28	3	0	0
29. Sangre	185	115	62	19	39	23	17	2
30. Yukon Gold	179	112	63	21	44	18	15	2
Mean	198	76	37	56	28	9	6	1
LSD (∝=0.05)	40	31	na	na	na	na	na	na

Table 3. Quality attributes, including shape, skin color, specific gravity, bruise potential and the general rating (breeder merit score) for advanced fresh market selections and cultivars, Crystal, ND, 2019. The trial was planted on May 17, vine killed on September 9, and harvested on October 7.

Clone	Shape[1]	Color[2]	Specific Gravity[3]	Black-spot Bruise[4]	Shatter Bruise[5]	General Rating[6]
1. AND00272-1R	1.9	3.9	1.0824	2.5	2.7	3.9
2. AND07130-2R	1.0	4.1	1.0759	2.1	3.0	3.6
3. ND6002-1R	3.0	3.4	1.0782	1.8	2.7	3.0
4. ND081571-2R	1.0	4.0	1.0787	2.0	2.2	4.0
5. ND102663B-3R	1.0	4.0	1.0831	1.5	3.1	4.3
6. ND102990B-2R	1.0	3.8	1.0837	1.4	2.5	3.8
7. ND102990B-3R	1.0	3.9	1.0879	2.8	2.4	3.8
8. ND113091B-2RY	1.0	3.8	1.0925	3.1	2.0	3.6
9. ND1212-1RSY	1.0	RSY	1.0816	1.8	1.8	2.1
10. ND1232B-2RY	1.1	3.9	1.0874	3.4	2.7	3.8
11. ND1240-2R	1.0	4	1.0834	2.3	2.8	3.6
12. ND1241-1Y	1.0	Y	1.1044	2.2	2.9	4.1
13. ND12128B-1R	1.3	3.8	1.0916	2.9	2.8	3.9
14. ND1382-2R	1.0	4.0	1.0674	1.7	3.2	3.4
15. ND1382-3R	1.0	4.0	1.0690	1.9	3.1	3.8
16. ND1393Y-3R	1.8	3.4	1.0792	2.8	2.9	3.2
17. ND1394B-1RSY	1.3	RSY	1.0816	3.1	3.2	3.8
18. ND13140B-3R	1.5	3.9	1.0867	2.5	3.1	3.5
19. ND13292B-3R	1.0	4.0	1.0746	1.4	2.6	3.6
20. ND13295B-1R	1.0	4.0	1.0741	1.6	2.9	3.8
21. Dakota Jewel	1.8	4.0	1.0889	2.6	2.9	3.8
22. Dakota Rose	2.3	4.0	1.0762	2.1	3.0	3.6
23. Dakota Ruby	1.0	4.0	1.0775	1.9	3.0	3.8
24. Gala	1.0	Y	1.0805	1.3	1.6	4.1
25. Red LaSoda	3.0	3.1	1.0836	2.2	2.2	3.1
26. Red Norland	2.3	3.0	1.0780	2.4	2.4	3.1
27. Red Pontiac	3.0	2.9	1.0779	2.4	2.8	3.0
28. Romanze	2.0	4.0	1.0835	2.8	2.2	2.8
29. Sangre	3.0	3.3	1.0740	1.3	2.3	3.0
30. Yukon Gold	1.5	Y	1.0915	2.3	2.6	3.8
Mean	1.5	na	1.0818	2.2	2.6	3.5
LSD (∝=0.05)	0.5	na	0.0058	na	Na	1.3

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

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

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

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

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

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

na = not applicable

Table 4. Agronomic assessments and general rating for advancing chip processing selections and cultivars, Hoople, ND, 2019. The chip processing was planted on May 28, 2018, vine killed on approximately September 13, and harvested on October 8 using a single-row Grimme harvester. The replicated plots were 20 feet long, with a 12-inch with-in row spacing, and 38 inches between rows.

Clone	Stand %	Stems per plant	Vine Size[1]	Vine Maturity[2]	Tubers per plant	General Rating[3]
1. ND7519-1	90	2.1	3.8	3.0	2.9	3.8
2. ND7799c-1	85	1.7	2.0	1.9	2.6	3.9
3. ND8331Cb-2	86	2.6	3.5	3.0	5.7	3.0
4. ND102642C-3	89	2.3	1.5	1.5	3.3	3.3
5. ND102922C-3	93	3.0	3.8	2.9	9.0	3.9
6. ND113508C-4	90	1.9	4.0	3.0	4.8	3.1
7. ND113509C-2	94	3.1	2.0	1.1	8.5	3.6
8. ND113533AB-2	90	2.2	2.3	2.4	4.6	4.0
9. ND122C-1	96	2.9	2.5	4.0	4.3	3.3
10. ND12107CB-1	90	2.6	3.0	3.4	5.0	4.0
11. ND13228CAB-3	93	3.1	1.0	1.1	5.7	3.3
12. ND1375CB-1	85	2.4	1.5	1.1	4.8	3.6
13. ND1446CB-8	81	1.8	4.3	4.0	3.3	3.3
14. Atlantic	80	2.2	2.8	3.0	3.7	3.5
15. Dakota Crisp	86	2.1	3.0	3.1	3.3	3.5
16. Dakota Diamond	88	2.1	3.8	1.8	3.0	3.1
17. Dakota Pearl	94	2.3	2.3	1.8	3.8	3.5
18. Ivory Crisp	95	3.4	3.5	3.1	4.8	3.3
19. Lamoka	85	2.6	1.8	4.0	2.8	3.1
20. Pike	86	1.9	1.8	3.1	2.4	3.1
21. Snowden	91	2.5	3.5	4.9	2.6	3.1
22. Waneta	90	1.3	1.5	3.0	2.0	3.9
Mean	89	2.4	2.7	2.9	4.2	3.5
LSD ($\propto$=0.05)	9	0.6	0.8	0.4	0.8	0.5

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

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

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

Table 5. Yield and grade for advancing chip processing selections and cultivars, Hoople, ND, 2019. The chip processing was planted on May 28, 2019, vine killed on approximately September 13, and harvested on October 8 using a single-row Grimme harvester. The replicated plots were 20 feet long, with a 12-inch with-in row spacing, and 38 inches between rows.

Clone	Total Yield cwt./a	Yield A Size cwt/a	A Size %	0-4 oz. %	4-6 oz. %	6-10 oz. %	>10 oz. %	US 2s & Culls %
1. ND7519-1	81	40	47	48	38	8	3	2
2. ND7799c-1	76	33	40	50	31	9	10	0
3. ND8331Cb-2	96	13	12	84	11	1	0	4
4. ND102642C-3	77	26	32	66	27	5	0	1
5. ND102922C-3	135	11	8	92	7	1	0	0
6. ND113508C-4	95	22	21	78	19	2	0	1
7. ND113509C-2	144	19	12	88	11	0	0	0
8. ND113533AB-2	101	28	23	73	20	3	3	1
9. ND122C-1	69	11	14	86	13	1	0	0
10. ND12107CB-1	131	52	38	58	32	5	1	3
11. ND13228CAB-3	67	1	1	99	1	0	0	0
12. ND1375CB-1	66	5	7	93	6	1	0	0
13. ND1446CB-8	78	34	38	59	28	10	3	1
14. Atlantic	78	36	33	64	22	11	2	1
15. Dakota Crisp	88	39	38	53	29	9	5	4
16. Dakota Diamond	78	37	41	50	32	9	7	2
17. Dakota Pearl	83	10	20	74	17	3	5	1
18. Ivory Crisp	116	45	36	56	26	9	5	4
19. Lamoka	60	20	24	74	20	4	1	1
20. Pike	35	6	13	87	11	1	0	0
21. Snowden	59	20	28	67	20	8	4	1
22. Waneta	60	24	40	54	34	6	6	0
Mean	85	25	26	71	21	5	3	1
LSD ($\propto$=0.05)	30	22	16	19	12	7	7	3

Table 6. Specific gravity and chip color (USDA chip chart and HunterLab L-value) after grading and following 8-weeks storage at 5.5C (42F) for advancing chip processing selections and cultivars, Hoople, ND, 2019. Due to reduced yields, we were unable to conduct chip evaluations from 3.3C, as in previous years. The chip processing was planted on May 28, 2019, vine killed approximately September 13, and harvested on October 8 using a single-row Grimme harvester. The replicated plots were 20 feet long, with a 12-inch with-in row spacing, and 38 inches between rows.

Clone	Specific Gravity[1]	Field Chip		5.5C Storage	
		Chart[1]	Hunter[2]	Chart	Hunter
1. ND7519-1	1.0809	1	62	5	57
2. ND7799c-1	1.0613	2	65	5	59
3. ND8331Cb-2	1.0845	2	60	4	61
4. ND102642C-3	1.0721	2	65	5	58
5. ND102922C-3	1.0779	2	60	6	55
6. ND113508C-4	1.0761	4	58	6	53
7. ND113509C-2	1.0741	3	59	5	58
8. ND113533AB-2	1.0780	2	63	5	58
9. ND122C-1	1.0773	3	59	8	51
10. ND12107CB-1	1.0830	3	58	9	44
11. ND13228CAB-3	1.0760	1	63	2	63
12. ND1375CB-1	1.0707	4	58	7	51
13. ND1446CB-8	1.0744	4	56	9	45
14. Atlantic	1.0826	4	58	8	47
15. Dakota Crisp	1.0673	4	54	9	46
16. Dakota Diamond	1.0700	7	51	9	41
17. Dakota Pearl	1.0772	3	60	4	59
18. Ivory Crisp	1.0770	4	57	8	50
19. Lamoka	1.0784	4	58	8	48
20. Pike	1.0762	4	57	9	44
21. Snowden	1.0839	5	56	8	45
22. Waneta	1.0853	2	63	4	62
Mean	1.0765	3	59	6	53
LSD (∝=0.05)	0.0075	2	5	2	6

1 Specific gravity determined by weight-in-air, weight-in-water method.

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

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

Table 7. Agronomic evaluations for advanced processing selections and cultivars grown at Oakes, ND, 2019. The processing trial was planted on May 13 and harvested September 4, 2019, 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	Stand %	Stems per plant	Vine Size[1]	Vine Maturity[2]	Tubers per plant	Hollow Heart/ Brown Center %	General Rating[3]
1. ND113065CB-1Russ	98	2.8	3.0	2.1	8.3	10	3.5
2. ND113065-2Russ	99	2.3	3.3	2.1	6.9	9	3.9
3. ND12108CAb-3Russ	99	1.9	3.8	2.8	6.7	4	3.8
4. ND12109CB-2Russ	95	1.7	3.5	3.3	5.6	4	3.5
5. ND12237Y-1Russ	95	2.0	3.8	2.8	7.8	3	3.8
6. ND13103B-1Russ	96	1.9	4.8	5.0	5.2	9	3.4
7. ND13213B-1Russ	98	1.7	4.0	3.5	6.5	1	3.4
8. ND13245C-3Russ	95	1.6	2.8	2.3	8.4	0	3.3
9. ND13245C-4Russ	96	2.3	3.0	3.3	11.9	10	3.1
10. ND13252B-6Russ	91	1.9	3.5	3.5	5.7	0	3.5
11. ND13252B-12Russ	94	1.9	3.3	3.3	9.0	3	3.5
12. Dakota Russet	95	1.4	3.5	3.4	6.6	5	3.8
13. Ranger Russet	99	1.8	4.8	4.0	5.8	0	3.4
14. Russet Burbank	93	2.6	4.6	3.3	9.2	31	2.6
15. Russet Norkotah	99	2.5	3.5	2.8	11.1	25	3.8
16. Umatilla Russet	96	2.7	4.3	4.0	11.3	19	3.3
Mean	96	2.1	3.7	3.2	7.9	8	3.5
LSD (∝=0.05)	6	0.5	0.8	0.7	1.4	9	0.4

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

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

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

Table 8. Yield and grade for advanced processing selections and cultivars grown at Oakes, ND, 2019. The processing trial was planted on May 13 and harvested September 4, 2019, using a single-row Grimme harvester. Entries were replicated four times; plots were twenty feet long, with a within-row spacing of 12 inches and 36 inches between rows.

Clone	Total Yield Cwt./A	US No. 1 Cwt./A	US No. 1 %	0-4 oz. %	4-6 oz. %	6-10 oz. %	>10 oz. %	US 2s & Culls %
1. ND113065CB-1Russ	321	225	70	28	39	14	18	2
2. ND113065-2Russ	309	245	80	19	39	16	25	2
3. ND12108CAb-3Russ	392	347	88	10	36	19	33	1
4. ND12109CB-2Russ	277	227	81	17	37	17	27	2
5. ND12237Y-1Russ	388	290	75	17	31	15	29	8
6. ND13103B-1Russ	286	213	75	12	30	16	29	14
7. ND13213B-1Russ	333	283	85	14	42	21	21	1
8. ND13245C-3Russ	290	192	66	34	45	13	7	0
9. ND13245C-4Russ	357	216	60	40	37	15	8	0
10. ND13252B-6Russ	266	219	83	16	38	20	34	2
11. ND13252B-12Russ	402	328	82	17	39	18	25	1
12. Dakota Russet	380	332	87	10	36	22	29	2
13. Ranger Russet	340	294	86	10	35	17	35	3
14. Russet Burbank	424	284	67	16	34	17	17	17
15. Russet Norkotah	446	322	72	26	40	16	16	2
16. Umatilla Russet	467	339	72	23	41	18	13	4
Mean	355	272	77	20	37	17	22	4
LSD (∝=0.05)	56	52	6	6	6	4	10	3

Table 9. Specific gravity and French fry evaluations following grading and after 8-weeks storage at 7.7C (45F). Entries grown at Oakes, ND, 2019. The processing trial was planted on May 13 and harvested September 4, 2019, 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	Specific Gravity[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. ND113065CB-1Russ	1.0843	0.6	1.4	67	2.6	2.8	17
2. ND113065-2Russ	1.0741	0.5	1.3	50	2.9	3.0	17
3. ND12108CAb-3Russ	1.0942	0.5	0.5	0	1.5	2.3	50
4. ND12109CB-2Russ	1.0878	0.4	0.4	8	1.0	3.3	100
5. ND12237Y-1Russ	1.0841	1.3	1.3	0	2.6	2.6	0
6. ND13103B-1Russ	1.0899	0.3	0.4	8	1.0	1.2	25
7. ND13213B-1Russ	1.0753	0.4	0.4	0	1.7	2.0	25
8. ND13245C-3Russ	1.0887	0.9	2.0	50	2.3	3.4	58
9. ND13245C-4Russ	1.1004	0.4	0.7	17	1.3	1.7	42
10. ND13252B-6Russ	1.0805	0.3	0.3	0	1.0	1.4	50
11. ND13252B-12Russ	1.0870	0.3	0.4	8	0.6	1.1	34
12. Dakota Russet	1.0860	0.3	0.3	0	0.5	0.6	8
13. Ranger Russet	1.0845	0.4	0.6	8	1.0	1.2	8
14. Russet Burbank	1.0800	1.1	1.3	25	1.8	2.7	75
15. Russet Norkotah	1.0800	0.8	1.8	42	3.1	3.6	50
16. Umatilla Russet	1.0873	0.3	0.5	8	1.1	1.3	25
Mean	1.0850	0.5	0.8	18	1.6	2.1	36
LSD (∝=0.05)	0.0087	0.2	0.7	35	0.7	0.7	52

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

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

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

Screening Cover Crops for Managing the Root-lesion Nematode, *Pratylenchus penetrans*

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Summary

Among many biotic factors limiting the yield of potato, root-lesion nematode, *P. penetrans*, causes significant loss in potato production. This nematode alone can cause serious loss in production but can open the way for infection from other pathogens which exacerbates the severity. Nematicides are very expensive and detrimental to environment. Cover crops which are non-hosts or poor hosts and kill the nematodes through bio-fumigation can be an effective, economic and environmentally rational approach for management of *P. penetrans* in potato fields. A total of 25 cover crops which are being used and will likely be utilized in our region were screened under controlled greenhouse conditions for their hosting and population reduction abilities to *P. penetrans*. A greenhouse experiment was conducted using pasteurized soil and nematodes were artificially inoculated in the soil. Among the cover crops, 23 out of 25 cover crops were found to be reducing a greater number of nematodes from the soil than non-planted control. Winter rye (Dylan) eliminated all the nematodes initially inoculated in the soil whereas three different cultivars of oilseed radish (Control, Image, Concorde) along with annual ryegrass, turnip (Pointer) and daikon radish (Eco-till) were found to reduce more than 90% of initial nematode population. Camelina (Bison) and forage pea (Arvika) were the only cover crops having final nematode population more than the non-planted control. However, the potato cultivar Red Norland serving as a susceptible check had low nematode reproduction compared with our previous experiment and variation was observed among replicates of the same cover crop. Therefore, this experiment needs to be repeated to confirm the results to provide reliable information regarding effectiveness of different cover crops for management of *P. penetrans* in potato fields. This research will help farmers select appropriate cover crop cultivars to minimize the nematode populations in potato fields to improve potato tuber production.

Background

Root-lesion nematodes (RLN), *Pratylenchus* spp., have a wide host range and cause economic losses in many crops including potato. Among the various species of RLN, *P. penetrans* causes the most damages in potato (Waeyenberge et al. 2009). *P. penetrans* alone can cause yield reduction approximately from 30% to 70% (Holgado et al. 2009, Lazarovits et al. 1991, Olthof 1989, Philis 1995), but the damage severity can be exacerbated in the association of *P. penetrans* with bacterium *Streptomyces scabies* (Holgado et el. 2009) and fungus *Verticillium dahlia* (Powelson and Rowe 1993). The economic threshold level of *P. penetrans* to potato was found to be 100 individuals/250 g of soil in Norway (Holgado et el., 2009) but it can range from 100 to 250 nematodes per 250 g of soil in some other studies (Brodie et al. 1993, Oostenbrink 1966).

Pratylenchus penetrans can be managed through different strategies. Chemical control of *P. penetrans* with nematicides is the best approach to protect the potato yield. Despite the maximum efficiency of nematicides to control the nematode, its usage has been minimized and restricted because it is expensive and has negative impacts on environment and organisms. Various environment-friendly approaches have been introduced for control of the root-lesion nematode including resistance but moderate resistance is limited only to few crops (Davis and MacGuidwin 2014). Crop rotation is also not that effective to manage the nematode because it has a wide host range.

Cover crops may provide an alternative means to manage *P. penetrans*. Cover crops generally reduce the nematode population through different mechanisms. Cover crops of Brassicaceae family can release glucosinolates which act as biofumigants and kill plant-parasitic nematodes when they are incorporated in the soil. Cover crops that are non-hosts or poor hosts of the nematodes can decrease nematode populations whereas cover crops that are good hosts can increase nematode population densities. Cover crops may also serve as trap crops that stimulate nematode hatching but do not allow nematode reproduction. Root-lesion nematode, *P. neglectus* was significantly reduced (66%) by leaf tissues of *Brassica rapa* containing glucobrassicanapin and progoitrin (Potter et al. 1998). Two oat cultivars (Nora and TAM 606) and two mustard cultivars (Pacific Gold and Ida Gold) were good hosts whereas a wheat cultivar (Norwest 553) and a perennial ryegrass mix were poor hosts for *P. penetrans* (Rudolf et al. 2017). However, the cover crop effectiveness to control *P. penetrans* in our region is not well known.

The objective of this project was to screen 25 cover crop species and cultivars to determine their hosting and population reduction abilities to the root-lesion nematode *P. penetrans*.

Materials and Methods

Selection of cover crop species and cultivars

A total of 25 cover crops that are being used or will be likely introduced to our region of North Dakota and Minnesota were selected for screening for hosting and population reduction abilities of *P. penetrans* under controlled greenhouse conditions (Table 1). Three control treatments including unplanted pasteurized soil, potato (Red Norland), and wheat (Glenn) were used in the experiment as comparison. The cover crop seeds were acquired from Forage and Biomass Crop Production Program (North Dakota State University, Fargo, ND), Allied Seed (Nampa, ID), and Great Northern AG (Plaza, ND).

Inoculum preparation, soil processing, and nematode extraction

Naturally *P. penetrans*-infested soil collected form a potato field in central Minnesota was used for inoculum increase in July of 2019. For the inoculum preparation, susceptible host of *P. penetrans,* potato Red Norland cultivar was pre-sprouted before planting. For the pre-sprouting, potatoes were spread in plastic trays with moist paper towels in the bottom and incubated for 15 days at room temperature of 22°C. That helps potato to sprout and develop some roots before planting and provides early food for nematode infection. Sprouted potatoes were cut into 2 to 3 pieces each with sprouts. Cutting of potatoes was done 3-4 days before planting in order to provide adequate time for healing of cut sections.

Potatoes were planted in plastic pots of 20 cm x 15 cm (1.5 kg soil capacity) and kept in the greenhouse with 16-hour day light and average temperature of 25 °C for 10 weeks. A single sprouted piece of potato was used per pot and was covered with appropriate amount of soil. After 10 weeks, the potatoes were harvested, and each soil and root sample collected from each pot with a plant were placed in a plastic tray (36 cm × 27 cm). Roots from each pot were separated from soil and then were rinsed with tap water. Those rinsed plant roots were cut into 1-cm small pieces and nematodes were extracted from those roots using Whitehead tray method (Whitehead and Hemming 1965) by incubation of 48 hours. Root-lesion nematodes were identified and counted under an inverted light microscope (Zeiss Axiovert 25, Carl Zeiss Microscopy, NY, USA). Then required number of fresh inoculum was prepared and the inoculum was kept at 4°C at the NDSU Nematology Laboratory before setting up the cover crop experiment.

Cover crop greenhouse experiment

A greenhouse experiment was conducted to screen 25 cover crop species and cultivars for management of *P. penetrans*. For the experiment, an initial population inoculation rate of 675 *P. penetrans*/kg of soil was used. This experiment was started in October, 2019.

The soil was collected from a potato field in Sargent County, ND and then was pasteurized before it was used for planting. Pasteurized soil was prepared by mixing slow release fertilizer (14-14-16 NPK) at a rate of 5 g per kg of soil. Each container and pot were filled with 160 g and 1 kg of pasteurized soil, respectively before planting. Containers were arranged in 14 × 7 well plastic racks and pots were arranged on a greenhouse bench, both in a completely randomized design (CRD). Pots were used for six cover crops with large root system including oilseed radish (cultivars: Image, Concorde and Control), daikon radish (cultivar: Eco-till), turnip (cultivars: Purple top and Pointer), and potato (Red Norland). All other entries of cover crops, non-planted pasteurized soil control and wheat (Glenn) were planted in containers.

A single pre-sprouted potato piece was placed below soil in center of each pot and covered with appropriate amount of soil. Other crops were direct-seeded (2-3 seeds per container depending upon seed size and germination) around the center of container or pot at 2-3 cm depth below the soil surface. A single plant was kept in all the pots or containers for all the entries. Excess plants were removed from the pots and containers before nematode inoculation. Each cultivar was replicated four times. Nematode artificial inoculation was done 15 days after planting. The experiment was conducted in the Agriculture Experiment Station, NDSU greenhouse with 16 hour- day light at an average temperature of 22 °C and kept for 12 weeks. Plant tops were removed before the soil, along with roots, were stored in a cold room (4 °C) in separate individual plastic bags. Nematodes were extracted within one week.

Nematode extraction form soil and roots, identification, and counting

After harvesting the trial, the soil and roots from containers and pots were processed differently. Nematodes were extracted from roots and soil in the containers using Whitehead tray method (Whitehead and Hemming 1965). For this, all the roots were cut into 1-cm long pieces and thoroughly mixed with all the soil from the same container and incubated for 48 hours. Nematode number obtained was converted to the total number of *P. penetrans* in 1 kg of soil. Nematodes from pots were extracted by using both Whitehead tray extraction method and sugar centrifugal-flotation method (Jenkins 1964). Soil and roots from a pot were placed in a tray (36 cm × 27 cm) and roots were separated and rinsed with tap water. Roots were cut into 1-cm pieces and nematodes were extracted using the Whitehead tray method after incubating for 48 hours. Remaining soil after separating roots were mixed thoroughly and a subsample of 200 g was taken from each pot for nematode extraction using the sugar centrifugal-flotation method. Extracted nematodes were kept in 50 ml suspension tubes and those nematodes in the tubes were identified and counted separately using an inverted light microscope (Zeiss Axiovert 25, Carl Zeiss Microscopy, NY, USA). Nematodes population extracted from 200 g of soil were converted to total number of *P. penetrans* in 1 kg of soil and nematode numbers obtained from roots of each plant were added to the corresponding nematode population from soil to get the final nematode population for each pot.

Data analysis

The average final nematode population was obtained from four replicates of each crop species/cultivar. Population reduction was calculated using the formula [(initial nematode population – final nematode population)/initial nematode population x 100]. Data were analyzed using the SAS software (SAS 9.4, SAS Institute Inc., Cary, NC). The general linear model (GLM) with Tukey’s honestly significant difference (HSD) mean separation at a significance level of 5% was used to determine the significant difference in the final nematode populations and population reduction (PR) for the screened cover crops.

Results and discussion

Camelina (Bison) had the highest final nematode population of *P. penetrans* among the cover crops followed by Forage pea (Arvika), and only those two cover crops had higher numbers of final nematode population than the non-planted control (Table 2, Fig. 1). In this experiment, forage oat reduced the nematode population by 84% (Table 2). It was also shown as a poor host in different reports (Forge et al. 2000, Vrain et al. 1996). However, some other studies (Bélair et al. 2002, Rudolf et al. 2017, Thies et al. 1995) reported oat as a good host of *P. penetrans* while Grabau et al. (2017) found no significant effect of oat on *P. penetrans*.

Three cultivars of oilseed radish (Control, Concorde, and Image) along with daikon radish cultivar Eco-till were found to reduce more than 90% of initial nematode population (Table 2, Fig. 2) in our experiment. Nevertheless, Grabau et al. (2017) found the oilseed radish cultivar Defender as a good host for the root-lesion nematode, *P. penetrans.* We found winter rye (Dylan) to eliminate all the initial nematodes from the soil while only 4 % of the initial nematode population was recovered from the soil planted with annual rye grass. These results showed winter rye and annual ryegrass as non-hosts for *P. penetrans*. Different studies have shown different status of winter rye as host for the root-lesion nematode. Mbiro (2016) found winter rye as a poor host for *P. penetrans* but it was found to be a good host by Marks and Townshend (1973). Rye appeared to be a host in greenhouse conditions but reduced nematode population in field experiment (Forge et al. 2000).

On average, sunn hemp, Mighty mustard (Kodiak), white mustard (Master), forage pea (Arvika), crimson clover (Dixie), all reduced the initial nematode population but some of the replicates for those cover crops during the experiment showed increased final nematode population which indicated their potential as possible hosts for *P. penetrans.* We noticed high reduction in initial nematode population on Japanese millet and foxtail millet (Siberian) in our study but those crops were found to be good hosts in a previous study conducted in Quebec, Canada (Bélair et al. 2002). Alfalfa cultivars Narragansett and Saranac were reported to have different effects on the nematode in an experiment (Miller 1978). These results indicated that some cover crops with different cultivars have shown variable effects against *P. penetrans.*

The potato cultivar Red Norland serving as a susceptible check had a very low nematode reproduction compared with our previous experiment. Similarly, the wheat control showed low nematode reproduction rates except one replicate during the experiment. As mentioned above, some replicates for cover crops such as sunn hemp, Mighty mustard, white mustard, forage pea, and crimson clover had variation in responses to *P. penetrans*. These observations indicated that this experiment needs to be repeated to confirm the results to provide reliable information.

Conclusions

Cover crops can be utilized effectively for management of root-lesion nematodes depending upon their hosting ability to the nematodes and for the improvement of soil health. We screened 25 cover crops which are being utilized or will be introduced in our region under the controlled greenhouse environment for management of the root-lesion nematode *P. penetrans*. Winter rye (Dylan) was found to eliminate all the artificially inoculated nematodes from the soil. We recovered almost 60% of initial population of nematodes from the non-planted control. Cover crops showed more population reduction capacity than the non-planted control indicating that they have potential to be used as effective cover crops for management of *P. penetrans.* This screening showed 23 out of 25 cover crop species and cultivars reduced a greater number of *P. penetrans* than the non-planted control. This experiment needs to be repeated to validate the results obtained as the potato cultivar Red Norland had low nematode reproduction and different studies reported variable efficiency of different cultivars of cover crops for management of *P. penetran* in potato fields.

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Table 1. List of cover crops and controls tested for the root-lesion nematode, *P. penetrans* under controlled greenhouse conditions.

Crop (Cultivar or Cultivar Not Stated = CNS)	**Scientific Name**	**Family**
Alfalfa (Bullseye)	*Medicago sativa* L.	Fabaceae
Annual ryegrass (CNS)	*Lolium multiflorum* L.	Poaceae
Camelina (Bison)	*Camelina sativa* (L.) Crantz	Brassicaceae
Carinata (CNS)	*Brassica carinata* L.	Brassicaceae
Crambe (Belann)	*Crambe abyssinica*	Brassicaceae
Crimson clover (Dixie)	*Trifolium incarnatum* L.	Fabaceae
Daikon radish (Eco-till)	*Raphanus sativus* L.	Brassicaceae
Ethiopian cabbage (CNS)	*Brassica carinata* L.	Brassicaceae
Faba bean (Petite)	*Vicia faba* Roth	Fabaceae
Flax (Carter)	*Linum usitatissimum* L.	Linaceae
Forage oat (CNS)	*Avena sativa* L.	Poaceae
Forage Pea (Arvika)	*Pisum sativum*	Fabaceae
Foxtail millet (Siberian)	*Setaria italica* subspp. R*ubofructa* (L.) P. Beauv.	Poaceae
Japanese millet (CNS)	*Echinochloa esculenta* L.	Poaceae
Mighty Mustard ™ brown mustard (Kodiak)	*Brassica juncea* L.	Brassicaceae
Oilseed radish (Concorde)	*Raphanus sativus* L.	Brassicaceae
Oilseed radish (Control)	*Raphanus sativus* L.	Brassicaceae
Oilseed radish (Image)	*Raphanus sativus* L.	Brassicaceae
Potato (Red Norland)	*Solanum tuberosum*	Solanaceae
Sunn hemp (CNS)	*Crotolara juncea* L.	Fabaceae
Turnip (Pointer)	*Brassica rapa subsp. rapa* L.	Brassicaceae

Turnip (Purple top)	*Brassica rapa subsp. rapa* L.	Brassicaceae
Wheat (Glenn)	*Triticum aestivum* L.	Poaceae
White mustard (Master)	*Sinapis alba* L.	Brassicaceae
White proso millet (CNS)	*Panicum miliaceum L*	Poaceae
Winter camelina (Joelle)	*Camelina sativa* (L.) Crantz	Brassicaceae
Winter rye (Dylan)	*Secale cereale* L.	Poaceae
Non-planted pasteurized soil control		

Table 2. Average final nematode population and nematode population reduction for different cover crops under the controlled greenhouse conditions.

Crop (Cultivar or Cultivar Not Stated = CNS)	Final nematode population [a]	Nematode population reduction (%) [b]
Alfalfa (Bullseye)	177.5	73.7
Annual ryegrass (CNS)	25.0	96.3
Camelina (Bison)	725.0	-7.4
Carinata (CNS)	260.0	61.5
Crambe (Belann)	278.8	58.7
Crimson clover (Dixie)	451.3	33.2
Daikon radish (Eco-till)	50.0	92.6
Ethiopian cabbage (CNS)	378.8	43.9
Faba bean (Petite)	116.3	82.8
Flax (Carter)	183.3	72.8
Forage oat (CNS)	111.3	83.5
Forage pea (Arvika)	490.0	27.4
Foxtail millet (Siberian)	132.5	80.4
Japanese millet (CNS)	126.3	81.3
Mighty mustard (Kodiak)	408.8	39.5
Oilseed radish (Concorde)	62.5	90.7
Oilseed radish (Control)	6.8	99.0
Oilseed radish (Image)	17.3	97.5
Sunn hemp (CNS)	425.0	37.0
Turnip (Pointer)	30.8	95.5
Turnip (Purple top)	133.0	80.3
White mustard (Master)	336.3	50.2
White proso millet (CNS)	208.8	69.1

Winter camelina (Joelle)	246.3	63.5
Winter rye (Dylan)	0.0	100.0
Non-planted pasteurized soil control	466.3	30.9

[a] Final nematode population is average of final nematode populations of four replications for all treatments.

[b] Nematode population reduction is average of % reduction in nematode populations from four replications for all treatments. Nematode population reduction (%) = (initial population on the tested crop - final population on the tested crop)/initial population on the tested crop x 100.

(-) sign indicates population increase.

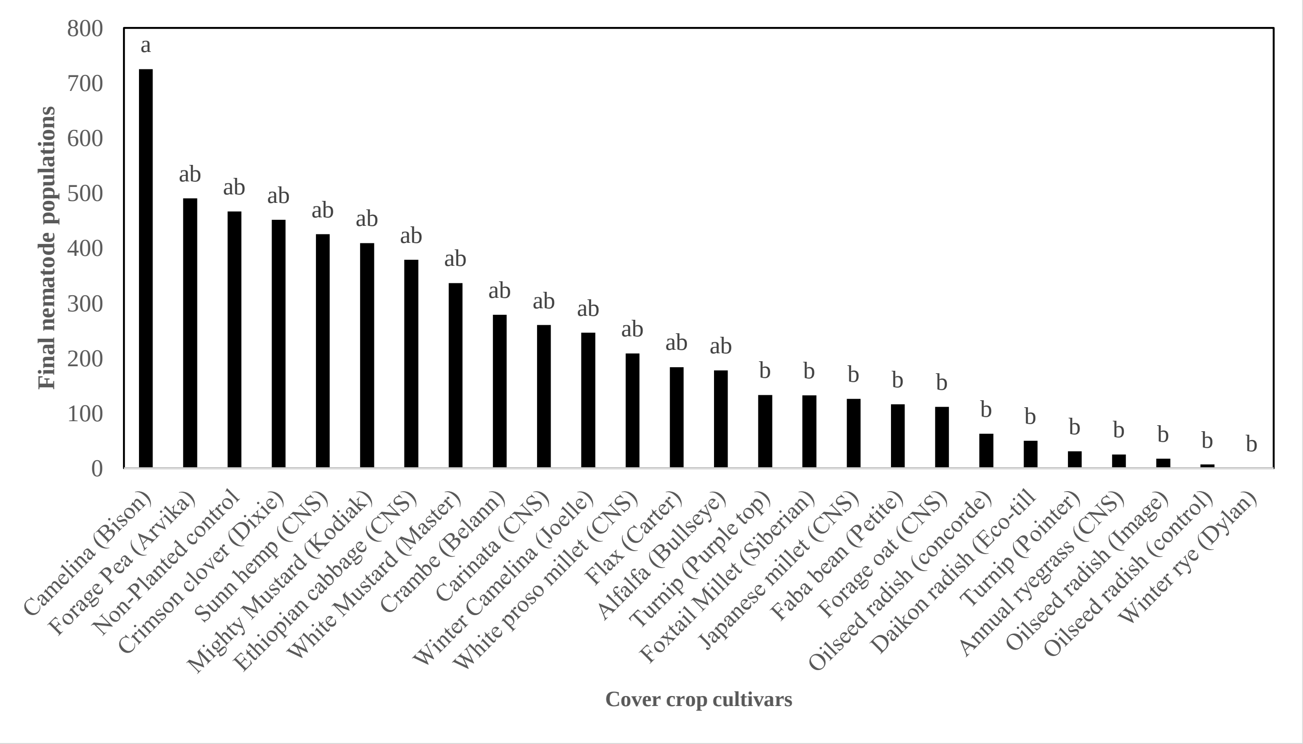

Fig. 1. Final nematode populations of *P*. *penetrans* on 25 cover crop species and cultivars grown in greenhouse conditions, with initial population of 675 *P*. *penetrans*/kg of soil. Final population is the mean of four replications for each treatment. Final populations with same letters are not significantly different according to the Tukey's honestly significant difference (HSD) ($P < 0.05$).

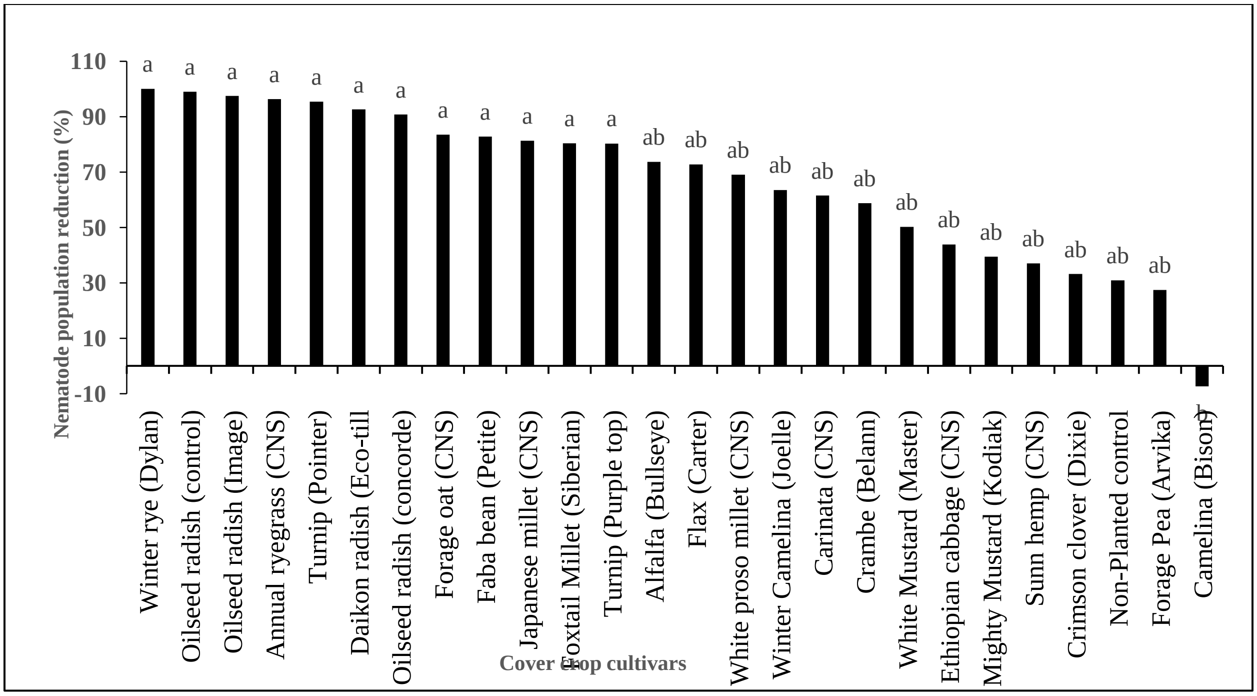

Fig. 2. Nematode population reduction (%) of *P. penetrans* by 25 different cover crop species and cultivars grown in greenhouse conditions, with initial population of 675 *P. penetrans*/kg of soil. Nematode population reduction is the mean of four replications for each treatment. Nematode population reductions with same letters are not significantly different according to the Tukey's honestly significant difference (HSD) (*P* < 0.05).

Response of ‘Atlantic’ and ‘Dakota Pearl’ Daughter Tubers from Mother Plants Exposed to Sublethal Glyphosate and Dicamba –Matthew Brooke and H. Hatterman-Valenti.

The increased use of glyphosate and dicamba tolerant soybean can result in off-target exposure and damages to seed potato tubers. For certified seed potato growers, this would affect yields in the current season as well as plant emergence the following growing season. The objective of this study was to determine the effects of ‘Atlantic’ and ‘Dakota Pearl’ potato (*Solanum tuberosum* L.) tubers, used for seed from mother plants that were previously exposed to glyphosate, dicamba, or the combination of both herbicides. Mother plants in 2018 received either glyphosate at 40 or 197 g ae ha^{-1}, dicamba at 20 or 99 g ae ha^{-1}, or the low or high combination of glyphosate and dicamba at the tuber initiation stage. Random samples of daughter tubers from each treatment were stored in a cooler until cut as 70 g seed pieces for plant back.

Two field locations were used near Oakes, ND. The soil type at the first location was a Gardena loam and had corn as a previous crop, while the second location was a Swenoda fine sandy loam and had soybean as the previous crop. Seed pieces, for both locations, were planted on May 13, 2019. At 8 weeks after planting (WAP), daughter tubers from mother plants receiving glyphosate at 197 g ha^{-1}, or the combination of glyphosate and dicamba, had reduced emergence by 17% and 24% when compared to the non-treated, respectively (Table 1). Furthermore, at 7 WAP, daughter tubers from mother plants receiving the combination of dicamba at 99 g ha^{-1} and glyphosate at 197 g ha^{-1} or glyphosate at 197 g ha^{-1} had reduced plant height by 16 and 20%, respectively, compared to the non-treated (Table 2). Daughter plants from the mother plants that received the combination of glyphosate at 197 g ha^{-1} and dicamba at 99 g ha^{-1} had 21% total yield reduction and canopy reduction when compared to the non-treated (Table 3). Results suggest that the combination of glyphosate at 197 g ha^{-1} and dicamba at 99 g ha^{-1}, carried over from mother plants to daughter tubers for both cultivars the following growing season, affecting emergence, plant growth, and total yield. Further research needs to evaluate the influence of environmental stresses on the potato response to sub-lethal amounts of glyphosate and/or dicamba.

Table 1. Plant emergence (percent) from seed pieces from mother plants that were treated with sublethal rates of glyphosate and/or dicamba the previous growing season, and evaluated weekly starting at five weeks after planting (WAP) in 2019 near Oakes, ND.

Cultivar		Plant Emergences[a]			
		5 WAP	6 WAP	7 WAP	8 WAP
		Plant Emergence (%)			
Atlantic		69	78	83	84
Dakota Pearl		71	84	90	93
Herbicide					
Glyphosate	Dicamba	5 WAP	6 WAP	7 WAP	8 WAP
g ae ha^{-1}		Plant Emergence (%)			
0	0	95 a	99 a	99 a	99 a
197	99	50 b	71 cd	82 b	86 b
40	20	80 a	90 ab	94 a	95 a
0	99	80 a	83 bc	85 b	86 b
197	0	45 b	59 d	69 c	75 c

Cultivar x Herbicide						
	Glyphosate	Dicamba	5 WAP	6 WAP	7 WAP	8 WAP
	——g ae ha^{-1}——		——— Plant Emergence (%) ———			
Atlantic	0	0	96 a	99 a	99 a	99
	197	99	61 cde	78 bcd	85 bc	87
	40	20	75 abc	84 abc	90 ab	91
	0	99	67 bcd	70 cde	73 de	74
	197	0	44 ef	54 e	63 e	68
Dakota Pearl	0	0	94 a	99 a	99 a	99
	197	99	41 f	64 de	78 cd	86
	40	20	88 ab	96 ab	98 a	99
	0	99	91 a	95 ab	97 ab	97
	197	0	45 def	64 de	74 cde	82
P value						
Cultivar			0.6344	0.2993	0.1700	0.1324
Herbicide			0.0066	0.0065	0.0029	0.0059
Cultivar x Herbicide			0.0265	0.0127	0.0388	0.0657

[a] Numbers followed by the same letter in a column are not significantly different according to LS Mean separation comparison at α=0.05. No significant differences within a column were observed when no letters are included.

Table 2. Daughter plant heights for seed pieces from mother plants that were treated with sublethal rates of glyphosate and/or dicamba the previous growing season, and measured weekly starting at five weeks after planting (WAP) in 2019 near Oakes, ND.

Cultivar		Plant Heights[a]				
		5 WAP	6 WAP	7 WAP	8 WAP	9 WAP
		——— Plant Height (mm) ———				
Atlantic		100	246	348	497	594
Dakota Pearl		102	226	343	483	585
Herbicide						
Glyphosate	Dicamba	5 WAP	6 WAP	7 WAP	8 WAP	9 WAP
—— g ae ha^{-1}——		——— Plant Height (mm) ———				
0	0	135 a	289a	411a	563a	655a
197	99	65 b	181b	269b	416c	526c
40	20	114 ab	247a	377a	503ab	598ab
0	99	126 a	282a	378a	533a	618a
197	0	65 b	180b	292b	434bc	550bc
P value						
Cultivar		0.8110	0.4053	0.7712	0.4848	0.7498
Herbicide		0.0414	0.0089	0.0100	0.0174	0.0230
Cultivar x Herbicide		0.6067	0.1425	0.1606	0.7139	0.8774

[a] Numbers followed by the same letter in a column are not significantly different according to LS Mean separation comparison at α=0.05. No significant differences within a column were observed when no letters are included.

Table 3. Total yield and marketable yield, of ‘Atlantic’ and ‘Dakota Pearl’ from potatoes treated with glyphosate and dicamba in 2019 at Oakes, ND.

Cultivar		Potato Yield[a]	
		Total Yield	Marketable Yield
		———T ha^{-1}———	
Atlantic		38	30
Dakota Pearl		39	30
Herbicide			
Glyphosate	Dicamba	Total Yield	Marketable Yield
—— g ae ha^{-1} ——		———T ha^{-1}———	
0	0	43 a	31 ab
197	99	34 b	27 bc
40	20	42 a	34 a
0	99	42 a	33 a
197	0	32 b	26 c
P value			
Cultivar		0.5643	0.7705
Herbicide		0.0185	0.0419
Cultivar x Herbicide		0.2031	0.2815

[a] Numbers followed by the same letter in a column are not significantly different according to LS Mean separation comparison at α=0.05. No significant differences within a column were observed when no letters are included.

Marketable yield includes U.S. No 1 and U.S No. 2 tubers > 4oz.

Potato response to pre-plant and at plant fertilizer treatments. H. Hatterman-Valenti and C. Auwarter.

Field research was conducted at the Northern Plains Potato Growers Association irrigated research site near Inkster, ND to evaluate the response of Russet Burbank potatoes to Paralign and other products in-furrow with 10-34-0 fertilizer. Plots were four rows by 20 ft. arranged in a randomized complete block design with 4 replicates. Seed pieces (2 oz) were planted on 36-inch rows and 12-inch spacing on May 31, 2019. Urea (46-0-0) at 50 pounds was applied at hilling (18 DAP), while additional nitrogen was applied through the irrigator three times during the season with 20 pounds of nitrogen per time. Extension recommendations were used for cultural practices throughout the year. The trial was desiccated September 19 and the middle two-rows harvested October 25. Row ‘A’, when harvested, was dug and weighed in the field. Row ‘B’, is bagged and the tubers were brought back to NDSU to be graded. A majority of the yield analysis comes from Row ‘B’.

2019 Inkster, ND Soil Test.

Depth	N	P	K	pH	EC	OM	S	Zn	Fe	Mn	Cu	Cl	Ca	Mg	Na	CEC
(in)	lb/a	ppm	ppm			%	lb/a	ppm	ppm	ppm	ppm	lb/a	ppm	ppm	ppm	
0-6	4	33	167	5.8	0.06	1.8	3	1.27	35.1	31.6	0.46	3.2	3311	231	14	18.9

PRE-Plant and Planting Treatment List.

1	**PRE-Plant**					
	46-0-0	104 lb/a	48N			
	11-52-0	96 lb/a	11N	50P		
	0-0-52-18	114 lb/a			59K	21S
	13.75-0-46	114 lb/a	16N		52K	
	At Planting					
	10-34-0	12.5 gpa	15N	50P		
	Total		**90N**	**100P**	**111K**	**21S**

2	**Pre-Plant**					
	46-0-0	104 lb/a	48N			
	11-52-0	96 lb/a	11N	50P		
	WC501	4 qt/ton				
	0-0-52-18	114 lb/a			59K	21S
	13.75-0-46	114 lb/a	16N		52K	
	At Planting					
	10-34-0	12.5 gpa	15N	50P		
	Total		**90N**	**100P**	**111K**	**21S**

3	**PRE-Plant**					
	46-0-0	104 lb/a	48N			
	11-52-0	96 lb/a	11N	50P		
	0-0-52-18	114 lb/a			59K	21S
	13.75-0-46	114 lb/a	16N		52K	
	At Planting					
	10-34-0	12.5 gpa	15N	50P		
	WC238	4 floz/a				
	Total		**90N**	**100P**	**111K**	**21S**

4	**Pre-Plant**					
	46-0-0	104 lb/a	48N			
	11-52-0	96 lb/a	11N	50P		
	WC501	4 qt/ton				
	0-0-52-18	114 lb/a			59K	21S
	13.75-0-46	114 lb/a	16N		52K	
	At Planting					
	10-34-0	12.5 gpa	15N	50P		
	WC238	4 floz/a				
	Total		**90N**	**100P**	**111K**	**21S**

5	**PRE-Plant**					
	46-0-0	104 lb/a	48N			
	11-52-0	96 lb/a	11N	50P		
	0-0-52-18	114 lb/a			59K	21S
	13.75-0-46	114 lb/a	16N		52K	
	At Planting					
	10-34-0	12.5 gpa	15N	50P		
	WC477	4 floz/a				
	Total		**90N**	**100P**	**111K**	**21S**

6	**Pre-Plant**					
	46-0-0	104 lb/a	48N			
	11-52-0	96 lb/a	11N	50P		
	WC501	4 qt/ton				
	0-0-52-18	114 lb/a			59K	21S
	13.75-0-46	114 lb/a	16N		52K	
	At Planting					
	10-34-0	12.5 gpa	15N	50P		
	WC477	4 floz/a				
	Total		**90N**	**100P**	**111K**	**21S**

7	**PRE-Plant**					
	46-0-0	104 lb/a	48N			
	11-52-0	96 lb/a	11N	50P		
	0-0-52-18	114 lb/a			59K	21S
	13.75-0-46	114 lb/a	16N		52K	
	At Planting					
	10-34-0	11 gpa	13N	44P		
	Paralign	3 gpa	2N	5P	1K	
	Total		**90N**	**99P**	**112K**	**21S**

8	**Pre-Plant**					
	46-0-0	104 lb/a	48N			
	11-52-0	96 lb/a	11N	50P		
	WC501	4 qt/ton				
	0-0-52-18	114 lb/a			59K	21S
	13.75-0-46	114 lb/a	16N		52K	
	At Planting					
	10-34-0	11 gpa	13N	44P		
	Paralign	3 gpa	2N	5P	1K	
	Total		**90N**	**99P**	**112K**	**21S**

9	**PRE-Plant**					
	46-0-0	104 lb/a	48N			
	11-52-0	96 lb/a	11N	50P		
	0-0-52-18	114 lb/a			59K	21S
	13.75-0-46	114 lb/a	16N		52K	
	At Planting					
	10-34-0	11 gpa	13N	44P		
	Redline	3 gpa	2N	4P	1K	
	Total		**90N**	**98P**	**112K**	**21S**

10	**Pre-Plant**					
	46-0-0	104 lb/a	48N			
	11-52-0	96 lb/a	11N	50P		
	WC501	4 qt/ton				
	0-0-52-18	114 lb/a			59K	21S
	13.75-0-46	114 lb/a	16N		52K	
	At Planting					
	10-34-0	11 gpa	13N	44P		
	Redline	3 gpa	2N	4P	1K	
	Total		**90N**	**98P**	**112K**	**21S**

11	**PRE-Plant**					
	46-0-0	104 lb/a	48N			
	11-52-0	96 lb/a	11N	50P		
	0-0-52-18	114 lb/a			59K	21S
	13.75-0-46	114 lb/a	16N		52K	
	At Planting					
	10-34-0	11 gpa	13N	44P		
	Paralign	3 gpa	2N	5P	1K	
	WC238	4 floz/a				
	Total		**90N**	**99P**	**112K**	**21S**

12	**Pre-Plant**					
	46-0-0	104 lb/a	48N			
	11-52-0	96 lb/a	11N	50P		
	WC501	4 qt/ton				
	0-0-52-18	114 lb/a			59K	21S
	13.75-0-46	114 lb/a	16N		52K	
	At Planting					
	10-34-0	11 gpa	13N	44P		
	Paralign	3 gpa	2N	5P	1K	
	WC238	4 floz/a				
	Total		**90N**	**99P**	**112K**	**21S**

13	**PRE-Plant**					
	46-0-0	104 lb/a	48N			
	11-52-0	96 lb/a	11N	50P		
	0-0-52-18	114 lb/a			59K	21S
	13.75-0-46	114 lb/a	16N		52K	
	At Planting					
	10-34-0	11 gpa	13N	44P		
	Redline	3 gpa	2N	4P	1K	
	WC238	4 floz/a				
	Total		**90N**	**98P**	**112K**	**21S**

14	**Pre-Plant**					
	46-0-0	104 lb/a	48N			
	11-52-0	96 lb/a	11N	50P		
	WC501	4 qt/ton				
	0-0-52-18	114 lb/a			59K	21S
	13.75-0-46	114 lb/a	16N		52K	
	At Planting					
	10-34-0	11 gpa	13N	44P		
	Redline	3 gpa	2N	4P	1K	
	WC238	4 floz/a				
	Total		**90N**	**98P**	**112K**	**21S**

15	**PRE-Plant**					
	46-0-0	104 lb/a	48N			
	11-52-0	96 lb/a	11N	50P		
	0-0-52-18	114 lb/a			59K	21S
	13.75-0-46	114 lb/a	16N		52K	
	At Planting					
	10-34-0	11 gpa	13N	44P		
	Paralign	3 gpa	2N	5P	1K	
	WC477	4 floz/a				
	Total		**90N**	**99P**	**112K**	**21S**

16	**Pre-Plant**					
	46-0-0	104 lb/a	48N			
	11-52-0	96 lb/a	11N	50P		
	WC501	4 qt/ton				
	0-0-52-18	114 lb/a			59K	21S
	13.75-0-46	114 lb/a	16N		52K	
	At Planting					
	10-34-0	11 gpa	13N	44P		
	Paralign	3 gpa	2N	5P	1K	
	WC477	4 floz/a				
	Total		**90N**	**99P**	**112K**	**21S**

17	**PRE-Plant**					
	46-0-0	104 lb/a	48N			
	11-52-0	96 lb/a	11N	50P		
	0-0-52-18	114 lb/a			59K	21S
	13.75-0-46	114 lb/a	16N		52K	
	At Planting					
	10-34-0	11 gpa	13N	44P		
	Redline	3 gpa	2N	4P	1K	
	WC477	4 floz/a				
	Total		**90N**	**98P**	**112K**	**21S**

18	**Pre-Plant**					
	46-0-0	104 lb/a	48N			
	11-52-0	96 lb/a	11N	50P		
	WC501	4 qt/ton				
	0-0-52-18	114 lb/a			59K	21S
	13.75-0-46	114 lb/a	16N		52K	
	At Planting					
	10-34-0	11 gpa	13N	44P		
	Redline	3 gpa	2N	4P	1K	
	WC477	4 floz/a				
	Total		**90N**	**98P**	**112K**	**21S**

There were small differences in canopy coverage (Table 1). At 41 DAP using the Canopeo App the top two treatments with the most canopy coverage were treatments 3 and 14. Both these treatments had WC238 added to the starter fertilizer at planting. At 53 DAP, treatment 14 had the highest percentage of canopy coverage with 95.64%. The only other treatment that had at least 95% coverage at this time was treatment 18 with 95.18%. All treatments had at least 90% canopy coverage.

All potato treatments had yields greater than 400 cwt/A (Table 2). Row 'A' potatoes yielded higher in 15 of the 18 treatments vs Row 'B'. This was attributed to muddy conditions during harvest. The highest potato yielding treatment was treatment 11 with 517 CWT/A, the only treatment to yield over 500 cwt/A, which was attributed to the high yield for 6-10 oz. tubers. The second highest yielding treatment with 497 cwt/A was treatment 8, which had the high yield for 4-6 oz. tubers. Both treatment 11 and 8 had Paralign in the starter fertilizer. The lowest total yields were with treatment 13 at 409 cwt/A, which had the lowest yield for > 10 oz. tubers and treatment 10 at 430 CWT/A, which had the lowest yield for 4-6 oz. tubers and 6-10 oz. tubers. When comparing potato yields for the treatments with and without WC501 added to the pre-plant MAP (all even # treatments), the treatments that were without WC501 had greater total yields six of the nine times (1 vs 2, 3 vs 4, 5 vs 6, 7 vs 8, 9 vs 10, 11 vs 12, 13 vs 14, 15 vs 16, and 17 vs 18). However, six of the nine times when WC501 was added, there was a greater percentage of marketable tubers. All treatments had at least 60% of the harvested tubers marketable (Fig. 1). Treatment 2 had the highest percentage of marketable tubers with 69%. Treatment 13 had the lowest percentage of marketable tubers with 60%, while also having the lowest percent of tubers greater than 10 ounces (8.6%).

Table 1. Percent green tissue covering a plot in response to fertilizer treatments.

	41 DAP		53 DAP	
TRT	% Canopy		% Canopy	
1	49.58	ab	91.62	ab
2	51.86	ab	90.76	ab
3	58.6	ab	93.43	ab
4	53.95	ab	93.31	ab
5	50.94	ab	92.85	ab
6	55.79	ab	92.99	ab
7	56.39	ab	90.34	ab
8	53.58	ab	93.01	ab
9	48.21	b	92.60	ab
10	46.48	bc	90.78	ab
11	55.08	ab	91.89	ab
12	55.59	ab	89.22	b
13	52.10	ab	94.26	ab
14	59.71	a	95.64	a
15	57.08	ab	94.23	ab
16	55.00	ab	93.92	ab
17	46.30	bc	93.25	ab
18	48.59	b	95.18	a
LSD (P=.05)	10.45		5.44	

Table 2. Potato yield and grade in response to pre-plant and at plant fertilizer treatments. High and low yields are bolded for each column.

	0-4oz		4-6oz		6-10oz		>10oz		Total		Marketable	
TRT	cwt/A		cwt/A		cwt/A		cwt/A		cwt/A		cwt/A	
1	71.9	a	183.3	ab	84.8	ab	152.0	a	492.0	ab	420.0	ab
2	58.8	a	180.1	b	90.8	a	151.6	a	481.3	ab	422.5	ab
3	61.0	a	187.0	ab	89.9	ab	155.1	a	493.0	ab	432.0	ab
4	62.7	a	172.9	b	87.5	ab	137.5	ab	460.7	ab	397.9	abc
5	74.9	a	168.3	bc	84.8	ab	**165.2**	a	493.2	ab	418.3	ab
6	65.8	a	171.3	bc	76.6	bb	123.5	ab	437.1	b	371.3	bc
7	82.3	a	177.6	b	75.9	ab	118.7	ab	454.4	ab	372.1	bc
8	72.0	a	**215.5**	a	88.6	ab	121.0	ab	497.0	ab	425.0	ab

9	66.8	a	173.9	b	87.7	ab	113.7	ab	442.1	ab	375.3	bc
10	66.9	a	**161.7**	bc	**71.3**	b	130.2	ab	430.0	bc	363.2	bc
11	64.4	a	204.4	ab	**97.1**	a	151.2	a	**517.1**	a	**452.7**	a
12	63.6	a	178.6	b	91.3	a	128.1	ab	461.5	ab	397.9	abc
13	80.7	a	177.5	b	70.4	ab	**81.2**	b	**409.7**	bc	**329.0**	bc
14	**82.5**	a	193.0	ab	78.7	ab	120.2	ab	474.4	ab	391.8	abc
15	64.0	a	175.3	b	91.0	a	146.8	a	477.1	ab	413.0	ab
16	**56.0**	a	164.4	bc	79.8	ab	160.4	a	460.6	ab	404.6	ab
17	76.1	a	174.2	b	86.4	ab	131.2	ab	467.9	ab	391.8	abc
18	56.8	a	177.9	b	91.0	a	163.3	a	489.0	ab	432.2	ab
LSD(P=.05)	32.9		32.7		19.7		65.3		64.0		70.7	

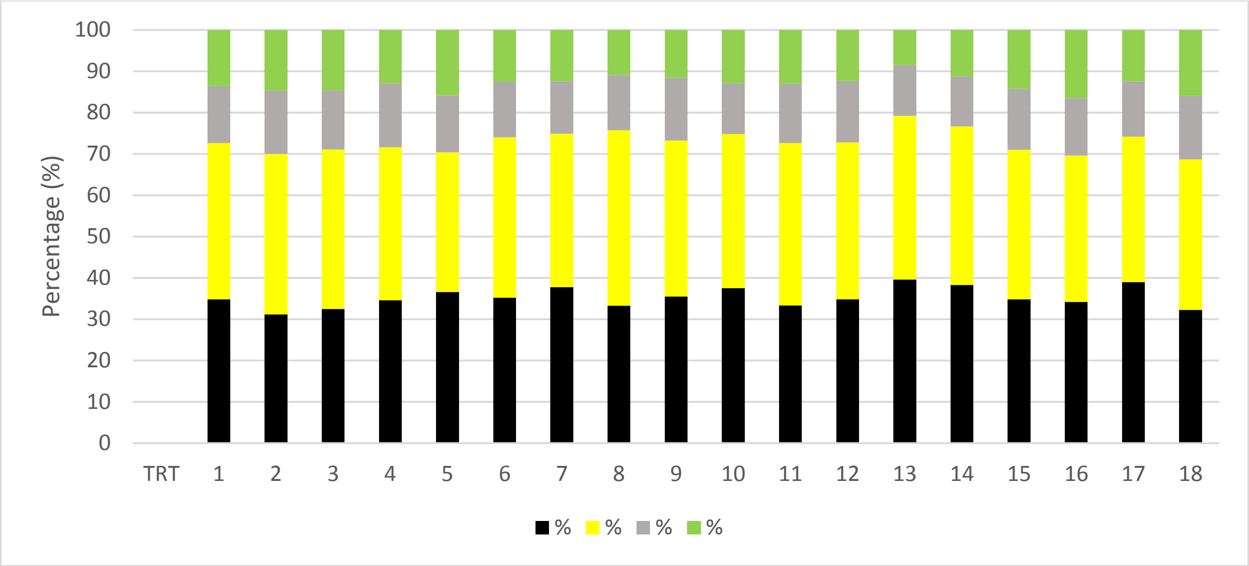

Figure 1. Percentage of tubers in each grade in response to fertilizer treatments.

Simulated hail injury to processing potatoes. H. Hatterman-Valenti and C. Auwarter.

Field research was conducted at the Northern Plains Potato Growers Association irrigated research site near Inkster, ND to evaluate simulated hail damage on Russet Burbank and Clearwater Russet potatoes. Plots were 4 rows by 20 feet arranged in a randomized complete block design with 4 replicates. Seed pieces (2 oz) were planted on 36-inch rows and 12-inch spacing on May 29, 2019. Extension recommendations were used for cultural practices throughout the year. The hail damage was simulated using a brushcutter with thermoplastic blades during tuber initiation (43 days after planting (DAP)), end of tuber initiation (55 DAP), early tuber bulking (77 DAP) and mid tuber bulking (91 DAP). Plants were desiccated September 19 and harvested October 25.

Treatments were applied to the middle two (Row ‘A’ and Row ‘B’) of the four-row plots with the outside rows treated as border rows to protect the research conducted. Treatments consisted of:

1 Untreated
2 50% defoliation at tuber initiation (TI)
3 100% defoliation at TI
4 50% defoliation at TI + 50% defoliation at early bulking (EB)
5 50% defoliation at TI + 100% defoliation at EB
6 100% defoliation at TI + 50% defoliation at EB
7 100% defoliation at TI + 100% defoliation at EB
8 50% defoliation at the End of TI
9 100% defoliation at the End of TI
10 50% defoliation at the End of TI + 50% defoliation at mid-bulking (Mid Bulk)

Row ‘A’, when harvested, was dug and weighed in the field. Row ‘B’, was bagged and the tubers brought back to NDSU to be graded. A majority of our yield analysis comes from Row ‘B’.

The Canopeo App was used to evaluate regrowth after simulated hail. Results indicated that the ‘Russet Burbank’ plants grew back quicker than the ‘Clearwater Russets’ 12 days after TI defoliation, suggesting that ‘Russet Burbank’ may be more adapted to ND growing conditions and has faster recovery from hail damage than ‘Clearwater Russet’ under similar ND conditions.

The Untreated (TRT 1) for ‘Russet Burbank’ had the highest yield at 556 CWT/A (Fig. 1). However, this was similar for total yield from plants that only received 50% defoliation at TI or the end of TI (TRTs 2 and 8). All treatments that received 100% defoliation any time during the season reduced the total yield by at least 250 CWT/A. ‘Clearwater Russet’ had a broader difference in total yield compared to ‘Russet Burbank’ in response to simulated hail (Fig. 7). ‘Clearwater Russet’ untreated and treatment 8 had the highest total yield at 477 and 447 cwt/A, respectively (Fig. 4). Their yields were significantly better than the next highest yield, treatment 2 with 378 cwt/A, and all these treatments were significantly better than treatments 4 and 10, with total yields of305 and 314 CWT/A, respectively. None of these treatments received 100% defoliation during the season. All remaining treatments yielded less than 184 cwt/A, with treatment 7 having the lowest total yield at 53 cwt/A. Only 15% of the yield with treatment 7 was marketable (Fig. 6).

There were 12 days different between the TI application and the End of TI defoliation. Total yield was significantly reduced for ‘Clearwater Russet’ 50% defoliation the earlier the defoliation occurred (Fig. 4). ‘Clearwater Russet’ yield for the TI application (TRT 2) was 377 cwt/A, while the End of TI application (TRT 8) yield was 447 cwt/A. Just opposite occurred with ‘Russet Burbank’, but with the 100% defoliation treatments. The 100% defoliation at TI (TRT 3) had 295 cwt/A while the End of TI application (TRT 9) had a smaller yield of 218 cwt/A (Fig. 1). Thus with ‘Clearwater Russet’, the earlier the defoliation the worse the yield, while with ‘Russet Burbank’, the earlier the defoliation occurred the higher the yield.

The number of cull tubers for ‘Russet Burbank’ was greatest when 100% defoliation occurred at the End of TI with 168 of the 200 tubers ≤ 4oz. (Fig. 2). This was followed by 50% defoliation at TI + 100% defoliation at EB (TRT5) with 150 of the 185 tubers ≤ 4oz. However, the greatest percentage of cull tubers occurred when plants received 100% defoliation at TI and EB (TRT7) with 85% of the tubers considered culls (Fig. 3). For 'Clearwater Russet', the greatest number of cull tubers occurred when 50% defoliation at the End of TI and mid-bulking (TRT10) with 118 of the 180 tubers ≤ 4oz. (Fig. 5). This was followed by 50% defoliation at TI + 100% defoliation at EB (TRT5) with 113 of the 140 tubers ≤ 4oz. Similar to 'Russet Burbank', the greatest percentage of cull tubers for 'Clearwater Russet' occurred when plants received 100% defoliation at TI and EB (TRT7) with 93% of the tubers considered culls (Fig. 6). In general, results suggest that when 50% defoliation occurs around the TI stage, tuber set number isn't reduced much, but plants do not have the ability to increase the size for all the tubers, so tuber size is greatly reduced. However, when 100% defoliation occurs around the TI stage, both the tuber set number as well as tuber size are greatly reduced. In the worst case scenario of 100% defoliation at TI and EB, approximately 15% of the tubers were marketable for 'Russet Burbank', while 7% were marketable for 'Clearwater Russet'.

CWT of Russet Burbank

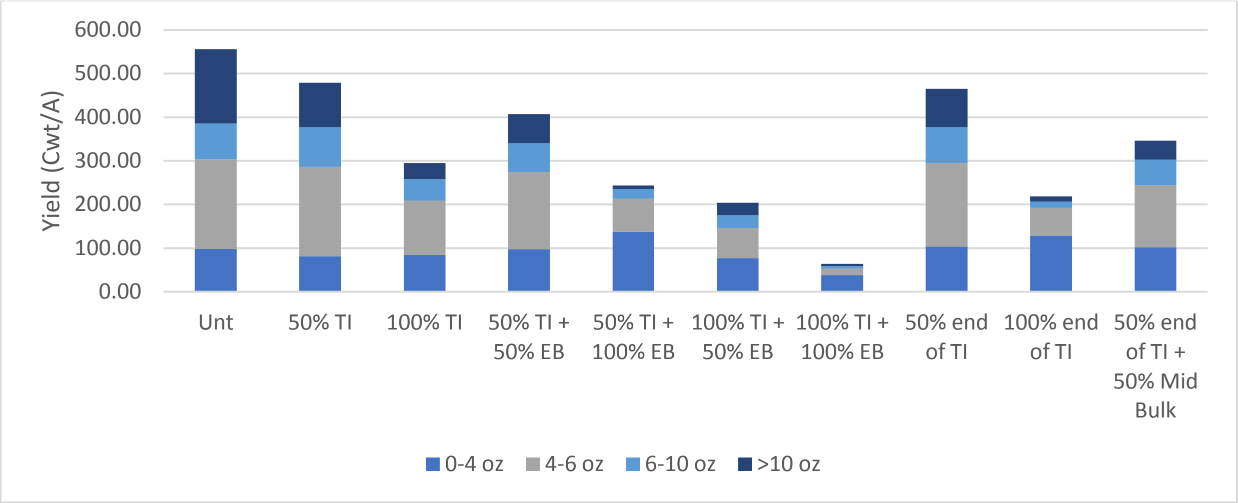

Figure 1. Total yield and grade for 'Russet Burbank'.

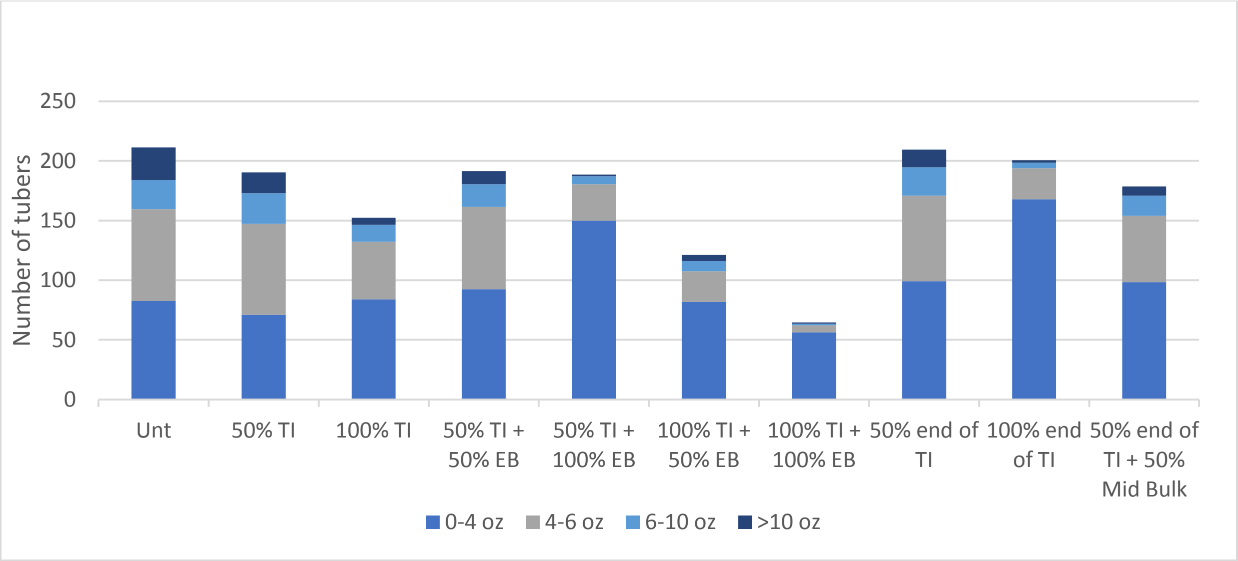

Figure 2. Tuber counts of 'Russet Burbank' in 20 ft. of row.

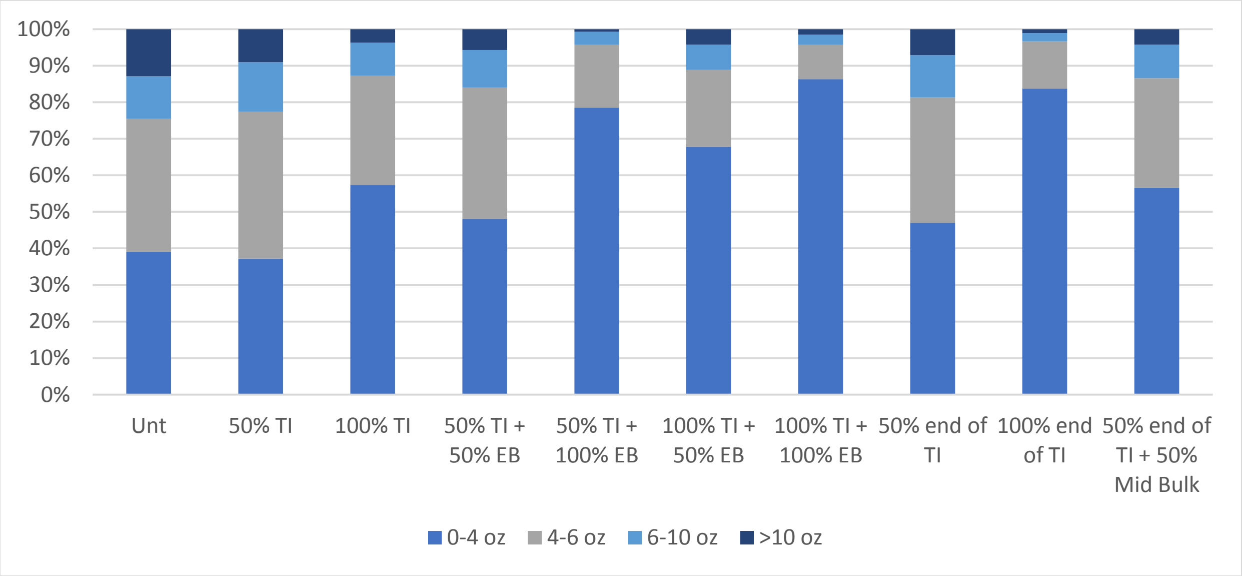

Figure 3. Percentage of 'Russet Burbank' tubers in various grades.

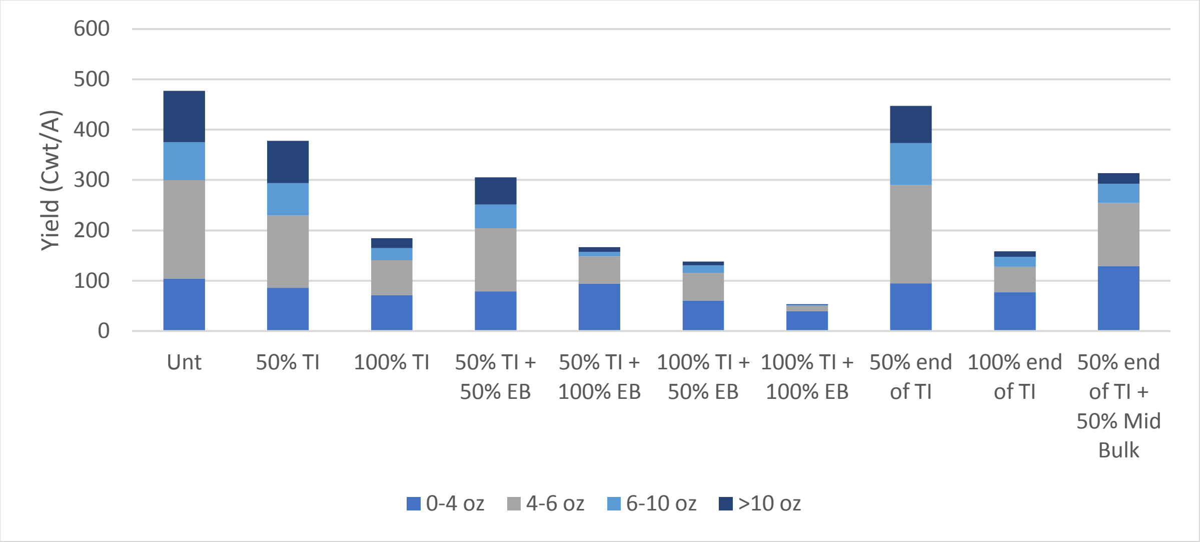

Figure 4. Total yield and grade for 'Clearwater Russet'.

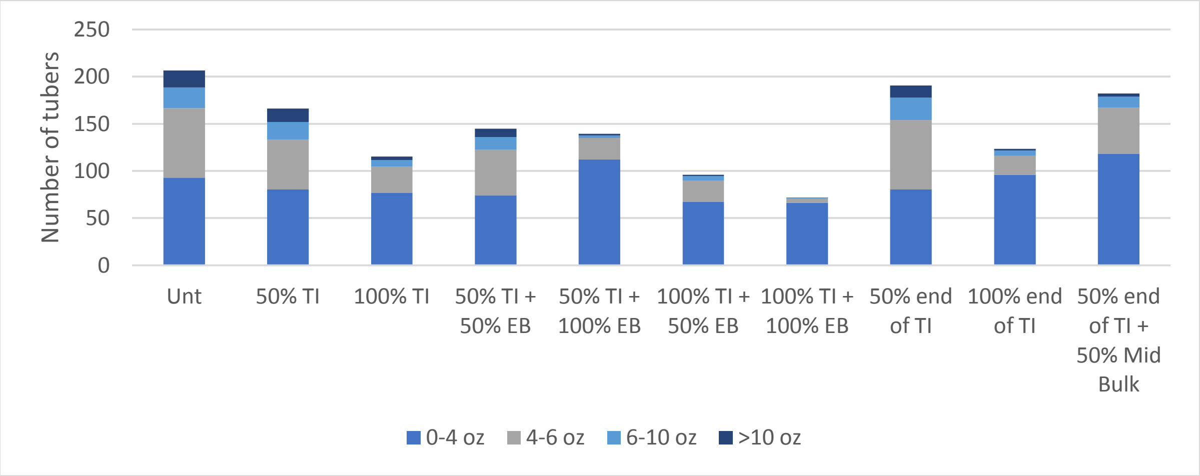

Figure 5. Tuber counts of 'Clearwater Russet' in 20 ft. of row.

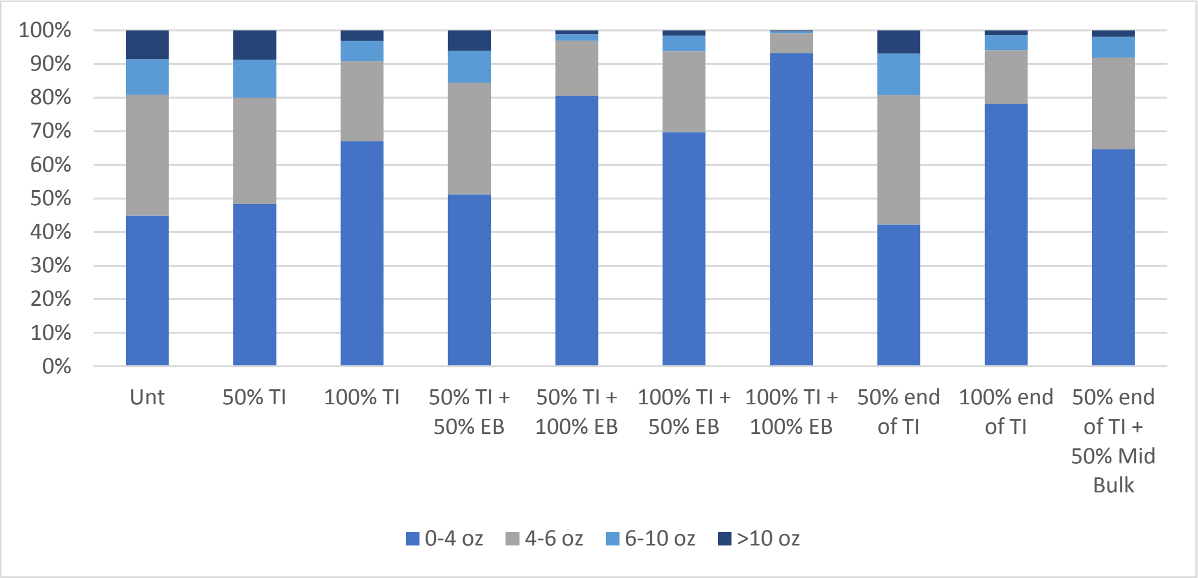

Figure 6. Percentage of 'Clearwater Russet' tubers in various grades.

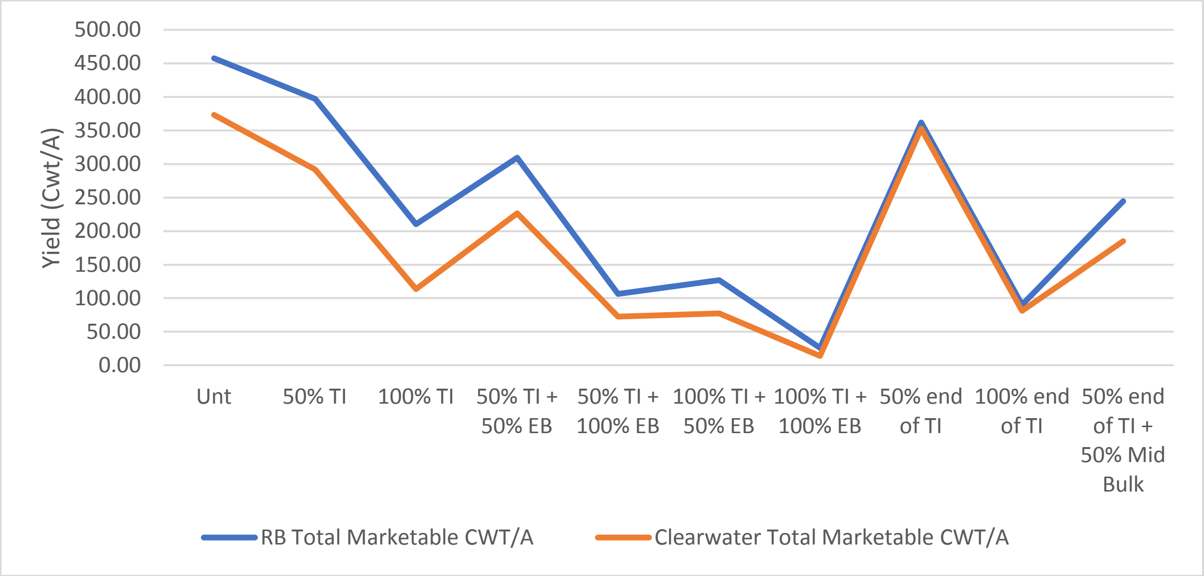

Figure 7. Marketable yield for 'Russet Burbank' and 'Clearwater Russet' in response to simulated hail.

In-furrow starter fertilizer study. H. Hatterman-Valenti and C. Auwarter

Field research was conducted at the Northern Plains Potato Growers Association irrigated research site near Inkster, ND to evaluate the response of starter in-furrow fertilizers versus grower standard practices (GSP) on Russet Burbank potatoes. Plots were four rows by 20 feet arranged in a randomized complete block design with 4 replicates. Seed pieces (2 oz) were planted on 36-inch rows and 12-inch spacing on May 31, 2019. At hilling (18 days after planting (DAP)), 50 pounds of 46-0-0 was applied and additional nitrogen was applied through the irrigator three times during the season with 20 lb of nitrogen per time. Extension recommendations were used for cultural practices throughout the year. The trial was desiccated September 19 and the middle two-rows harvested October 25. Row 'A', when harvested, was dug and weighed in the field. Row 'B', was bagged and the tubers are brought back to NDSU to be graded. Most of the yield analysis comes from Row 'B'.

Soil Test.

Depth	N	P	K	pH	EC	OM	S	Zn	Fe	Mn	Cu	Cl	Ca	Mg	Na	CEC
(in)	lb/a	ppm	ppm			%	lb/a	ppm	ppm	ppm	ppm	lb/a	ppm	ppm	ppm	
0-6	4	33	167	5.8	0.06	1.8	3	1.27	35.1	31.6	0.46	3.2	3311	231	14	18.9

Pre-Plant Fertilizer Blend.

0-0-60	200 lbs/a	120K
21-0-0-24	110 lbs/a	23N & 26S
46-0-0	80 lbs/a	37N
Boron	2 lbs/a	2B
Zinc	3 lbs/a	3Zn
Copper	2 lbs/a	2Cu

Treatments.

1	**Soil**		4N			**2**	**Soil**		4N		
	Pre-Plant		60N		120K		**Pre-Plant**		60N		120K
	Planting						**Planting**				
	10-34-0	17 gpa	20N	68P			JRS 2025*	20 gpa	26.4N	88.8P	
	OneUp	3 gpa	1.25N	4.36P	1.56K						
	Total		**85.25N**	**72.36P**	**121.56K**		**Total**		**90.4N**	**88.8P**	**120K**
	Tuber Initiation (TI)										
	OneUp	1 qt/a									
	20 DA TI										
	OneUp	1 qt/a									
3	**Soil**		4N			**4**	**Soil**		4N		
	Pre-Plant		60N		120K		**Pre-Plant**		60N		120K
	Planting						**Planting**				
	JRS 2025*	20 gpa	26.4N	88.8P			10-34-0	25 gpa	29N	100P	
	Total		**90.4N**	**88.8P**	**120K**		**Total**		**93N**	**100P**	**120K**
	TI										
	IT 1402	0.5 pt/a									
	20 DA TI										
	IT 1402	0.5 pt/a									

*Used N & P #'s from Simplot liquid ammonium phosphate 11-37-0 fertilizer.

Applications.

7/16/19 (46 DAP) – TI app			**8/5/19 (66 DAP) – 20 DA TI app**	
Time:	9:30 AM		Time:	10:30 AM
Air Temp:	72 F		Air Temp:	76 F
Rel. Humidity:	77%		Rel. Humidity:	68%

Wind:	4 MPH		Wind:	7.3 MPH
Cloud Cover:	0%		Cloud Cover:	0%
App Equip:	CO2 press. backpack		App Equip:	CO2 press. backpack
Operating pressure:	40 PSI		Operating pressure:	40 PSI
Nozzle Size:	8002		Nozzle Size:	8002
Nozzle Type:	Flat Fan		Nozzle Type:	Flat Fan
Spray Volume:	20 GPA		Spray Volume:	20 GPA

Results.

The Canopeo app showed little differences both 41 and 53 DAP (Fig. 1). Row ‘A’ potatoes yielded higher in all the treatments which was attributed to muddy conditions during harvest. The potatoes in both row ‘A’ and ‘B’ had the lowest yield in treatment 4 the grower standard practice (GSP). The two highest potato-yielding treatments both had JRS 2025 fertilizer applied in-furrow at planting (Fig. 2). Potatoes in treatment 3 had a yield of 489 cwt/A, and potatoes in treatment 2 had a yield of 474 cwt/A. Potatoes in treatment 1 had 469 CWT/A, while the yield from the GSP treatment was approximately 8, 5, and 4% less than yields from treatments 3, 2, and 1, respectively. Plants in Treatment 2 had the fewest cull tubers at 68 cwt/A, while treatment 3 had the most cull tubers at 88 cwt/A.

Tuber numbers in 20 ft. of row generally mimicked total yield results with treatment 3 at 193 potatoes, followed by treatment 2 (179), treatment 4 (178) and treatment 1 at 177 potatoes (Fig. 3). Even though plants in Treatment 3 had the most unmarketable tubers in 20 ft. of row with 77, these plants also had the most marketable tubers in 20 ft. of row at 116.

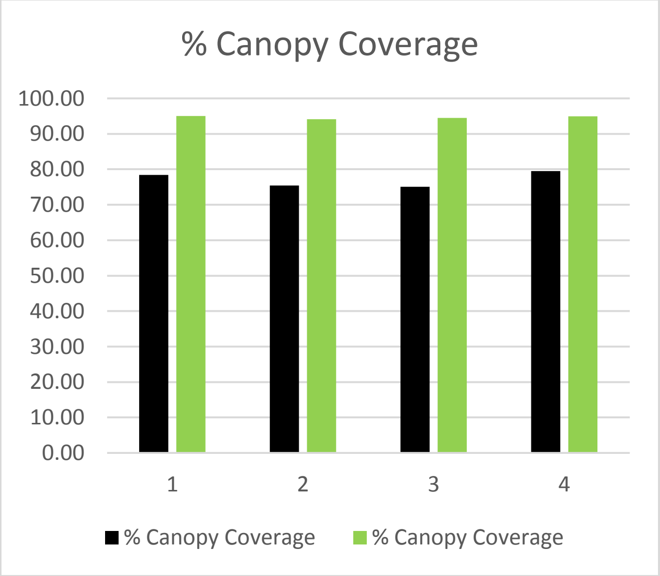

Figure 1. Percent green tissue coverage from the Canopeo App.

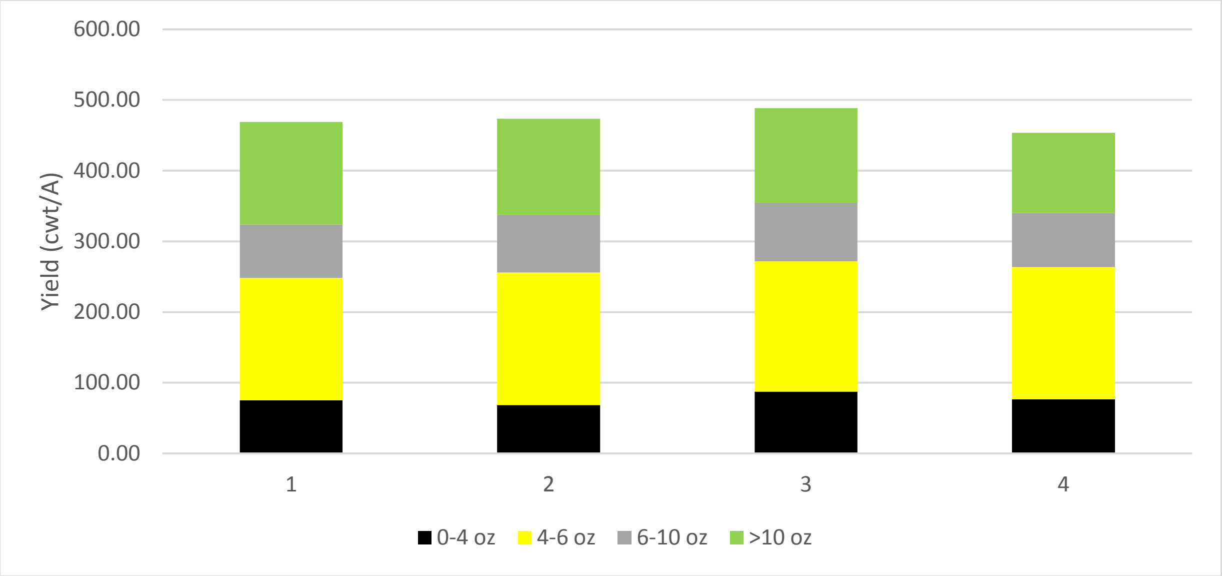

Figure 2. Total yield and grade for 'Russet Burbank' following in-furrow starter fertilizer treatments.

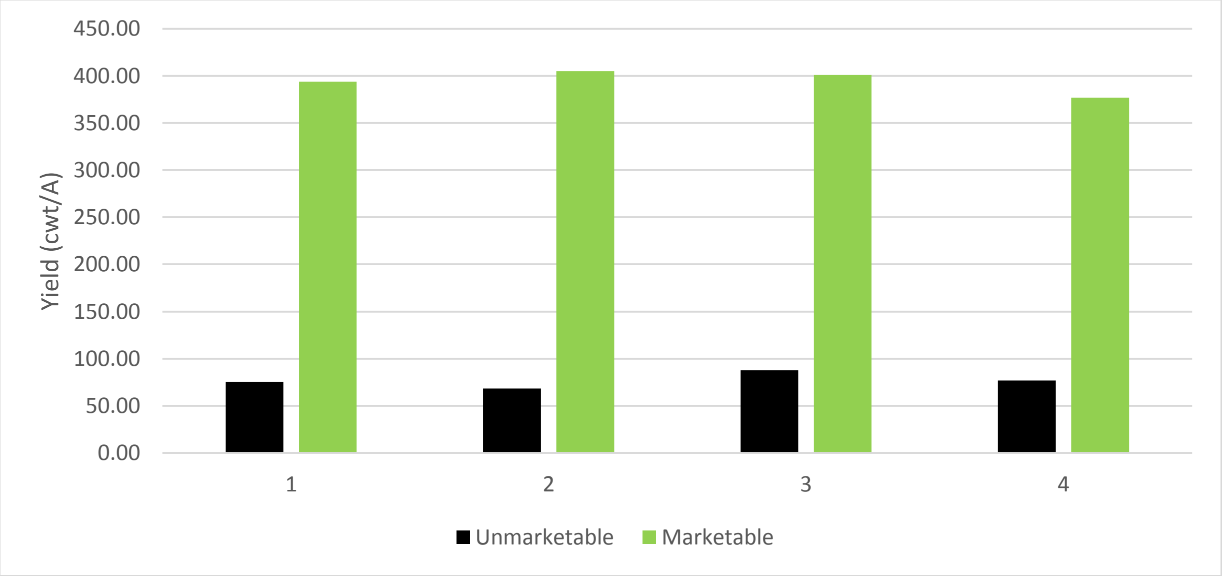

Figure 3. Marketable and cull yield for 'Russet Burbank' following in-furrow starter fertilizer treatments.

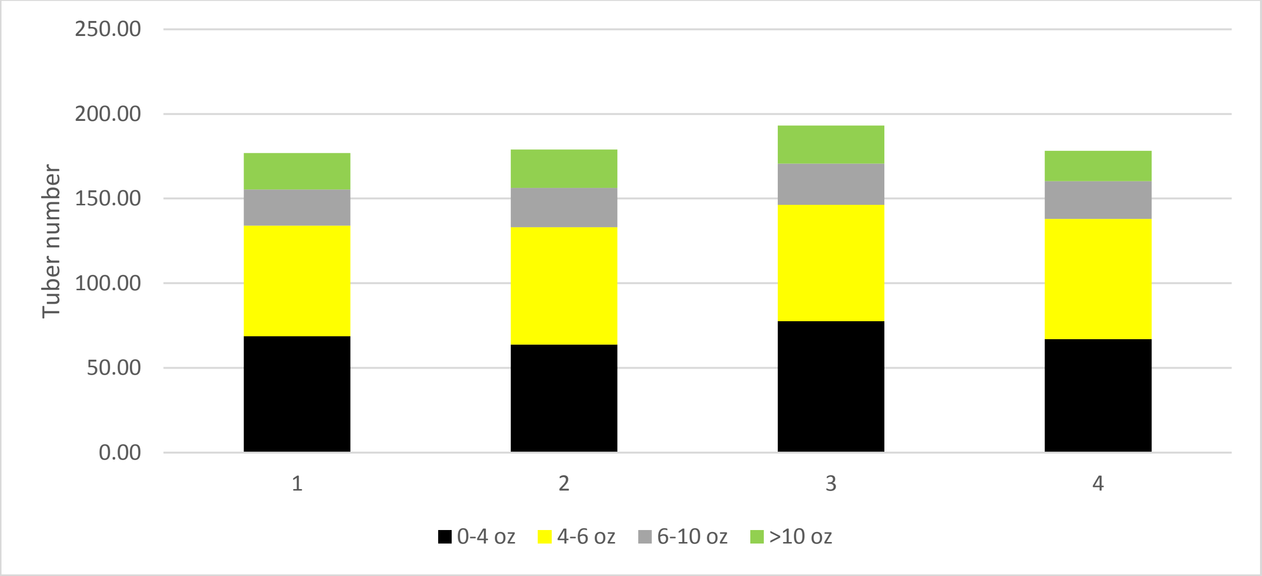

Figure 3. 'Russet Burbank' tuber numbers in each grade harvested from 20 ft. of row following in-furrow starter fertilizer treatments.