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Impact of Sublethal Dicamba and Glyphosate Rates on Three Chipping Potato Cultivars

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ABSTACT: The recent increase in weedy species resistant to glyphosate has led to the development and release of dicamba resistant soybean varieties. However, with increased utilization of dicamba, herbicide off-target injury has become a major issue for regional farmers. Investigating the impact of drift rates of these two ubiquitous agronomic herbicides, this research explores their effects on three irrigated chipping potato cultivars (Atlantic, Dakota Pearl, and Lamoka) as measured through visible injury, tuber quality reduction, and yield reduction. Herbicides were sprayed at the tuber initiation stage and consisted of dicamba at 99g ae ha^{-1}, glyphosate at 197g ae ha^{-1}, dicamba + glyphosate at 99g ae ha^{-1} + 197g ae ha^{-1}, and 20 g ae ha^{-1} + 40 g ae ha^{-1}, respectively, and an untreated control. At seven days after treatment (DAT), high dicamba + glyphosate caused the most damage, with 28% based on visible ratings. Low dicamba + glyphosate was not different from the untreated control. Furthermore, at 21 DAT, visible injury increased to 36% for the high dicamba + glyphosate treatment. The high combination of dicamba + glyphosate resulted in a 60% yield reduction compared to the untreated control, which averaged 1021 cwt ha^{-1}. Tuber specific gravity was also lower for plants sprayed with dicamba. Results from the two field trials suggest that not only can sublethal rates of dicamba + glyphosate greatly decrease potato yields; tuber specific gravity is also reduced, potentially influencing chipping quality.

INTRODUCTION

North Dakota is a unique and diverse agricultural state. However, soybean is the top crop in North Dakota by acres, with 7.2 million acres planted in 2017 and an estimated value of $2.1 billion (USDA-NASS, 2018). The introduction of dicamba-tolerant soybeans in 2017 provided growers with an option to control glyphosate-resistant weeds. Soybean acres often exist adjacent to other broadleaf crops, such as potatoes, which can be sensitive to dicamba vapor, drift, or spray-tank contamination. In many cases, glyphosate-tolerant crops and now dicamba-tolerant soybeans have been grown next to potatoes.

New formulations of dicamba alone or combined with glyphosate have been developed with the goal of reducing dicamba volatilization. Even so, dicamba volatilization was so problematic in 2017 that the North Dakota implemented new dicamba application restrictions (EPA, 2017). It is likely that instances of herbicide drift, vapor drift, or spray tank contamination, and the subsequent injury are going to occur, especially for counties south of I-94, where potato planting often occurs by mid-April. In addition, research has shown cultivar differences to sub-lethal glyphosate rates for russet-skinned and red-skinned cultivars (Crook, 2016), but research has not evaluated white-skinned cultivars.

A crop such as potato is unique because it can suffer direct yield losses from dicamba and/or glyphosate drift, and the daughter tubers derived from the mother plants exposed to these herbicides may be severely inhibited when used as seed. Previous research has shown that visible injury to ‘Russet Burbank’ potato can vary by almost 40% for the same sub-lethal herbicide rate that caused nearly twice the total yield loss (Hatterman-Valenti et al., 2017). It was concluded that the less responsive plants (lower visible injury and less total yield reduction) were stressed from higher air temperatures. However, mother plants that displayed less visible injury and less total yield reduction may have transferred more herbicide to daughter tubers considering plant emergence five weeks after planting was significantly reduced when compared to seed from mother plants receiving the same sub-lethal herbicide rates, but during cooler air temperatures.

The objective of this research is to determine the impact of sub-lethal dicamba and glyphosate on emergence and graded yield of chipping seed potatoes. This research will benefit potato growers, potato processors, agronomists, and research institutions to understand the effect of dicamba and glyphosate on chipping potato seed tubers.

MATERIALS & METHODS

Field experiments were be conducted in 2018 at the North Dakota State University (NDSU) Irrigated Research Site, located three miles south of Oakes, North Dakota (46.07 N, -98.09 W; elevation 392 m). This site is irrigated, with an Embden coarse-loamy, mixed, superactive, frigid Pachic Hapludolls soil type (USDA-NRCS, 2017). This makes for very good drainage with large water requirements.

This experiment was set up as a randomized complete block design (RCBD) two-factor arrangement, with three cultivars, four replicates, five treatments and two locations in Oakes in both years. Similar experimental methods were used in 2014 and 2015 (Crook A 2016). The treatments consist of a non-treated control, Dicamba (Clarity®, BASF Corporation, Research Triangle Park, NC, 27709), and/or glyphosate (PowerMax®, Monsanto Company, St. Louis, MO, 63167). Dicamba treatments were 99, 20, and 0 g a.e. ha^{-1}. The doses are at 2 and 9% of the field use rate of 1120 g ae ha^{-1} (Anonymous, 2010). Glyphosate treatments were 197, 40, and 0 g a.e. ha^{-1}. The doses are at 5 and 23% of the field use rate of 846 g ae ha^{-1}. (Anonymous, 2012). (Table 1).

Table 1. Glyphosate and dicamba treatments applied to Atlantic, Dakota Pearl, and Lamoka potatoes in Oakes, ND.

#	Treatment	Herbicide rate
		g ae ha^{-1}
1	Non-treated	0
2	Glyphosate	197
3	Dicamba	99
4	Glyphosate	40
	Dicamba	20
5	Glyphosate	197
	Dicamba	99

Tuber initiation (TI) was selected on the importance of developing of daughter tubers. Certified Atlantic, Dakota Pearl, and Lamoka seed potatoes were cut into 70g ± 5g seed pieces, insuring that every seed piece had two or more eyes/seed. After the seeds were cut, they were stored for two weeks induce suberization and seed conditioning prior to planting.

Each experimental unit (EU) contained two rows with 20 seed pieces planted in each row (40 total seed pieces/EU). All seed tubers were planted 31 cm apart with a 91 cm spacing between each row at 35,880 seed pieces ha^{-1}. The row length was 6.1 m long with a seed depth of 10 cm. A 1.5 m gap of five 'Red Norland' potato separated each treatment.

Treatments of both dicamba and glyphosate were applied with a CO_2 backpack sprayer equipped with a 1.8m boom and four XR11002 flat fan nozzles (TEEJET Spraying Systems Company, Wheaton, IL 60189) 45cm apart at 138kPa and an output of 140 L ha^{-1}. Treatments were applied in progression of lowest to highest dose starting with glyphosate treatments first to mitigate cross contamination of EU's. The application of these treatments complied with the new 2017 North Dakota rules for dicamba application. The treatments were applied at tuber initiation on June 29th, which is the cutoff date for dicamba in North Dakota.

Data was taken throughout the season. Stand count was measured along with ratings for visual control and crop injury will be taken 7 and 21 days after treatment. Additional notes on yield and specific gravity was collected.

RESULTS & DISCUSSION

The data collected were subjected to analysis of variance using Mixed Model procedure using JMP® Pro 14.0.0 (64-bit) SAS Institute Inc., 100 SAS Campus Dr., Cary, NC 27513). Because the stand was low for Lamoka there was an interaction between rate by treatment. A test of homogeneity of variance between location 1 and location 2 indicated that the environments could be combined. Cultivar and herbicide treatments were considered fixed and replicates were considered random within the model. Tukey's HSD pairwise comparisons (P=0.05) were used to separate treatment means.

Table 2 depicts the herbicide injury for Lamoka, Dakota Pearl, and Atlantic 21 days after application. High dicamba + glyphosate had the most significant visual plant injury with Dakota Pearl at 41%. There was one exception. The third treatment for Lamoka, low dicamba + glyphosate treatment showed abnormally high levels of injury. This could be explained by the poor stand count for Lamoka of 45%.

	Treatment				
Variety	High Dicamba + High Glyphosate	High Dicamba	High Glyphosate	Low Dicamba + Low Glyphosate	Untreated
	-----% injury -----				
Atlantic	38a	14b	8bc	5cd	0d
Dakota Pearl	41a	18b	16bc	10c	0d
Lamoka	31b	28b	9c	45a	0d

Table2: Yield for Atlantic, Dakota Pearl, and Lamoka. By herbicide treatments, 2018.

Table 3 shows the effects dicamba and glyphosate have on yield. The untreated potatoes have a significantly higher yield than the rest of the treatments with yields as high as 1157 cwt/hectare. High dicamba + high glyphosate treatments have the lowest yields. In the case of Atlantic high dicamba + high glyphosate, yield is significantly lower than the rest of Atlantic treatments. Lamoka was the lowest performer overall. This pattern may also be explained by the poor stand count.

	Treatment				
Variety	untreated	Low Dicamba + Low Glyphosate	High Glyphosate	High Dicamba	High Dicamba + High Glyphosate
	-----Cwt/hectare-----				
Atlantic	1157a	1048bc	983c	804d	673e
Dakota Pearl	1113a	1021b	894c	788d	705d
Lamoka	794a	625b	623b	528c	443c

Table 3: Yield for regionally grown chipping potato cultivars by herbicide treatment, pooled across environments, 2018

Figure 1 shows the specific gravity (SG) of all three varieties. No interaction was detected, thus variety was pooled. The untreated control had a significantly higher SG than the rest of the treatments. High dicamba + glyphosate has a significantly lower SG than the rest of the treatment below 1.085.

The 2018 results demonstrate the non-negligible impact of dicamba and glyphosate drifts rates on chipping potatoes, reducing both yields and specific gravity.

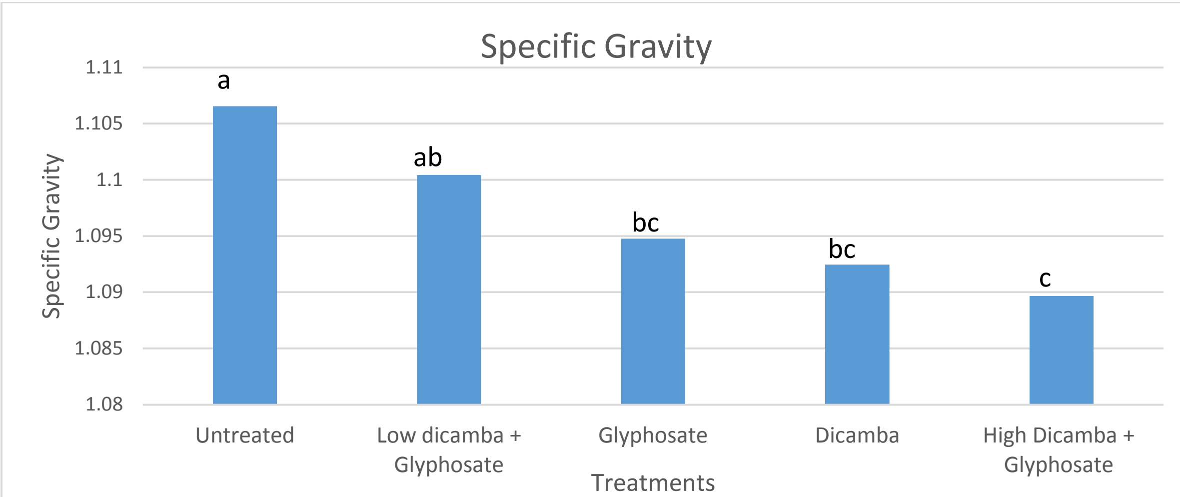

Figure 1: Specific gravity of Atlantic, Dakota Pearl, and Lamoka by herbicide treatment pooled across variety and treatment, 2018

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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 2017 and 2018. 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 and May 19, 2018 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 and from August 31 to September 28 in 2018. It should be noted that a killing frost ended the desiccation intervals on September 28. 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 and October 7, 2018. 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 (Table 1). 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. (Table 1). After September 17, total and marketable yield was lower, although not significantly so. Similarly, there were significant differences in the percentage of >10 oz. U.S. number 1 and total >10 oz. tubers among vine desiccation dates. The maximum percentage of >10 oz. tubers was observed also on the September 17 vine desiccation date. However, the percentage of >10 oz. US #1 tubers continued to increase with each later vine desiccation date although not significantly so. There were very few significant differences among other tuber size grades and among unusable tuber percentages (Table 1). Although specific gravity of tubers generally increased with each vine desiccation date, there were no significant differences observed among dates of desiccation.

The grade analysis 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 (Table 1). 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 (Table 2). 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 (Table 2). 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

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Table 1. Effect of the time of vine desiccation on yield, tuber quality, and economic return in 2017.

Application Dates	Total Yield (cwt/a)	Market Yield (cwt/a)	10 oz. & over (%)			6 - 9 oz. (%)			>6 oz. (%)	4 - 6 oz (%)			Unusables (%)				Specific Gravity	Contract ($/cwt)	Gross return/acre ($)
			US No. 1	US No. 2	Total	US No. 1	US No. 2	Total	Total	US No. 1	US No. 2	Total	Total	Under-size	Hollow Heart	Other			
Aug 29, Sept 4	536.84	471.01	21.15	0.28	21.43	38.53	0.93	39.45	60.88	26.73	0.08	26.80	12.30	10.98	0.68	0.65	1.080	8.45	3,975.50
Sept 4, 10	568.24	501.74	28.65	0.75	29.40	36.15	0.35	36.50	65.90	22.23	0.10	22.33	11.75	7.58	2.48	1.70	1.080	8.43	4,228.35
Sept 10, 17	595.71	526.01	26.45	0.80	27.25	35.95	0.20	36.15	63.40	24.78	0.05	24.83	11.70	8.73	1.75	1.23	1.084	8.68	4,566.17
Sept 17, 22	621.68	563.06	30.68	0.18	30.85	37.05	0.28	37.33	68.18	22.40	0.00	22.40	9.43	7.50	1.20	0.73	1.087	8.65	4,870.20
Sept 22, 27	597.53	529.92	31.33	0.30	31.63	34.98	0.18	35.15	66.78	21.93	0.05	21.98	11.25	8.18	1.95	1.13	1.083	8.47	4,490.89
Sept 27, Oct 4	608.51	553.34	33.80	0.50	34.30	34.65	0.83	35.48	69.78	20.65	0.45	21.10	9.15	7.38	0.65	1.13	1.086	8.77	4,848.09
$LSD_{P = 0.05}$	45.46	44.30	5.17	NS	5.44	NS	NS	NS	NS	NS	0.27	NS	NS	1.35	NS	NS	NS	NS	366.79

Table 2. Effect of the time of vine desiccation on yield, tuber quality, and economic return in 2018.

Application Dates	Total Yield (cwt/a)	Market Yield (cwt/a)	10 oz. & over (%)			6 - 9 oz. (%)			>6 oz. (%)	4 - 6 oz (%)			Unusables (%)				Specific Gravity	Contract ($/cwt)	Gross return/acre ($)
			US No. 1	US No. 2	Total	US No. 1	US No. 2	Total	Total	US No. 1	US No. 2	Total	Total	Under-size	Hollow Heart	Other			
Aug 31, Sept 8	567.53	463.10	13.80	0.45	14.25	37.08	0.48	37.55	51.80	29.48	0.38	29.85	18.40	14.68	2.33	1.40	1.077	7.85	3640.71
Sept 8, Sept 13	567.32	448.77	16.10	0.20	16.30	36.63	0.33	36.95	53.25	25.53	0.15	25.68	21.08	13.80	6.35	0.93	1.077	7.75	3502.54
Sept 13, Sept 20	590.41	454.35	15.43	0.43	15.85	35.00	0.28	35.28	51.13	25.48	0.10	25.58	23.23	13.30	8.98	0.95	1.081	7.68	3516.34
Sept 20, Sept 27	605.39	491.67	19.35	0.20	19.55	36.65	0.43	37.08	56.63	24.28	0.20	24.48	18.83	12.68	5.40	0.75	1.083	8.13	4017.80
Sept 27 Killing Frost Sept 28	605.91	514.95	18.83	0.78	19.60	36.95	0.48	37.43	57.03	27.48	0.33	27.80	15.20	11.45	2.80	0.95	1.079	8.11	4186.72
Killing Frost Sept 28	600.73	506.92	17.60	0.38	17.98	39.10	0.28	39.38	57.35	27.13	0.00	27.13	15.55	11.33	3.40	0.83	1.083	8.28	4204.51
$LSD_{P = 0.05}$	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.004	NS	NS

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

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Summary: Nitrogen (N) fertilizer is used routinely in potato cultivation to maximize yield. However, it also affects sugar, free amino acid and protein concentrations in potato tubers. The role of N fertilization on potato plant establishment, tuber growth and yield has been extensively studied. However, reports on potato post-harvest storage and reducing sugar accumulation are limited and inconclusive. Our previous study has shown an increased level of soluble proteins and expression of key enzymes at harvest in response to higher N rate. A field trial was conducted in 2018 at Becker, MN, with five contrasting cultivars to evaluate effect of high N fertilizer level of 360 lbs/ac on tuber physiology. After harvest, tuber yield, size distribution and tuber quality components (reducing sugar and fry color) were evaluated. Tubers were stored at 40 and 48F after reconditioning for further physiological and biochemical studies. All the cultivars had a slight decline in total yield at the higher N application of 360 lbs/ac except cultivars Umatilla Russet. Highest total yield was recorded in Russet Burbank at 240 lbs/ac N rate. Russet Burbank, Umatilla Russet and Lamoka had close to 20% tubers in the greater than10 oz size category, whereas Clearwater and MN13142 had less than 5% of the tubers in size category. Specific gravity decreased with increasing N fertilizer rate and lowest gravities were recorded in Russet Burbank. Umatilla Russet did not show such decline in response to higher N fertilizer rate. Higher N rate affected tuber reducing sugars. Lamoka had the lowest reducing sugars at harvest. Russet Burbank and Clearwater had a decline in reducing sugars with increasing N rate at harvest. Umatilla Russet and MN13142 showed no such response. Three cultivars (Russet Burbank, Clearwater and Lamoka) showed a linear increase in cellular soluble protein concentration with increasing N rate. Umatilla Russet and MN13142 did not show a clear trend. Contrary to other cultivars, Umatilla Russet and MN13142 had significantly lower cellular soluble protein concentration at 240 lbs/ac N rate. These two cultivars had a different physiological response to increased N rate. Changes in cellular soluble protein concentrations could be related to differential enzyme expression. The effects of altered enzyme expression at harvest needs to be further explored during storage to understand the effect on processing quality.

Introduction:

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

N fertilization influences processing quality and several authors have reported either a decrease or an increase in reducing sugar (RS) concentrations when N fertilizer is applied (Westermann et al. 1994, Kolbe et al. 1995). It has been proposed that N fertilization influences tuber sugar content and chip color at harvest by interfering with tuber chemical maturation (Herman et al. 1996, Iritani and Weller 1997).

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

Material and methods:

To gain a better understanding of nitrogen fertilizer response, five potato cultivars and clones (Russet Burbank, Umatilla Russet, Clearwater, Lamoka and MN13142) having a wide variation in their Cold-Induced Sweetening (CIS) resistance were selected. Seed quality of Lamoke was poor and had a high incidence of fusarium. MN 13142 seed was limited and many seed pieces were less than 1 ounce. In 2018, the cultivars were planted on May 14, 2018 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 treatments, 120, 240, and 360 lbs acre^{-1}. All plots received 40 lbs N acre^{-1} as Environmentally Smart Nitrogen - ESN (Agrium, Inc., Calgary, AB, Canada; 44-0-0) at planting (05/14/2018) 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 at each specific N rate treatment, respectively, and then hilled in on 22 May 2018. The post-hilling application of reminder 40 and 80 lbs N acre^{-1} to achieve 240 and 360 lbs N acres^{-1} rates was further split into four applications of 10 and 20 lbs N acre^{-1} as urea and ammonium nitrate – UAN (28-0-0) on 9, 16, 23, and 30 July 2018, respectively. All potatoes were harvested on September 25, 2018 and suberized for three weeks at room temperature. At harvest, yield and yield attributes were recorded. Tubers were stored at 40 and 48F 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:

The results on yield and size distribution, in response to N fertilizer rate are summarized here.

1. **Effect of N fertilizer rate on yield components and yield**

   Cultivars showed differential response to N fertilizer regimes in terms of US No. 1 tubers (Table 1). Cultivars, Clearwater, MN13142, and Russet Burbank had curvilinear response to increasing N fertilizer rate. Lamoka had reduction in US no. 1 tubers whereas Umatilla Russet has higher US no. 1 tubers yield with increasing N rate. All the cultivars had a decline in US no. 2 tubers with increasing N rate. MN13142 had higher percentage of US no. 1 tubers compared to Clearwater and Lamoka. Industry recommendation for tuber size is 68 to 74% 6oz tubers and 28-40% 10 oz tubers. Compared to Russet Burbank and Umatilla Russet, clone MN13142 and Clearwater had very low percentage of tubers (<5%) in 10 oz size (Table 1). Considering the seed quality of these cultivars clone MN13142 performed very well. Clearwater and Lamoka performed lowest in terms of tuber size and yield.

   Total and marketable yield were parallel to US no. 1 tuber yield. Russet Burbank had the highest total and marketable yield followed by Umatilla Russet. Because of the poor seed quality for MN13142 and Lamoka, a yield performance comparison of these two clones with Russet Burbank and Umatilla Russet is compromised.

   Specific gravity (SG) of the tubers is an important trait for the acceptability of new cultivars. The recommended range is 1.082 to 1.088. Umatilla Russet had the highest SG of 1.086 where as MN13142 had an SG of 1.081 and Russet Burbank had an SG of 1.079. It is important to note that, all cultivars had reduced 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).

2. **Effect of N fertilizer rate on tuber quality at harvest**

Tuber quality at harvest determines the long-term storability and processing quality of potato tubers. Tubers were evaluated for sugar content (sucrose and glucose) and fry color along with other biochemical parameters associated with cold-sweetening resistance. In order to evaluate cultivars for stem-end defects (SED) sugars were evaluated at the bud and stem ends of the tubers. Here we are presenting the tuber sugar content and fry color in response to N fertilization rate (Table 2).

No clear effect of N rate on sucrose concentration was observed. Sucrose concentration does not affect the processing quality but could severely affect long-term storage. High sucrose concentration could lead to high levels of reducing sugar formation that affect processing quality. Therefore, it is desirable to have tubers with low levels of sucrose. MN13142 and Clearwater had lower concentrations of sucrose compared to Russet Burbank and Umatilla Russet. It is interesting to note that Russet Burbank and Clearwater had a wide difference in sucrose concentrations between their bud end and stem end (Table 2). For MN13142, sucrose concentrations at the stem end declined with increasing N fertilization rate.

Reducing sugar glucose is one of the most important factor in determining cold-sweetening resistance and long-term storability. Lamoka being a chipping cultivar, had the lowest glucose concentration both at the bud and stem ends. All cultivars had lower glucose concentration at bud end. This is not surprising because of the active unloading of sugars until harvest. Among the four processing cultivars, Russet Burbank had the highest glucose concentrations at the stem end followed by Clearwater, MN13142 and Umatilla Russet. Increasing N fertilizer rate reduced glucose concentrations in some cultivars. This could be due to a diversion of photo assimilates towards vegetative growth and less partitioning to sink tissue. The reduction in glucose concentration was most evident in Russet Burbank and Clearwater. MN13142 and Umitilla Russet had no significant reduction in glucose in response to increasing N fertilizer rate. This could be related to their growth habit and maturity. Russet Burbank, Umatilla Russet and Clearwater are full season cultivars. Whereas, Lamoka is medium-late season cultivar and MN13142 is a midseason.

Fry color followed glucose concentrations in the tubers. As the glucose was low at bud end, reflectance was higher at bud end in all cultivars (Table 2). As per the USDA scale, a reflectance of 44 or higher is considered as USDA 1. Reflectance between 36 –and 44 is considered as USDA 2. In current study, Lamoka had fry color in USDA 1 category followed by MN13142 and Clearwater. Russet Burbank had a USDA 3 fry color. The greater difference in reflectance between bud and stem end for Russet Burbank is indicative of a stem end defect. Increasing N fertilizer rate did not affect fry color as measured by reflectance at harvest.

3. **Effect of N fertilizer rate on tuber cellular physiology**

While increasing fertilizer rate showed cultivar specific response, it does affects cellular physiological processes. Excess available cellular N alters cellular free amino acids and nitrogen metabolism. To understand the physiological and biochemical changes in response to high fertilizer rate, we evaluated tuber N concentration, soluble protein contents and expression of certain enzymes. These evaluations will be followed at various time intervals during storage to explore the mechanisms involved. Here we present cellular soluble protein concentration in response to increasing N fertilization rate. Altered enzyme expression may lead to higher reducing sugar formation during storage. Because all enzymes are proteins, altered enzyme expression could be reflected in terms of soluble protein concentration.

The effects of N fertilizer on soluble protein concentration was cultivar-specific. Contrary to reducing sugars, soluble protein content increased with increasing N rate in Russet Burbank, Clearwater and Lamoka (Fig 1). MN13142 and Umatilla Russet did not show any clear trend. Clearly, these two cultivars have different physiological response. Clearwater, Lamoka and Russet Burbank were more responsive to higher N fertilization rates. A high N status in the cell can result in higher metabolic activity of key starch synthesizing enzymes (Liu et al. 2016; Braun et al. 2016; Meyer and Stitt 2001). The increase in soluble protein content may be due to a higher expression of starch metabolizing and other enzymes. Muttucumaru et al. (Muttucumaru et al. 2013) reported a substantial increase in asparagine and total free amino acid in response to increasing N fertilization.

A high concentration of free amino acids may lead to their incorporation in various cellular proteins including the proteins involved in starch synthesis or degradation. N supply has been reported to affect the sugar concentration and interconversion of simple sugars and complex carbohydrates such as fructans (Halford et al. 2011). In the present study, higher N fertilizer rate showed a decline in glucose concentration at harvest in Russet Burbank and Clearwater and no clear pattern in MN13142 and Umitilla. Previous studies have not reported a consistent trend in term of N rate and RS accumulation. Muttucumaru et al. (2013) reported both increases and decreases in glucose concentration with an increase N fertilizer rate.

Conclusion:

The cultivars tested responded differently to N fertilizer rate. Russet Burbank, Clearwater and Lamoka had a slight decrease in total yield and reducing sugars at harvest with increasing N. But these cultivars had higher concentration of cellular soluble proteins in response to higher N rate. Umatilla Russet and MN13142 demonstrated a different physiological response. Clearly, there are two groups in terms of carbohydrate metabolism. They need to be further explored for their long-term storability. Further, storage and biochemical evaluations will be performed to understand the long-term storability and investigate the physiological mechanism of cold-induced sweetening resistance.

Acknowledgement:

The research funding from Northern Plains Potato Grower Association (NPPGA) and Cavendish Farms is gratefully acknowledged. The research was partly funded by Minnesota Department of Agriculture – Crop Research Grant. The author thanks Dr. Darrin Haagenson, USDA-ARS Potato Research Lab, East Grand Forks, MN for storage analysis of the tubers.

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APPENDIX I

Figure 1: Effect of N rate on tuber soluble protein content. Data represents 3 replicates ±SE.

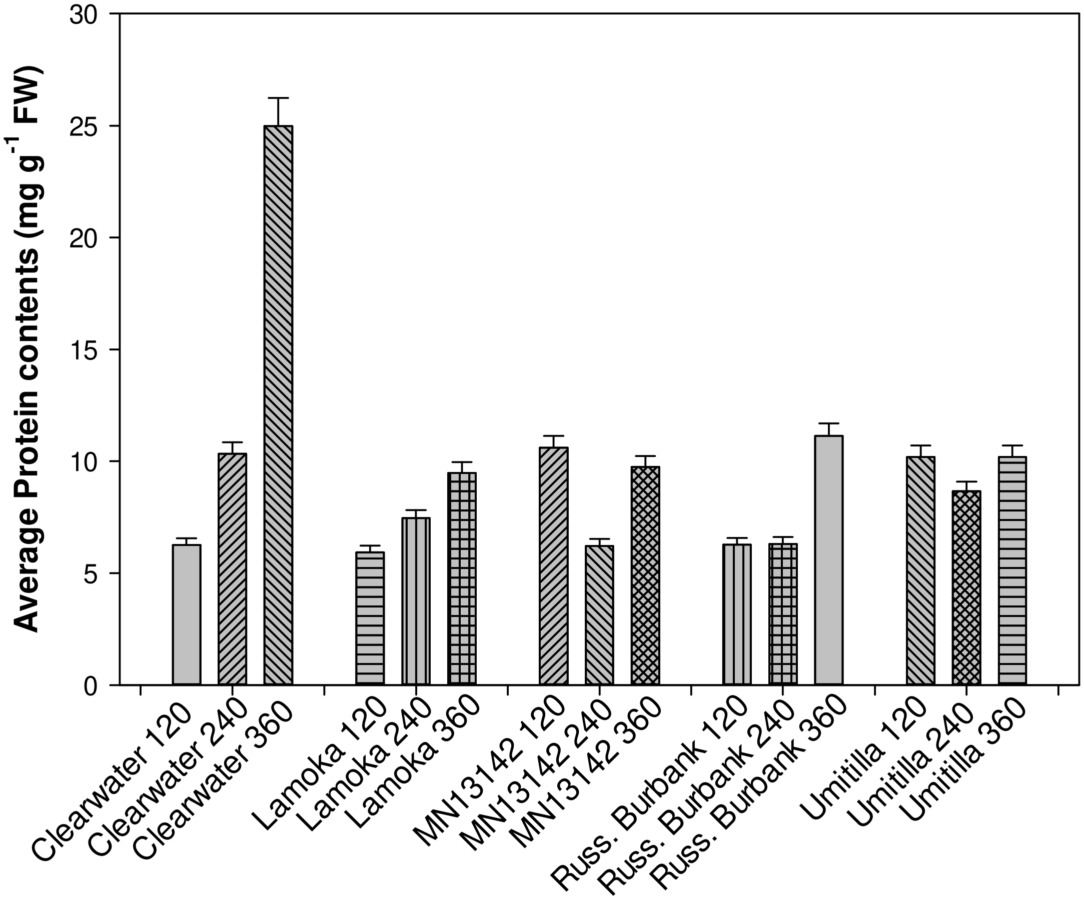

Table 1: Yield and yield components in five potato cultivars in response to N fertilizer rates.

Data represents means of 3 replicates ± SD

SN	Cultivars - N Rate (lbs/ac)	Yield (CWT/ac)				Percentage		Specific Gravity
		Total Yield	US No. 1	US No. 2	Marketable	> 6 oz.	> 10oz.	
1	Clearwater - 120	368.6 ± 47.4	206.3 ± 55.4	162.4 ± 09.5	214.1 ± 57.7	11.1 ± 06.7	0.6 ± 0.0	1.093 ± 0.004
2	Clearwater - 240	400.1 ± 20.8	254.1 ± 27.5	145.9 ± 13.2	261.1 ± 27.0	16.5 ± 03.1	0.6 ± 0.1	1.086 ± 0.006
3	Clearwater - 360	399.6 ± 10.6	256.6 ± 16.8	143.0 ± 15.2	265.5 ± 19.0	25.0 ± 00.5	2.3 ± 0.7	1.086 ± 0.006
7	Lamoka - 120	178.3 ± 18.9	150.0 ± 16.2	28.3 ± 04.1	153.2 ± 18.9	54.4 ± 09.1	21.2 ± 6.7	1.081 ± 0.004
8	Lamoka - 240	153.1 ± 80.2	132.6 ± 67.3	20.4 ± 14.2	133.9 ± 68.4	67.1 ± 03.8	33.8 ± 6.7	1.078 ± 0.001
9	Lamoka - 360	134.5 ± 62.6	106.5 ± 52.6	28.0 ± 11.4	108.7 ± 54.6	38.5 ± 13.6	8.2 ± 7.4	1.080 ± 0.002
10	MN13142 - 120	355.9 ± 11.3	276.4 ± 13.4	79.5 ± 12.2	285.5 ± 13.2	32.3 ± 07.6	2.7 ± 0.3	1.091 ± 0.002
11	MN13142 - 240	387.6 ± 32.9	311.8 ± 30.7	76.5 ± 06.5	322.6 ± 31.7	42.3 ± 03.3	5.3 ± 1.2	1.081 ± 0.001
12	MN13142 - 360	368.0 ± 16.6	297.1 ± 29.2	70.0 ± 12.7	304.8 ± 24.4	39.9 ± 05.2	4.9 ± 3.4	1.081 ± 0.002
13	Russet Burbank - 120	549.1 ± 36.3	445.9 ± 39.1	103.2 ± 04.8	468.9 ± 47.8	42.5 ± 10.1	10.4 ± 3.9	1.081 ± 0.001
14	Russet Burbank - 240	588.4 ± 48.1	476.1 ± 42.9	112.3 ± 17.3	520.4 ± 41.3	58.9 ± 08.0	23.4 ± 11.0	1.079 ± 0.002
15	Russet Burbank - 360	560.8 ± 37.5	471.5 ± 30.7	89.2 ± 07.7	496.4 ± 41.2	57.4 ± 03.2	20.8 ± 2.7	1.079 ± 0.002
16	Umatilla - 120	415.2 ± 19.3	327.7 ± 11.1	87.5 ± 10.4	345.7 ± 14.6	53.1 ± 02.3	21.2 ± 4.4	1.086 ± 0.002
17	Umatilla - 240	493.5 ± 24.0	409.9 ± 22.8	83.6 ± 01.6	443.8 ± 32.0	73.2 ± 06.6	36.3 ± 11.9	1.086 ± 0.003
18	Umatilla - 360	504.4 ± 33.8	435.1 ± 45.0	69.3 ± 11.7	464.5 ± 39.1	72.9 ± 03.7	39.5 ± 2.5	1.086 ± 0.005

Table 2: Effect of N fertilizer rate on tuber quality attributes at harvest

Data represents means of 3 replicates ± SD

SN	Cultivars - N Rate (lbs/a	Sucrose[a]		Glucose[a]		Refectance[b]	
		Stem End	Bud End	Stem End	Bud End	Stem End	Bud End
1	Clearwater - 120	0.29 ± 0.1	0.56 ± 0.1	1.25 ± 0.3	0.43 ± 0.1	43.86 ± 0.6	46.47 ± 1.0
2	Clearwater - 240	0.33 ± 0.0	0.59 ± 0.0	0.95 ± 0.1	0.28 ± 0.0	32.25 ± 1.5	45.90 ± 2.1
3	Clearwater - 360	0.26 ± 0.1	0.54 ± 0.1	0.88 ± 0.0	0.24 ± 0.0	41.37 ± 3.3	44.32 ± 3.5
4	Lamoka - 120	0.66 ± 0.0	0.51 ± 0.0	0.18 ± 0.1	0.03 ± 0.0	46.33 ± 4.4	47.48 ±2.6
5	Lamoka - 240	0.72 ± 0.0	0.63 ± 0.0	0.08 ± 0.5	0.02 ± 0.0	47.22 ± 0.3	45.82 ± 4.7
6	Lamoka - 360	0.64 ± 0.0	0.59 ± 0.0	0.08 ± 0.0	0.02 ± 0.0	50.52 ± 0.0	49.36 ± 2.0
7	MN13142 - 120	0.58 ± 0.0	0.58 ± 0.1	1.07 ± 0.2	0.55 ± 0.1	39.72 ± 3.1	45.08 ± 1.7
8	MN13142 - 240	0.50 ± 0.1	0.60 ± 0.0	0.84 ± 0.1	0.38 ± 0.1	38.81 ± 4.2	45.29 ± 2.7
9	MN13142 - 360	0.47 ± 0.0	0.59 ± 0.0	0.86 ± 0.1	0.46 ± 0.1	39.54 ± 4.2	44.85 ± 2.5
10	Russet Burbank - 120	0.43 ± 0.0	0.78 ± 0.1	2.29 ± 0.4	0.43 ± 0.1	27.27 ± 3.5	40.47 ± 2.4
11	Russet Burbank - 240	0.28 ± 0.0	0.79 ± 0.0	1.76 ± 0.0	0.22 ± 0.0	28.64 ± 3.0	44.00 ± 2.1
12	Russet Burbank - 360	0.4 ± 0.1	0.82 ± 0.1	1.34 ± 0.2	0.21 ± 0.1	30.58 ± 2.9	43.92 ± 1.3
13	Umatilla - 120	0.70 ± 0.1	0.70 ± 0.0	0.93 ± 0.2	0.22 ± 0.1	41.39 ± 0.9	45.75 ± 1.0
14	Umatilla - 240	0.72 ± 0.0	0.82 ± 0.0	0.84 ± 0.1	0.19 ± 0.0	41.85 ± 0.7	47.26 ± 2.1
15	Umatilla - 360	0.71 ± 0.1	0.87 ± 0.0	0.96 ± 0.0	0.25 ± 0.1	38.81 ± 5.2	45.19 ± 3.2

a Sucrose = mg/g fresh weight

a Glucose = mg/g fresh weight

b Reflectance = %

Pressure flattening and bruise susceptibility among new fresh market and chip varieties

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Summary:
In order to test varietal differences in pressure bruise susceptibility, storage facilities at the USDA-ARS (East Grand Forks, MN) worksite were renovated in 2018. Pressure was applied across 1000# totes in a controlled temperature and humidity environment, and quality (water loss, bruise #, and bruise area) was assessed after 4 months of storage. The impact of variety selection, N management, and fluming resident time on bruise susceptibility was evaluated. In early storage evaluations, differences in pressure bruising were detected among chip clones. Nitrogen level impacted the total bruise # and area/tuber, but no differences were detected between the red varieties tested in 2018. Additional tests are being evaluated in the current storage campaign, including the impact of fluming time on bruise development and subsequent data will be compiled upon the completion of the storage season.

Procedures:

Storage structure:

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 (Figure 1). 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. Four pressure totes were tested in each tower and each tote (shelf) had independent pressure plate and air-flow regulation capabilities. In 2018, applied tote pressure equaled that of an 18' pile height. Air flow was monitored with a hot-wire anemometer. In 2018, only one storage temperature was evaluated (46°F). Humidified air was directed through the tote from 3'' gated valves; the front forklift holes were filled during storage to ensure that desired airflow was achieved at each storage tote.

Plant Material

Grower chip variety evaluation. On 10/02/2018 five chip varieties were collected from Hoople, ND grower facilities. Three varieties: Dakota Pearl 'A', Dakota Pearl 'B' and Lady Claire were harvested on 10/02/2018 and were sampled directly from the clod hopper or bin immediately after loading. Two other varieties: Waneta and Variety 'X' were sampled from the grower's storage facility within 48hr of harvest. All samples were brought to the lab and sorted into 5 replicate mesh bags containing 10 tubers/bag per variety.

Figure 1. One of three pressure towers located at the USDA-ARS facility (EGF, MN) (1A). Foam insulation is removed from the top shelves for picture clarity. Air flow is directed through the tote from a 3'' duct located at the back wall (not shown). The front forklift holes are filled to ensure humidified air is uniformly directed through the tote (1.5 cfm/cwt). A chip variety collected from a cooperator clod hopper at Hoople, ND (1B).

Nitrogen study: Samples were obtained from a Nitrogen field study (4 Nitrogen Levels: 80,120, 160, 200lb, 2 varieties: Dark Red Norland (DRN) and 6002-R). This field study was directed by Dr. Andy Robinson at the NPPGA farm in Grand Forks, ND. Samples were harvested on 10/02/2018 and were stored on a trailer overnight. Samples were brought to the USDA lab for grading (size and color) on 10/03/18. A mesh bag was filled with 8 tubers of uniform size for each of the 4 field replicates (N treatments and varieties).

SNAC Chip Trial: Samples were obtained from a Potatoes USA sponsored SNAC chip trial grown in Hoople, ND. In 2018, 12 chip clones representing elite breeding lines from 7 public breeding programs were evaluated. Following grading in EGF, 4 replicates of 8 tubers/clone were placed in mesh bags and layered within the pressure tote.

Red size: Sampling occurred from an East Grand Forks, MN wash plant. A red variety was separated into B size and unsized treatments. Five replicated mesh bags were collected containing Bs or the mixed 'ungraded' sample.

<u>Sampling and pressure adjustment</u>

Immediately upon placement of tubers (8 -10 tubers/treatment) into mesh sacks, total bag weights were recorded. Specific gravity of a subsample was also 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 (Figure 2). Bottle jack gauge pressure was adjusted to simulate pressures exerted within an 18' pile. 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.   After the gauge pressure was verified, shelf openings were covered with rigid foam insulation.

Samples were suberized for 2 weeks at 55°F, 95% RH. Following suberization, the temperature was lowered to 46°F at a cooling rate of (0.4°F/day). After approximately 4 months of storage, totes were removed, and sample bags weights recorded to determine water loss. Each individual tuber was evaluated for flattened and depressed areas. These areas were circled and diameter was measured with a digital caliper. The total number of flattened depressions per tuber and total impacted area was calculated and reported. In the SNAC chip trial, tuber discoloration notes were also recorded after peeling.

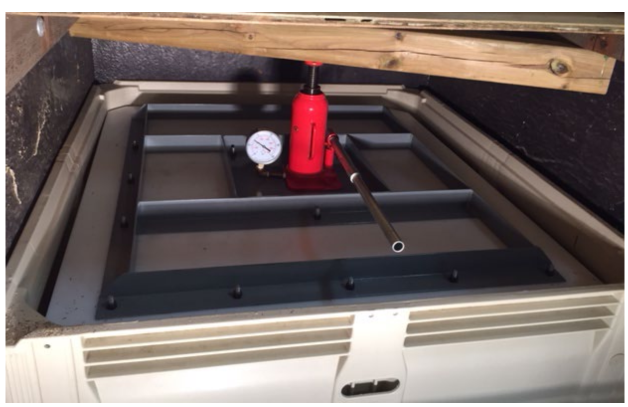

Figure 2. Reinforced UHMW pressure plate equipped with bottle jack/gauge.

Results:

With many samples still remaining in storage, the following data represents the first retrieved storage samples. A final storage summary will be compiled and published in the Valley Potato Grower Magazine at the conclusion of the 2018-19 storage season.

Grower chip variety evaluation. The overall objective of this study was to determine if varietal differences in bruising could be detected in the devised storage tote pressure structure. Five chipping varieties were selected, and differences in water loss, bruise #, and bruise area were characterized. The pressure plates were removed on 01/31/2019, and differences in bruise #, area, and water loss were detected among the five varieties (Table 1). Dakota Pearl had the lowest bruising, where the highest damage was observed from Waneta. In general, increased water loss during storage was associated with increased bruising. Waneta and Variety 'X' had the highest water loss after 4 months of storage and experienced the high incidence of bruising. This study will be repeated in 2019.

Table 1. Bruising after 4 months of storage_Hoople grower chip varieties

Variety	Water Loss (%)	Bruises/Tuber	Bruise Area (in^2) per Tuber
Dakota Pearl – farm 'A'	3.81	2.63	1.04
Dakota Pearl – farm 'B'	5.79	3.43	1.59
Lady Claire	5.36	3.30	1.69
'X' variety	7.58	3.93	2.41
Waneta	8.12	4.53	2.73

Nitrogen study: The objective of this study was to evaluate the impact of Nitrogen management on postharvest quality. Pressure plates were removed on 01/31/2019. No differences in bruise # or bruise area were detected between the two varieties when averaged across Nitrogen treatment (Figure 3). Dark Red Norland and 6002-R had 3.59 and 3.58 bruises per tuber, and the total bruised area was 1.85 and 1.92 in^2 for DRN and 6002-R, respectively. Although no differences in bruising were detected between the varieties, there was a significant difference in water loss after 4 months of storage. Averaged across all nitrogen levels, 6002-R had 6% reduction in weight, where the Dakota Red Norland sample lost 4.2%. The higher water losses from 6002-R could be attributed to the increased skinning observed in that variety (Figure 4). Additional statistical analyses on the impact of nitrogen level on bruising are ongoing. The field and storage trial will be repeated in 2019.

Red size test: Storage totes will be opened on 02/12/2019

SNaC Chip Trial: Storage totes will be opened on 02/21/2019

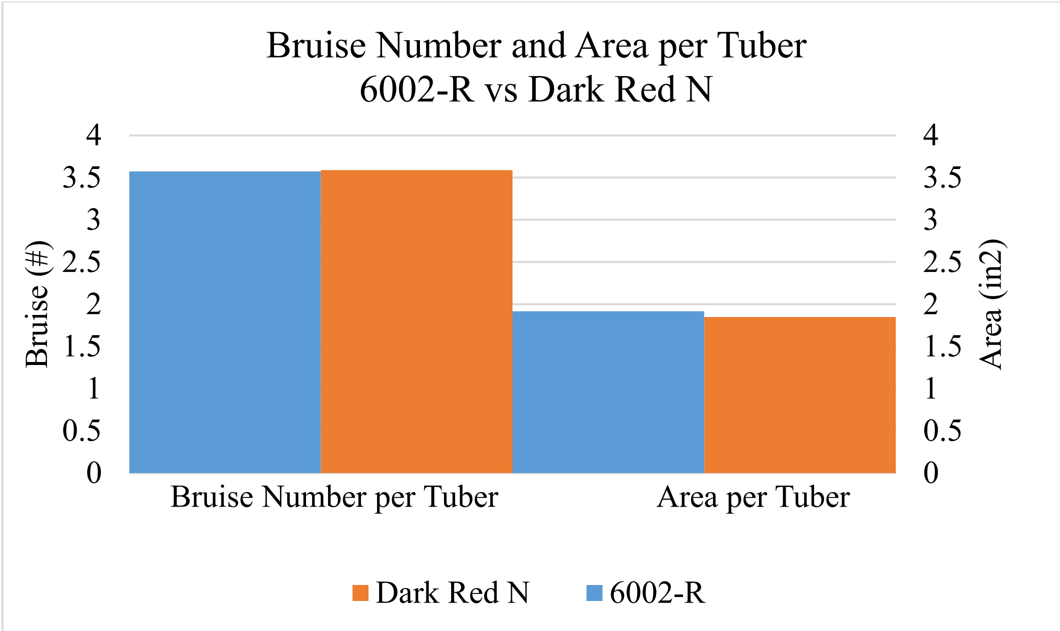

Figure 3. No differences in total bruise number or bruise area were detected between 6002-R and Dark Red Norland after 4 months of storage (averaged across N levels).

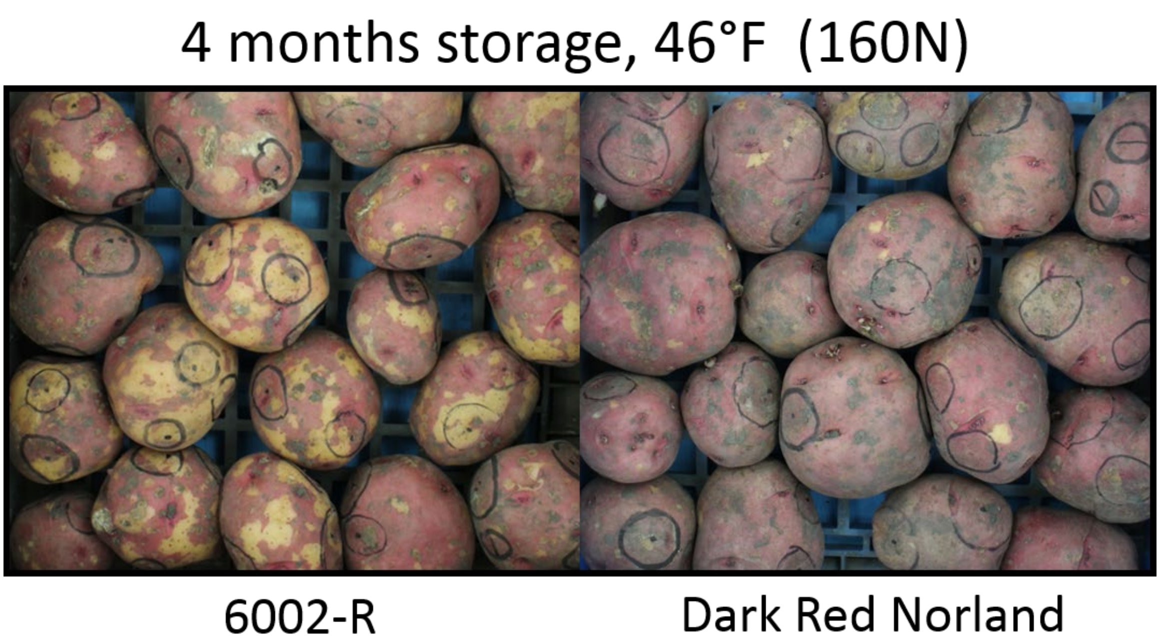

Figure 4. Although 6002-R had higher water loss at 4 months of storage, there were no differences in bruising between the varieties across all nitrogen levels (160N is shown). Impacted areas were circled and measured within 24 hours of removing the pressure plate.

Adjuvant Comparison with Potato Desiccants, Grand Forks1. H. Hatterman-Valenti and C. Auwarter.

This study was conducted at the Northern Plains Potato Growers Association dryland research site near Grand Forks, ND to evaluate different adjuvants when added to a common vine desiccant, diquat, on 'Red Norland' potato. Plots were 4 rows by 20 feet arranged in a randomized complete block design with 4 replicates. Seed pieces (2 oz) were planted on 36-inch rows and 12-inch spacing on June 19, 2018. Extension recommendations were used for cultural practices throughout the year. Plots were sprayed on August 27 with a CO2 pressurized sprayer equipped with 8002 XR flat fan nozzles with a spray volume of 20 GPA and a pressure of 40 psi. Plots were rated 1, 3 and 8 days after planting (DAP).

Table 1. Herbicide application information.

Date:	8/27
Air Temperature (F):	57
Relative Humidity (%):	78
Wind (MPH):	10
Soil Moisture:	Excess
Cloud Cover (%):	100
Next Rain:	8/31

Table 2. Percent Necrosis on Leaves and Stems, NDVI and Canopy Cover ratings.

Trt No.	Treatment Name	Rate	Rate Unit	Appl Code	---------1 DAA---------		----------------3 DAA----------------			--------------8 DAA--------------		
					Leaf Senescence	NDVI	Leaf Senescence	Stem Senescence	NDVI	Leaf Senescence	Stem Senescence	Canopy
1	Reglone	1	pt/a	A	13.8 a	0.73150 a	48.8 a	25.0 a	0.50565 b	87.5 a	80.0 a	4.546 b
2	Reglone	1	pt/a	A	11.3 a	0.68550 a	47.5 a	22.5 a	0.53558 b	83.8 a	71.3 a	9.944 b
	Preference	0.25	% v/v	A								
3	Reglone	1	pt/a	A	13.8 a	0.69143 a	45.0 a	21.3 a	0.52878 b	85.0 a	75.0 a	6.004 b
	Accudrop	0.25	% v/v	A								
4	Reglone	1	pt/a	A	8.3 a	0.69730 a	43.3 a	20.0 a	0.53187 b	70.0 a	60.0 a	13.912 b
	Noble	3	fl oz/a	A								
5	Reglone	1	pt/a	A	16.3 a	0.73373 a	43.8 a	21.3 a	0.54995 b	84.7 a	78.3 a	3.479 b
	Accudrop	0.25	% v/v	A								
	Noble	3	fl oz/a	A								
6	Reglone	1	pt/a	A	16.7 a	0.66645 a	36.7 a	18.3 a	0.56087 b	88.3 a	73.3 a	8.924 b
	Preference	0.25	% v/v	A								
	Interlock	4	fl oz/a	A								
7	Reglone	1	pt/a	A	17.5 a	0.67120 a	53.8 a	27.5 a	0.54123 b	81.3 a	73.8 a	8.075 b
	Accudrop	0.25	% v/v	A								
	Interlock	4	fl oz/a	A								
8	Reglone	1	pt/a	A	15.0 a	0.74157 a	47.5 a	22.5 a	0.52398 b	77.0 a	68.8 a	5.326 b
	AG8050	6.4	fl oz/a	A								
9	Reglone	1	pt/a	A	18.8 a	0.74090 a	45.0 a	25.0 a	0.52208 b	81.3 a	71.3 a	9.186 b
	AG14039	8	fl oz/a	A								
10	Untreated				0.0 b	0.68137 a	0.0	0.0 b	0.80433 a	0.0 b	0.0 b	51.429 a
			LSD P=.05		7.19	0.1000	18.71	12.25	0.0335	14.37	15.44	5.52 – 14.51

Reglone alone provided just as much leaf and stem necrosis as reglone plus an adjuvant (Table 2). The use of NDVI or % Canopy Coverage data resulted in similar statistical results as using % necrosis data. The use of NDVI or %Canopy Cover provides ways to evaluate necrosis without the subjectiveness of the visible rating system.

Adjuvant Comparison with Potato Desiccants, Grand Forks2. H. Hatterman-Valenti and C. Auwarter.

This study was conducted at the Northern Plains Potato Growers Association dryland research site near Grand Forks, ND to evaluate different adjuvants when added to a common vine desiccant, diquat, on 'Red Norland' potato. Plots were 4 rows by 20 feet arranged in a randomized complete block design with 4 replicates. Seed pieces (2 oz) were planted on 36-inch rows and 12-inch spacing on June 19, 2018. Extension recommendations were used for cultural practices throughout the year. Plots were sprayed on August 27 with a CO2 pressurized sprayer equipped with 8002 XR flat fan nozzles with a spray volume of 20 GPA and a pressure of 40 psi. Plots were rated 1, 3 and 8 days after planting (DAP).

Table 1. Herbicide application information.

Date:	8/27
Air Temperature (F):	57
Relative Humidity (%):	78
Wind (MPH):	10
Soil Moisture:	Excess
Cloud Cover (%):	100
Next Rain:	8/31

Table 2. Percent Necrosis on Leaves and Stems, NDVI and Canopy Cover ratings.

Trt No.	Treatment Name	Rate	Rate Unit	Appl Code	-----------1 DAA----------		-------------------3 DAA------------------			-----------------8 DAA----------------		
					Leaf Senescence	NDVI	Leaf Senescence	Stem Senescence	NDVI	Leaf Senescence	Stem Senescence	Canopy
1	Untreated				0.0 b	0.69073 a	0.0 b	0.0 b	0.79793 a	0.0 b	0.0 b	41.14 a
2	Reglone	1	pt/a	A	15.0 a	0.70277 a	53.8 a	30.0 a	0.53830 b	86.3 a	78.8 a	3.64 b
3	Reglone Activate Plus	1 0.1	pt/a % v/v	A A	13.8 a	0.73803 a	53.8 a	26.3 a	0.50120	93.3 a	85.0 a	1.89 b
4	Reglone AG17054	1 0.1	pt/a % v/v	A A	7.5 ab	0.69960 a	47.5 a	25.0 a	0.50658 b	78.8 a	70.0 a	7.40 b
5	Reglone AG17055	1 0.1	pt/a % v/v	A A	10.0 ab	0.78647 a	55.0 a	28.8 a	0.52905 b	87.5 a	76.3 a	4.29 b
6	Reglone AG17056	1 0.1	pt/a % v/v	A A	3.3 ab	0.81165 a	58.3 a	31.7 a	0.53815 b	86.7 a	76.7 a	3.34 b
7	Reglone Activate Plus	1 0.25	pt/a % v/v	A A	10.0 ab	0.68360 a	53.8 a	27.5 a	0.50933 b	89.5 a	81.3 a	2.89 b
				LSD P=.05	8.73	0.148	16.53	11.24	0.040	12.24	12.90	3.48 – 10.55

Reglone alone provided just as much leaf and stem necrosis as reglone plus an adjuvant (Table 2). The use of NDVI or % Canopy Coverage data resulted in similar statistical results as using % necrosis data. The use of NDVI or %Canopy Cover provides ways to evaluate necrosis without the subjectiveness of the visible rating system.

Evaluating SOP vs MOP programs in Russet Burbank potato. H. Hatterman-Valenti and C. Auwarter.

This study was conducted at the Northern Plains Potato Growers Association Irrigated research site near Inkster, ND to evaluate sulfate of potash (SOP) vs muriate of potash (MOP) grower standard programs (GSP) in Russet Burbank potato production in North Dakota. Plots were 4 rows by 20 feet arranged in a randomized complete block design with 4 replicates. Planting was delayed by rain. Seed pieces (2 oz) were planted on 36-inch rows and 12-inch spacing on June 4, 2018. Fertilizer was spread and incorporated prior to planting, with the goal being 100 lb K. Extension recommendations were used for cultural practices throughout the year. Plots were harvested on October 17 and graded into various categories after harvest.

Table 1. Yield (CWT/A) of Russet Burbank potatoes comparing 2 different fertilizers.

Trt No.	Treatment Name	------------------------------------CWT/A----------------------------------					
		Total	0-4 oz	4-6 oz	6-12 oz	>12 oz	>4 oz
1	GSP 100% MOP	462.5 a	54.0 a	106.7 a	223.1 a	78.7 a	408.5 a
2	65% MOP 35% SOP	371.3 a	69.5 a	88.8 a	173.4 a	39.5 a	301.7 a
3	50% MOP 50% SOP	416.6 a	65.8 a	85.2 a	195.2 a	70.5 a	350.9 a
4	100% SOP	425.6 a	60.5 a	110.3 a	224.1 a	30.8 a	365.1 a
	LSD P=.05	63.5	42.0	38.9	57.3	42.9	75.6

Table 2. Tuber counts in Russet Burbank potato comparing 2 different fertilizers.

Trt No.	Treatment Name	-----------Tuber Counts in 20 Row ft-----------				
		Total	0-4 oz	4-6 oz	6-12 oz	>12 oz
1	GSP 100% MOP	162.3 a	42.0 a	47.0 a	59.5 a	11.3 a
2	65% MOP 35% SOP	152.3 a	55.8 a	39.0 a	46.5 a	5.8 a
3	50% MOP 50% SOP	154.0 a	51.5 a	37.3 a	52.3 a	9.5 a
4	100% SOP	164.3 a	48.1 a	48.0 a	60.0 a	5.0 a
	LSD P=.05	43.4	27.7	17.6	14.4	5.8

No significant differences were observed during this trial. The two highest yielding treatments were the ones that only used one potash source, not a blend. The GSP treatment resulted in a marketable yield that was 42 CWT/A higher, compared to all others. The 100% SOP had the greatest number of tubers and the most tubers in the 4-6 and 6-12 oz size. The planting delay, shorter growing season, and more moist trial location may have influenced results and reduced chloride injury.

Evaluating Single and Repeat Hail Event in 'Clearwater' potato. H. Hatterman-Valenti and C. Auwarter.

This study was conducted at the Northern Plains Potato Growers Association Irrigated research site near Inkster, ND to evaluate yield and grade responses to single or double simulated hail events at various potato growth stages for 'Clearwater' potato production in North Dakota. Plots were 4 rows by 20 feet arranged in a randomized complete block design with 4 replicates. Planting was delayed by rain. Seed pieces (2 oz) were planted on 36-inch rows and 12-inch spacing on June 4, 2018. Extension recommendations were used for cultural practices throughout the year. Simulated hail at either 50% or 99% defoliation occurred at one of four application timings: tuber initiation (TI) on 7/16 or 42 days after planting (DAP), end of tuber initiation (ETI) on 7/31 or 57 DAP, early tuber bulking (ETB) on 8/20 or 77 DAP, and mid bulking (MB) on 8/31 or 88 DAP. Plots were harvested on October 17 and graded into various categories on November 15.

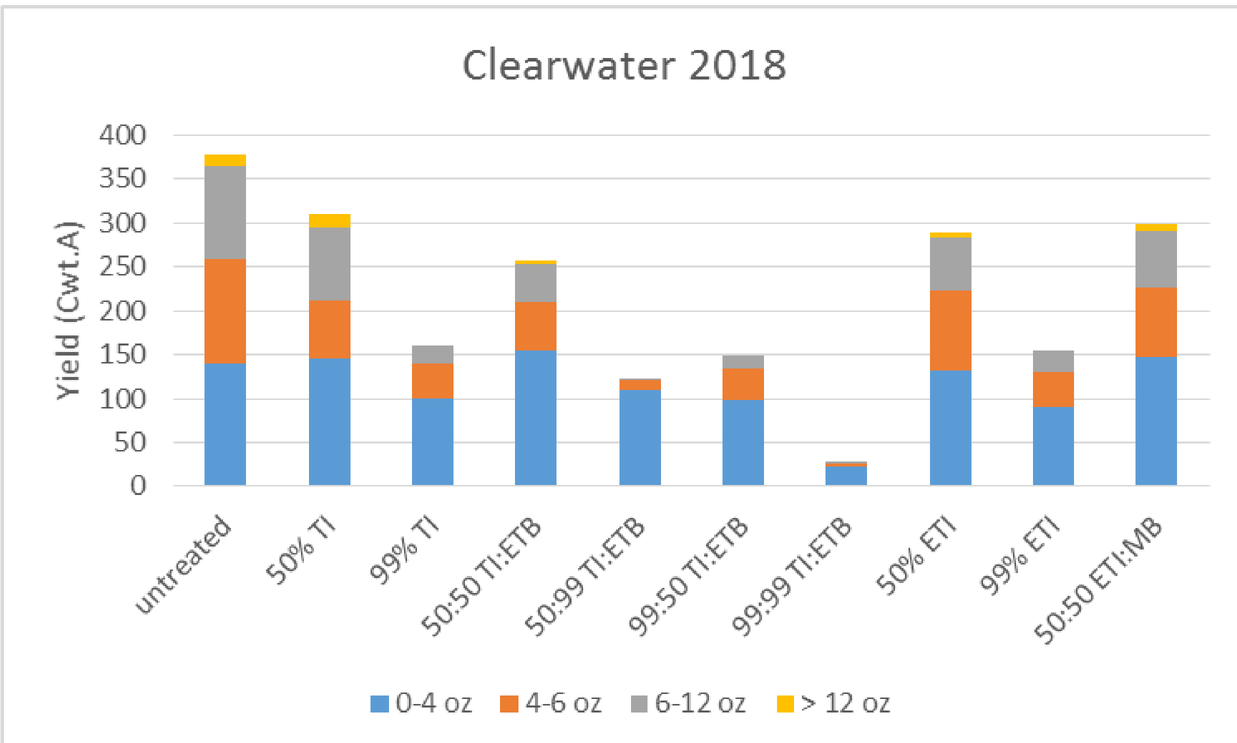

Figure 1. Tuber grade (CWT/A) for each weight category with 'Clearwater' potatoes receiving simulated hail events.

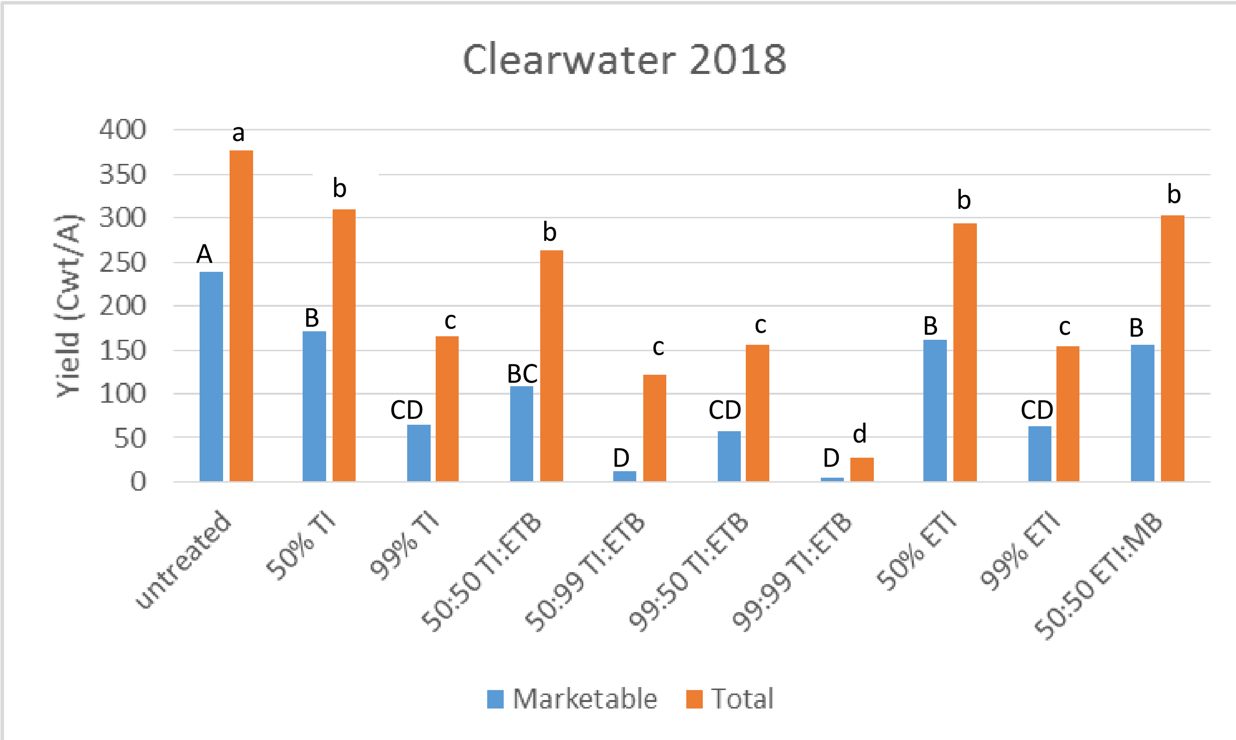

Figure 2. 'Clearwater' marketable and total yield in response to simulated hail events.

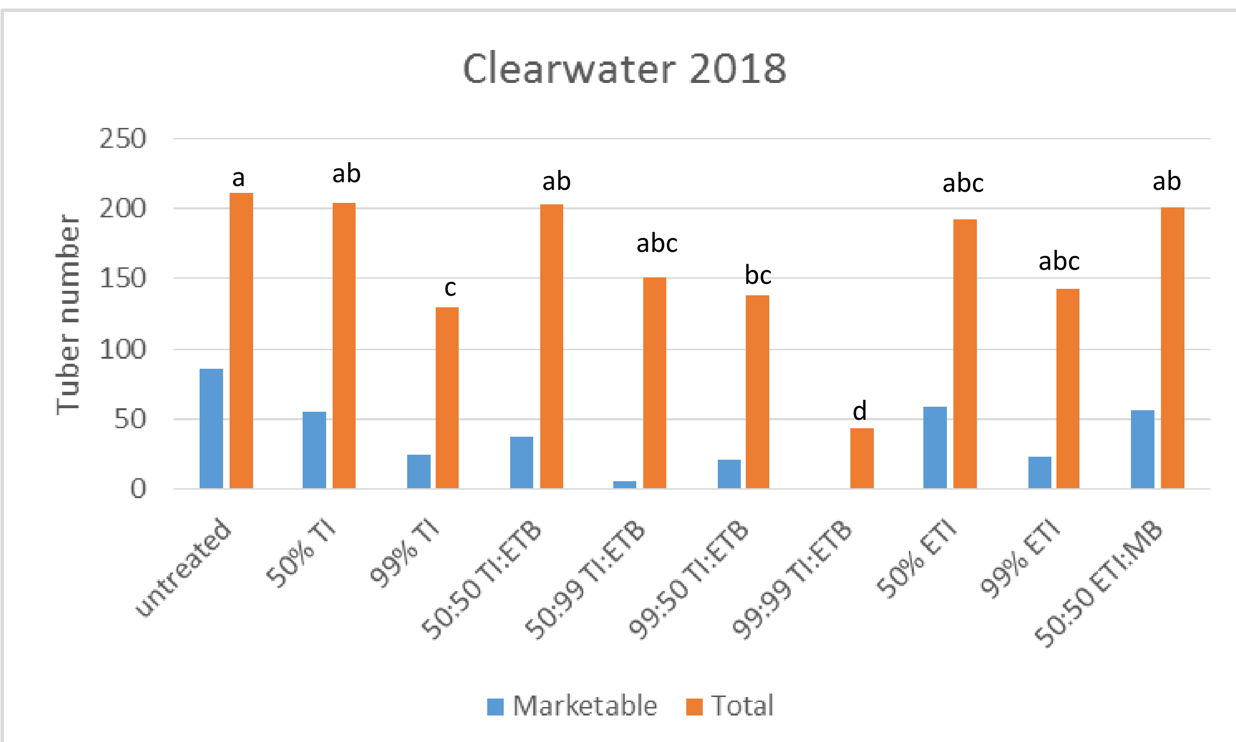

Figure 3. 'Clearwater' marketable and total tuber counts in response to simulated hail events.

Yield reductions were primarily due to lower yield in the > 12 oz, 6-12 oz, and 4-6 oz categories (Figure 1). Cull yield was similar to the untreated for most simulated hail events with the most notable exception occurring when 99% defoliation occurred at tuber initiation (TI) and again at early tuber bulking (ETB). All hail treatments lowered marketable and total yield compared to the untreated (Figure 2). Even though defoliation at the beginning and end of tuber initiation varied by 15 days, the marketable and total yield were similar. Having 99% defoliation for the second simulated hail event virtually eliminated any marketable yield. Marketable yield reductions were generally due to an increase in cull tubers except for 99% TI, 99/50 TI/ETB, and 99/99 TI/ETB where both tuber size and tuber number were decreased (Figure 3).

Baseline Evaluation of Pollinator Landscape Plantings Bordering Commercial Potato

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Executive Summary – *Potatoes and Pollinators*: This is a continuing research proposal to assess the impact of floral plantings (i.e. establishing pollinator habitat) on the population dynamics of pollinators and natural enemies (i.e. predators and parasitoids) and the potential positive impacts these populations may have on the neighboring commercial production fields (e.g. biocontrol services – the mortality imposed on pest insect species by the natural enemies fostered in the floral plantings).

We will A) assess the pollinator and natural enemy communities found in these plantings and B) compare pollinator populations in commercial potato fields with and without border plantings of wild flowers and/or native plants. The R.D. Offutt CO. has established ~1200 ac of wildflowers in plots adjacent to commercial potato production, often in the corners of fields housing pivots or along roadsides (Fig 1). Floral plantings show significantly greater floral coverage and flowering plant species richness (number of species per unit area) than neighboring unmanaged/unplanted field edges (Fig 2) Adjacent to these fields are other commercial production fields wherein floral plantings have not been established, instead they have unmanaged corners and field edges. These two neighboring systems provided an excellent living lab to assess and compare the effects of floral plantings on pollinator and natural enemy populations and services.

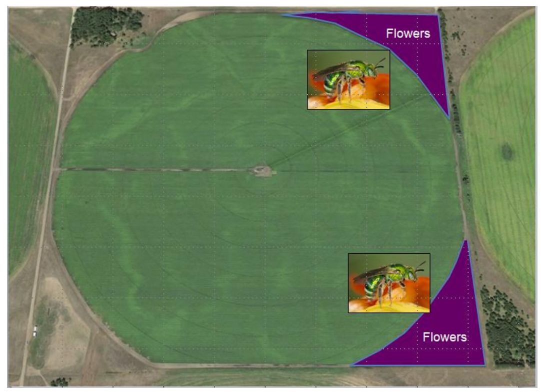

Figure 1. Representative area of floral plantings neighboring commercial potato production fields

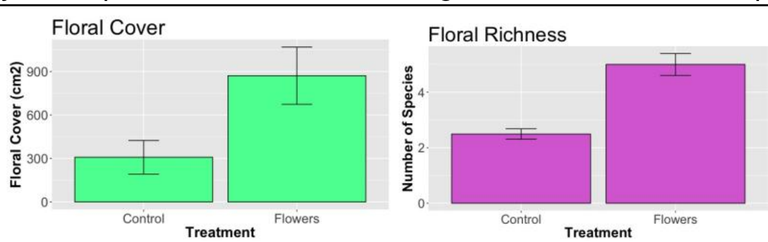

Figure 2. Comparison of floral cover and flowering plant species richness (#species/unit area) in floral planted vs unmanaged edges. Floral plantings have significantly more floral coverage and richness.

Our procedures were expanded and adapted somewhat from those in our original proposal. The techniques utilized provided more data, expanded our means of estimating population and gave a better assessment of biocontrol services than simply counting natural enemies.


Figure 3. Bee bowls – plastic containers in colors attractive to pollinators. Containers hold catch fluid (e.g. alcohol or water and detergent) where in pollinators become trapped.

Procedures – A) Pollinator communities in the unmanaged and floral planting habitats were assessed and compared by walking monthly, replicated sampling transects at multiple sampling fields in Central MN. Static sampling was also conducted; replicated pan traps and 'bee bowls' (plastic containers in colors known to be attractive to pollinators filled with a catch fluid, Fig 3), were established in all sampling areas and monitored weekly. In addition, 'bee houses' (Fig 4), small diameter tubes (preferred by native bees as nests) stacked into a container (we used 10" PVC pipe) were pre-weighed and established in each sample location. At the end of the season, the bee houses were collected and weighed to assess the population of native pollinators that utilized them as nest sources. Weights of bee houses established in floral plantings was compared to those placed into non-managed field edges. This provides an indirect estimate of native pollinating bee species establishing in floral plantings versus non-managed field edges. Pollinators and natural enemies were identified to species when possible with particular attention paid to native and bumblebee species. Individual specimens of species which could not be identified in the field were returned to the laboratory at either the NWROC or NCROC and identified.

To assess potential biocontrol services (the benefits to neighboring commercial fields garnered from improving natural enemy populations in floral plantings) Sentinel prey stations (Fig 5) were established in both floral plantings, unmanaged edges and in the commercial fields adjacent to both. These stations incorporated frozen Colorado Potato Beetle (CPB) eggs on potato leaf pieces collected from commercial fields and lab colonies prior to the field season. The leaf pieces were attached to cardstock and then the cardstock was clipped to plants in sample areas. This technique has been used successfully in other biological control trials (Hough-Goldstein et al 1993, Hu et al 1999). Sentinel prey stations were checked 1 week post-establishing and replaced or removed until the next sampling period. The number of eggs actively fed upon were assessed. Feeding damage, either complete consumption or content removal via a predator with piercing/sucking mouthparts (like the Assassin Bug in Fig 5), results in a different form of damage to the egg than simple dehydration.

Figure 4. 'Bee house' – small diameter straws/tubes, preferred by native pollinator bee species, staked into a larger container.

Figure 5. Sentinel prey station – frozen Colorado Potato Beetle eggs on potato leaf pieces, attached to cardstock and clipped to plants. The insect on the cardstock is an Assassin Bug, a known predator of CPB eggs that pierces the egg with it's stylet-like mouthparts and drains the contents similar to the way an aphid would feed on a plant.

B) Sampling transects (and/or pan traps) were conducted in the commercial potato fields adjacent to the pollinator landscape plantings. Commercial fields lacking adjacent pollinator landscape plantings of the same size were identified and sampled for pollinators and natural enemies throughout the summer in a similar manner (to act as a non-treated control comparison). Populations of pollinators in the two types of fields were compared and pollinator and natural enemy services will be determined.

Results & Discussion. *Pollinators* - Floral plantings had no effect on the *species richness* of pollinators, that is, the number of species of pollinators in floral planted margins was no different than that in unmanaged edges. There was, however, a significant effect on pollinator abundance (Fig 6); that is, a *greater number* of pollinators in present in floral planted edges than in unmanaged edges. So the floral plantings did not attract a greater number of pollinator species, floral cover did result in greater numbers of pollinators of those species present in both planted and unmanaged edges. The lack of different species of pollinators in the floral plantings may have resulted in the less than optimum establishment of some of the flowering plants in those planted areas. There were a number of different seed sources used in establishing these floral plantings, and they incorporated slightly different species of flowering plants. Some of these species were more successful than others in establishing. Of the pollinator species in each location, there were significantly more individuals in the floral plantings, which indicates that the plants in the different seed sources that were successful in establishing did attract more pollinators. It seems, therefore, that selecting the correct seed mixture will influence the success of the these floral plantings. Selecting the correct seed mixture will influence the success of the these floral plantings. So, floral plantings will attract pollinators, if they establish well.

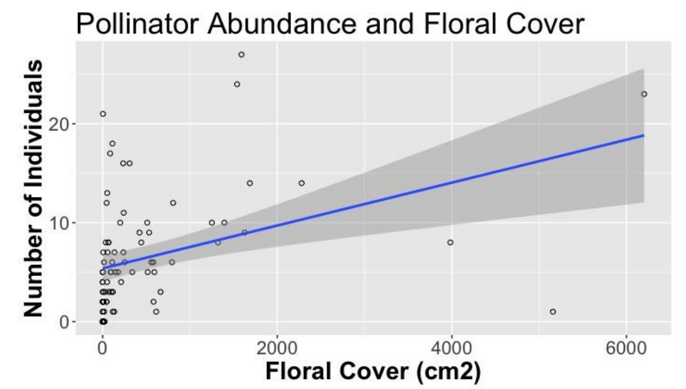

Figure 6. The relationship of floral cover and pollinator abundance. As floral cover increased, so did the number of pollinator individuals.

Natural Enemies and Biocontrol Services – Transects and capture techniques indicated there was a significant effect of floral plantings on natural enemy numbers. There were significantly more natural enemies, especially CPB predators, in floral plantings than in unmanaged edges (P=0.000051, Fig 7). Floral plantings do attract predators.

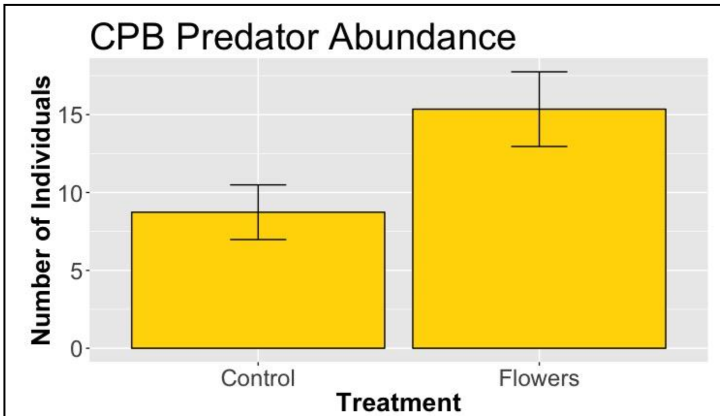

Figure 7. Presence of Colorado Potato Beetle predators in floral planted edges and unmanaged edges (control). Significantly more predators were recovered from the floral planted edges than unmanaged edges.

Sentinel prey sites established in floral and unmanaged edges also indicated that there was a significant effect on the rate of predation on the frozen CPB eggs. There was significantly more predation on frozen CPB eggs in floral planted edges than there was in unmanaged edges (P=0.0000034), Fig 8). This indicates that floral plantings attract natural enemies including species that prey on CPB eggs. If this also includes predators that feed on CPB adults, it may provide additional mortality to immigrating post-wintering CPB as they cross floral plantings to enter production fields.

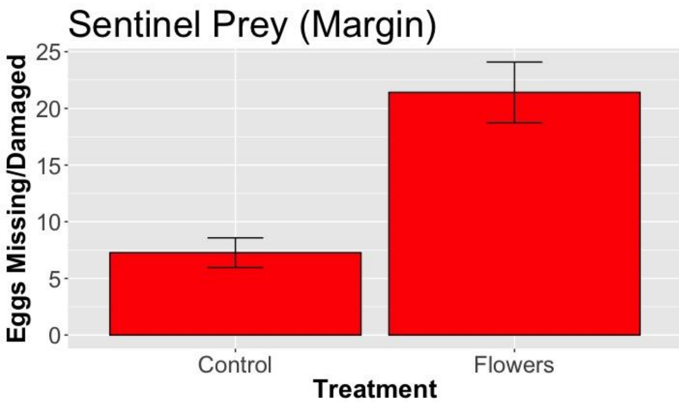

Figure 8. Predation of sentinel prey (frozen Colorado Potato Beetle eggs) by predators within floral planted edges and unmanaged edges (control). Significantly more eggs were preyed upon in floral edges than in unmanaged edges.

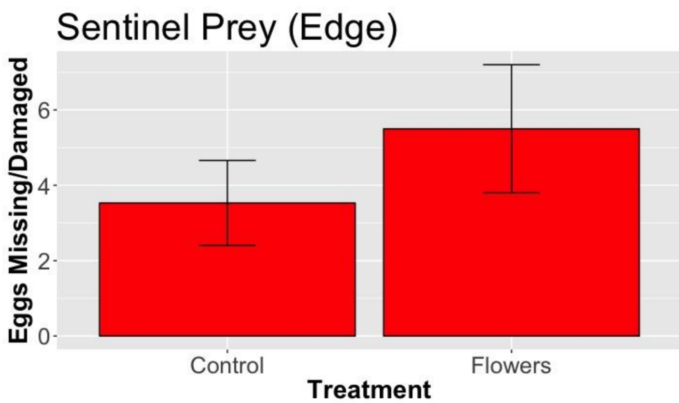

Figure 9. Predation of sentinel prey (frozen Colorado Potato Beetle eggs) by predators in commercial production fields bordering either floral planted edges or unmanaged edges (control). There was no significant difference in the number of eggs destroyed in commercial fields bordering either planting type.

Floral plantings, however, did not effect the predation of sentinel prey within adjacent commercial fields. No more sentinel prey eggs were destroyed by predators in commercial fields bordering floral plantings than in commercial fields bordering unmanaged edges (P=0.23, Fig 9). So, while there may be greater predation within the floral plantings, this does not It also suggests there may be some value to utilizing a trap crop technique whereby suitable species are planted within the floral plantings to arrest immigrating CPB and stimulate oviposition. These trap plants can then be treated or destroyed, decreasing immigrating beetle pressure. Evaluating the potential of such a technique will require more research.

Other results are still being analyzed but will be presented at extension events later in the year.

The research for this project is conducted by Eric Middleton, PhD Candidate, Dept. of Entomology, U.Minnesota, 219 Hodson Hall, 1980 Folwell Ave, St Paul, MN 55108. All slides and figures courtesy of Mr. Middleton.

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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. This work is partially supported by a MN Specialty Crop Block Grant.

Procedures - Colorado potato beetle adults were sampled from 10 potato production areas within Minnesota and North Dakota (Table 1). Overwintering and summer adults (when available) were sampled, and, as expected, higher resistance levels are expected to be found in summer adults of the same location (the beetles' detoxification systems are somewhat impaired by overwintering). Larvae were not sampled due to the difficulty in successfully transporting and maintaining this life stage of the beetle (handling mortality would have been extremely high). Their resistance levels would also be lower than that of adults.

Sampled beetles were assessed for susceptibility to up to 6 different insecticides (from 5 different modes of action): 2 neonicotinoids MOA Group 4 (Clothianidin [Belay], and Thiomethoxam [Actara]), an Avamectin MOA Group 6 (AgriMek), an Anthranilic Diamide MOA Group 28 (Chlorantraniliprole [Coragen]), a Spinosyn MOA Group 5 (Blackhawk), and a METI insecticide, Tolfenpyrad MOA Group 21 (Torac). All are registered insecticide currently used in foliar application management of CPB. All are formulations that contain only one active ingredient formulations; it was felt they should provide sufficient data to extrapolate resistance status of mixed products. Resistance / tolerance of CPB from each sampled area were assessed using a 'drip test', a type of direct exposure bioassay. We originally planned on also conducting 'dip' bioassays (adults are dipped into mixed material and then observed) but data from these trials was highly variable. While dip tests can provide good in-field indications of the expected efficacy of an insecticide, they are less suitable for calculating rates of resistance. It was decided, therefore, to use only drip test bioassays; they provided the best standardized results, were more precise and provided the necessary data to calculate response rates (i.e. ressiatance ratios).

Gradient concentrations of insecticides were used in trials to determine how much insecticide is required to kill 50% of the population (i.e. the Lethal Dose 50% or 'LD_{50}'). All concentrations were based on high recommended label rates of that insecticide for control of CPB. We used label rates instead of arbitrary concentrations of active ingredient (e.g. parts per million) as it provided data that was more indicative of what effect a tested insecticide can be expected to have on CPB populations at sampled locations. At least 6 different rates of each insecticide were applied (i.e. 0X, 1X, 5X, 10X, 50X, and 100X the insecticide's highest recommended label rate for CPB control) and the %mortality was assessed at each rate. Each insecticide rate was replicated 4 times. These data were then used to create dose-response curves (e.g. Fig 1)where % mortality was shown on the Y axis and insecticide rate on the X-axis. It is important in calculating dose-response curves to have both a lower and upper 'discriminating dose'. The lower discriminating is a rate that kills no individuals in the test population whereas the upper discriminating dose should all or nearly all of the individuals in the test population. The lower discriminating dose in our trials was 0X and the high discriminating dose was 100X the high label rate for the insecticide being tested. Concentrations were prepared using commercial insecticides purchased within season and diluted or concentrated to the appropriate rates using reverse osmosis treated water.

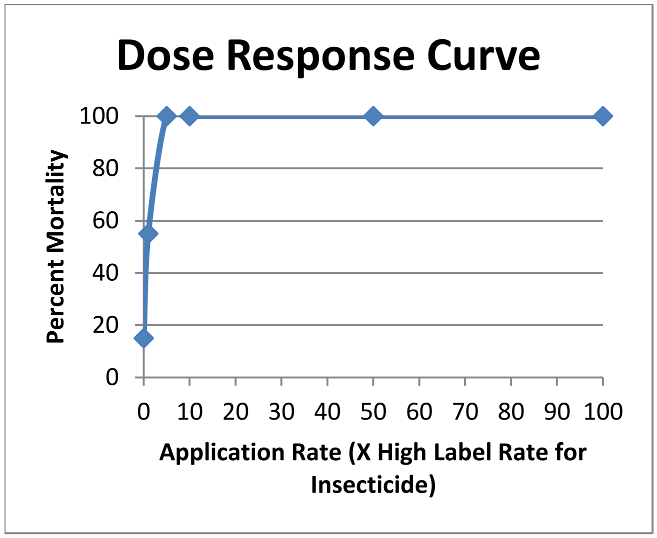

Figure 1. An example of a dose response curve for a population of CPB treated with an increasing rate gradient of insecticide. Note the rate at which 50% of the population die in response to the toxin (LD_{50}) is approximately at 1X the high label rate (i.e. this population is susceptible to this insecticide).

Drip tests were conducted by using a microsyringe (Fig 2) to apply a 10 µl (10 microliters) drop to the underside of the abdomen of each individual insect. After the insecticide had dried, CPB were placed onto leaf disc in petrie plates and left to feed for up to 7 days (169 hours). Beetles were assessed for mortality at 24, 48 (to assess any handling mortality) and finally at 169 hrs after application to assess mortality. Beetles were assessed as dead if, after being placed onto their backs, they moved or tried to right themselves. Any insect not at least attempting to right itself was assessed as dead or fatally impacted by the insecticide.

Figure 2. Microapplicator; dispenses 10 microliters per button push.

The only way to determine if a population of insects is developing resistance is to calculate the LD_{50} of a suspected resistant population and compare it to that of population known to be susceptible to the insecticide. Adult CPB were obtained from a 'naïve' laboratory colony (never exposed to neonicotinoid insecticides) maintained by French Agricultural Research, INC in Lamberton MN. LD_{50}s were calculated for each insecticide tested. LD_{50} values of sampled and susceptible populations were compared using PROBIT analyses. These analyses provided a measurement of how much more insecticide it took to kill the sampled population than the susceptible population. We expressed the efficacy response in terms of 'times LD_{50} rate of susceptible populations'; that is, if a CPB population is rated at 7X resistant, that means it takes 7X the amount of insecticide to kill CPB from the sampled field than it does to kill the susceptible population. Because insecticide application rates (i.e. label rates) are calculated from an insecticides efficacy on susceptible populations, this provides a good indication of the effect of a label rate application.

Samples were obtained by UMN personnel from 10 locations in MN and ND to assess levels of resistance across the potato production areas of both states, several in response to specific reports of product failure. Levels of insecticide insensitivity were calculated for each sample site, but it was not possible to assess all insecticides for all locations; this was mostly due to either insufficient beetles from the sampled field or from the naïve population (our supplier is recovering from a colony collapse in 2017 and rebuilding populations is slower than anticipated).

Results – Only the neonicotinoids Belay (ai = Clothianidin) and Actara (ai= Thiomethoxam) were assessed as previous data indicated that most populations in MN and ND are starting to show decreased susceptibility to Admire (ai = Imidacloprid).

Wide Spread Tolerance of Neonicotinoid Insecticides - A number of sites reported low to medium levels of resistance to at least one of the two neonicotinoids tested (Table 1) but there was also evidence for reduced susceptibility to several other insecticide modes of action. Most locations where neonicotinoid efficacy was assessed showed evidence for CPB populations having decreased susceptibility to those insecticides. One of two exceptions was Crookston, where, despite research plots having been established for a number of years now, has never had commercial potato production. The other location where the CPB population was still completely susceptible to neonicotinoids was an organic field in Central MN, geographically isolated from commercial potato production, where neonicotinoid had never been used.

Neonicotinoid tolerance was well-established in Central Minnesota with the populations at many locations being resistant (Table 1). Our bioassay data indicated: it would require 7X the label rate of Belay (ai = Clothianidin) and 6X the label rate of Actara (ai = Thiomethoxam) to control CPB populations sampled from Big Lake, that CPB populations in Hubbard MN were susceptible to Belay but required 6X label rate for management, and that CPB populations in Rice MN would require 10X the label rate of Actara and 49X the rate of Belay (considered a high rate of resistance – see bottom of Table 1). However, bioassays of the CPB population collected from an organic field near Sabeka indicate they were susceptible to both Belay and Actara. Results from fields sampled in the Red River Valley (RRV) were more variable: our bioassays indicated CPB populations from Larimore would take up to 9X the label rate of Belay for management, oddly, bioassays of CPB sampled from a field at nearby Arvilla indicated it would require 19X the label rate of Actara but are susceptible to Actara. Bioassays on CPB populations collected from Crookston and Erskine both indicated these populations were susceptible to to both Acatara and Belay.

Tolerance to Other Insecticide Groups – What was most concerning from our trials was the indication that tolerance is developing to other insecticide groups used in foliar applications to manage CPB. Bioassays of CPB populations sampled from Arvilla in ND and from Rice in Central MN both showed moderate (medium) rates of resistance to the Anthranilic Diamide, Coragen (ai = Rynaxypyr). Cross resistance is a type of resistance wherein the mechanism that confers resistance against one insecticide mode of action provides resistance to another, different mode of action. Cross resistance has yet tobe reported between the diamides and the neonicotinoids (Foster et al 2012, Scott 2015), however, it has been reported that resistance to diamides can develop rapidly (Troczka 2017). Consequently it is very possible this diamide resistance is the result of use patterns.

Moderate resistance to avermectins (AgriMek) was indicated by the bioassays of CPB populations from Hubbard MN (8X label rate). Cross-resistance has been reported between Abamectin (avermectins) and Imidacloprid (neonicotinoids). For example, Wang et al (2007) found that the same enzymatic processes are involved in the physiological resistance to Abamectin and to neonicotinoids.

There was one location where moderate Spinosad resistance was indicated; our bioassays indicate that it would take up to 28X label rate to manage the CPB populations collected from an organic production field near Sabeka MN. This was an isolated area (20-30 mi from conventional commercial production) and had relied only on the active ingredient, spinosad for CPB management.

Discussion and Conclusions – The development of insecticide resistance in MN has, so far, been geographically variable, and in some cases, isolated. The examples from geographically isolated sample locations (e.g. the Sabeka location) indicates that we can lose any of these insecticides if they are not correctly managed. It underscores the need for adoption of appropriate resistance management tactics. Rotating modes of action, incorporating and maximizing other non-chemically based control tactics, using thresholds where available and active scouting of fields can all contribute to retaining different modes of action in the CPB management toolbox.

Literature Cited

Foster, S.P., Denholm, I., Rison, J.L., Portillo, H.E., Margaritopoulis, J. and Slater, R., 2012. Susceptibility of standard clones and European field populations of the green peach aphid, Myzus persicae, and the cotton aphid, Aphis gossypii (Hemiptera: Aphididae), to the novel anthranilic diamide insecticide cyantraniliprole. *Pest management science*, *68*(4), pp.629-633.

Scott, I.M., Tolman, J.H. and MacArthur, D.C., 2015. Insecticide resistance and cross- resistance development in Colorado potato beetle Leptinotarsa decemlineata Say (Coleoptera: Chrysomelidae) populations in Canada 2008–2011. *Pest management science*, *71*(5), pp.712-721.

Troczka BJ, Williamson MS, Field LM, Davies TGE. 2017. Rapid selection for resistance to diamide insecticides in Plutella xylostella via specific amino acid polymorphisms in the ryanodine receptor. *Neurotoxicology*. 60:224-233.

Wang, L. and Wu, Y., 2007. Cross-resistance and biochemical mechanisms of abamectin resistance in the B-type Bemisia tabaci. *Journal of Applied Entomology*, *131*(2), pp.98-103.

Table 1. Partial results from resistance trials conducted in 2018. The Resistance (X-rate) is the amount of insecticide required to control CPB at that location compared o the amount required to control a susceptible population. Resistance rate in bold indicate potential resistant populations to that mode of action.

Location	Product	Insecticide Group (grp. No.)	Resistance (X rate)**
Arvilla	Abamectin (AgriMek) clothianidin (Belay) Thiomethoxam (Actara)* Rynaxypyr (Coragen)* Spinosad (Blackhawk) Tolfenpyrad (Torac)	Avermectins (6) Neonicotinoids (4A) Neonicotinoids (4A) Anthranilic Diamides (28) Spinosyns (5) METIs*** (21)	1X 1X **19X** **21X** 1X 1.5X
Becker	Spinosad (Blackhawk)	Spinosyns (5)	1X
Bentru	Abamectin (AgriMek) Spinosad (Blackhawk)	Avermectins (6) Spinosyns (5)	1X 1X
Big Lake	Abamectin (AgriMek) Clothianidin (Belay) Thiomethoxam (Actara) Spinosad (Blackhawk)	Avermectins (6) Neonicotinoids (4A) Neonicotinoids (4A) Spinosyns (5)	3X **7X** **6X** 4X
Crookston	Abamectin (AgriMek) Clothianidin (Belay) Thiomethoxam (Actara) Rynaxapyr (Coragen) Spinosad (Blackhawk)	Avermectins (6) Neonicotinoids (4A) Neonicotinoids (4A) Anthranilic Diamides (28) Spinosyns (5)	1X 1X 4X 1X 3X
Erskine	Thiomethoxam (Actara)	Neonicotinoids (4A)	2X
Hubbard	Abamectin (AgriMek) Clothianidin (Belay) Thiomethoxam (Actara) Rynaxypyr (Coragen) Spinosad (Blackhawk)	Avermectins (6) Neonicotinoids (4A) Neonicotinoids (4A) Anthranilic Diamides (28) Spinosyns (5)	**8X** 1X **6X** 2X 1X
Larimore	Clothianidin (Belay)	Neonicotinoids (4A)	**9X**
Rice	Abamectin (AgriMek) Clothianidin (Belay)* Thiomethoxam (Actara)* Rynaxypyr (Coragen)* Spinosad (Blackhawk)	Avermectins (6) Neonicotinoids (4A) Neonicotinoids (4A) Anthranilic Diamides (28) Spinosyns (5)	3X **49X** **10X** **24X** 1.5X
Sabeka	Abamectin (AgriMek) Clothianidin (Belay) Thiomethoxam (Actara) Spinosad (Blackhawk)	Avermectins (6) Neonicotinoids (4A) Neonicotinoids (4A) Spinosyns (5)	1X 1X 2X **28X**

* Summer collected adults (likely higher resistance rates)
It is generally considered: ***susceptible* **= 0X-3X**, ***minor*** **= 3X-5X**, ***low*** **= 5X to 10X**, ***medium*** **= 10X-40X**, ***high*** **= 40X-160X**, ***extremely high*** **>160X**). Shen JL and Wu YD, *Insecticide Resistance in Cotton Bollworm and its Management* (in Chinese). China Agricultural Press,Beijing, China, pp. 259–280 (1995).
*** Mitochondrial Electron Transport Inhibitors

Managing PVY Vectors, 2018

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Executive Summary – This is a research and outreach program that 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. A network of suction traps was established in MN and ND in grower cooperator fields. The co-operators change and ship weekly samples from the traps to the Entomology Lab at the UMN-Northwest Research & Outreach Center in Crookston. The trap samples are sorted and identified and the weekly population information disseminated to seed potato growers through a number of digital communication venues (including blog, Twitter, digital newsletter, targeted email and email ListServes).

Procedures – i) Aphid Alert Trapping Network. A network of 20 - 3m tall suction traps has been established in the seed potato production areas of Minnesota and North Dakota. These traps consist of a fan 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.

Results – There was suitable Low Level Jet wind events in the spring of 2018 to assist the immigration of vector species that do not over-winter in MN & ND (e.g. the Green Peach Aphid) (Fig. 1). While these LLJs don't ensure the immigration of vectors from the south, they are necessary to facilitate their immigration and therefore the presence of these LLJs indicates these vectors might be present.

Aphid Alert had 19 traps established and reporting regularly throughout the growing season of 2018 (Fig 2). Trap capture was, of course extremely variable. While most traps functioned well in 2018, there were some occasions of trap failure which required maintenance (part replacement, charge failure, etc).

Results from traps were identified (Fig 3) and information disseminated via the blog (aphidalert.blogspot.com, Fig 4), Twitter (@MNSpudBug), the NPPGA's electronic weekly newsletter (Spud Bytes), selected email service and 2 ListServes (UMN's CropConsultants and NDSU's NDSU-AGDAKOTA). Data included the weekly trap catch per area (Fig 5), the Cumulative PVY Vector Risk Index (Fig 6) and, for comparison, the PVY Vector Risk Index from the previous year (Fig 7). The seasonal trap catch for 2018 is presented in Figure 8.

Overall, aphid vector population recovered from traps were very light compared to previous years (Fig 6 vs Fig 7). The species composition indicated that the Risk from these vectors should be relatively low. While MN seed lots had similar rejection rates to last year, ND seed lots had a higher than expected rejection rate. It may be that there is an unaccounted source of vectoring the virus or that late season agronomic practices may require adjustment to compensate for vector presence. These factors will be examined and commented on during the upcoming extension season. Results from vector research to be conducted later this winter will be incorporated into extension communication (including the AphidAlert blog and other electronic dissemination media).

FIGURES

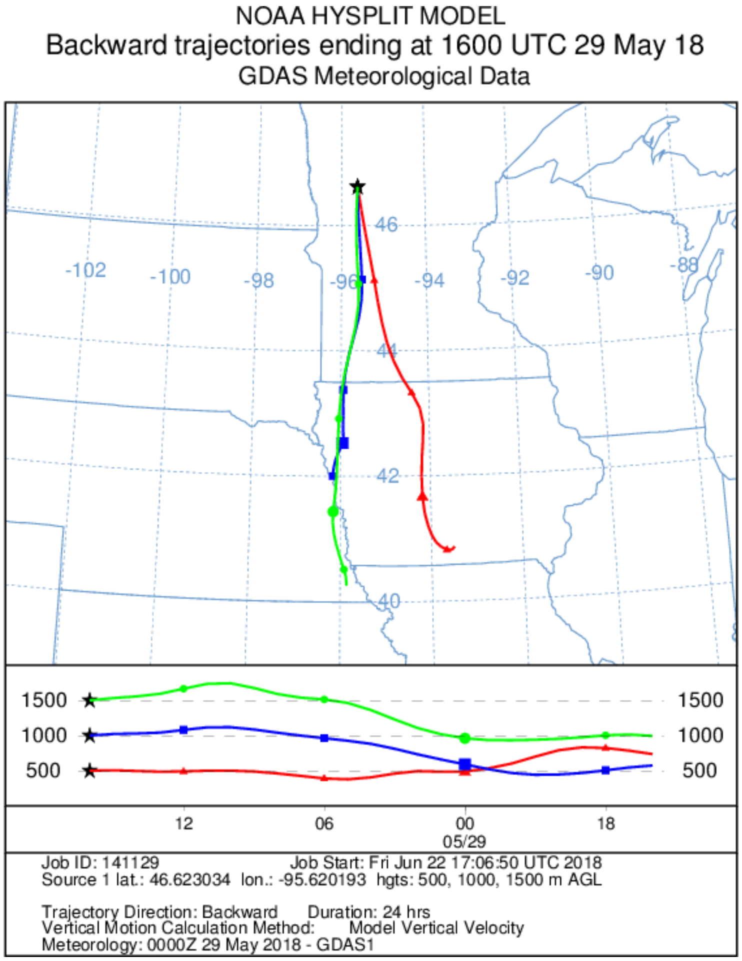


Figure 1. Ouput of NOAA Hybrid Single Particle Lagrangian Integrated Trajectory Model (HYSPLIT) 24hr period starting June 22, 2019 and showing the direction and duration of Low Level Jet (LLJ) events at 500m, 1000m, and 1500m AGL. These wind event meet the characteristics of those LLJs that facilitate immigration of vector species overwintering in southern states (e.g Green Peach Aphid).

Figure 2. Original Aphid Alert trap locations, 2018. Trapping reports variable by the week depending on activity.

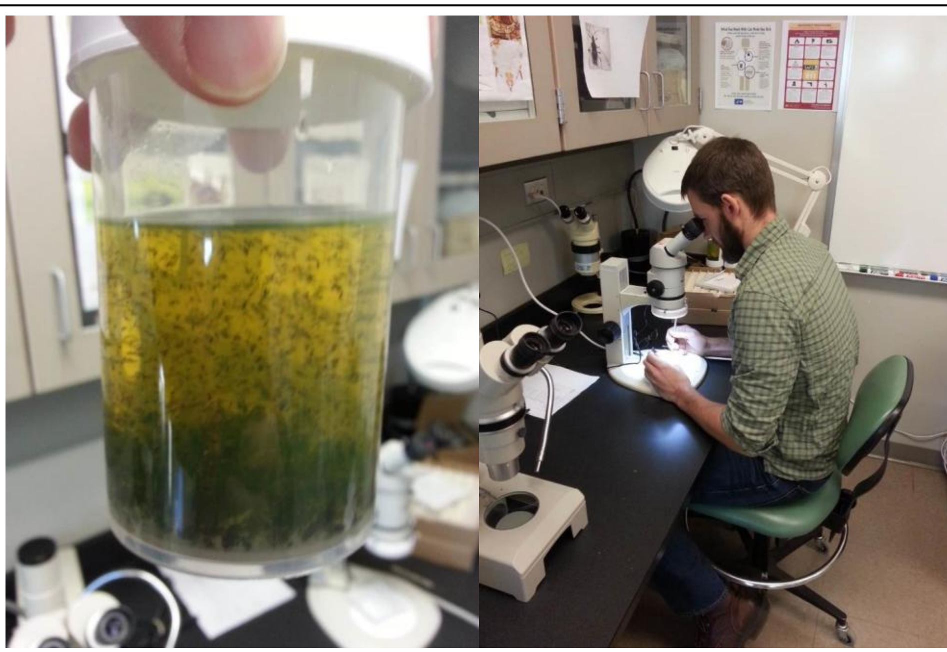
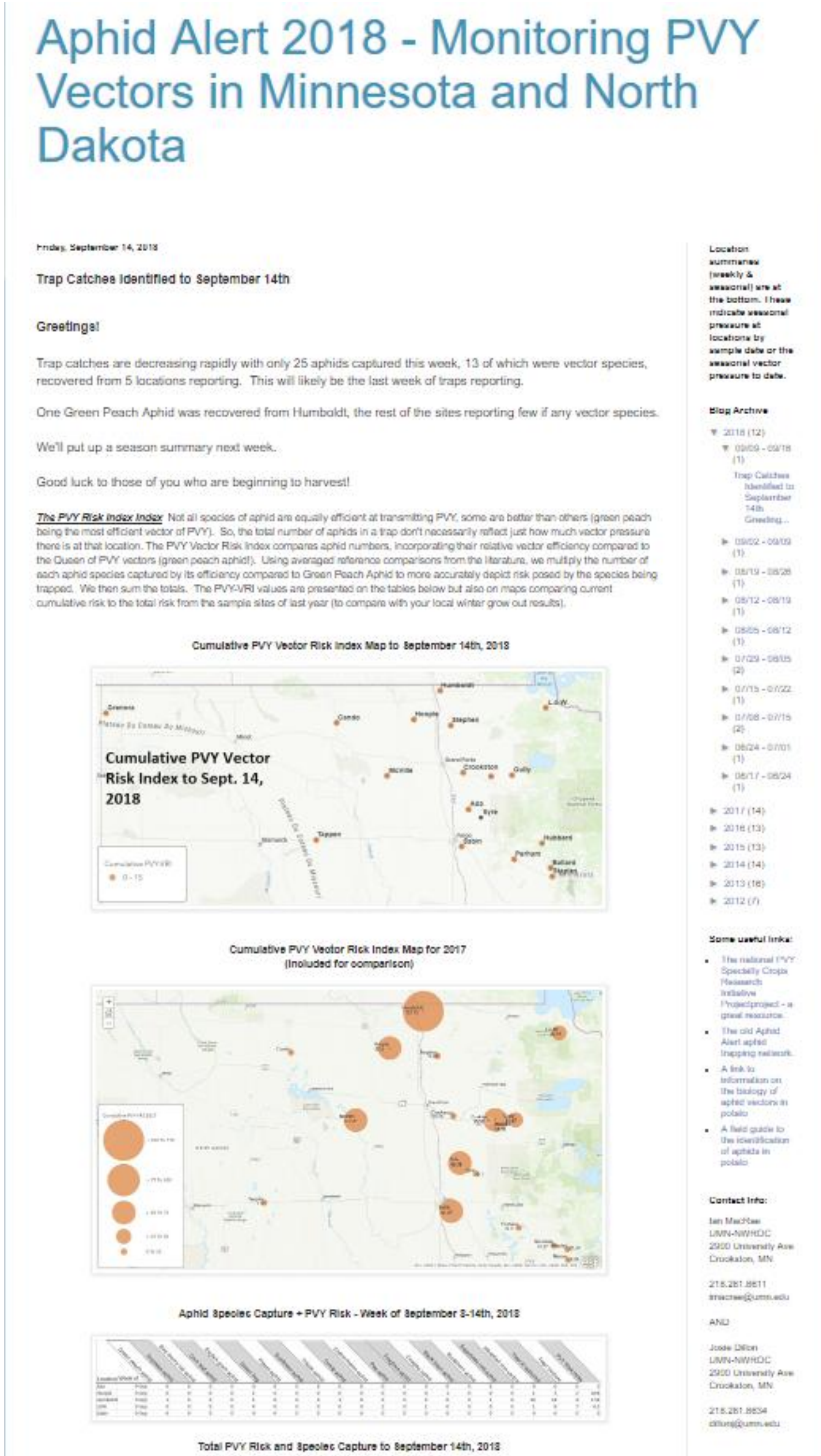


Figure 3. Aphid alert trap collection jar with typical weekly catch (on left), aphids are sorted from catch and identified (on right).



Aphid Alert 2018 - Monitoring PVY Vectors in Minnesota and North Dakota

Friday, September 14, 2018

Trap Catches Identified to September 14th

Greetings!

Trap catches are decreasing rapidly with only 25 aphids captured this week, 13 of which were vector species, recovered from 5 locations reporting. This will likely be the last week of traps reporting.

One Green Peach Aphid was recovered from Humboldt, the rest of the sites reporting few if any vector species.

We'll put up a season summary next week.

Good luck to those of you who are beginning to harvest!

The PVY Risk Index Index Not all species of aphid are equally efficient at transmitting PVY, some are better than others (green peach being the most efficient vector of PVY). So, the total number of aphids in a trap don't necessarily reflect just how much vector pressure there is at that location. The PVY Vector Risk Index compares aphid numbers, incorporating their relative vector efficiency compared to the Queen of PVY vectors (green peach aphid!). Using averaged reference comparisons from the literature, we multiply the number of each aphid species captured by its efficiency compared to Green Peach Aphid to more accurately depict risk posed by the species being trapped. We then sum the totals. The PVY-VRI values are presented on the tables below but also on maps comparing current cumulative risk to the total risk from the sample sites of last year (to compare with your local winter grow out results).

Cumulative PVY Vector Risk Index Map to September 14th, 2018

Cumulative PVY Vector Risk Index Map for 2017 (Included for comparison)

Aphid Species Capture + PVY Risk - Week of September 8-14th, 2018

Total PVY Risk and Species Capture to September 14th, 2018

Location summaries (weekly & seasonal) are at the bottom. These indicate seasonal pressure at locations by sample date or the seasonal vector pressure to date.

Blog Archive

- 2018 (12)
  - 09/09 - 09/16 (1)
    - Trap Catches Identified to September 14th Greeting...
  - 09/02 - 09/09 (1)
  - 08/19 - 08/26 (1)
  - 08/12 - 08/19 (1)
  - 08/05 - 08/12 (1)
  - 07/29 - 08/05 (2)
  - 07/15 - 07/22 (1)
  - 07/08 - 07/15 (2)
  - 06/24 - 07/01 (1)
  - 06/17 - 06/24 (1)
- 2017 (14)
- 2016 (13)
- 2015 (13)
- 2014 (14)
- 2013 (18)
- 2012 (7)

Some useful links:

- The national PVY Specialty Crops Research Initiative Project/project - a great resource
- The old Aphid Alert aphid trapping network
- A link to information on the biology of aphid vectors in potato
- A field guide to the identification of aphids in potato

Contact Info:

Figure 4. Aphid Alert blog (aphidalert.blogspot.com) updated 2X week. Includes weekly trap catches, cumulative seasonal PVY Vector Risk Index and, for comparison, the PVY Vector Risk Index of the previous year.

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 Sunflowe r 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	11	1	12	0	7	4	2	0	4	1	0	22	3	0	0	14	86	72	**3.89**
Ballard	0	11	8	1	1	0	1	3	4	0	0	0	0	8	1	4	0	3	45	42	**4.31**
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	0	0	15	2	0	0	16	12	1	0	0	21	2	22	3	1	0	7	102	95	**8.87**
Gully	1	1	1	2	19	0	0	2	8	1	3	1	1	3	4	4	0	11	62	51	**5.55**
Hoople	1	0	13	8	14	0	8	1	7	4	3	1	4	10	5	1	0	6	86	80	**7.41**
Hubbard	0	0	0	0	0	0	2	1	0	0	0	0	0	2	0	0	0	0	5	5	**0.23**
Humboldt	0	2	1	1	4	0	2	0	5	1	5	0	0	3	1	1	0	12	38	26	**1.94**
LOW	1	1	1	1	8	0	6	0	7	0	1	0	1	9	1	2	0	8	47	39	**3.72**
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	24	0	3	0	6	0	2	0	2	12	4	7	0	16	132	116	**13.48**
Sabin	1	13	4	8	22	0	7	0	2	5	1	0	7	8	12	6	0	16	112	96	**11.83**
Staples	0	12	10	3	5	0	0	5	4	2	4	0	1	10	10	2	0	4	72	68	**5.67**
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	1	0	1	4	0	0	0	0	0	0	0	5	14	9	**2.33**
Grand Total	**11**	**81**	**98**	**32**	**144**	**3**	**58**	**39**	**52**	**18**	**23**	**29**	**32**	**123**	**51**	**39**	**0**	**152**	**985**	**833**	**87.86**

Figure 5. The weekly trap catch by site from all Aphid Alert traps. This information includes by site: catch by species, the sum of all aphids captured, the number of non-vectors captured (to provide better insight into the flight period of winged aphids through the season) , total number vectors captured, and the weekly PVY Vector Risk index.

Figure 6. The cumulative PVY Vector Risk Index value expressed visually on a map. This map include the total PVY Vector Risk Index up to the reporting week.

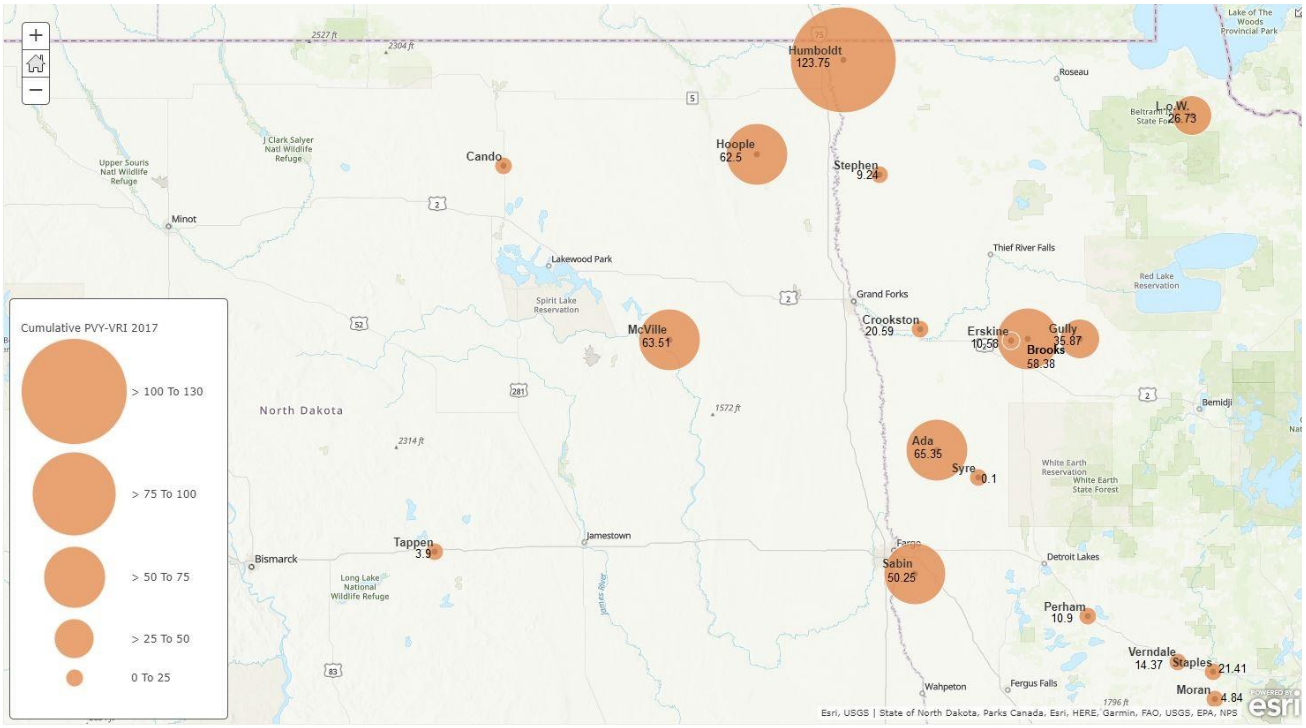


Figure 7. The cumulative PVY Vector Risk Index for 2017, included on the 2018 map for comparison.

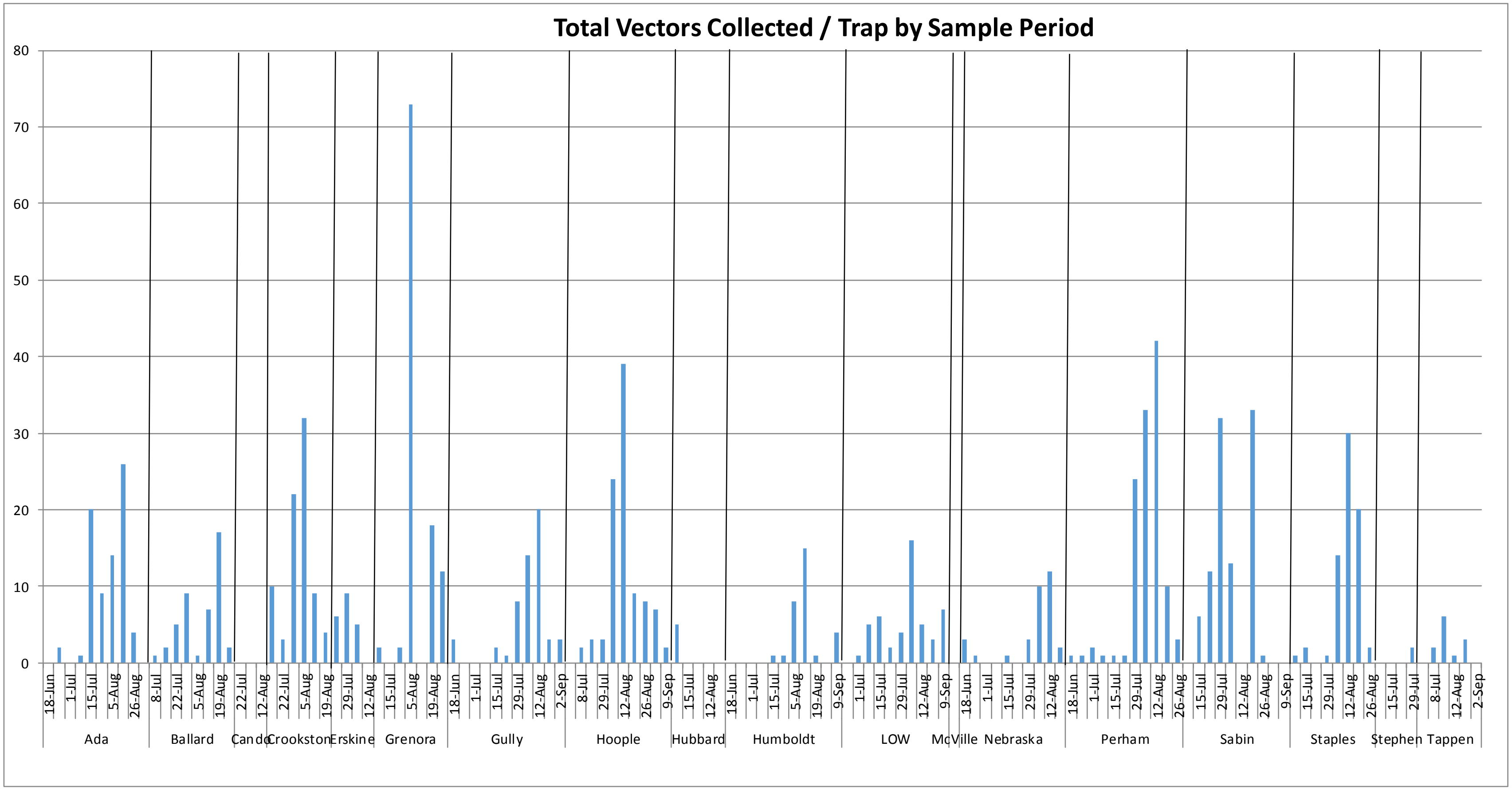


Figure 8. The total seasonal trap catch by location for the Aphid Alert Network 2018. Vertical bars represent total vector catch by week at each trap location.

Carryover of herbicides in potato production systems

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Eric Brandvik, Research specialist
Peter Ihry, Ag Tech

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.

The purpose of this project was to evaluate the effects of imazamox carryover in soil on potato growth, development and tuber yield. Soil characteristics were 84% sand, 12% silt and 4% clay with 1.25% organic matter and a pH of 6.6. Raptor was applied at 0, 1, 2 and 4 oz/a in the August 15, 2017. Following herbicide application, the field was planted to a mustard green manure crop, was tilled that fall, but not fumigated. Russet Burbank and Umatilla Russet whole seed (2-3 oz) and cut seed (2-2.5 oz) were planted on May 11, 2018 and harvested in September 19, 2018. There were no significant changes to yield following a late summer treatment of imazamox. Without fall fumigation it seemed that microbial breakdown of imazamox occurred and there were no carryover issues as yields were similar across treatments.

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.

Research objective

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 in a commercial potato field near Hubbard, Minnesota to determine the carryover potential of imazamox the year prior to potato. Soil characteristics were 84% sand, 12% silt and 4% clay with 1.25% organic matter and a pH of 6.6. On August 15, 2017 imazamox treatments were applied with a 45-foot boom attached to a tractor with GPS. Imazamox was applied at 0, 1, 2, 4 and 8 oz/a. Following herbicide application, the field was planted to a mustard green manure crop, was tilled that fall, but not fumigated. Russet Burbank and Umatilla Russet whole seed (2-3 oz) and cut seed (2-2.5 oz) were planted on May 11, 2018 and harvested in September 19, 2018.

Results

Raptor treatments had no effect on yield or marketable yield. The rates of 1 and 2 oz/a Raptor caused an increase in tubers <4 oz, and decrease in tubers sized 10-14 oz. This slight shift in tuber size resulted in a smaller percentage of tubers <6 oz when compared to the non-treated check. Differences were found between Russet Burbank and Umatilla Russet, which was expected. One important item that was learned, is that without fall fumigation it seemed that microbial breakdown of imazamox occurred and there were no carryover issues as yields were similar across treatments.

Future work

In 2018, plots were established using the same rates of Raptor. In the fall, half of the plots were fumigated with metam-sodium. We will plant potatoes in these plots in 2019 to determine if fumigation has a role in imazamox carryover in the soil to potato plants.

Table 1. Effects of Raptor (imazamox) on Russet Burbank and Umatilla Russet yield in 2018 near Hubbard, MN.

Herbicide	Rate (oz/a)	<4 oz		4-6 oz	6-10 oz	10-14 oz		>14 oz		Total yield	Marketable yield	US#1 >4 oz	US#2 >4 oz	>6 oz		>10 oz	
		cwt/a												%			
Non-treated	0	104	ab*	153	205	71	a	22	ab	555	452	434	18	53	ab	17	a
Raptor	1	130	a	173	184	49	b	10	b	546	416	404	12	44	b	11	b
Raptor	2	127	ab	173	188	53	ab	19	ab	560	433	412	21	46	ab	13	ab
Raptor	4	105	b	162	202	67	ab	28	a	564	459	442	17	53	a	17	a
p-value		*0.0376*		*0.3565*	*0.3404*	*0.0364*		*0.0055*		*0.8848*	*0.2322*	*0.2360*	*0.3348*	*0.0129*		*0.0021*	

*Means separated with Tukey pair-wise comparison at p=0.05

Table 2. Effects of Raptor (imazamox) on Russet Burbank and Umatilla Russet tuber number in 2018 near Hubbard, MN.

Herbicide	Rate (oz/a)	<4 oz		4-6 oz	6-10 oz	10-14 oz		>14 oz		Total yield	Marketable yield	US#1 >4 oz	US#2 >4 oz	>6 oz		>10 oz	
		tuber number/a												%			
Non-treated	0	60,031	ab	49,958	43,469	9,892	a	2,133	ab	165,483	105,452	102,366	3,086	34	ab	8	ab
Raptor	1	76,282	a	56,369	39,463	6,897	b	985	b	179,996	103,714	101,277	2,437	28	b	5	b
Raptor	2	72,963	ab	56,436	39,887	7,474	ab	1,815	ab	178,575	105,612	101,854	3,758	28	ab	6	ab
Raptor	4	60,130	b	52,571	43,005	9,353	ab	2,712	a	167,770	107,640	104,672	2,968	34	a	8	a
p-value		*0.0405*		*0.3448*	*0.3307*	*0.0403*		*0.0095*		*0.1943*	*0.8906*	*0.8911*	*0.5133*	*0.0240*		*0.0062*	

Table 3. Effects of Raptor (imazamox) on Russet Burbank cut, Russet Burbank whole, Umatilla Russet cut and Umatilla Russet whole seed on yield in 2018 near Hubbard, MN.

Seed type	**<4 oz**		**4-6 oz**		**6-10 oz**		**10-14 oz**		**>14 oz**		**Total yield**	**Marketable yield**		**US#1 >4 oz**		**US#2 >4 oz**		**>6 oz**		**>10 oz**	
	——— cwt/a ———																	——— % ———			
RB cut	133	a	172	ab	172	c	50	b	11	b	537	405	b	389	b	15	b	43	c	11	c
RB whole	141	a	199	a	177	bc	31	b	12	b	560	419	ab	411	ab	8	b	39	c	7	c
Umatilla cut	78	b	128	c	214	ab	88	a	38	a	546	468	a	452	a	16	ab	62	a	23	a
Umatilla whole	111	a	161	b	215	a	72	a	22	b	580	469	a	443	ab	27	a	53	b	16	b
p-value	*<0.0001*		*<0.0001*		*0.0016*		*<0.0001*		*<0.0001*		*0.2297*	*0.0091*		*0.0206*		*0.0003*		*<0.0001*		*<0.0001*	

Table 4. Effects of Raptor (imazamox) on Russet Burbank cut, Russet Burbank whole, Umatilla Russet cut and Umatilla Russet whole seed on tuber number in 2018 near Hubbard, MN.

Seed type	**<4 oz**		**4-6 oz**		**6-10 oz**		**10-14 oz**		**>14 oz**		**Total yield**		**Marketable yield**	**US#1 >4 oz**	**US#2 >4 oz**		**>6 oz**		**>10 oz**	
	——— tuber number/a ———																——— % ———			
RB cut	76,871	a	56,414	ab	37,069	b	6,961	bc	1,068	b	178,382	a	101,512	99,078	2,434	b	26	c	5	bc
RB whole	79,704	a	64,977	a	38,426	ab	4,408	c	1,141	b	188,656	a	108,952	107,707	1,245	b	24	c	3	c
Umatilla cut	46,075	b	41,512	c	44,597	a	12,290	a	3,578	a	148,052	b	101,977	99,255	2,723	b	42	a	11	a
Umatilla whole	64,385	ab	52,196	b	45,509	a	9,935	ab	2,140	b	174,164	a	109,779	104,468	5,311	a	34	b	7	b
p-value	*0.0001*		*<0.0001*		*0.0037*		*<0.0001*		*<0.0001*		*0.0003*		*0.2058*	*0.2590*	*<0.0001*		*<0.0001*		*<0.0001*	

Non-treated | **1 oz/a Raptor** | **2 oz/a Raptor** | **4 oz/a Raptor**

Figure 1. Pictures of 0, 1, 2 and 4 oz/a Raptor on June 8, 2018.

Effects of planting configuration and plant population density on the N response of Russet Burbank tuber yield and size

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Summary

The conventional hilled-row planting configuration for potato agriculture is non-uniform, with three to four times the space between rows as there is between plants within rows. This non-uniformity may both increase inter-plant competition for sunlight and soil N and decrease the efficiency with which the crop, as a whole, collects both. In turn, increased light and nutrient interception may be expected to increase crop yield and decrease nutrient losses. To increase planting uniformity, some growers have begun planting potatoes in beds with multiple, closely spaced rows between each pair of furrows. To evaluate whether this approach produces the anticipated benefits in terms of yield and soil N interception, we conducted an experiment with Russet Burbank potatoes near Staples, MN. A conventional hilled-row configuration was compared with a bed configuration, at population densities of 9,500 and 12,500 plants$\cdot$ac^{-1}, fertilized at whole-season N rates of 80, 160, or 240 lbs$\cdot$ac^{-1} N using a split-plot randomized complete block design with four blocks. Whole plots were defined by planting configuration and subplots by planting density and N rate. Averaged across densities and N rates, the bed plots had more Colorado potato beetle damage than the hilled-row plots. Hilled-row plots had higher marketable yields and more large tubers than bed plots. Averaged across planting configuration and N rate, high-density subplots had more undersized (< 3 oz.) tubers and U.S. No. 1 tubers, and fewer large (> 14 oz.) tubers and U.S. No. 2 tubers, than low-density subplots. In the hilled-row plots, the percentage of yield in tubers over 10 ounces was higher in low-density subplots. This effect of density was not significant in the bed plots. Bed plots had a higher prevalence of hollow heart, but also higher tuber specific gravity and dry matter content, than hilled-row plots. High-density subplots had a somewhat higher prevalence of scab than low-density subplots. Petiole NO_3^--N concentration was higher in hilled-row plots than bed plots, decreased with density, and increased with N rate. Soil water NO_3^--N concentration was also higher in hilled-row plots and increased with N rate. Overall, switching from the hilled-row configuration to the bed configuration was not supported by the results from this study. However, this experiment may have been compromised by poor Colorado potato beetle control early in the season, which affected bed plots substantially more than hilled-row plots. Poor beetle control is not typical of commercial fields, and this year's results may therefore be a poor indicator of how the bed configuration would perform in commercial practice.

Background

The conventional hilled-row planting configuration for potato agriculture has the benefit of providing rapid drainage to the soil around the tubers. However, because each row of plants has a furrow on either side of it, this configuration is not as space-efficient as a uniform configuration would be. Spacing between plants within rows is compact, increasing inter-plant competition, while spacing between rows is wide, reducing the efficiency with which the crop intercepts water, sunlight, and nutrients.

To correct these issues with the hilled-row configuration, growers have begun to plant potatoes in beds, in which multiple, more closely spaced rows of potatoes are planted between each pair of furrows. Plant spacing within each row is increased relative to the hilled-row configuration to compensate for the decreased between-row distance, making the planting arrangement relatively uniform. If greater uniformity improves the efficiency with which water, light, and nutrients are intercepted by the crop, the bed configuration can be expected to increase yield and decrease N losses due to NO_3^--N leaching compared to the hilled-row configuration. Because the distance to the nearest neighboring plant is maximized in a uniform distribution, competition among plants for resources, and the negative effects of high planting density on individual plants, are minimized. Based on this, we expect the responses of individual plants to differences in planting density to be weaker in a bed configuration than a hilled-row configuration.

To test these predictions, an experiment was conducted with Russet Burbank potatoes near Staples, MN. We compared a conventional hilled-row configuration with a bed configuration, at population densities of 9,500 and 12,500 plants·ac^{-1}, fertilized at whole-season N rates of 80, 160, or 240 lbs·ac^{-1} N. The specific objectives of this study were to determine whether the bed-planting configuration increased N uptake and tuber yield and decreased N requirements and N losses to leaching relative to the conventional hilled-row configuration, and whether these benefits were more pronounced at the higher density.

Methods

The study was conducted on 2018 at the Central Lakes College Agricultural and Energy Center near Staples, MN, under a linear irrigation system. The soil at the site is a Verndale sandy loam, and the previous crop was edible beans.

Initial soil samples to a depth of two feet (for NO_3^--N concentration) and six inches (for other characteristics) were collected on May 29. The two-foot samples were extracted with 2 N KCl and the extracts analyzed for NO_3^--N and NH_4^+-N using a Wescan Nitrogen Analyzer. The six-inch samples were 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. Results are presented in Table 1.

Preplant fertilizer was broadcast and incorporated over the entire plot area after soil sampling on May 29, two days before planting. The application was uniform over planting configuration and plant population treatments. Fertilizer application consisted of 500 lbs·ac^{-1} MOP (0-0-60), 200 lbs·ac^{-1} SulPoMag (0-0-22-18S-11Mg), 167 lbs·ac^{-1} diammonium phosphate (18-46-0), and 114 lbs·ac^{-1} ESN (Environmentally Smart Nitrogen, Agrium, Inc.; 44-0-0). In total, this provided 80 lbs·ac^{-1} N, 344 lbs·ac^{-1} K_2O, 77 lbs·ac^{-1} P_2O_5, 36 lbs·ac^{-1} S, and 22 lbs·ac^{-1} Mg.

The planting configuration, plant population density, and N rate treatments were arranged in a split-plot randomized complete block design with four blocks. Whole plots were defined by planting configuration (bed or hilled-row). Bed plots were 12 feet wide, with seven rows spaced 20.5 inches apart. Hilled-row plots were 18 feet wide, with six rows spaced 36 inches apart. Adjacent plots were separated by three feet.

Each whole plot was divided into six, 40-foot-ong subplots defined by planting density (9,500 or 12,500) and N application rate (80, 160 or 240 lbs·ac^{-1} N total). The within-row spacing of the seed pieces in bed plots was 32 inches at the low planting density and 24.5 inches at the high density. In hilled-row plots, within-row spacing was 18.5 inches at low density and 14 inches at high density. In the subplots receiving 160 or 240 lbs·ac^{-1} N, the additional N (beyond the 80 lbs·ac^{-1} N applied to the whole field) was applied as ESN by hand immediately after the whole-field fertilizer application. The planting and fertilizer treatments are summarized in Table 2.

Suction-tube lysimeters were installed both within and between the planting rows on June 1 (blocks 3 and 4) and 4 (blocks 1 and 2) to sample soil water at a depth of four feet. Lysimeters were flushed on June 6. The lysimeters between rows were installed several inches deeper than those within rows. In the hilled-row plots, this arrangement was enforced by the hilled-row topography, and the same vertical positioning was used in the bed plots to keep sampling depths consistent between the two treatments. Soil water samples were collected on 17 dates: June 13, 21, and 26; July 2, 9, 18, and 25; August 2, 9, 16, 20, and 30; September 6, 14, 19, and 26; and October 3. The samples have been tested for NO_3-N and NH_4-N concentration using a Wescan Nitrogen Analyzer.

Plant stand was measured on July 20 as the percentage of seed tubers in 40 feet of row that produced aboveground shoots. On the same day, because Colorado potato beetle control was poor, beetle damage was assessed in each plot. Damage was given a score of 0 to 5 based on the percentage of defoliation, where 0 indicated no damage, 1 indicated 1 – 20% defoliation, 2 indicated 21 – 40% defoliation, 3 indicated 41 – 60% defoliation, 4 indicated 61 – 80% defoliation, and 5 indicated greater than 80% defoliation. No plots received a score of five.

Petioles were collected from each plot on July 2 and 20 and August 2 to measure petiole NO_3^--N concentration. The petiole of the fourth leaf from the tip of the shoot was collected for each of 20 shoots per subplot. Petiole samples were analyzed for water-extractable NO_3^--N concentrations using a Wescan Nitrogen Analyzer.

Vine samples were collected on September 7. Fifteen linear feet of row were sampled from each plot. In the hilled-row plots, all 15 feet were sampled from an interior row. In the bed plots, 3.2 feet of an edge row and 11.8 feet of the adjacent interior row were sampled. Vine samples were weighed. A subsample was taken from each sample, weighed, dried, and re-weighed. The dried tissue will be analyzed for total N concentration in order to estimate N uptake. The vines remaining in the field were killed with desiccant spray September 19.

Tubers were harvested from the same area used for vine samples on October 4, 126 days after planting. Tubers were sorted and graded on October 30. A 25-tuber sample was taken for quality measurements, including the prevalences of hollow heart, brown center, and scab and tuber specific gravity and dry matter content.

Data were analyzed using the MIXED procedure with SAS 9.4m3® software (copyright 2015, SAS Institute, Inc.). Stand, beetle damage, yield, and tuber quality variables were modeled as functions of planting configuration, population density, N application rate, and their interaction, 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.

Ideally, soil water NO_3^--N concentration could have been analyzed in the same manner as petiole NO_3^--N concentration, but there were too many gaps in the data for the model to execute. Instead, the data for each sampling date were analyzed separately, as functions of configuration, N rate, lysimeter placement (within or between rows), their interactions, and block. The data for the last three sample dates (September 19 and 26 and October 3) were too sparse to permit analysis.

In all models, 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

Plant stand and Colorado potato beetle damage

Results for plant stand and the Colorado potato beetle damage assessment, both measured on July 20 (50 days after planting) are presented in Table 3. Stand was significantly higher in the bed plots (averaged across densities and N rates) and the low-density subplots (averaged across configurations and N rates) than in the hilled-row plots and high-density plots, respectively.

Stand was highest at and N rate of 160 lbs·ac^{-1} N in the bed plots, but lowest at this N rate in the hilled-row plots, resulting in a significant effect of the interaction between planting configuration and N rate. This effect is difficult to explain and may not be meaningful

Calculated stand sometimes exceeded 100%, especially in the bed plots configuration at low density. This is due, at least in part, to the greater impact of noise in the count data when few plants are expected to occur in 40 feet of sampled row. Just 15 plants were expected in the sampled area in the bed configuration at low density.

Beetle damage was more severe in the bed plots than the hilled-row plots. The effect of the interaction among planting configuration, planting density, and N rate was also significant, but this effect is difficult to interpret. Because the main effect of planting configuration was quite pronounced, the presence of the significant three-way interaction effect does not invalidate it. It is not clear why the Colorado potato beetle damage was worse in the bed plots, nor whether this result was due to greater beetle activity in the bed plots, poorer shoot growth in those plots, or a combination of the two.

Tuber size and yield at harvest

Results for tuber yield and size at harvest are presented in Table 4. Total tuber yield per acre was higher in hilled-row plots than bed plots and higher in high-density subplots than low-density subplots. The effect of the interaction among planting configuration, planting density, and N rate, was marginally significant. This effect is difficult to interpret. Marketable yield (yield excluding undersized tubers) generally paralleled total yield, but the effect of plot configuration on marketable yield was only marginally significant, while the effect of planting density was not statistically significant. Planting density affected total yield more than marketable yield because much of the difference in total yield between high- and low-density subplots was due to high yields of undersized tubers in high-density subplots.

Yields of both U.S. No. 1 and U.S. No. 2 grade tubers were higher in the hilled-row plots than the bed plots, but the difference was only significant for U.S. No. 2 tubers. High-density subplots (averaged across planting configuration and N rate) had higher yields of U.S. No. 1 tubers and lower yields of U.S. No. 2 tubers than low-density subplots, indicating that high planting density confers benefits in terms of potato grade as well as yield. The benefit of density for U.S. No. 1 potato yield were more pronounced in bed plots than hilled-row plots. The effect of N rate on potato grade differed between hilled-row plots and bed plots. In hilled-row plots, the yield of U.S. No. 1 potatoes decreased, while the yield of U.S. No. 2 potatoes increased, as the application rate of N increased. In bed plots, the yield of U.S. No. 1 tubers was numerically higher at 240 lbs·ac^{-1} N than at the lower rates, while the yield of U.S. No. 2 tubers was numerically higher at

160 lbs·ac^{-1} N than at 80 or 240 lbs·ac^{-1} N, though none of these differences were statistically significant.

Tuber quality

Tuber quality results are presented in Table 5. Averaged across density and N rate, bed plots had a significantly higher prevalence of hollow heart and higher tuber specific gravity than hilled-row plots, with similar but less significant results for tuber dry matter content. Averaged across configuration and N rate, high-density subplots tended to have a higher prevalence of scab than low-density subplots.

Petiole NO_3^--N concentrations

Results for petiole NO_3^--N concentrations are presented in Table 6. Averaged across treatments, petiole NO_3^--N decreased significantly from each sample date to the next. For the most part, the slope of this decline was unrelated to treatment factors, the exception being planting configuration. Season-average petiole NO_3^--N concentration was higher in hilled-row plots than bed plots (averaged across planting densities and N rates), and this difference became smaller from each sample date to the next, no longer being significant by the third date (August 3).

Averaged across planting configurations and N rates, plants in low-density subplots had a slightly higher season-average petiole NO_3^--N concentration than high-density subplots. This suggests that lower planting density decreases inter-plant competition for nutrients and increases the ability of individual plants to take up soil N.

Averaged across planting configurations and densities, subplots receiving 240 lbs·ac^{-1} N total had a higher season-average petiole NO_3^--N concentration than subplots receiving 160 lbs·ac^{-1} N, which had a higher concentration than subplots receiving 80 lbs·ac^{-1} N. This result indicates that, as expected, plant tissue N concentrations are limited by soil N availability.

No other interactions among planting configuration, planting density, N rate, and date were significantly related to petiole NO_3^--N concentration.

Soil water NO_3^--N concentration

Results for soil water NO_3^--N concentration are presented in Table 7. Planting configuration was a significant predictor of soil water NO_3^--N concentration on six of the 14 sample dates presented. In each case, the concentration was higher in the hilled-row plots than the bed plots.

The application rate of N was also significantly related to soil water NO_3^--N concentration on six sample dates. On July 18 and 25, the subplots receiving 160 or 240 lbs·ac^{-1} N had higher concentrations than those receiving 80 lbs·ac^{-1} N. On all later dates on which the effect of N rate was significant, the subplots receiving 240 lbs·ac^{-1} N had a higher mean soil water NO_3^--N concentration than those receiving 80 or 160 lbs·ac^{-1} N.

Lysimeter placement within the plot was only significantly related to soil water NO_3^--N concentration on three dates. On June 26 and July 2, the lysimeters placed within rows had higher concentrations than those placed between rows. The opposite was true on August 30.

The effect of N rate on soil water NO_3^--N concentration differed between the two planting configurations on three dates (July 18 and August 9 and 16). In each case, the N response was more pronounced in the hilled row plots (with higher N rates producing higher soil water concentrations) than in the bed plots.

The interaction between planting configuration and lysimeter placement was significant on three dates. On July 9, lysimeters placed between rows in bed plots had a lower mean concentration than those placed within rows or those in hilled-row plots. The results were similar on July 25, except that the difference between lysimeters within and between rows in bed plots was not significant. On August 20, the results were similar to those of July 25 except that the lysimeters within rows in the hilled-row plots had a similar (low) mean soil water NO_3^--N concentration to those placed between rows in bed plots.

The response of soil water NO_3^--N concentration to N rate depended on lysimeter placement on July 18 and August 9. In each case, the concentrations found in lysimeters placed between rows were positively related to the application rate of N while the concentrations found in lysimeters placed within rows peaked at an N rate of 160 $lbs \cdot ac^{-1}$ N total.

On August 9 and 20, the effect of the interaction among planting configuration, N rate, and lysimeter placement was significant. In each of these cases, soil water NO_3^--N concentration varied more with lysimeter placement and N rate in the hilled-row plots than the bed plots.

Conclusions

In terms of yield, the conventional hilled-row planting configuration performed better than the bed configuration in this study. However, the effects of N rate on tuber yield and size in this study were surprisingly limited, since Russet Burbank yield and tuber size are typically limited primarily by N in irrigated systems. It is possible that the late planting date (May 31) and resulting short growing season greatly diminished the potential for N rate to influence crop performance.

In addition to lower petiole NO_3^--N concentrations, the bed plots had lower soil water NO_3^--N concentrations than the hilled-row plots on several sampling dates. Thus, the differences in petiole NO_3^--N concentration are not explained by greater NO_3^--N leaching from the bed plots. Vines were not noticeably larger in the bed plots, making a dilution effect on petiole NO_3^--N an unlikely explanation. It is possible that the bed plots lost more N than the hilled-row plots through pathways other than NO_3^--N leaching, that plant tissue N in the bed plots is more likely to occur in forms other than petiole NO_3^--N than tissue N in hilled-row plots, or much of the N taken up by plants in bed plots was lost to Colorado potato beetles, which did significantly more damage to plants in bed plots than hilled-row plots. These mechanisms may also explain the lower yields observed in bed plots.

Individual plants in the bed configuration were expected to be less sensitive to planting density than those in the hilled-row configuration. If this had occurred, whole-field variables that are positively related to density, like yield per acre, would have increased more with density in beds than hilled rows. Whole-field variables that are negatively related to planting density, like soil water NO_3^--N concentration, would have decreased more with density in beds than hilled rows. Variables that are determined mostly by the access of individual plants to light, water, or nutrients, like tuber size and grade and petiole NO_3^--N concentration, would have been less responsive to density in beds. Some of our results were consistent with these expectations. Marketable yield numerically increased with planting density in beds but did not respond to density in hilled rows. The percentage of yield in tubers over 10 ounces decreased significantly less at higher density in beds than hilled rows. Petiole NO_3^--N concentration numerically decreased less in beds than hilled rows at high density. However, tuber grade, in terms of both U.S. No. 1 yield and U.S. No. 2 yield, was more sensitive to density in the beds than hilled rows, contrary to expectation.

Overall, results for 2018 do not support changing planting configuration and density from the conventional hilled-row configuration. However, these results may be an effect of the poor Colorado potato beetle control in this field in the first half of the season. Beetle damage may have depressed yield, tuber size, and petiole NO_3^--N concentration, and the bed plots suffered substantially more damage, overall, than the hilled-row plots. Better beetle control (combined with a more typical planting date) in future research may reveal an advantage to bed planting not evident in this study.

Table 1. Initial soil characteristics of the study site in Staples, MN, in 2018.

0 - 2 feet	0 - 6 inches											
NO_3-N	Bray P	K	SO_4-S	Ca	Mg	Fe	Mn	Zn	Cu	B	Organic matter	pH
mg·kg^{-1} soil												
8.2	31	110	8	1320	133	28	22	3.3	0.63	0.18	1.6	6.5

Table 2. Planting configuration, population density, and N application rate treatments applied to Russet Burbank potatoes near Staples, MN, in 2018. Whole plots were defined by planting configuration, while subplots were defined by planting density and N rate.

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)	9500	32	80
			160
			240
	12500	24.5	80
			160
			240
Hilled row (row spacing 36.0 inches)	9500	18.5	80
			160
			240
	12500	14	80
			160
			240

[1]30 lbs·ac^{-1} N was applied as DAP (18-46-0), with the rest as ESN (Environmentally Smart Nitrogen, Agrium, Inc.; 44-0-0), all at planting.

Table 3. Effects of planting configuration, planting density, and N application rate on percent stand and severity of Colorado potato beetle damage on July 20 to Russet Burbank potato plants grown near Staples, MN, in 2018. The beetle damage score ranged from 0 (no damage) to 5 (over 80% defoliation).

Planting configuration	Planting density (seed pieces·ac^{-1})	Total N applied[1] (lbs·ac^{-1})	Stand (%)	Beetle damage score
Bed	9500	80	99	1.83 abc
		160	109	1.56 abcd
		240	101	2.16 ab
	12500	80	97	1.93 abc
		160	99	2.47 a
		240	94	0.92 bcde
Hilled row	9500	80	96	0.73 cde
		160	94	0.25 ef
		240	93	0.06 f
	12500	80	92	0.56 def
		160	89	0.25 ef
		240	94	1.00 bcde
Significance of model effects (P-values)	Planting configuration		**0.0276**	**0.0205**
	Planting density		**0.0095**	0.5303
	N rate		0.3607	0.5463
	Configuration*density		0.2484	0.3122
	Configuration*N rate		**0.0416**	0.4890
	Density*N rate		0.3450	0.8128
	Configuration*density*N rate		0.3878	**0.0356**

Table 4. Effects of planting configuration, planting density, and N application rate on tuber yield, size, and grade of Russet Burbank potatoes grown near Staples, MN, in 2018.

Planting configuration	Planting density (seed pieces·ac^{-1})	Total N applied[1] (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}									%	
Bed	9500	80	44	88	100	18	24	275 e	142	89	231 d	51	15
		160	58	81	99	51	83	372 bcd	167	147	313 bc	61	35
		240	53	99	76	51	48	327 de	157	117	274 cd	53	29
	12500	80	58	110	123	55	20	365 bcd	245	63	308 bc	53	19
		160	67	109	102	45	28	351 cd	218	66	284 cd	47	18
		240	53	129	128	60	32	402 abc	309	40	349 ab	55	23
Hilled row	9500	80	53	82	116	86	50	387 abc	219	114	334 abc	65	35
		160	38	56	92	105	102	391 abc	200	154	354 ab	76	52
		240	43	71	77	98	119	408 ab	210	156	366 ab	71	52
	12500	80	52	100	143	85	49	430 a	297	80	378 a	65	31
		160	59	111	135	67	46	417 ab	263	95	358 ab	59	27
		240	70	105	108	70	33	386 abc	213	102	316 bc	54	26
Significance of model effects (P-values)	Planting configuration		0.6910	*0.0607*	0.5657	**0.0320**	0.1267	**0.0436**	0.3579	**0.0206**	*0.0797*	0.1026	**0.0332**
	Planting density		*0.0751*	**0.0003**	**<0.0001**	0.5690	**0.0016**	**0.0203**	**<0.0001**	**<0.0001**	0.1545	**0.0313**	**0.0006**
	N rate		0.8761	0.4837	**0.0269**	0.6526	*0.0816*	0.4419	0.7459	0.1769	0.6204	0.7661	*0.0827*
	Configuration*density		0.5099	0.5744	0.5608	**0.0319**	0.2977	0.2154	*0.0873*	0.6089	0.1448	0.2507	*0.0718*
	Configuration*N rate		0.4448	0.6295	0.2034	0.5773	0.7973	0.1906	*0.0752*	0.5128	0.2486	0.8265	0.9020
	Density*N rate		0.8273	0.5283	0.4632	0.1212	*0.0925*	0.1427	0.6714	0.3734	0.1066	0.1332	**0.0252**
	Configuration*density*N rate		0.3814	0.6934	0.1888	0.9882	0.2997	*0.0850*	*0.0971*	0.8407	*0.0754*	0.4409	0.6991

[1]30 lbs·ac^{-1} N was applied as DAP (18-46-0) with the rest as ESN (Environmentally Smart Nitrogen, Agrium, Inc.; 44-0-0) at planting.

Table 5. Effects of planting configuration, planting density, and N application rate on tuber quality (prevalence of hollow heart / brown center and scab; tuber specific gravity; and tuber dry matter content) of Russet Burbank tubers grown near Staples, MN, in 2018.

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	9500	80	21	5	1.0882	24.9
		160	6	0	1.0879	24.9
		240	15	4	1.0919	24.5
	12500	80	15	8	1.0914	24.0
		160	16	13	1.0935	25.2
		240	12	8	1.0885	24.9
Hilled row	9500	80	5	0	1.0889	23.7
		160	4	8	1.0825	21.9
		240	5	4	1.0830	22.6
	12500	80	16	4	1.0897	24.0
		160	7	8	1.0877	23.6
		240	2	4	1.0835	22.2
Significance of model effects (P-values)	Planting configuration		**0.0080**	0.6805	**0.0070**	*0.0607*
	Planting density		0.5110	*0.0821*	0.1956	0.5422
	N rate		0.1574	0.5446	0.3241	0.4036
	Configuration*density		0.5445	0.2532	0.9006	0.3869
	Configuration*N rate		0.8342	0.5356	0.1946	0.1038
	Density*N rate		0.3450	0.6700	0.1927	0.2854
	Configuration*density*N rate		0.1885	0.4392	0.5766	0.4126

[1]30 lbs·ac^{-1} N was applied as DAP (18-46-0), with the rest as ESN (Environmentally Smart Nitrogen, Agrium, Inc.; 44-0-0), all at planting.

Table 6. Effects of planting configuration, planting density, N application rate, and sampling date on petiole NO_3^--N concentration in Russet Burbank potato plants grown near Staples, MN, in 2018.

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**
Bed	9500	80	23279	7455	1983
		160	24597	12368	6012
		240	25882	11524	4312
	12500	80	22884	8844	4873
		160	24993	8383	1085
		240	26599	13325	5419
Hilled row	9500	80	28296	12400	2783
		160	28050	12746	4904
		240	29033	17203	6963
	12500	80	25907	9621	1860
		160	28534	11435	3630
		240	29108	14771	5956
Significance of model effects (P-values	Date		**<0.0001**		
	Configuration		**<0.0001**		
	Density		*0.0969*		
	N rate		**<0.0001**		
	Configuration*density		0.1626		
	Configuration*N rate		0.7230		
	Density*N rate		0.1815		
	Configuration*density*N rate		**0.0200**		
	Configuration*date		**0.0097**		
	Density*date		0.5996		
	N rate*date		0.4270		
	Configuration*density*date		0.8220		
	Configuration*N rate*date		0.5047		
	Density*N rate*date		0.2230		
	Configuration*density*N rate*date		0.7047		

Table 7. Effects of planting configuration, N application rate, and lysimeter placement on soil water NO_3^--N concentration under Russet Burbank potatoes grown near Staples, MN, in 2018. Gaps in the data prevented a repeated-measures analysis, and results for each sampling date were therefore analyzed separately.

Planting configuration	Total N applied[1]	Lysimeter placement	Soil water NO_3^--N (ppm)													
			6/13	**6/21**	**6/26**	**7/2**	**7/9**	**7/18**	**7/25**	**8/2**	**8/9**	**8/16**	**8/20**	**8/30**	**9/6**	**9/14**
Bed	80	Between rows	10	22	42	35	64	60	70	52	63 d	71	65 c	54	70	56
		In row	11	30	39	60	97	68	77	85	82 d	62	76 bc	55	34	51
	160	Between rows	9	28	34	50	62	82	76	47	64 d	52	68 c	77	50	53
		In row	11	33	38	82	103	108	110	62	72 d	50	72 c	41	5	35
	240	Between rows	10	29	38	55	69	78	87	92	89 cd	74	71 c	84	83	74
		In row	10	41	49	66	113	73	94	125	94 cd	75	155 ab	90	197	80
Hilled row	80	Between rows	18	39	48	59	73	78	74	85	115 cd	69	88 bc	99	81	86
		In row	14	21	56	73	91	71	80	65	75 d	77	39 c	18	28	52
	160	Between rows	22	43	49	67	117	78	106	75	141 bc	124	99 bc	127	124	95
		In row	10	31	63	69	94	99	108	137	199 a	132	109 bc	91	70	74
	240	Between rows	7	14	41	73	120	122	139	172	185 ab	145	210 a	148	184	113
		In row	8	26	73	96	119	94	97	118	75 d	127	91 bc	47	109	153
Configuration			0.1667	0.8479	*0.0584*	0.2225	0.2821	0.3842	*0.0527*	*0.0527*	**0.0008**	**0.0032**	0.2184	0.3833	0.3697	**0.0146**
N rate			0.2747	0.6247	0.8504	0.3210	0.1796	**0.0158**	**0.0065**	**0.0154**	0.1045	0.1420	**0.0310**	0.4811	**0.0273**	*0.0663*
Placement			0.3742	0.8096	*0.0922*	*0.0517*	0.1166	0.6869	0.7383	0.4600	0.4817	0.9021	0.5724	*0.0733*	0.3722	0.6857
Configuration*N rate			0.2751	0.2882	0.8977	0.5290	0.5110	*0.0996*	0.3916	0.4647	*0.0560*	*0.0607*	0.5153	0.6260	0.5522	0.5207
Configuration*placement			0.1848	0.1021	0.2441	0.5680	*0.0846*	0.2262	*0.0725*	0.3145	0.1599	0.9351	**0.0202**	0.1668	0.2222	0.9826
N rate*Placement			0.6863	0.1869	0.3870	0.9807	0.8417	*0.0592*	0.1603	0.4862	*0.0819*	0.9545	0.7614	0.9711	0.5049	0.4083
Configuration*N rate*placement			0.4561	0.4164	0.9007	0.6470	0.6425	0.8673	0.4218	0.2390	*0.0703*	0.8959	*0.0558*	0.5134	0.3225	0.6921

[1]30 lbs·ac^{-1} N was applied as DAP (18-46-0), with the rest as ESN (Environmentally Smart Nitrogen, Agrium, Inc.; 44-0-0), all at planting.

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·ac^{-1} P_2O_5, 300 lbs·ac^{-1} K_2O, 2.6 lbs·ac^{-1} B, 2 lbs·ac^{-1} Zn, and 15 lbs·ac^{-1} Mg in any treatment to which these nutrients were applied. The application rate for S was 20 lbs·ac^{-1} where MES10 or MESZ was applied, 30 lbs·ac^{-1} where K-Mag was applied, and 50 lbs·ac^{-1} where K-Mag was applied with MES10 or MESZ. Fertilization with K increased plant stand, tuber yield, and tuber size and decreased tuber specific gravity and dry matter content. Despite relatively low initial soil P concentrations, fertilization with P_2O_5 had no significant effects on tuber yield, size, or quality. Fertilization with B in the form of Aspire increased tuber size and decreased tuber specific gravity relative to similar treatments receiving MOP instead of Aspire. Tuber specific gravity and dry matter content were positively related to the application rate of S. Applying Zn had no effect on tuber yield, size, or quality, nor on plant stand or stem count. The soils in the study site were not deficient in this element, so this result was expected. Aspire was effective in supplying K and B to Russet Burbank potato plants, while MES10 and MESZ were both effective in supplying S. Since there was no response to P_2O_5 application, we could not evaluate these products as P_2O_5 sources.

Background

Phosphorus (P), potassium (K), sulfur (S), boron (B), and zinc (Zn) are soil nutrients known to be 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

The study was conducted in 2018 at the Sand Plain Research Farm in Becker, MN, on a Hubbard loamy sand soil. The previous crop was rye. To measure initial soil characteristics, soil samples to a depth of six inches were collected on April 23 and sent to the University of Minnesota Research Analytical Laboratory (St. Paul, MN) to be analyzed for Bray P_2O_5; NH_4OAc-extractable K_2O, 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 1. Because of the low soil pH and Ca concentration, pelletized lime was broadcast on the entire field at 1,100 lbs·ac^{-1} on May 1. Twelve nutrient treatments were broadcast by hand on May 3, shortly before planting. The nutrients applied, their rates of application, and their fertilizer sources are described in Table 2.

Plots were laid out in a randomized complete block design with four replicates. Whole ("B") seed of Russet Burbank potatoes were planted by hand on May 3, with three-foot spacing between rows and one-foot spacing within rows. Each plot consisted of four, 20-foot rows with the middle two rows used for sampling and harvest. 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, Agrium, Inc.). Twenty lbs·ac^{-1} N were applied in each of two applications of 28% UAN on June 28 and July 19.

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 in the harvest rows was assessed on May 30 and June 13, and the number of stems per plant for 10 harvest-row plants was determined on June 13 and 20. Leaf petioles (4th leaf from the terminal) were sampled on June 19, July 2, 11, and 24, and August 7. Petioles will be analyzed for NO_3-N concentrations using a Wescan Nitrogen Analyzer, for N and S concentrations using an Elementar CNS analyzer, and for nutrient elemental concentrations using inductively coupled plasma analysis, to be performed by the Research Analytical Laboratory of the University of Minnesota.

Vines were killed with Reglone desiccant and LI 700 surfactant on September 13 and chopped on September 24. Tubers were harvested on September 26. Two, 18-ft sections of row were harvested from each plot. Total tuber yield and graded yield were measured. Subsamples of tubers were collected to determine tuber specific gravity and dry matter content and the incidence of hollow heart, brown center, and scab. Samples will be analyzed for N and S concentrations using an Elementar CNS analyzer. Additional tubers were sent to the Research Analytical Laboratory of the University of Minnesota to measure nutrient elemental concentrations using inductively coupled plasma 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. Plant stand, stems per plant and tuber yield and quality 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. All treatments receiving K had significantly greater total and marketable yield than the treatments receiving only N at planting (treatment 1) or N with P (treatment 2). The same was true of the percentage of yield represented by tubers over six or 10 ounces. Application of P fertilizer, regardless of form, did not significantly affect total or marketable when compared with the N with K treatment (treatment 3).

Consistent with some previous studies conducted at Becker, B fertilization (the use of Aspire in place of MOP) increased the percentage of yield represented by tubers weighing over 10 ounces, while decreasing the yield of tubers weighing between three and six ounces. B fertilization did not significantly affect total or marketable yield.

The contrast comparing MES10 with MESZ was not significant for any yield variable, indicating that Zn availability did not limit yield in this field in this year. Since the initial soil Zn concentration was sufficient, this result is not surprising. Similarly, yield did not respond to the application rate of S, indicating that S did not limit yield. The initial soil concentration of SO_4-S was deficient (5 $mg \cdot kg^{-1}$). The recommended application rate for S on deficient soils in potato fields is 20 – 30 $lbs \cdot ac^{-1}$, and any treatment receiving S received at least 20 $lbs \cdot ac^{-1}$. The presence of elemental S in MES10 and MESZ did not substantially affect tuber yield or size, based on the yields of treatments 9 through 11, in which S was provided in the form of K-mag, either with no other S source (treatment 9), MES10 (treatment 10), or MESZ (treatment 11).

Tuber quality

Results for tuber quality are presented in Table 4. Brown center co-occurred consistently with hollow heart, and scab was absent from the study. These variables are therefore not presented. The prevalence of hollow heart was not related to fertilizer treatment. Tuber dry matter content and specific gravity were lower in the treatments receiving K_2O (treatments 3 – 12) than those to which K_2O was not applied (treatments 1 and 2). These differences were significant in pairwise comparisons in most cases.

In the contrast comparing treatments receiving MOP (treatments 4, 5, and 7) with similar treatments receiving Aspire (treatments 12, 6, and 8, respectively), the treatments receiving MOP had slightly higher specific gravity than those receiving Aspire. This difference is likely due to the positive effect of B (present in Aspire and not in MOP) on tuber size. In the linear contrast on the application rate of S among the treatments receiving P and K (treatments 4 – 8), both dry matter content and specific gravity tended to increase with the application rate of S.

Plant stand, stems per plant

Results for plant stand and the number of stems per plant are presented in Table 5. The treatments receiving K (treatments 3 – 12) had substantially higher stand on May 30 than the treatments that received no K (treatments 1 and 2). Based on the results of contrast statements, the treatments receiving MES10 (treatments 5, 6, and 10) had more stems per plant on June 20 than similar treatments receiving MESZ (treatments 7, 8, and 11). There were no other significant relationships between treatment applied and plant stand or the number of stems per plant.

Conclusions

Not surprisingly, the most important factor influencing tuber yield, size, and quality in this study was whether K was applied. However, the lack of response to P application was unexpected, given the relatively low Bray soil P concentration of the study site. The B provided by Aspire increased tuber size and decreased tuber specific gravity, and applying S, whether through K-Mag, MES10, or MESZ, increased tuber specific gravity and dry matter content. Applying S as a blend of SO_4-S and elemental S, as opposed to SO_4-S alone, did not have detectable effects on tuber yield, size, or quality. However, it should be noted that the form of S applied differed with application rate. Treatments receiving K-Mag (which provides SO_4-S only) had higher application rates than those receiving MES10 or MESZ (which provide both elemental S and SO_4-S) without K-Mag. The Zn in MESZ had no significant effects on plant or tuber performance, but the soils of the study site had sufficient Zn concentrations prior to treatment. Aspire, MES10, and MESZ were effective fertilizers in this study and were comparable in performance to conventional fertilizers.

Table 1. Soil chemical properties prior to fertilizer treatments in the study site at the Sand Plain Research Farm in Becker, MN, in 2018. 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												
NO_3-N	Bray P	K	SO_4-S	Ca	Mg	Fe	Mn	Zn	Cu	B	Cation exchange capacity	Organic matter	pH
($mg \cdot kg^{-1}$ soil)											($meq \cdot 100g^{-1}$)		
2.5	16.0	75.5	5.0	270	30	63	42	1.2	0.62	0.18	7.5	4.85	6.45

Table 2. Nutrient sources and application rates from fertilizer treatments applied to Russet Burbank potatoes at the Sand Plain Research Farm in Becker, MN, in 2018.

Treatment	Fertilizers applied[1]	Nutrients broadcast at planting (lbs/ac)[2]						
		N	P_2O_5	K_2O	S	B	Zn	Mg
1	Check	34.4	0	0	0	0	0	0
2	MAP	34.4	80	0	0	0	0	0
3	MOP	34.4	0	300	0	0	0	0
4	MAP + MOP	34.4	80	300	0	0	0	0
5	MES10 + MOP	34.4	80	300	20	0	0	0
6	MES10 + Aspire	34.4	80	300	20	2.6	0	0
7	MESZ + MOP	34.4	80	300	20	0	2	0
8	MESZ + Aspire	34.4	80	300	20	2.6	2	0
9	MAP + MOP + KMag	34.4	80	300	30	0	0	15
10	MES10 + MOP + KMag	34.4	80	300	50	0	0	15
11	MESZ + MOP + KMag	34.4	80	300	50	0	2	15
12	MAP + Aspire	34.4	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. KMag: 0-0-22S-11Mg

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

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 2018.

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	58 bc	115	117 c	53 c	15 c	359 d	220 ef	80 d	301 c	51 c	18 cd
2	MAP	99 a	146	82 d	26 d	11 c	363 d	187 f	77 d	264 c	33 d	10 d
3	MOP	46 c	108	141 ab	101 a	63 ab	458 bc	300 ab	112 bcd	412 ab	66 ab	35 ab
4	MAP + MOP	63 bc	126	148 ab	75 bc	49 b	461 abc	267 bcd	130 ab	398 ab	59 bc	27 bc
5	MES10 + MOP	57 bc	129	151 a	93 ab	69 ab	499 a	308 a	134 ab	442 a	62 ab	32 ab
6	MES10 + Aspire	54 bc	113	131 bc	80 ab	82 a	459 abc	280 abcd	125 abc	406 ab	64 ab	35 ab
7	MESZ + MOP	52 c	129	140 ab	74 bc	51 ab	446 bc	276 abcd	117 abc	394 ab	59 abc	28 b
8	MESZ + Aspire	47 c	103	142 ab	96 ab	80 ab	469 abc	294 abc	128 ab	422 ab	68 a	38 a
9	MAP + MOP + KMag	73 b	117	143 ab	84 ab	58 ab	475 abc	258 cde	144 ab	402 ab	59 abc	29 ab
10	MES10 + MOP + KMag	65 bc	123	131 bc	92 ab	54 ab	465 abc	307 a	92 cd	400 ab	59 abc	31 ab
11	MESZ + MOP + KMag	63 bc	119	153 a	88 ab	59 ab	481 ab	270 abcd	149 a	419 ab	62 ab	30 ab
12	MAP + Aspire	55 bc	108	136 ab	84 ab	58 ab	440 c	253 de	132 ab	386 b	63 ab	32 ab
Significance of treatment (P-value)		**0.0072**	0.1120	**<0.0001**	**0.0015**	**0.0114**	**<0.0001**	**0.0003**	**0.0157**	**<0.0001**	**<0.0001**	**0.0006**
Contrasts	MOP vs. Aspire (4, 5, 7 vs. 12, 6, 8)	0.4218	**0.0109**	0.1172	0.4890	0.1245	0.3701	0.5484	0.9065	0.6805	0.1223	**0.0460**
	MES10 vs. MESZ (5, 6, 10 vs. 7, 8, 11)	0.4912	0.5504	0.2320	0.8012	0.6274	0.5119	0.1816	0.2404	0.7957	0.6590	0.7617
	Linear contrast on S application rate	0.2857	0.6833	0.9924	0.3525	0.9721	0.1888	0.2014	0.5698	0.5130	0.7651	0.8986

[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. KMag: 0-0-22S-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 2018. Scab was absent from the study, while brown center consistently co-occurred with hollow heart. These variables are therefore not presented.

Treatment	Fertilizers applied[1]	Hollow heart	Dry matter	Specific gravity
		%		
1	Check	9.0	22.6 ab	1.0821 ab
2	MAP	4.8	23.2 a	1.0831 a
3	MOP	4.1	21.4 cde	1.0788 de
4	MAP + MOP	2.0	21.4 cde	1.0790 cde
5	MES10 + MOP	2.0	21.3 cde	1.0782 de
6	MES10 + Aspire	6.0	21.2 de	1.0774 e
7	MESZ + MOP	2.0	22.1 bc	1.0808 bc
8	MESZ + Aspire	5.1	22.1 bc	1.0784 de
9	MAP + MOP + KMag	5.1	21.6 cd	1.0783 de
10	MES10 + MOP + KMag	2.9	22.0 bcd	1.0806 bc
11	MESZ + MOP + KMag	3.0	21.5 cde	1.0801 cd
12	MAP + Aspire	3.0	20.7 e	1.0786 de
	Significance of treatment (P-value)	0.4736	**0.0034**	**0.0002**
Contrasts	MOP vs. Aspire (4, 5, 7 vs. 12, 6, 8)	0.1243	0.3797	*0.0718*
	MES10 vs. MESZ (5, 6, 10 vs. 7, 8, 11)	0.8830	0.1955	0.1137
	Linear contrast on S application rate	0.8231	*0.0955*	*0.0551*

[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. KMag: 0-0-22S-11Mg

Table 5. Effects of fertilizer treatment on stand and the number of stems per plant of Russet Burbank potato plants grown at the Sand Plain Research Farm in Becker, MN, in 2018.

Treatment	Fertilizers applied[1]	Stand (%)		Stems / plant	
		May 30	June 13	June 13	June 20
1	Check	3 c	100	2.4	3.5
2	MAP	7 c	99	2.0	3.8
3	MOP	65 ab	97	2.0	3.1
4	MAP + MOP	65 ab	99	1.9	3.4
5	MES10 + MOP	59 ab	99	2.1	3.0
6	MES10 + Aspire	66 ab	100	2.2	3.5
7	MESZ + MOP	53 b	98	2.1	3.0
8	MESZ + Aspire	62 ab	96	2.2	3.0
9	MAP + MOP + KMag	75 a	99	2.1	3.1
10	MES10 + MOP + KMag	51 b	97	1.9	3.5
11	MESZ + MOP + KMag	69 ab	99	2.2	2.8
12	MAP + Aspire	66 ab	99	1.9	3.0
	Significance of treatment (P-value)	**<0.0001**	0.3403	0.6354	0.1641
Contrasts	MOP vs. Aspire (4, 5, 7 vs. 12, 6, 8)	0.4275	0.4660	0.5961	0.9669
	MES10 vs. MESZ (5, 6, 10 vs. 7, 8, 11)	0.6905	0.2277	0.5176	*0.0580*
	Linear contrast on S application rate	0.7099	0.6122	0.5158	0.7653

[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. KMag: 0-0-22S-11Mg

Evaluation of new controlled-release urea fertilizer products as N sources for Russet Burbank potatoes

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Summary

Controlled-release urea fertilizers provide one approach to providing N through a large portion of the growing season in a single application. The objective of this study was to evaluate the effectiveness of three new, proprietary controlled-release urea fertilizers (referred to as resin urea, coated urea, and coated urea with Zn, all 44-0-0) relative to ESN (Agrium, Inc.; 44-0-0) and uncoated urea (46-0-0) with subsequent applications of 28% UAN. Fifteen treatments were applied at hilling, including a check receiving no N beyond 40 $lbs \cdot ac^{-1}$ N applied to all treatments at planting; each controlled-release product applied at 110, 160, or 210 $lbs \cdot ac^{-1}$ N at emergence; and uncoated urea applied at 110 $lbs \cdot ac^{-1}$ N at emergence, with or without five subsequent applications of UAN at a rate of 20 $lbs \cdot ac^{-1}$ N per application. As N application rate increased, total and marketable yield, the yield of U.S. No. 2 tubers, and the proportion of yield represented by tubers over ten ounces generally increased, while the yield of U.S. No. 1 tubers generally decreased. N source had no significant effect on total or marketable yield or the yield U.S. No. 1 tubers. The treatments receiving the experimental controlled-release fertilizers had higher yields of U.S. No. 2 tubers than those receiving ESN or urea/UAN at the same application rates and, except for the treatments receiving coated urea, also had greater proportions of their yields represented by tubers weighing over ten ounces. Neither N source nor rate had any effect on tuber quality, including tuber dry matter content, specific gravity, and the occurrence of hollow heart, brown center or scab. Leaflet chlorophyll content, petiole NO_3-N concentration, and N uptake into both vines and tubers increased with N application rate. Petiole NO_3-N concentration decreased more rapidly throughout the season in the treatments receiving ESN than in the other treatments, averaged across N application rates. In the first two weeks after hilling, ESN released its urea content much more rapidly than the experimental fertilizers. Resin urea and coated urea with Zn had the highest release rates in June, especially in the first half of the month. Overall, the experimental fertilizers, particularly resin urea and coated urea with Zn, produced similar yields and more large tubers than ESN or urea/UAN. However, this came at the cost of having more yield represented by U.S. No. 2 tubers. These effects of N source on tuber size and grade may be attributable to the timing of N release, since the fertilizers producing the largest tubers and highest yields of U.S. No. 2 tubers (resin urea and coated urea with Zn) had notably high N release rates in the first half of June.

Background

Uncoated urea is water soluble and rapidly degraded into ammonia, which is readily converted into nitrate. As a result, when used as an N fertilizer, it is highly prone to losses through leaching and volatilization. A traditional method for mitigating this problem is to apply a moderate amount of urea early in the season and to sustain soil N availability later in the season with subsequent, light applications of liquid urea and ammonium nitrate (UAN). A disadvantage of this approach is that it requires additional labor and use of equipment. Controlled-release urea fertilizers offer one approach to providing sufficient urea over a large portion of the growing season with a single application.

The objective of this study was to evaluate the effectiveness of three new, proprietary controlled-release urea products (referred to as resin urea, coated urea, and coated urea with Zn; all 44-0-0) with a similar pre-existing product (Environmentally Smart Nitrogen; ESN; Agrium, Inc.; 44-0-0) and uncoated urea (46-0-0) with subsequent applications of UAN (28-0-0).

Materials and methods

The study was conducted on a Hubbard loamy sand soil at the Sand Plain Research Farm in Becker, MN, in 2017. Selected soil chemical characteristics on April 13, before any fertilizer was applied, are presented in Table 1.

Fifteen treatments were applied at hilling in a randomized complete-block design with four blocks. These included a check treatment that received no N at emergence, 12 treatments receiving 110, 160 or 210 $lbs \cdot ac^{-1}$ N at emergence as ESN, resin urea, coated urea, or coated urea with Zn (all 44-0-0), and two treatments receiving 110 $lbs \cdot ac^{-1}$ N as urea, one of which also received 100 $lbs \cdot ac^{-1}$ N in five applications of 28% UAN. All treatments received 40 $lbs \cdot ac^{-1}$ N at planting in addition to what they received at emergence, for a total of 40, 150, 200, or 250 $lbs \cdot ac^{-1}$ N. The treatments are summarized in Table 2.

MOP (0-0-60) was broadcast at 200 $lbs \cdot ac^{-1}$ on April 14, followed by 200 $lbs \cdot ac^{-1}$ SulPoMag (0-0-21.5-21S-10.5Mg) on April 17, providing 164 $lbs \cdot ac^{-1}$ K_2O, 44 $lbs \cdot ac^{-1}$ S, and 22 $lbs \cdot ac^{-1}$ Mg.

On April 24, 40 $lbs \cdot ac^{-1}$ N, 103 $lbs \cdot ac^{-1}$ P_2O_5, 182 $lbs \cdot ac^{-1}$ K_2O, 41 $lbs \cdot ac^{-1}$ S, 21 $lbs \cdot ac^{-1}$ Mg, 1.1 $lb \cdot ac^{-1}$ Zn, and 0.6 $lbs \cdot ac^{-1}$ B were banded in at row opening as a blend of DAP (18-46-0), MOP, SulPoMag, BluMin (17.5% S, 35.5% Zn), and Granubor (14.3% B). Sixty plots were planted by hand with whole "B" Russet Burbank seed with three-foot spacing between rows and one-foot spacing within rows. Each plot consisted of four, 20-foot rows, with the middle two rows used for sampling and harvest.

Emergence fertilizer was banded and hilled in according to treatment (Table 2) on May 11. Post-hilling applications of 20 $lbs \cdot ac^{-1}$ N as 28% UAN were applied to plots receiving Treatment 15 on each of five dates: June 26 and July 6, 13, 20, and 27.

The number of stems per plant for 10 harvest-row plants was determined on June 13, and plant stand in the harvest rows was assessed on June 22.

Leaf petioles (4^{th} leaf from the terminal) were sampled on June 14 and 27, July 11 and 25, and August 8. Petiole NO_3-N concentrations were determined using a Wescan N analyzer. On the same dates that petioles were collected, terminal leaflet chlorophyll content (4^{th} leaf from the terminal) was determined using a SPAD-502 chlorophyll meter (Konica-Minolta, Inc.).

Vine samples were collected from 10 feet of each harvest row on September 13. All vines in the sample were weighed, and a subsample was taken to determine dry matter content, tissue N concentration, and N uptake.

The remaining vines were chopped on September 13, and tubers were harvested on September 27. Two, 18-foot sections were harvested from each plot. Total and graded tuber yield were measured. Twenty-five-tuber subsamples were collected to determine the prevalences of hollow heart, brown center, and scab, as well as tuber dry matter content, specific gravity, and N concentration.

We employed two methods to determine the relative release rates of the four different controlled-release fertilizers used in this study. The first was to weigh out three, three-gram samples of each product, soak them in distilled water for 24 hours, dry them, and re-weigh them to determine the fertilizer weight lost. The second was to weigh out 30, three-gram samples of each product and seal them in flat, plastic mesh pouches. The pouches containing each product were buried in groups of 10 at emergence in three of the four plots fertilized with 210 $lbs \cdot ac^{-1}$ N of that product at emergence. One pouch was removed from each plot on each of 10 sample dates, rinsed, dried, and weighed to determine how much fertilizer was released. Fertilizer pouches were collected on May 15, 19, 24, and 30, June 5, 15, and 29, July 20, August 18, and September 13.

Data were analyzed with SAS 9.4m3® software (copyright 2015, SAS Institute, Inc.) using the MIXED procedure. For most variables, treatments were compared in two statistical models.

In the first model, for each dependent variable, treatment and block were treated as fixed effects. In the second model, only treatments receiving either 150 or 250 $lbs \cdot ac^{-1}$ N were included (because there was no treatment receiving urea/UAN at 200 $lbs \cdot ac^{-1}$ N), and N source, application rate, their interaction, and block were treated as fixed effects.

SPAD readings and petiole NO_3-N concentrations were evaluated in repeated-measures analyses in two ways: (1) with treatment, sampling date, their interaction, and block as fixed effects and all treatments included; and (2) with source, rate, sampling date, their interactions, and block as fixed effects and only treatments receiving 150 or 250 $lbs \cdot ac^{-1}$ N included.

Fertilizer prill release rates from the buried pouches were analyzed in a repeated-measures analysis with the percentage of fertilizer released as a function of date, fertilizer, and their interaction. Because the release trial was replicated three times for each fertilizer, and the three replicates were chosen at random from the four blocks available, fertilizer release was analyzed as a completely randomized design.

In all repeated-measures analyses, sample date was the repeated-measures variable, plot was the subject, and the covariance matrix had a spatial power structure.

Means were calculated and post-hoc pairwise comparisons made using the LSMEANS statement with the DIFF option. Pairwise comparisons were only evaluated where the P-value of the treatment effect in the model was less than 0.10, and pairwise comparisons with P-values less than 0.10 were considered significant.

Results and discussion

Tuber yield

Results for tuber yield are presented in Table 3. Total and marketable yield generally increased with the application rate of N, but did not differ among the four sources at any given rate. The highest total and marketable yields were in the treatment receiving 160 $lbs \cdot ac^{-1}$ N at emergence as ESN (treatment 3, which received 200 $lbs \cdot ac^{-1}$ N in total). In the analyses of the effects of N application rate and source (which did not include the check treatment or the treatments receiving 200 $lbs \cdot ac^{-1}$ N), total and marketable yield increased with application rate but were not related to N source.

Yields of U.S. No. 1 tubers generally decreased, while yields of U.S. No. 2 tubers increased, as N application rate increased. These trends were significant in the analyses of the effects of N application rate and source. These analyses also found that ESN and urea/UAN had significantly lower yields of U.S. No. 2 tubers and numerically lower marketable yields than the other sources, but numerically larger yields of U.S. No. 1 tubers. These results suggest that increases in marketable yield in this study came in the form of U. S. No. 2 tubers, at the expense of U.S. No. 1 tubers.

The percentage of yield represented by tubers weighing more than 10 ounces generally increased with the application rate of N, as did the yield of tubers weighing more than 14 ounces. N source had significant effects on tuber size, as well. In the analysis of the effects of N application rate and source, the treatments receiving resin urea (treatments 5 and 7) had more of their yield represented by tubers over six ounces than those receiving any other N source, and more of their yield in tubers over 10 ounces than those receiving any other source except coated urea with Zn (treatments 11 and 13). Both of these pairs of treatments had more of their yield in tubers over 10 ounces and higher yields of tubers over 14 ounces than the treatments receiving ESN (treatments 2 and 4) or urea/UAN (treatments 14 and 15).

Plant stand and tuber quality

Results for plant stand, stems per plant, and tuber quality are presented in Table 4. Treatment had no effect on the prevalence of stand, stems per plant, hollow heart, brown center or scab, nor on tuber dry matter content or specific gravity.

Leaflet chlorophyll content

Results for leaflet chlorophyll content (SPAD meter readings) are presented in Table 5. The effects of N treatment, sampling date, and their interaction were all significant. Leaflet chlorophyll content generally decreased over time for all treatments, but the decrease was much greater in the zero-N check treatment (treatment 1) than in any other treatment. Chlorophyll content also tended to decline more rapidly over time in treatments receiving 150 lbs·ac^{-1} total N than treatments receiving higher application rates, especially across the last two sampling dates (July 25 and August 8). For each source, the treatment receiving 150 lbs·ac^{-1} N had a lower chlorophyll content on the last two dates than either of the treatments receiving the higher rates. On the last sampling date (August 8), the treatment receiving 200 lbs·ac^{-1} N of each N source consistently had lower leaflet chlorophyll contents than that receiving N from the same source at 250 lbs·ac^{-1}. It was not clear that N source affected leaflet chlorophyll concentration.

In the analysis of the effects of N application rate and source, leaflet chlorophyll content varied significantly with the interaction between date, N source, and N application rate. N treatment had no significant effect on chlorophyll content on the first sampling date, so the date*source*rate interaction means that the chlorophyll contents resulting from the highest and lowest application rates diverged to a larger degree with some N sources than they did with others. Application rate had the strongest effect on August 8 chlorophyll content when the N source was urea/UAN (treatments 14 and 15) and the weakest effect when the source was coated urea without Zn (treatments 8 and 10). The strong effect of application rate on late-season chlorophyll content when the N source was urea/UAN was presumably due to the lack of post-hilling UAN applications in the low-N-rate treatment (treatment 14).

Petiole NO_3-N concentration

Results for petiole NO_3-N concentration are presented in Table 6. Similar to leaflet chlorophyll content, the effects of treatment, date, and their interaction were significant. Petiole NO_3-N concentration decreased rapidly between June 14 and 27 in the check treatment (treatment 1) without changing significantly after that. The treatment receiving 110 lbs·ac^{-1} N as urea with no subsequent UAN applications (treatment 14) had one of the highest petiole NO_3-N concentrations on June14, but a significantly lower concentration than any treatment except for the check on July 11. Among the remaining treatments, petiole NO_3-N generally increased with N application rate, especially later in the season.

In the analysis of the effects of N application rate and source, which excluded the treatments receiving 200 lbs·ac^{-1} total N, N source had no significant effect on whole-season average petiole NO_3-N concentration. However, concentrations changed differently across the season among different N sources. The treatments receiving ESN (treatments 2 and 4) had high petiole NO_3-N concentrations relative to treatments receiving other N sources at the same N rate on June 14, but relatively low concentrations on July 25.

N uptake

N uptake results are presented in Table 7. N uptake into vines, tubers, and the sum of the two generally increased with N application rate, except that vine N uptake for ESN and tuber N uptake for resin urea were slightly greater in the treatments receiving 200 $lbs \cdot ac^{-1}$ total N than those receiving 250 $lbs \cdot ac^{-1}$ total N. In the analysis of the effects of N application rate and source, N source was significantly related to vine N uptake, with the treatments receiving resin urea (treatments 5 and 7) or uncoated urea with UAN (treatments 14 and 15) having greater uptake than the treatments receiving ESN (treatments 2 and 4) or coated urea (treatments 8 and 10).

Fertilizer release from prills

When fertilizer prills were immersed in distilled water for 24 hours, ESN released, by far, the largest percentage of its fertilizer content, at 18.7 ± 1.4% (mean ± S.D.). The release rates for resin urea, coated urea, and coated urea with Zn were 2.7 ±0.3%, 4.9 ± 0.6%, and 2.6 ± 1.1%, respectively.

Release of urea from buried pouches of prills installed *in situ* are presented in Figure 1. The initial release rate of urea from ESN was much greater than those of the other controlled-release fertilizers, so that the cumulative percentage fertilizer release from ESN prills was significantly higher than that of any other fertilizer from May 15 until June 5, when resin urea's cumulative release of urea was no longer significantly lower. Coated urea had released more fertilizer than resin urea or coated urea with Zn on May 15, 19, and 24, the difference being statistically significant on the last two of these dates. However, by June 15, coated urea had released significantly less of its content than any other fertilizer, and this remained the case until September 13, when all fertilizers had released approximately 99% of their content. Resin urea and coated urea with Zn released their content more rapidly between May 24 and June 15 than ESN or coated urea without Zn.

Conclusions

The experimental controlled-release urea fertilizers had higher yields of U.S. No. 2 tubers than either ESN or urea/UAN applied at the same rate. However, this came at a small cost to U.S. No. 1 tuber yield, and the effect of N source on overall marketable yield was not significant.

Treatments receiving resin urea and coated urea with Zn had more of their yield in tubers weighing more than 10 ounces than those receiving ESN or urea/UAN, and treatments receiving resin urea had more of their yield in tubers over six ounces than any other source.

Tuber yield and size and the yield of U.S. No. 2 tubers generally increased with N application rate. The opposite was true of the yield of U.S. No. 1 tubers.

N application rate, unlike N source, had significant effects on leaflet chlorophyll content, petiole NO_3-N concentration, and tuber N uptake, all of which are expected to be highly responsive to N fertilization. This is consistent with the limited effect of N source on total or marketable tuber yield, but not with the significant effect of source on tuber size or the yield of U.S. No. 2 tubers. Based on the N release rates of prills buried *in situ*, yields of large tubers and U.S. No. 2 tubers were related to the mean daily release of fertilizer from prills in June, especially in the first half of the month. Possibly, N available in the soil in early June is particularly relevant to plant resource requirements for tuber bulking, which is expected to begin in late June to early July.

Table 1. Selected soil characteristics in the top two feet (NO_3-N concentration) or six inches (other variables) in the study field at Becker, MN, in 2017, on April 13, prior to all fertilizer applications.

0 - 2 feet	0 - 6 inches					
NO_3-N	Bray P	K	SO_4-S	Zn	Organic matter	pH
ppm						
3.0	32	110	3	1.6	2.3	5.2

Table 2. Treatments applied to Russet Burbank potatoes at Becker, MN, in 2017, to evaluate the effectiveness of controlled-release urea products as N sources.

Treatment #	Emergence fertilizer[1]	Starter N (lbs/ac as DAP[1])	Emergence N (lbs/ac)	N as UAN[1] post-hilling (lbs/ac)	Total N applied (lbs/ac)
1	Control	40	0	0	40
2	ESN	40	110	0	150
3	ESN	40	160	0	200
4	ESN	40	210	0	250
5	Resin Urea	40	110	0	150
6	Resin Urea	40	160	0	200
7	Resin Urea	40	210	0	250
8	Coated Urea	40	110	0	150
9	Coated Urea	40	160	0	200
10	Coated Urea	40	210	0	250
11	Coated Urea+Zn	40	110	0	150
12	Coated Urea+Zn	40	160	0	200
13	Coated Urea+Zn	40	210	0	250
14	Urea	40	110	0	150
15	Urea	40	110	100	250

[1]DAP: 18-46-0. ESN, resin urea, coated urea: 44-0-0. Urea: 46-0-0. UAN: 28-0-0.

Table 3. Effects of N source and rate on tuber yield and size distribution of Russet Burbank potatoes at Becker, MN, in 2017. Values within a column that share a letter are not significantly different from each other (α = 0.10); pairwise comparison are only presented where the P-value of the effect of treatment is less than 0.1000.

Treatment #	Emergence fertilizer[1]	Starter N (lbs/ac as DAP[1])	Emergence N (lbs/ac)	N as UAN[1] post-hilling (lbs/ac)	Total N applied (lbs/ac)	Tuber yield										
						0-3 oz	3-6 oz	6-10 oz	10-14 oz	> 14 oz	Total yield	#1s > 3 oz.	#2s > 3 oz	Marketable yield	> 6 oz	> 10 oz
						cwt·ac^{-1}									%	
1	Control	40	0	0	40	40 a	132 a	182	80 e	16 e	450 d	280 e	171 abc	410 c	62 e	21 e
2	ESN	40	110	0	150	29 b	92 bc	208	148 cd	74 d	551 c	434 ab	117 e	522 b	78 cd	40 d
3	ESN	40	160	0	200	21 cde	75 cd	188	164 abcd	152 a	599 a	446 a	153 bcd	579 a	84 ab	53 abc
4	ESN	40	210	0	250	27 bc	85 bc	197	172 abc	107 bcd	587 ab	432 abc	155 bcd	560 a	81 bcd	48 bcd
5	Resin Urea	40	110	0	150	14 e	61 d	184	183 ab	125 abc	566 bc	443 a	123 de	552 ab	87 a	54 ab
6	Resin Urea	40	160	0	200	20 cde	70 cd	169	164 abcd	145 ab	568 bc	396 d	173 abc	549 ab	84 ab	54 ab
7	Resin Urea	40	210	0	250	19 cde	71 cd	157	188 a	158 a	594 ab	396 d	198 a	575 a	85 ab	58 a
8	Coated Urea	40	110	0	150	20 cde	87 bc	198	152 cd	89 cd	545 c	422 abcd	123 de	526 b	81 bcd	44 cd
9	Coated Urea	40	160	0	200	22 bcd	71 cd	172	184 ab	123 abc	572 abc	424 abcd	148 bcde	550 ab	84 ab	54 ab
10	Coated Urea	40	210	0	250	21 bcd	74 cd	175	173 abc	149 a	593 ab	400 cd	193 a	571 a	84 ab	54 ab
11	Coated Urea+Zn	40	110	0	150	17 de	86 bc	170	169 abc	126 abc	568 bc	435 ab	133 de	551 ab	82 bc	52 abc
12	Coated Urea+Zn	40	160	0	200	21 cde	81 bcd	177	170 abc	136 ab	585 ab	409 bcd	176 ab	564 a	83 abc	52 abc
13	Coated Urea+Zn	40	210	0	250	24 bcd	81 bcd	169	157 bcd	154 a	585 ab	390 d	195 a	561 a	82 bc	53 ab
14	Urea	40	110	0	150	26 bc	100 b	198	153 cd	73 d	550 c	433 abc	117 e	524 b	77 d	41 d
15	Urea	40	110	100	250	23 bcd	77 cd	186	140 d	145 ab	572 abc	432 abc	140 cde	549 ab	82 abc	50 bc
					Treatment significance (P-value)	**0.0006**	**0.0022**	0.3775	**<0.0001**	**<0.0001**	**<0.0001**	**<0.0001**	**0.0001**	**<0.0001**	**<0.0001**	**<0.0001**
Effects of source, rate, and source*rate, excluding treatments receiving 200 lbs/ac total N					**Source significance (P-value)**	**0.0334**	0.1081	0.1118	*0.0873*	**0.0366**	0.5646	0.2927	**0.0073**	0.2249	**0.0192**	**0.0097**
					Rate significance (P-value)	0.4122	0.2036	0.1060	0.5526	**0.0004**	**0.0005**	**0.0087**	**<0.0001**	**0.0015**	0.1172	**0.0105**
					Source*rate significance (P-value)	0.5294	0.4930	0.8943	0.4857	0.6502	0.7378	0.2572	0.1105	0.6586	0.3392	0.7262

[1]DAP: 18-46-0. ESN, resin urea, coated urea: 44-0-0. Urea: 46-0-0. UAN: 28-0-0.

Table 4. Effects of N source and rate on the prevalences of hollow heart, brown center, and scab; dry matter content; and specific gravity of Russet Burbank potatoes at Becker, MN, in 2017.

Treatment #	Emergence fertilizer[1]	Starter N (lbs/ac as DAP[1])	Emergence N (lbs/ac)	N as UAN[1] post-hilling (lbs/ac)	Total N applied (lbs/ac)	Plant stand, June 22 (%)	Stems per plant, June 13	Hollow heart	Brown center	Scab	Dry matter	Specific gravity
								%				
1	Check	40	0	0	40	95	2.5	0	0	0	21.4	1.0832
2	ESN	40	110	0	150	96	2.5	1	1	0	22.6	1.0835
3	ESN	40	160	0	200	92	2.4	0	0	1	22.8	1.0853
4	ESN	40	210	0	250	94	2.3	0	1	0	22.7	1.0825
5	Resin Urea	40	110	0	150	92	2.4	0	0	0	22.5	1.0856
6	Resin Urea	40	160	0	200	92	2.4	0	0	0	21.4	1.0848
7	Resin Urea	40	210	0	250	94	2.4	0	0	1	22.1	1.0827
8	Coated Urea	40	110	0	150	92	2.6	2	1	0	22.5	1.0840
9	Coated Urea	40	160	0	200	96	2.3	0	0	0	21.9	1.0839
10	Coated Urea	40	210	0	250	94	2.4	0	1	0	21.5	1.0810
11	Coated Urea+Zn	40	110	0	150	95	2.3	1	1	2	22.0	1.0827
12	Coated Urea+Zn	40	160	0	200	95	2.3	0	0	0	22.1	1.0822
13	Coated Urea+Zn	40	210	0	250	91	2.6	1	1	0	22.1	1.0838
14	Urea	40	110	0	150	94	2.4	0	0	0	22.3	1.0820
15	Urea	40	110	100	250	95	2.2	2	2	1	22.3	1.0830
					Treatment significance (P-value)	0.8419	0.8454	0.7216	0.8634	0.6710	0.3236	0.4406
Effects of source, rate, and source*rate, excluding treatments receiving 200 lbs/ac total N					Source significance (P-value)	0.7433	0.7604	0.8356	0.8277	0.6944	0.5785	0.5813
					Rate significance (P-value)	1.0000	0.6280	0.7593	0.5584	0.9746	0.3904	0.2004
					Source*rate significance (P-value)	0.4818	0.3583	0.4403	0.8277	0.3424	0.6105	0.2324

[1] ESN, resin urea, coated urea: 44-0-0. Urea: 46-0-0. DAP: 18-46-0. UAN: 28-0-0.

Table 5. Effects of N treatment on SPAD readings taken from the terminal leaflet of the fourth leaf from the shoot tip (20 leaves from 20 plants per plot) of Russet Burbank potato plants Becker, MN, in 2017. Values within a row that share an uppercase letter, and values within a column that share a lowercase letter, are not significantly different from each other (α = 0.10). Pairwise comparisons between treatments are not presented for June 14 because no two treatments had significantly different SPAD readings from each other on that date.

Treatment #	Emergence fertilizer[1]	Starter N (lbs/ac as DAP[1])	Emergence N (lbs/ac)	N as UAN[1] post-hilling (lbs/ac)	Total N applied (lbs/ac)	SPAD readings					
						June 14	June 27	July 11	July 25	August 8	Average across dates
1	Check	40	0	0	40	45.5 A, -	43.9 A, bc	36.0 B, b	29.0 C, f	22.2 D, h	35.3 h
2	ESN	40	110	0	150	45.9 A, -	44.9 A, abc	41.0 B, a	36.9 C, e	31.1 D, g	39.9 g
3	ESN	40	160	0	200	46.0 A, -	44.3 A, abc	41.2 B, a	37.9 C, bcde	37.7 C, e	41.4 def
4	ESN	40	210	0	250	46.1 A, -	45.4 A, abc	40.9 B, a	39.5 B, abcd	39.7 B, cde	42.3 abcd
5	Resin Urea	40	110	0	150	45.3 A, -	45.4 A, abc	40.6 B, a	38.3 C, bcde	33.6 D, f	40.6 efg
6	Resin Urea	40	160	0	200	45.8 A, -	43.6 B, c	41.7 B, a	39.5 C, abcd	39.4 C, cde	42.0 bcd
7	Resin Urea	40	210	0	250	46.3 A, -	44.9 A, abc	41.2 B, a	40.7 B, a	42.7 B, ab	43.2 a
8	Coated Urea	40	110	0	150	45.8 A, -	44.9 A, abc	41.2 B, a	37.7 C, de	38.5 C, de	41.6 cde
9	Coated Urea	40	160	0	200	45.8 A, -	45.9 A, ab	41.5 B, a	39.9 B, abc	39.5 B, cde	42.5 abcd
10	Coated Urea	40	210	0	250	45.8 A, -	46.2 A, a	40.9 B, a	39.7 B, abcd	40.9 B, bc	42.7 ab
11	Coated Urea+Zn	40	110	0	150	45.6 A, -	45.8 A, ab	40.0 B, a	37.8 C, cde	33.6 D, f	40.5 fg
12	Coated Urea+Zn	40	160	0	200	45.5 A, -	46.1 A, a	40.3 B, a	40.3 B, ab	38.5 B, de	42.1 abcd
13	Coated Urea+Zn	40	210	0	250	45.2 A, -	46.1 A, a	41.2 B, a	40.1 B, ab	40.1 B, cd	42.5 abc
14	Urea	40	110	0	150	45.3 A, -	45.7 A, ab	40.4 B, a	36.8 C, e	30.8 D, g	39.8 g
15	Urea	40	110	100	250	45.8 A, -	45.5 A, abc	40.5 C, a	40.1 C, ab	43.6 B, a	43.1 a
Average across treatments						45.7 A	45.2 A	40.6 B	38.3 C	36.8 D	
Treatment significance (P-value)											**<0.0001**
Date significance (P-value)						**<0.0001**					
Treatment*date significance (P-value)						**<0.0001**					

Effects of N source and rate, sampling date, and their interactions, on terminal leaflet SPAD readings, excluding treatments receiving 200 lbs/ac total N		
	Source	0.2051
	Rate	**<0.0001**
	Source*rate	0.2095
	Sampling date	**<0.0001**
	Date*source	*0.0540*
	Date*rate	**<0.0001**
	Date*source*rate	**0.0322**

[1] ESN, resin urea, coated urea: 44-0-0. Urea: 46-0-0. DAP: 18-46-0. UAN: 28-0-0.

Table 6. Effects of N treatment on NO_3-N concentrations of petioles taken from the fourth leaf from the shoot tip (20 leaves from 20 plants per plot) of Russet Burbank potato plants at Becker, MN, in 2017. Values within a row that share an uppercase letter, and values within a column that share a lowercase letter, are not significantly different from each other (α = 0.10).

Treatment #	Emergence fertilizer[1]	Starter N (lbs/ac as DAP[1])	Emergence N (lbs/ac)	N as UAN[1] post-hilling (lbs/ac)	Total N applied (lbs/ac)	Petiole NO3-N concentrations (ppm) June 14	June 27	July 11	July 25	August 8	Average across dates
1	Check	40	0	0	40	13084 A, g	1712 B, d	1090 B, f	2072 B, e	178 B, e	3627 g
2	ESN	40	110	0	150	18117 A, bcde	13952 B, abc	12162 B, abcd	1873 C, e	1310 C, cde	9483 de
3	ESN	40	160	0	200	21429 A, a	14837 B, abc	12787 B, abcd	7039 C, bc	1447 D, cde	11508 bc
4	ESN	40	210	0	250	19990 A, ab	15223 B, ab	12287 C, abcd	7854 D, b	2079 E, cde	11487 bc
5	Resin Urea	40	110	0	150	14906 A, fg	12471 B, c	10166 B, d	3329 C, de	420 D, de	8258 f
6	Resin Urea	40	160	0	200	18894 A, abcde	14512 B, abc	12872 B, ab	3111 C, de	2359 C, bcde	10350 cd
7	Resin Urea	40	210	0	250	17089 A, def	14455 B, abc	13756 BC, ab	11289 C, a	3240 D, abc	11966 ab
8	Coated Urea	40	110	0	150	17533 A, cde	13213 B, bc	12126 B, abcd	3467 C, de	211 D, e	9310 def
9	Coated Urea	40	160	0	200	17003 A, def	15286 A, ab	12854 B, ab	6593 C, bc	1658 D, cde	10679 c
10	Coated Urea	40	210	0	250	18930 A, abcde	15756 B, a	11670 C, bcd	8750 D, b	4552 E, ab	11932 ab
11	Coated Urea+Zn	40	110	0	150	17613 A, bcde	12972 B, bc	10231 C, cd	4739 D, cd	727 E, de	9256 def
12	Coated Urea+Zn	40	160	0	200	19586 A, abcd	15164 B, ab	12816 B, abc	7458 C, b	1317 D, cde	11268 bc
13	Coated Urea+Zn	40	210	0	250	16926 A, ef	15197 A, ab	14278 B, a	11272 C, a	2638 D, bcd	12062 ab
14	Urea	40	110	0	150	19968 A, abc	14395 B, abc	5691 C, e	1314 D, e	462 D, de	8366 ef
15	Urea	40	110	100	250	18637 A, bcde	15764 B, a	13724 BC, ab	12439 C, a	5098 D, a	13132 a
Average across treatments						17980 A	13661 B	11234 C	6173 D	1846 E	
Treatment significance (P-value)											<0.0001
Date significance (P-value)						<0.0001					
Treatment*date significance (P-value)						<0.0001					

Effects of N source and rate, sampling date, and their interactions, on terminal leaflet SPAD readings, excluding treatments receiving 200 lbs/ac total N		
	Source	0.7505
	Rate	**<0.0001**
	Source*rate	0.1632
	Sampling date	**<0.0001**
	Date*source	**0.0140**
	Date*rate	**<0.0001**
	Date*source*rate	*0.0882*

[1] ESN, resin urea, coated urea: 44-0-0. Urea: 46-0-0. DAP: 18-46-0. UAN: 28-0-0.

Table 7. Effects of N treatment on vine, tuber, and total (vine plus tuber) N uptake of Russet Burbank potatoes at Becker, MN, in 2017.

Treatment #	Emergence fertilizer[1]	Starter N (lbs/ac as DAP[1])	Emergence N (lbs/ac)	N as UAN[1] post-hilling (lbs/ac)	Total N applied (lbs/ac)	Vine N uptake (lbs/ac)	Tuber N uptake (lbs/ac)	Total N uptake (lbs/ac)
1	Check	40	0	0	40	4 g	86 g	90 f
2	ESN	40	110	0	150	13 ef	156 f	169 e
3	ESN	40	160	0	200	17 cdef	176 bcde	193 bcd
4	ESN	40	210	0	250	15 def	198 a	213 ab
5	Resin Urea	40	110	0	150	16 def	162 ef	179 de
6	Resin Urea	40	160	0	200	17 cde	192 ab	209 abc
7	Resin Urea	40	210	0	250	26 ab	188 abc	214 a
8	Coated Urea	40	110	0	150	10 fg	161 ef	172 e
9	Coated Urea	40	160	0	200	16 def	173 cdef	189 cde
10	Coated Urea	40	210	0	250	20 bcd	184 abcd	204 abc
11	Coated Urea+Zn	40	110	0	150	13 def	167 def	180 de
12	Coated Urea+Zn	40	160	0	200	18 cde	187 abc	205 abc
13	Coated Urea+Zn	40	210	0	250	23 abc	201 a	225 a
14	Urea	40	110	0	150	15 def	163 ef	178 de
15	Urea	40	110	100	250	28 a	194 a	222 a
Treatment significance (P-value)						**<0.0001**	**<0.0001**	**<0.0001**

		Vine N uptake	Tuber N uptake	Total N uptake
Effects of source, rate, and source*rate, excluding treatments receiving 200 lbs/ac total N	**Source significance (P-value)**	**0.0444**	0.6018	0.5205
	Rate significance (P-value)	**<0.0001**	**<0.0001**	**<0.0001**
	Source*rate significance (P-value)	0.4361	0.7264	0.9162

[1] ESN, resin urea, coated urea: 44-0-0. Urea: 46-0-0. DAP: 18-46-0. UAN: 28-0-0.

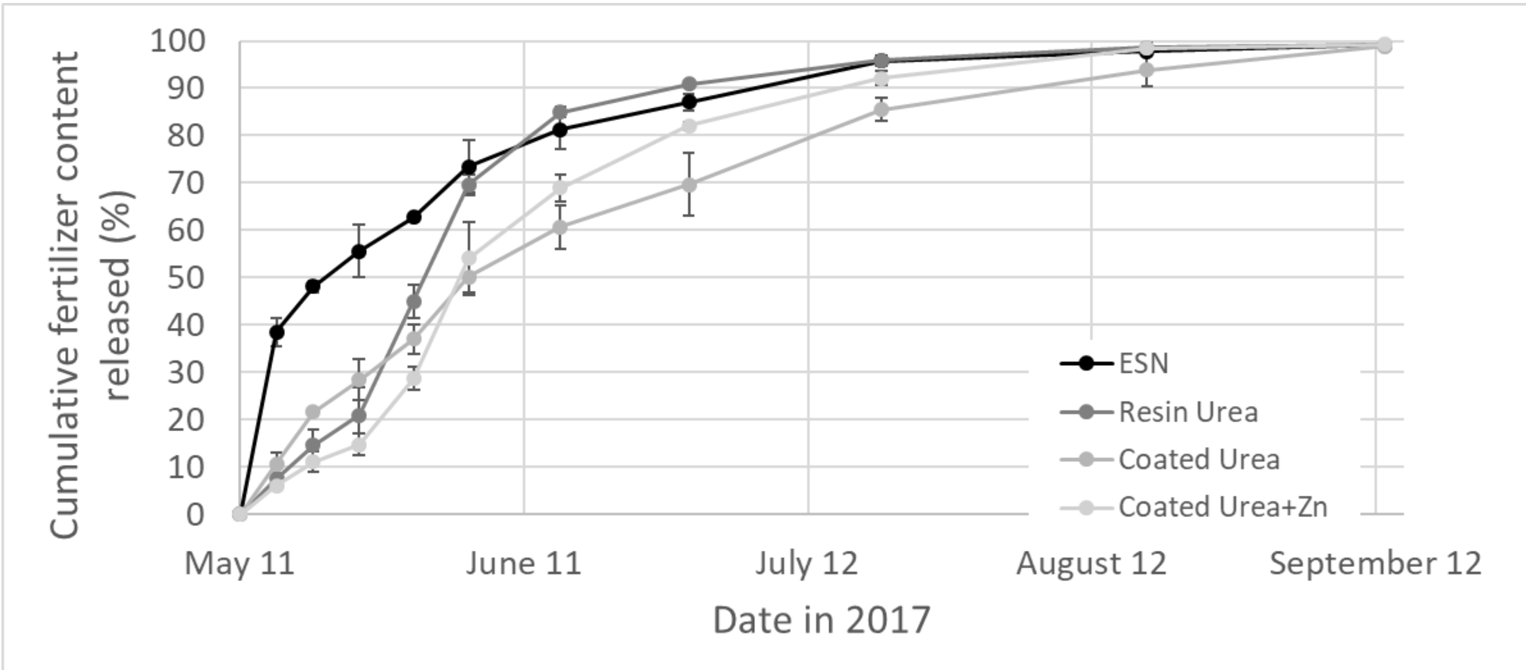

Figure 1. Average cumulative fertilizer release over time for ESN, resin urea, coated urea, and coated urea with Zn from mesh pouches of prills buried in the study site in Becker, MN, in 2017.

Evaluation of polyhalite as a K source in Russet Burbank potatoes

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Summary

Polyhalite is a naturally occurring mineral with the chemical formula $K_2SO_4.MgSO_4.2CaSO_4.2H_2O$ and an approximate fertilizer value of 0-0-14-19S-3Mg-12Ca that may have potential as a cost-effective nutrient source for crops. Because of its high S, Mg, and Ca contents, polyhalite may be ideal for crops grown in acidic, sandy, low-organic-matter soils, which are frequently deficient in these elements. The experiment was conducted at the Sand Plain Research Farm in Becker, MN on an acidic, sandy, low organic matter soil with Russet Burbank potato as the test crop. Fifteen treatments were evaluated using Polysulphate (a brand of polyhalite produced by ICL) as a K source relative to muriate of potash (MOP; 0-0-60), sulfate of potash (SOP; 0-0-48-17S), and K-Mag (Mosaic Co.; 0-0-22-22S-11Mg). A randomized complete block design experiment with four blocks was used. We also compared two polymer-coated urea products, Agrocote Max Urea 1-2M (ICL; 44-0-0) and Environmentally Smart Nitrogen (ESN; Agrium, Inc.; 44-0-0), as N sources. Among eight treatments, each K source was broadcast before planting to provide 200 $lbs{\cdot}ac^{-1}$ K_2O, with or without an additional 200 $lbs{\cdot}ac^{-1}$ K_2O as MOP banded at emergence, with N supplied by ESN with UAN. Additional treatments included two zero-K checks (one for each N source), treatments receiving 200 $lbs{\cdot}ac^{-1}$ K_2O as Polysulphate, with or without 200 $lbs{\cdot}ac^{-1}$ K_2O as MOP at emergence, with N provided by Agrocote Max plus UAN; treatments receiving 160 or 200 $lbs{\cdot}ac^{-1}$ N as Agrocote Max without UAN; a treatment receiving 160 $lbs{\cdot}ac^{-1}$ N as ESN without UAN, and a treatment receiving 400 $lbs{\cdot}ac^{-1}$ K_2O as MOP before planting. Relative to the zero-K check treatments, the treatments receiving K at either rate had higher total and marketable yields, larger tubers, a lower prevalence of hollow heart, lower terminal leaflet chlorophyll content, lower tuber glucose concentration, and lighter French fry color. Most of these differences were also evident between the lower and higher application rates of K, with treatments receiving the higher rate also having lower tuber specific gravity and dry matter content than those receiving the lower rate. In contrast, K source had few significant effects. When no MOP was applied at emergence, treatments receiving SOP or K-Mag before planting produced more of their yield in tubers over ten ounces than treatments receiving MOP, with K-Mag showing the same advantage for tubers over six ounces. These differences were not apparent when MOP was applied at emergence. There was also a negative relationship between S rate (which differed by K source) and stem-end tuber glucose concentration that was largely attributable to a low glucose concentration in the treatment receiving K-Mag before planting and MOP at emergence. All K sources that provided S provided a sufficient amount, possibly explaining the lack of K source effects. The two N sources also produced very similar results. Treatments receiving ESN had higher leaflet chlorophyll contents than those receiving Agrocote Max on the second sampling date (July 3) but not on subsequent dates, and the treatments receiving Agrocote Max produced higher stem-end French fry reflectance values than those receiving ESN when K was applied (but not in the check treatments). Overall, polyhalite was an effective source of K for Russet Burbank potatoes, but its high S content did not confer an advantage over other K sources in this study, while Agrocote Max and ESN performed very similarly, though plants receiving Agrocote Max produced lighter stem-end (but not bud-end) French fries.

Background

Polyhalite is a naturally occurring mineral with the chemical formula $K_2SO_4.MgSO_4.2CaSO_4.2H_2O$ and an approximate fertilizer value of 0-0-14-19S-3Mg-12Ca. There are large deposits of polyhalite worldwide, sparking interest in whether it can be used as a cost-efficient nutrient source for crop production. Because it has high contents of S, Mg, and Ca relative to its K content, compared to sulfate of potash (SOP; 0-0-48-17S), using polyhalite to meet crop K requirements would mean applying large amounts of S, Mg, and Ca. Polyhalite may therefore be ideal for crops grown in acidic, sandy soils with low organic matter, which are often low in all three of these elements. Such soils are frequently used for potato agriculture.

The primary purpose of this study is to evaluate Polysulphate, a brand of polyhalite produced by ICL, as a K source for Russet Burbank potatoes grown in a sandy, acidic, low-organic-matter soil in central Minnesota, relative to SOP, muriate of potash (MOP; 0-0-60), and K-Mag (Mosaic Co.; 0-0-22-22S-11Mg). The secondary purpose is to compare the polymer-coated urea fertilizers Agrocote Max Urea 1-2M (ICL; 44-0-0) and Environmentally Smart Nitrogen (ESN; Agrium, Inc.; 44-0-0) as sources of N.

Methods

Study design

The study was conducted in 2018 at the Sand Plain Research Farm in Becker, MN, on a Hubbard loamy sand soil. The previous crop was rye. Fifteen treatments were applied in a randomized complete block design with four blocks. The treatments were defined by the K and N sources used and the rate and timing of K and N application. These treatments are described in Table 1.

Soil sampling

To measure initial soil characteristics, soil samples to a depth of six inches were collected on April 23 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

On May 7, pre-planting K was broadcast by hand according to treatment. On May 9, 40 $lbs \cdot ac^{-1}$ N, 102 $lbs \cdot ac^{-1}$ P_2O_5, 2 $lbs \cdot ac^{-1}$ Zn, and 0.5 $lbs \cdot ac^{-1}$ B were banded in throughout the field as a blend of 222 $lbs \cdot ac^{-1}$ DAP (18-46-0), 2.5 $lbs \cdot ac^{-1}$ ZnO (80% Zn), and 4 $lbs \cdot ac^{-1}$ Boron 15 (15% B). Sixty plots were then planted with whole "B" Russet Burbank seed potatoes. Potatoes were spaced 12" apart within rows with 36" between rows. Each plot consisted of four, 20-foot rows with the middle two rows used for sampling and harvest.

Emergence, stand, and post-hilling UAN applications

The plots were hilled on May 22. Prior to hilling, K and N fertilizers were side-dressed by hand along either side of each hill, according to treatment. The plots were re-hilled for weed control on June 5. Stand was again assessed on June 13 and 20, and the number of stems per plant was calculated for ten harvest-row plants per plot on June 20 and 27. UAN was applied according to treatment on July 5 and 19.

Petiole sampling and leaflet chlorophyll content

The petiole of the fourth leaf from the shoot tip was collected from 20 shoots per plot at five times throughout the growing season: June 19, July 3, 16, and 26, and August 7 (28, 42, 55, 65, and 77 days after the emergence fertilizer application, respectively). Petiole samples will be analyzed for NO_3-N concentration using a Wescan Nitrogen Analyzer, for N and S concentrations using an Elementar CNS analyzer, and for nutrient elemental concentrations using inductively coupled plasma spectrometer, to be performed by the University of Minnesota Research Analytical Laboratory. On the same days petioles were collected, leaflet chlorophyll content was determined for the terminal leaflet of the fourth leaf from the shoot tip for 20 shoots per plot using a SPAD-502 Chlorophyll Meter (Konica Minolta, Inc.).

Harvest

Vines were sprayed with the desiccant Reglone and the surfactant LI-700 on September 13 and chopped on September 24. Tubers were harvested on September 27 (141 days after planting) and sorted by weight and USDA grade on October 23 and 24 (26 and 27 days after harvest). 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 and dry matter content were determined. These samples will be analyzed for N and S concentrations using an Elementar CNS analyzer and for nutrient elemental concentrations using inductively coupled plasmolysis, to be performed by the University of Minnesota Research Analytical Laboratory. Additional samples were sent to the USDA/ARS Potato Research Worksite in East Grand Forks, MN for sugar analysis and fry quality.

Data analysis

Data were analyzed with SAS 9.4m3® software (copyright 2015, SAS Institute, Inc.) using the MIXED procedure. Data for stand and stem counts, tuber yield and quality, and tuber sugar concentrations and fry quality were analyzed as functions of treatment and block. CONTRAST statements were used to compare similar treatments receiving N as ESN versus Agrocote Max (treatments 1, 3, and 8 versus 2, 4, and 7), to compare the check treatments (treatments 1 and 2) with the treatments receiving 200 $lbs \cdot ac^{-1}$ K_2O (treatments 3, 4, 9, 11, and 14), and to compare this last group of treatments with those receiving 400 $lbs \cdot ac^{-1}$ K_2O (treatments 5 – 8, 10, 12, 13, and 15). Data for SPAD-502 readings were analyzed as a function of treatment, sampling date, their interaction, and block, in a repeated-measures analysis with sampling date as the repeated-measures variable, plot as the subject, and a spatial power covariance matrix structure. Contrasts were not performed in the repeated-measures analysis. Instead, a second analysis was performed on SPAD-502 readings, split by date, in order to evaluate the treatment effect and contrasts for each date separately. Mean values for each treatment (on each date, for SPAD-502 readings) 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

Tuber yield and size

Results for tuber yield and size are presented in Table 3. The amount of K applied to a treatment had a strong effect on both tuber yield and size. As a group, treatments receiving 400 lbs·ac^{-1} K_2O had higher yields and more of their yield in tubers over six or ten ounces than treatments receiving 200 lbs·ac^{-1} K_2O, which had higher yields and more of their yields in tubers over six or ten ounces than treatments that received no K fertilizer. The treatments receiving 200 lbs·ac^{-1} K_2O received the full amount at planting, while most treatments receiving 400 lbs·ac^{-1} K_2O received half at planting and half at emergence, raising the question of whether the apparent effect of the application rate of K_2O was actually an effect of timing. However, the treatment that received 400 lbs·ac^{-1} K_2O as MOP at planting with no K at emergence (treatment 13) had the highest total and marketable yields and the greatest percentage of yield in tubers over six or ten ounces in the study. This suggests that application rate, and not the presence or absence of an emergence K application, was the factor influencing tuber yield and size.

The yield of 3- to 6-ounce tubers was positively related to the application rate of S, largely because of relatively high yield in this size class among treatments receiving Polysulphate and low yield in the treatment receiving 400 lbs·ac^{-1} K_2O before planting with no K at emergence (treatment 13). There were no other effects of S rate on tuber yield or size.

When K was applied at 200 lbs·ac^{-1} K_2O, the treatment receiving MOP before planting (treatment 11) had significantly less of its yield in tubers over 6 ounces than the treatment receiving K-Mag (treatment 14) and less of its yield in tubers over 10 ounces than the treatments receiving K-Mag or SOP (treatment 9). However, these differences in tuber size were not evident among the treatments receiving each K source at 200 lbs·ac^{-1} K_2O before planting with 200 lbs·ac^{-1} K_2O as MOP at emergence (treatments 5, 10, 12, and 15).

Treatments receiving Agrocote Max (treatments 2, 4, and 7) had similar tuber yields and size distributions to similar treatments receiving ESN (treatments 1, 3, and 8). Applying Agrocote Max at 200 versus 240 lbs·ac^{-1} N (treatment 7 versus 6), or applying 240 lbs·ac^{-1} N as Agrocote Max with UAN or Agrocote Max alone (treatments 4 and 6) had no significant effect on tuber yield or size, suggesting that 200 lbs·ac^{-1} N was an adequate N rate for this site.

Tuber quality

Results for tuber quality are presented in Table 4. Brown center co-occurred consistently with hollow heart, and scab was not detected in the study. Results for these variables are not presented. The prevalence of hollow heart was significantly related to treatment. Hollow heart prevalence generally decreased with the application rate of K, except that the treatment receiving 400 lbs·ac^{-1} K_2O as MOP divided between preplant and emergence applications (treatment 12) had a higher prevalence of hollow heart than any other treatment receiving K.

Tuber specific gravity was also significantly related to treatment. The zero-K check treatment receiving Agrocote Max (treatment 2) had much lower tuber specific gravity than any other treatment receiving 0 or 200 lbs·ac^{-1} K_2O (treatments 1, 3, 4, 9, 11, and 14). As a result, the contrast comparing ESN and Agrocote Max and the contrast comparing the check treatments to the treatments receiving 200 lbs·ac^{-1} K_2O were both marginally significant. The treatments receiving 400 lbs·ac^{-1} K_2O (treatments 5-8, 10, 12 – 13, and 15), taken as a group, had significantly lower specific gravity and tuber dry matter content than the treatments receiving 200 lbs·ac^{-1} K_2O, indicating that K availability plays an important role in these characteristics.

Plant stand and stems per plant

Results for plant stand and the number of stems per plant are presented in Table 5. K and N treatments had no significant effects on stand or stem counts.

Terminal leaflet chlorophyll content (SPAD-502 readings)

Results for terminal leaflet chlorophyll content (SPAD-502 readings) are presented in Table 6. Across all treatments, SPAD readings increased between June 19 and July 16 and decreased between July 26 and August 7. Treatment effects on SPAD readings generally became more pronounced after June 19, resulting in a significant date*treatment interaction effect. When each date was analyzed separately, treatment was found to have no significant effect on SPAD readings on June 19. On the next sampling date, July 3, treatments receiving Agrocote Max (treatments 2, 4, and 7), as a group, had lower SPAD readings than similar treatments receiving ESN (treatments 1, 3, and 8). Because this difference was not significant on any subsequent sampling date, this result may suggest that Agrocote Max was slower to release its urea content than ESN. The two contrasts on the application rate of K were both highly significant on all sampling dates after June 19, with SPAD reading decreasing as the application rate of K increased. Since yield was limited by K availability in this site, overall plant growth was presumably also K-limited, with the result that plants with more K grew larger and effectively diluted their chlorophyll content more than plants receiving less K. K source and S rate did not appear to affect leaflet chlorophyll content.

Tuber sugars and French fry reflectance

Results for tuber sugars and French fry reflectance values (measured with a Photovolt reflectometer) are presented in Table 7. Treatment had no effect on sucrose concentration, except that treatments receiving Agrocote Max (treatments 2, 4, and 7) had somewhat higher sucrose concentrations in the bud end of the tuber than similar treatments receiving ESN (treatments 1, 3, and 8).

Tuber glucose concentrations were significantly related to treatment, with both contrasts on K rate being highly significant for both stem-end and bud-end glucose concentration. Tuber glucose concentrations decreased as the application rate of K increased. The contrast on S rate was also significant for stem-end glucose, driven by low glucose concentrations in the treatment receiving K-Mag before planting with MOP at emergence (treatment 15, which received S at 200 $lbs \cdot ac^{-1}$ S) compared to the treatments receiving MOP alone (treatments 11-13, which received no S).

The two contrasts of stem-end French fry reflectance on K rate were both highly significant, with higher K treatments producing lighter colored French fries. For French fries made from the bud end of the tuber, this difference was only significant in the comparison between the check treatments (treatments 1 and 2) and the treatments receiving 200 $lbs \cdot ac^{-1}$ K (treatments 3, 4, 9, 11, and 14), not in the comparison between the two non-zero K rates. On average, treatments receiving Agrocote Max as an N source (treatments 2, 4, and 7) had higher stem-end French fry reflectance values than similar treatments receiving ESN (treatments 1, 3, and 8). In pairwise comparisons, this difference was significant when K was applied, but the effect was reversed and the difference not significant in the check treatments, indicating that the choice of N sources had a meaningful impact on stem-end Fry color so long as the plants were provided with K.

Conclusions

In this study, potassium application was clearly essential for optimum tuber yield, size, glucose concentration, French fry color, and the prevalence of hollow heart. Furthermore, treatments receiving 400 $lbs\cdot ac^{-1}$ K_2O performed better than those receiving 200 $lbs\cdot ac^{-1}$ K_2O in most respects, indicating that, even when supplied with 200 $lbs\cdot ac^{-1}$ K_2O, the performance of Russet Burbank potato plants was K-limited in this system. Potassium decreased tuber specific gravity and dry matter content, which is a common side effect of treatments that increase tuber yield and size.

The treatment with the highest yield and largest tubers in this study was the treatment receiving 400 $lbs\cdot ac^{-1}$ K_2O as MOP before planting, with none at emergence. This suggests that, while 200 $lbs\cdot ac^{-1}$ K_2O is not sufficient to meet potato plant needs, it is not necessary to divide K application into preplant and emergence applications. The full quantity may be supplied before planting at no cost to marketable yield. The effects of K source were much less evident than the effects of K rate. Aside from some tuber size differences between treatments receiving MOP at planting versus SOP or K-Mag, K source had no statistically significant effects on tuber yield or size. No other effects of K source were evident in this study. The weak response to K source may be due in part to the fact that all K sources that provided S provided at least as much as recommended for potatoes in S-deficient soils (20 – 30 $lbs\cdot ac^{-1}$). Treatments receiving K as SOP received 71 $lbs\cdot ac^{-1}$ S, while those receiving K-Mag and Polysulphate received 200 and 271 $lbs\cdot ac^{-1}$ S, respectively. This may also explain why the only significant effects of K source in pairwise comparisons were in comparisons between treatments receiving MOP versus an S-providing source.

The two N sources we evaluated, ESN and Agrocote Max, performed similarly. Terminal leaflet SPAD increased earlier in the season when ESN was the N source than when Agrocote Max was. Treatments receiving Agrocote Max had higher bud-end sucrose concentrations and stem-end French fry reflectance values than similar treatments receiving ESN, though each of these results was only marginally significant ($0.05 < P < 0.10$). The effect on French fry reflectance may be more meaningful than the statistical significance suggests, since it was significant when K was applied (comparing treatments 3 and 4 and treatments 7 and 8), and K is consistently applied in production systems. Notably, there was no parallel trend in bud-end fry color, which was almost identical between the two N sources.

Overall, we found that polyhalite (Polysulphate) was an adequate source of preplant K for Russet Burbank potatoes in this system, producing yields and size distributions similar to other K sources. We did not find a significant benefit to the high S content of polyhalite, possibly because all K sources that provided any S, provided sufficient S. The two N sources performed very similarly, though Agrocote Max may provide an advantage in terms of stem-end (but not bud-end) fry color.

Table 1. Treatments applied to Russet Burbank potato plants at the Sand Plain Research Farm in Becker, MN, in 2018 in order to evaluate the effectiveness of Polysulphate (polyhalite) as a K and S source for potatoes.

Treatment #	Preplant K[1]	Emergence K[1]	Total K	Planting N[2]	Emergence N[2]	Post-hilling N[2]	Total N
1	0	0	0	40 DAP	160 ESN	2 * 20 UAN	240
2	0	0	0	40 DAP	160 Agrocote Max	2 * 20 UAN	240
3	200 Polysulphate	0	200	40 DAP	160 ESN	2 * 20 UAN	240
4	200 Polysulphate	0	200	40 DAP	160 Agrocote Max	2 * 20 UAN	240
5	200 Polysulphate	200 MOP	400	40 DAP	160 ESN	2 * 20 UAN	240
6	200 Polysulphate	200 MOP	400	40 DAP	200 Agrocote Max	0	240
7	200 Polysulphate	200 MOP	400	40 DAP	160 Agrocote Max	0	200
8	200 Polysulphate	200 MOP	400	40 DAP	160 ESN	0	200
9	200 SOP	0	200	40 DAP	160 ESN	2 * 20 UAN	240
10	200 SOP	200 MOP	400	40 DAP	160 ESN	2 * 20 UAN	240
11	200 MOP	0	200	40 DAP	160 ESN	2 * 20 UAN	240
12	200 MOP	200 MOP	400	40 DAP	160 ESN	2 * 20 UAN	240
13	400 MOP	0	400	40 DAP	160 ESN	2 * 20 UAN	240
14	200 K-Mag	0	200	40 DAP	160 ESN	2 * 20 UAN	240
15	200 K-Mag	200 MOP	400	40 DAP	160 ESN	2 * 20 UAN	240

[1]Polysulphate (ICL; 0-0-14-19S-3Mg-12Ca); SOP (0-0-48-17S); MOP (0-0-60); K-Mag (0-0-22-22S-10.8Mg)

[2]DAP (diammonium phosphate 18-46-0); ESN (Environmentally Smart Nitrogen; Agrium, Inc.; 44-0-0), Agrocote Max (ICL; 44-0-0), UAN (urea and ammonium nitrate; 28-0-0)

Table 2. Initial soil characteristics in the study site at the Sand Plain Research Farm in Becker, MN, in 2018.

0 - 2 feet	0 - 6 inches											
NO_3-N	Bray P	K	SO_4-S	Ca	Mg	Fe	Mn	Zn	Cu	B	Organic matter	pH
ppm												
2.6	28	81	6	507	62	60	46	2.5	1.26	0.16	1.7	5.3

Table 3. Yield, size distribution, and grade of Russet Burbank potato tubers produced at the Sand Plain Research Farm in Becker, MN, in an evaluation of Polysulphate (polyhalite) as a K and S source for potatoes.

Treatment #	K rate and source[1]	N rate and source[1]	Tuber yield										
			0-3 oz	3-6 oz	6-10 oz	10-14 oz	> 14 oz	Total yield	#1s > 3 oz.	#2s > 3 oz	Marketable yield	> 6 oz	> 10 oz
			cwt·ac^{-1}									%	
1	0	240, ESN + UAN	108 a	188 a	121 f	37 g	11 d	465 e	288 de	69 cd	357 f	36 g	10 f
2	0	240, AM + UAN	99 ab	179 abc	132 ef	39 g	15 cd	465 e	262 e	104 a	366 f	40 fg	12 def
3	200, Poly	240, ESN + UAN	96 abc	173 abcd	156 cde	53 efg	33 bc	512 bcd	315 cd	101 ab	416 cde	47 def	17 bcde
4	200, Poly	240, AM + UAN	85 bcd	180 abc	176 bcd	60 cdefg	24 bcd	525 abc	354 bc	86 abc	440 bcd	49 bcde	16 cdef
5	400, Poly + MOP	240, ESN + UAN	77 cdef	175 abc	202 a	67 bcde	24 bcd	546 a	417 a	51 d	468 ab	54 bcd	17 cde
6	400, Poly + MOP	240, AM	90 abc	188 a	160 cd	70 bcde	25 bcd	534 ab	378 ab	66 cd	443 bcd	48 def	18 bcd
7	400, Poly + MOP	200, AM	81 bcde	186 ab	163 bcd	82 abc	29 bcd	541 ab	382 ab	78 abcd	459 abc	51 bcde	21 bc
8	400, Poly + MOP	200, ESN	64 ef	165 abcde	179 abc	83 ab	42 b	533 ab	404 a	65 cd	469 ab	57 ab	23 ab
9	200, SOP	240, ESN + UAN	84 bcd	167 abcd	151 de	65 bcdef	27 bcd	494 cde	336 bc	74 bcd	410 de	48 cdef	18 bcd
10	400, SOP + MOP	240, ESN + UAN	70 def	159 cde	181 abc	78 abcd	34 bc	521 abcd	402 a	50 d	451 abcd	56 abc	21 bc
11	200, MOP	240, ESN + UAN	105 a	174 abc	158 cd	44 fg	10 d	492 de	319 cd	68 cd	387 ef	43 efg	11 ef
12	400, MOP + MOP	240, ESN + UAN	70 def	168 abcd	189 ab	69 bcde	44 b	540 ab	409 a	61 cd	470 ab	55 abcd	20 bc
13	400, MOP	240, ESN + UAN	59 f	140 e	190 ab	96 a	67 a	552 a	414 a	79 abcd	493 a	64 a	30 a
14	200, K-Mag	240, ESN + UAN	83 bcd	149 de	186 ab	56 defg	34 bc	509 bcd	357 bc	69 cd	426 bcde	54 bcd	18 bcd
15	400, K-Mag + MOP	240, ESN + UAN	82 bcde	162 bcde	165 bcd	82 abc	44 b	536 ab	379 ab	75 bcd	454 abc	54 bcd	23 ab
	Significance of treatment (P-value)		**0.0026**	*0.0998*	**0.0002**	**0.0036**	**0.0113**	**0.0003**	**<0.0001**	0.1071	**<0.0001**	**0.0002**	**0.0018**
Contrasts	**ESN vs. Agrocote**		0.8945	0.4687	0.5852	0.7687	0.4357	0.5505	0.8239	0.2682	0.6163	0.9844	0.7914
	Check vs. low K		*0.0606*	*0.0975*	**0.0001**	**0.0379**	*0.0943*	**0.0008**	**0.0003**	0.5125	**0.0010**	**0.0008**	**0.0354**
	Low vs. high K		**0.0009**	0.8539	**0.0415**	**0.0002**	**0.0141**	**0.0003**	**<0.0001**	**0.0494**	**<0.0001**	**0.0026**	**0.0008**
	Linear on S rate		0.5956	**0.0252**	0.2321	0.7913	0.2743	0.5809	0.4889	0.1826	0.8591	0.1983	0.6406

[1]Polysulphate (ICL; 0-0-14-19S-3Mg-12Ca); SOP (0-0-48-17S); MOP (0-0-60); K-Mag (0-0-22-22S-11Mg)

[2]ESN (Environmentally Smart Nitrogen; Agrium, Inc.; 44-0-0), Agrocote Max (ICL; 44-0-0), UAN (urea and ammonium nitrate; 28-0-0)

Table 4. Quality characteristics of Russet Burbank potato tubers produced at the Sand Plain Research Farm in Becker, MN, in 2018, in an evaluation of Polysulphate (polyhalite) as a K and S source for potatoes. Brown center co-occurred consistently with hollow heart, and scab was not detected in this study. Results for these characteristics are not presented.

Treatment #	K rate and source[1]	N rate and source[1]	Hollow heart (% of tubers)	Specific gravity	Dry matter content (% dry weight)
1	0	240, ESN + UAN	28 a	1.0817 a	22.8
2	0	240, AM + UAN	26 ab	1.0783 cd	22.2
3	200, Poly	240, ESN + UAN	22 abc	1.0820 a	23.3
4	200, Poly	240, AM + UAN	12 cdef	1.0799 abc	22.3
5	400, Poly + MOP	240, ESN + UAN	7 def	1.0800 abc	22.1
6	400, Poly + MOP	240, AM	6 ef	1.0803 abc	22.4
7	400, Poly + MOP	200, AM	11 def	1.0797 abc	23.0
8	400, Poly + MOP	200, ESN	11 def	1.0791 bcd	21.6
9	200, SOP	240, ESN + UAN	23 ab	1.0818 a	22.3
10	400, SOP + MOP	240, ESN + UAN	11 def	1.0812 ab	22.4
11	200, MOP	240, ESN + UAN	16 bcde	1.0817 a	22.2
12	400, MOP + MOP	240, ESN + UAN	25 ab	1.0767 d	21.4
13	400, MOP	240, ESN + UAN	15 bcdef	1.0785 bcd	21.7
14	200, K-Mag	240, ESN + UAN	18 abcd	1.0821 a	22.7
15	400, K-Mag + MOP	240, ESN + UAN	4 f	1.0788 bcd	22.2
Significance of treatment (P-value)			**0.0045**	**0.0205**	0.1630
Contrasts	**ESN vs. Agrocote**		0.3123	*0.0831*	0.8483
	Check vs. low K		**0.0228**	*0.0936*	0.9004
	Low vs. high K		**0.0123**	**0.0009**	**0.0469**
	Linear on S rate		0.5817	0.3333	0.2001

[1]Polysulphate (ICL; 0-0-14-19S-3Mg-12Ca); SOP (0-0-48-17S); MOP (0-0-60); K-Mag (0-0-22-22S-11Mg)

[2]ESN (Environmentally Smart Nitrogen; Agrium, Inc.; 44-0-0), Agrocote Max (ICL; 44-0-0), UAN (urea and ammonium nitrate; 28-0-0)

Table 5. Plant stand and number of stems per plant for Russet Burbank potato plants grown at the Sand Plain Research Farm in Becker, MN, in 2018, in an evaluation of Polysulphate (polyhalite) as a K and S source for potatoes.

Treatment #	K rate and source[1]	N rate and source[2]	Plant stand (%)		Stems / plant	
			June 13	June 20	June 20	June 27
1	0	240, ESN + UAN	100.0	100.0	4.2	4.1
2	0	240, AM + UAN	96.5	97.9	3.2	3.2
3	200, Poly	240, ESN + UAN	97.2	100.0	3.7	3.7
4	200, Poly	240, AM + UAN	100.0	100.0	4.0	3.7
5	400, Poly + MOP	240, ESN + UAN	100.0	100.0	4.4	3.7
6	400, Poly + MOP	240, AM	100.0	100.0	3.8	3.8
7	400, Poly + MOP	200, AM	98.8	99.0	3.6	4.0
8	400, Poly + MOP	200, ESN	100.0	100.0	3.8	3.3
9	200, SOP	240, ESN + UAN	99.3	99.3	4.2	3.6
10	400, SOP + MOP	240, ESN + UAN	97.9	99.3	3.4	3.9
11	200, MOP	240, ESN + UAN	100.0	100.0	3.7	3.6
12	400, MOP + MOP	240, ESN + UAN	100.0	98.6	3.3	2.8
13	400, MOP	240, ESN + UAN	98.8	99.9	3.2	2.9
14	200, K-Mag	240, ESN + UAN	100.0	100.0	3.6	3.7
15	400, K-Mag + MOP	240, ESN + UAN	99.3	99.3	3.9	3.7
Significance of treatment (P-value)			0.3279	0.7826	0.7019	0.2301
Contrasts	**ESN vs. Agrocote**		0.4824	0.1225	0.3908	0.8687
	Check vs. low K		0.2408	0.1711	0.7112	0.9535
	Low vs. high K		0.9303	0.4514	0.5365	0.3771
	Linear on S rate		0.6355	0.4701	0.2068	0.3624

[1]Polysulphate (ICL; 0-0-14-19S-3Mg-12Ca); SOP (0-0-48-17S); MOP (0-0-60); K-Mag (0-0-22-22S-11Mg)

[2]ESN (Environmentally Smart Nitrogen; Agrium, Inc.; 44-0-0), Agrocote Max (ICL; 44-0-0), UAN (urea and ammonium nitrate; 28-0-0)

Table 6. Terminal leaflet chlorophyll content (SPAD-502 readings) of Russet Burbank potato plants grown at the Sand Plain Research Farm in Becker, MN, in 2018, in an evaluation of Polysulphate (polyhalite) as a K and S source for potatoes.

Treatment #	K rate and source[1]	N rate and source[2]	Terminal leaflet chlorophyll content (SPAD-502 readings)					
			June 19	July 3	July 16	July 26	August 7	Average across dates
1	0	240, ESN + UAN	41.0 ab, D	45.1 a, C	47.7 a, A	47.4 a, AB	46.2 a, BC	45.5 a
2	0	240, AM + UAN	41.8 a, C	44.1 ab, B	46.4 ab, A	46.4 a, A	44.6 a, B	44.6 ab
3	200, Poly	240, ESN + UAN	40.2 abc, C	42.0 cd, B	44.7 cde, A	43.8 c, A	42.4 b, B	42.6 c
4	200, Poly	240, AM + UAN	41.2 ab, BC	40.8 defg, C	43.7 cdef, A	43.4 cd, A	42.6 b, AB	42.3 c
5	400, Poly + MOP	240, ESN + UAN	39.3 c, C	40.9 defg, B	42.3 f, A	41.2 e, AB	39.9 cd, BC	40.7 d
6	400, Poly + MOP	240, AM	40.6 abc, BC	39.8 fg, C	42.8 f, A	42.0 de, AB	41.4 bc, AB	41.3 d
7	400, Poly + MOP	200, AM	40.0 bc, B	39.7 fg, B	43.2 def, A	42.0 de, AB	39.1 d, B	40.8 d
8	400, Poly + MOP	200, ESN	40.2 bc, B	40.0 efg, B	42.7 f, A	41.7 e, A	39.3 d, B	40.8 d
9	200, SOP	240, ESN + UAN	41.3 ab, C	43.1 bc, B	46.5 ab, A	45.8 ab, A	42.8 b, BC	43.9 b
10	400, SOP + MOP	240, ESN + UAN	39.2 c, D	40.8 defg, BC	42.7 f, A	41.4 e, B	40.1 cd, CD	40.8 d
11	200, MOP	240, ESN + UAN	39.9 bc, D	41.6 cde, C	44.9 bcd, A	43.8 c, AB	42.8 b, BC	42.6 c
12	400, MOP + MOP	240, ESN + UAN	40.0 bc, BC	39.4 g, C	42.3 f, A	41.5 e, AB	40.5 cd, BC	40.7 d
13	400, MOP	240, ESN + UAN	40.3 abc, BC	39.5 fg, C	43.0 ef, A	41.3 e, B	39.8 cd, BC	40.8 d
14	200, K-Mag	240, ESN + UAN	40.3 abc, C	41.2 def, BC	44.9 bc, A	44.7 bc, A	42.6 b, B	42.7 c
15	400, K-Mag + MOP	240, ESN + UAN	40.4 abc, B	40.7 defg, B	42.9 f, A	42.0 de, A	40.7 cd, B	41.3 d
Average across treatments			40.4 D	41.2 C	44.0 A	43.2 B	41.6 C	
Significance of treatment (P-value)								**<0.0001**
Significance of date (P-value)			**<0.0001**					
Significance of treatment*date (P-value)			**0.0438**					
Results of analysis split by date	**Significance of treatment (P-value**		0.3638	**<0.0001**	**<0.0001**	**<0.0001**	**<0.0001**	
	Contrasts	**ESN vs. Agrocote**	0.3877	**0.0219**	0.2558	0.5363	0.3965	
		Check vs. low K	0.1538	**<0.0001**	**0.0006**	**0.0005**	**0.0002**	
		Low vs. high K	0.1136	**<0.0001**	**<0.0001**	**<0.0001**	**<0.0001**	
		Linear on S rate	0.3713	0.3079	0.5629	0.7734	0.7346	

[1]Polysulphate (ICL; 0-0-14-19S-3Mg-12Ca); SOP (0-0-48-17S); MOP (0-0-60); K-Mag (0-0-22-22S-11Mg)

[2]ESN (Environmentally Smart Nitrogen; Agrium, Inc.; 44-0-0), Agrocote Max (ICL; 44-0-0), UAN (urea and ammonium nitrate; 28-0-0)

Table 7. Tuber sucrose and glucose contents and French fry reflectance values (Photovolt reflectometer) of Russet Burbank potato tubers produced at the Sand Plain Research Farm in Becker, MN, in 2018, in an evaluation of Polysulphate (polyhalite) as a K and S source for potatoes.

Treatment #	K rate and source[1]	N rate and source[2]	Sucrose (mg/g)		Glucose (mg/g)		Reflectance	
			Stem end	Bud end	Stem end	Bud end	Stem end	Bud end
1	0	240, ESN + UAN	0.302	0.975	3.296 ab	0.459 b	25.0 fg	41.9
2	0	240, AM + UAN	0.230	1.078	3.661 a	0.619 a	23.5 g	43.0
3	200, Poly	240, ESN + UAN	0.296	1.022	2.949 bc	0.198 c	25.2 fg	44.4
4	200, Poly	240, AM + UAN	0.257	1.047	2.469 cd	0.137 cd	29.0 de	44.5
5	400, Poly + MOP	240, ESN + UAN	0.345	1.026	1.747 e	0.125 cd	32.2 abc	43.6
6	400, Poly + MOP	240, AM	0.359	0.958	2.037 de	0.047 d	30.7 abcd	44.8
7	400, Poly + MOP	200, AM	0.296	1.016	2.112 de	0.071 cd	32.6 ab	45.9
8	400, Poly + MOP	200, ESN	0.325	0.892	1.768 e	0.128 cd	28.8 de	45.7
9	200, SOP	240, ESN + UAN	0.313	1.079	3.180 ab	0.171 cd	26.6 ef	44.8
10	400, SOP + MOP	240, ESN + UAN	0.275	1.005	1.736 e	0.077 cd	33.5 a	45.6
11	200, MOP	240, ESN + UAN	0.248	0.939	2.491 cd	0.167 cd	29.3 cde	45.1
12	400, MOP + MOP	240, ESN + UAN	0.308	1.006	1.986 de	0.109 cd	30.5 abcd	43.9
13	400, MOP	240, ESN + UAN	0.293	0.957	2.297 cde	0.081 cd	29.7 bcde	43.8
14	200, K-Mag	240, ESN + UAN	0.288	0.996	2.281 de	0.168 cd	27.3 ef	44.0
15	400, K-Mag + MOP	240, ESN + UAN	0.291	0.967	1.636 e	0.056 d	30.6 abcd	45.1
Significance of treatment (P-value)			0.5580	0.4841	**<0.0001**	**<0.0001**	**<0.0001**	0.1361
Contrasts	**ESN vs. Agrocote**		0.1287	*0.0581*	0.7397	0.7754	*0.0648*	0.5195
	Check vs. low K		0.6302	0.8227	**0.0011**	**<0.0001**	**0.0044**	**0.0045**
	Low vs. high K		0.1457	0.2034	**<0.0001**	**0.0200**	**<0.0001**	0.6447
	Linear on S rate		0.2596	0.3300	**0.0295**	0.8064	0.4366	0.9501

[1]Polysulphate (ICL; 0-0-14-19S-3Mg-12Ca); SOP (0-0-48-17S); MOP (0-0-60); K-Mag (0-0-22-22S-11Mg)

[2]ESN (Environmentally Smart Nitrogen; Agrium, Inc.; 44-0-0), Agrocote Max (ICL; 44-0-0), UAN (urea and ammonium nitrate; 28-0-0)

Evaluation of a Slow Release Boron Source for Russet Burbank Potatoes

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Summary

Potassium (K) and Boron (B) are both known to play important roles in improving potato tuber yield, size, quality, and storability, and both nutrients are often deficient in the soils in which potatoes are grown. Both nutrients have limited periods of availability to plants after they are applied, with B being more prone to leaching from the soil than K. In addition, B is required in only small amounts, and the window between deficiency and excess is narrow, making it difficult to maintain soil B at desirable levels across an entire field and throughout the period of plant need. EXPCMT (Mosaic Co.; 0-0-58-0.5B) is a slow-release B fertilizer in which B is co-granulated with K. This is intended to reduce the challenges of applying B evenly and maintaining adequate soil B well after application. The slow-release characteristic of this fertilizer may also make fall K application, which growers find more convenient than spring application, more efficacious. To evaluate this product, we applied four fertilizer treatments (a zero-B check, a K-only treatment using MOP – 0-0-60, a K plus B treatment using MOP and granular B, and a K plus B treatment using EXPCMT) at two times (the fall or spring before planting), plus a spring-emergence split application of MOP and granular B, to Russet Burbank potatoes. We used a randomized complete block design with four blocks. Stand on May 31 was higher in almost all plots receiving K than the check plots, the exception being plots receiving MOP plus B in the fall. Treatments receiving K in the spring, including the split-application treatment, had higher stand than those receiving K in the fall. The number of stems per plant on June 20 was slightly higher in treatments receiving K in the fall than in the spring, but the two check plots had very different stem counts, casting doubt on the importance of the apparent effect of application timing on stem count. Applying K increased tuber marketable yield and size, and both yield and size were higher in treatments receiving K in spring than those receiving it in fall. The increase in yield with spring application came mostly in the form of U.S. No.2 tubers. The split-application treatment had the highest marketable yield and percentage of yield in tubers over six or ten ounces, of the nine treatments. Applying K decreased tuber dry matter and, to a smaller degree, tuber specific gravity, relative to the check treatments. Applying B had no clear effect on any variable tested. Overall, the benefits of K fertilization were clear, and spring application produced higher yields and larger tubers than fall application, with the spring-emergence split application showing the greatest effect. The lack of B response was unexpected, given the deficient soil B concentration of the study site. However, previous, related studies in the same location have shown that the benefits of B application in terms of tuber yield and size are inconsistently achieved.

Background

Both potassium (K) and boron (B) are known to play a vital role in improving 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 optimize tuber yield and quality, but very little B is required to obtain these benefits. Furthermore, the difference between deficient and excess soil B concentrations is relatively narrow, making uniform B fertilization at the optimum rate for crop production both important and difficult.

Another challenge with both nutrients, but especially B, which is highly soluble in water and prone to leaching from the soil, is matching the timing of nutrient availability with the timing of maximum 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 before plants are present to take it up.

EXPCMT (Mosaic Co.; 0-0-58-0.5B) is a fertilizer product in which B is co-granulated with K 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, while the slow-release characteristics are expected to simplify the challenge of matching the timing of nutrient availability with the timing of nutrient need.

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-emergence application of MOP and granular B was included for comparison with the slow-release formula applied in spring.

Materials and methods

The study was conducted at the Sand Plain Research Farm in Becker, MN, in 2018, on a Hubbard loamy sand soil. The previous crop was rye.

Soil samples were taken to a depth of two feet (for NO_3^--N) or six inches (for other characteristics) on November 14, 2017, just before fall fertilizer treatments were applied. The two-foot samples were analyzed for NO_3^--N concentration using a Wescan Nitrogen Analyzer. The six-inch samples were 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; LOI soil organic matter content; and cation exchange capacity (direct method). The results of these analyses are presented in Table 1.

Nine treatments were applied in a randomized complete block design with four blocks. Eight of the treatments were divided into two groups of four based on application timing, with one group receiving fertilizer treatments in the fall and the other receiving them in the spring. The four treatments applied at each of these times were (1) a check receiving no K_2O or B, (2) 300 $lbs \cdot ac^{-1}$ K_2O as muriate of potash (MOP; 0-0-60), (3) a treatment receiving the same rate of K_2O as MOP plus 2.6 $lbs \cdot ac^{-1}$ B as granulated B (15% B); and (4) a treatment receiving the same rates of K_2O and B as EXPCMT (Mosaic Co.; 0-0-58-0.5B). The ninth treatment received 300 $lbs \cdot ac^{-1}$ K_2O as MOP and 2.6 $lbs \cdot ac^{-1}$ B as granulated B, split evenly between the spring application date and emergence. The fall application treatments were broadcast by hand on November 14, 2017. The spring application treatments were broadcast by hand on April 23, 2018. The emergence application of the split-application treatment was hand-applied as a side dress on May 21. The treatments are summarized in Table 2.

The field was cultivated and rolled on May 1, 2018. On May 2, the field was planted, and 50 $lbs \cdot ac^{-1}$ 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 (18-46-0) and 2.8 $lbs \cdot ac^{-1}$ Blu-Min (17.5 % S, 35.5% Zn). Whole "B" Russet Burbank seed potatoes were planted with 12-inch spacing in rows three feet apart. Each study plot was four rows wide and 20 feet long, with the central two rows designated as harvest rows. These rows were marked at each end with a red Chieftain seed potato, so that the harvested area of Russet Burbank in each plot was six feet wide and 18 feet long, or 84 square feet. A buffer strip three feet wide along the edges of the field and five feet wide along its ends was planted with Russet Burbank seed with 12-inch spacing.

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.

At emergence, on May 21, 170 lbs·ac^{-1} N and 30 lbs·ac^{-1} S were banded to all treatments as 327 lbs·ac^{-1} ESN (Environmentally Smart Nitrogen, Agrium, Inc.; 44-0-0) and 125 lbs·ac^{-1} ammonium sulfate (22-0-0-24S) and hilled in. Twenty lbs·ac^{-1} N were applied in each of two post-hilling applications of 28% UAN (urea and ammonium nitrate), on July 5 and 26. In total, 240 lbs·ac^{-1} N were applied to the study field.

Plant stand in the harvest rows was assessed on May 31 and June 13, and the number of stems per plant was determined for 10 harvest-row plants on June 13 and 20. Petioles were sampled on June 14 and 27, July 11 and 24, and August 8. The petiole of the fourth leaf from the shoot tip was collected from each of 20 shoots per plot. Petiole K and B concentration will be determined on a dry-weight basis by the Research Analytical Laboratory of the University of Minnesota using inductively coupled plasma analysis.

Vines were killed with Reglone and LI 700 on September 13 and chopped on September 24. Tubers were harvested on September 27. Total tuber yield and graded yield were measured on October 8. Sub-samples of tubers were collected to determine tuber specific gravity and dry matter and the prevalence of hollow heart, brown center, and scab.

Data were analyzed with SAS 9.4m3® software (copyright 2015, SAS Institute, Inc.) using the MIXED procedure. For stand and stem count and tuber yield and quality, 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. Linear contrasts of the effects of K fertilization (treatments 1 and 5 contrasted with treatments 2 – 4 and 6 – 8), B fertilization (treatments 2 and 6 contrasted with treatments 3 and 7), and spring versus fall K applications (treatments 2 – 4 contrasted with treatments 6 – 8) were analyzed using CONTRAST statements.

Results and discussion

Plant stand and stems per plant

Results for plant stand and the number of stems per plant are presented in Table 3. Plant stand on May 31 was significantly higher in almost all K-fertilized treatments than it was in the check treatments (treatments 1 and 5). The exception was the treatment receiving MOP and granular B in the fall (treatment 3), which had stand similar to the check treatments on this date, resulting in a significant negative effect of adding granular B to MOP that is probably not biologically meaningful. Stand was significantly higher in the treatments receiving K in the spring, including the treatment receiving split K and B applications (treatments 6 – 9), than the treatments receiving K in the fall (treatments 2 – 4). Emergence was sporadic and slow in 2018 due to cold and then usually hot temperatures. All plots had 100% stand by June 13.

The number of stems per plant on June 13 was unrelated to treatment, but there was a significant treatment effect on June 20. A significant contrast on spring versus fall K application indicated that treatments receiving K in the fall (treatments 2 – 4) had somewhat more stems per plant than those receiving K in the spring (treatments 6 – 8). The treatment receiving split applications (treatment 9) had relatively few stems per plant, similar to the other treatments receiving K in the spring. However, the two check treatments, which were treated identically, had very different numbers of stems per plant on June 20 (3.3 for treatment 1 and 4.6 for treatment 5, the latter being the highest average in the study), casting doubt on whether the apparent effect of application timing on stem count is meaningful.

For the most part, the treatments receiving EXPCMT did not have different stand and stem counts than those receiving MOP with granular B at the same time, aside from the low May 31 stand in the treatment receiving MOP with granular B in the fall (treatment 3).

Tuber yield

Tuber harvest results are presented in Table 4. Total and marketable yields were greatly enhanced by the addition of K, regardless of application timing.

Treatments receiving K in the spring, including the split-application treatment (treatments 6 – 9) had a larger percentage of yield in tubers over six or ten ounces than those receiving K in the fall (treatments 2 – 4). This was true specifically when comparing the treatments receiving MOP without B (treatments 2 and 6) or MOP with granular B (treatments 3 and 7), but the differences in the percentages of yield in tubers over six or ten ounces between the treatments receiving EXPCMT in the fall versus spring (treatment 4 versus 8) were not significant. The split-application treatment (treatment 9) had the highest percentages of yield in tubers over six or ten ounces, indicating a yield benefit of emergence-applied K. The yield gains in treatments receiving spring-applied K came mostly in the form of U.S. No. 2 tubers. All treatments receiving K had significantly more yield in tubers over six or ten ounces than either of the check treatments, with the improved yield coming in the form of U.S. No. 1 tubers.

Consistent with these results, the check treatments had the highest yields of undersized tubers, while the treatments receiving K in the spring, including the split-application treatment (treatments 6 – 9) had significantly smaller yields of undersized tubers than those receiving K in the fall. Consequently, while there was no effect of application timing on total tuber yield, treatments receiving K only in the spring (treatments 6 – 8) had higher marketable yields than those receiving K in the fall (treatments 2 – 4), based on the contrast on application timing. The split-application treatment had the highest total and marketable yields, again indicating a benefit of emergence-applied K.

The two treatments receiving EXPCMT (treatments 4 and 8) both had the same marketable yield, which was the highest yield among treatments receiving K in the fall (treatments 2 – 4) but the lowest among treatments receiving K only in the spring (treatments 6 – 8). That EXPCMT performed relatively well among fall-applied K treatments but relatively poorly among spring-applied K treatments may suggest that the slow-release formulation prevents K from being released and lost in a fall application but also prevents it from being released and becoming plant-available in a spring application. However, the excellent yield performance of the split-application treatment (treatment 9) contradicts this inference.

The contrasts on B application (comparing treatments 2 and 6 with 3 and 7) indicated little effect of B on tuber yield or size, aside from a weak negative effect of B on the yield of 10-14-ounce tubers that may not be meaningful.

Tuber quality

Tuber quality results are presented in Table 5. Scab was not detected in the study and brown center co-occurred consistently with hollow heart. Results for these variables are not presented in the table.

Treatment had no effect on the prevalence of hollow heart or tuber specific gravity, except for a tendency for treatments receiving K in one application (treatments 2 – 4 and 6 – 8) to have lower specific gravity than the check treatments (treatments 1 and 5). The split-application treatment (treatment 9) also had relatively low specific gravity but was not included in the contrast.

There was a treatment effect on tuber dry matter content, with treatments receiving K in a single application (treatments 2 – 4 and 6 – 8) having lower dry matter content than the check treatments (treatments 1 and 5). The split-application treatment (treatment 9) also had low dry matter content. There was a weak tendency for treatments receiving only spring-applied K (treatment 6 – 8) to have lower tuber dry matter content than those receiving only fall-applied K (treatments 2 – 4).

No effects of fertilization with B on tuber quality were detected, and the tuber quality of treatments fertilized with EXPCMT was not significantly different from that of treatments fertilized with MOP and granular B at the same application time.

Conclusions

Fertilizing with K, regardless of timing, increased tuber yield and size while decreasing tuber specific gravity and (more so) dry matter. Spring K application provided greater yield and size benefits than fall application. The treatment receiving split applications produced yield and quality results similar to the treatments receiving K only in the spring, but with numerically high marketable yield and percentage of yield in tubers over ten ounces even compared to this group. These results indicate that K fertilization is more effective the closer the application time is to the time of plant need. They also suggest that a slow-release K fertilizer with release dynamics matched well to both application timing and the time of peak plant need should have advantages over MOP applied in either fall or spring. Based on the performance of EXPCMT in this study, the release dynamics of this product may be better suited to fall application than spring application, though it performed significantly worse than the spring-emergence split application in either case.

Fertilization with B did not produce the tuber yield and size benefits observed in some previous years. The soil in the study field was deficient in B (2 $mg \cdot kg^{-1}$ soil, compared to a recommended range of 20 – 40 $mg \cdot kg^{-1}$ soil for potatoes), so this lack of response to B fertilization was unexpected. Three similar studies on B-deficient soils at the same field station between 2015 and 2017 indicate that B fertilization may result in increased tuber yield (2017) or size (2015 and 2017), but sometimes fail to generate either benefit (2016). The cause of this variation in the efficacy of B fertilization is not yet apparent, but it may be due to uneven plant emergence.

Table 1. Soil characteristics of the study site at the Sand Plain Research Farm in Becker, MN, on November 14, 2017, before fertilizer treatments were applied. 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
($mg \cdot kg^{-1}$ soil)					
2.2	31	65	597	67	6.0

0 - 6 inches							
Micronutrients					Other characteristics		
Fe	Mn	Zn	Cu	B	pH	Organic matter	Cation exchange capacity
($mg \cdot kg^{-1}$ soil)						(%)	($meq \cdot 100g^{-1}$)
55.6	35.1	1.53	0.99	0.18	5.4	1.8	9.1

Table 2. Treatments applied to irrigated Russet Burbank potatoes at the Sand Plain Research Farm in Becker, MN, in 2018.

Treatment	Fertilizer application timing	Fertilzers applied[1]	Nutrients applied ($lbs \cdot ac^{-1}$)[2]	
			K_2O	B
1	Fall (November 14, 2017)	Check	0	0
2		MOP	300	0
3		MOP + 15% B	300	2.6
4		EXPCMT	300	2.6
5	Spring (April 23, 2018)	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 $lbs \cdot ac^{-1}$ N, 140 $lbs \cdot ac^{-1}$ P, 30 $lbs \cdot ac^{-1}$ S and 1 $lb \cdot ac^{-1}$ Zn.

[3]Half applied in spring, half at emergence

Table 3. Effects of K and B treatments on stand and number of stems per plant for Russet Burbank plants grown at the Sand Plain Research Farm in Becker, MN, in 2018. Stand was 100% in all plots in June 13, and these results are therefore not included.

Treatment	Fertilizer application timing	Fertilzers applied[1]	Stand (%)	Stems / plant	
			May 31	**June 13**	**June 20**
1	Fall	Check	10 c	2.2	3.3 c
2		MOP	41 b	2.8	3.9 abc
3		MOP + 15% B	15 c	2.4	3.8 bc
4		EXPCMT	38 b	2.2	4.1 ab
5	Spring	Check	22 c	2.3	4.6 a
6		MOP	79 a	2.3	3.2 c
7		MOP + 15% B	81 a	2.2	3.3 c
8		EXPCMT	72 a	2.7	3.4 bc
9	Split[2]	MOP + 15% B	74 a	2.7	3.3 c
Significance (P-value)			**<0.0001**	0.6651	**0.0300**
Contrasts	K effect (trts 1 & 5 vs. 2-4, 6-8)		**<.0001**	0.5398	0.2211
	B effect (trts 2 & 6 vs. 3 & 7)		*0.0835*	0.4057	1.0000
	Fall vs. Spring K (trts 2-4 vs. 6-8)		**<0.0001**	0.8109	**0.0150**

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

[2]Half applied in spring, half at emergence

Table 4. Effect of K and B treatments on yield, size, and grade of Russet Burbank tubers grown at the Sand Plain Research Farm in Becker, MN, in 2018.

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	141 a	174 ab	81 b	19 e	2 d	418 c	228 b	49 cde	277 d	24 e	5 f
2		MOP	95 c	175 ab	171 a	56 d	32 c	529 b	389 a	45 de	434 c	48 d	16 e
3		MOP + 15% B	106 bc	195 a	172 a	50 d	30 c	553 ab	406 a	41 e	446 bc	45 d	14 e
4		EXPCMT	101 c	181 ab	176 a	71 cd	38 c	567 ab	410 a	56 cde	467 bc	50 cd	19 de
5	Spring	Check	121 ab	183 ab	99 b	17 e	4 d	423 c	247 b	54 cde	301 d	27 e	4 f
6		MOP	66 d	122 d	172 a	132 a	64 ab	557 ab	404 a	87 ab	491 ab	65 a	35 ab
7		MOP + 15% B	65 d	142 cd	188 a	104 b	55 bc	554 ab	421 a	68 bcd	489 ab	62 ab	28 bc
8		EXPCMT	73 d	161 bc	169 a	89 bc	48 bc	540 b	391 a	76 abc	467 bc	57 bc	25 cd
9	Split[2]	MOP + 15% B	60 d	118 d	187 a	130 a	87 a	582 a	417 a	105 a	522 a	69 a	37 a
Significance (P-value)			**<0.0001**	**0.0012**	**<0.0001**	**<0.0001**	**<0.0001**	**<0.0001**	**<0.0001**	**0.0160**	**<0.0001**	**<0.0001**	**<0.0001**
Contrasts	K effect (trts 1 & 5 vs. all others)		**<.0001**	0.1319	**<.0001**	**<.0001**	**<.0001**	**<.0001**	**<.0001**	0.3098	**<.0001**	**<.0001**	**<.0001**
	B effect (trts 2 & 6 vs. 3 & 7)		0.5351	0.1330	0.5217	*0.0675*	0.5981	0.5250	0.2480	0.3488	0.7900	0.3300	0.1352
	Fall vs. Spring K (trts 2-4 vs. 6-8)		**<0.0001**	**0.0004**	0.7398	**<0.0001**	**0.0138**	0.9681	0.7656	**0.0067**	**0.0450**	**<0.0001**	**<0.0001**

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

[2]Half applied in spring, half at emergence

Table 5. Effects of K and B treatments on quality of Russet Burbank tubers grown at the Sand Plain Research Farm in Becker, MN, in 2018. Brown center co-occurred perfectly with hollow heart, and scab was absent from the study. Therefore, neither variable is presented.

Treatment	Fertilizer application timing	Fertilzers applied[1]	Hollow heart (% of tubers)	Specific Gravity	Dry matter (%)
1	Fall	Check	11	1.0812	22.8 a
2		MOP	5	1.0809	21.7 bcd
3		MOP + 15% B	12	1.0791	21.5 cd
4		EXPCMT	11	1.0820	21.9 bc
5	Spring	Check	3	1.0830	22.5 ab
6		MOP	16	1.0806	21.6 cd
7		MOP + 15% B	4	1.0795	21.1 cd
8		EXPCMT	7	1.0790	20.9 d
9	Split[2]	MOP + 15% B	11	1.0791	21.5 cd
		Significance (P-value)	0.2736	0.3328	**0.0251**
Contrasts	K effect (trts 1 & 5 vs. all others)		0.4599	*0.0818*	**0.0005**
	B effect (trts 2 & 6 vs. 3 & 7)		0.5436	0.2753	0.3829
	Fall vs. Spring K (trts 2-4 vs. 6-8)		0.9266	0.3509	*0.0934*

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

[2]Half applied in spring, half at emergence

Evaluation of Ivory Russet as Processing Cultivar for Central Minnesota

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Summary

Ivory Russet is a new potato cultivar developed by the Dutch company HZPC. While it has many promising attributes as a processing potato and has performed well in diverse geographic locations, there is limited information on how this cultivar performs in Minnesota. The objective of this study was to determine the rate and timing of N application that optimize Ivory Russet tuber yield and quality. Three application regimes were applied to provide variations in the timing of N availability: (1) uncoated urea at emergence with subsequent UAN applications, (2) ESN before planting with uncoated urea at emergence, and (3) ESN at emergence with subsequent UAN applications. Each of these regimes was applied at three rates: 160, 240, and 320 lbs·ac^{-1} N total, with 40 lbs N/A of the total N applied at planting as diammonium phosphate. Russet Burbank was also grown under the third regime as a standard for comparison. Potato plant responses were measured in terms of stand, stems per plant, tuber yield, size, and grade, tuber quality (hollow heart, scab, specific gravity, and dry matter content), and tuber sugar content and French fry quality at harvest. Ivory Russet marketable yield was highest when fertilized with ESN at emergence and subsequent UAN at a rate of 320 lbs·ac^{-1} N total, but similar yields were obtained with urea at emergence with subsequent UAN at 240 or 320 lbs·ac^{-1} N total or with ESN before planting and urea at emergence at 240 lbs·ac^{-1} N total. Averaging across N regimes, Ivory Russet tuber specific gravity decreased as the application rate of N increased. Effects of N regime and rate on Ivory Russet tuber sugar concentrations and fry reflectance values were not significant. Comparing Ivory Russet with Russet Burbank, Ivory Russet had lower total and marketable yields than Russet Burbank under the same N regime and rate, but also had less of its yield in tubers over 10 ounces and more in medium size classes, especially at high N rates. Hollow heart was absent from Ivory Russet, while three percent of Russet Burbank tubers had hollow heart at each of the three N rates. Ivory Russet tubers had lower glucose concentrations in both the stem and bud ends than Russet Burbank tubers, and fries made from Ivory Russet had higher reflectance values than Russet Burbank fries, indicating better fry quality. Ivory Russet tubers had higher sucrose concentrations in the stem end, but lower sucrose in the bud end, than Russet Burbank. Overall, highest yields for Ivory Russet were achieved with the following N treatments: 1) 320 lbs·ac^{-1} N total when ESN was applied at emergence with subsequent UAN; 2) 240 – 320 lbs·ac^{-1} N total when uncoated urea was applied at emergence with subsequent UAN; and 3) 240 lbs·ac^{-1} N total when ESN was applied before planting with uncoated urea at emergence. Ivory Russet produced lower marketable yields than Russet Burbank at all N rates, but it had advantages in terms of tuber size distribution, lower hollow heart incidence, tuber glucose concentration, and fry reflectance values.

Background

Ivory Russet is a new potato cultivar developed by HZPC Holland B.V. It is early maturing, stores well, and has good potential for baking and processing. It has high dry matter content, medium to high specific gravity, white flesh and brown skin, and is resistant to several common potato diseases. Ivory Russet is among the potato cultivars accepted by McDonald's for fry production, increasing its economic potential for growers. However, more research is needed to determine the optimum rate and timing of N application for tuber yield and quality under Minnesota conditions. The objective of this study was to determine the optimal N rate and timing for Ivory Russet under irrigated conditions in central Minnesota.

To determine how Ivory Russet responds to N rate and timing, it was evaluated under three different N fertilization regimes. In the first regime, most of the N was applied as uncoated urea at emergence with subsequent applications of 28% UAN, providing a large pulse of N soon after emergence and five smaller pulses throughout tuber initiation and bulking. In the second regime, most of the N was applied shortly before planting in the form of Environmentally Smart Nitrogen (ESN; 44-0-0; a polymer-coated urea by Agrium, Inc.), with the rest applied as uncoated urea at emergence, providing a large, extended pulse of N release between planting and emergence with a second, shorter pulse soon after emergence, leaving little soil N by the end of tuber bulking. This is similar to the regime recommended by HZPC. In the third regime, most of the N was applied as ESN at emergence with subsequent applications of 28% UAN, providing a large, extended pulse of N at emergence and five smaller pulses throughout tuber initiation and bulking. In all three regimes, 40 $lbs \cdot ac^{-1}$ N were banded as DAP (18-46-0) at row opening, and each regime was applied at the same three total N rates: 160, 240, and 320 $lbs \cdot ac^{-1}$ N.

As a benchmark, the performance of Ivory Russet was compared to that of Russet Burbank, the most widely grown frying potato cultivar in the region. For this cultivar comparison, Russet Burbank was grown with ESN at emergence and UAN post-hilling at each of the above total N rates.

Methods

Study design

The study was conducted in 2018 at the Sand Plain Research Farm in Becker, MN, on a Hubbard loamy sand soil. The previous crop was rye.

Twelve treatments were applied in a randomized complete block design with four blocks. The first nine treatments were designed to evaluate Ivory Russet's N response with three N fertilization regimes. In each regime, 40 $lbs \cdot ac^{-1}$ N were banded as DAP at row opening. In addition, each treatment received 120, 200, or 280 $lbs \cdot ac^{-1}$ N as either: (1) urea at emergence and UAN post-hilling, (2) ESN just before planting and urea at emergence, or (3) ESN at emergence and UAN post-hilling. In the remaining three treatments, Russet Burbank plants received the third of these regimens at the same rates as Ivory Russet to compare the performance of the two cultivars. These treatments are described in Table 1.

Soil sampling

To measure initial soil characteristics, soil samples to a depth of six inches were collected on April 23 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

SulPoMag (0-0-22-22S-11Mg) and MOP (60-0-0) were each broadcast applied at a rate of 200 $lbs \cdot ac^{-1}$ on May 9, providing 164 $lbs \cdot ac^{-1}$ K, 44 $lbs \cdot ac^{-1}$ S, and 22 $lbs \cdot ac^{-1}$ Mg. At the same time, ESN was broadcast by hand in plots receiving treatments 4 – 6.

On May 11, 40 $lbs \cdot ac^{-1}$ N, 102 $lbs \cdot ac^{-1}$ P_2O_5, 181 $lbs \cdot ac^{-1}$ K_2O, 40 $lbs \cdot ac^{-1}$ S, 20 $lbs \cdot ac^{-1}$ Mg, 1 $lb \cdot ac^{-1}$ Zn, and 0.6 $lbs \cdot ac^{-1}$ B were banded in throughout the field as a blend of 222 $lbs \cdot ac^{-1}$ DAP (18-46-0), 180 $lbs \cdot ac^{-1}$ SulPoMag, 235 $lbs \cdot ac^{-1}$ MOP, 2.8 $lbs \cdot ac^{-1}$ BluMin (17.5% S, 35.5% Zn), and 4 $lbs \cdot ac^{-1}$ 15% B. Forty-eight plots, each 20 feet long and 12 feet (4 rows) wide, were then planted with cut "A" seed (Ivory Russet) or whole "B" seed (Russet Burbank). Seed pieces were spaced 9” apart in Ivory Russet plots and 12” apart in Russet Burbank plots. Plots were arranged in two sections, each three plots across and eight plots long.

Emergence

The plots were hilled on May 22. Prior to hilling, urea or ESN was side-dressed by hand along either side of each hill, according to treatment. Hilling buried this fertilizer approximately 2 inches below the soil surface. Plant stand was assessed for the harvest rows in each plot on June 12 and 20. On the second date, the number of stems per plant was calculated for ten harvest-row plants per plot. In plots receiving all treatments except 4 – 6, UAN (28-0-0) was applied on five dates after hilling, at 4, 12, or 20 $lbs \cdot ac^{-1}$ N per application, according to treatment. Application dates were June 21 and July 5, 12, 23, and 30 (30, 44, 51, 62, and 69 days after hilling, respectively).

Petiole sampling

The petiole of the fourth leaf from the shoot tip was collected from 20 shoots per plot at five times throughout the growing season: June 20, July 2, 17, and 26, and August 7 (29, 41, 56, 65, and 77 days after hilling, respectively). Petiole NO_3-N concentration results will be determined using a Wescan Nitrogen Analyzer.

Harvest

Vines were killed on September 10. Tubers were harvested on September 18 (145 days after planting) and sorted by weight and USDA grade on October 3 (15 days after harvest). 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 and dry matter content were determined. Samples were sent to the USDA/ARS Potato Research Worksite in East Grand Forks, MN for sugar analysis and fry quality.

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 treatments 1 – 9 were analyzed as functions of N regime, N rate, their interaction, and block. In the second model, data from treatments 7 – 12 were analyzed as functions of cultivar, N rate, their interaction, and block. Means for each level of cultivar or N regime, N rate, 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

Comparison of N regimes applied to Ivory Russet

Plant stand and stems per plant

Results for plant stand and stems per plant are presented in Table 3. Plant stand on June 12 was slightly but significantly lower in the plots receiving ESN before planting and urea at emergence (treatments 4-6) than the plots receiving the other two N regimes (treatments 1-3 or 7-

9). The difference in average stand was less than 3% and may not be biologically meaningful. The response of the number of stems per plant to N rate depended on how N was applied. Stem number tended to decrease as the N rate increased among treatments receiving urea at emergence (treatments 1-3), peaked at 240 $lbs \cdot ac^{-1}$ N among treatments receiving ESN at emergence (treatments 7-9), and were lowest at 240 $lbs \cdot ac^{-1}$ N among treatments receiving ESN before planting (treatments 4-6). This interaction is difficult to interpret as a response to the treatments applied.

Tuber yield

Results for tuber yield are presented in Table 4. N regime had significant effects on tuber yield in three size classes: 0 to 3 ounces, 3 to 6 ounces, and over 14 ounces. However, N regime had no significant effect on overall tuber yield or the percentage of yield represented by tubers over 6 or 10 ounces. The response of Ivory Russet marketable yield to N rate depended on N regime. Among the treatments receiving urea at emergence with subsequent UAN (treatments 1-3), the strongest yield response to N rate occurred between 160 and 240 $lbs \cdot ac^{-1}$ N total, while the strongest response occurred between 240 and 320 $lbs \cdot ac^{-1}$ N when ESN was applied at emergence with subsequent UAN (treatments 7-9). The treatments receiving ESN before planting with urea at emergence (treatments 4-6) had peak yield at 240 $lbs \cdot ac^{-1}$ N. Adding N beyond 240 $lbs \cdot ac^{-1}$ N total under this N regime may have harmed early growth by producing an excessive soil NH_4^+-N concentration. In contrast, the treatments receiving urea or ESN at emergence and UAN thereafter (treatments 1-3 and 7-9), which provided little N right after planting, showed a positive response to increasing N rate across the three rates tested.

Tuber quality

Results for tuber quality are presented in Table 5. There were no N regime or rate effects on the prevalence of hollow heart or on tuber dry matter content. Scab was detected in just four plots, split evenly between two treatments, resulting in an effect of the interaction between N regime and N rate that was statistically significant but probably not meaningful. Tuber specific gravity decreased as the application rate of N increased, with no effect of N regime.

Tuber sugars

Results for tuber sucrose and glucose concentrations and French-fry reflectance are presented in Table 6. Stem-end glucose concentrations were higher in Ivory Russet plants receiving ESN at emergence and UAN later in the season (treatments 7-9) than in those receiving urea at emergence and UAN later (treatments 1-3). There were no other effects of N regime or timing on tuber sugars or fry reflectance. Bud-end sucrose concentrations tended to increase with the application rate of N, but there were no other effects of N rate on tuber sugars or fry reflectance. The effect of the regime*rate interaction on the reflectance of French fries made from the stem ends of tubers was marginally significant, but this effect is difficult to interpret.

<u>Comparison between Ivory Russet and Russet Burbank</u>

Plant stand and stems per plant

Results for plant stand and stems per plant are presented in Table 7. Cultivar, N rate, and their interaction had no significant effects on plant stand or the number of stems per plant.

Tuber yield

Results for tuber yield are presented in Table 8. Russet Burbank plants produced higher yields than Ivory Russet plants under the same N fertilization regime, with more of their yield represented by tubers over 6 or 10 ounces. The only tuber size category in which Russet Burbank did not produce significantly greater yield was the 3- to 6-ounce category. Overall, the size distribution of Ivory Russet favored medium-sized (3- to 10-ounce) tubers over large (over 10-ounce) tubers, relative to Russet Burbank.

Plots receiving 320 $lbs \cdot ac^{-1}$ N had a larger percentage of their yield in tubers weighing over 6 or 10 ounces than plots fertilized at the two lower rates.

Tuber quality

Results for tuber quality are presented in Table 9. The prevalence of hollow heart was 3% at all N rates in Russet Burbank (treatments 10-12), which was significantly higher than the prevalence in Ivory Russet (treatments 7-9), from which hollow heart was absent. Scab was not detected in either cultivar under this N regime. In both cultivars, tuber specific gravity was highest in the treatment receiving 160 $lbs \cdot ac^{-1}$ N, but the lowest specific gravity was observed at 240 $lbs \cdot ac^{-1}$ N in Russet Burbank and 320 $lbs \cdot ac^{-1}$ N in Ivory Russet. There were no significant effects of cultivar or N rate on tuber dry matter content.

Tuber sugars

Results for tuber sucrose and glucose concentrations and French-fry reflectance are presented in Table 10. Ivory Russet tubers had lower glucose concentrations than Russet Burbank tubers in both the stem end and the bud end. Sucrose concentrations were higher in Ivory Russet than Russet Burbank in the stem ends of tubers, but the reverse was true in the bud ends. The reflectance of French fries made from Ivory Russet Tubers was consistently higher than that of fries made from Russet Burbank. This is consistent with the lower glucose concentrations in Ivory Russet tubers and indicative of low acrylamide content in the finished fries. The main effect of the application rate of N was not related tuber sugars or fry color among these treatments, but there was an effect of the cultivar*rate interaction on stem-end glucose. Russet Burbank plants fertilized at 160 $lbs \cdot ac^{-1}$ N had much a much higher mean stem-end glucose concentration than those fertilized at higher N rates, while Ivory Russet showed a trend in the opposite direction.

Conclusions

Ivory Russet had lower tuber glucose concentrations and higher French fry reflectance values at harvest than Russet Burbank, indicating better fry quality. . In addition, hollow heart was almost absent from Ivory Russet in this study, and the cultivar had more of its yield in 3- to 6-ounce tubers and less of its yield in tubers over 10 ounces than Russet Burbank. Russet Burbank produced substantially higher marketable yields at all three N rates. However, Ivory Russet had a more desirable tuber size distribution, especially at high N rates, and the yield of Ivory Russet tubers between 3 and 10 ounces approached that of Russet Burbank at an N rate of 320 $lbs \cdot ac^{-1}$ N total.

The highest marketable yield achieved in Ivory Russet (422 $CWT \cdot ac^{-1}$) occurred when ESN was applied at emergence with five subsequent applications of UAN at a total N rate of 320 $lbs \cdot ac^{-1}$ N, but comparable yields were observed when uncoated urea was applied at emergence followed by UAN at 240 or 320 $lbs \cdot ac^{-1}$ N total, as well as when ESN was applied before planting and uncoated urea at emergence at 240 lbs·ac^{-1} N total. Based on these results, the optimum N rate for Ivory Russet is at least 320 lbs·ac^{-1} N with ESN at emergence and UAN after, or 240 lbs·ac^{-1} N under the other two regimes tested. We found no effects of N rate or timing on tuber quality, except that tuber specific gravity decreased as the N rate increased in both cultivars.

Table 1. N treatments applied to irrigated Ivory Russet and Russet Burbank potato plants at the Sand Plain Research Farm in Becker, MN, in 2018.

Treatment	Cultivar	Preplant N (rate[1] and source[2])	Planting N (rate[1] and source[2])	Emergence N (rate[1] and source[2])	Post-hilling N (rate[1] and source[2])	Total N rate[1]
1	Ivory Russet	0	40 DAP	100 urea	20 UAN	160
2	Ivory Russet	0	40 DAP	140 urea	60 UAN	240
3	Ivory Russet	0	40 DAP	180 urea	100 UAN	320
4	Ivory Russet	100 ESN	40 DAP	20 urea	0	160
5	Ivory Russet	140 ESN	40 DAP	60 urea	0	240
6	Ivory Russet	180 ESN	40 DAP	100 urea	0	320
7	Ivory Russet	0	40 DAP	100 ESN	20 UAN	160
8	Ivory Russet	0	40 DAP	140 ESN	60 UAN	240
9	Ivory Russet	0	40 DAP	180 ESN	100 UAN	320
10	Russet Burbank	0	40 DAP	100 ESN	20 UAN	160
11	Russet Burbank	0	40 DAP	140 ESN	60 UAN	240
12	Russet Burbank	0	40 DAP	180 ESN	100 UAN	320

[1]lbs·ac^{-1} N

[2]DAP: diammonium phosphate (18-46-0); urea (46-0-0); ESN (Enviromentally Smart Nitrogen, Agrium, Inc.; 44-0-0); UAN: urea and ammonium nitrate (28-0-0)

Table 2. Initial soil characteristics of the study site in Becker, MN, in 2018.

0 - 2 feet	0 - 6 inches											
NO_3-N	Bray P	K	SO_4-S	Ca	Mg	Fe	Mn	Zn	Cu	B	Organic matter	pH
ppm												
3.4	16	94	5	930	151	30	24	0.8	0.33	0.21	1.5	6.1

Table 3. Effect of N regime and rate on plant stand and the number of stems per plant for Ivory Russet potato plants grown at the Sand Plain Research Farm in Becker, MN, in 2018. Values within the same column that have a letter in common are not significantly different from each other (i.e. P > 0.10). Letters are only included where the P-value of the effect in the model is less than 0.10.

N regime[1]	Total N rate (lbs·ac^{-1})	Stand on June 12 (%)	Stand on June 20 (%)	Stems / plant on June 20
Urea/UAN	Average of all	99.5 a	98.4	3.4
ESN/urea		96.7 b	98.4	3.8
ESN/UAN		99.5 a	98.1	3.7
Effect of N source (P-value)		**0.0060**	0.9594	0.2319
Average of all	160	99.3	99.3	3.9
	240	98.4	97.0	3.5
	320	97.9	98.6	3.5
Effect of N rate (P-value)		0.3129	0.2710	0.1252
Urea/UAN	160	100.0	100.0	3.7 abc
	240	99.0	96.4	3.4 bcd
	320	99.5	99.0	3.1 cd
ESN/urea	160	98.4	99.5	4.2 a
	240	97.4	99.0	3.0 d
	320	94.3	96.9	4.3 a
ESN/UAN	160	99.5	98.4	3.8 ab
	240	99.0	95.8	4.1 a
	320	100.0	100.0	3.1 d
Effect of N rate * N source (P-value)		0.2182	0.4238	**0.0061**

Table 4. Effect of N regime and rate on tuber yield, size, and grade for Ivory Russet potato plants grown at the Sand Plain Research Farm in Becker, MN, in 2018. Values within the same column that have a letter in common are not significantly different from each other (i.e. P > 0.10). Letters are only included where the P-value of the effect in the model is less than 0.10.

N regime[1]	Total N rate ($lbs \cdot ac^{-1}$)	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
		$cwt \cdot ac^{-1}$									%	
Urea/UAN	Average of all	44 a	159 ab	177	41	5 b	427	360	23	383	52	11
ESN/urea	Average of all	39 b	148 b	177	48	14 a	426	364	23	387	56	14
ESN/UAN	Average of all	47 a	175 a	179	35	4 b	440	368	25	393	49	9
Effect of N source (P-value)		**0.0220**	*0.0506*	0.9790	0.3880	*0.0503*	0.1924	0.6618	0.7109	0.5667	0.1190	0.1106
Average of all	160	50 a	188 a	150 b	22 c	2 b	411 b	346 b	15 c	361 b	42 c	5 c
Average of all	240	42 b	166 b	186 a	40 b	7 b	440 a	374 a	24 b	398 a	52 b	10 b
Average of all	320	37 c	129 c	197 a	63 a	15 a	441 a	373 a	31 a	404 a	62 a	18 a
Effect of N rate (P-value)		**0.0004**	**<0.0001**	**<0.0001**	**0.0005**	**0.0208**	**0.0014**	**0.0038**	**0.0002**	**0.0002**	**<0.0001**	**0.0004**
Urea/UAN	160	56	198 a	126 e	12	1	392 e	324 d	12	336 e	35	3
Urea/UAN	240	42	166 bcd	193 abc	43	2	446 ab	377 abc	27	404 abc	53	10
Urea/UAN	320	34	114 e	213 a	69	13	444 abc	380 ab	30	409 ab	67	18
ESN/urea	160	45	182 abc	164 d	28	3	421 cd	355 bc	21	376 d	46	7
ESN/urea	240	37	144 de	190 abc	54	16	441 abc	383 a	21	405 abc	59	15
ESN/urea	320	34	118 e	178 bcd	62	24	416 de	354 c	27	381 cd	63	20
ESN/UAN	160	49	184 abc	161 d	26	2	421 cd	358 bc	14	372 d	44	6
ESN/UAN	240	49	187 ab	173 cd	21	3	434 bcd	361 abc	24	385 bcd	45	6
ESN/UAN	320	43	155 cd	201 ab	59	7	465 a	385 a	37	422 a	57	14
Effect of N rate * N source (P-value)		0.1430	0.2442	**0.0094**	0.3920	0.5514	**0.0175**	**0.0265**	0.1589	**0.0179**	0.1111	0.5897

Table 5. Effect of N regime and rate on tuber quality for Ivory Russet potato plants grown at the Sand Plain Research Farm in Becker, MN, in 2018. Values within the same column that have a letter in common are not significantly different from each other (i.e. P > 0.10). Letters are only included where the P-value of the effect in the model is less than 0.10.

N regime[1]	Total N rate ($lbs{\cdot}ac^{-1}$)	Hollow heart	Scab	Tuber specific gravity	Tuber dry matter content (%)
		% of tubers			
Urea/UAN	Average of all	0	2.3	1.0821	22.1
ESN/urea		0.3	2.0	1.0822	22.1
ESN/UAN		0	0	1.0819	22.4
Effect of N source (P-value)		0.3827	0.3586	0.9504	0.6986
Average of all	160	0	0	1.0835 a	22.5
	240	0	2.0	1.0821 b	22.3
	320	0.3	2.3	1.0807 c	21.9
Effect of N rate (P-value)		0.3827	0.3586	**0.0064**	0.2013
Urea/UAN	160	0	0 b	1.0836	22.2
	240	0	0 b	1.0817	22.0
	320	0	7.0 a	1.0811	22.2
ESN/urea	160	0	0 b	1.0833	22.2
	240	0	6.0 a	1.0820	22.6
	320	1.0	0 b	1.0812	21.6
ESN/UAN	160	0	0 b	1.0835	23.0
	240	0	0 b	1.0825	22.3
	320	0	0 b	1.0798	21.8
Effect of N rate * N source (P-value)		0.4269	*0.0588*	0.7782	0.3924

Table 6. Effect of N regime and rate on tuber sucrose and glucose concentrations and French fry reflectance values (Photovolt) for Ivory Russet potato plants grown at the Sand Plain Research Farm in Becker, MN, in 2018. Values within the same column that have a letter in common are not significantly different from each other (i.e. P > 0.10). Letters are only included where the P-value of the effect in the model is less than 0.10.

N regime[1]	Total N rate ($lbs \cdot ac^{-1}$)	Stem			Bud		
		Sucrose (mg/g)	Glucose (mg/g)	Reflectance	Sucrose (mg/g)	Glucose (mg/g)	Reflectance
Urea/UAN	Average of all	0.551	1.501 b	36.6	0.836	0.163	48.4
ESN/urea		0.603	1.611 ab	35.6	0.837	0.121	48.0
ESN/UAN		0.591	1.799 a	35.6	0.901	0.142	48.9
Effect of N source (P-value)		0.7290	*0.0687*	0.4842	0.1858	0.2826	0.3665
Average of all	160	0.610	1.642	35.9	0.812 b	0.149	47.9
	240	0.535	1.726	36.1	0.858 ab	0.139	48.4
	320	0.602	1.543	35.8	0.905 a	0.138	49.0
Effect of N rate (P-value)		0.4849	0.3465	0.9294	*0.0797*	0.8950	0.1890
Urea/UAN	160	0.564	1.463	36.9 ab	0.763	0.153	48.0
	240	0.475	1.758	35.1 bcd	0.846	0.187	48.4
	320	0.616	1.283	37.7 a	0.900	0.150	48.9
ESN/urea	160	0.631	1.814	34.1 cd	0.805	0.128	47.6
	240	0.543	1.472	37.1 ab	0.820	0.129	47.7
	320	0.635	1.546	35.8 abcd	0.885	0.106	48.7
ESN/UAN	160	0.634	1.649	36.7 abc	0.867	0.167	48.0
	240	0.586	1.948	36.2 abcd	0.908	0.101	49.2
	320	0.554	1.800	33.9 d	0.929	0.158	49.5
Effect of N rate * N source (P-value)		0.8637	0.1396	*0.0558*	0.9169	0.5074	0.9675

Table 7. Effect of cultivar and N application rate on plant stand and the number of stems per plant for Ivory Russet and Russet Burbank potato plants grown at the Sand Plain Research Farm in Becker, MN, in 2018.

Cultivar	Total N rate ($lbs \cdot ac^{-1}$)	Stand on June 12 (%)	Stand on June 20 (%)	Stems / plant on June 20
Ivory Russet	Average of all	99.5	98.1	3.7
Russet Burbank		99.9	99.8	3.8
Effect of cultivar (P-value)		0.2905	0.2168	0.5274
Average of both	160	99.7	98.9	3.8
	240	99.5	97.9	4.0
	320	100.0	100.0	3.5
Effect of N rate (P-value)		0.5830	0.4365	0.2476
Ivory Russet	160	99.5	98.4	3.8
	240	99.0	95.8	4.1
	320	100.0	100.0	3.1
Russet Burbank	160	99.8	99.4	3.7
	240	100.0	100.0	3.9
	320	100.0	100.0	3.8
Effect of cultivar * N rate (P-value)		0.5830	0.5550	0.2734

Table 8. Effect of cultivar and N application rate on tuber yield, size, and grade for Ivory Russet and Russet Burbank potato plants grown at the Sand Plain Research Farm in Becker, MN, in 2018. Values within the same column that have a letter in common are not significantly different from each other (i.e. P > 0.10). Letters are only included where the P-value of the effect in the model is less than 0.10.

Cultivar	Total N rate ($lbs \cdot ac^{-1}$)	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**
		$cwt \cdot ac^{-1}$									%	
Ivory Russet	Average of all	47 b	175	179 b	35 b	4 b	440 b	368 b	25 b	393 b	49 b	9 b
Russet Burbank		59 a	187	245 a	73 a	24 a	589 a	487 a	43 a	530 a	58 a	16 a
Effect of cultivar (P-value)		**0.0019**	0.3726	**<0.0001**	**0.0002**	**0.0008**	**<0.0001**	**<0.0001**	**0.0083**	**<0.0001**	**0.0135**	**0.0002**
Average of both	160	59 a	201 a	199	43 b	4 b	506 b	423	25 b	447 b	47 b	9 b
	240	53 ab	187 a	212	44 b	12 b	508 b	426	29 b	455 b	52 b	10 b
	320	47 b	155 b	225	76 a	25 a	529 a	434	48 a	482 a	61 a	18 a
Effect of N rate (P-value)		**0.0417**	**0.0346**	0.1808	**0.0044**	**0.0088**	*0.0837*	0.6060	**0.0122**	**0.0203**	**0.0107**	**0.0003**
Ivory Russet	160	49	184	161	26	2 c	421	358	14	372	44	6
	240	49	187	173	21	3 c	434	361	24	385	45	6
	320	43	155	201	59	7 bc	465	385	37	422	57	14
Russet Burbank	160	69	219	236	60	7 bc	591	487	35	523	51	11
	240	57	187	250	67	21 b	582	491	35	525	58	15
	320	52	155	249	93	44 a	593	483	58	542	65	23
Effect of cultivar * N rate (P-value)		0.2977	0.4940	0.4823	0.7907	**0.0493**	0.1924	0.3254	0.6825	0.4018	0.7156	0.4296

Table 9. Effect of cultivar and N application rate on tuber quality for Ivory Russet and Russet Burbank potato plants grown at the Sand Plain Research Farm in Becker, MN, in 2018. Values within the same column that have a letter in common are not significantly different from each other (i.e. P > 0.10). Letters are only included where the P-value of the effect in the model is less than 0.10.

Cultivar	Total N rate ($lbs \cdot ac^{-1}$)	Hollow heart	Scab	Tuber specific gravity	Tuber dry matter content (%)
		% of tubers			
Ivory Russet	Average of all	0 b	0	1.0819	22.4
Russet Burbank		3.0 a	0	1.0817	22.0
Effect of cultivar (P-value)		**0.0041**	-	0.7769	0.2856
Average of both	160	1.5	0	1.0833 a	22.6
	240	1.5	0	1.0812 b	22.2
	320	1.5	0	1.0809 b	21.8
Effect of N rate (P-value)		0.9990	-	*0.0574*	0.1358
Ivory Russet	160	0	0	1.0835 a	23.0
	240	0	0	1.0825 a	22.3
	320	0	0	1.0798 b	21.8
Russet Burbank	160	3.0	0	1.0831 a	22.2
	240	3.0	0	1.0800 b	22.2
	320	3.1	0	1.0820 ab	21.7
Effect of cultivar * N rate (P-value)		0.9990	-	*0.0878*	0.6516

Table 10. Effect of cultivar and N application rate on tuber sucrose and glucose concentrations and French fry reflectance values (Photovolt) for Ivory Russet and Russet Burbank potato plants grown at the Sand Plain Research Farm in Becker, MN, in 2018. Values within the same column that have a letter in common are not significantly different from each other (i.e. P > 0.10). Letters are only included where the P-value of the effect in the model is less than 0.10.

Cultivar	Total N rate ($lbs \cdot ac^{-1}$)	Stem			Bud		
		Sucrose (mg/g)	Glucose (mg/g)	Reflectance	Sucrose (mg/g)	Glucose (mg/g)	Reflectance
Ivory Russet	Average of all	0.591 a	1.799 b	35.7 a	0.901 b	0.140 b	48.8 a
Russet Burbank		0.426 b	2.729 a	27.1 b	1.021 a	0.238 a	41.4 b
Effect of cultivar (P-value)		**0.0154**	**0.0004**	**<0.0001**	**0.0287**	**0.0179**	**<0.0001**
Average of both	160	0.560	2.493	31.3	0.972	0.224	44.5
	240	0.488	2.203	32.4	0.965	0.147	45.1
	320	0.478	2.096	30.5	0.946	0.195	45.8
Effect of N rate (P-value)		0.5088	0.3046	0.4338	0.9035	0.2388	0.2134
Ivory Russet	160	0.634	1.649 d	36.9	0.867	0.162	47.8
	240	0.586	1.948 bcd	36.2	0.908	0.101	49.2
	320	0.554	1.800 cd	33.9	0.929	0.158	49.5
Russet Burbank	160	0.486	3.337 a	25.7	1.078	0.287	41.2
	240	0.390	2.459 b	28.5	1.023	0.194	41.0
	320	0.402	2.391 bc	27.2	0.963	0.232	42.1
Effect of cultivar * N rate (P-value)		0.9333	*0.0673*	0.3667	0.3792	0.8643	0.5837

Data Report for UMN Potato Breeding Program 2018

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Author's note: This is my first data report, so I'm not entirely sure of the intended format. I have chosen to discuss the two projects highlighted in last year's proposal first and then go on to discuss other accomplishments of the breeding program. Although the focus of our funding from Area II, the NPPGA, and Simplot was to complete the first two projects, both proposed projects were in support of building a breeding pipeline, and therefore I thought our progress in all stages of the pipeline would be of interest.

Seedling Tuber Production

Aim: The Potato Breeding Program at the University of Minnesota is located on the Saint Paul Campus, within the suburb of Falcon Heights. The campus is a center for agricultural research. While it is an ideal environment for innovation and collaboration, the campus presents limitations in terms of space. Specifically, it is not possible to produce 50,000 to 100,000 seedling tubers from true seed – standard for a large-scale breeding program – in the greenhouses on the Saint Paul Campus. We compared two feasible methods of seedling tuber production in terms of cost, efficiency, and ease of disease control. The first method was to grow mini-tubers outdoors, following the example of Dr. Walter DeJong at Cornell. The second method was rapid cycling of minitubers through growth chambers following the example of the CETS phytotrons(1).

Methods: We compared two methods of mini tuber production outdoor and growth chamber based.

Outdoor

Unselected potato true seed (TPS), supplied to us by Dr. Isabel Vales at Texas A&M university, was planted in plug trays and germinated in growth chambers. In total 1627 TPS were planted. Those which sprouted were transferred to 4" and then 6" pots and grown outdoors behind the greenhouses on black weed fabric. At the end of the season, vine kill was performed manually with scissors. TPS was planted in May and harvested in September. We screened for PVY and PVS using ELISA tests on 175 randomly sampled plants.

Indoor

We grew three rounds of unselected TPS in growth chambers on the Saint Paul campus (February – May, May – September, and October -- January). We use a Conviron 3 tiered growing environment with stable environmental conditions (200 umol, 20 degrees C, 20% relative humidity). Seedlings were germinated in plug trays and transplanted. The first two sets of plants were grown in 4 inch pots. The final set of plants were grown in 6 inch pots. At maturity vines were killed manually with scissors. For the first two rounds 1186 plants were grown in the growth chamber, for the third round only 500 plants were grown. In the first two rounds TPS from Texas was used, while in the third we relied on legacy seed from Dr. Florian Lauer. In the summer experiment 27 Texas families were split between the growth chamber and outdoor conditions. We screened those 27 families for PVY and PVS using ELISA tests on 175 randomly sampled plants.

Results: We were able to produce 1,107 minitubers outside and 1,137 minitubers in the growth chambers. All plants tested negative for PVY and PVS. However, some of the outdoor plants exhibited signs of distress including: mosaic symptoms of unknown cause, purpling of leaves, rolled leaves, and Colorado potato beetle feeding pressure. We also observed some incidence of scab at harvest. The growth chamber plants exhibited none of these symptoms. Producing a single round of growth chamber seedlings takes 178 person hours. We spent 338 person hours on the outdoor plants. While this means that growing minitubers outdoors is less time intensive overall, this can only be done in the busiest part of the year when researchers have the most other demands on their time. 68.04% of the plants grown outdoors in summer 2018 produced tubers while only 38.2% of growth chamber plants grown at the same time produced tubers. We increased pot size for the following round and achieved 48.2% tuberization, however the TPS used in this experiment was from 1990-2000, and that likely effected tuberization rates. We expect that fresh TPS and larger pots will improve tuberization rates.

Conclusions: We determined that we are able to produce more minitubers in the growth chambers than outdoors. Furthermore, those tubers experience less disease pressure and require less researcher time during our field season. We plan to continue to use 6" pots to address the low rate of tuberization. We will also experiment with other changes to the growth chamber conditions to increase tuberization. Furthermore, we will use the TPS generated in our crossing block (below). Fresh TPS will result in healthier plants. Finally, the growth chamber we have access to currently produces 200 umol of light. We have purchased two new growth chambers, each with 3 tiers which produces 500 umol of light per tier. This not only increases our capacity in terms of space, but we hypothesize that increased light will increase the tuberization rate and speed the growth cycle. These improvements will increase our capacity to produce minitubers, although we still expect to rely partially on exchange with other programs to produce a sufficiently large FY1. Interaction with other programs has the added advantage of broadening the program's genetic base.

Crossing Block

Aim: Conventional wisdom among the US potato breeders and experts at the US potato genebank is that there is a particular time of year for each greenhouse when potatoes most reliably flower. This seems to be dependent on the placement of the greenhouse and the particular angles and details of the roofs. We held multiple crossing blocks across the year to identify peak flowering conditions in the greenhouses on the UMN campus. This will allow us to optimize the timing of all future crossing blocks and efficiently create new germplasm.

Methods: We held three crossing blocks. The first was planted in June and developed buds in July. This crossing block focused on red and russet clones. Unfortunately, due to the high temperatures in July, the buds all fell off. The second was planted in October and crosses were made in December. Fruits were harvested in January. It was focused on chipping varieties. The third was planted in December and will flower in February. It contains red and russet parents.

Results: Our summer crossing block was unsuccessful. Our December crossing block contained 10 parents, we made 28 successful crosses resulting in 75 fruits. We are waiting for the fruits to mature for harvest. We expect to pollinate our third crossing block in February.

Conclusions: We will perform future crossing blocks in the winter.

Field Year 1 (FY1)

Aim: Potatoes are highly heterozygous, meaning that even a cross between two high performing cultivars largely produces plants with no or low commercial value. Therefore, the first step in selecting new potato varieties is to grow out a single example of a large number of individuals from a cross and select the most promising 1-5% based on visual appearance. In the first summer of the re-vamped UMN potato breeding program, we carried out such a screen in order to build germplasm for the breeding program.

Methods: Previous to the crossing blocks described above, no crosses had been made at the University of Minnesota in the past several years. Therefore, we relied on unselected seedling tubers from other breeding programs to carry out FY1. Our material included mini tubers generated from true seed left over from the previous breeders: Dr. Lauer and Dr. Thill. It also included donations from: Texas A&M, the University of Wisconsin, the University of Maine, and the University of Colorado. In total we had 27,531 single hills planted at the North Central Research and Outreach Center (NCROC) in Grand Rapids, MN. These represented 177 unique families. Of these single hills: 47% were chip, 27% russet, and 20% fresh market evenly divided between red skinned and yellow skinned varieties. Harvest took place in early September. Visual selection was performed by Dr. Laura Shannon and Dr. Cari Schmitz Carley, assisted by the research technicians (Katelyn Filbrandt and Rachel Figueroa), graduate students (Husain Agha and Colin Jones), and undergraduate students (Jessi Huege and Heather Tuttle) associated with the program. Plot maintenance was performed by Keith Mann at the NCROC with input from Dr. Schmitz Carley and Dr. Shannon. Fields were rogued twice, resulting in the removal of all individuals showing visual symptoms associated with potato viruses.

Results: We selected 2.6% of the material, leaving us with 652 clones for FY2.

Conclusions: We will take a similar approach in 2019. Although we will use 3ft within-row spacing rather than the 2ft spacing we used in 2018, having negotiated for more land at the station. Increased spacing between genetically distinct individuals will improve precision of in-season and harvest evaluations. We have generated 2,500 minitubers this year. Additionally, we have solicited unselected material from: Texas A&M, the University of Oregon, The University of Colorado, The University of Maine, and North Dakota State University. In order to rebalance our program from the chip focus of last year we will preferentially solicit russet and red families. While last year only 5 acres were available at NCROC, this year we have access to 11 acres, and we will be able to increase to 15 acres in 2020 and the following years. The program will grow accordingly.

Virus Purification of Legacy Material

Aim: When Dr. Thill unexpectedly passed in the middle of the field season, there was a variety 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 in Becker, MN. These lines show visual evidence of multiple virus infections. In order to evaluate Dr. Thill's clones for release we must first put them through anti-viral tissue culture to generate clean plantlets.

Methods: The anti-viral tissue culture process can take more than a year to produce clean plantlets. Therefore, we started by examining the 60 remaining clones from Dr. Thill with the goal of eliminating ones with disqualifying features. We eliminated 10 using visual selection for things like pink eyes on russets and yellow flesh in chipping varieties. We eliminated 2 because they had previously been evaluated in the regional trials and were rated "marginal". Finally, we genotyped all clones on the 22k SolCAP SNP array and determined that there were 2 pairs of duplicates and 2 known released varieties. Of these 44 unique clones, 3 are no longer eligible for PVP certification because tubers have been sold in the past several years. Those were eliminated as well. Two were already available in tissue culture, leaving us with 39 legacy clones for clean-up via anti-viral tissue culture.

Katelyn Filbrandt, our tissue culture specialist, 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 subcultured into magentas and grown to increase number for minituber generation. Plantlets which retained virus are currently being re-treated with antiviral media and heat treatment.

Results: Eighteen clones have tested PVY and PVS negative using Agdia strips and are being subcultured and grown at large scale in magentas. Seventeen clones still tested positive for PVY and are undergoing another cycle of anti-viral tissue culture. The remaining four clones have not grown sufficiently after heat treatment to be tested for virus.

Furthermore, PCA analysis based on SNP genotyping using the DNA marker array suggested that the UMN legacy material is genetically in line with the chip and fry material from other programs that has been submitted to the national chip and fry processing trials (Figure 1). It also contains the spread of diversity found in these other programs.

Conclusions: We will evaluate 18 clones from the legacy material from Dr. Thill this summer in the field.

Nitrogen Efficiency of Red Potatoes

Aim: Potatoes are heavily fertilized and irrigated on the sandy soils of Central Minnesota. These cultivation practices contribute to high levels of nitrogen leaching into ground water. One proactive path toward mitigating this phenomenon is planting varieties which require less added nitrogen. Our lab is working to identify and develop such varieties.

Methods: We have two parallel experiments addressing this aim. The first is Colin Jones's master's thesis. Jones examined nitrogen use efficiency in 12 late stage cultivars from Dr. Thill's breeding program (these were all grown from tubers previously planted in trial fields, rather than the clean seed we describe generating above) and two widely grown cultivars (Red LaSota and Dakota Rose). The experiment was conducted at the UMN Sand Plains Research Farm in Becker, MN, on well drained, irrigated, sandy loam soil. Two row plots directly abutted each other lengthwise. Plots were 20' long with 3-foot row spacing and 12" plant spacing. The field was planted in a split-block design with blocks containing two nitrogen treatments and each nitrogen treatment containing all varieties. Due to constraints on field space there were 3 replications in year one and 4 in year two. Nitrogen treatment groups were brought up to levels of 90 lb N/ac (Low-N) and 180 lb N/ac (High-N) with side-dressed urea at hilling, ~20-24 DAP. Pesticides and herbicides were applied to label limits as standard for the Sand Plains Research Farm. Irrigation was scheduled by checkbook system. Phenotypes were taken at ~45 days after planting and at harvest. The early phenotyping was done by excavating individual plants chosen from each plot at random, excluding row-end plants, to collect root and above ground data. Plants were brought back to lab and dissected.

The second experiment was a Nitrogen curve for 8 fresh market red varieties using 5 nitrogen levels (0,45,90,130, and 180 lbs/acre). We focused on fresh market varieties because the purpose of this experiment was not only to examine nitrogen efficiency, but also to trial three fresh market red varieties that Peter Imle maintained on his seed farm after Dr. Thill's passing. These were the only three legacy varieties for which we had clean seed. In addition to the three Pine Lake Wild Rice varieties, we included one of Dr. Thompson's clones – ND6002-

1R, and four commercial cultivars: Red Norland, Dark Red Norland, Red LaSota, and Chieftan. This experiment also took place at the Sand Plains Research Farm, using 15' plots with 1' plant spacing. They were grown with 4 replications. Only emergence counts and tuber phenotypes at harvest were taken for this experiment.

Results:

Jones' Thesis

We found almost no significant differences between how varieties reacted to nitrogen (Table 1). Furthermore, nitrogen level had minimal effect at the ~45 days after planting pre-bulking stage. However, treatment did have a significant effect on phenotype at harvest. Variety was a significant determinant for most phenotypes. We observed high variance between years which obscured significant differences between nitrogen use efficiency across years. In general varieties which yielded best at low N were also those that yielded best at high N. We examined two components of nitrogen use efficiency: uptake and yield. Uptake was highly correlated with yield at high N but not at low N, suggesting that at low N plants use the available nitrogen but high yielders are able to make use of extra N at higher concentrations (Figure 2). Varieties differed in their reliance on uptake vs. utilization to efficiently use nitrogen (Figure 3).

Nitrogen Curve

We only have a single year of data for this experiment and so results are preliminary. We observed a variety of yield responses to decreased nitrogen (Figure 4). Chieftain and Dark Red Norland both exhibit yield decrease with each incremental decrease in nitrogen. ND6002-1R, Red Norland, Red LaSota, and MN12009PLWR-02R only show a yield decrease below half N. MN120054PLWR-02R and MN120054PLWR-03R show consistent yield across all trials with added nitrogen. It is important to note that both MN120054PLWR-02R and MN120054PLWR-03R were low yielding over all, most likely due to dry rot in the seed, and this limits our ability to draw conclusions about nitrogen use efficiency. We did not see significant effects of nitrogen on disease presence, tuber skin color, or tuber skinning in year 1.

Conclusions: We need additional years of data before we can identify varieties which can yield reliably with less nitrogen. We submitted a proposal to the MDA to this effect and appreciate the support letters from members of the NPPGA and Area II. The combined results across two experiments suggest that lower levels of nitrogen than half N are needed to see responses consistently across cultivars. Our results suggest that fresh market red skinned potatoes show differences in both uptake and utilization and that efficiency in these two distinct traits could be stacked in a single variety to improve nitrogen use efficiency over all.

Promising Cultivars

Aim: We have inherited four cultivars from Dr. Thill's breeding program which were maintained by collaborators after his passing. Peter Imle has maintained three red fresh market varieties and Dr. Carl Rosen and Dr. Sanjay Gupta have maintained a russet. We are evaluating these varieties for potential release. We are able to fast track them because we don't have to put them through antiviral tissue culture.

Methods: We received tissue culture plantlets for MN13142 this fall. We tested them for virus using ELISAs and then multiplied the plantlets via subculture. We are potted the resulting plantlets in the greenhouse to produce minitubers.

We grew the three red varieties maintained by Peter Imle this summer. They were grown at the Sand Plains Research Center in Becker at 5 nitrogen levels (0,45,90,130, and 180 lbs/acre). They were grown in 4 reps using 15' plots with 1' plant spacing. They were graded at the East Grand Forks Potato Storage Research Facility. In an effort to confirm our conclusions from grading we brought a sample of tubers harvested from this experiment to the NPPGA field day to survey growers about color and shape. We collected 15 responses.

Results: After over wintering on the Saint Paul campus the seed for the three red varieties seemed to have developed dry rot which may have decreased yield. MN12054PLWR-03R and MN12054PLWR-02R were both very low yielders. MN12009PLWR-02R had higher yield suggesting that without the dry rot problem it may yield comparably to the check varieties (Figure 5). All three varieties, but particularly MN12009PLWR-02R had nice dark red skin, between Red Norland and Dark Red Norland (Figure 6). It also did well in the survey with 15/15 growers rating its shape and appearance acceptable and 13/15 indicating that it had the correct color.

Conclusions: Of the three red fresh market varieties, MN12009PLWR-02R seems like the most promising potential release. We will grow all three again in the summer of 2019, and generate clean seed for entry into the North Central Regional Trials.

Dr. Rosen and Dr. Gupta report that MN13142 distinguishes itself in terms of dormancy and skin thickness. We will trial it in 2019 and enter it in Dr. Darrin Haagenson's storage trials at the East Grand Forks Potato Storage Research Facility. One of the outstanding questions about this variety is whether or not it makes marketable French fries; we will test this with material harvested in 2019. Additionally, we will work with Justin Dagen and Black Gold to generate clean seed from the minitubers generated at Valley Tissue Culture, which is a prerequisite for grower trials or entry into the national fry processing trial.

Acknowledgements

Team: Dr. Cari Schmitz Carley directly oversees our breeding program including working out all the logistics. She also headed up the crossing block project. Rachel Figueroa took the lead on comparing mini tuber production strategies. Katelyn Filbrandt did all of the tissue culture and virus testing work described. Colin Jones lead the nitrogen and root growth project. Other members of the lab who assisted in these projects include: Husain Agha, Sophy Fitzcollins, Jessi Huege, Akpevwe Ikoba, Nhung Pham, and Heather Tuttle. Keith Mann and his team took care of our fields at the NCROC while Ron Faber took care of our field in Becker. Pam Warnke and

Roger Meissner supported greenhouse operations. Doug Brinkman and Dr. Gary Gardner have provided invaluable advice and support with figuring out the growth chambers. Tina Lozano from Dr. Carl Rosen's lab and Mitch Johnston from Dr. Tom Michaels lab stepped in when we were short on people for planting. Dr. Jeff Endelman, Dr. Susie Thompson, Jennifer Flynn, Scott Woodford, and Becky Eddy have been particularly generous with their time and advice.

Germplasm: We are grateful to the following people who have contributed germplasm to the above projects: Sandi Aarestad and Valley Tissue Culture, Dr. John Bamberg and the NRSP6 potato genebank, Dr. Jeff Endelman and the University of Wisconsin Potato Breeding Program, Dr. Sanjay Gupta, Dr. Dave Holms and the University of Colorado Potato Breeding Program, Peter Imle, Dr. Greg Porter and the University of Maine Potato Breeding Program, Dr. Carl Rosen, and Dr. Isabel Vales and the Texas A&M Potato Breeding Program.

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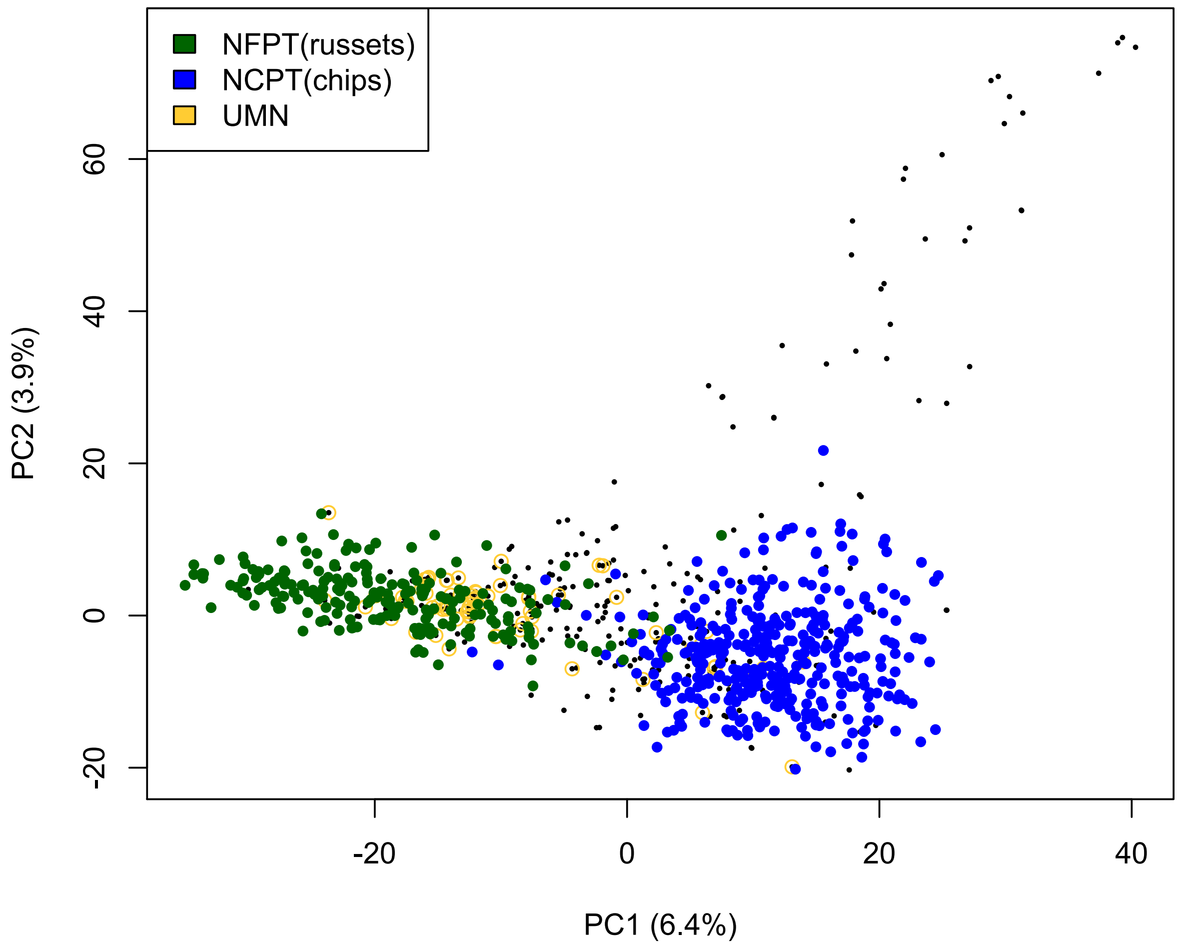

Figure 1 Principal component analysis for UMN legacy germplasm as compared to that from other programs. Black dots are from a diversity panel from Hirsch et al (2). The green dots are from the National Fry Processing Trial while the blue dots are from the National Chip Processing Trial. PCA is a measure of similarity, the proximity of two dots to one another mirrors the genetic similarity between those two clones. What this image shows is that the UMN program under Dr. Thill (in yellow) contained much of the diversity in chips and russets other programs have, but nothing unusual.

Table 1. Mixed Model in R (using LME4):

X ~ Treatment*Variety + (1|Rep) + (1|Year)

I.e. Treatment (Fixed), Variety (Fixed), Interaction, Rep (Random), Year(Random)

Shovelomics results – **45 days** after planting – pre tuber-bulking/tuber-set phase.

Response Variable	Treatment	Variety	Interaction
Total Root Wt.	*	***	NS
Stolon Wt.	NS.	***	NS.
Stolon Length	NS	***	NS
'Hooks'	*	***	NS
Tuber Wt.	NS	***	NS
Tuber Count	NS	***	NS
Vine Dry Wt.	*	***	NS

Signif. Codes: | *** ≤ 0.001 | ** ≤ 0.01 | * ≤ 05. | . ≤ 0.1 | NS ≤ 1. |

Harvest results – **90 days** after planting (vine-kill)

Response Variable	Treatment	Variety	Interaction
Total Yield	***	***	NS
Smalls	**	***	NS
Medium	***	***	*
Large	*	**	NS
Tuber Dry Wt.	***	***	NS
Vine Dry %	***	***	NS†
Vine Wet Wt.	***	**	NS
Vine Dry Wt.	***	**	NS
Vine N %	***	***	NS
Tuber N %	***	***	*
Avg. Plant N %	***	***	NS
Total Plant N (g) †	***	**	NS
NUE (Use)	***	***	NS
NUtE (Utilization)	***	***	NS. (p=.05666)
NUpE (Uptake)	***	**	NS

Signif. Codes: | *** ≤ 0.001 | ** ≤ 0.01 | * ≤ 05. | . ≤ 0.1 | NS ≤ 1. |

† Derived by multiplying Vine%N by Haulm ***Wet*** weight and Tuber%N by Total Yield

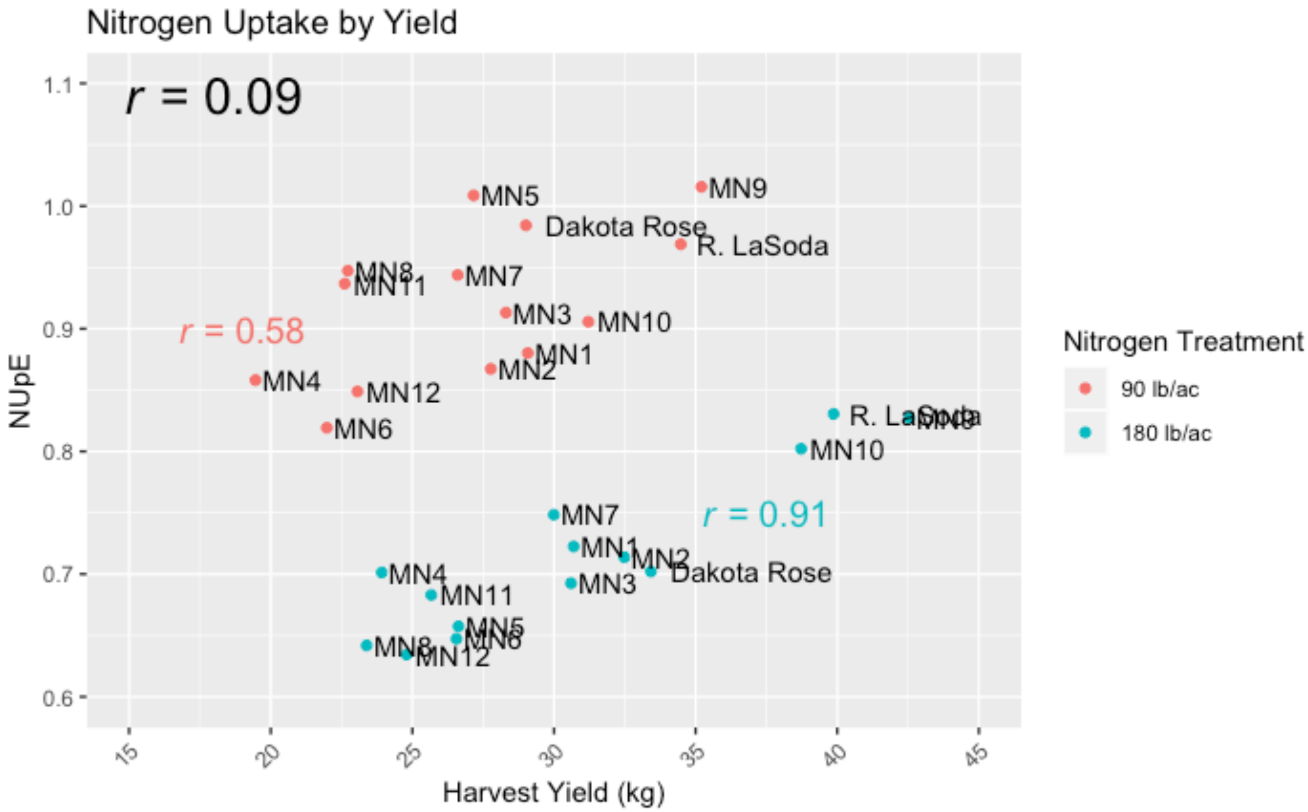

Figure 2. The correlation between nitrogen uptake and yield. At low N the amount of N absorbed by the plant showed no relationship to yield. This is essentially because all available nitrogen is taken up by all varieties. At high N, nitrogen uptakes differed more and this correlated directly to yield. This suggests that while yield uptake at high N may depend on nitrogen uptake, yield at low N depends on a different mechanism.

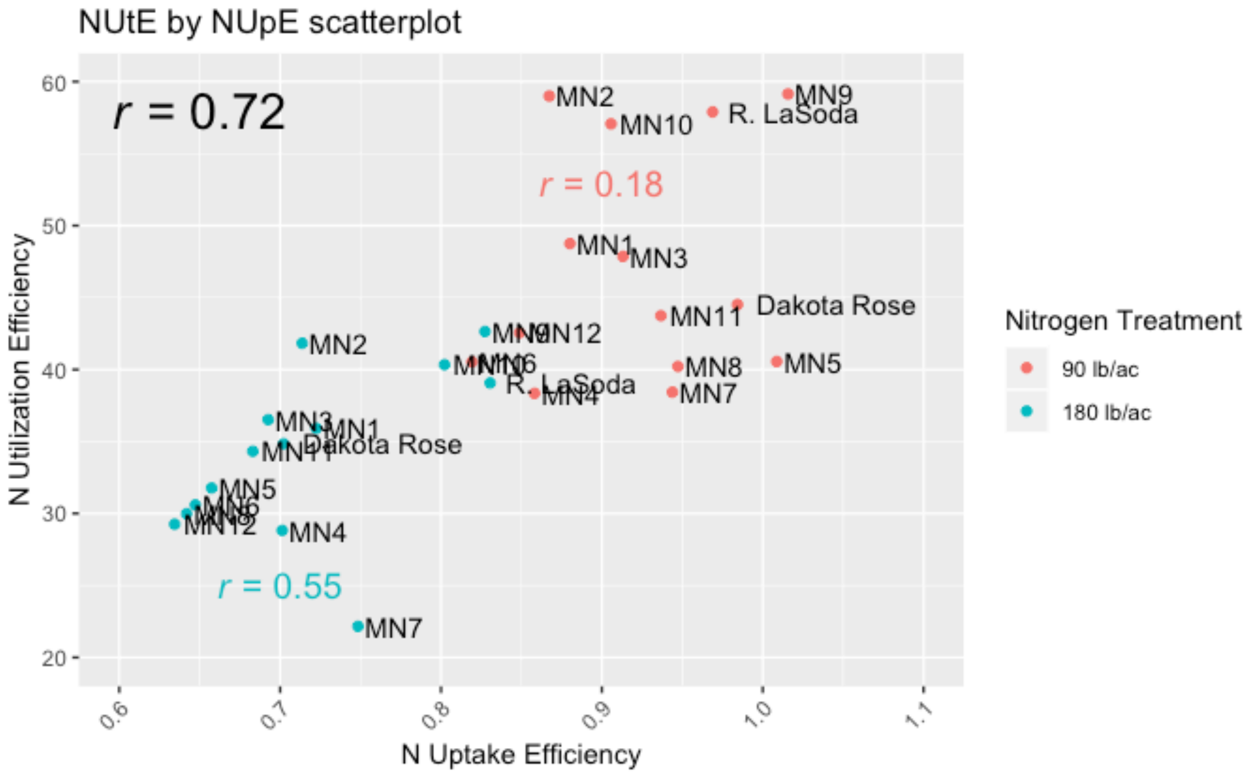

Figure 3. The correlation between nitrogen utilization and uptake. Nitrogen utilization and uptake are essentially uncorrelated other than that both efficiencies are higher at low N than high N for all plants. This suggests that the ability to uptake nitrogen and the ability to translate nitrogen to yield are two distinct traits. This suggests that nitrogen efficiency over all could be improved in new varieties by combining uptake and utilization efficiency into a single plant.

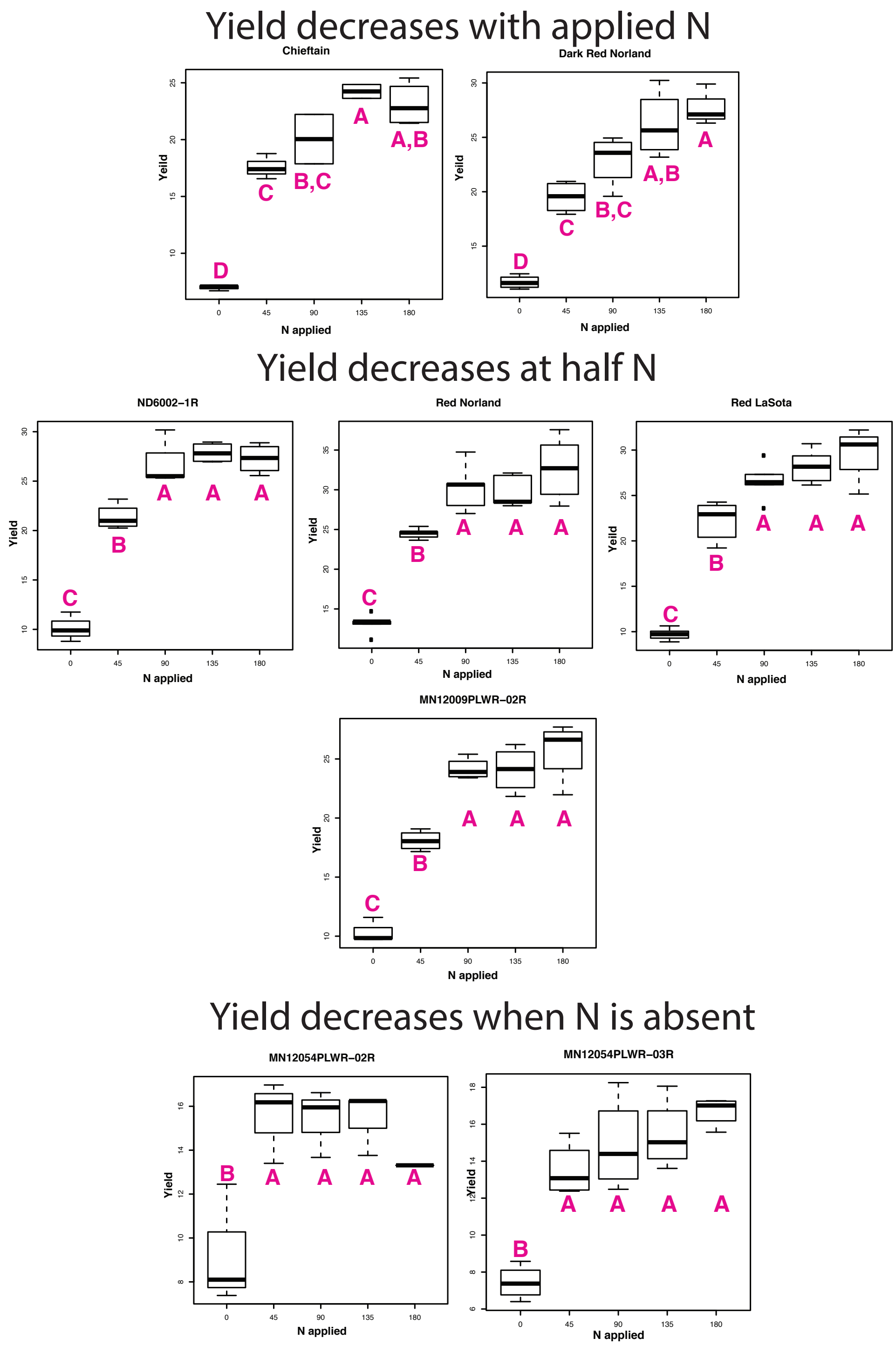

Figure 4. Yield response to nitrogen curve across fresh market red varieties

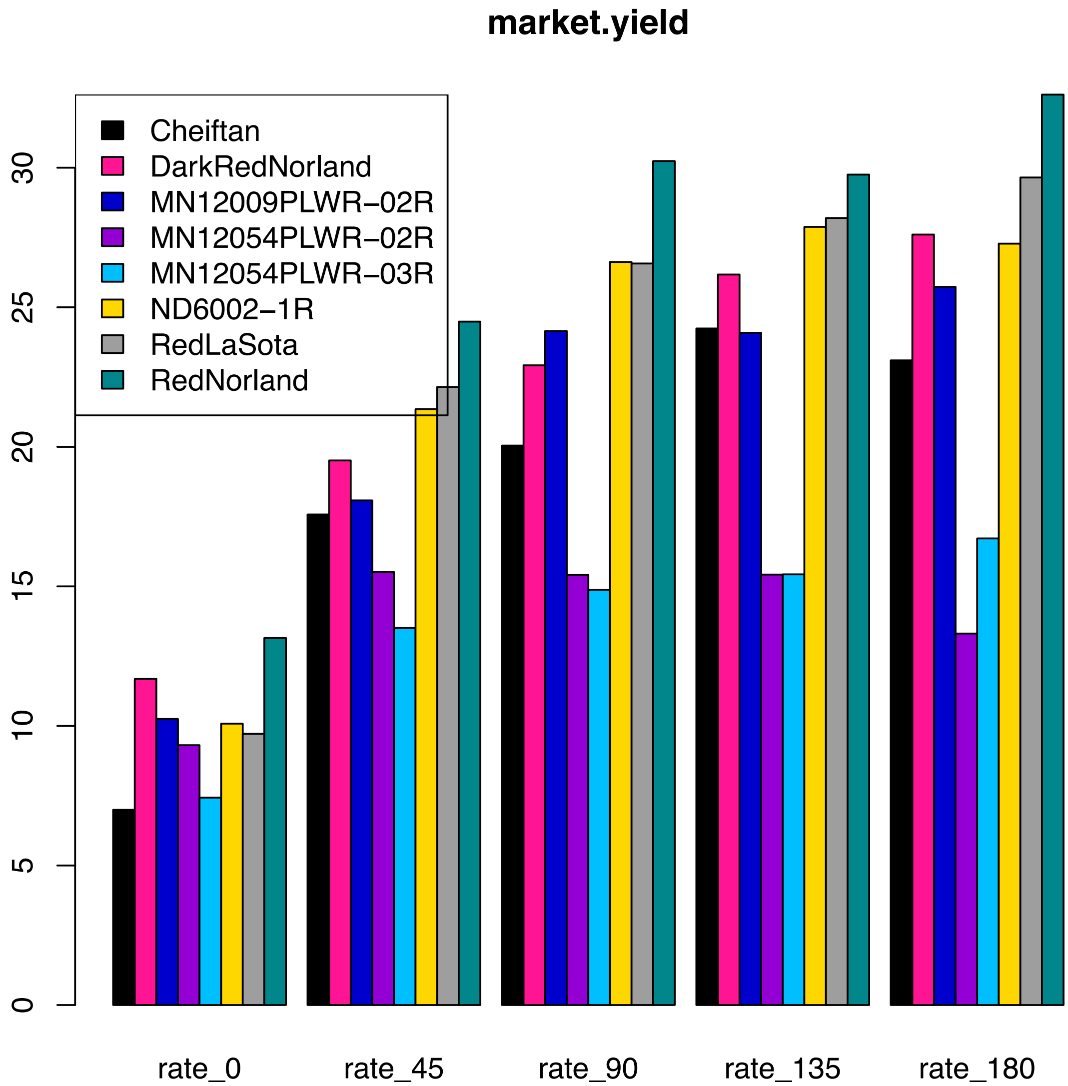

Figure 5. Marketable yield across 5 nitrogen rates (in lbs/acre) for eight fresh market red varieties.

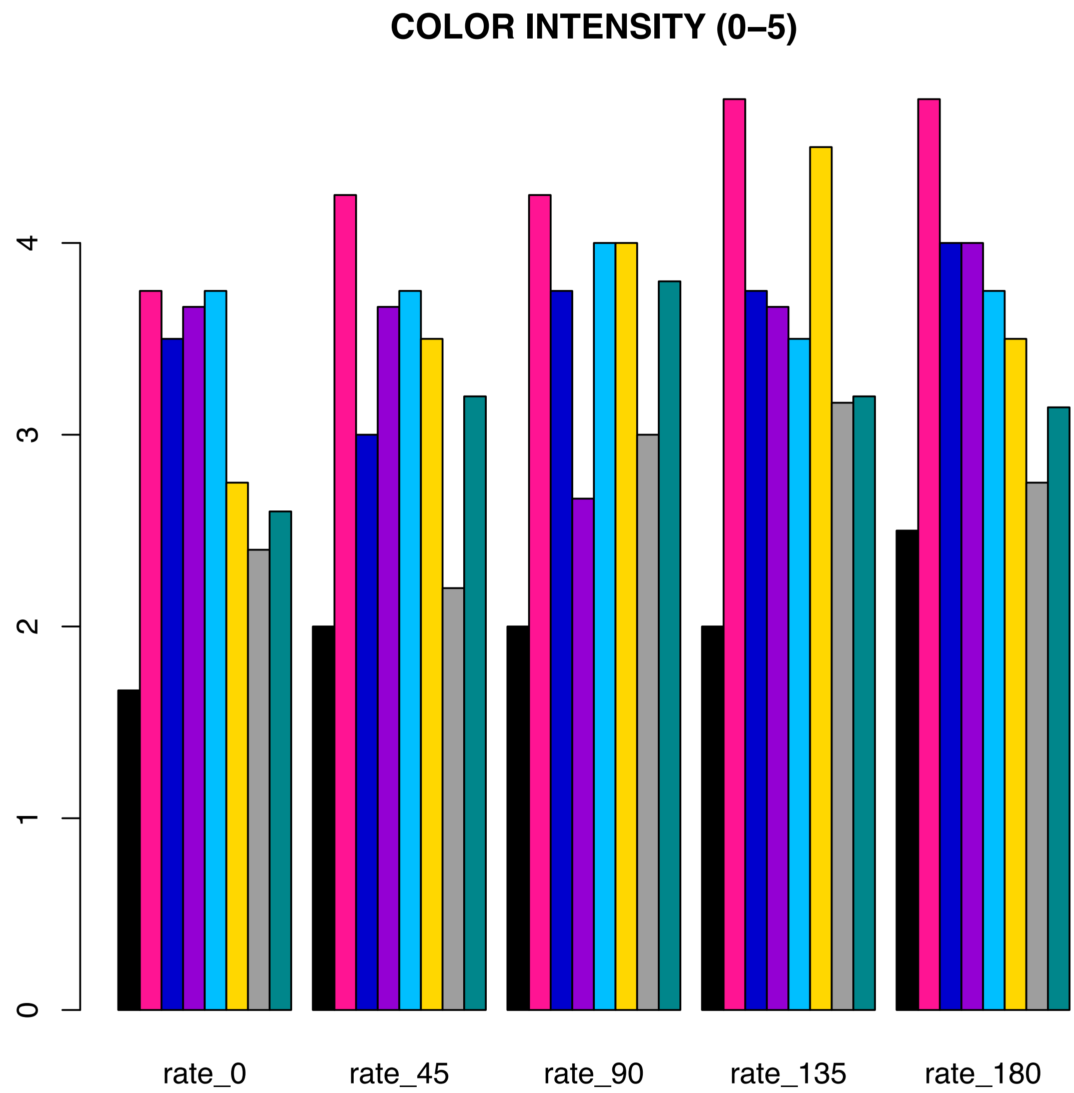

Figure 6. Skin color across 5 nitrogen rates (in lbs/acre) for eight fresh market red varieties. 0 is lightest and 5 is darkest. Black is Cheiftan. Pink is Dark Red Norland. Dark blue is MN12009PLWR-02R. Purple is MN12054PLWR-02R. Sky blue is MN12054PLWR-03R. Yellow is ND6002-1R. Gray is Red LaSota. Green is Red Norland.

Potato Breeding and Production for the Northern Plains
2018 Summary

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In 2018, nearly 19% of hectares (ha) planted in the major seven states producing fall potatoes (ID, WA, ND, WI, OR, ME & MN) were planted to cultivars (or selections thereof) developed by the NDSU potato breeding program. Dakota Russet, a beautiful dual-purpose russet release (2012), accounted for 0.8% of planted ha; commercial production doubled compared to 2017. Dakota Trailblazer (2009) is finding market niches in North America and the southern hemisphere where sustainability attributes are valued and where high specific gravity is difficult to attain; it utilizes one-third less nitrogen than Russet Burbank, and is highly resistant to *Verticillium* wilt, saving ~$494/ha fumigation cost for standard commercial processing cultivars. Russet Burbank, identified in the early 1900s, is the most widely grown commercially acceptable potato cultivar, accounting for 37% of ha; it is susceptible to pathogens and physiological disorders, and requires high amounts of fertilizers, water, and other inputs. In 2018, 29,947 ha of potato were planted in ND, with 29,542 ha harvested; due to adverse summer (dry) & harvest (rain, snow, freezing temps) conditions, a 3% decrease in total production was estimated.

Potato is a significant horticultural crop in ND, MN and the Northern Plains. The potato breeding program as part of the potato improvement team at NDSU is involved in breeding, germplasm enhancement efforts, selection of improved genotypes, evaluation, and development of superior cultivars for stakeholder adoption in ND, MN, and beyond. Our efforts are focused on incorporating durable and long-term pest (biotic) and abiotic stress resistances, improved sustainability including nutrient and water-use efficiency, enhanced quality and nutritional attributes, and high yield and marketability, via the use of conventional breeding techniques. To address the needs of Northern Plains/Minnesota Area II potato producers and our associated industry, the following research objectives were established for 2018:

- Identify outstanding germplasm and release improved potato cultivars adapted to the northern plains, possessing superior yield, disease/pest resistance, and quality attributes via traditional breeding methods.
- Identify and adopt innovative breeding methods.
- Conduct production related evaluations for promising selections and newly released cultivars, for inclusion in cultivar specific management profiles.

In 2018, 65 parents were used for hybridizing; 1750 flower clusters were pollinated, with a 43% success rate. Three hundred thirty-four new families were created, with about one-third incorporating PVY resistance across market types. At our certified seed location near Baker, MN, 33,435 seedlings were evaluated, representing 179 segregating families; 774 selections across market types were retained. Unselected seedling tubers were shared with programs in ID, ME, OR, and TX. Maintenance and increase lots included 352 second, 142 third year, and 221 fourth year and older selection; 118 second year, 57 third, and 126 fourth year and older, selections were retained for further evaluation in 2019. As in previous years, 13 Chilean selections from the INIA program at Osorno, Chile, were evaluated in collaboration with Drs. Gary Secor and Julio Kalazich (professor emeritus INIA); they serve as a unique germplasm resource for introgressing resistance to abiotic and biotic stresses, and for improving quality including nutritional attributes.

Irrigated trial sites were at Oakes, Larimore and Inkster, ND, and at Park Rapids, MN. At Oakes, trials were focused on fresh market selections and 16 dual-purpose russet selections, compared to industry standards. As in recent previous years, fresh market genotypes were plagued by common scab. Several russets early in the evaluation process were identified as having excellent agronomic and processing qualities. The Larimore trial site included the Processing Trial (21 selections, cultivars and industry standards), the preliminary processing trial with 55 entries, a second year of the Dakota Russet depth study, maintenance of out-of-state selections, and out-of-state seedlings (single hill selections from the ID, ME and TX programs). The National French Fry Processing trial had 38 selections from US breeding programs compared to Russet Burbank and Ranger Russet in the three tiered trial; NDSU entries were ND12241YB-2Russ in Tier 1, and ND050032-4Russ in Tier 3. ND12241YB-2Russ has been advanced in the 2019 NFPT. The North Central Regional trial included 25 entries, eight from NDSU: AND00272-1R, ND081571-2R, ND102663B-3R, ND113113-2PSY, ND1232B-2RY, ND1241-1Y, ND1243-1PY, and ND12128B-1R. Significant rain, snow, and very cold temperatures at harvest resulted in losses due to frost and processing quality was compromised. Promising advancing dual-purpose russet selections include ND8068-5Russ, ND039194AB-1Russ, ND050032-4Russ, ND060735-4Russ, ND081764B-4Russ, ND091938BR-2Russ, and ND12241YB-1Russ. Three trials were planted at Inkster, the metribuzin sensitivity screening conducted in collaboration with Dr. Harlene Hatterman-Valenti's program (results are being used to validate the new screening model developed by Razi Ibrahim in his Master's thesis work), an early harvest trial focused on ND8068-5Russ (ND8068-5Russ and ND050032-4Russ had excellent early yield and quality beginning in early August), and a sugar end screening trial. Information from the three trials will be used in development of cultivar specific management profiles for advancing selections and new cultivar releases. Trials at Park Rapids, MN, included a processing trial with 15 entries, a common scab screening trial with 68 entries across market types, the replicated screening trial for *Verticillium* wilt resistance (25 genotypes across market types) conducted in collaboration with Dr. Neil Gudmestad's program, and a trial evaluating a biostimulant for potato production.

Non-irrigated research sites include Crystal, Hoople and Grand Forks, ND. At Crystal, the Fresh Market Trial included 30 entries (18 advancing selections compared to 12 industry standards). The Preliminary Fresh Market Trial included 56 selections (primarily red skinned and white fleshed) compared to 16 industry standards. Promising selections identified include ND1241-1Y, ND102663B-3R, ND081571-2R, ND081571-3R, ND102990B-2R, ND1243-1PY, ND13236C-10R, and ND13179CB-1R. Chip processing trials were grown at Hoople; the Chip Processing Trial included 10 advancing chip selections compared to 10 chip industry standards. The National Chip Processing Trial (NCPT), included 103 unreplicated selections (Tier 1) and 44 replicated entries (Tier 2) from US potato breeding programs compared to 4 industry chip selections; 9 were NDSU selections. The Preliminary Chip Processing Trial included 47 selections compared to 10 industry chip standards. Outstanding chip selections included ND113307C-3, ND1221-1, ND12180ABC-8, ND14348AB-1, ND14437CAB-1, and ND14437CAB-2. Defoliation trials focused on Colorado Potato Beetle (CPB) resistance were planted at the NPPGA Research Farm south of Grand Forks**,** included advancing selections and 63 seedling families with glycoalkaloid mediated resistance, glandular trichomes, and/or the two mechanisms stacked; while these were damaged by heavy rains in June, results indicated some foliar resistance in advancing selections. Replicated trials addressing nitrogen management and vine kill options to achieve optimum skin set for Dakota Ruby were also grown at this site. Heavy rains in September precluded us from completing the vinekill study; we were able to harvest some replicates of the N management study. Data analysis and processing evaluations from storage are on-going for all 2018 trials.

ND050032-4Russ and ND060735-4Russ will be submitted for pre-release in 2019. ND7519-1 had excellent performance in the national SNAC trial and will repeat in 2019; it will also be submitted for release consideration in 2019. ND8068-5Russ (very early dual-purpose russet), ND7799c-1 (high yielding chip processing selection), and ND6002-1R (bright red skinned fresh selection) have been through pre-release and continue to gain interest across North America. ND1241-1Y, ND081571-3R, and ND113207-1R, amongst many others have garnered significant attention from producers in the Northern Plains. Many excellent red skinned selections with late blight resistance breeding including ND102990B-2R will be evaluated for late blight resistance in 2019.

Research results will be disseminated via the Valley Potato Grower magazine as in previous years. Research results for the Crystal Fresh Market Trial, Hoople Chip Processing Trial, and the Larimore Processing Trial are summarized in Tables 1-7.

Thank you to our many producer, industry, and research cooperators in North Dakota, Minnesota, the North Central region and beyond. We are particularly grateful to Dave and Andy Moquist, Lloyd, Steve and Jamie Oberg, Carl, Michael and Casey Hoverson, James Thompson, and Keith McGovern, Nick David and all at the RD Offutt Company for hosting on-farm trial locations; we couldn’t do this work without you. We are very grateful to the Northern Plains Potato Growers Association and the Minnesota Area II Potato Research and Promotion Council for the continued support and cooperation in providing resources of land, certified seed, research funding, and equipment resources.

Table 1. Agronomic evaluations for advanced fresh market selections and cultivars, Crystal, ND, 2018. The fresh market trial was planted on May 30, vinekilled on approximately September 10, and harvested with a single-row Grimme harvester on September 25, 2018. The replicated plots were 20 feet long, with a 12-inch with-in row spacing, and 36 inches between rows.

Clone	% Stand	Vine Size[1]	Vine Maturity[2]	Stems per Plant	Shape[3]	Color[4]	General Rating[5]
1. ND6002-1R	88	1.8	1.8	1.8	2.5	4.1	3.6
2. ND081571-2R	90	2.0	1.3	2.1	1.0	4.4	4.0
3. ND081571-3R	99	2.5	1.4	2.6	1.3	4.0	3.6
4. ND7102663B-3R	100	2.0	2.5	1.9	1.1	4.3	3.4
5. ND102990B-2R	100	2.5	1.4	2.5	1.0	4.4	4.3
6. ND113091B-2RY	98	2.0	1.3	1.9	1.0	3.4	3.4
7. ND1232B-1RY	86	2.0	1.0	2.1	1.1	4.1	3.5
8. ND1241-1Y	93	2.3	1.0	1.7	1.0	Y	3.4
9. ND1243-1PY	80	4.3	3.6	2.1	1.0	P	3.6
10. ND12128B-1R	94	1.8	1.0	2.3	1.0	4.3	3.1
11. ND1360B-1RY	98	5.0	3.3	2.4	1.8	4.0	3.4
12. ND1382-2R	95	4.5	4.0	2.1	1.0	4.4	3.8
13. ND13179CB-1R	93	3.0	2.1	2.1	1.8	3.8	3.5
14. ND13193B-1R	93	2.5	3.8	2.5	1.0	4.0	3.3
15. ND13236C-10R	98	3.3	2.0	2.4	1.0	4.3	3.8
16. ND13236C-11R	91	4.4	3.8	2.6	1.0	3.9	2.9
17. ND13239C-3R	98	4.0	2.8	2.8	1.0	4.0	3.5
18. ND13241C-6R	98	3.5	2.5	2.2	1.9	4.1	3.4
19. All Blue	99	3.3	1.9	2.3	4.4	P	2.9
20. Dakota Jewel	91	1.8	1.0	1.7	2.5	4.5	3.5
21. Dakota Rose	95	1.3	1.0	2.3	3.0	3.6	3.5
22. Dakota Ruby	96	2.5	1.8	2.8	1.0	4.8	4.1
23. Gala	99	2.0	1.1	2.8	2.0	Y	3.5
24. Red LaSoda	68	2.5	1.5	5.5	3.0	3.0	2.9
25. Red Norland	99	1.5	1.0	2.2	2.8	3.0	2.9
26. Red Pontiac	100	3.5	2.4	2.3	2.8	2.9	2.6
27. Romanze	83	4.3	2.9	2.0	2.8	3.0	2.9
28. Sangre	89	2.5	3.0	1.7	3.0	3.0	2.8
29. Soraya	85	3.3	1.6	1.9	2.5	Y	2.6
30. Yukon Gold	94	2.0	1.0	1.7	2.5	Y	3.5
Mean	93	2.8	2.0	2.3	1.8	NA	3.4
LSD ($\propto$=0.05)	13	0.8	0.8	1.9	0.8	NA	0.4

[1] Vine size – scale 1-5, 1 = small, 5 = large.
[2] Vine maturity – scale 1-5, 1 = early, 5 = late.
[3] Shape = 1-5; 1 = round, 2 = oval, 3 = oblong, 4 = blocky, 5 = long.
[4] Color = 1-5; 1 = white/buff, 2 = pink, 3 = red, 4 = bright red, 5 = dark red, P = purple, Y = yellow. NA = not applicable
[5] General Rating = 1-5; 1 = poor and unacceptable, 3 = fair, 4 = excellent, 5 = perfect.

Table 2. Yield and grade for advanced fresh market selections and cultivars, Crystal, ND, 2018. The fresh market trial was planted on May 30, vinekilled on approximately September 10, and harvested with a single-row Grimme harvester on September 25, 2018. The replicated plots were 20 feet long, with a 12-inch with-in row spacing, and 36 inches between rows.

Clone	Total Yield Cwt./A	A Size Tubers Cwt./A	A Size %	0-4 oz. %	4-6 oz. %	6-10 oz. %	>10 oz. %	US No. 2 %	Culls %
1. ND6002-1R	200	113	56	36	44	12	7	0	1
2. ND081571-2R	184	64	34	65	31	3	1	0	0
3. ND081571-3R	222	84	37	62	30	7	1	0	0
4. ND7102663B-3R	181	39	21	79	19	2	0	0	0
5. ND102990B-2R	255	55	21	79	19	3	0	0	0
6. ND113091B-2RY	249	63	23	76	19	4	1	0	0
7. ND1232B-1RY	218	71	30	69	27	4	0	0	0
8. ND1241-1Y	150	47	29	69	25	4	1	0	0
9. ND1243-1PY	250	146	54	41	44	11	3	1	1
10. ND12128B-1R	150	22	13	86	12	1	0	0	1
11. ND1360B-1RY	297	142	47	44	35	11	9	0	0
12. ND1382-2R	245	75	30	70	25	4	0	0	0
13. ND13179CB-1R	276	160	59	26	42	17	14	0	2
14. ND13193B-1R	163	11	6	94	6	0	0	0	0
15. ND13236C-10R	316	68	21	79	18	2	1	0	0
16. ND13236C-11R	162	28	17	81	16	1	0	0	2
17. ND13239C-3R	242	115	42	55	36	6	2	0	1
18. ND13241C-6R	233	49	18	81	17	1	1	0	0
19. All Blue	163	34	17	82	14	3	0	0	0
20. Dakota Jewel	186	101	46	41	31	15	10	1	3
21. Dakota Rose	229	137	59	28	42	17	13	0	0
22. Dakota Ruby	273	74	27	73	24	3	0	0	0
23. Gala	300	86	31	68	27	4	0	0	0
24. Red LaSoda	212	69	30	24	20	10	36	1	12
25. Red Norland	269	156	59	18	42	17	19	0	3
26. Red Pontiac	272	128	47	22	31	15	21	0	10
27. Romanze	222	102	43	53	35	8	4	0	0
28. Sangre	216	115	55	22	39	16	14	0	10
29. Soraya	271	106	35	28	25	10	6	0	31
30. Yukon Gold	161	83	47	40	35	12	12	0	1
Mean	226	85	35	56	28	8	6	0	3
LSD ($\propto$=0.05)	57	43	14	17	11	5	9	1	5

Table 3. Quality attributes, including specific gravity, internal disorders and bruise potential for advanced fresh market selections and cultivars, Crystal, ND, 2018. The fresh market trial was planted on May 30, vinekilled on approximately September 10, and harvested with a single-row Grimme harvester on September 25, 2018. The replicated plots were 20 feet long, with a 12-inch with-in row spacing, and 36 inches between rows. No hollow heart or brown center were found, thus not reported.

Clone	Tubers per Plant	Specific Gravity[1]	Black-spot Bruise[2]	Shatter Bruise[3]
1. ND6002-1R	5.9	1.0860	2.5	2.7
2. ND081571-2R	8.0	1.0833	1.4	2.2
3. ND081571-3R	8.2	1.1009	2.4	2.8
4. ND7102663B-3R	9.0	1.0974	2.3	2.7
5. ND102990B-2R	11.7	1.0833	1.5	2.6
6. ND113091B-2RY	10.9	1.0940	3.5	1.5
7. ND1232B-1RY	9.6	1.0938	3.2	1.9
8. ND1241-1Y	6.9	1.1068	2.0	2.2
9. ND1243-1PY	9.2	1.0934	2.8	2.9
10. ND12128B-1R	8.5	1.1019	2.5	2.7
11. ND1360B-1RY	9.3	1.0849	2.3	2.4
12. ND1382-2R	11.3	1.0861	2.2	2.4
13. ND13179CB-1R	7.2	1.0887	2.4	2.8
14. ND13193B-1R	10.8	1.0931	2.3	2.6
15. ND13236C-10R	15.1	1.0884	2.3	2.6
16. ND13236C-11R	8.8	1.1004	2.7	2.1
17. ND13239C-3R	8.2	1.0862	2.2	2.3
18. ND13241C-6R	11.9	1.1083	2.1	2.5
19. All Blue	8.4	1.0973	3.3	2.1
20. Dakota Jewel	5.8	1.0860	3.3	3.3
21. Dakota Rose	5.8	1.0833	2.9	2.5
22. Dakota Ruby	12.0	1.0917	1.6	1.6
23. Gala	13.3	1.0830	3.4	1.4
24. Red LaSoda	12.0	1.0859	3.4	2.7
25. Red Norland	5.2	1.0791	3.8	3.1
26. Red Pontiac	5.0	1.0835	2.1	2.8
27. Romanze	8.1	1.0954	3.6	2.4
28. Sangre	5.2	1.0809	2.7	2.3
29. Soraya	6.5	1.0773	3.0	1.7
30. Yukon Gold	4.8	1.0963	3.1	2.4
Mean	8.8	1.0905	2.6	2.4
LSD ($\propto$=0.05)	4.9	0.0107	0.8	0.7

[1] Determined using weight-in-air, weight-in-water method.
[2] Blackspot bruise determined by the abrasive peel method, scale 1-5, 1=none, 5=severe. As an example, Ranger Russet typically rates as a 4.0 or greater.
[3] Shatter bruise is evaluated using a bruising chamber with digger chain link baffles. Tubers are stored at 45F prior bruising. Shatter bruises are rated on a scale of 1-5, with 1 = none and 5 = many and severe.

Table 4. Agronomic and quality assessments for advancing chip processing selections and cultivars, Hoople, ND, 2018. The chip processing was planted on May 31, 2018, vinekilled approximately September 11, and harvested on September 26 using a single-row Grimme harvester. The replicated plots were 20 feet long, with a 12-inch with-in row spacing, and 36 inches between rows.

Clone	Stand %	Vine Size[1]	Vine Matur-ity[2]	Specific Gravity[3]	Shatter Bruise[4]	Black-spot Bruise[5]	General Rating[6]
1. ND7519-1	89	3.8	3.3	1.0989	2.8	2.0	3.3
2. ND7799c-1	78	3.0	3.4	1.0877	2.1	1.2	4.0
3. ND8331Cb-2	93	4.0	3.0	1.1017	2.5	1.5	3.3
4. ND092018C-2	89	3.3	3.3	1.0997	2.9	3.2	2.0
5. ND102631AB-1	94	2.5	1.5	1.0928	3.1	1.3	3.3
6. ND102917C-1	76	2.5	3.5	1.0812	2.9	1.2	2.7
7. ND102921C-3	93	4.0	3.0	1.0918	2.5	1.3	3.5
8. ND102922C-3	91	3.0	2.5	1,0902	2.4	1.6	3.3
9. ND113278-3	89	3.0	1.1	1.0929	2.8	3.3	3.3
10. ND113307C-3	94	4.0	3.6	1.0917	3.1	1.5	3.1
11. Atlantic	94	3.8	3.3	1.0951	2.4	1.6	3.3
12. Dakota Crisp	93	4.3	4.0	1.0869	2.2	2.2	3.5
13. Dakota Diamond	83	4.8	3.8	1.0932	2.8	1.5	3.4
14. Dakota Pearl	88	3.5	3.1	1.0950	2.7	1.2	3.4
15. Ivory Crisp	88	4.3	4.0	1.0917	2.9	1.3	1.5
16. Lamoka	75	4.3	3.8	1.1020	2.2	2.4	3.3
17. Norchip	91	3.8	3.0	1.0963	2.0	2.6	2.9
18. NorValley	81	3.8	3.0	1.0874	2.5	2.4	3.0
19. Snowden	95	4.5	4.0	1.0905	1.9	2.7	3.3
20. Waneta	63	3.0	3.0	1.0866	1.9	1.6	3.1
Mean	87	3.6	3.2	1.0928	2.5	1.9	3.1
LSD ($\propto$=0.05)	11	0.6	0.6	0.0079	0.8	0.8	0.6

[1] Vine size – scale 1-5, 1 = small, 5 = large.
[2] Vine maturity – scale 1-5, 1 = early, 5 = late.
[3] Specific gravity determined by weight-in-air, weight-in-water method.
[4] Shatter bruise – scale 1-5, 1= none; 5 = severe.
[5] Blackspot bruise determined by the abrasive peel method, scale 1-5, 1=none, 5=severe. For example, Ranger Russet, a blackspot bruise susceptible cultivar, generally rates as a 4.0 or higher
[6] General rating based on yield, appearance, tuber size profile, shape, set, defects; scale of 1 to 5; 1 = poor, 5 = excellent (perfect).

Table 5. Yield and grade for advancing chip processing selections and cultivars, Hoople, ND, 2018. The chip processing was planted on May 31, 2018, vinekilled approximately September 11, and harvested on September 26 using a single-row Grimme harvester. The replicated plots were 20 feet long, with a 12-inch with-in row spacing, and 36 inches between rows.

Clone	Total Yield cwt./a	Yield A Size cwt/a	A Size %	0-4 oz. %	4-6 oz. %	6-10 oz. %	>10 oz. %	US 2s & Culls %
1. ND7519-1	247	166	67	16	45	22	13	4
2. ND7799c-1	270	131	48	35	35	13	17	0
3. ND8331Cb-2	235	121	51	44	42	9	2	3
4. ND092018C-2	249	146	58	39	45	13	2	1
5. ND102631AB-1	225	135	60	20	43	17	9	11
6. ND102917C-1	133	61	47	24	33	13	25	4
7. ND102921C-3	243	113	46	50	38	8	4	0
8. ND102922C-3	270	114	42	58	34	8	0	0
9. ND113278-3	224	129	58	31	45	13	11	0
10. ND113307C-3	275	194	70	18	48	22	12	0
11. Atlantic	316	167	54	13	37	17	29	4
12. Dakota Crisp	340	195	57	18	39	18	23	2
13. Dakota Diamond	343	170	50	11	32	18	34	5
14. Dakota Pearl	275	148	54	37	42	12	8	1
15. Ivory Crisp	268	133	50	24	36	14	18	9
16. Lamoka	236	132	56	14	37	19	30	0
17. Norchip	324	153	46	44	38	9	4	6
18. NorValley	279	135	47	18	32	16	32	2
19. Snowden	290	169	58	23	42	16	17	2
20. Waneta	174	94	55	18	37	18	27	0
Mean	262	141	54	28	39	15	16	3
LSD ($\propto$=0.05)	53	39	9	10	7	5	10	5

Table 6. Chip color (USDA chip chart and HunterLab L-value) after grading and following 8-weeks storage at 3.3C (38F) and 5.5C (42F) for advancing chip processing selections and cultivars, Hoople, ND, 2018. The chip processing was planted on May 31, 2018, vinekilled approximately September 11, and harvested on September 26 using a single-row Grimme harvester. The replicated plots were 20 feet long, with a 12-inch with-in row spacing, and 36 inches between rows.

	Field Chip		3.3C Storage		5.5C Storage	
Clone	Chart[2]	Hunter[3]	Chart	Hunter	Chart	Hunter
1. ND7519-1	4	57	8	41	4	59
2. ND7799c-1	5	59	8	42	5	52
3. ND8331Cb-2	5	55	8	43	5	54
4. ND092018C-2	5	54	10	32	7	48
5. ND102631AB-1	5	56	7	45	5	56
6. ND102917C-1	6	53	9	36	8	45
7. ND102921C-3	5	55	8	44	5	52
8. ND102922C-3	5	54	9	38	6	52
9. ND113278-3	5	55	9	35	6	54
10. ND113307C-3	4	56	9	34	8	47
11. Atlantic	6	53	10	35	8	46
12. Dakota Crisp	5	56	9	35	8	44
13. Dakota Diamond	7	52	9	35	8	41
14. Dakota Pearl	5	55	8	41	8	50
15. Ivory Crisp	6	54	10	33	5	47
16. Lamoka	5	59	9	38	8	52
17. Norchip	6	50	10	33	6	43
18. NorValley	6	53	9	35	8	49
19. Snowden	6	52	9	33	7	48
20. Waneta	5	57	7	47	5	54
Mean	5	55	9	38	6	50
LSD ($\propto$=0.05)	1	5	1	6	1	5

[1] Potato Chip Color Reference Standard, Courtesy of B.L. Thomas, B.L. Thomas and Associates, Cincinnati, Ohio, Potato Chip Institute International. 1 = white, 10 = very dark; 4 and below acceptable.
[2] HunterLab L value – 60 minimum, 70 preferred.

Table 7. Agronomic, yield and quality evaluations for advanced processing selections and cultivars, full season dual-purpose russet trial, Larimore, ND, 2018. The processing trial was planted on May 22, killed by frost on September 29, and harvested on October 21, 2018, 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. Due to frost damage, the trial was not graded; additionally, processing quality was compromised, so French fry evaluations were not conducted.

Clone	Vine Size[1]	Vine Maturity[2]	Total Yield Cwt/acre	Specific Gravity[3]	% Hollow Heart[4]	General Rating
1. AH66-4	2.3	1.8	497	1.0866	3	3.1
2. ND8068-5Russ	2.0	1.0	299	1.0885	5	2.9
3. ND050032-4Russ	3.3	3.8	527	1.0878	27	3.5
4. ND060735-4Russ	3.3	3.8	441	1.0939	25	3.6
5. ND070927-2Russ	3.3	2.4	522	1.0896	5	3.3
6. ND113100-1Russ	3.3	2.5	386	1.0893	10	3.1
7. ND12154AB-2Russ	4.0	3.3	523	1.0984	3	3.6
8. ND12241YB-2Russ	4.0	3.5	474	1.1043	24	3.6
9. ND13245C-3Russ	2.5	1.8	411	1.0952	4	2.6
10. ND13245C-4Russ	3.3	3.5	401	1.1109	25	2.5
11. ND13245C-7Russ	3.0	2.5	500	1.0961	4	3.3
12. Alpine Russet	4.0	4.0	591	1.0919	0	3.3
13. Alturas	4.3	3.8	539	1.0929	5	3.1
14. Bannock Russet	4.0	4.0	454	1.0775	30	3.6
15. Clearwater Russet	4.0	4.0	453	1.1037	8	3.5
16. Dakota Russet	3.8	4.0	441	1.0859	11	4.1
17. Ranger Russet	3.8	3.5	496	1.1037	9	2.6
18. Russet Burbank	4.0	3.0	541	1.0892	15	1.9
19. Russet Norkotah	3.0	2.0	471	1.0824	23	4.3
20. Shepody	3.8	2.5	478	1.0853	4	2.5
21. Umatilla Russet	4.0	3.5	613	1.1009	0	2.8
Mean	3.5	3.0	475	1.0926	11	3.2
LSD ($\propto$=0.05)	0.7	0.7	129	0.0116	10	0.6

[1] Vine size – scale 1-5, 1 = small, 5 = large.
[2] Vine maturity – scale 1-5, 1 = early, 5 = late.
[3] Determined using weight-in-air, weight-in-water method.
[4] Hollow heart includes brown center.

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

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Summary

Root-lesion nematode, *Pratylenchus penetrans*, is known to cause detrimental effect on growth and yield of potato. Infection by this nematode increases stress in plants making them vulnerable to other plant pathogens. Planting resistant potato cultivars and use of non- or poor hosts in crop rotation plan is an effective, economic and environmentally sound approach to manage this nematode in fields. A total of 13 crop cultivars including five from potatoes and eight from rotational crops (corn, soybean, wheat and barley) were evaluated in the greenhouse to determine their hosting abilities to *P. penetrans*. Two greenhouse experiments were set up in July and October 2018, respectively, using naturally infested field soil from a potato field in Central Minnesota. In experiment 1, potato cultivar Russet Norkotah was classified as a very good host, three cultivars (Russet Burbank, Ranger Russet, and Milva) as good hosts, and cultivar Yukon Gold as a minor host. In experiment 2, three potato cultivars (Russet Norkotah, Ranger Russet, and Russet Burbank) were good hosts while the rest of the cultivars were minor hosts. Among the rotational crops, *P. penetrans* reproduced more in soybean and corn cultivars than in barley and wheat cultivars. Barley cultivars Quest and Morex, and wheat cultivar Barlow were minor hosts while all the other rotational crop cultivars were good hosts from the combined experiments. No crops tested were identified as non-hosts and poor hosts of *P. penetrans*. Our results indicate high virulence of the *P. penetrans* populations in some potato, corn and soybean cultivars with ability to reproduce quickly. Information from this study will help growers understand host status of different cultivars to *P. penetrans* to select better crop cultivars to suppress nematode populations and increase potato tuber yield.

Background

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

Host status of *P. penetrans* is cruicial to develop effective crop rotational scheme in order to manage this nematode. *P. penetrans* populations were incresed to higher levels in potato and the rotational crops oat and corn than in rye, wheat and sorgho-sudangrass in pot experiments

(Florini and Loria 1990). Hosting ability was found to be variable within cultivars of crops (Florini and Loria 1990; Be´lair et al. 2007; Zasada and Moore 2014). Hence, information on hosting suitability of specific crop cultivars to *P. penetrans* is important for designing a successful rotational plan. However, the resistant or susceptible levels of potato cultivars to *P. penetrans* population in our region and the host status of Northern-grown crops in rotation with potato to *P. penetrans* are not well known.

The objectives of the project were to 1) evaluate five potato cultivars used in ND and MN for resistance reactions to the root-lesion nematode *P. penetrans*; and 2) determine the host range of *P. penetrans* for 8 cultivars of corn, soybean, wheat and barley grown in rotation with potato in our region.

Materials and Methods

Selection of crop cultivars

A total of 13 crop cultivars were selected from potato crop and rotational crops including corn, soybean, wheat, and barley which are commonly grown in the region of North Dakota and Minnesota. Five potato cultivars were used in this study which include Yukon Gold, Russet Burbank, Milva, Russet Norkotah, and Ranger Russet. Two cultivars were selected for each of the four rotational crops (Table 1). All the seed potatoes were provided by potato research facilities at the North Dakota State University, obtained from seed potato farms. Other crop seeds were taken from seed stocks at Nematology Laboratory, NDSU, obtained from NDSU breeding programs and extention personnel.

Preparation of crop seeds

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

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

Narurally infested soil was collected from a potato field in central Minnesota. This field was identified to be infested with *P. penetrans* during our previous soil surveys. Infested soil was put in plastic bags holding approximately 15 kg of soil. Bags with infested soil were placed in coolers to prevent heat stress to nematodes during transportation. Later, these bags were stored at 4°C in cold room to avoid changes in nematode populations until soils were processed within 2-3 days. Infested soils from plastic bags were spread in a big plastic tray and mixed throughly for hours to ensure uniform nematode distribution. Three sub-samples of 0.2 kg were taken from the bulk of mixed soil. Nematodes were extracted separately from each sub-sample using sugar centrifugal-floatation technique (Jenkins 1964). Root-lesion nemaotdes were identified and counted under an inverted light microscope and recorded as total number of individuals per 0.2 kg of soil. Species identity of root-lesion nematodes in this field was confirmed as *P. penetrans* using the molecular method developed in our lab (Baidoo et al. 2017). Average of nematode populations from three sub-samples was calculated and used to determine the initial nematode density in the greenhouse trials.

Greenhouse experiments

Two greenhouse trials were conducted to evaluate the hosting ability of different crop cultivars to *P. penetrans*. In the first and second experiments, the initial population density of *P. penetrans* was 450 per plant per pot during planting. Experiments 1 and 2 were set up in July and October of 2018, respectively. Nematode populations used in both trials were obtained from the same field as described above.

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

Nematode extraction from soil and roots, and identification and counting

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

Reproduction factor and ratings

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

Data analysis

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

Results

First experiment

Potato cultivar, Russet Norkotah and soybean cultivar, 50948N had the highest reproduction of *P. penetrans* compared to all other potato cultivars and rotational crop cultivars of corn, soybean, wheat and barley (Table 1). There was significant variation in reproduction of *P. penetrans* on these cultivars (Fig. 1). Population of *P. penetrans* declined by 80 % in the non-planted control (Fig. 1). Based on Rf values of potato cultivars, Russet Norkotah was classified as a very good host (Rf = 10), and Russet Burbank, Milva, and Ranger Russet were good hosts (Rf = 5.0 to 8.0) while Yukon Gold was a minor host (Rf = 2.1) of *P. penetrans* (Table 1). Similarly, almost all the rotational crop cultivars were good hosts (Rf = 5.0 to 9.8) except that wheat cultivar Barlow and barley cultivar Quest were ranked as minor hosts (Rf = 4.2 to 4.7). Percentage of nematodes recovered from soil and roots were variable between individual cultivars. Overall, 13 to 50% of the total nematodes were recovered from root tissues of the tested cultivars after growth of 90 days while the rest of the nematodes were obtained from soil.

Second experiment

Potato cultivars, Russet Norkotah and Ranger Russet, had the highest reproduction of *P. penetrans* compared to all other potato cultivars and rotational crop cultivars of corn, soybean, wheat and barley (Table 1). There was significant variation in reproduction of *P. penetrans* on these cultivars (Fig. 2). Population of *P. penetrans* declined by 100% in the non-planted control (Fig. 2). Potato cultivars Russet Burbank, Russet Norkotah, and Ranger Russet were good hosts while Yukon Gold and Milva were minor hosts (Table 1). Similarly, wheat cultivar Barlow, corn cultivar GX89VT2P, and barley cultivars Quest and Morex were minor hosts (Rf = 3.5 to 4.5) whereas all other rotational crops were good hosts (Rf = 5.00 to 6.3) (Table 1). Percentage of nematodes recovered from soil and roots were variable between individual cultivars. In general, 22 to 61% of the total nematodes were recovered from root tissues of the tested cultivars and the rest of the nematodes was recovered from soil.

Both experiments combined

Average of Rf values of each crop cultivar across two experiments was used to rank the hosting suitability to *P. penetrans*. Both barley cultivars, Quest and Morex, and one of the wheat cultivars, Barlow, were minor hosts with Rf of 4.1-4.4 while all the other rotational crop cultivars were ranked as good hosts with Rf of 5.2-8.0 (Table 2). Potato cultivars had variation in hosting abilities from minor to good hosts. Russet Burbank, Russet Norkotah, and Ranger Russet were designated as good hosts with Rf of 6.1-8.8 while Yukon Gold and Milva were classified as minor hosts with Rf of 3.5-4.8 (Table 2).

Conclusions

Host preference evaluation of nematodes in different crop cultivars is crucial to develop effective crop roation scheme as a strategy for nematode management in crop fields. In this study, we determined the hosting suitabilities of crop cultivars including potato and rotational crops (soybean, corn, wheat, and barley) to *P. penetrans* using naturally infested field soil under greenhouse conditions. *P. penetrans* populations used in this study were observed to reproduce well in most of the tested crop cultivars. Three potato cultivars were good hosts of *P. penetrans*. Two potato cultivars were ranked as minor hosts but still increased the population by at least 3.5-fold. The combined result of two trials showed two barley and one wheat cultivars as minor hosts while soybean and corn as good hosts. *P. penetrans* populations were observed to increase more than 8-fold in a single crop cycle in some potato and soybean cultivars. Our results indicate high virulence of these *P. penetrans* populations from a potato field in Central Minnesota, with ability to reproduce quickly. It would be wise for farmers to avoid the incorporation of cultivars which are good hosts of *P. penetrans* in rotational scheme with potato crop in order to manage this nematode. Barley cultivars which were minor hosts in this study have shown potential to be used as comparatively better rotational crop with potato. In future, a wide scale screening of more crop cultivars is required considering the well reproduction of *P. penetrans* in the tested cultivars and some variation in hosting abilities among individual crop cultivars.

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

Crop	Cultivar	Experiment 1[a]		Experiment 2	
		Rf[b]	Host ranking[c]	Rf	Host ranking
Wheat	Elgin	7.4	G	5.0	G
	Barlow	4.2	M	4.5	M
Corn	DK 43-46	8.0	G	5.5	G
	GX89VT2P	6.3	G	4.0	M
Soybean	SB88007N	7.9	G	6.3	G
	50948N	9.8	G	6.1	G
Barley	Quest	4.7	M	3.5	M
	Morex	5.0	G	3.8	M
Potato	Yukon Gold	2.1	M	4.9	M
	Russet Burbank	6.6	G	5.6	G
	Milva	5.0	G	4.5	M
	Russet Norkotah	10.0	VG	7.5	G
	Ranger Russet	8.0	G	7.4	G
Control	Non-planted	0.2	-	0.0	-

[a] Experiment 1 and 2 were conducted during July 2018 and October 2018, respectively, with initial nematode density of 450 *P. penetrans*/pot/plant.
[b] Rf (reproductive factor) is the mean reproductive factor of replications (n = 5) for each crop cultivar and was calculated by dividing the final population of target nematodes by the initial population of the nematodes.
[c] Host ranking was based on the categorization of reproductive factors into five classes: N = non-host (Rf < 0.1), P = poor host (Rf = 0.1 to 0.9), M = minor host (Rf = 1.0 to 4.9), G = good host (Rf = 5.0 to 9.9), and VG = very good host (Rf ≥ 10) as described by Smiley et al. (2014).

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

Crop	Cultivar	Average of reproductive factors in two trials	
		Rf [a]	Host ranking [b]
Wheat	Elgin	6.2	G
	Barlow	4.4	M
Corn	DK 43-46	6.8	G
	GX89VT2P	5.2	G
Soybean	SB88007N	7.1	G
	50948N	8.0	G
Barley	Quest	4.1	M
	Morex	4.4	M
Potato	Yukon Gold	3.5	M
	Russet Burbank	6.1	G
	Milva	4.8	M
	Russet Norkotah	8.8	G
	Ranger Russet	7.7	G
Control	Non-planted	0.1	-

[a] Rf (reproductive factor) values are the average of reproductive factors of *P. penetrans* among replications (n = 10) for each crop cultivar across two experiments. Rf of nematodes was calculated by dividing the final population of target nematodes by the initial population of the nematodes.
[b] Host ranking is based on the categorization of reproduction factor into five classes: N = non-host (Rf < 0.1), P = poor host (Rf = 0.1 to 0.9), M = minor host (Rf = 1.0 to 4.9), G = good host (Rf = 5.0 to 9.9), and VG = very good host (Rf $\geq$ 10), as described by Smiley et al. (2014).

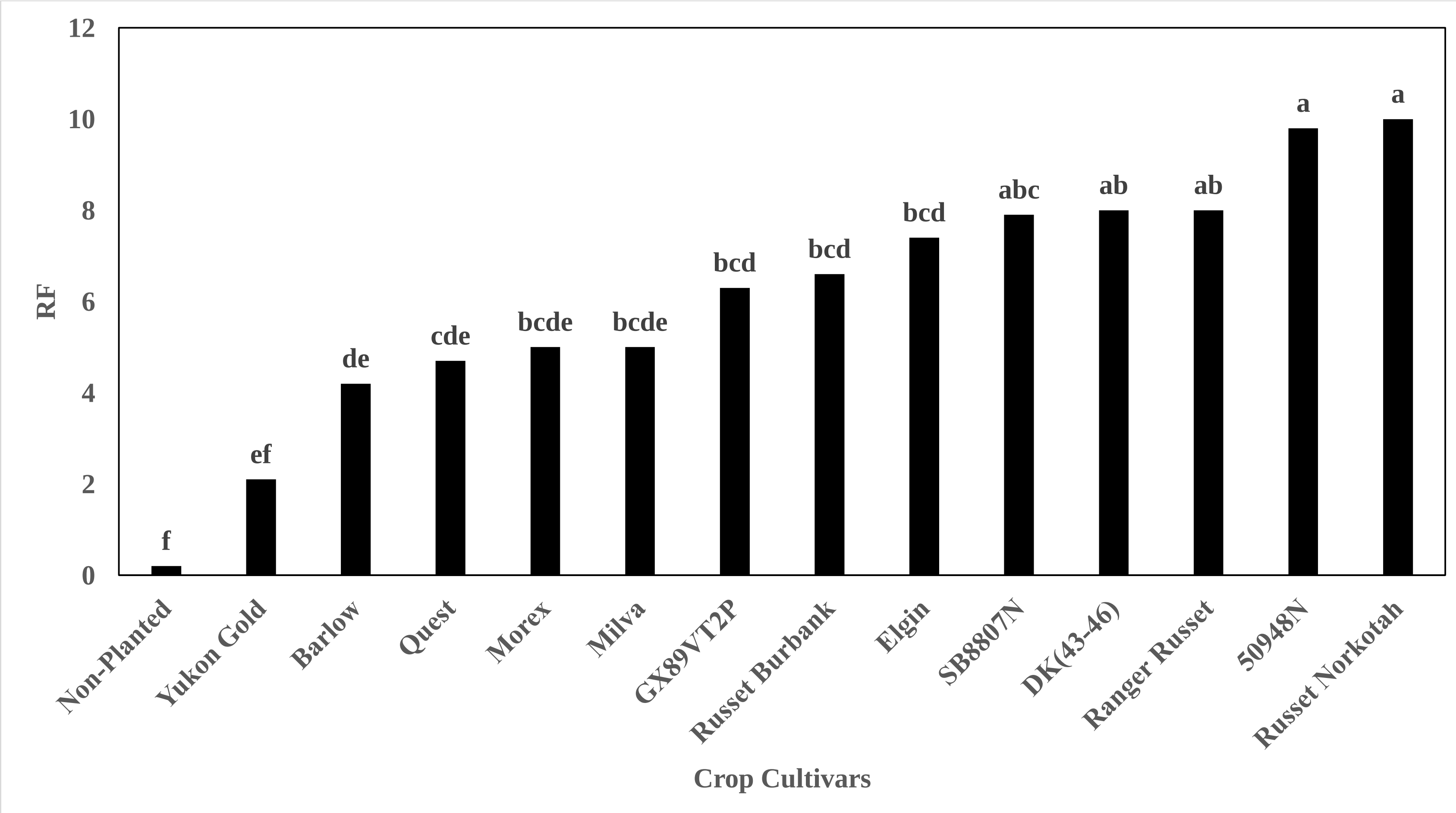

Fig. 1. Reproductive factor (Rf) values (ratio of final nematode population / initial population) of *P. penetrans* on thirteen crop cultivars grown in greenhouse conditions, with an initial density of 450 *P. penetrans*/pot/plant. Rf is the mean of five replications for each cultivar in experiment 1 conducted in July 2018. Rf values with same letters are not significantly different according to F-protected least significant different test ($P < 0.05$).

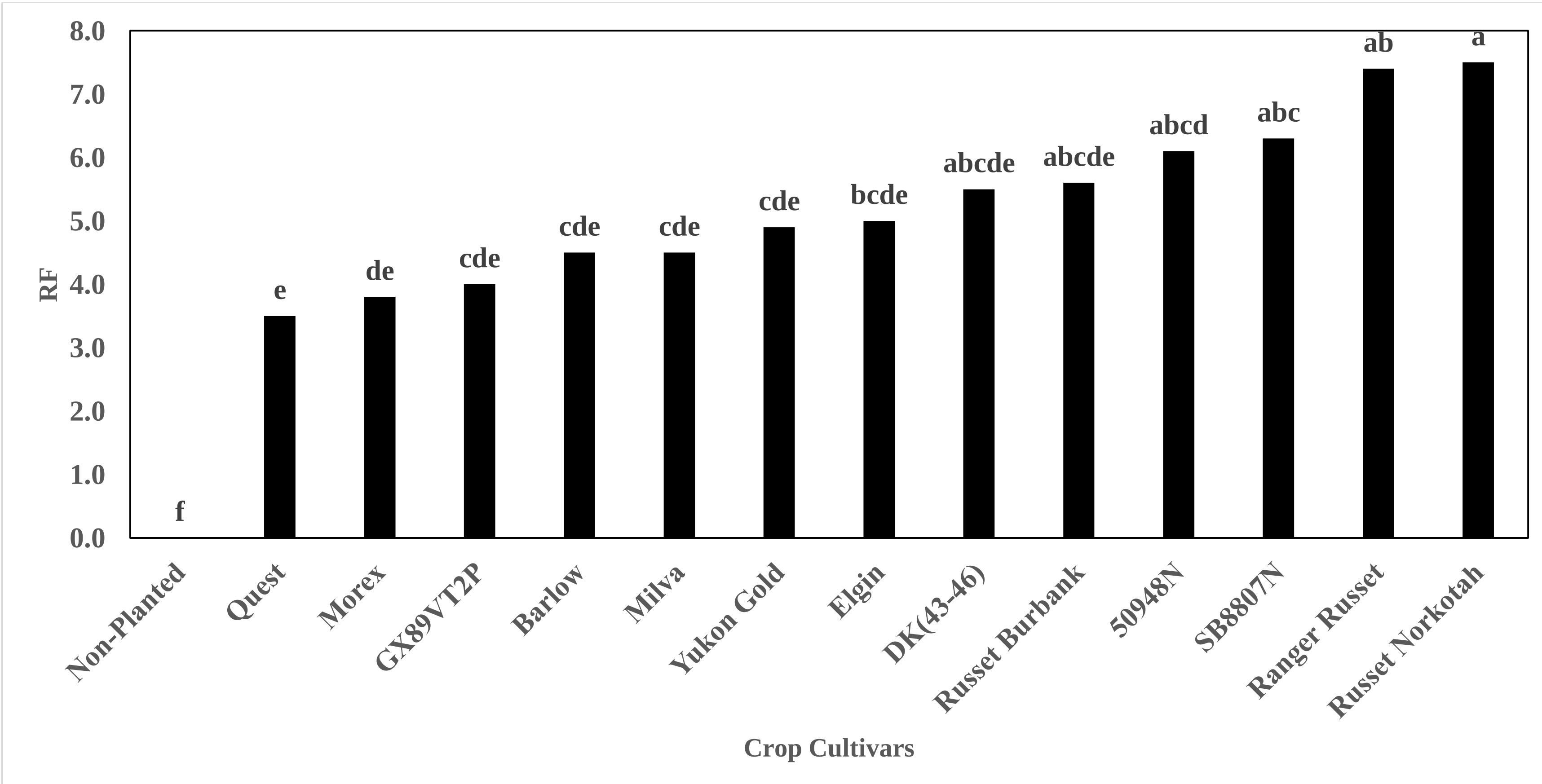

Fig. 2. Reproductive factor (Rf) values (ratio of final nematode population / initial population) of *P. penetrans* on thirteen crop cultivars grown in greenhouse conditions, with an initial density of 450 *P. penetrans*/pot/plant. Rf is the mean of five replications for each cultivar in experiment 2 conducted in October 2018. Rf values with same letters are not significantly different according to F-protected least significant different test ($P < 0.05$).