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NORTHERN PLAINS POTATO GROWERS ASSOCIATION

2017

RESEARCH REPORTS

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Bacterial Pathogens Associated with Potato Soft Rot and Black Leg In Minnesota and North Dakota

Final Report – February 2, 2017

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Collaborator: Andrew Robinson, Extension Potato Agronomist, Department of Plant Sciences, NDSU and UMN

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Summary

Several different pathogens cause soft rot diseases of potato. In the U.S., the most common are *Pectobacterium carotovorum* and *P. atrosepticum*. More recently, *Dickeya dianthicola* has emerged as an aggressive pathogen of black leg in the U.S. The purpose of this project was to conduct a survey of bacteria causing soft rot and black leg in production and certified seed fields in MN and ND. Specific protocols were included for estimating the frequency of *Dickeya* in the these states.

Stem and tuber samples with aerial soft rot or black leg symptoms were obtained from 18 collection times from commercial and seed fields. Samples were collected from six counties in MN and four in ND. Of 55 samples processed by October 15, presumptive soft rot bacteria were isolated from 48 samples. A total of 193 isolates were purified and stored, 126 of which were verified as soft rot enterobacteria (SRE). All isolates and tissue samples were tested with ADE1/ADE2 primers specific for *Dickeya* sp. Isolates were identified by 16S rDNA amplification and sequencing. Pathogenicity and phenotypic assays conducted on all isolates supported isolate identifications and completed Koch's postulates.

Dickeya dianthicola was detected in and isolated from only one sample, which came from a commercial field in MN. The tissue and three isolates from that sample tested positive with ADE1/ADE2 primers, and the isolates were identified as *D. dianthicola* by 16S rDNA sequencing. Four other MN tissue samples from commercial fields and one sample from a ND seed field tested positive for *Dickeya* sp. but none of the corresponding isolates were identified as *Dickeya*. This could be because *Dickeya* was not isolated on crystal violet pectate medium (CVP) as were other SREs, or because ADE1/ADE2 primers produced false positives with those samples. These results are being verified with additional PCR tests for identification of *Dickeya*. The majority of the 126 SRE isolates were identified as *P. wasabiae* (40%) and *P. carotovorum* subsp. *carotovorum* (37%), with 10% identified as *P. carotovorum* subsp. *brasiliensis* and only 6% (all from ND) as *P. atrosepticum*.

In conclusion, *Dickeya* was detected infrequently in potato stem and tuber samples from MN and ND in 2016. PCR detection of *Dickeya* with *pelADE* primers can identify isolates of *Dickeya* and tissues infected with *Dickeya*; however, results with *pelAD*E should be verified by other means, as some isolates of *Pectobacterium* test positive with this assay. This study identified, for the first time, that *P. wasabiae* and *P. carotovorum* subsp. *brasiliensis* are present

in potato production in MN and ND. We further confirmed the presence of *D. dianthicola* in MN. These findings will be submitted to the journal "Plant Disease".

Background

Soft rot diseases are found most years in the Northern Plains. In some years, like 2013, excessive rains and prolonged wet periods create ideal conditions. Soft rot symptoms in potato can take several forms. Black leg, non-emergence, tuber soft rots, and stem and leaf blights can develop depending on when and where the infection occurred. The specific bacteria causing the disease also influence the types and severities of symptoms. There are several common types of bacteria causing soft rot diseases. The most common are *Pectobacterium carotovorum, P. wasabiae*, and *P. atrosepticum.* In 2014-15, a particularly aggressive type of soft rot bacteria belonging to the genus *Dickeya* caused losses in the seed industry in Northeastern U.S. The pathogen, *Dickeya dianthicola* has since emerged as an aggressive pathogen of black leg in several U.S. seed-producing states. There is limited information on the species of soft rot bacteria present in the Northern Great Plains. The goal of this project was to provide baseline information on the species associated with soft rot diseases in certified seed and commercial potato in Minnesota and North Dakota. By determining the prevalence of *D. dianthicola* we can better understand the threat of this emerging pathogen in the region. MN Area II Potato Growers funded soft rot surveys in commercial potato production in MN and ND. A parallel soft rot survey in seed in ND and MN was supported by USDA/ARS and by MDA. This report covers progress on the survey of MN and ND seed and commercial potato.

Progress in 2016

Sample processing and bacterial isolations

In 2016, a total of 55 samples (32 MN and 23 ND) were processed as of October 15 (**Table 1**). Samples from six MN and four ND counties were obtained (**Table 2**). About twenty tuber samples from MN collected after harvest are being processed and results from these is not included in this report. Isolates of soft rot bacteria were obtained by culture-dependent methods. Briefly, a small piece of infected plant tissue was suspended in phosphate buffer and serial dilutions spread on an improved semi-selective crystal violet pectate (CVP) medium containing AG366 pectin. For all samples, representative colonies causing pits on CVP were purified by repeated sub-culturing and retested for pectolytic activity on CVP. All isolates were catalogued and stored in glycerol stocks at -80C. In addition to purified isolates, small sections of plant samples and dilutions of plant extracts of all samples have been catalogued and stored at -80C.

PCR and DNA sequencing reactions

DNA was extracted using the DNeasy Blood and Tissue kit (Qiagen). DNA was extracted from all tissue samples (32 MN and 23 ND) and from all purified isolates (a total of 193: 110 and 83 from MN and ND, respectively). PCR amplification of the 16S rDNA gene of control DNA was completed and the products sequenced (ACGT Inc). DNA from *P. carotovorum* subsp. *carotovorum*, *P. wasabiae*, *D. dadantii* and *D. dianthicola* was obtained from Amy Charkowski (UW Madison) for use as controls in PCR and sequencing reactions. DNA of isolates and plant

materials obtained from commercial potato plants with black leg symptoms was included in PCR and sequencing reactions as controls. Sequences were compared using NCBI's BLAST tool.

Phenotypic characterizations

Pathogenicity and phenotypic assays (gram reaction, growth at 37 C, facultative anaerobic growth, pitting on CVP, and lack of fluorescence) were completed on all isolates. Results from phenotypic results were consistent with identification by 16S rDNA. In general, isolates identified as *P. wasabiae* failed to grow at 37C, while isolates of *P. carotovorum* subsp. *carotovorum, P. carotovorum* subsp. *brasiliensis,* and *D. dianthicola* grew at 37C.

Evaluation of PCR primers designed for detection of Dickeya

The primer pair pelADE1/2 is commonly used for diagnosis of soft rots caused by *Dickeya*. All MN (and ND) isolates and tissue samples were tested with ADE1/ADE2 primers. While processing samples from ND with classic black leg symptoms typical of *Dickeya*, we noted that few and sometimes none of the bacteria isolated tested positive with the pelADE1/2 primers. Thus, comparisons using pelADE1/2 in PCR reactions testing both infected plant samples and those obtained with purified isolates were made.

False positive identifications of isolates as *Dickeya* sp. were obtained with the ADE1/ADE2 primers. Six isolates tested positive for *Dickeya* with ADE1/ADE2 primers but were identified as *P. carotovorum* subsp. *carotovorum, P. carotovorum* subsp. *brasiliensis,* or *P. wasabiae* by 16S rDNA sequencing. Mixed cultures could explain these results, but isolates were purified multiple times and re-evaluate with similar results. No false negatives were detected, i.e. tissues were negative but isolates were positive for *Dickeya*.

Black leg and soft rot enterobacteria in MN

Dickeya dianthicola was detected in and isolated from only one sample, which came from a commercial field in MN (**Table 1**). The tissue and three isolates from that sample tested positive with ADE1/ADE2 primers, and the isolates were identified as *D. dianthicola* (**Table 1**) by 16S rDNA sequencing. Four other MN tissue samples from commercial fields and one stem sample from ND seed tested positive for *Dickeya* sp., but none of the corresponding isolates were identified as *Dickeya* by 16S sequencing or by PCR with ADE1/ADE2 primers (**Table 3**). This could be because *Dickeya* was not isolated on CVP, or because ADE1/ADE2 primers produced false positives with those samples. We are currently reevaluating these ADE+ tissue samples with other PCR tests for *Dickeya*.

Of 193 isolates evaluated, 126 were identified as soft rot enterobacteria (SRE). The majority of isolates were identified as *P. wasabiae* (40%) and *P. carotovorum* subsp. *carotovorum* (37%), with 10% identified as *P. carotovorum* subsp. *brasiliensis* and only 6% (all from ND) as *P. atrosepticum* (**Table 1**). Additional PCR tests with primers BR1f and L1r were used to verify isolates as *P. carotovorum* subsp. *brasiliensis*.

Conclusions

Dickeya was detected infrequently in potato stem and tuber samples from MN and ND in 2016. PCR detection of *Dickeya* with *pelADE* primers can identify isolates of *Dickeya* and tissues infected with *Dickeya*; however, results with *pelAD*E should be verified by other means,

as some isolates of *Pectobacterium* test positive with this assay. This study identified, for the first time, that *P. wasabiae* and *P. carotovorum* subsp. *brasiliensis* are present in potato production in MN and ND. We further confirmed the presence of *D. dianthicola* in MN. These findings will be submitted to the journal "Plant Disease".

Table 1. Description of soft rot stem and tuber samples from MN and ND processed between June 24 and October 15, 2016

Sample class	State	Number of collection areas	Number of samples processed	Number tissues samples positive for *Dickeya*[a]	Number of samples with pectolytic bacteria	Number of isolates stored	# isolates *Dickeya dianthicola*	# isolates Pa	# isolates Pc. sp.	# isolates Pcb	# isolates Pcc	# isolates Pw	# SRE[b] isolates in collection
Commercial	MN	3	12	5	11	49	3	0	1	5	21	12	42
	ND	1	1	0	1	3	0	0	0	0	0	0	0
Seed	MN	8	20	0	16	61	0	0	3	2	2	21	28
	ND	6	22	1	20	80	0	8	1	3	18	23	53
TOTALS		18	55	6	48	193	3	8	5	13	41	56	126

[a]PCR positive reaction for *Dickeya* with pelADE1/2 primers

[b]SRE= soft rot enterobacteria: *Dickeya dianthicola* (Dd), *Pectobacterium atrosepticum* (Pa), *Pectobacterium carotovorum spp.* (Pc), *Pectobacterium carotovorum* subsp. *brasiliensis* (Pcb), *Pectobacterium carotovorum* subsp. *carotovorum* (Pcc), *Pectobacterium wasabiae* (Pw).

Table 2. County origin of commercial and seed potato samples from Minnesota and North Dakota.

MN County	Sample Class	
	Commercial	Seed
Becker	4	2*
Clearwater	0	10
Lake of the Woods	0	3*
Polk	2	6
Roseau	0	1
Sherburne	4	0
Total	**10**	**22**

*samples not labeled as seed or commercial, but suspected to from seed

ND County	Sample Class	
	Commercial	Seed
Inkster	1*	0
Grafton	0	3
Pembina	0	4
Walsh	0	15
Total	**1**	**22**

*samples not labeled as seed or commercial, but suspected to be commercial

Table 3. Comparison of isolate identifications with tissue and isolate reactions with ADE1/2 primers.

	Reaction class based on *pelADE* primers[a]				
16S identification	Tissue (+) Isolate (+)	Tissue (+) Isolate (-)	Tissue (-) Isolate (+)	Tissue (-) Isolate (-)	# Isolates
Dickeya dianthicola (Dd)	3	0	0	0	3
Pectobacterium atrosepticum (Pa)	0	0	0	8	8
Pectobacterium carotovorum spp. (Pc sp.)	0	1	0	4	5
Pectobacterium carotovorum subsp. *brasiliensis (Pcb)*	1	2	0	10	13
Pectobacterium carotovorum subsp. *carotovorum (Pcc)*	2	14	2	23	41
Pectobacterium wasabiae (Pw)	0	3	1	52	56

Grand total = 126and

[a](+) indicates a band of the correct size was amplified with ADE1/2 primers; (-) indicates no band was produced.

Baseline Evaluation of Pollinator Landscape Plantings Bordering Commercial Potato

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Executive Summary – ***Potatoes and Pollinators*:** This is a new research proposal to assess the impact of field border plantings of wild flower and/or native species on the population dynamics of pollinators. We will A) assess the pollinator communities found in these plantings and B) compare pollinator populations in potato fields with and without border plantings of wild flowers and/or native plants.

Rationale – There is no doubt that insect pollinators provide an invaluable economic and ecological service. Insects pollinate approximately 75%-85% of all food crop species in N. America and Europe; their economic contribution alone, in absence of the overwhelming ecological services, was estimated in 2005 at approximately US$167B worldwide (Gallai et al. 2009). There is, unfortunately, considerable evidence that pollinator populations are in decline in the U.S. and Europe (e.g. Biesmeijer et al. 2006, National Research Council of the National Academies 2007, Stokstad 2007). No single driver has been identified for these declines, but one important contributing factor is thought to be habitat loss, often resulting from the propagation of agricultural monocultures (e.g. Potts et al. 2010).

A number of programs funded or coordinated by either public or private support have attempted to conserve pollinator populations with plantings of wildfowers and/or native plants to diversify food sources for pollinators foraging within commercial agricultural landscapes. One such program is Operation Pollinator (Syngenta Crop Protection, Basel Switzerland). This program facilitates increasing biodiversity in agricultural habitats. In 2015, R.D. Offutt CO. planted ~500-600 ac of wildflowers in plots adjacent to commercial potato production, often in the corners of fields housing pivots or along roadsides. The plantings are in the vicinity of Grand Rapids, Wadena, Staples, and Perham MN. These pollinator landscape plantings may provide additional foraging locations for a number of insect pollinator species.

While honeybees are by far the most heavily managed pollinator, other pollinators may be important in crop production but little is known about their activity (Goulson 2003). Potatoes may provide an excellent research site for assessing the populations of these species. While commercial potatoes do not require pollination, and therefore have been largely ignored in pollinator landscape studies, pollinator visitation to potato fields may occur. Honeybees, however, may comprise a very small proportion of that community. Potatoes can be insect pollinated under natural conditions but require buzz pollination, or sonication. This process involves insects using flight muscles to shake pollen from flowers with poricidal anthers (the anthers have small holes, like a pepper shaker, that dispense pollen). This technique is common in many bumblebee species but is not used by honeybees. Honeybees have been demonstrated to not pollinate potatoes (Sanford and Hanneman 1981) while some species of bumblebee have

been found to selectively buzz-pollinate the plant, for example, the yellow-banded bumblebee, *Bombus terricola* Kirby (Batra 1993). This particular species, along with many other native bee species once common in Minnesota, has been under recent decline (Hatfield et al. 2012, Minnesota Department of Natural Resources 2015). Pollinator landscape plantings adjacent to commercial potatoes may, therefore, present a unique opportunity to provide additional foraging locations for important native pollinators. However, there is little data on the effectiveness of these techniques in potato.

We propose to provide baseline data on the pollinator communities attracted to pollinator landscape plantings near Minnesota commercial potato fields and to assess any impact such plantings may have on pollinator visits to commercial potatoes.

Procedures – A) Pollinator communities in the pollinator landscape plantings will be assessed by walking weekly, replicated sampling transects through a number of the same pollinator landscape plantings. Insect pollinator species will be identified and recording in place at regular intervals. In addition, pan traps will be assessed as a viable potential sampling method. If appropriate, these may augment or replace observational sampling. Pan traps used for monitoring pollinators are modified, small pans, painted multiple bright floral colors on the inside. Trap fluid is generally soapy water, consequently they must be checked within 24 hours to ensure trap catch and prevent excessive evaporation of fluid.

Pollinator landscape plantings to be sampled will be selected to provide a variety of size and be representative of commercial potato production. Pollinators will be identified to species when possible with particular attention paid to native and bumblebee species. Individual specimens of species which cannot be identified in the field will be returned to the laboratory at either the NWROC or NCROC and identified.

B) Similar sampling transects (and/or pan traps) will be conducted in the commercial potato fields adjacent to the pollinator landscape plantings. Commercial fields lacking adjacent pollinator landscape plantings of the same size (and preferably variety) will be identified and sampled for pollinators throughout the summer in a similar manner. Populations of pollinators in the two types of fields will then be compared.

Dr. Ian MacRae is located at the UMN-Northwest Research & Outreach Center in Crookston and has an active potato entomology program covering both MN and ND.

Dr. Chris Philips is located at the UMN- North Central Research & Outreach Center in Grand Rapids and has an active research program incorporating pollinator conservation and landscape impacts on agroecosystems.

Both are members of the Entomology department, have research and extension responsibilities, and conduct research in the general region of the pollinator plantings. The two research teams will cooperate on collecting and analyzing data and outreach activities resulting from the project.

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Results 2016 - Pollinator communities were sampled from pollinator plantings adjacent to commercial potato fields at three locations near Park Rapids, MN. Other commercial fields in close proximity had adjacent non-managed habitat (i.e. not planted into pollinator habitat). Non-managed areas were used as controls and pollinator and natural enemy (predators and parasitoids) were compared across pollinator plantings and control habitats. Population and community structure of pollinators, pests, and natural enemies were also compared between the pollinator plantings and commercial potato fields. Not all dates have had sampled insects completely sorted and consequently the data presented are only preliminary.

In comparing populations in planted pollinator habitat or unmanaged habitat bordering commercial potato fields, preliminary data indicate no significant differences in the abundance (Fig 1) or richness (Fig 2) of pollinators, natural enemies or pests; however, significant differences in abundance were observed in all three of these groups with increased distance into the commercial potato field (Fig 3).

These data indicate that while there does not seem to be an apparent difference in the number or richness of pollinators or natural enemies found in the control vs pollinator planting habitats, that pollinator plantings may well serve as reservoirs for both of these groups for commercial potato fields (note the decreasing number of both groups as distance into the commercial field increase, indicating the insects are immigrating from the edge. This may serve as a source for additional biological control services in commercial fields. At this point, we have not been able to see a significant difference between pollinator plantings and non-managed habitat adjacent to commercial fields. However, as the population and community structure analyses proceed, this may change.

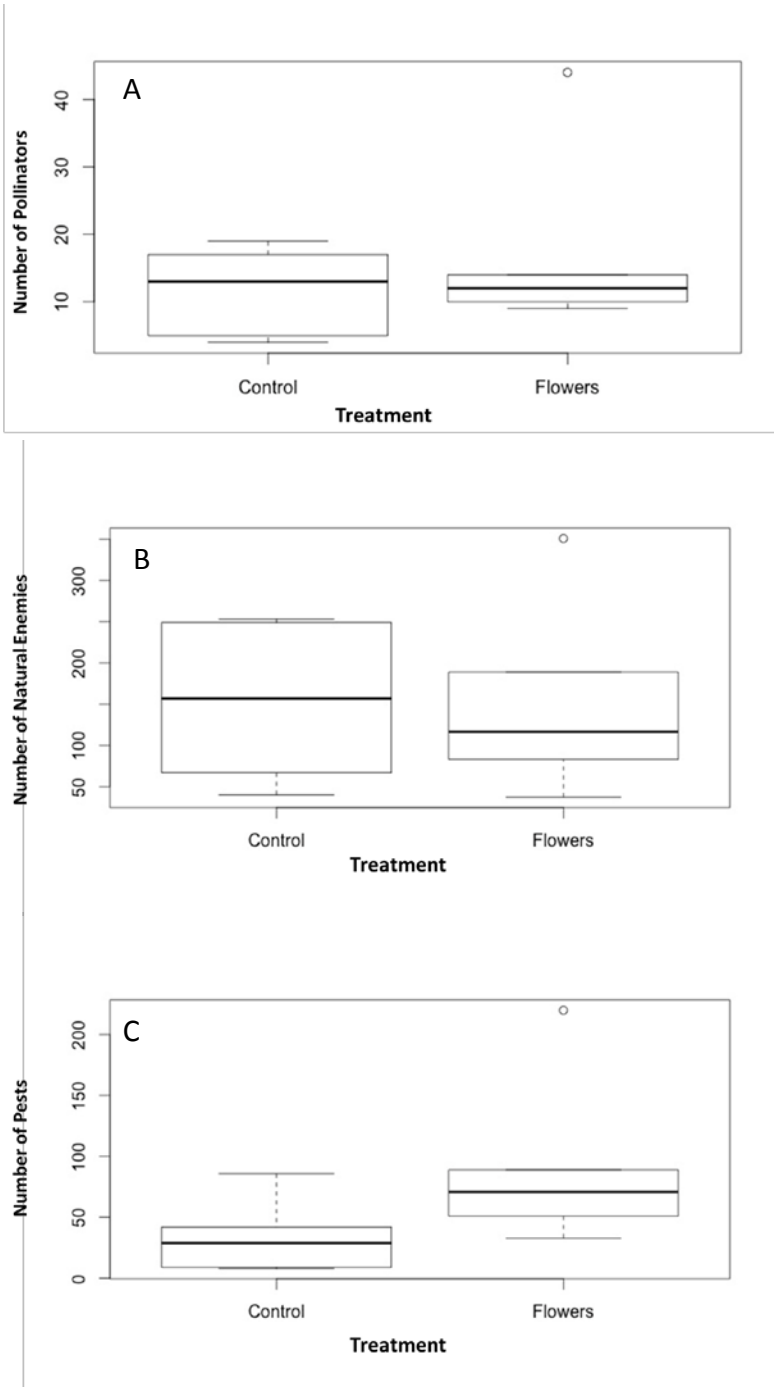

Figure 1. Total abundance of (A) pollinators, (B) natural enemies and (C) pest in wildflower plots adjacent to commercial potato fields (Flowers) and in unmanaged field margins (control). No significant differences were detected for any group.

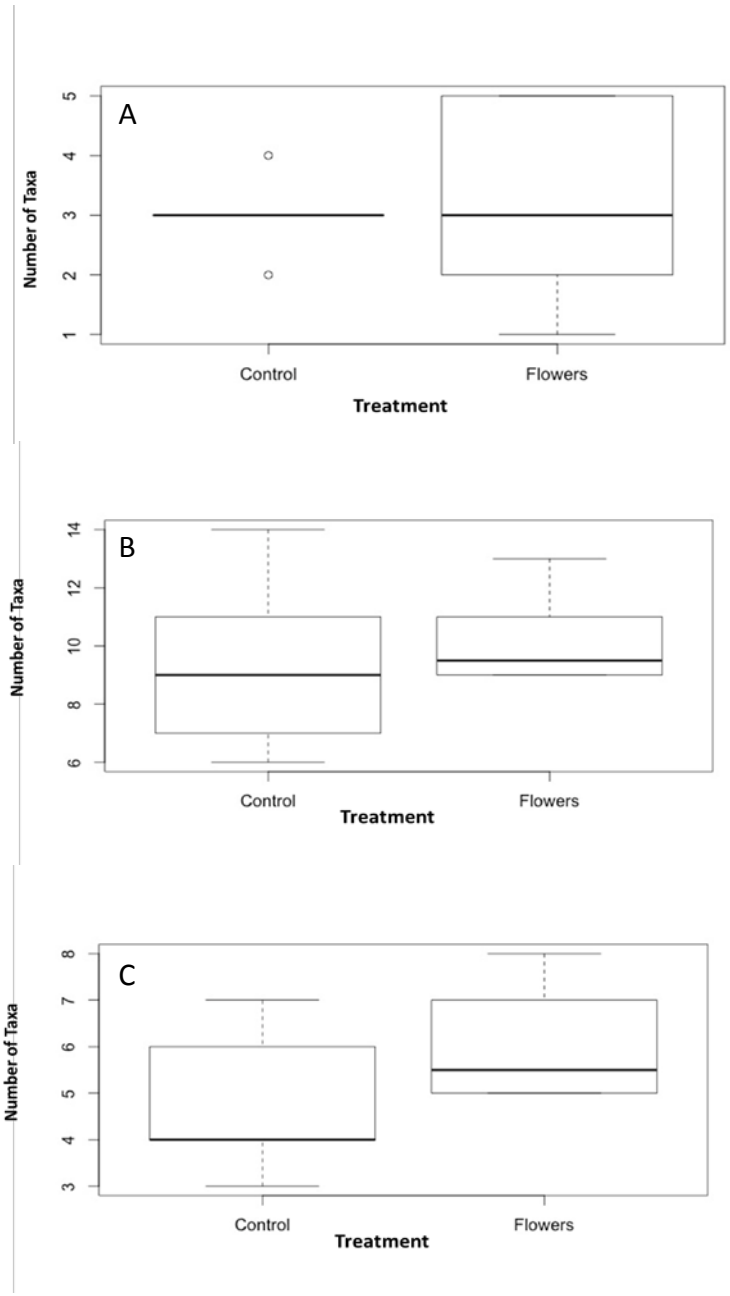

Figure 2. Total number of species of (A) pollinators, (B) natural enemies and (C) pest in wildflowers in plots adjacent to commercial potato fields (Flowers) and in unmanaged field margins (control). No significant differences were detected for any group.

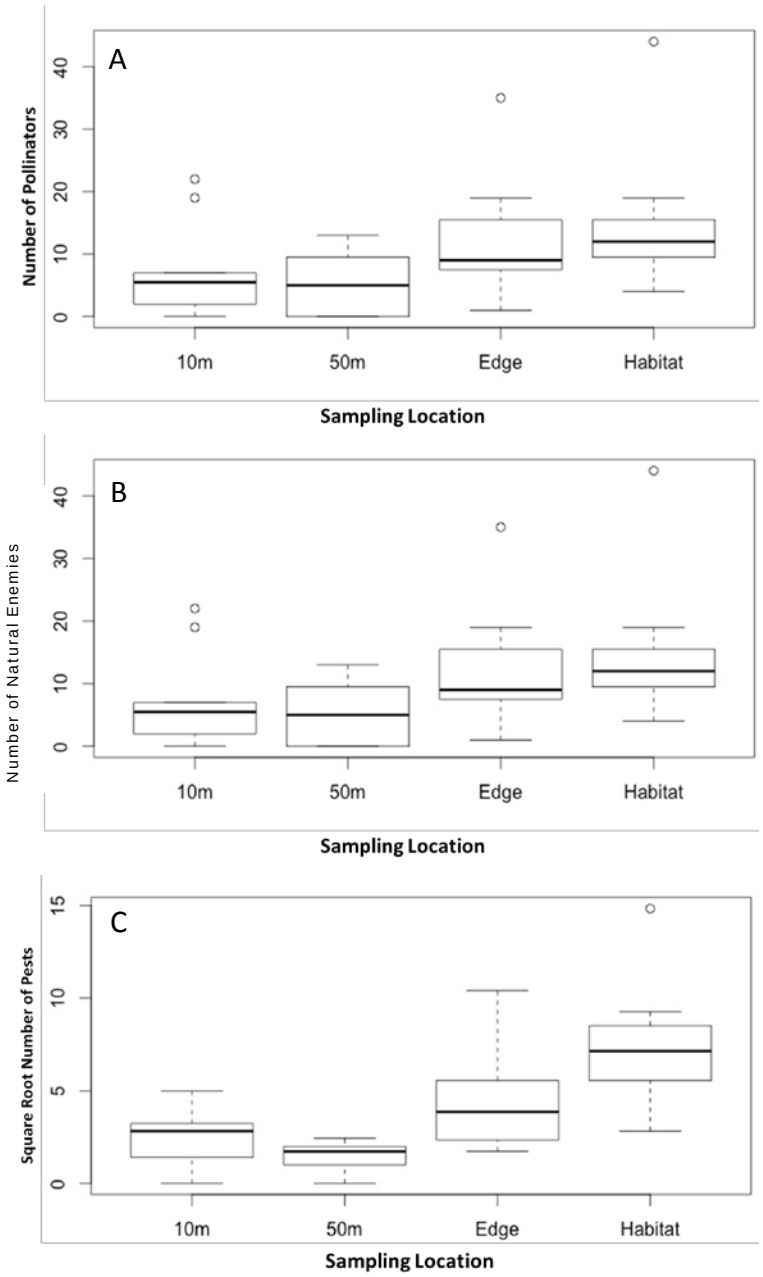

Figure 3. Total abundance of (A) pollinators, (B) natural enemies and (C) pest in wildflower plots adjacent to commercial potato fields (habitat) and at different distances within the potato fields. Significant differences were detected for pollinators ($p=0.04$), Natural enemies ($p<0.001$) and pests ($p<0.001$).

Boron Fertilization Effects on Tuber Stolon Retention and Reducing Sugar Concentrations

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Summary

Boron (B) plays a key role in the formation of a lignified, wound-sealing tissue layer during plant organ abscission as well as carbohydrate transport. We hypothesized that foliar B fertilization of potato plants shortly before vine kill would improve the abscission of stolons from the stem ends of tubers, reducing the percentage of tubers that retained stolons and improving tuber storage characteristics. Furthermore, previous research has found that B fertilization can increase tuber size and decrease tuber concentrations of reducing sugars in plants grown in B-deficient soils, and we predicted similar effects in our system. To test these possibilities, we planted Alpine Russet potatoes, a cultivar with a known tendency for tubers stolon retention, in a site with B-deficient soil. Treatments were applied with and without early- to midseason B applications and with and without heavy foliar B applications shortly before vine kill, with the heavy applications provided at two rates. Specifically, we used the following (six) treatments: (1) a zero-B check, (2) a treatment receiving 2 lbs·ac^{-1} granular B at planting, (3) two treatments receiving 2.2 or 4.4 lbs·ac^{-1} foliar B in two applications within 10 days before vine kill, and (4) two treatments receiving 0.55 or 0.825 lbs·ac^{-1} foliar B in four midseason applications plus 2.2 or 4.4 lbs·ac^{-1} foliar B, respectively, within 10 days before vine kill. Heavy foliar applications of B shortly before vine kill showed signs of B toxicity, but did not reduce tuber stolon retention rates. Glucose concentrations in the stem end tended to decrease ($P = 0.1$) with B application relative to the zero B control. This translated to a numerically lighter chip color. The treatments receiving midseason, light, foliar applications of B had decreased yields of undersized tubers compared to those receiving only the heavy applications shortly before vine kill. Tuber specific gravity was also lower in the four treatments receiving heavy applications of B shortly before vine kill than in the other two treatments, especially the zero-B check and is possibly related to B toxicity effects on vines, which in turn affected the ability of Alpine Russet tubers to mature properly.

Background

Boron (B) plays an important role in the abscission, or separation, of plant organs from the plant body, as occurs when leaves detach from broadleaf trees in autumn. In particular, B plays a key role in forming a lignified abscission layer, which serves as a scar, sealing the abscission wound. Boron is also involved in carbohydrate transport in plants.

Proper abscission of the potato stolon from the tuber is vital to long-term tuber storage. If the abscission does not occur or the abscission layer does not form, the tuber is left vulnerable to infection through the open wound where the stolon was broken off. B has been found to be important to successful tuber storage in large part because of its role in forming the protective abscission layer.

Alpine Russet potato tubers are known to frequently retain a short length of stolon after harvest. This trait is undesirable, because it can decrease the storability of the tubers and additional processing is required to ensure that all stolons have been removed before the tubers can be made into French fries. One objective of this study is to evaluate whether the application of a relatively large amount of B within 10 days before vine kill serves to correct this undesirable characteristic of Alpine Russet tubers. To address this question, we compared stolon retention rates in a zero-B

check treatment and a treatment receiving the recommended rate of granular B at planting compared with four different treatments receiving 2.2 or 4.4 lbs·ac^{-1} foliar B shortly before vine kill.

B is important to potato plants for many purposes beyond stolon abscission. For example, B-deficient plants produce smaller tubers with surface cracking and localized browning under the skin near the stolon end. B fertilization may also lower reducing sugar concentrations of potatoes grown in low-B soils. The objectives of this study were to evaluate the effects of heavy late-season foliar B applications on stolon retention rates and the effects of light midseason foliar B applications on tuber size distribution and quality.

Methods

Study design

The study was conducted in 2016 at the Sand Plain Research Farm in Becker, MN, on a Hubbard loamy sand soil. The previous crop was rye.

Six treatments were applied in a randomized complete block design with four blocks. These treatments included a zero-boron check treatment (treatment 1), a treatment receiving 2 lbs·ac^{-1} B as granular Boron 15 broadcast by hand at planting (treatment 2), two treatments receiving a total of either 2.2 or 4.4 lbs·ac^{-1} B as Borosol 10 in two applications in late summer before vine kill (treatments 5 and 6), and two treatments receiving 0.55 or 0.825 lbs·ac^{-1} B as Borosol 10 in four light mid-summer applications plus 2.2 or 4.4 lbs·ac^{-1} B as Borosol 10 in late summer (2.75 or 5.225 lbs·ac^{-1} B as Borosol 10 in total, respectively; treatments 3 and 4).

Soil sampling

To measure initial soil characteristics, soil samples to a depth of six inches were collected on March 28 and analyzed for Bray P, NH_4-Ac extractable K, Ca, and Mg, DTPA-extractable Fe, Mn, Zn, and Cu, $Ca(H_2PO_2)_2$/Ba-extractable SO_4-S, hot-water-extractable B, organic matter based on loss on ignition, and water pH. Soil samples to a depth of two feet were collected on April 11, dried for 48 hours at 95°F, and extracted in 2N KCl. The extract was analyzed for NO_3-N concentration using a Wescan nitrogen analyzer.

Planting

On April 15, in a field 240 feet long and 42 feet wide, 24 plots, each 20 feet long and 12 feet wide, were planted with Alpine Russet cut "A" seed with three-foot spacing between rows and one-foot spacing within rows. Plots were arranged three across, with seven, seven-foot-wide alleys running across the rows dividing the plots into eight groups. The field was surrounded by a buffer strip of Alpine Russet potato plants five feet wide on both ends and three feet (one row) wide along each side. Within each plot, the central two rows were designated at harvest rows, and a single Red Norland potato was planted at the end of each harvest row to visually demarcate the boundaries between plots during harvest.

Immediately before planting, SulPoMag (0-0-22-11S-22Mg) and MOP (0-0-60) were broadcast-applied to the whole field, each at 200 lbs·ac^{-1}, providing 164 lbs·ac^{-1} K, 44 lbs·ac^{-1} S, and 22 lbs·ac^{-1} Mg. At row opening, 40 lbs·ac^{-1} N, 102 lbs·ac^{-1} P_2O_5, 181 lbs·ac^{-1} K_2O, 40 lbs·ac^{-1} S, 20 lbs·ac^{-1} Mg, and 1 lb·ac^{-1} Zn were banded in as a blend of 222 lbs·ac^{-1} DAP (18-46-0), 180 lbs·ac^{-1} SulPoMag, 235 lbs·ac^{-1} MOP, and 2.8 lbs·ac^{-1} BluMin (17.5% S, 35.5% Zn).

Boron Treatments

The six treatments tested are described in Table 1. Two treatments received Borosol 10 in four applications at rates of 1 or 1.5 pints·ac^{-1} throughout the growing season (treatments 3 and 4, which received 0.55 and 0.825 lbs·ac^{-1} B, respectively, in these four applications). These applications occurred on June 28, July 12 and 25, and August 5 (41, 55, 68, and 79 days after hilling, respectively).

Four treatments received either 1 gal·ac^{-1} (treatments 3 and 5) or 2 gal·ac^{-1} (treatments 4 and 6) of Borosol 10 in each of two late-summer applications (totaling 2.2 or 4.4 lbs·ac^{-1} B). These heavy applications were made on August 17 and 23 (91 and 97 days after hilling).

Emergence

The plots were hilled on May 18. During hilling, 200 lbs·ac^{-1} N were banded in as Environmentally Smart Nitrogen (ESN, Agrium, Inc.).

Early-season plant stand was assessed for the harvest rows in each plot on June 2. At the same time, the number of stems per plant was calculated for ten harvest-row plants per plot.

Petiole sampling

The petiole of the fourth leaf from the shoot tip was collected from 20 shoots per plot at five times throughout the growing season. Petioles were dried for 24 hours at 140°F, ground, and sent to the Research Analytical Laboratory at the University of Minnesota to be analyzed for elemental concentrations using inductively coupled plasma analysis. Petioles were collected on June 6 and 30, July 14 and 28, and August 9 (19, 43, 57, 71, and 83 days after hilling, respectively).

Harvest

Vines were chopped on August 29. Tubers were harvested on September 7 and sorted by weight and USDA grade. One-hundred 6- to 10-ounce tubers from each plot were examined for stolon remnants.

Twenty-five-tuber subsamples were collected for each plot and stored at 45°F for two months, at which time they were assessed for hollow heart, brown center, and scab, and their specific gravity and dry matter content were determined.

Sixteen-tuber subsamples were collected for each plot and sent to USDA-ARS (East Grand Forks, MN) to determine the sucrose and glucose concentrations of the stem ends and bud ends, as well as the darkness of French fries made from the tubers. Fry color was determined based on a subjective chip color scale that ranged from 1 (lightest) to 5 (darkest), as well as an objective lightness score determined by a HunterLab D25 NC spectrophotometer.

Data analysis

Data were analyzed with SAS 9.4m3® software (copyright 2015, SAS Institute, Inc.) using the GLM procedure. For each dependent variable, treatment and block were used as predictor variables. Means were calculated and Waller-Duncan post-hoc pairwise comparisons between treatments made using the MEANS statement with the WALLER option with the threshold K ratio set to 50, equivalent to alpha = 0.10. Pairwise comparisons are only presented where the overall significance (P-value) of treatment in the model is less than 0.05.

In each model, four CONTRAST statements were used. The first compared the zero-B check treatment (treatment 1) with the remaining treatments. The second compared the treatment receiving granular B at planting (treatment 2) with the treatments receiving foliar B (treatments 3

– 6). The third compared the treatments receiving B at planting or in midseason (treatments 2 – 4) with those receiving no treatments prior to 10 days before vine kill (treatments 1, 5, and 6). The fourth contrast compared the treatments receiving one versus two gal·ac^{-1} Borosol 10 within 10 days before vine kill (treatments 3 & 5 vs. treatments 4 & 6).

Results and discussion

Initial soil B

Initial soil characteristics are presented in Table 2. B fertilization at 2 lbs·ac^{-1} is recommended when soil B concentration is lower than 1 ppm. Initial soil B in the study field averaged 0.11 ppm (range 0.095 – 0.128 ppm), well below this threshold. There is reason to expect fertilization with B to have a measurable effect on potato plants grown in this field. The high rates of foliar B before harvest resulted in B toxicity and enhanced vine kill (Figure 1).

Plant stand and stems per plant

Plant stand and the number of stems per plant are presented in Table 3. Neither variable was related to treatment.

Tuber yield

Tuber yield results are presented in Table 4. The yield of undersized tubers (under three ounces) was significantly related to treatment. As a group, the treatments receiving no B at planting or midsummer (treatments 1, 5 and 6) had higher yield in this size class than the treatments that received B at planting or midsummer (treatments 2 - 4). This is consistent with the expectation that B fertilization prevents the production of small tubers characteristic of B deficiency if B is provided before tuber bulking. However, the treatment receiving granular B at planting (treatment 2) had a slightly higher yield of undersized tubers than the zero-B check (treatment 1), which is in contrast to findings in other studies with B fertilization conducted at Becker. Additional studies are needed to evaluate soil and B effects on tuber size. Tuber yield and size were not otherwise significantly related to treatment.

Tuber quality

Tuber quality results are presented in Table 5. The proportion of tubers bearing stolon remnants on their stem ends was highly variable among plots, but unrelated to treatment. Hollow heart was not detected in the tuber subsamples, and only one tuber had brown center. The treatment receiving granular B (treatment 2) had a significantly higher prevalence of scab than the treatments receiving foliar B (treatments 3-6).

Specific gravity was highest in the zero-B check treatment (treatment 1), followed by the treatment receiving granular B at planting (treatment 2). Consequently, the contrast statement comparing the check with the other five treatments was statistically significant. It is possible that the high application rates of B resulted in premature plant death, slowing down late season tuber maturation. Alpine Russet is a long season potato and heavy applications of B in August may have reduced the ability for tubers to bulk and mature properly. This may also explain why the plots receiving the heavier pre-vine-kill application (treatments 4 and 6) had lower tuber dry-matter content than those receiving the lighter application (treatments 3 and 5).

Tuber sugars and fry color

Tuber sugar and fry color results are presented in Table 6. When comparing all six treatments, the overall effect of B treatment was not significant for tuber sucrose or glucose in either the stem or bud end of the tuber, nor for either measure of fry color. However, the contrast comparing the mean stem-end glucose concentration of the zero-B check treatment (treatment 1) with those of the B-fertilized treatments (treatments 2 – 6) did find a significant effect (P=0.1), with the check treatment having a higher stem-end glucose concentration than the others. This effect was reflected numerically in the subjective chip color scores. Because B is known to play a role in sugar translocation, these effects, though statistically weak, should be investigated further.

Conclusions

Because B is known to aid in plant organ abscission, we had hypothesized that B fertilization, particularly close to vine kill, would decrease the percentage of tubers that retained lengths of stolon after harvest, but we found no evidence that this occurred. B application tended to decrease tuber reducing sugar concentrations relative to the zero B control. Light foliar applications of B in midsummer apparently tended to decrease yields of undersized tubers, but no similar effect was observed for granular B applied at planting. Additional studies are required to understand the conditions under which B fertilization reduces yields of undersized tubers. The heavy application of foliar B within 10 days before vine kill appeared to reduce tuber specific gravity, possibly by causing early plant death, slowing down tuber maturation.

Table 1. B treatments applied to irrigated Alpine Russet potato plants at the Sand Plain Research Farm in Becker, MN, in 2016.

Treatment	Boron application method[1]	Boron applied before vine kill (lbs·ac^{-1})	Total boron applied (lbs·ac^{-1})
1	Zero-boron check	0	0
2	Boron 15 broadcast at planting	0	2
3	Borosol 10, 4 X 1 pint/ac late summer, 2 X 1 gal/ac before vine kill	2.2	2.75
4	Borosol 10, 4 X 1.5 pint/ac late summer, 2 X 2 gal/ac before vine kill	4.4	5.225
5	Borosol 10, 2 X 1 gal/ac before vine kill	2.2	2.2
6	Borosol 10, 2 X 2 gal/ac before vine kill	4.4	4.4

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

Table 2. Soil characteristics of the study site at the beginning of the season (April 11 for NO_3-N; March 28 for all other characteristics) at the Sand Plain Research Farm in Becker, MN, in 2016.

0 - 2 feet	0 - 6 inches											
Primary macronutrients			Secondary macronutrients			Micronutrients					Other characteristics	
NO_3-N	Bray P	K	SO_4-S	Ca	Mg	Zn	Fe	Mn	Cu	B	Organic matter	pH
ppm											%	
2.32	26	62	1	434	73.2	0.48	22.4	8.9	0.33	0.11	0.9	5.9

Figure 1. Symptoms of B toxicity in leaves of Russet Burbank potato plants following the two heavy foliar applications of B within 10 days before vine kill.

Table 3. Mean plant stand and number of stems per plant for each B treatment applied to Alpine Russet potato plants grown at the Sand Plain Research Farm in Becker, MN, in 2016.

Treatment	Boron application method[1]	Boron applied before vine kill (lbs·ac^{-1})	Plant stand (%)	Stems / plant
1	Zero-boron check	0	100.0	3.08
2	2 lbs·ac^{-1} as Boron 15 broadcast at planting	0	100.0	3.13
3	2.75 lbs·ac^{-1} in 6 applications of Borosol 10	2.2	100.0	3.40
4	4.95 lbs·ac^{-1} in 6 applications of Borosol 10	4.4	100.0	3.28
5	2.2 lbs·ac^{-1} in 2 applications of Borosol 10	2.2	99.3	3.00
6	4.4 lbs·ac^{-1} in 2 applications of Borosol 10	4.4	100.0	3.00
Treatment significance (P-value)			0.4509	0.6193
Treatment MSD (P < 0.1)			--	--
Contrasts	Zero-boron check vs. others (1 vs. 2-6)		0.6611	0.6882
	Boron preplant vs. foliar (2 vs. 3&4)		1.0000	0.3747
	Effect of early B fertilization (2-4 vs. 1,5&6)		0.3332	0.1394
	Pre-vine-kill application size (3 & 5 vs. 4 & 6)		0.2296	0.7463

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

Table 4. Effect of B treatment on tuber yield, size, and grade for Alpine Russet potato plants grown at the Sand Plain Research Farm in Becker, MN, in 2016.

Treatment	Boron application method[1]	Boron applied before vine kill (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}									%	
1	Zero-boron check	0	19 cd	79	164	169	167	598	511	68	579	84	66
2	2 lbs·ac^{-1} as Boron 15 broadcast at planting	0	21 cd	77	182	151	161	592	505	66	571	84	62
3	2.75 lbs·ac^{-1} in 6 applications of Borosol 10	2.2	22 bc	74	170	174	183	623	535	66	601	85	67
4	4.95 lbs·ac^{-1} in 6 applications of Borosol 10	4.4	16 d	83	171	154	165	589	496	76	573	83	64
5	2.2 lbs·ac^{-1} in 2 applications of Borosol 10	2.2	28 a	64	163	174	153	582	509	45	554	84	64
6	4.4 lbs·ac^{-1} in 2 applications of Borosol 10	4.4	27 ab	80	174	162	162	606	518	61	579	82	63
Treatment significance (P-value)			**0.0087**	0.8760	0.8061	0.5401	0.8042	0.4632	0.3307	0.5301	0.4258	0.9680	0.8017
Treatment MSD (P < 0.1)			5.5	--	--	--	--	--	--	--	--	--	--
Contrasts	Zero-boron check vs. others (1 vs. 2-6)		0.1401	0.8052	0.4925	0.6218	0.8902	0.9920	0.9187	0.7087	0.8366	0.9905	0.5339
	Boron preplant vs. foliar (2 vs. 3&4)		0.3856	0.8810	0.3739	0.3519	0.4906	0.4581	0.4622	0.7221	0.3930	0.8735	0.2943
	Effect of early B fertilization (2-4 vs. 1,5&6)		**0.0010**	0.6921	0.4302	0.3466	0.4594	0.6314	0.9256	0.2233	0.3821	0.8196	0.9732
	Pre-vine-kill application size (3 & 5 vs. 4 & 6)		0.1527	0.2881	0.5532	0.1609	0.7716	0.7425	0.2202	0.2594	0.9074	0.4001	0.4668

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

Table 5. Effect of B treatment on Alpine Russet tuber quality (prevalences of hollow heart, brown center, scab, and stem retention; tuber try matter content and specific gravity) at the Sand Plain Research Farm in Becker, MN, in 2016.

Treatment	Boron application method[1]	Boron applied before vine kill (lbs·ac^{-1})	Tuber quality					
			Hollow heart	Brown center	Scab	Tubers with stems	Dry matter	Specific gravity
			%					
1	Zero-boron check	0	0	1	4	40.5	19.0	1.0730 a
2	2 lbs·ac^{-1} as Boron 15 broadcast at planting	0	0	0	11	38.8	18.7	1.0699 ab
3	2.75 lbs·ac^{-1} in 6 applications of Borosol 10	2.2	0	0	6	44.0	19.3	1.0690 b
4	4.95 lbs·ac^{-1} in 6 applications of Borosol 10	4.4	0	0	1	46.0	17.9	1.0668 bc
5	2.2 lbs·ac^{-1} in 2 applications of Borosol 10	2.2	0	0	6	44.3	18.5	1.0653 c
6	4.4 lbs·ac^{-1} in 2 applications of Borosol 10	4.4	0	0	1	39.8	17.3	1.0669 bc
Treatment significance (P-value)			--	--	0.2374	0.7479	0.2867	**0.0088**
Treatment MSD (P < 0.1)			--	--	--	--	--	0.0034
Contrasts	Zero-boron check vs. others (1 vs. 2-6)		--	--	0.7610	0.6466	0.3562	**0.0015**
	Boron preplant vs. foliar (2 vs. 3&4)		--	--	*0.0626*	0.2215	0.8676	0.2166
	Effect of early B fertilization (2-4 vs. 1,5&6)		--	--	0.3741	0.6707	0.4721	0.8710
	Pre-vine-kill application size (3 & 5 vs. 4 & 6)		--	--	0.1158	0.7590	*0.0569*	0.7907

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

Table 6. Effect of B treatment on sucrose and glucose concentrations in the stem ends and bud ends of tubers and two measures of fry color (a subjective chip color score and a lightness score determined by a HunterLab D25 NC spectrophotometer) for Alpine Russet tubers grown at the Sand Plain Research Farm in Becker, MN, in 2016.

Treatment	Boron application method[1]	Boron applied before vine kill (lbs·ac^{-1})	Sucrose (mg/g)		Glucose (mg/g)		Fry color	
			Stem end	Bud end	Stem end	Bud end	Chip color 1 = lightest 5 = darkest	HunterLab score (higher = lighter)
1	Zero-boron check	0	0.34	0.77	2.42	0.91	4.00	44.2
2	2 lbs·ac^{-1} as Boron 15 broadcast at planting	0	0.36	0.69	2.12	0.90	3.75	45.8
3	2.75 lbs·ac^{-1} in 6 applications of Borosol 10	2.2	0.35	0.83	2.23	1.01	3.50	45.2
4	4.95 lbs·ac^{-1} in 6 applications of Borosol 10	4.4	0.41	0.67	2.34	1.12	3.75	43.0
5	2.2 lbs·ac^{-1} in 2 applications of Borosol 10	2.2	0.43	0.74	2.10	0.77	3.75	44.9
6	4.4 lbs·ac^{-1} in 2 applications of Borosol 10	4.4	0.44	0.58	1.82	0.97	3.25	46.2
Treatment significance (P-value)			0.7897	0.6218	0.1664	0.1907	0.3032	0.2081
Treatment MSD (P < 0.1)			--	--	--	--	--	--
Contrasts	Zero-boron check vs. others (1 vs. 2-6)		0.3881	0.5533	*0.0999*	0.6251	0.1233	0.4462
	Boron preplant vs. foliar (2 vs. 3&4)		0.7626	0.6386	0.4082	0.1466	0.6546	0.1312
	Effect of early B fertilization (2-4 vs. 1,5&6)		0.6312	0.6846	0.3761	0.1024	1.0000	0.5503
	Pre-vine-kill application size (3 & 5 vs. 4 & 6)		0.5822	0.1429	0.5895	0.1106	0.5844	0.5838

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

Developing a qPCR Assay to Determine Population Densities of Root-lesion Nematodes (*Pratylenchus penetrans*) in Soils to Be Planted to Potato

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Summary

Pratylenchus penetrans is the most economically damaging root-lesion nematode species affecting potato. This nematode causes economic losses on potato when acting alone, but even more severe losses by interacting with *Verticillium* wilt fungi, causing the Potato Early Dying disease. This disease causes significant reduction in tuber size and total marketable yield and thus can become a limiting factor in potato production. Accurate identification and quantification of *P. penetrans* prior to planting are essential for developing effective nematode control measures. However, distinction between *P. penetrans* and other *Pratylenchus* spp. based on morphology is a tedious task. A real-time quantitative PCR (qPCR) assay (SYBR Green I-based) was developed to discriminate, identify and quantify *P. penetrans* in field soil. *P. penetrans*-specific qPCR primers were designed from the D2-D3 genomic region. The specificity of the primers was evaluated using eight isolates of *P. penetrans* populations, 12 isolates of six closely related *Pratylenchus* species, and 19 isolates of other nematode species. A standard curve relating threshold cycle and log values of nematode number was generated from artificially infested soils. There was a high correlation between the *P. penetrans* numbers artificially added to soil or estimated from naturally infested field soils by conventional methods, and the numbers quantified using the qPCR assay. The qPCR assay will not only be useful for differentiating *P. penetrans* from mixed populations of *Pratylenchus* spp. and from other nematodes commonly present in potato fields, but also for efficient detection and quantification of *P. penetrans* from field soil. The assay requires no expertise in nematode taxonomy and morphology, and can serve as a useful diagnostic tool in research, diagnostic labs and extension services for pest management.

Background

Root-lesion nematodes (*Pratylenchus* spp.) are the most common nematode pests of potato. Several species in this group are detrimental to potato (Mahran et al. 2010). In the Midwest, the important species include *P. penetrans*, *P. neglectus*, *P. scribneri*, *P. thornei*, and *P. crenatus*. Among the species, *P. penetrans* is the most economically damaging species (Waeyenberge et al. 2009). Potato plant growth was negatively correlated with densities of *P. penetrans* and the yield of potatoes was reduced by 50% in an affected field in Norway (Holgado et al. 2009). In northeastern USA and Canada, *P. penetrans* causes economic losses on potato when acting alone, but even more severe losses by interacting with *Verticillium* wilt fungi, causing the Potato Early Dying disease complex. This disease complex causes significant reduction in tuber size and total marketable yield and therefore can become a limiting factor in potato production (Mahran et al. 2010).

Accurate identification of *P. penetrans* and awareness of population densities in fields are critical for designing effective measures to control this nematode. However, it is quite often difficult to separate *P. penetrans* from other *Pratylenchus* species based on their morphology. It is a challenge to count *P. penetrans* using the traditional microscopic method from a large number of field soil samples when other closely related nematodes are also present. Molecular technologies provide a rapid and accurate alternative to the microscopic method. A number of molecular techniques have been developed to detect and identify *P. penetrans* (Sato et al. 2007, Waeyenberge et al. 2009, Mokrini et al. 2013). However, there are no published procedures in the USA for identifying and quantifying *P. penetrans* using DNA extracted directly from field soil. The NDSU nematology team aims to develop a qPCR assay to determine population densities of *P. penetrans* in soils to be planted to potato. Sensitive and accurate detection and quantification of *P. penetrans* are important to help growers perform risk assessment and make the best management strategies for controlling the disease to increase potato yield and quality.

The objectives of the project were to 1) design new species-specific qPCR primers to identify *P. penetrans* and to discriminate the species from other closely related *Pratylenchus* species and other nematodes commonly present in MN and ND potato fields; and 2) develop a qPCR assay to quantify this species directly in DNA extracts of soil.

Materials and Methods

DNA extraction from pure culture and soil

Separate cultures of *Pratylenchus* spp. namely *P. penetrans*, *P. neglectus*, *P. thornei*, and *P. scribneri* were maintained on carrot discs at 22 °C in an incubator for three months at the North Dakota State University Nematology Laboratory. The nematodes were extracted from the carrot discs for DNA extraction as described by Subbotin et al. (2001). The DNA suspension was stored at -20 °C and used as DNA template. The same procedure was followed to extract DNA from other vermiform nematode species commonly found in potato fields in Minnesota and North Dakota. Total DNA was extracted from artificially infested soils and naturally infested field soils using the MoBio PowerSoil DNA Isolation Kit according to the manufacturers' protocol. DNA was stored at –20 °C prior to qPCR.

Primer design, specificity and sensitivity

The D2-D3 genomic region of the 28S rRNA gene of three populations of *P. penetrans* originating from three different potato fields in Minnesota was sequenced using the D2A/D3B universal primer set (Subbotin et al., 2008). The sequence information was compared with the published D2A/D3B sequence information of *P. penetrans* and other *Pratylenchus* spp. in GenBank. All the D2-D3 sequences collected were aligned with the DNASTAR software. To determine putative species-specific DNA fragments for *P. penetrans*, regions of the D2/D3 sequences conserved within *P. penetrans* but divergent from other *Pratylenchus* spp. in the aligned sequences were selected. Putative primers were synthesized and salt-purified. Each primer pair was evaluated on the basis of target specificity, amplification efficiency, endpoint fluorescence, and melting curve profile. The forward primer Pp-D2D3-F2 and the reverse primer Pp-D2D3-R2 (Table 1) was used for all the experiments.

The primer pair was evaluated for specificity to *P. penetrans* using DNA from 8 isolates of *P.*

penetrans from USA, 12 isolates of other *Pratylenchus* spp., and 19 isolates of other plant-parasitic nematodes (Table 2). Nematode DNA from a nematode community including *Helicotylenchus* sp., *Hoplolaimus* sp., *Tylenchorhynchus* sp. *Heterodera* sp., and *Paratrichodorus* sp. was extracted and used as a control in addition to a soil DNA extract from potato field soil without detectable *P. penetrans*. Detection sensitivity was performed using a fine textured sandy-loam soil (S-19) that did not have any detectable *P. penetrans* and autoclaved (121°C, 115 kPa) for 30 min for two consecutive days. Different numbers (0.5, 1, 2, 3, and 5) of *P. penetrans* were added to 0.5 g of autoclaved soil. The sensitivity of the qPCR assay was determined by detection of quantification cycle (Cq) values at the minimum level of infestation.

Real-time PCR assay

The qPCR assay was performed using the Bio-Rad CFX96 Touch™ Real-time PCR Detection System. The SsoAdvanced™ Universal SYBR® Green Supermix was used according to the instruction. The cycling conditions were as follows: incubation at 95 °C for 5 min; 35 cycles of 95 °C for 10 s and 66 °C for 20 s; and 72 °C for 30 s followed by melting curve analysis using the default settings to evaluate the amplification specificity. Non-template control, using ddH_2O instead of DNA in the PCR, was run for each experiment. All DNA templates were run in duplicates or triplicates. The data were analyzed using a computer program (Bio-Rad CFX Manager Software V3.1).

Development and validation of standard curves

The standard curve for the qPCR assay was generated from a specified number of *P. penetrans* added to a sterilized soil (S-19). Quarter-gram samples of the soil were infested with vermiform *P. penetrans* from pure culture at five population densities (0.5, 1, 5, 25, 125, and 625 / 0.25 g of soil). The soil standard curve was generated by plotting Cq versus log of the number of *P. penetrans* per gram of soil. Amplification efficiencies and the slopes of the plots were automatically generated from the slope of a plot of cycle threshold (Cq) (y-axis) and log of DNA (x-axis) ($E = 10^{(1/-m)} - 1$; where m is the slope). The soil standard curve was validated using the autoclaved soil inoculated with lower numbers of vermiform *P. penetrans* at 1, 5, 10, 20, 40, and 80 / 0.25 g of soil.

Pratylenchus penetrans detection and quantification in field soils

The qPCR assay was validated by comparing *P. penetrans* estimates determined by the qPCR assay and two conventional methods, Centrifugal sugar flotation (Jenkins 1964) and Whitehead tray method (Whitehead and Hemming, 1965). A total of 20 soil samples from potato fields or fields with a history of potato were collected from Minnesota. These fields were infested with different population densities of *P. penetrans* and other plant-parasitic and non-plant-parasitic nematodes. For each field soil sample, 600 g was collected for molecular and traditional nematode assays. The 600 g field soil was mixed thoroughly and divided into three subsamples of 200 g each. Two sets of subsamples were used for nematode identification and quantification using microscopy-based procedures and the third set for DNA extraction and qPCR.

For the molecular assay, 200 g of the field soil was air-dried at room temperature in petri dish overnight (9 h) and ground in 70 x 90 mm porcelain mortar with pestle for 4 min to obtain a smooth, homogenous texture; stones, roots debris and other materials were removed. A sub-

sample of 0.25 g was collected by at least 30 tiny scoops from different parts of the sample using a spatula. DNA was extracted from the 0.25 g subsample and amplified using the species-specific primer set Pp-D2D3-F2/R2. DNA extractions and qPCR amplifications were performed three times for each field sample under the optimum conditions. A no-DNA template (water) was used as a negative control and DNA from pure *P. penetrans* suspension was used as a positive control.

Statistical analysis

The PROC REG in SAS was used to establish the correlation relationship ($R^2 > 0.5$, $P < 0.05$) between nematode numbers based on the qPCR assay and the traditional extraction and microscopic methods. The number of *P. penetrans* estimated by qPCR was regressed against the number of *P. penetrans* artificially added to autoclaved soil or quantified by the conventional method. An acceptance of the null hypothesis ($P > 0.05$) indicates no significant difference between nematode counts obtained from the two procedures.

Results

Primer specificity and sensitivity

The primer pair Pp-D2D3-F2/Pp-D2D3-R2 was designed based on the D2D3 genomic region of *P. penetrans*. It produced the expected amplification only for *P. penetrans* but not from the other 23 plant-parasitic nematode species (31 isolates) used as control (Table 2). The Cq values of different numbers of *P. penetrans* isolates ranging from 23.42 to 27.23 produced a single melting peak from the qPCR, indicating the primers are very specific for identifying this nematode species (Fig. 1). Detection sensitivity of the assay was performed using a fine textured sandy-loam soil (S-19). The average Cq values obtained for the different numbers (0.5, 1, 2, 3, and 5) of *P. penetrans* added to 0.5 g of autoclaved soil were 31.83 ± 0.4, 30.84 ± 0.2, 30.39 ± 1.0, 29.04 ± 0.65 and 28.02 ± 0.7, respectively, suggesting that lower proportion of the nematode could have been detected.

Generation and validation of standard curves from soil

The standard curve was generated from the artificially infested soils at different densities (0.5, 1, 5, 25, 125, and 625 *P. penetrans* / 0.25 g of soil). The equation obtained by plotting the Cq values verses the log of the starting materials was described as $y = -3.508x + 30.731$ (Fig. 2). The amplification efficiency (E) was 92.8% and the Cq values ranged from 32.88 to 21.52; and the relationship between the Cq values and the densities of *P. penetrans* showed highly significant linearity ($R^2 = 0.983$, $P < 0.001$). No amplification was observed with control soils that were not infested with *P. penetrans*.

The equation of the above standard curve was used to estimate known numbers of *P. penetrans* in soil. Based on their Cq values, the average qPCR estimates for the infestation rates (1, 5, 10, 20, 40 or 80 / 0.25 g of soil) were 1.77, 11.09, 18.93, 43.96, 80.62 and 216.85/ 0.25 g of soil, respectively. Thus, the correlation between the numbers of *P. penetrans* added to soil and the numbers determined by real-time PCR was highly significant ($R^2 = 0.91$, $P < 0.001$), described by the equation $y = 2.69x - 7.6$.

Quantification of P. penetrans from field soil

Correlation analysis was conducted to determine the relationship between nematode numbers detected by the qPCR assay and the numbers determined by the two traditional microscopic methods for the 20 soil samples collected from infested fields in Minnesota (Table 3). There was a strong and significant positive correlation (R^2 = 0.82; P < 0.001) between the numbers of *P. penetrans* quantified based on the qPCR assay and Sugar centrifugal extraction method described by the equation y = 8.66x – 393 (Fig. 3). Whitehead tray method showed a relatively weaker but significant positive correlation (R^2 = 0.61; P < 0.001) described by the equation y = 12.23x – 411 (Fig. 4). Similarly, there was significant positive correlation (y = 0.5305x+22.731; R^2 = 0.75; P < 0.001) between the Sugar centrifugal extraction and quantification method, and the Whitehead tray method of extraction and quantification (Fig. 5).

Conclusions

An efficient and a reliable diagnostic assay to quantify the presence of plant-parasitic nematodes in soil is critical for making management decisions. In this study, we report on the development of a qPCR assay for *P. penetrans* based on the D2D3 genomic region of the 28S rDNA gene. *Pratylenchus penetrans* was quantified directly in DNA extracts from field soils using a species-specific qPCR (SYBR Green I-based). The qPCR assay was evaluated based on primer specificity, sensitivity, efficiency, and the relationship between *P. penetrans* numbers estimated from field soils by conventional methods and the qPCR assay. The assay was specific and able to differentiate *P. penetrans* from other *Pratylenchus* spp. and non-*Pratylenchus* plant-parasitic nematodes commonly found in potato fields in Minnesota and North Dakota. The assay produced a single amplification product in melting curve analyses without specific amplification when DNA from non-target nematodes were used. The qPCR assay was sensitive and detected genomic DNA of a single juvenile added to 1 g of sterilized soil. Artificially and naturally infested field soils with different *P. penetrans* population densities were used to validate the assay.

Identification and quantification of plant-parasitic nematodes directly from soil DNA extract is an extra step in technological advancement compared to quantification using individual nematodes from nematode suspension or communities. We present a protocol using a SYBR Green I dye species-specific qPCR assay to detect and quantify *P. penetrans* directly from infested soils from potato fields. The assay obviates the time-consuming steps of conventional nematode extraction, microscopic identification, and counting and requires no expertise in nematode taxonomy and morphology, and can serve as a useful diagnostic tool not only in research, but also in diagnostic labs and extension services for pest management.

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Table 1. Sequences of the qPCR primers developed for identifying *Pratylenchus penetrans*.

Species	Primer name	Sequence (5'-3')	PCR product size (bp)
Pratylenchus penetrans	F: Pp-D2D3-F2	GGTTTTCGGGCTCATATGGGTTC	113
	R: Pp-D2D3-R2	TTTACGCCGAGAGCTAGGGATTGTG	

Table 2. Plant-parasitic nematodes used to evaluate specificity of the qPCR primers for differentiating *Pratylenchus penetrans* from other nematodes.

Code	Species	Cq value	Origin	Source
P.P 9C1	*P. penetrans*	27.23	MN, USA	G. Yan
P.P 154	*P. penetrans*	23.42	MN, USA	G. Yan
P16	*P. penetrans*	23.92	MN, USA	G. Yan
P.P. Edling	*P. penetrans*	25.39	MN, USA	G. Yan
P.P Dechane	*P. penetrans*	24.15	MN, USA	G. Yan
P. P67	*P. penetrans*	24.00	MN, USA	G. Yan
P-59	*P. penetrans*	23.45	MN, USA	G. Yan
Pp-W	*P. penetrans*	23.55	WI, USA	A. Skantar
Pc	*P. crenatus*	N/A	MD, USA	A. Skantar
P.t Oregon	*P. thornei*	N/A	OR, USA	R. Smiley
Pt	*P. thornei*	N/A	USA	R. Smiley
Pn-O	*P. neglectus*	N/A	OR, USA	R. Smiley
Pn-N	*P. neglectus*	N/A	ND, USA	G. Yan
Pz21	*P. zeae*	N/A	Singapore	A. Skantar
Pz20	*P. zeae*	N/A	NC, USA	A. Skantar
Ps	*P. scribneri*	N/A	ND, USA	G. Yan
Ps-c	*P. scribneri*	N/A	USA	A. Skantar
Pt	*P. thornei*	N/A	OR, USA	R. Smiley
Pa[±]	*P. agilis*	N/A	MD, USA	A. Skantar
MB-3[a]	*P. allius*	N/A	ND, USA	G. Yan
Hg13[a]	*Hoplolaimus* sp.	N/A	ND, USA	G. Yan
Mn36[a]	*Mesocriconema* sp.	N/A	ND, USA	G. Yan
Ha[±]	*H. avenae*	N/A	USA	R. Smiley
Hs	*H. schachtii*	N/A	ND, USA	B. Nelson
Hf	*H. filipjevi*	N/A	USA	R. Smiley
Hc	*H. ciceri*	N/A	Syria	F. Toumi
Hsm	*Helicotylenchus* sp.	N/A	MN, USA	G. Yan
Pfp	*Paratylenchus* sp.	N/A	MN, USA	G. Yan
Hsm	*Hoplolaimus* sp.	N/A	MN, USA	G. Yan
Xsm	*Xiphinema* sp.	N/A	MN, USA	G. Yan
Tsm	*Tylenchorhynchus* sp.	N/A	MN, USA	G. Yan
Cw	*Cactodera weissi*	N/A	USA	A. Skantar
Ge	*Globodera ellingtonae*	N/A	USA	A. Skantar
Gp	*G. pallida*	N/A	IN, USA	A. Skantar
Gr56	*G. rostochiensis*	N/A	Canada	A. Skantar
Gr38	*G. rostochiensis*	N/A	NY, USA	A. Skantar

Gt	*G. tabacum tabacum*	N/A	USA	A. Skantar
Gtc	*G. tabacum tabacum*	N/A	USA	A. Skantar
Mn	*Meloidogyne naasi*	N/A	USA	A. Skantar
NC	Nematode community	N/A	MN, USA	G. Yan
SDE	Soil DNA extract	N/A	MN, USa	G. Yan

[NC] Nematode community; [SDE] Soil DNA extract from potato fields; [N/A] Not available

Table 3. Comparison of *Pratylenchus penetrans* estimations by different methods in 200 g of soil.

Field Sample ID	Sugar Centrifugation Method	Whitehead tray method	qPCR assay
S-1	663	354	3,068
S-2	224	98	925
S-3	213	126	937
S-4	260	231	878
S-5	120	176	697
S-6	143	80	592
S-7	126	120	547
S-8	201	56	463
S-9	64	173	289
S-10	42	25	284
S-11	133	115	234
S-12	140	125	188
S-13	75	40	127
S-14	12	22	86
S-15	42	18	77
S-16	13	0	0
S-17	13	0	0
S-18	0	40	0
S-19	0	0	0
S-20	0	0	0

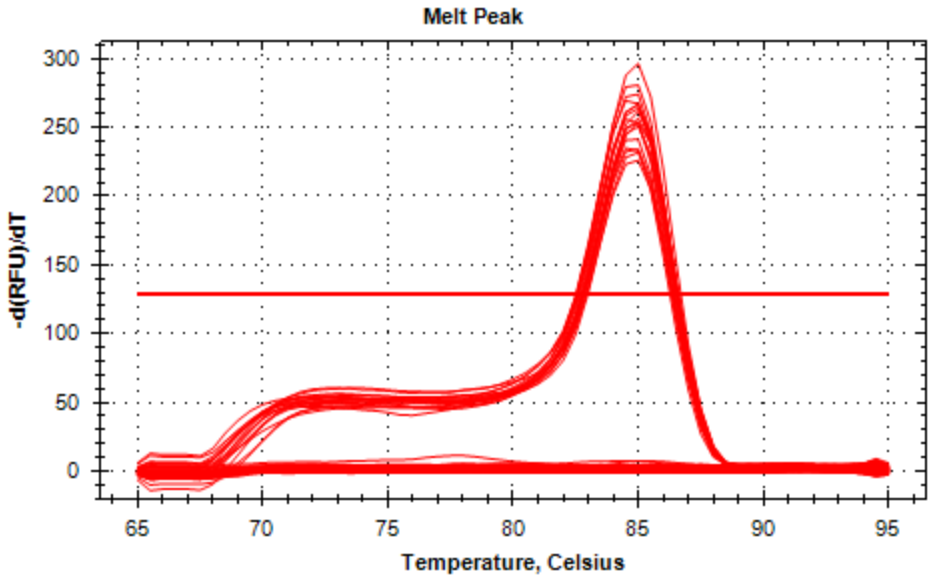

Fig. 1. Melting curve profiles of *Pratylenchus penetrans*-specific products with melting temperature at 85°C. Control reactions without *P. penetrans* DNA template did not produce any amplification.

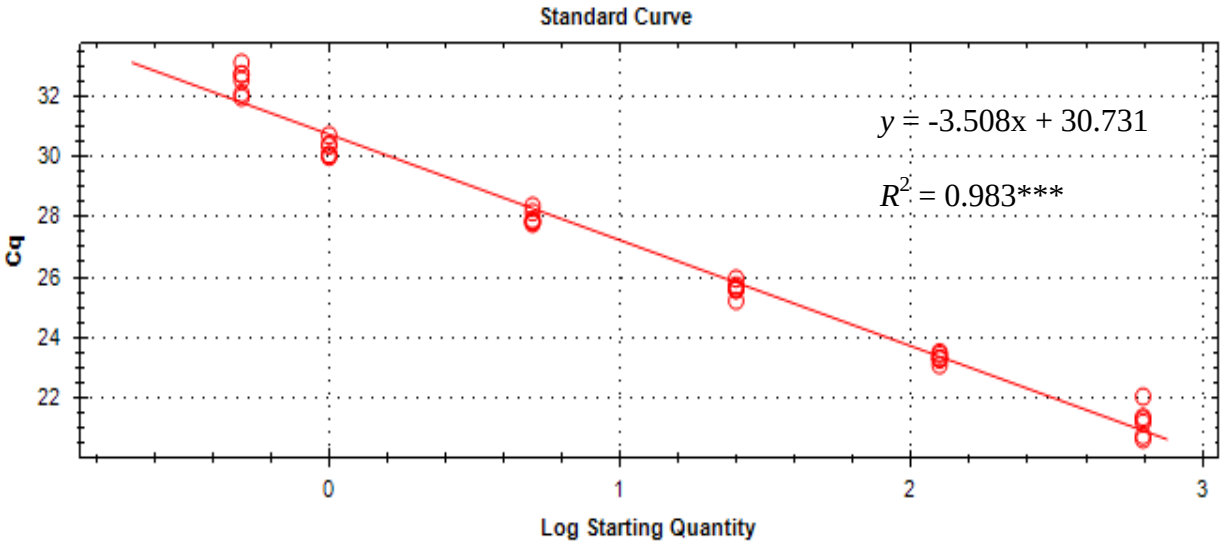

Fig. 2. Standard curve of the qPCR assay for *Pratylenchus penetrans*: quantification cycle number (Cq) plotted against the log of the number of *P. penetrans* (0.5, 1, 5, 25, 125, and 625) added into 0.25 g of sterilized soil. The DNA was extracted in duplicates and the qPCR were run in triplicates. *** indicates significant at $P < 0.001$.

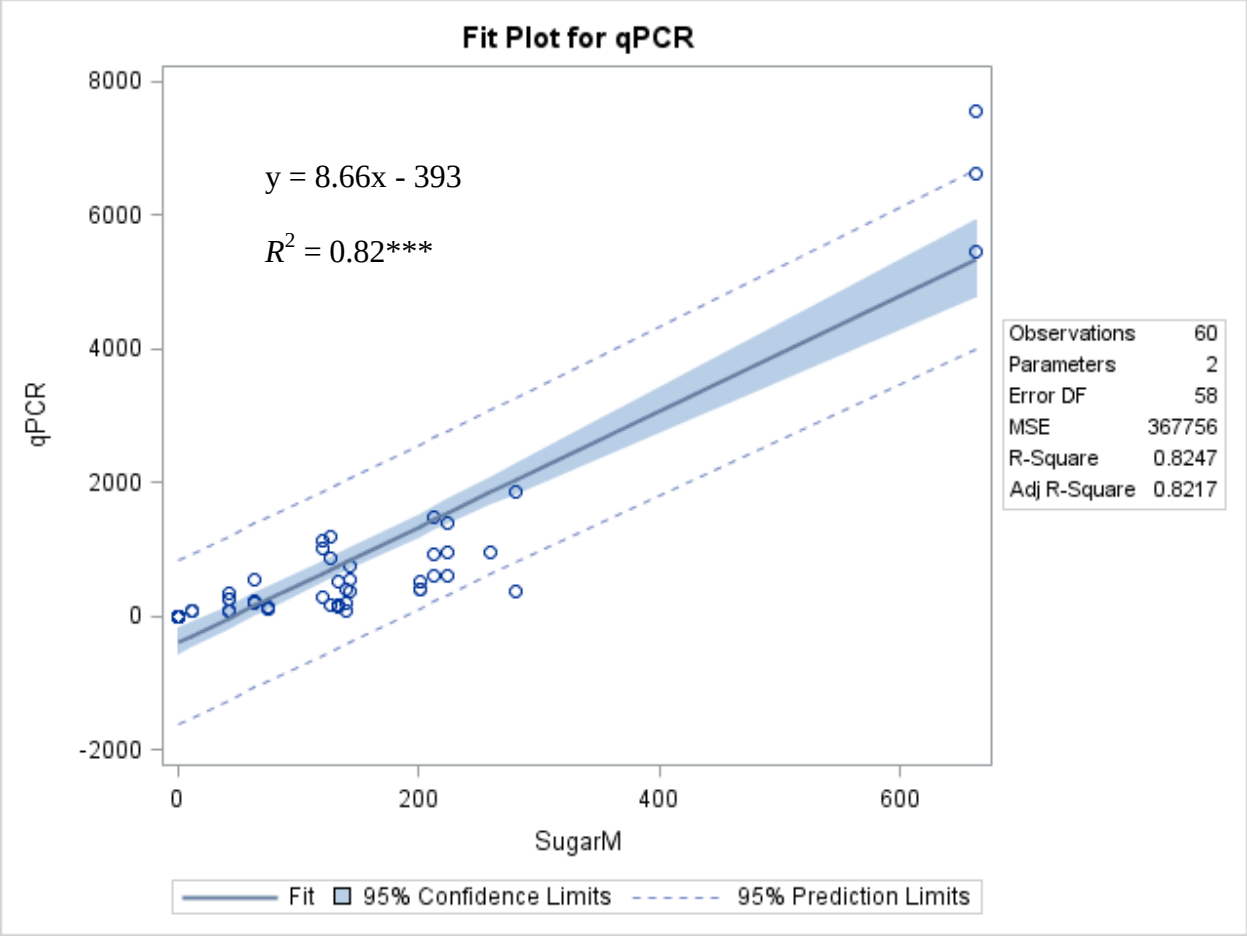

Fig. 3. Correlation between the numbers of *Pratylenchus penetrans* determined by the qPCR and by the Centrifugal sugar flotation extraction and microscopic counting method (SugarM) from 20 different field soil samples; *** indicates significant at $P < 0.001$. DNA was extracted from each field sample in triplicates.

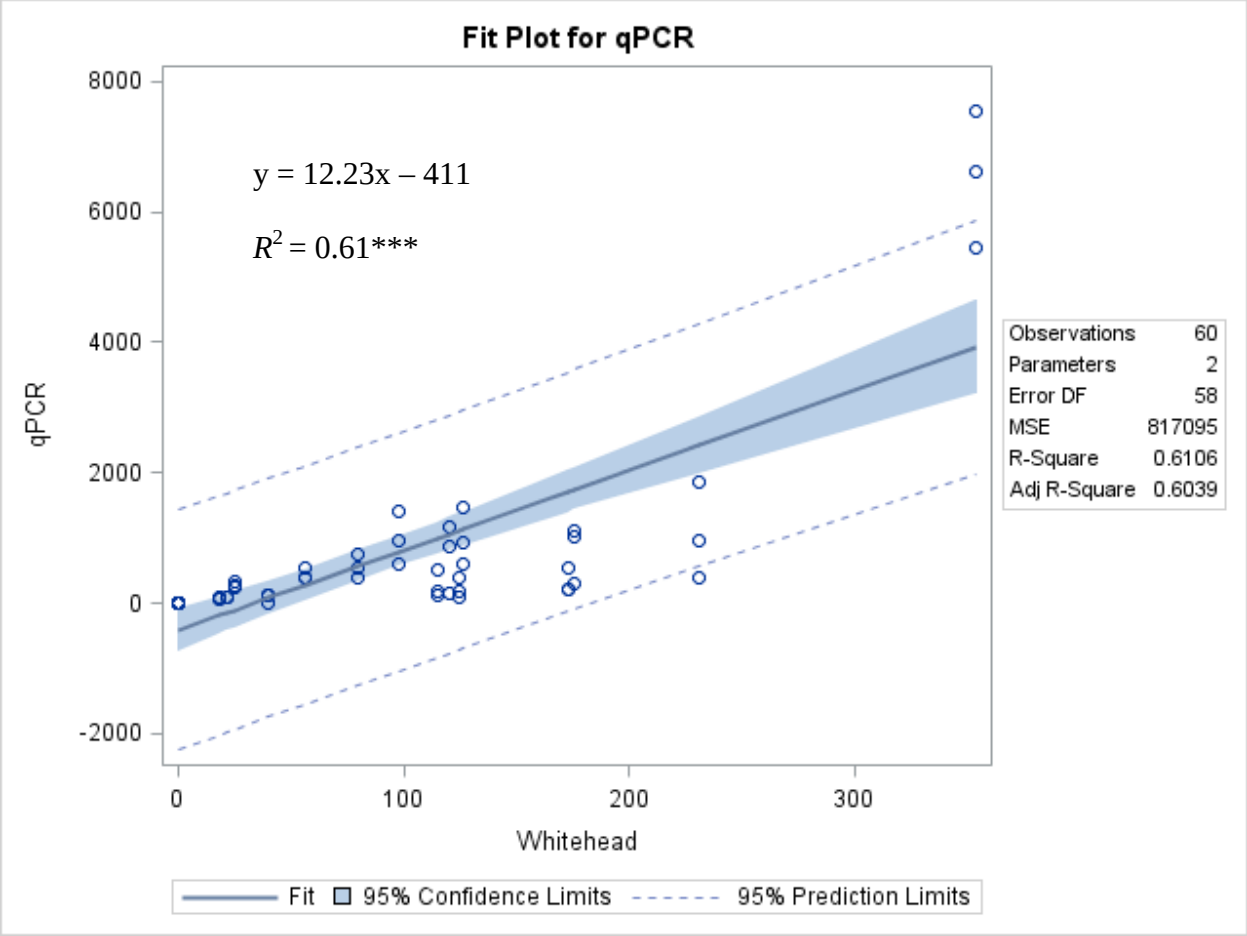

Fig. 4. Correlation between the numbers of *Pratylenchus penetrans* determined by the qPCR and by the Whitehead tray extraction and microscopic counting method (Whitehead) from 20 different field soil samples; *** indicates significant at $P < 0.0001$. DNA was extracted from each field sample in triplicates.

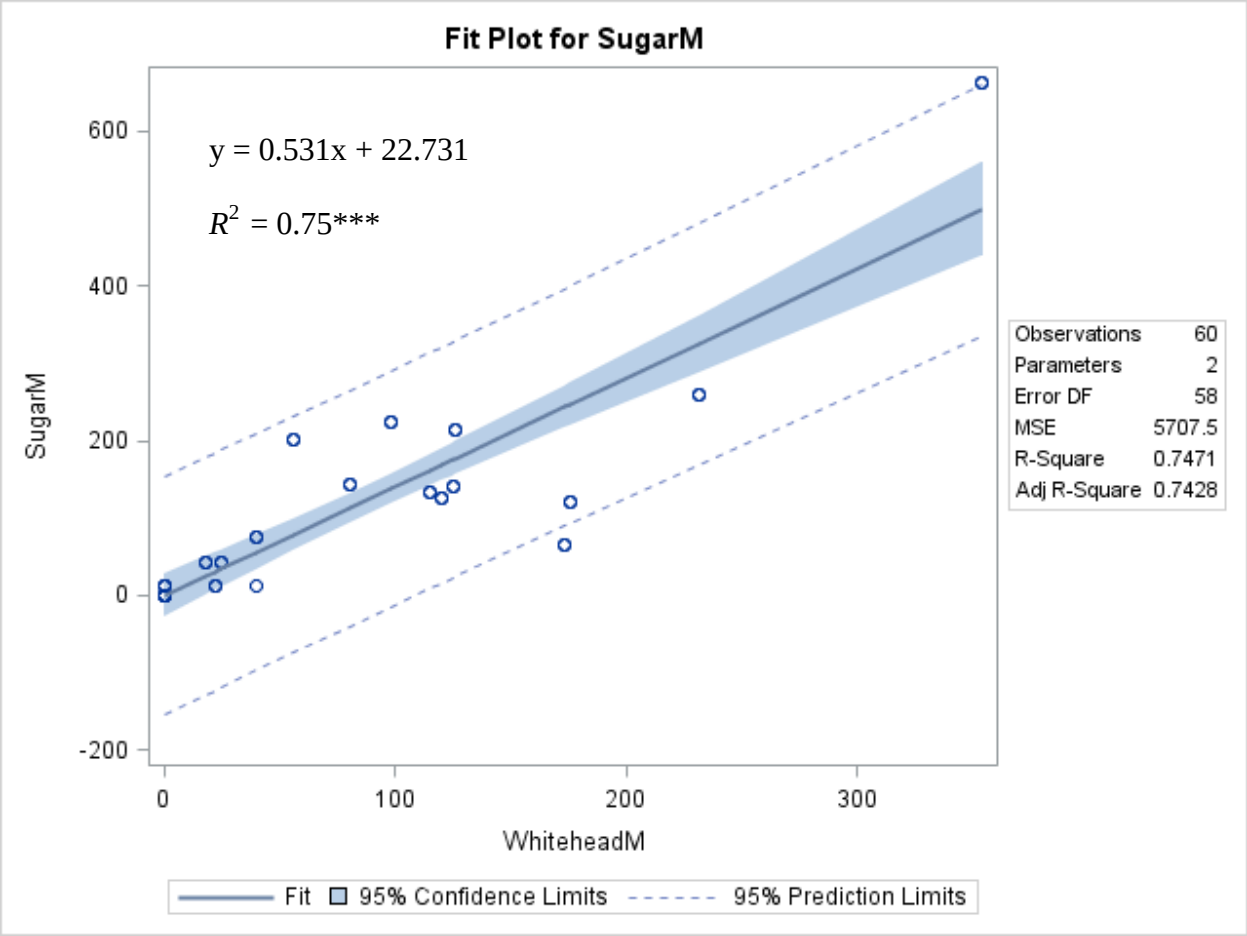

Fig. 5. Correlation between the numbers of *Pratylenchus penetrans* determined by the Centrifugal sugar flotation extraction and microscopic counting method (SugarM) and by the Whitehead tray extraction and microscopic counting method (WhiteheadM) from 20 different field soil samples; *** indicates significant at $P < 0.0001$. DNA was extracted from each field sample in triplicates.

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

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Summary

Fumigation is commonly used by potato growers to control soil-borne pathogens. Its short-term benefits include improved disease control and healthier root systems, which may decrease nutrient input requirements. However, fumigation also eliminates beneficial soil organisms, which may depress the soil community's capacity for pathogen control and nutrient cycling. The goal of our research was to determine the interactive effects of fumigation and N application rate on soil microbial respiration and mineral N concentrations and Russet Burbank leaf greenness and tuber yield, size, quality, sucrose and glucose concentrations, and frying quality. We applied treatments in a split-plot randomized complete block design with four blocks. Whole plots received either Chloropicrin, Vapam, or no fumigant, and each whole plot was split into subplots, each receiving N at one of five total rates (including 40 lbs·ac^{-1} N as DAP at planting): (1) 40 lbs·ac^{-1}, 120 lbs·ac^{-1}, 180 lbs·ac^{-1}, 240 lbs·ac^{-1}, and 300 lbs·ac^{-1}. Fumigation treatments were applied in October and November 2015, and N treatments were applied at shoot emergence in 2016. Soil 24-hour CO_2 production, NH_4-N, and NO_3-N were determined for six-inch soil samples collected before fumigation in 2015 and before planting, during the growing season, and after harvest in 2016. Leaflet SPAD readings were taken at five times between hilling and harvest to measure leaf greenness. Tuber yield, size, quality, sugar concentrations, and frying quality were determined after harvest. Soil from the fumigated plots showed low rates of microbial respiration compared to the non-fumigated plots during the growing season but recovered to non-fumigated levels by harvest. The fumigated plots had elevated NH_4-N concentrations before planting, and the plots fumigated with Chloropicrin had high NH_4-N and low NO_3-N relative to the non-fumigated plots, indicating that fumigation may interfere with nitrification. Leaflet SPAD increased with N application rate but did not respond to fumigation treatment. Total and marketable yields were higher, in the fumigated plots than in the non-fumigated plots, but did not plateau at lower N rates. However, the percentage of yield represented by tubers weighing over six ounces was higher and plateaued at a lower N rate in fumigated plots than in non-fumigated plots, suggesting that fumigation may decrease N requirements for tuber bulking but not for tuber yield. Tuber quality was not meaningfully related to fumigation treatment. The same was true of tuber sucrose and glucose concentrations and French fry reflectance in both the stem ends and bud ends of tubers. Stem-end sucrose concentration and the glucose concentration in both ends of the tuber decreased with increasing N application rate. Bud-end sucrose concentration and French fry reflectance increased with N rate, except that reflectance was relatively high for stem-end French fries from tubers grown at the lowest N rate. Overall, we found that while fumigation increased marketable yield at all N rates tested and decreased N requirements for tuber bulking, it lowered soil microbial activity/diversity during the growing season. Microbial activity was low in all treatments at harvest suggesting that soil improvement practices should be considered following a potato crop.

Background

Fumigation of potato fields to control pathogens has well-known short-term benefits. Most directly, fumigation decreases disease incidence. An apparent consequence of this is that potato plants in fumigated soil have healthier root systems, which may result in a decreased requirement for nutrient

inputs. However, a major drawback of soil fumigation is that it eliminates beneficial soil organisms in addition to the pathogens. The benefits such organisms provide include pathogen control and nutrient cycling activities. Consequently, once a field is fumigated, additional applications of fumigant are required to control pathogens each time potatoes are planted in the field and nutrient cycling may be disrupted during and beyond the years when fumigant is applied.

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

Methods

Study design

The study was conducted at the Sand Plain Research Farm in Becker, Minnesota, on a Hubbard loamy sand soil. The previous crop was soybeans. Potatoes have been grown at this site in a 3-year rotation without fumigation since 2000 with the last crop of potatoes grown in 2014. Fumigation treatments were arranged in a randomized complete block design with four blocks and three fumigation treatments. The fumigation treatments were: no fumigation with tillage on November 11, 2015; fumigation with Chloropicrin on October 14, 2015 at 100 lbs/A applied in strips followed by hilling; and fumigation with Vapam at 70 gallons/A injected at 6" and 10" on November 3, 2015.

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

The subplots were arranged in six columns and ten rows, with the columns running parallel to the planting rows for the length of the field (300 feet) and the rows running across the planting rows for the width of the field (150 feet). Two, 8-foot-wide alleys were placed between every two columns, and irrigation lines were placed along these alleys and the field edges (four lines in total, with 50-foot spacing between lines). A single alley was placed between the fifth and sixth rows of subplots, separating blocks 1 and 2 from blocks 3 and 4. This alley was 30 feet wide for most of its length, but only 10 feet wide between whole plots where Vapam was applied, because the size of the Vapam application equipment required these plots to be placed further from the ends of the field than originally planned. A summary of the treatments is presented in Table 1.

Soil sampling

Soil samples to a depth of 6 inches were collected on October 12, 2015, and April 19, July 6, and October 10, 2016. The samples were then dried at 95°C for 48 hours, ground, and extracted with 2N KCl. The extracts were analyzed for NH_4-N and NO_3-N concentrations using a Wescan nitrogen analyzer. Soil microbial respiration rates were determined on dried samples using Solvita Soil CO_2 Burst Test kits.

Planting and N treatments

The subplots were planted with Russet Burbank whole "B" seed potatoes on May 2, 2016, with one-foot spacing within rows and three-foot spacing between rows. Each subplot was seven rows wide. In each subplot, the fourth and fifth rows from the irrigation alley were designated as harvest rows. In these two rows, the first and last seed potato in each subplot was replaced with a Norland Red potato to identify the boundaries between subplots during harvest. Each adjacent pair of whole plots was surrounded by a buffer strip of Russet Burbank potato plants five feet wide on the ends and three feet (one row) wide along the sides. At row opening, 40 $lbs \cdot ac^{-1}$ N, 102 $lbs \cdot ac^{-1}$ P_2O_5, 181 $lbs \cdot ac^{-1}$

K_2O, 40 lbs·ac^{-1} S, 20 lbs·ac^{-1} Mg, 1 lb·ac^{-1} Zn, and 0.6 lbs·ac^{-1} B were banded in as a blend of DAP (18-46-0), MOP (0-0-60), SulPoMag (0-0-22-20S-10Mg), BluMin (0-0-0-0.5S-1Zn), and Boron 15 (0-0-0-15).

Environmentally Smart Nitrogen (ESN; 44-0-0; Agrium, Inc.) was hand-broadcast on subplots per the assigned N treatments at shoot emergence, on June 2 and then hilled in.

Plant stand and leaflet SPAD

For each plot, plant stand in the harvest rows and the number of stems per plant for ten plants in the harvest rows were recorded on June 8. On 5 days throughout the summer, relative greenness in the terminal leaflet of the fourth leaf from the tip of 10 harvest-row shoots per plot was recorded with a SPAD meter, generating a single average SPAD meter reading for each plot. SPAD readings were taken on June 16 and 23, July 6 and 19, and August 3 (i.e., 14, 21, 34, 47, and 62 days after the emergence fertilizer was applied).

Harvest, tuber quality, and tuber sugars and fry color

Tubers were harvested on September 28. They were sorted by size and USDA grade during the following week. Representative 25-tuber samples were evaluated for hollow heart, brown center, dry matter content, and specific gravity. Representative 20-tuber subsamples from each plot were sent to USDA-ARS (East Grand Forks, MN) to determine the sucrose and glucose concentrations of the stem and bud ends of the tubers. Samples from the stem and bud ends were French-fried by USDA, and their reflectances were determined using a Photovolt reflectometer.

Data analysis

The data were analyzed with SAS 9.4m3® software (copyright 2015, SAS Institute, Inc.) using the MIXED procedure. For each dependent variable, fumigation treatment, N treatment, and their interaction were treated as fixed effects, and block and the interaction between block and fumigation treatment (the factor differentiating whole plots) were treated as random effects. Marginal means for dependent variables at each level of fumigation*nitrogen were determined using the LSMEANS statement, and post-hoc pairwise comparisons (alpha = 0.05) were conducted using the DIFF option. Pairwise comparisons are only presented where the significance (P-value) of fumigation, N treatment, or their interaction in the model is less than 0.05.

Results and discussion

Soil respiration

The results of 24-hour CO_2 burst tests (a measure of soil respiration) are presented in Table 2. 24-hour CO_2 production from soil samples collected on October 12, 2015, before fumigant or N treatments were applied, was related to N treatment. The subplots receiving 180 lbs·ac^{-1} total N had, on average, significantly lower CO_2 production than those receiving any other rate. Because N had not yet been applied this effect was due to field variability within the experimental site.

Soil CO_2 production from samples collected on April 19, 2016, after fumigation treatments were applied but before N treatments were, was significantly related to fumigation treatment, with the plots receiving no fumigant having higher CO_2 production than those receiving Chloropicrin or Vapam, and the plots receiving Chloropicrin having higher CO_2 production than those receiving Vapam. In soil samples collected on July 6, 2016, after both fumigation and N treatments were applied, soil CO_2 production was significantly related only to fumigation treatment. The plots receiving no fumigant had higher CO_2 production than those receiving Chloropicrin or Vapam, which did not have significantly different CO_2 production from each other. Soil CO_2 production from samples collected on October 10, 2016, after harvest, was not significantly related to fumigation treatment, N treatment,

or their interaction. Soil microbial activity as measured by CO_2 production decreased in the non-fumigated plots through the growing season, which may be due to low amounts of residues associated with the crop.

Soil NH_4-N and NO_3-N

Soil NH_4-N and NO_3-N concentration results are presented in Table 3. On October 12, 2015, before the fumigation treatments were applied, neither soil NH_4-N concentration nor soil NO_3-N concentration were related to fumigation treatment, N treatment, or their interaction. On April 17, 2016, several months after the fumigation treatments were applied but before any fertilizer applications, the treatments receiving Vapam or Chloropicrin had significantly higher soil NH_4-N and total mineral N concentrations than the non-fumigated treatments. No similar effect was seen for NO_3-N. On July 6, 34 days after ESN was applied at shoot emergence, soil mineral N concentrations increased with N application rate for all three fumigation treatments. The plots receiving Chloropicrin showed a much stronger response of NH_4-N to N rate than those receiving Vapam or no fumigant. They had a significantly higher mean NH_4-N concentration than the treatment receiving Vapam at an N application rate of 240 lbs·ac^{-1}, and a higher concentration than either of the other treatments at 300 lbs·ac^{-1} N. The treatments receiving no fumigant had a significantly higher mean soil NO_3-N concentration than the fumigated treatments when N was applied at 300 lbs·ac^{-1}, but not at other N rates. Both the non-fumigated treatments and the treatments receiving Chloropicrin showed similar responses of total soil mineral N to the application rate of N, but the treatments receiving Vapam showed a much weaker response of mineral N to the application rate of N. The treatments receiving Vapam had a significantly lower mean soil mineral N concentration than the treatments receiving Chloropicrin at an N application rate of 240 lbs·ac^{-1}, and a lower mineral N concentration than either of the other fumigation treatments at 300 lbs·ac^{-1} N. On October 10, after tuber harvest, mineral N was unrelated to fumigation treatment, N treatment, and their interaction.

The elevated pre-planting NH_4-N concentrations of the fumigated plots and the tendency for mineral N to take the form of NH_4-N in plots treated with Chloropicrin may both be the results of a negative effect of soil fumigation on soil nitrification processes, which convert NH_4^+ to NO_3^-. This is consistent with the negative effect of fumigation on overall microbial respiration observed in the CO_2 burst tests. The positive effects of fumigation are to eliminate soil borne diseases. Verticillium assays were not available at the time of this report.

It is not clear why Vapam-treated plots showed weaker responses of soil mineral N to the application rate of N than plots treated with Chloropicrin or non-fumigated plots. Vapam-treated plots did not produce higher tuber yields than Chloropicrin-treated plots (see below). Perhaps plants in Vapam-treated plots took up more N, resulting in higher tissue N concentrations or vine biomass. Ongoing analyses will determine whether this is the case.

Plant stand and leaflet SPAD

Plant stand and leaflet SPAD results are presented in Table 4. Neither fumigation treatment nor N treatment were significantly related to plant stand six days after the emergence fertilizer was applied. There was an effect of the interaction between fumigation treatment and N treatment on the number of stems per plant, suggesting that plants responded differently to N treatment under different fumigation regimens. However, the number of stems per plant fluctuated apparently at random with increasing N application rate for all three fumigation treatments, and it is unlikely that this interaction effect is biologically significant.

SPAD readings, which indicate the relative density of chlorophyll per unit area in the measured leaflet, increased with N application rate on all five sampling dates. SPAD generally declined over time, while the response of SPAD to N rate grew stronger, especially at higher N rates. Fumigation treatment had no effect on SPAD. There was a significant effect of the interaction between fumigation

treatment and N treatment on SPAD readings on the final sampling date, August 3. The plots receiving Chloropicrin had lower SPAD than the plots receiving no fumigant or Vapam in the low-N control subplots (40 lbs·ac^{-1} N), while the plots receiving Vapam had lower SPAD than the other two treatments in the highest-N subplots (300 lbs·ac^{-1} N).

Tuber yield, size, and grade

Tuber yield, size, and grade results are presented in Table 5. Nitrogen treatment had strong effects on tuber yield and size distribution that were largely consistent across fumigation treatments. Total and marketable yield were lower for the control treatments receiving only 40 lbs·ac^{-1} N than they were for any other treatment among plots receiving Vapam or no fumigation. The same trend was seen in the plots receiving Chloropicrin, except that the subplots receiving 180 or 300 lbs·ac^{-1} N did not have significantly greater total yield than the control subplots (though they did have greater marketable yield). Total and marketable yield showed weak responses to N application rate at rates between 180 and 300 lbs·ac^{-1} N regardless of fumigation treatment. There was no evidence that yields peaked at lower N rates for fumigated plots than for non-fumigated plots.

Fumigation treatment affected the yields of 6-10-ounce and 10-14-ounce tubers, as well as total yield, marketable yield, the yield of U.S. No. 2 tubers, and the proportion of yield represented by tubers weighing over 6 ounces. In each case, fumigated plots had higher values than the non-fumigated control plots. There was a marginally significant effect of the interaction between fumigation treatment and N treatment on the percentage of yield represented by tubers weighing over 6 ounces. The plots receiving either Chloropicrin or Vapam had more of their yields in tubers over six ounces than the non-fumigated plots did in the subplots receiving 40 to 180 lbs·ac^{-1} N, but not in the subplots receiving higher application rates.

Tuber quality

Tuber quality results are presented in Table 6. The prevalence of disqualifying hollow heart and brown center were related to fumigation treatment, N treatment, and their interaction. This was due to relatively high prevalence of both conditions in the subplots receiving no fumigant and 180 or 300 lbs·ac^{-1} N. It is possible that the likelihood of these conditions increase with N application rate only when no fumigant is applied, but it is not obvious why this should be the case. Tuber dry matter content was significantly related to the application rate of N. The subplots receiving 40 lbs·ac^{-1} N had lower dry matter content, on average, than those receiving 120 to 240 lbs·ac^{-1} N. Tuber specific gravity was not related to fumigation treatment, N treatment, or their interaction.

Tuber sugars and French fry color

Tuber sugar and French fry reflectance results are presented in Table 7. Fumigation treatment and its interaction with N application rate did not significantly affect tuber sucrose or glucose concentrations, nor the reflectance values observed for French fries made from the tubers.

The sucrose concentration of the stem end of the tuber generally decreased as the application rate of N increased, except that the subplots receiving Chloropicrin and 180 lbs·ac^{-1} N had the highest stem-end sucrose concentration in the study. The effect of N rate was especially pronounced between the lowest N rate (40 lbs·ac^{-1} N) and the second lowest (120 lbs·ac^{-1} N). In contrast to stem-end sucrose, bud-end sucrose tended to increase as N application rate increased, though this positive relationship was weaker than the negative relationship observed for stem-end sucrose. Sucrose concentrations were over an order of magnitude higher in the bud ends of tubers than in the stem ends.

Concentrations of glucose decreased with increasing N application rate in both the stem ends and the bud ends of tubers. The effect of N rate was stronger at lower application rates, but, especially in bud end tissue, N rate affected tuber glucose concentration across the range of application rates

tested. Glucose concentrations were about three times as high in the stem ends of tubers as in the bud ends.

The reflectance of French fries made from the bud ends of tubers increased with increasing N application rate, especially at application rates between 40 and 180 lbs·ac^{-1} N. The same was true for French fries made from the stem ends of tubers for N rates between 180 and 300 lbs·ac^{-1} N, but reflectance decreased with increasing N application rate for rates between 40 and 120 lbs·ac^{-1} N. The cause of relatively high reflectance scores at 40 lbs·ac^{-1} N is uncertain, though perhaps the stem ends of these tubers lack sufficient asparigine for a more robust Maillard reaction to darken the French fries. French fries made from the bud end of the tuber had approximately 60% higher reflectance than those made from the stem end, indicating lighter fries. This is probably a direct consequence of the lower glucose concentrations observed in the bud ends of tubers compared to the stem ends.

Conclusions

Based on our results for soil respiration, fumigation decreases overall soil microbial activity significantly. Our soil NH_4-N and NO_3-N concentration results indicate that nitrification, in particular, is inhibited by fumigation. Our yield results indicate an advantage of fumigation in terms of tuber yield and size. However, tuber yield did not plateau at a lower application rate for fumigated plots than for non-fumigated plots, although the percentage of yield represented by tubers over six ounces did, suggesting that fumigation may decrease N requirements for tuber bulking, but not for yield. The concentration of glucose (a reducing sugar) in the tuber decreased as N application rate increased, but fumigation had no effect on this relationship. Overall, fumigation treatment appeared to affect soil N cycling processes and overall microbial activity, but fumigated plots had higher tuber yields and larger tubers than non-fumigated plots.

Table 1. Fumigation and N treatments applied to irrigated Russet Burbank potatoes at the Sand Plain Research Farm in Becker, MN, in 2016.

Fumigation treatment (whole plots)	Nitrogen applicaton rate, lbs·ac^{-1} (subplots)	
	Emergence (ESN)[1]	Total[2]
None	0	40
	80	120
	140	180
	200	240
	260	300
Chloropicrin	0	40
	80	120
	140	180
	200	240
	260	300
Vapam	0	40
	80	120
	140	180
	200	240
	260	300

[1]ESN = Environmentally Smart Nitrogen (Agrium, Inc., 44-0-0)
[2]Each plot received 40 lbs·ac-1 N at planting as MAP (18-46-0)

Table 2. Effects of fumigation and N treatments on soil microbial respiration as measured by CO_2 production in a 24-hour period at 70°F using a Solvita CO_2 Burst Test kit.

Treatments		Solvita CO_2 burst test results			
Fumigation treatment	Nitrogen application rate (lbs/ac)	October 12, 2015	April 19, 2016	July 6, 2016	October 10, 2016
		ppm increase in CO_2 after 24 hours incubation at 70°F			
None	40	56.0 ab	40.9 a	30.6 abc	22.7
	120	48.0 abc	39.4 ab	36.8 ab	17.3
	180	42.8 bc	36.4 abc	21.0 cde	17.7
	240	60.9 ab	33.9 abcd	39.0 a	23.5
	300	50.0 abc	34.1 abc	25.3 bcd	25.8
Chloropicrin	40	56.2 ab	35.1 abc	11.0 ef	13.7
	120	54.3 ab	31.8 abcde	12.0 ef	26.0
	180	33.6 c	26.4 bcdef	11.9 ef	17.7
	240	60.1 ab	30.8 abcde	8.6 f	15.3
	300	54.5 ab	24.5 cdef	16.5 def	17.4
Vapam	40	63.1 a	18.4 ef	18.9 def	29.6
	120	53.0 abc	20.5 def	13.1 ef	17.6
	180	42.5 bc	16.4 f	11.3 ef	19.1
	240	48.7 abc	23.2 cdef	13.2 ef	24.8
	300	48.3 abc	20.4 ef	13.9 def	21.4
Fumigation significance (P-value)		0.9936	**0.0049**	**0.0002**	0.2158
Nitrogen significance (P-value)		**0.0130**	0.4729	0.4136	0.8030
Fumigation*Nitrogen (P-value)		0.7428	0.8617	0.1662	0.1751

Values within the same column that have a letter in common are not significantly different from each other (i.e. P > 0.05). Letters are only included where the P-value of the effect of fumigation, N treatment, or their interaction is less than 0.10.

Table 3. Effects of fumigation and N treatments on NH_4-N and NO_3-N concentrations in the top six inches of soil on October 12, 2015, and April 19, July 6, and October 10, 2016, in plots used to grow Russet Burbank potatoes at the Sand Plain Research Farm in Becker, MN.

Treatments		Soil mineral N											
Fumigation treatment	Nitrogen application rate (lbs/ac)	October 12, 2015			April 19, 2016			July 6, 2016			October 10, 2016		
		NH_4-N	NO_3-N	Total	NH_4-N	NO_3-N	Total	NH_4-N	NO_3-N	Total	NH_4-N	NO_3-N	Total
		(ppm)											
None	40	1.95	6.08	8.02	2.22 ef	4.74	6.96 e	1.47 e	3.75 c	5.21 e	0.40	3.15	3.55
	120	1.75	5.64	7.39	1.72 f	10.27	11.98 abcde	3.24 cde	6.23 c	9.47 cde	0.56	3.56	4.12
	180	1.78	6.21	7.98	1.98 f	5.55	7.52 de	5.49 cde	16.62 bc	22.31 bcde	0.33	4.93	5.26
	240	1.83	6.18	8.01	2.40 ef	4.85	7.24 de	9.82 bc	17.03 bc	26.84 bc	0.37	5.26	5.62
	300	1.99	7.05	9.04	2.32 ef	5.70	8.02 cde	8.45 cd	47.04 a	55.50 a	0.59	4.35	4.94
Chloropicrin	40	2.03	5.46	7.48	6.40 abc	7.17	13.57 ab	1.66 de	5.72 c	7.37 de	0.60	4.14	4.73
	120	2.01	6.23	8.24	7.19 a	6.86	14.05 ab	5.26 cde	9.61 bc	14.87 cde	0.53	3.85	4.39
	180	1.79	5.99	7.78	6.59 ab	5.72	12.30 abcd	7.49 cde	9.81 bc	17.30 cde	0.60	4.83	5.43
	240	1.87	5.90	7.77	6.51 ab	6.46	12.96 abc	16.82 b	19.39 bc	36.20 b	0.58	5.32	5.90
	300	1.74	5.40	7.14	7.42 a	6.06	13.48 ab	31.83 a	25.24 b	57.08 a	0.44	6.34	6.87
Vapam	40	1.83	5.57	7.40	6.05 abc	6.17	12.21 abcde	2.00 de	6.39 c	8.38 de	0.53	4.22	4.74
	120	1.85	5.84	7.68	4.82 bcd	11.32	16.13 a	2.13 de	11.52 bc	13.65 cde	0.56	3.66	4.22
	180	1.65	5.24	6.89	3.62 def	8.62	12.25 abcde	5.51 cde	13.00 bc	18.52 bcde	0.52	3.23	3.74
	240	1.84	6.07	7.90	4.30 cde	6.11	10.41 bcde	1.67 de	12.69 bc	14.37 cde	0.65	3.05	3.69
	300	1.87	5.47	7.35	5.42 abcd	4.91	10.33 bcde	6.85 cde	16.80 bc	23.65 bcd	0.57	3.26	3.84
Fumigation significance (P-value)		0.7169	0.1278	0.1616	**0.0004**	0.5929	**0.0003**	**0.0023**	0.2642	**0.0267**	0.1913	0.1151	0.1001
Nitrogen significance (P-value)		0.6481	0.9066	0.9267	0.5010	0.1125	*0.0946*	**<0.0001**	**0.0001**	**<0.0001**	0.9428	0.3153	0.2627
Fumigation*Nitrogen (P-value)		0.9046	0.4521	0.4000	0.7284	0.7914	0.9003	**<0.0001**	**0.0144**	*0.0611*	0.5929	0.1516	0.1548

Values within the same column that have a letter in common are not significantly different from each other (i.e. $P > 0.05$). Letters are only included where the P-value of the effect of fumigation, N treatment, or their interaction is less than 0.10.

Table 4. Effects of fumigation and N treatment on plant stand and stems per plant on June 2 and leaflet SPAD readings (chlorophyll concentration) on five dates in 2016 for Russet Burbank potatoes at the Sand Plain Research Farm in Becker, MN.

Treatments		Early-season vigor (June 8)		SPAD readings				
Fumigation treatment	**Nitrogen application rate (lbs/ac)**	**Stand (%)**	**Stems / plant**	**June 16**	**June 23**	**July 6**	**July 19**	**August 3**
None	40	100.0	3.9 abcd	39.2 e	35.1 f	31.6 e	30.0 g	23.2 f
	120	100.0	3.8 bcd	42.4 bcd	42.0 e	39.6 cd	34.6 ef	27.7 e
	180	100.0	4.2 ab	42.7 abcd	44.4 bcd	40.9 bc	37.1 cde	33.8 d
	240	99.3	3.5 d	44.0 a	46.1 ab	42.7 ab	38.8 bc	37.8 c
	300	99.3	3.9 abcd	43.7 ab	44.6 abcd	44.0 a	41.3 ab	41.0 ab
Chloropicrin	40	100.0	4.1 abc	39.9 e	36.6 f	32.2 e	32.2 fg	21.2 g
	120	100.0	3.4 d	41.6 d	42.9 de	37.9 d	34.8 ef	28.5 e
	180	100.0	3.7 bcd	41.7 d	45.0 abc	42.0 abc	37.9 cd	34.5 d
	240	100.0	4.4 a	42.9 abcd	45.5 abc	43.8 a	38.5 bc	38.5 c
	300	100.0	4.2 ab	42.9 abcd	45.9 ab	43.6 ab	41.8 a	42.2 a
Vapam	40	100.0	3.7 bcd	38.9 e	36.5 f	33.8 e	30.7 g	23.2 f
	120	100.0	3.6 cd	42.2 cd	43.4 cde	41.0 bc	35.1 de	28.7 e
	180	100.0	4.0 abcd	43.4 abc	46.0 ab	41.8 abc	37.0 cde	33.8 d
	240	100.0	3.6 bcd	42.3 cd	46.7 a	43.9 a	38.8 bc	38.9 c
	300	99.3	3.9 abcd	43.5 abc	45.4 abc	44.0 a	40.9 ab	39.3 bc
Fumigation significance (P-value)		0.4219	0.3850	0.4070	0.2519	0.4690	0.5567	0.7754
Nitrogen significance (P-value)		0.1955	*0.0862*	**<0.0001**	**<0.0001**	**<0.0001**	**<0.0001**	**<0.0001**
Fumigation*Nitrogen (P-value)		0.6892	**0.0426**	0.1225	0.8543	0.3089	0.9610	**0.0177**

Values within the same column that have a letter in common are not significantly different from each other (i.e. P > 0.05). Letters are only included where the P-value of the effect of fumigation, N treatment, or their interaction is less than 0.10.

Table 5. Effects of fumigation and N treatment on tuber yield, grade, and size for Russet Burbank potatoes grown at the Sand Plain Research Farm in Becker, MN, in 2016.

Treatments		Tuber yield										
Fumigation treatment	**Nitrogen application rate (lbs/ac)**	**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}									**%**	
None	40	76 a	234 b	53 g	2 f	0 f	364 g	183 e	105 cd	288 g	15 f	1 g
	120	40 c	186 c	183 e	38 e	6 ef	454 ef	308 bc	106 cd	414 ef	50 d	10 ef
	180	36 c	183 cd	204 bcde	58 de	8 def	489 bcde	355 ab	98 cd	453 bcde	55 cd	14 de
	240	35 c	138 fg	201 cde	72 bcd	24 bcdf	471 def	331 ab	105 cd	436 cde	63 abc	21 abc
	300	34 c	122 g	187 de	94 ab	29 ab	466 ef	344 ab	88 d	432 de	66 a	26 a
Chloropicrin	40	58 b	273 a	140 f	13 f	2 f	485 cde	249 cd	178 ab	427 e	31 e	3 fg
	120	29 c	179 cd	243 ab	72 bcd	12 cdef	535 ab	357 ab	149 abc	506 ab	61 abc	16 cde
	180	40 c	172 cde	226 abcd	66 cd	21 bcde	526 abc	345 ab	141 abcd	486 abc	60 abc	17 bcde
	240	39 c	154 def	244 a	83 abc	25 bc	544 a	377 a	129 bcd	505 ab	64 ab	20 abcd
	300	39 c	144 efg	222 abcd	90 ab	24 bc	520 abc	339 ab	142 abcd	481 abcd	65 ab	22 abc
Vapam	40	57 b	245 ab	111 f	10 f	0 f	423 f	197 de	169 ab	366 f	28 e	2 g
	120	34 c	189 c	236 abc	55 de	5 ef	519 abcd	300 bc	185 a	485 abc	57 bcd	12 e
	180	30 c	159 cdef	226 abcd	98 a	28 abc	541 a	341 ab	170 ab	511 a	65 ab	23 ab
	240	36 c	154 def	236 abc	89 abc	25 bc	540 a	310 bc	194 a	504 ab	65 ab	21 abc
	300	35 c	142 efg	225 abcd	95 ab	44 a	540 a	358 ab	147 abc	505 ab	67 a	26 a
Fumigation significance (P-value)		0.3500	0.2479	0.0032	0.0096	0.1806	0.0006	0.1165	0.0045	0.0004	0.0007	0.2734
Nitrogen significance (P-value)		<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.4556	<0.0001	<0.0001	<0.0001
Fumigation*Nitrogen (P-value)		0.1410	0.2787	0.5002	0.1124	0.2909	0.2111	0.4700	0.6962	0.1592	0.0663	0.2645

Values within the same column that have a letter in common are not significantly different from each other (i.e. P > 0.05). Letters are only included where the P-value of the effect of fumigation, N treatment, or their interaction is less than 0.10.

Table 6. Effects of fumigation and N treatment on the prevalence of hollow heart and brown center, tuber dry matter content, and tuber specific gravity for Russet Burbank potatoes grown at the Sand Plain Research Farm in Becker, MN, in 2016.

Treatments		Tuber quality			
Fumigation treatment	**Nitrogen application rate (lbs/ac)**	**Hollow heart (%)**	**Brown center (%)**	**Dry matter content (%)**	**Specific gravity**
None	40	0 c	0 c	21.1 e	1.0719
	120	0 c	0 c	23.0 ab	1.0751
	180	14 a	14 a	21.9 abcde	1.0774
	240	4 bc	4 bc	22.6 abcd	1.0799
	300	7 b	8 b	22.6 abcd	1.0738
Chloropicrin	40	0 c	0 c	21.4 de	1.0741
	120	3 bc	3 bc	21.8 bcde	1.0803
	180	2 bc	2 c	22.7 abc	1.0737
	240	3 bc	3 bc	22.0 abcde	1.0755
	300	1 bc	1 c	21.6 cde	1.0779
Vapam	40	0 c	0 c	21.8 bcde	1.0769
	120	0 c	0 c	23.1 ab	1.0788
	180	5 bc	5 bc	23.2 a	1.0821
	240	0 c	0 c	22.5 abcde	1.0804
	300	0 c	0 c	21.4 cde	1.0750
Fumigation significance (P-value)		**0.0474**	*0.0516*	0.2551	0.2529
Nitrogen significance (P-value)		**0.0071**	**0.0054**	**0.0139**	0.2035
Fumigation*Nitrogen (P-value)		*0.0789*	*0.0504*	0.2656	0.3428

Values within the same column that have a letter in common are not significantly different from each other (i.e. P > 0.05). Letters are only included where the P-value of the effect of fumigation, N treatment, or their interaction is less than 0.10.

Table 7. Effects of fumigation and N treatment on stem-end and bud-end tuber sucrose and glucose concentrations and the reflectance of French fries made from the stem ends and bud ends of tubers of Russet Burbank potato plants grown at the Sand Plain Research Farm in Becker, MN, in 2016.

Treatments		Sugars				Reflectance	
Fumigation treatment	**Nitrogen application rate (lbs/ac)**	**Sucrose**		**Glucose**		**(Photovolt reflectometer)**	
		Stem	**Bud**	**Stem**	**Bud**		
		(mg/g)				**Stem**	**Bud**
None	40	0.065 ab	0.424 b	2.649 a	0.958 a	25.8 ab	40.4 ab
	120	0.020 bc	0.503 ab	2.194 bcd	0.705 abc	24.0 b	38.0 bc
	180	0.000 c	0.483 ab	2.224 bc	0.617 bc	25.3 b	43.6 a
	240	0.004 c	0.512 ab	1.883 de	0.527 bc	25.9 ab	45.2 a
	300	0.009 c	0.516 ab	1.843 de	0.497 bc	28.6 a	41.8 ab
Chloropicrin	40	0.038 abc	0.440 ab	2.500 ab	1.047 a	26.7 ab	40.7 ab
	120	0.021 bc	0.486 ab	2.040 cd	0.680 abc	25.3 b	40.6 ab
	180	0.075 a	0.398 b	1.634 e	0.650 abc	25.0 b	42.7 ab
	240	0.020 bc	0.492 ab	1.895 cde	0.579 bc	24.4 b	44.4 a
	300	0.005 c	0.510 ab	1.869 de	0.469 bc	26.1 ab	45.1 a
Vapam	40	0.034 abc	0.405 b	2.766 a	1.216 a	26.4 ab	34.6 c
	120	0.010 c	0.476 ab	2.210 bcd	0.740 ab	25.3 b	42.7 ab
	180	0.025 abc	0.478 ab	1.987 cde	0.630 abc	23.9 b	43.3 a
	240	0.000 c	0.502 ab	1.925 cde	0.520 bc	26.5 ab	44.1 a
	300	0.000 c	0.576 a	1.947 cde	0.374 c	26.7 ab	42.3 ab
Fumigation significance (P-value)		0.4824	0.7177	0.3153	0.9063	0.8098	0.5566
Nitrogen significance (P-value)		**0.0394**	*0.0707*	**<0.0001**	**<0.0001**	*0.0615*	**0.0016**
Fumigation*Nitrogen (P-value)		0.3508	0.9344	0.2391	0.9001	0.6116	0.1968

Values within the same column that have a letter in common are not significantly different from each other (i.e. P > 0.05). Letters are only included where the P-value of the effect of fumigation, N treatment, or their interaction is less than 0.10.

Effects of Rotational Crops on Non-irrigated Potato Production in the Red River Valley

Submitted to the MN Area II and NPPGA

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Executive Summary

As cropping system continue to change from small grains to broadleaf crops there is less known on the effect these crops have on the soil and the production of potato following these crops. There seems to be more diseases and blemish problems that affect potato production and quality. Canola has been shown to be beneficial to increasing potato yield and reducing blemishes in Maine. In 2015, the Northern Canola Growers Association funded a project to examine the effect of growing canola, wheat and dry bean prior to potato. The first year of this project found no difference between Red Norland and Atlantic yield, graded yield or dirt clod weight by treatment.

Research Objective

1) Determine the effects of the previous crop (dry edible bean, canola, or wheat) on potato quality and yield, potato tuber blemishes and dirt clod weight.

Current Research

As cropping system continue to change from small grains to broadleaf crops there is less known on the effect these crops have on the soil and the production of potato following these crops. North Dakota canola production is rapidly rising, with North Dakota farmers growing 80% of the United States canola on approximately 1.4 million acres. Traditionally in the Red River Valley, potatoes follow small grains or dry beans. Less is known about following canola with potato.

There seems to be more diseases and blemish problems that affect the quality of potatoes. The effects of crops grown prior to potato is important the study. Cover crops or green manure systems have focused on plants in the mustard family. Canola is in the mustard family (Brassicaceae). Radishes and other mustards have been shown to have biofumigant properties when green manure is tilled into the soil, but it is unknown how canola could improve potato quality and yields in the growing conditions of the Red River Valley.

There is data to suggest that following canola with potatoes can be advantageous for potato quality and production. Over seven two-year rotations, Larkin et al. (2010) reported in Maine that potatoes yielded best when following canola. The canola rotation resulted in 14.7% higher potato yield compared to following green bean and 8.2% higher when compared to following a barley/clover mixture. Additionally, this same study found that canola prior to potato reduced the amount blemishes in potato. Canola in rotation with potato had an 18-38% reduction of Rhizoctonia canker, black scurf, and common scab when compared to the other rotational crops. Our intentions are to determine the effects of canola, dry bean, and wheat on potato production and quality in the Red River Valley.

Procedures

A project was initiated in 2015 at the Grand Forks, ND potato research farm. Canola, dry beans and spring wheat was planted in plots measuring 15 x 40 ft following field corn. Plots were randomized as a complete block with a factorial arrangement of treatments. Four replicates were used. Treatment A was crop (canola, dry edible bean, and spring wheat) and treatment B was tillage (fall chisel plow followed by spring field cultivation and no tillage with a light spring tillage to plant potatoes). After harvest in 2015, plots were either tilled using a 5 ft

chisel plot or not tilled. On May 13, 2016, Red Norland and Atlantic potatoes were planted and grown according to NDSU recommended practices. Plots were soil sampled by previous crop and fertilized accordingly so each plot had equal amounts of nitrogen. At harvest the amount of soil clods collected on a single row potato digger were collected and weighted to determine what effect previous crop and tillage has on soil. Tubers were weighted and graded. A subsample of 20 tubers was surveyed for surface blemishes.

There were no differences between potato cultivars or between treatments. Total yield of potato was numerically greater following canola that was chisel plowed in the fall (Figure 1), but was not significant. A similar response was observed for the graded yield (Figure 2). The amount of dirt clods by treatment was not statistically different, but the canola chisel plowed in the fall had a numeric advantage. No differences existed between blemishes (data not shown). This first year of potatoes in rotation with other crops did not show an advantage of following a single crop.

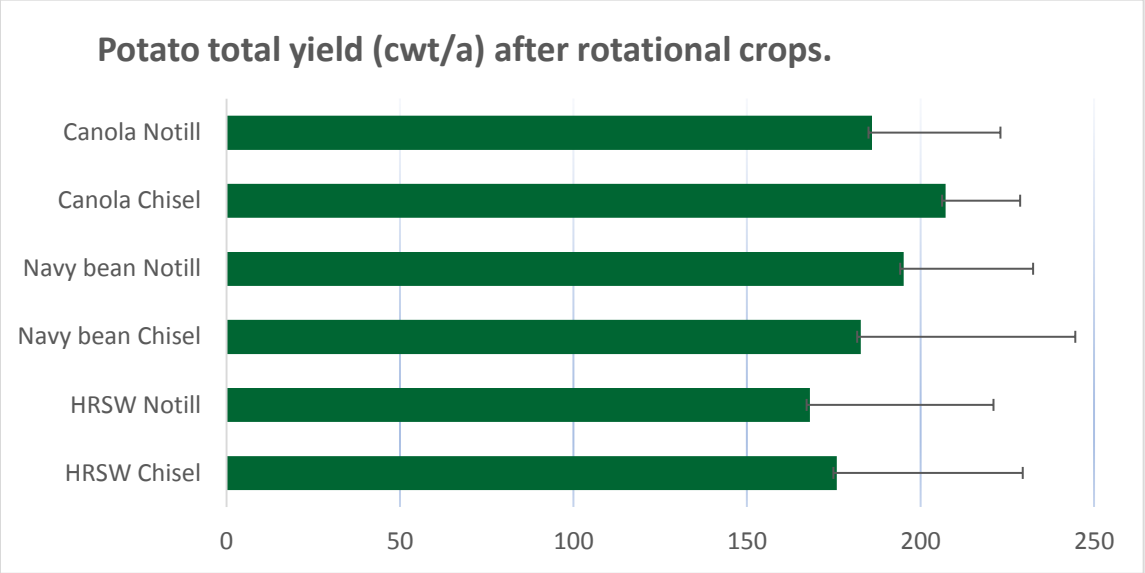

Figure 1. Total yield of Red Norland and Atlantic (cwt/a) following canola, navy bean, and hard red spring wheat (HRSW) and use of chisel plow in the fall and no till at Grand Forks, ND, 2016. Bars represent the standard deviation.

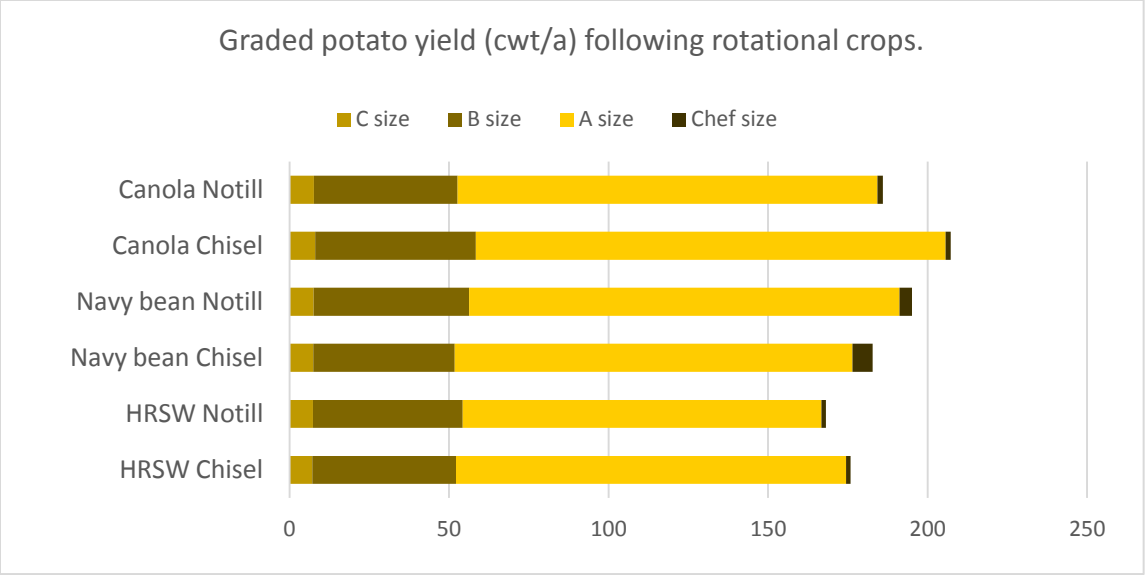

Figure 2. Graded yield of Red Norland and Atlantic (cwt/a) following canola, navy bean, and hard red spring wheat (HRSW) and use of chisel plow in the fall and no till at Grand Forks, ND, 2016. Bars represent the standard deviation.

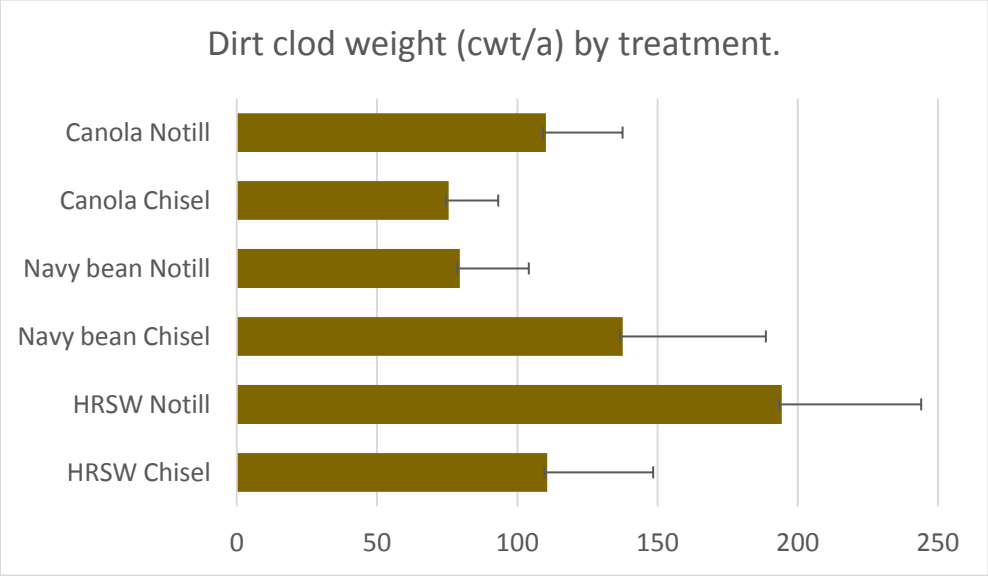

Figure 3. Dirt clod weight (cwt/a) as collected on harvester following canola, navy bean, and hard red spring wheat (HRSW) and use of chisel plow in the fall and no till at Grand Forks, ND, 2016. Bars represent the standard deviation.

Evaluation of Chelated Nutrient Products on Yield and Quality of Russet Burbank Potatoes

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Summary

Chelation of plant nutrients is a method of preventing nutrients from forming biologically unavailable precipitates in the soil. The fertilizer products Redline and Blue Tsunami (West Central, Inc.) are chelates of nutrients prone to precipitation. We evaluated the effect of these products on plant stand, the number of stems per plant, and tuber yield, size, grade, and quality in Russet Burbank potatoes grown at the Sand Plain Research Farm in Becker, MN. Six treatments were applied: (1) a low-P check treatment receiving N in the form of 28% UAN, (2) a low-micronutrient check treatment receiving N and P in the form of ammonium polyphosphate, (3) a treatment receiving ammonium polyphosphate with Equation, (4) a treatment receiving ammonium polyphosphate with Equation and Blue Tsunami, (5) a treatment receiving ammonium polyphosphate with Equation and Redline at 3 gal·ac^{-1}, and (6) a treatment receiving ammonium polyphosphate with Equation and Redline at 5 gal·ac^{-1}. Blue Tsunami appeared to decrease the number of stems per plant, as did Redline applied at 3 gal·ac^{-1}, but not at 5 gal·ac^{-1}. Because Redline only appeared to depress stem number at an application rate of 3 gal·ac^{-1} and not at 0 or 5 gal·ac^{-1}, it is doubtful that the difference in stem number is attributable to this product. Total and marketable yields were higher for most treatments receiving ammonium polyphosphate than for the treatment receiving N in the form of 28% UAN, indicating some yield benefit to ammonium polyphosphate relative to UAN. The exception was the treatment receiving Redline at 5 gal·ac^{-1}, possibly indicating that the application of Redline at this rate is excessive and detrimental to tuber yield. We found no effects of the products tested on tuber size, grade, or quality relative to the ammonium polyphosphate control.

Background

Some plant nutrients chemically interact with each other or with inorganic soil constituents to form biologically unavailable precipitates. Such precipitation reactions can be prevented by applying nutrients in chelates. West Central, Inc., produces chelated nutrient products for commercial agriculture, including the products Redline and Blue Tsunami. Redline contains N, P, K, and Zn, Fe, Mn, and Cu chelated with ortho-ortho EDDHA. Blue Tsunami contains NH_4-N and chelated Zn. The objective of this research was to evaluate Equation, Blue Tsunami, and Redline as sources of micronutrients for Russet Burbank potato plants.

Methods

Study design and treatments

The study was conducted in 2016 at the Sand Plain Research Farm in Becker, MN, on a Hubbard loamy sand soil. The previous crop was rye. Plots were arranged in a randomized complete block design with four replicates and six treatments. One control treatment received 33.6 lbs·ac^{-1} N as 28% UAN at planting, with no other nutrients applied at that time. A second treatment received 33.6 lbs·ac^{-1} N and 114.1 lbs·ac^{-1} P as ammonium polyphosphate applied at 30 gal·ac^{-1}. All other treatments received 30 gal·ac^{-1} in total of liquid fertilizer that included ammonium polyphosphate with 0.5 gal·ac^{-1} Equation plus either no other amendment (treatment 3), 0.5 gal·ac^{-1} Blue Tsunami (treatment 4), or 3 or 5 gal·ac^{-1} Redline (treatments 5 and 6, respectively). A summary of the treatments is presented in Table 1.

Soil sampling

Samples from the top six inches of soil were collected from each block on March 28, 2016. These samples were analyzed for P (using the Bray test); K, Ca, and Mg (using NH_4OAc extraction); SO_4-S (using $Ca[H_2PO_2]_2$ / Ba extraction); B (using hot water extraction); Cu, Fe, Mn, and Zn (using DTPA extraction); soil water pH; and soil organic matter content (based on loss on ignition). Soil samples to a depth of two feet were collected on April 11, dried for 48 hours at 95°F, and extracted in 2N KCl. The extract was analyzed for NO_3-N concentration using a Wescan nitrogen analyzer. The initial soil characteristics of the study site are presented in Table 2.

Planting fertilizing procedures

A 240- by 42-foot field was planted on May 5 using Russet Burbank whole "B" seed with three-foot spacing between rows and one-foot spacing between tubers within rows. Each plot was 12 feet (four rows) wide and 20 feet long. The plots were arranged in eight groups of three plots, each group separated from neighboring groups by seven-foot-wide alleys running across the planting rows. The field was surrounded by a buffer strip of Russet Burbank potatoes five feet wide at both ends and three feet (one row) wide along the edges.

The central two rows of each plot were designated as harvest rows. Each end of each harvest row was marked with a Chieftain red potato to produce a visible boundary between the tubers of different plots during harvest.

Prior to planting, 200 $lb \cdot ac^{-1}$ SulPoMag (0-0-22-11S-22Mg) and 200 $lbs \cdot ac^{-1}$ MOP (0-0-60) were broadcast on the field. At row opening, 28% UAN, ammonium polyphosphate, Equation, Blue Tsunami, and Redline were applied in a band 2-3 inches to the side 2-3 inches below the tuber according to the treatment assigned to each plot (Table 1). The rows were hilled on June 2, at which time, 200 $lbs \cdot ac^{-1}$ N were applied as ESN.

Plant stand and petioles

In each plot, plant stand in the harvest rows and the number of stems per plant for 10 plants in the harvest rows were assessed on July 6. Petioles were sampled June 16 and 29, July 12 and 26, and August 9 (i.e., 14. 27, 40, 54, and 68 days after hilling). The petiole of the fourth expanded leaf from the end of the shoot was collected from each of 20 shoots per plot on each date. The petioles were dried for 48 hours at 140°F, ground, and sent to the Research Analytical Laboratory at the University of Minnesota to have their elemental concentrations determined by inductively coupled plasma analysis. Results of petiole analyses are in progress and not available at the time of this report.

Harvest, sorting, and tuber quality

Vines were chopped on September 12. The tubers were harvested on September 20 and sorted by size and USDA grade on October 3. 25 representative tubers per plot were separated and stored at 48°F for approximately six weeks, after which tuber specific gravity and dry matter content were determined. The prevalences of hollow heart, brown center, and scab were also determined from these samples.

Data analysis

The data were analyzed with SAS 9.4m3® software (copyright 2015, SAS Institute, Inc.), using the GLM procedure with treatment and block as predictor variables for each response variable. Post-hoc pairwise comparisons were made using the WALLER option for the MEANS procedure, with the threshold K ratio set at 50 ($\alpha = 0.10$). Pairwise comparisons are only presented where the P-value of the effect of treatment in the model is less than 0.10.

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. Only one harvest-row tuber (in treatment 3) had not produced a plant as of July 6, and stand was consequently unrelated to fertilization treatment.

In contrast, the number of stems per plant was significantly related to treatment, with the treatment receiving 3 gal·ac^{-1} Redline (treatment 5) having significantly fewer stems per plant than any other treatment except the one receiving Blue Tsunami (treatment 4), which had significantly fewer stems per plant than any of the remaining treatments except for the one receiving ammonium polyphosphate with no other products (treatment 2). It is possible that the application of Blue Tsunami in treatment 4 resulted in a decrease in the number of stems per plant relative to the treatment receiving ammonium polyphosphate and Equation without Blue Tsunami (treatment 3). The same is not likely to be true of the application of Redline in treatment 5, given that the treatment receiving Redline at a higher rate (treatment 6) had nearly the same number of stems per plant as the treatment receiving ammonium polyphosphate and Equation without Redline (treatment 3). Stem number differences in the study due to treatment are difficult to explain and require further investigation.

Tuber yield

Results for tuber yield are presented in Table 4. Treatment had no effect on yield in any size category, nor in the yield of U.S. No. 1 or U.S. No. 2 tubers, nor in the percentage of yield represented by tubers over 6 or 10 ounces. However, treatment was significantly related to total yield and total marketable yield. Specifically, the treatment receiving 28% UAN at planting (treatment 1) and the one receiving 5 gal·ac^{-1} Redline (treatment 6) had lower yields than the other four treatments.

Yield in treatment 1 may have been limited by P availability, since this treatment received no P at planting while all other treatments received at least 96.6 lbs·ac^{-1} P. However, P deficiency cannot explain the low total and marketable yields observed in treatment 6 (relative to treatments 2 – 5), which received nearly as much P as any other treatment. Perhaps 5 gal·ac^{-1} is an excessive application rate for Redline applied to potatoes when banded close to the tuber.

Tuber quality

Tuber quality results are presented in Table 4. Brown center was not detected. None of the other tuber quality variables measured were significantly related to treatment.

Conclusions

The use of Blue Tsunami at 0.5 gal·ac^{-1} or Redline at 3 gal·ac^{-1} in addition to Equation at 0.5 gal·ac^{-1} appeared to decrease the number of stems per plant relative to the use of Equation alone. However, because the use of Redline at 5 gal·ac^{-1} had no such apparent effect, it is doubtful whether these differences in stem number are attributable to the products applied.

Most treatments receiving ammonium polyphosphate, with or without West Central products, had higher total and marketable yields than the treatment receiving UAN as an N source. The exception was the treatment receiving Redline at 5 gal·ac^{-1}. It is possible that the application of Redline at this rate is excessive and detrimental to yield. We found no clear evidence that the chelated products affected tuber size, grade, or quality. Results of petiole analysis are still in progress.

Table 1. Treatments applied to irrigated Russet Burbank potatoes at the Sand Plain Research Farm in Becker, MN, in 2016.

Treatment	Products applied[1] (gal·ac^{-1})					Nutrients applied (lbs·ac^{-1})							
	UAN	Ammonium polyphosphate	Equation	Blue Tsunami	Redline	N	P	K	B	Cu	Fe	Mn	Zn
1	11.7	0	0	0	0	33.6	0	0	0	0	0	0	0
2	0	30.0	0	0	0	33.6	114.1	0	0	0	0	0	0
3	0	29.5	0.5	0	0	33.0	112.7	0.52	0.05	0.01	0.03	0.03	0.03
4	0	29.0	0.5	0.5	0	32.8	110.8	0.52	0.05	0.01	0.03	0.03	0.46
5	0	26.5	0.5	0	3.0	31.4	103.0	2.26	0.05	1.74	1.76	1.76	1.76
6	0	24.5	0.5	0	5.0	30.3	96.6	3.42	0.05	2.90	2.92	2.92	2.92

[1]UAN: 28-0-0. Ammonium polyphosphate: 10-34-0. Equation: 0-10-10-1(B)-0.1(Cu)-05(Fe)-0.5(Mn)-0.5(Zn). Blue Tsunami: 8-0-0-10(Zn). Redline: 6-12-2-0.05(Cu)-0.3(Fe)-0.04(Mn)-1(Zn).

Table 2. Soil characteristics of the study site in the Sand Plain Research Farm in Becker, MN, at the beginning of the 2016 season (soil samples collected on April 11 for NO_3-N, March 28 for all other characteristics).

0 - 2 feet	0 - 6 inches												
Primary macronutrients			**Secondary macronutrients**				**Micronutrients**					**Other characteristics**	
NO_3-N (ppm)	Bray P (ppm)	NH_4OAc-K (ppm)	NH_4OAc-Ca (ppm)	NH_4OAc-Mg (ppm)	SO_4-S (ppm)	Hot Water B (ppm)	DTPA-Cu (ppm)	DTPA-Fe (ppm)	DTPA-Mn (ppm)	DTPA-Zn (ppm)	Water pH	O.M. LOI (%)	
2.61	27	97	307	59	2.0	0.110	0.349	25.6	11.10	0.61	5.7	1.0	

Table 3. Effect of treatment on percent stand and number of stems per plant on July 6 for Russet Burbank potato plants grown at the Sand Plain Research Farm in Becker, MN, in 2016. Values within the same column that have a letter in common are not significantly different from each other (i.e. P > 0.05). Letters are only included where the P-value of the effect of fumigation, N treatment, or their interaction is less than 0.10.

Treatment	Products applied[1] (gal·ac^{-1})	Stand (%)	Stems per plant
1	UAN (11.7)	100	4.25 a
2	Ammonium polyphosphate (30)	100	4.10 ab
3	Polyphosphate (29.5) + Equation (0.5)	99	4.20 a
4	Polyphosphate (29) + Equation (0.5) + Blue Tsunami (0.5)	100	3.80 bc
5	Polyphosphate. (26.5) + Equation (0.5) + Redline (3)	100	3.70 c
6	Polyphosphate (24.5) + Equation (0.5) + Redline (5)	100	4.17 a
	Treatment significance (P-value)	0.4000	**0.0367**
	Treatment MSD (P < 0.1)	--	0.36

[1]Equation: 0-10-10-1(B)-0.1(Cu)-05(Fe)-0.5(Mn)-0.5(Zn). Blue Tsunami: 8-0-0-10(Zn).
Redline: 6-12-2-0.05(Cu)-0.3(Fe)-0.04(Mn)-1(Zn).

Table 4. Effect of treatment on tuber yield, size, and grade for Russet Burbank potatoes grown at the Sand Plain Research Farm in Becker, MN, in 2016. Values within the same column that have a letter in common are not significantly different from each other (i.e. P > 0.05). Letters are only included where the P-value of the effect of fumigation, N treatment, or their interaction is less than 0.10.

Treatment	Products applied[1] (gal·ac^{-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	UAN (11.7)	34	102	201	145	86	568 b	138	430	534 b	76	41
2	Ammonium polyphosphate (30)	40	115	194	164	114	627 a	193	434	587 a	75	44
3	Polyphosphate (29.5) + Equation (0.5)	49	132	211	124	114	629 a	197	431	580 a	71	38
4	Polyphosphate (29) + Equation (0.5) + Blue Tsunami (0.5)	42	116	212	149	109	628 a	205	423	586 a	75	41
5	Polyphosphate. (26.5) + Equation (0.5) + Redline (3)	41	112	213	161	104	632 a	204	427	590 a	76	42
6	Polyphosphate (24.5) + Equation (0.5) + Redline (5)	43	104	197	141	102	587 b	179	408	544 b	75	41
	Treatment significance (P-value)	0.5561	0.7883	0.8450	0.3483	0.8535	**0.0021**	0.4955	0.9960	**0.0279**	0.9102	0.9168
	Treatment MSD (P < 0.1)	--	--	--	--	--	26	--	--	35	--	--

[1]Equation: 0-10-10-1(B)-0.1(Cu)-05(Fe)-0.5(Mn)-0.5(Zn). Blue Tsunami: 8-0-0-10(Zn). Redline: 6-12-2-0.05(Cu)-0.3(Fe)-0.04(Mn)-1(Zn).

Table 5. Effect of treatment on tuber quality (the prevalence of hollow heart, brown center, and scab; dry matter content; and specific gravity) for Russet Burbank potatoes grown at the Sand Plain Research Farm in Becker, MN, in 2016. Values within the same column that have a letter in common are not significantly different from each other (i.e. P > 0.05). Letters are only included where the P-value of the effect of fumigation, N treatment, or their interaction is less than 0.10.

Treatment	Products applied[1] (gal·ac^{-1})	Tuber Quality				
		Hollow Heart	Brown Center	Scab	Dry matter	Specific Gravity
		%				
1	UAN (11.7)	4	0	0	22.4	1.0817
2	Ammonium polyphosphate (30)	3	0	5	23.5	1.0829
3	Polyphosphate (29.5) + Equation (0.5)	3	0	4	22.9	1.0837
4	Polyphosphate (29) + Equation (0.5) + Blue Tsunami (0.5)	1	0	1	23.6	1.0840
5	Polyphosphate. (26.5) + Equation (0.5) + Redline (3)	4	0	4	22.7	1.0816
6	Polyphosphate (24.5) + Equation (0.5) + Redline (5)	3	0	1	23.2	1.0814
	Treatment significance (P-value)	0.7542	--	0.2540	0.2686	0.3292
	Treatment MSD (P < 0.1)	--	--	--	--	--

[1]UAN: 28-0-0. Ammonium polyphosphate: 10-34-0. Equation: 0-10-10-1(B)-0.1(Cu)-05(Fe)-0.5(Mn)-0.5(Zn). Blue Tsunami: 8-0-0-10(Zn). Redline: 6-12-2-0.05(Cu)-0.3(Fe)-0.04(Mn)-1(Zn).

Evaluation of glycoalkaloid content, storage, and processing quality of advanced breeding materials.

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Summary

Resistance to cold sweetening in storage was assessed among advanced breeding lines. In the 2015 storage campaign, 8 of 88 clones evaluated chipped directly from 42°F or were classified as 'Class A' clones. An additional 13 clones were designated 'Class B', or provided acceptable quality chips from 45°F, but not 42°F after 7 months of storage. The USDA-ARS Potato lab in East Grand Forks is enhancing in-house lab capabilities to include analysis of glycoalkaloids. Total glycoalkaloid (TGA) content from tubers cannot exceed 20 mg/ 100g FW as higher levels can cause sickness. To optimize an extraction procedure, leaf and tuber tissue from potato lines possessing wide variability in TGA content and sensitivity to Colorado potato beetle defoliation were sampled from a 2016 Field Trial. Total glycoalkaloid analysis was achieved utilizing a liquid chromatography separation method with UV detection, but additional studies are required to improved TGA extraction efficiency and lab reproducibility before analysis of TGA from advanced breeding lines can be completed.

Background

Glycoalkaloids are a natural compound found in many plant tissues that can result in bitterness in high levels (> 20mg/ 100 g FW). Prior to the release of a new potato variety, breeders must quantify tuber total glycoalkaloid levels (TGA) to ensure safe levels are maintained. Breeders have long recognized that variation in foliar glycoalkaloid content may also impact Colorado potato beetle (CPB) sensitivity, where plants containing increased glycoalkaloids or altered glycoalkaloid composition may have improved resistance to CPB defoliation. In addition to TGA, the ability to quantify small changes in glycoalkaloid metabolism may help improve our understanding of natural host defense mechanisms against CPB feeding. The USDA-ARS location in East Grand Forks, MN is equipping the analytic laboratory to routinely quantify TGA from promising new varieties while also fulfilling our objective of characterizing storage and processing quality (cold sweetening resistance) among new public breeding lines. Potato sugar concentrations may vary widely among potato clones and sugar accumulation in storage may result in off-color chips, especially at temperatures below 45°F. Considerable cost savings could be achieved at reduced temperature storage through decreased shrinkage, lower incidence of disease pressure, and decreased need for sprout inhibition. However, prolonged cold storage often results in off color product (increased acrylamide formation) resulting from enhanced sugar accumulation, and 'cold sweetening' remains a challenge to growers and processors.

Methods

Glycoalkaloid Field Trial

A replicated field trial was conducted at the NPPGA Research Farm in Grand Forks, ND. Twenty-four clones (varying in glycoalkaloid content) were kindly provided by Dr. Asunta

(Susie) Thompson. The experimental design was a randomized complete block arranged as a split block with three replicates. Chemical control for Colorado potato beetle (CPB) (Admire Pro- 8oz.a) was applied to seed pieces to one block and no chemical was applied to the second. CPB defoliation notes and leaf tissue samples were collected on July 18 and August 9, and tubers were harvested on September 30, 2016.

Advanced Storage / Processing Evaluation

Promising new chipping or dual frozen/fresh market clones were obtained from eight public breeding programs and were grown in an irrigated field trial, Larimore, ND in 2015; potatoes were harvested September 18, 2015. After suberization for two weeks at 55°F, potatoes were stored at 48, 45, 42, and 38°F. Samples for sugar and chip color were obtained immediately after suberization (time 0) and after 3, 6, and 7 months. Additionally, at seven months of storage, a subsample of potatoes stored at 42 and 38°F was reconditioned at 55°F for four weeks before color assessment and sugars were determined. Sucrose rating (glucose and sucrose concentrations) was determined with a YSI 2700 biochemical analyzer (Yellow Springs Instruments). Chips (thickness of 20 slices/inch or roughly 0.05 inches/slice) were fried in canola oil (365°F) for 90 seconds. Chip color ratings were determined using the Snack Food Association five point scale (1 light, 5 dark) and a Hunterlab color score (HunterLab D25 with DP-9000 processor) was also recorded.

Results and Discussion:

Glycoalkaloid Method Development

Plant Tissue

As expected, potato clone selection impacted Colorado potato beetle sensitivity (Table 1). Dakota Russet and ND8291C-2Russ had the highest defoliation damage on July 18. In contrast, decreased or minimal defoliation was observed in Russet Burbank, Red Norland, Dakota Diamond, and several numbered experimental clones from the first sampling point (Table 1). Average across clones, the defoliation damage increased nearly 60% by August 9th. After this sampling point, beetle populations overwhelmed the plots and no additional leaf tissues were collected; tubers were hand harvested on September 30, 2016.

Total glycoalkaloid extraction and separation

Quantification of total glycoalkaloids (TGA) often implies the quantification of α-solanine, and α-chaconine. These are the most abundant glycoalkaloid compounds in potato tubers, and commercially available standards permit easy confirmation. Separation and quantification of solanine and chaconine were determined by high performance liquid chromatography with ultra violet detection (HPLC-UV). Solanine and chaconine were eluted isocratically using a 4.6 x 150 mm, 5µm Zorbax Eclipse XDB-C18 column (Agilent Technologies) with 40/60 v/v acetonitrile/0.01 M Tris-HCL, pH 7.78 at a flow rate of 1 mL min^{-1}.

Efforts to extract glycoalkaloids from fresh tissue were futile (data not shown), and all subsequent analysis were carried out on freeze-dried tissue. Freeze-dried tissue was finely

ground to pass a 0.5mm mesh screen. Peak identity and solanine/chaconine concentration were determined by comparison with commercial standards. During the analysis of foliar extractions, two or three additional compounds were often identified. Several classes of glycoalkaloids, including leptine and leptinidine compounds have been identified with HPLC and other research has indicated a close association of these compound with increased resistance to CPB. Unfortunately, more sophisticated/costly mass spectroscopy methods will be necessary to confirm unknown peak identity as commercial standards for leptine or leptidinine do not exist.

To date, the highest extraction efficiency of spiked samples is only 50%, which prevented a complete analysis of the 2016 field samples. A challenge with UV detection is that many compounds absorb in the same region, interfering with the detection of the desired compound, especially at low concentrations. Additional studies are being conducted including the addition of co-solvents and solid phase extraction to improve extraction efficiency and reproducibility. LC/MS will be used to unequivocally confirm identities of minor peaks. After extraction efficiency is improved, TGA contents of freeze-dried tubers from the 2016 NPPGA field study will be reported in the Valley Potato Grower magazine.

Advanced Storage / Processing Evaluation

For the 2015 crop, storage and processing quality of 88 clones was evaluated in East Grand Forks, MN with the storage evaluations concluding June, 2016. Of the 88 clones examined, 61 entries represented eight public breeding programs and the remaining 27 included named commercial checks. The NDSU breeding program had submitted eight advanced chipping/ fry market clones. The UMN potato breeding had not submitted any advanced selections for testing at the East Grand Forks worksite in 2015. Similar to prior years, optimum storage conditions were evaluated by examining sugars/chip colors throughout seven months of storage at contrasting storage temperatures (48,45,42, and 38°F), and clones were classified by their cold sweetening resistance (Sowokinos and Glynn, 2000). The three classes (A, B, and C) are defined as:

- Class A: Clones that can be chipped directly from 42°F storage (Table 2)
- Class B: Clones that chip from 45°F, but not 42°F storage (Table 3)
- Class C: Clones that chip neither from 45°F nor 42°F (Table 4).

Sowokinos, J.R. and M. Glynn. 2000. Marketing potential of advanced potato breeding clones. *Valley Potato Grower*, 6(110):6-8.

For brevity, clone physical attributes and breeding source was not included in tables and additional information on clones may be found by contacting Darrin Haagenson at Darrin.Haagenson@ars.usda.gov or 701-219-4905. From the 2015-16 storage campaign, eight clones were classified as 'Class A' (Table 2). Although three clones (AC05153-1W, NDTX071109C-1W, and TX09403-14W) had elevated glucose levels (>0.25 mg/g) at seven months of 42°F storage, all eight class A clones had superior chip color scores. Of the eight 2015 class A clones, two NDSU clones: ND7519-1 and ND7799c-1 are also being evaluated in the 2016-17 storage campaign. For the 2016 crop, the six week chip color for both ND lines was at or improved from the commercial checks with ND7519-1 having slightly better color (Figure 1). A slight stem end defect was observed in both the ND7799c-1 and Dakota Pearl samples.

Thirteen clones provided acceptable chip color ratings when chipping directly from 45°F at seven months of storage, and were classified as 'Class B' clones (Table 3). Of the 13 clones, 3 breeding lines are being evaluated from the 2016 crop in East Grand Forks (AF3001-6, AF4157-6, and MSR127-2). Of these three clones, MSR127-2, from Michigan State University, is also a participant in the 2016 Potatoes USA SNAC Trial.

The 'Class C' clones that gave an unacceptable chip color following seven months of storage at 45°F or 42°F, and the 48°F sugar data and chip color ratings are shown in Table 4. Of the 50 clones classified as Class C in 2015, 13 were included in the 2016 crop evaluation and sugar/chip profiles are currently being reexamined. Lastly, clones were also stored at 38°F, but none of the clones tested at 38°F in 2015-16 gave an acceptable chip color after seven months storage, and reconditioning did not improved chip color ratings from any clones stored at 38°F in 2015-2016.

Table 1. Defoliation[1] Ratings from a NPPGA Field Trial, (Grand Forks, 2016).

Entry	18-Jul	9-Aug
463-4	1.8	2.7
Ebt 5-31-2	2.8	3.8
Ebt 5-31-3	1.5	3.2
Ebt 6-5-3	3.0	4.1
Ebt 6-12-1	1.2	2.9
Ebt 6-21-12	3.3	4.3
Ebt 6-31-5	2.0	3.5
N142-71	2.5	4.0
ND4100C-19	1.3	3.1
ND5873-23	1.2	2.5
ND5873-29	1.7	2.5
ND8291C-2Russ	3.7	4.0
ND092018C-2	2.2	3.6
ND092018C-3	2.2	3.7
ND092019C-4Russ	2.8	4.1
ND113065CB-1Russ	2.7	3.7
ND113224C-3Russ	1.2	3.0
Q115-6	2.2	2.8
Dakota Diamond	1.2	3.1
Dakota Pearl	1.8	3.6
Dakota Russet	3.7	4.3
Lenape	2.3	3.6
Red Norland	1.3	3.0
Russet Burbank	1.0	2.2
LSD (*p<0.05)*	0.5	0.4

[1]Defoliation Rating: 0 = no defoliation, 5 = 100% defoliation;

Table 2. Class A Clones. Potato Clones Providing Acceptible Chip Color following 7 months of Storage at 42°F.

	45°F				42°F				42RC [4]				
Clone	CC [2]	Hunter [3]	Sucrose mg/g	Glucose [1] mg/g	CC	Hunter	Sucrose mg/g	Glucose mg/g	CC	Hunter	Sucrose mg/g	Glucose mg/g	2016 crop [6] 16-17 Storage
AC00206-2W	*** [5]	***	***	***	2	53	0.803	0.289	2	58	0.454	0.040	
AC05153-1W	2	55	1.008	0.723	2	54	3.305	0.621	2	57	2.993	0.342	x
B3015-1	2	58	1.685	0.027	2	53	4.703	0.058	2	53	1.497	0.116	
MSV498-1	2	58	0.545	0.036	2	54	0.608	0.157	2	56	2.686	0.042	
ND7519-1	2	57	0.683	0.050	2	56	0.585	0.187	2	56	0.688	0.052	x
ND7799C-1	2	57	0.720	0.065	2	59	1.046	0.092	3	56	1.076	0.071	x
NDTX071109C-1W	***	***	***	***	2	60	2.860	0.520	2	55	0.537	0.486	
TX09403-14W	***	***	***	***	2	54	0.623	0.500	2	56	0.519	0.097	

[1] Acceptable values for glucose are 0.25 mg/g (0.025%) or less.

[2] Chip color (CC) ratings are from the Potato Chip/Snack Food Association five-code standard: 1 and 2 are acceptable, 3 is marginal, and 4 and 5 are unacceptable.

[3] Hunter Lab color values (lighter chip = high #)

[4] RC = Reconditioned at 55F for 4 wks following 6 months of storage .

[5] ***= No sample.

[6] Clones are being evaluated in EGF, 2016-2017 storage season.

Table 3. Class B Clones. Potato Clones Providing Acceptible Chip Color following 7 months of Storage at 45°F, but not 42°F.

	45°F				42°F				42RC [4]				
Clone	CC [2]	Hunter [3]	Sucrose mg/g	Glucose [1] mg/g	CC	Hunter	Sucrose mg/g	Glucose mg/g	CC	Hunter	Sucrose mg/g	Glucose mg/g	2016 Crop [1] 16-17 Storage
AF3001-6	2	58	0.545	0.044	3	53	1.400	0.176	2	56	0.734	0.148	x
AF4157-6	2	58	0.770	0.061	3	54	1.239	0.388	2	57	0.771	0.071	x
AF4975-3	2	52	0.702	0.792	3	46	1.180	1.160	3	46	1.765	0.477	
B2842-1	2	55	1.167	0.053	3	50	1.248	0.556	3	52	1.157	0.137	
B2940-2	2	52	1.244	0.998	3	46	2.521	1.852	3	49	1.439	1.164	
IVORY CRISP	2	52	0.720	0.177	3	48	0.930	0.524	2	54	0.507	0.232	x
LADY CLAIRE	2	54	0.470	0.351	4	43	1.113	0.839	3	54	0.682	0.232	x
MANISTEE	2	60	0.779	0.263	3	53	0.859	0.429	3	54	0.443	0.170	
MCBRIDE	2	57	0.761	0.106	3	54	1.272	0.288	2	53	1.051	0.211	
MSR127-2	2	55	0.872	0.104	3	50	1.139	0.160	3	51	0.759	0.120	x
MST191-2Y	2	56	0.879	1.000	4	47	1.339	1.911	3	52	0.824	0.343	
MSV033-1	2	53	0.626	0.140	3	52	1.046	0.319	2	55	0.934	0.253	
NORVALLEY	2	61	0.389	0.714	3	48	0.633	0.130	2	55	0.600	0.181	

[1] Acceptable values for glucose are 0.25 mg/g (0.025%) or less.

[2] Chip color (CC) ratings are from the Potato Chip/Snack Food Association five-code standard: 1 and 2 are acceptable, 3 is marginal, and 4 and 5 are unacceptable.

[3] Hunter Lab color values (lighter chip = high #)

[4] RC = Reconditioned at 55F for 4 wks following 6 months of storage .

[5]Clones are being evaluated in EGF, 2016-2017 storage season.

Table 4. Class C Clones. Potato Clones Providing Non Acceptable Chip Color following 7 months of Storage at 45°F or 42°F; 48°F data is reported.

	48°F				
Clone	CC [2]	Hunter [3]	Sucrose mg/g	Glucose [1] mg/g	2016 Crop [4] 16-17 Storage
AC03452-2W	2	60	0.044	0.813	
AF3362-1	3	49	1.513	1.943	x
AF4124-7	3	50	0.672	1.453	
AF4172-2	3	49	0.449	0.925	
AF4296-3	3	54	0.115	0.980	x
AF4648-2	2	56	0.400	0.288	x
AO01114-4	4	43	0.832	1.228	
AO03123-2	3	57	1.204	0.729	
AO96141-3	4	41	1.336	1.714	x
AOR06267-3	3	50	0.665	0.468	
B2869-29	3	52	1.012	0.472	
BANNOCK RUSSET	3	50	0.801	1.186	
BINTJE	3	46	0.710	1.212	
BNC366-1	3	49	0.949	0.122	
CO05068-1RU	2	56	0.726	0.138	x
CO05110-6RU	3	50	0.939	0.937	
CO05175-1RW	3	53	0.905	1.522	
COLORADO ROSE	4	50	0.329	1.218	
COTX03134-1W	3	50	0.435	0.629	
CV08032-1	4	42	0.057	3.149	
CV08104-5	2	58	0.429	0.912	
CV08247-1	2	56	0.476	1.128	
DAKOTA RUBY	3	44	1.751	0.979	
DAKOTA RUSSET	3	53	0.666	0.512	x
FV15732-09	2	60	0.502	0.062	

	48°F				
Clone	CC	Hunter	Sucrose mg/g	Glucose mg/g	2016 Crop [4] 16-17 Storage
GOLDRUSH	4	47	0.057	2.186	
ND7818-1Y	2	56	2.695	0.775	
ND8068-5RUSS	3	56	0.647	0.722	x
NDTX081648CB-13W	2	58	1.159	0.248	
NDTX091908AB-2W	2	58	0.710	0.167	
NDTX102514ABC-5W	3	50	1.425	1.627	
POR06V12-3	2	56	0.818	0.842	x
RANGER RUSSET	4	47	0.164	1.216	x
RED NORLAND	4	44	0.158	1.916	
RUSSET BURBANK	3	45	0.807	2.493	x
SANGRE	4	42	0.151	2.113	
SILVERTON	3	46	0.934	1.085	
SMILIN'EYES	3	45	1.865	1.778	
TETON RUSSET	4	46	0.394	0.644	
TX08352-5RU	4	41	0.177	1.742	
TX09396-1W	3	53	2.736	0.176	
UMATILLA	3	53	0.629	0.971	x
V07087-1	3	52	2.127	1.572	
V08053-1	2	57	0.560	0.366	
W8405-1R	4	40	0.386	2.278	
W8822-1	2	58	0.194	0.366	x
W8886-3R	4	43	0.141	2.173	
W8890-1R	3	43	0.917	2.846	
W8893-1R	4	46	1.337	1.663	
YUKON GOLD	4	36	1.322	4.515	x

[1] Acceptable values for glucose are 0.25 mg/g (0.025%) or less.

[2] Chip color (CC) ratings are from the Potato Chip/Snack Food Association five-code standard: 1 and 2 are acceptable, 3 is marginal, and 4 and 5 are unacceptable.

[3] Hunter Lab color values (lighter chip = high #)

[4] Clones are being evaluated in EGF, 2016-2017 storage season.

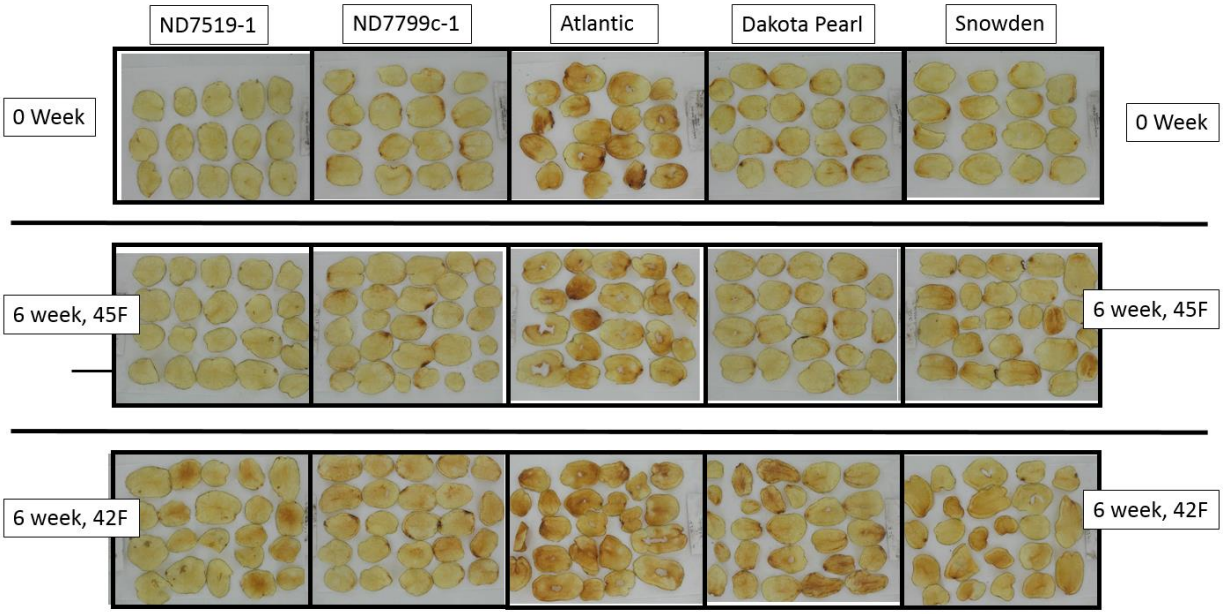

Figure 1. Chip Color Data of NDSU Breeding Lines ND7519-1 and ND7799c-1 and commercial checks at 6 weeks of storage at 45 and 42°F. (2016 crop)

Field Evaluation of Aspire (Mosaic Co.) as a Potassium and Boron Source for Irrigated Russet Burbank Potato Production

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Summary
Potassium (K) and boron (B) are both essential nutrients for potato production, promoting tuber yield, internal quality, and storability. However, because the range between deficient and toxic soil concentrations of B is narrow, and because only small quantities are required to meet the needs of potato plants, uniform application of B is both important and difficult. Aspire (Mosaic Co.; 0-0-58-0.5B) is a fertilizer intended to facilitate uniform application of B by incorporating it with a macronutrient (K) in a ratio at which these two nutrients are typically required. In a field study conducted at the Sand Plain Research Farm in Becker, MN, we evaluated the effectiveness of Aspire as a source of K and B for Russet Burbank potatoes. A control treatment received neither K nor B. In five treatments, K was applied at 300 lbs lbs·ac^{-1} K_2O as either KCl (muriate of potash) or Aspire. Two KCl treatments and one Aspire treatment were fertilized in a single pre-plant application. One KCl and one Aspire treatment were split into two equal applications: one at planting and one at emergence. One of the single-application KCl treatments also received B as Granubor (U.S. Borax, Inc.) at a B rate equal to the two Aspire treatments. At the low soil test K level (58 ppm) where this study was conducted, K fertilization was required for optimum yield and tuber size. Marketable yield nearly doubled with K application regardless of source relative to the zero K control. Soil test B was also low, but B application did not affect total or marketable yield. It did affect tuber size distribution, although application timing was important. Preplant application of 2.5 lbs B/ac as Aspire significantly increased tuber size, but when B application was split between preplant and emergence tuber size was not affected. This suggests that the effect of B on tuber size occurs during tuber initiation rather than tuber bulking. It also shows that when soil test B is 0.1 ppm, a preplant B rate of 1.25 lb/ac is insufficient to increase tuber size. Effects of B source were not as clear. Granubor application produced similar effects on tuber size as Aspire, but numerically the effects of Granubor were consistently less than Aspire. Applying K and B had no significant effects on the incidence of hollow heart, brown center, and scab; or on tuber dry matter percentage and specific gravity.

Background

Potatoes have a very high demand for potassium (K) relative to other vegetable crops. K can influence the yield and size distribution of potato tubers, as well as their specific gravity and storage characteristics. Boron (B) is important for integrity of plant cell walls, where it binds pectins together, and in calcium absorption. In both these roles, B availability is vital to tuber internal quality and storability, as well as yield. B also increases the concentration of vitamin C in potato tubers.

The importance of these nutrients in potato production is clear. However, because B is a micronutrient that is required and applied in very small quantities, uniform application can be difficult to achieve. Uneven application is a potential problem, because the range between deficient and toxic soil concentrations of B is narrower than for any other plant nutrient. Aspire (Mosaic Co.: 0-0-58-0.5B) is a product designed to facilitate uniform B application by combining it in fertilizer granules with K, which is easier to distribute evenly since it is required in large quantities.

The objectives of this study were to: (1) evaluate Russet Burbank potato response to Aspire relative to K (KCl) without B, (2) evaluate the effectiveness of Aspire relative to KCl blended with supplementary granular B, and (3) compare the effectiveness of a single pre-plant application of K to split pre-plant and emergence applications of both Aspire and KCl (without B). 2016 was the 2nd year of this study.

Materials and Methods

The study was conducted at the Sand Plain Research Farm in Becker, MN, on a Hubbard loamy sand soil. The previous crop was rye. Selected soil chemical properties before planting were as follows (0-6"): pH, 6.1; organic matter, 1.1%; Bray P1, 17 ppm; ammonium acetate extractable K, Ca, and Mg, 58, 550, and 123 ppm, respectively; Ca-phosphate extractable SO_4-S, 2.0 ppm; hot water extractable B, 0.1 ppm; and DTPA extractable Fe, Mn, Cu, and Zn, 38, 10, 0.3, and 0.7 ppm, respectively. Extractable nitrate-N in the top 2 ft of soil before planting was 18 lb/A.

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 April 27 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

Six treatments were compared (Table 1). Treatment 1 was a control that received no K or B fertilizer. All other treatments received 300 lbs·ac^{-1} K_2O as either KCl (treatments 2, 3, and 5) or Aspire (treatments 4 and 6). K was applied in either a single broadcast application preplant on April 26 (treatments 2 – 4) or split into two equal applications (treatments 5 and 6): one preplant and the second sidedressed at emergence on May 24. The preplant fertilizer application was disked in to a depth of about 6" prior to planting. Emergence fertilizer was surface-applied along the row and incorporated during hilling. One of the preplant KCl treatments (#3) also received 2.5 lbs·ac^{-1} B as Granubor (U.S. Borax, Inc.), equivalent to the B received by the treatments with Aspire as the K source (#4 and #6).

At planting all treatments (including the control) received 30 lbs·ac^{-1} N and 136 lbs·ac^{-1} P_2O_5 as MAP (monoammonium phosphate, 11-52-0), along with 1 lb·ac^{-1} Zn and 0.5 lb·ac^{-1} S as Blu-Min Zinc Granular with Sulfur (Kronos Micronutrients: 35.5% Zn; 17.5% S). They also received 140 lbs·ac^{-1} N as ESN (Environmentally Safe Nitrogen, 44-0-0, Agrium, Inc.) that was banded and slightly hilled on May 25 after emergence; 26 lbs·ac^{-1} N as ammonium sulfate (21-0-0-24S) that was banded and incorporated during hilling on June 2; and 40 lbs·ac^{-1} N as 28% urea-ammonium nitrate split into two equal applications on June 27 and July 18. The ammonium sulfate also supplied 30 lbs·ac^{-1} S to all treatments.

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. Samples of rain and irrigation water were collected on two dates for chloride, nitrate-N, phosphate-P, and sulfate-S analysis by ion chromatography: rainfall on May 25 and September 6 and irrigation water on July 2 and August 25.

Plant stand in the harvest rows and the number of stems per plant for 10 harvest-row plants were measured on June 8. Leaf petioles (4th leaf from the terminal) were sampled on June 14 and 28, July 14 and 27, and August 8. Petiole K and B concentration will be determined on a dry-weight basis by the Research Analytical Laboratory of the University of Minnesota using inductively coupled plasma analysis.

Vines were chopped on September 12 and tubers were harvested on September 29. Two, 18-ft sections of row were harvested from each plot. Total tuber yield and graded yield were measured. Sub-samples of tubers were collected to determine tuber specific gravity and dry matter and the incidence of hollow heart, brown center, and scab.

Data were analyzed using the GLM procedure in SAS 9.4. Dependent variables were modeled as functions of treatment and block. Significant differences between treatments at alpha = 0.10 were determined with Waller-Duncan k-ratio t tests. Three contrasts were performed for each variable analyzed: (1) a comparison of the zero-K treatment (treatment 1) with those receiving KCl without B (treatments 2 and 5); (2) a comparison of treatments receiving KCl with those receiving Aspire at the same times and rates (treatments 2 and 5 versus 4 and 6); and (3) a comparison of treatments receiving K in a single application versus two (treatments 2 and 4 versus 5 and 6).

Table 1. Nutrient sources, application timing, and K and B application rates of fertilizer treatments applied to Russet Burbank potatoes.

Treatment #	Nutrient sources[1]	Application timing and rates of K and B (lbs·ac^{-1} K_2O and B)					
		Pre-plant		Emergence		Total applied	
		K	B	K	B	K	B
1	None	0	0	0	0	0	0
2	KCl	300	0	0	0	300	0
3	KCl + B	300	2.5	0	0	300	2.5
4	Aspire	300	2.5	0	0	300	2.5
5	KCl split	150	0	150	0	300	0
6	Aspire split	150	1.25	150	1.25	300	2.5

[1]KCl (muriate of potash): 0 -0-60; B: Granubor (sodium borate) 14% B; Aspire: 0-0-58-0.5B.

Results

Analysis of rainfall and irrigation water

Concentrations of chloride, nitrate-N, and phosphate-P were below the 0.1 mg/L detection limit for rainfall samples collected in both May and September. Sulfate-S was below the detection limit in May, but was measureable at 0.1 mg/L in September. The field plots were adjacent to a large area where coal ash from a nearby coal-fired power plant is stored, but the sulfate-S concentrations in rainfall show that atmospheric deposition provides a minimal amount of S for crop plants.

Mean concentrations for the two irrigation water samples collected in July and August were: chloride, 25.6 mg/L; nitrate-N, 8.2 mg/L; phosphate-P <0.1 mg/L; and sulfate-S, 4.8 mg/L. Depending on the volume of irrigation water applied, this water source could supply some of the crop N and S requirements and a larger proportion of its chloride requirement.

Tuber yield and size distribution

Results for tuber yield and size distribution are presented in Table 2. At the low soil test K level (58 ppm) where this study was conducted, K fertilization was required for optimum yield and tuber size. The control with no K applied had significantly lower total and marketable yields, and significantly lower percentages of its yield in both the >6 oz. and >10 oz. size categories, than any of the treatments receiving K. This was consistent with results in 2015, although the magnitude of differences in both yield and tuber size were much greater in 2016. In 2016 there was a significantly greater yield of #2 grade tubers with single vs. split fertilizer application (treatments 2 and 4 vs. 5 and 6), but a similar effect was not observed in 2015.

Soil test B at this site was in the low range, but B application as either Aspire or Granubor had no effect on total or marketable yield. Results did indicate that B plays a role in increasing tuber size, although application timing was important. When 2.5 lbs B/ac were applied preplant as Aspire (treatment 4), yields of unmarketable tubers <3 oz. and tubers in the 3-6 oz. size class were significantly less than for KCl without B (treatment 2). Preplant Aspire also had significantly greater percentages of its yield in both the >6 oz. and >10 oz. size categories than pre-plant KCl without B. Similar comparisons between split applications of Aspire (treatment 6) and KCl without B (treatment 5) found no tuber size differences. These same application timing differences in tuber size occurred in 2015, suggesting that the effect of B on tuber size occurs during tuber initiation rather than tuber bulking. It also shows that when soil test B is 0.1 ppm or less, a pre-plant B rate of 1.25 lb/ac is insufficient to increase tuber size.

Pre-plant KCl + B (treatment 3) also had significantly lower yield of tubers <3 oz. than pre-plant KCl without B, and its effect was statistically the same as preplant Aspire. This indicates there is no difference between applying B as Granubor or Aspire. However, effects of B source on other tuber size classes were not as clear. Yield of 3-6 oz. tubers was numerically less with KCl + B than KCl without B, and yields of >6 oz. and >10 oz. tubers were numerically greater for KCl + B than KCl without B, but the differences were not significant. There were also no significant yield differences in any of these size classes between KCl + B and Aspire, although in every case KCl + B was numercally intermediate between KCl without B and Aspire. This consistent trend suggests that Granubor as a B source can increase tuber size, but that it may not be as effective as B applied at the same rate with Aspire.

In 2015, the treatment receiving KCl with Granubor showed the same numerically intermediate tuber size distribution pattern relative to the KCl without B and Aspire treatments applied in a single application. However, for all size classes except 10-14 oz., KCl with Granubor was significantly different than KCl without B and statistically the same as Aspire. One difference between the two years was that soil test B was twice as high in 2016 as 2015, but it was low in both years (0.125 vs. 0.o58), so the difference probably did not affect response to B fertilization.

Tuber quality

Results for tuber quality are presented in Table 3. Fertilizer treatment had no significant effects on the incidence of hollow heart, brown center, and scab; or on tuber dry matter percentage and specific gravity.

Petiole K and B concentrations
Results of petiole tissue analysis were not available at the time of this report.

Conclusions

At the low soil test K level (58 ppm) where this study was conducted, K fertilization was required for optimum yield and tuber size. The control with no K applied had significantly lower total and marketable yields, and significantly lower percentages of its yield in both the >6 oz. and >10 oz. size categories, than any of the treatments receiving K.

Soil test B was also low, but B application as either Aspire or Granubor had no effect on total or marketable yield. Results did indicate that B plays a role in increasing tuber size, although application timing was important. Preplant application of 2.5 lbs B/ac as Aspire significantly increased tuber size, but when B application was split between preplant and emergence tuber size was not affected. This suggests that the effect of B on tuber size occurs during tuber initiation rather than tuber bulking. It also shows that when soil test B is 0.1 ppm or less, a preplant B rate of 1.25 lb/ac is insufficient to increase tuber size.

Effects of B source were not as clear. Granubor application produced similar effects on tuber size as Aspire, but numerically the effects of Granubor were consistently less than Aspire. This suggests that Granubor could be a less effective B source than Aspire.

Applying K and B had no significant effects on the incidence of hollow heart, brown center, and scab; or on tuber dry matter percentage and specific gravity.

Table 2. Effects of nutrient sources, application timing, and K and B application rates on tuber yield and size distribution of Russet Burbank potatoes.

Treatment #	Nutrient sources[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	None	67 a[2]	124 c	134 b	29 b	9 b	362 b	245 b	117 b	295 b	47 c	10 c
2	KCl	62 ab	174 a	204 a	128 a	63 ab	631 a	342 a	289 a	569 a	62 b	30 b
3	KCl + B	47 c	149 abc	201 a	144 a	77 a	618 a	350 a	268 a	571 a	68 ab	36 ab
4	Aspire	52 c	138 bc	206 a	157 a	110 a	663 a	374 a	290 a	612 a	71 a	40 a
5	KCl split	55 bc	143 bc	215 a	142 a	84 a	639 a	387 a	251 a	583 a	69 ab	35 ab
6	Aspire split	53 bc	154 ab	193 a	135 a	96 a	630 a	376 a	254 a	577 a	67 ab	36 ab
Overall treatment significance		*[3]	*	**	**	*	**	**	**	**	**	**
Treatment MSD (P < 0.1)		10	27	31	29	56	50	57	42	56	7	9
Contrasts:												
Control vs. others (1 vs. 2 - 6)		++	*	**	**	*	**	**	**	**	**	**
KCl vs. Aspire (2 & 5 vs. 4 & 6)		++	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Single vs. split (2 & 4 vs. 5 & 6)		NS	NS	NS	NS	NS	NS	NS	++	NS	NS	NS

[1]KCl (muriate of potash): 0-0-60; B: Granubor (sodium borate), 14% B; Aspire: 0-0-58-0.5B.

[2]Means followed by the same letter are not significantly different at $\alpha = 0.1$.

[3]NS: not significant. ++, *, **: significant at 10%, 5%, and 1%, respectively.

Table 3. Effects of nutrient sources, application timing, and K and B application rates on tuber quality of Russet Burbank potatoes.

Treatment #	Nutrient sources[1]	Tuber quality				
		Hollow heart	Brown center	Scab	Dry matter	Specific gravity
		%				
1	None	1	1	0	21.2	1.0742
2	KCl	1	1	0	21.0	1.0757
3	KCl + B	0	0	0	21.3	1.0765
4	Aspire	1	1	0	21.4	1.0763
5	KCl split	0	0	0	21.4	1.0767
6	Aspire split	0	0	0	20.8	1.0765
Overall treatment significance		NS[2]	NS	--	NS	NS
Treatment MSD (P < 0.1)		--	--	--	--	--
Contrasts:						
Control vs. others (1 vs. 2 - 6)		NS	NS	--	NS	NS
KCl vs. Aspire (2 & 5 vs. 4 & 6)		NS	NS	--	NS	NS
Single vs. split (2 & 4 vs. 5 & 6)		NS	NS	--	NS	NS

[1]KCl (muriate of potash): 0-0-60; B: Granubor (sodium borate), 14% B; Aspire: 0-0-58-0.5B.

[2]NS: not significant.

Field Evaluation of Aspire and MicroEssentials SZ (Mosaic Co.) as Potassium, Boron, Phosphorus, Sulfur, and Zinc Sources for Irrigated Russet Burbank Potato Production

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Summary

Potassium (K), boron (B), phosphorus (P), sulfur (S), and zinc (Zn) are all essential plant nutrients that may require application in fertilizers for optimum potato production. However, because the range between deficient and toxic soil concentrations of B is narrow, and because only small quantities are required to meet the needs of potato plants, uniform application of B is both important and difficult. Aspire (Mosaic Co., 0-0-58-0.5B) is a fertilizer intended to facilitate uniform application of B by incorporating it with a macronutrient (K) in a ratio at which these two nutrients are typically required. Similarly, MicroEssentials SZ (MESZ, Mosaic Co., 12-40-0-10S-1Zn) is a fertilizer designed to facilitate uniform distribution of the essential nutrients S and Zn by combining them in fertilizer granules with N and P, plant nutrients required in larger quantities. In a field study conducted at the Sand Plain Research Farm in Becker, MN, we evaluated the effectiveness of Aspire and MESZ as nutrient sources for Russet Burbank potatoes. Six fertilizer treatments applied at planting were compared: 1) Control with no fertilizer at planting; 2) MAP (monoammonium phosphate, 11-52-0); 3) MAP + KCL (muriate of potash, 0-0-60); 4) MAP + Aspire; 5) MESZ + KCl; and 6) MESZ + Aspire. Treatments 2 – 6 received 80 lbs·ac^{-1} P_2O_5. Treatments 3 – 6 received 300 lbs·ac^{-1} K_2O. Treatments 2 – 4 received 17 lbs·ac^{-1} N and treatments 5 and 6 received 24 lbs·ac^{-1} N, 20 lbs·ac^{-1} S, and 2 lbs·ac^{-1} Zn. Treatments 4 and 6 received 2.6 lbs·ac^{-1} B. P fertilization was required for optimum yield, but yield response to P required application of adequate K as well. When P was applied without K, marketable yield was significantly less than for the control with no P or K. This was due to significantly greater yield of unmarketable tubers <3 oz. in size. Similar effects of P on tuber size were consistent across all size classes, and similar comparisons between the P but no K treatment, and the treatments receiving both P and K, showed similar reductions in tuber size when P was applied without K. These results are consistent with our previously reported research on the role of P in tuber set and tuber size. Application of Aspire also increased tuber size. This was probably due to the B provided by Aspire, which is consistent with results in a separate report showing that application of B when soil test B is low increases tuber size. The S and Zn supplied by MESZ did not affect tuber yield or size distribution. None of the fertilizer treatments had significant effects on the incidence of hollow heart, brown center, and scab; or on tuber dry matter percentage and specific gravity.

Background

Potatoes have a very high demand for potassium (K) relative to other vegetable crops. K can influence the yield and size distribution of potato tubers, as well as their specific gravity and storage characteristics. Boron (B) is important for integrity of plant cell walls, where it binds pectins together, and in calcium absorption. In both these roles, B availability is vital to tuber internal quality and storability, as well as yield. B also increases the concentration of vitamin C in potato tubers.

An important function of P is its essential role in energy transformations within cells, and therefore it is a controlling factor in plant metabolism. In potatoes, P nutrition is an important factor in tuber set, so it affects tuber number, tuber size, and both total and marketable yields. S is a component of several essential amino acids and therefore required for many proteins. S deficiencies and the

need for S fertilization became less important in large areas of the U.S. when high S coal was burned in many power plants and emission standards were less stringent than today. Emission controls, low S coal, and replacement of coal with less expensive natural gas have reduced the contribution of atmospheric deposition as a source of S for crop production. Zn is a micronutrient required in small amounts, but it is a component of a number of enzymes that are necessary for metabolic reactions in plants. Zn deficiency can occur when high-yielding crops are grown on sandy, low organic matter soils. So potatoes, which produce large amounts of biomass and therefore have high nutrient demands, and are commonly grown on soils that may be low in Zn, are a crop that could benefit from Zn fertilization.

B is a micronutrient that is required and applied in very small quantities, so uniform application can be difficult to achieve. Uneven application is a potential problem, because the range between deficient and toxic soil concentrations of B is narrower than for any other plant nutrient. Aspire (Mosaic Co.: 0-0-58-0.5B) is a fertilizer product designed to facilitate uniform B application by combining it in fertilizer granules with K, which is easier to distribute uniformly since it is required in large quantities.

Similarly, MicroEssentials SZ (MESZ, Mosaic Co.: 12-40-0-10S-1Zn) is a fertilizer product designed to facilitate uniform distribution of S and Zn by combining them in fertilizer granules with N and P, plant nutrients required in larger quantities. In addition, it contains both readily available SO_4-S and slowly available elemental S, to reduce potential leaching losses of SO_4-S and promote season-long S availability. When applied as a starter fertilizer in proximity to potato seed pieces, the formulation of MESZ also increases acidity in the root zone and may increase early-season P uptake.

The objectives of this study were to evaluate Russet Burbank potato response to: (1) Aspire as a nutrient source of K and B, and (2) MESZ as a nutrient source of P, S, and Zn.

Materials and methods

The study was conducted at the Sand Plain Research Farm in Becker, MN, on a Hubbard loamy sand soil. The previous crop was rye. Selected soil chemical properties before planting were as follows (0-6“): pH, 6.1; organic matter, 1.1%; Bray P1, 17 ppm; ammonium acetate extractable K, Ca, and Mg, 58, 550, and 123 ppm, respectively; Ca-phosphate extractable SO_4-S, 2.0 ppm; hot water extractable B, 0.1 ppm; and DTPA extractable Fe, Mn, Cu, and Zn, 38, 10, 0.3, and 0.7 ppm, respectively. Extractable nitrate-N in the top 2 ft of soil before planting was 18 lb/A.

Plots were laid out in a randomized complete block design with four replicates. Potatoes were planted by hand on April 27 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.

Six fertilizer treatments were compared (Table 1). They were broadcast applied on April 26 and then disked in to a depth of 6 inches and included: 1) Unfertilized control (no P, K, N, S, or B at planting); 2) MAP (monoammonium phosphate, 11-52-0); 3) MAP + KCl (muriate of potash, 0-0-60); 4) MAP + Aspire (0-0-58-0.5B); 5) MESZ (MicroEssentials SZ, 12-40-0-10S-1Zn) +

KCl); and 6) MESZ + Aspire. Treatments 2 – 6 received 80 lbs·ac^{-1} P_2O_5. Treatments 3 – 6 received 300 lbs·ac^{-1} K_2O. Treatments 2 – 4 received 17 lbs·ac^{-1} N and treatments 5 – 6 received 24 lbs·ac^{-1} N, 20 lbs·ac^{-1} S, and 2 lbs·ac^{-1} Zn. Treatments 4 and 6 received 2.6 lbs·ac^{-1} B. Treatments 2-6 were supplement with urea to provide a total N application at planting of 30 lbs·ac^{-1}.

All treatments (including the control) received 140 lbs·ac^{-1} N as ESN (Environmentally Safe Nitrogen, 44-0-0, Agrium, Inc.) that was banded and slightly hilled on May 25 after emergence; 26 lbs·ac^{-1} N as ammonium sulfate (21-0-0-24S) that was banded and incorporated during hilling on June 2; and 40 lbs·ac^{-1} N as 28% urea-ammonium nitrate split into two equal applications on June 27 and July 18. The ammonium sulfate also supplied 30 lbs·ac^{-1} S to all treatments.

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. Samples of rain and irrigation water were collected on two dates for chloride, nitrate-N, phosphate-P, and sulfate-S analysis by ion chromatography: rainfall on May 25 and September 6 and irrigation water on July 2 and August 25.

Plant stand in the harvest rows and the number of stems per plant for 10 harvest-row plants were measured on June 8. Leaf petioles (4th leaf from the terminal) were sampled on June 14 and 28, July 14 and 27, and August 8. Petiole K, B, P, and S concentrations will be determined on a dry-weight basis by the Research Analytical Laboratory of the University of Minnesota using inductively coupled plasma analysis.

Vines were chopped on September 12 and tubers were harvested on September 29.
Two, 18-ft sections of row were harvested from each plot. Total tuber yield and graded yield were measured. Sub-samples of tubers were collected to determine tuber specific gravity and dry matter percentage and the incidence of hollow heart, brown center, and scab.

Data were analyzed using the GLM procedure in SAS 9.4. Dependent variables were modeled as functions of treatment and block. Significant differences between treatments at alpha = 0.10 were determined with Waller-Duncan k-ratio t tests. Four contrasts were performed for each variable analyzed: (1) comparison of the zero-P control (treatment 1) with those receiving P (treatments 2-6); (2) comparison of zero-K (treatments 1 and 2) with those receiving K (treatments 3-6); (3) comparison of the P sources MAP and MESZ applied at the same K rate (treatments 3 and 4 vs. 5 and 6); and (4) comparison of the K sources KCl and Aspire (treatments 3 and 5 vs. 4 and 6).

Table 1. Nutrient sources and P, K, N, S, Zn, and B application rates in fertilizer treatments applied preplant to Russet Burbank potatoes.

Treatment #	Nutrient sources[1]	Nutrient application rates (lbs·ac^{-1})					
		P_2O_5	K_2O	N[2]	S[3]	Zn	B
1	None	0	0	0	0	0	0.0
2	MAP + Urea	80	0	30	0	0	0.0
3	MAP + KCl + Urea	80	300	30	0	0	0.0
4	MAP + Aspire + Urea	80	300	30	0	0	2.6
5	MESZ + KCl + Urea	80	300	30	20	2	0.0
6	MESZ + Aspire + Urea	80	300	30	20	2	2.6

[1]MAP (monoammonium phosphate): 11-52-0; Urea: 46-0-0; KCl (muriate of potash): 0-0-60; Aspire: 0-0-58-0.5B; MESZ (MicroEssentials SZ) 12-40-0-10S-1Zn.

[2]All treatments received 26 lbs N/ac at emergence as ammonium sulfate (21-0-24); 140 lbs N/ac at emergence as ESN (Environmentally Smart Nitrogen, 44-0-0); and 40 lbs N/ac post-hilling as UAN (urea-ammonium nitrate, 28-0-0).

[3]All treatments received 30 lbs S/ac at emergence as ammonium sulfate (21-0-24).

Results

Analysis of rainfall and irrigation water

Concentrations of chloride, nitrate-N, and phosphate-P were below the 0.1 mg/L detection limit for rainfall samples collected in both May and September. Sulfate-S was below the detection limit in May, but was measureable at 0.1 mg/L in September. The field plots were adjacent to a large area where coal ash from a nearby coal-fired power plant is stored, but the sulfate-S concentrations in rainfall show that atmospheric deposition provides a minimal amount of S for crop plants.

Mean concentrations for the two irrigation water samples collected in July and August were: chloride, 25.6 mg/L; nitrate-N, 8.2 mg/L; phosphate-P <0.1 mg/L; and sulfate-S, 4.8 mg/L. Depending on the volume of irrigation water applied, this water source could supply some of the crop N and S requirements and a larger proportion of its chloride requirement.

Tuber yield and size distribution

Results for tuber yield and size distribution are presented in Table 2. Soil test P at the experimental site was in the medium range (17 ppm Bray P1) and P fertilization was required for maximum yield. However, at the low soil test K level (58 ppm) where this study was conducted, optimum yield response to P required application of adequate K as well. The control with no P applied (treatment 1) had significantly lower total and marketable yields than the four treatments (3-6) receiving both 80 lbs·ac^{-1} P_2O_5 and 300 lbs·ac^{-1} K_2O. At the same P rate, but with no K applied (treatment 2), marketable yield was significantly less than for the control with no P or K. Total yields for these two treatments were statistically the same. The reason for the difference in marketable yield was that applying P without K resulted in significantly greater yield of unmarketable tubers <3 oz. in size.

Significant differences in tuber size between the control with no P or K, and treatment 2 with P but no K, were consistent across all size classes except the 6-10 oz. category. Applying P with no K resulted in greater yields of 3-6 oz. tubers, reduced yields of 10-14 oz. and >14 oz. tubers, and lower yield percentages of >6 oz. and >10 oz. tubers. Similar comparisons between treatment 2

and treatments 3-6 which received both P and K, showed similar reductions in tuber size when P but no K was applied. This included significantly reduced yield of 6-10 oz. tubers.

These effects of P on tuber size are consistent with our previously reported research that found P could reduce tuber size because of its role in tuber set. High P can increase tuber set, resulting in more tubers at harvest, but they are smaller in size compared with potatoes fertilized at lower P rates with reduced tuber set. The present study indicates that high P and low P should be viewed as relative terms. The 80 lbs·ac^{-1} P_2O_5 applied in the P treatments was less than the current University of Minnesota recommendation for the experimental site. When soil test P is 17 ppm Bray P1, the recommendation for high yields (>500 cwt/ac) is 100 lbs·ac^{-1} P_2O_5. So for treatments 3-6 that were supplied with adequate K, the applied P rate may actually have been too low for optimum yield. However, when yield was limited by insufficient K in treatment 2, the same P rate was excessive and reduced marketable yield by reducing tuber size.

The only significant difference between the P sources MAP (treatments 3 and 4) and MESZ (treatments 5 and 6) was for reduced yield of U.S. #2 tubers less than 3 oz. in size with MAP (treatment 2 with MAP and no K was excluded from this comparison). This was solely due to MAP + Aspire (treatment 4) having significantly lower amounts of these marketable, but malformed tubers than the other three treatments included in this comparison. The cause of this difference is unclear, so it may have been an aberration. It was not due to MAP or Aspire, because the two MAP treatments and the two Aspire treatments were significantly different from each other. The two MESZ treatments were similar, but the Zn or additional S in MESZ couldn't have been the cause since the MESZ treatments were not significantly different from MAP + KCl (which received no Zn and less S).

Comparison of the K sources KCl (treatments 3 and 5) and Aspire (treatments 4 and 6) found that the Aspire treatments had lower yields of 3-6 oz. and 6-10 oz. tubers, higher yields of >14 oz. tubers, and a higher percentage of their yield >10 oz. in size. These tuber size differences were probably due to the B content of Aspire. In a separate 2016 report, a two-year study on Aspire found strong evidence that when soil B is low (as the 0.1 ppm soil test B in this study was), supplying adequate B increases tuber size.

Tuber quality

Results for tuber quality are presented in Table 3. Fertilizer treatment had no significant effects on the incidence of hollow heart, brown center, and scab; or on tuber dry matter percentage and specific gravity.

Petiole K and B concentrations

Results of petiole tissue analysis were not available at the time of this report.

Conclusions

P fertilization was required for optimum yield, but yield response to P required application of adequate K as well on this low K soil. Understandably, the control with no P or K applied had significantly lower total and marketable yields than the four treatments receiving both P and K. However, when the same P rate was applied without K, marketable yield was significantly less

than for the control with no P or K. Total yields for these two treatments were comparable. The reason for the difference in marketable yield was that applying P without K resulted in significantly greater yield of unmarketable tubers <3 oz. in size. Similar effects of P on tuber size were consistent across all size classes, and similar comparisons between the P but no K treatment and the treatments receiving both P and K showed similar reductions in tuber size when P was applied without K. These results are consistent with our previously reported research on the role of P in tuber set and tuber size.

Comparison of the P sources MAP and MESZ did not find any differences that could be attributed to the S and Zn that were also supplied by MESZ. Comparison of the K sources KCl and Aspire found increases in tuber size with Aspire. This was probably due to the B provided by Aspire, which is consistent with results in a separate report showing that application of B when soil test B is low increases tuber size.

None of the fertilizer treatments had significant effects on the incidence of hollow heart, brown center, and scab; or on tuber dry matter percentage and specific gravity.

Table 2. Effects of nutrient sources and P, K, S, Zn, and B application rates at planting on tuber yield and size distribution of Russet Burbank potatoes.

Treatment #	Nutrient sources[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	None	16 d[2]	72 d	146 cd	88 c	76 c	399 b	297 b	101 c	383 b	78 a	41 bc
2	MAP	73 a	137 a	126 d	25 d	9 d	371 b	239 c	131 c	297 c	42 b	9 d
3	MAP + KCl	57 b	117 abc	202 a	153 b	97 bc	627 a	385 a	243 a	570 a	72 a	40 c
4	MAP + Aspire	37 c	109 bc	173 bc	177 a	121 ab	617 a	415 a	202 b	580 a	76 a	48 ab
5	MESZ + KCl	52 b	125 ab	187 ab	169 ab	100 bc	632 a	385 a	247 a	580 a	72 a	42 abc
6	MESZ + Aspire	55 b	101 c	172 bc	163 ab	153 a	645 a	378 a	266 a	590 a	76 a	49 a
Overall treatment significance		**[3]	**	**	**	**	**	**	**	**	**	**
Treatment MSD (P < 0.1)		13	21	29	23	41	45	52	39	50	7	8
Contrasts:												
P vs. no P (1 vs. 2 - 6)		**	**	++	**	NS	**	**	**	**	**	NS
K vs. no K (1 & 2 vs. 3 - 6)		NS	NS	**	**	**	**	**	**	**	**	**
MAP vs. MESZ (3 & 4 vs. 5 & 6)		NS	NS	NS	NS	NS	NS	NS	++	NS	NS	NS
KCl vs. Aspire (3 & 5 vs. 4 & 6)		NS	++	++	NS	*	NS	NS	NS	NS	NS	*

[1]MAP (monoammonium phosphate): 11-52-0; KCl (muriate of potash): 0-0-60; Aspire: 0-0-58-0.5B; MESZ (MicroEssentials SZ): 12-40-0-10S-1Zn.

[2]Means followed by the same letter are not significantly different at $\alpha = 0.1$.

[3]NS: not significant. ++, *, **: significant at 10%, 5%, and 1%, respectively.

Table 3. Effects of nutrient sources and P, K, S, Zn, and B application rates at planting on the incidence of hollow heart, brown center, and scab; and tuber dry matter percentage and specific gravity of Russet Burbank potatoes.

Treatment #	Nutrient sources[1]	Tuber quality				
		Hollow heart	Brown center	Scab	Dry matter	Specific gravity
		%				
1	None	1	1	0	22.2	1.0770
2	MAP	2	2	0	21.4	1.0770
3	MAP + KCl	0	0	0	21.6	1.0761
4	MAP + Aspire	1	1	0	21.9	1.0790
5	MESZ + KCl	0	0	0	21.4	1.0784
6	MESZ + Aspire	4	4	1	21.4	1.0769
Overall treatment significance		NS[2]	NS	NS	NS	NS
Treatment MSD (P < 0.1)		--	--	--	--	--
Contrasts:						
P vs. no P (1 vs. 2 - 6)		NS	NS	NS	NS	NS
K vs. no K (1 & 2 vs. 3 - 6)		NS	NS	NS	NS	NS
MAP vs. MESZ (3 & 4 vs. 5 & 6)		NS	NS	NS	NS	NS
KCl vs. Aspire (3 & 5 vs. 4 & 6)		NS	NS	NS	NS	NS

[1]MAP (monoammonium phosphate): 11-52-0; KCl (muriate of potash): 0-0-60 Aspire: 0-0-58-0.5B; MESZ (MicroEssentials SZ):12-40-0-10S-1Zn;.

[2]NS: not significant.

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

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Summary: Polyhalite is a naturally occurring mineral consisting of sulfate forms of potassium, magnesium, and calcium with a chemical formula of $K_2SO_4 \cdot MgSO_4 \cdot 2CaSO_4 \cdot 2H_2O$ and an approximate fertilizer value from one known mineral deposit of 0-0-14-19S-3.6Mg-12.1Ca. Because of relatively large deposits worldwide, there is interest in whether polyhalite can be used as an economical nutrient source for crop production. The overall objective of this study was to determine the effectiveness of polyhalite as a nutrient source for potato production in Minnesota. The study was conducted at the Sand Plain Research Farm in Becker, Minnesota on an acid, low organic matter Hubbard loamy sand soil with low soil test K, Ca, Mg. and S. Eight treatments varying in K fertilizer source and other amendments (lime, $MgSO_4$, and $CaSO_4$) supplying different rates of S, Mg, and Ca were tested: 1) control (no K, S, Mg, or Ca application); 2) 400 lb K_2O/A as polyhalite (Sirius Minerals, Plc), which also supplied 543 lb/A S, 103 lb/A Mg, and 340 lb/A Ca; 3) 400 lb K_2O/A as KCl (muriate of potash); 4) 400 lb K_2O/A as KCl, plus 410 lb/A S and the same amounts of Mg and Ca as treatment 2; 5) 300 lb K_2O/A as polyhalite and 100 lb K_2O/A as KCl, which also supplied 407 lb/A S, 77 lb/A Mg, and 255 lb/A Ca; 6) 200 lb K_2O/A as polyhalite and 200 lb K_2O/A as KCl, which also supplied 272 lb/A S, 52 lb/A Mg, and 170 lb/A Ca ; 7) 400 lb K_2O/A as KCl, plus 136 lb/A S and the same amounts of Mg and Ca as treatments 2 and 4; and 8) 400 lb K_2O/A as KCl, plus 272 lb/A S lb/A and the same amount of Ca as treatments 2, 4, and 7. Russet Burbank was the cultivar tested. At the low soil test K level found at this experimental site, K fertilization was required for optimum yield and tuber size. At the low soil test K level found at this experimental site, K fertilization was required for optimum yield and tuber size. The treatment receiving all of its K as polyhalite had the greatest total and marketable yields. Yields were significantly greater than two of the treatments receiving all of their K from KCl and numerically greater than the other. As the percentage of K applied as polyhalite increased, there were significant increases in tuber size. There were indications that tuber size differences were associated with application of other nutrients in addition to K, but there was no clear pattern in S, Ca, or Mg rates or sources showing which of those nutrients affected tuber size. Adequate K nutrition was required for light fry color. Dark fry color was associated with higher glucose concentrations in the bud and stem ends of tubers. The three treatments that did not receive Mg had the darkest fry color, indicating that Mg was also important for light fry color. Changes in K, sulfate-S, Ca, and Mg soil test levels between Spring and Fall indicated that polyhalite was as effective as other sources tested in supplying these nutrients.

Background

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

crop like potatoes. Soils that might benefit from a polyhalite application would likely be low organic matter, acidic, sandy soils, which are often low in S, Ca, and Mg in addition to K..

The overall objective of this study was to determine the effectiveness of polyhalite as a nutrient source for potato production in Minnesota. 2016 is the 3rd year of the study. Treatments with gypsum and Epsom salts were added to those studied in previous years to better evaluate effects of the Ca, Mg, and S contained in polyhalite. We are also studying residual effects of polyhalite applied to potatoes on succeeding crops of corn and soybeans, but that research is not discussed in this report.

Materials and Methods

This study was conducted at the Sand Plain Research Farm in Becker, Minnesota on a Hubbard loamy sand soil. The previous crop was rye. Selected soil chemical properties before planting were as follows (0-6"): pH, 6.1; organic matter, 1.1%; Bray P1, 17 ppm; ammonium acetate extractable K, Ca, and Mg, 58, 550, and 123 ppm, respectively; Ca-phosphate extractable SO_4-S, 2.0 ppm; hot water extractable B, 0.1 ppm; and DTPA extractable Fe, Mn, Cu, and Zn, 38, 10, 0.3, and 0.7 ppm, respectively. Extractable nitrate-N in the top 2 ft of soil before planting was 18 lb/A. Soil samples from the 0-6 inch depth were collected from each plot prior to fertilizer application and then again following harvest and analyzed for ammonium acetate extractable K, Ca, and Mg, and Ca-phosphate extractable SO_4-S.

Four, 20-ft rows were planted for each plot with the middle two rows used for sampling and harvest. Whole "B single drop" seed of Russet Burbank potatoes were hand planted in furrows on April 21, 2016. Row spacing was 12 inches within each row and 36 inches between rows. Each treatment was replicated four times in a randomized complete block design. Belay for beetle control and the systemic fungicide Quadris were banded at row closure. Weeds, diseases, and other insects were controlled using standard practices. Rainfall was supplemented with sprinkler irrigation using the checkbook method of irrigation scheduling. Samples of rain and irrigation water were collected on two dates for nitrate-N and sulfate-S analysis: rainfall on May 25 and September 6 and irrigation water on July 2 and August 25.

Eight treatments varying in K fertilizer source and other amendments ($MgSO_4$, $CaSO_4$, and lime) supplying different rates of S, Mg, and Ca were tested (Table 1): 1) control (no K, S, Mg, or Ca application); 2) 400 lb K_2O/A as polyhalite (Sirius Minerals, Plc), which also supplied 543 lb/A S, 103 lb/A Mg, and 340 lb/A Ca; 3) 400 lb K_2O/A as KCl (muriate of potash); 4) 400 lb K_2O/A as KCl, plus $CaSO_4$ (gypsum – SuperCal SO4) and $MgSO_4$ (Epsom salts) to provide 410 lb/A S and the same amounts of Mg and Ca as treatment 2; 5) 300 lb K_2O/A as polyhalite and 100 lb K_2O/A as KCl, which also supplied 407 lb/A S, 77 lb/A Mg, and 255 lb/A Ca; 6) 200 lb K_2O/A as polyhalite and 200 lb K_2O/A as KCl, which also supplied 272 lb/A S, 52 lb/A Mg, and 170 lb/A Ca ; 7) 400 lb K_2O/A as KCl, plus pelletized lime (SuperCal 98G) and $MgSO_4$ to provide 136 lb/A S and the same amounts of Mg and Ca as treatments 2 and 4; and 8) 400 lb K_2O/A as KCl, plus $CaSO_4$ which supplied 272 lb/A S lb/A and the same amount of Ca as treatments 2, 4, and 7.

Similar research on polyhalite was conducted in 2014 and 2015 and previously reported, but treatments 4 and 8 were added in 2016 to better evaluate effects of the Ca, Mg, and S contained in polyhalite.

On April 19, one-half the amount of each fertilizer treatment was broadcast followed by incorporation to a depth of about 6 inches with a field cultivator. After emergence on May 24, the other half of each fertilizer treatment was applied by hand as a sidedress and incorporated during hilling on May 25.

At planting, all plots received fertilizer that was banded 3 inches to each side and 2 inches below the seed piece, including 30 lbs N/A, 136 lbs P_2O_5/A, 1.5 lbs S/A, 1.0 lb B/A, and 2 lbs Zn/A, applied as a blend of MAP (monoammonium phosphate), EZ20, and Granubor. All treatments received a total of 240 lbs N/A, which included the 30 lbs N/A at planting, 170 lb N/A as ESN (Environmentally Safe Nitrogen, 44-0-0, Agrium, Inc.) applied at emergence/hilling on May 25, and two applications of 28% UAN (urea-ammonium nitrate) at the rate of 20 lb N/A on June 30 and July 16.

Plant stands were measured on June 2 and the number of stems per plant on July 6. Petiole samples were collected from the 4th leaf from the terminal on five dates: June 14 and 28, July 14 and 26, and August 8. Petioles will be analyzed for N, S, K, Mg, and Ca on a dry weight basis. In addition SPAD readings, which measure the intensity of the green color of plant leaves, and are used as an indirect measurement of leaf N, were recorded on the 4th leaf from the terminal on June 16, July 14 and 26, and August 9.

Vines were killed by chopping on September 6 and tubers were machine-harvested on September 15. Two, 18-ft sections of row were harvested from each plot. Total tuber yield and graded yield were measured. Sub-samples of tubers were collected to determine tuber specific gravity and dry matter, tuber K, S, Mg and Ca concentrations, and the incidence of hollow heart, brown center, and scab. In addition, subsamples of tubers were sent to the USDA/ARS, Potato Research Worksite in East Grand Forks for sugar analysis and frying quality.

Table 1. Fertilizer treatments applied to Russet Burbank potatoes in 2016.

Fertilizer treatment[1]				Nutrients applied (lbs·ac^{-1})			
Treatment #	K_2O lbs·ac^{-1} as polyhalite	K_2O lbs·ac^{-1} as KCl	Other amendments	K_2O	SO_4-S	Mg	Ca
1	0	0	None	0	0	0	0
2	400	0	None	400	543	103	340
3	0	400	None	400	0	0	0
4	0	400	$MgSO_4$ + $CaSO_4$	400	410	103	340
5	300	100	None	400	407	77	255
6	200	200	None	400	272	52	170
7	0	400	$MgSO_4$ + lime	400	136	103	340
8	0	400	$CaSO_4$	400	272	0	340

[1]Polyhalite: 0-0-14.1-19S-3.6Mg-12.1Ca. KCl (muriate of potash): 0-0-60. MgSO4 (Epsom salts): 0-0-0-12.9S-9.8Mg. $CaSO_4$ (gypsum): 0-0-0-17S-21Ca. Lime: 0-0-0-36Ca.

Results

Tuber Yield and Size Distribution

Results for tuber yield and size distribution are presented in Table 2. As expected, the control treatment with no K, S, Mg, or Ca applied had significantly lower total and marketable yields than all of the other treatments. It also had the greatest yield of unmarketable 0-3 oz. tubers and was significantly lower than all other treatments in the percentage of its yield >6 oz. and >10 oz.

Treatment 2, which received all of its K as polyhalite and had no other amendment applied, produced the greatest total and marketable yields. It was significantly greater in both yield categories than treatments 7 and 8, which received all their K as KCl and also received either Epsom salts + lime or gypsum; and numerically greater than treatment 3, which also received all its K as KCl, but had no other amendment applied.

As the percentage of K applied as polyhalite increased (treatments 3, 6, 5, and 2), there were significant linear decreases in yield of tubers <3 oz. and 3-6 oz. in size, and significant linear increases in >14 oz. tubers and the percentage of total yield in tubers >6 oz. and >10 oz. None of these treatments had any other amendments applied, so as the amount of polyhalite increased the amounts of S, Mg, and Ca increased in a corresponding manner. And because KCl was the K source to balance the total K rate, the amount of chloride applied decreased as polyhalite increased. Therefore, these effects of polyhalite on tuber size were due to increases in Ca, Mg, or S, either singly or in some combination, or to decreases in chloride either acting alone or in combination with one or more of the nutrients that increased. Changes in the amount of polyhalite applied had no effect on total or marketable yield.

Treatment 8, with all K as KCl and also receiving gypsum, had the 2nd lowest total and marketable yields. It had significantly lower total yield than treatments 2, 5, and 6 and significantly lower marketable yield than treatments 2, 4, 5, and 6. These differences were associated with significantly lower percentage yield of tubers >6 oz. for treatment 8 compared with treatments 2 and 4, but they were not closely related to differences in application of Ca, S, or Mg.

Tuber Quality, Plant Stand, and Number of Stems per Plant

Results for tuber quality, plant stand, the number of stems per plant are presented in Table 3. Treatment effects on incidence of hollow heart, brown center, and scab could not be determined, because none of these disorders occurred in this study.

The control treatment with no K, S, Mg, or Ca applied had both significantly greater tuber dry matter percentage and specific gravity than any of the other treatments. There were no significant differences among any of the other treatments in tuber dry matter. Treatment 8 with KCl + gypsum had significantly lower tuber specific gravity than all of the other treatments except for treatment 3 which received only K as KCl. This suggests the possibility Ca or S could have been involved in this response, but this appears unlikely since similar differences did not occur for treatments 4 and 7 which also received both Ca and S.

None of the fertilizer treatments affected percent plant stand or the number of stems per plant.

Tuber Sugar Concentrations and Fry Color

Tuber sucrose and glucose concentrations and frying quality (visual chip color and Hunter Lab scores) of chipped, fried potatoes are presented in Table 4. Differences in K source had no effect on either sugar concentrations or fry color and there were no significant differences among any of

the fertilizer treatments in either stem or bud end sucrose. Treatment 8 had the highest stem end glucose concentration and was significantly greater than treatments 3, 4, 5, and 7. However, there was no evident pattern in the types of other amendments applied among these treatments, suggesting that neither S, Mg, nor Ca were the cause of this difference. The control treatment with no K, S, Mg, or Ca applied had significantly greater concentration of bud end glucose than all other treatments, none of which were significantly different from each other. Bud end glucose was about twice as high for the control as all others. These differences indicate that K nutrition was an important factor in bud end glucose.

The control had significantly darker fry color than any of the other treatments by both of the measurements used. Treatments 3 and 7 had the lightest fry color by both measurements and they were both significantly different from treatment 8. The three treatments that did not receive Mg had the darkest fry color, indicating that Mg was also important for light fry color.

Overall, these results suggest that differences in tuber glucose are important determinants of fry color, and that when soil K and Mg are low, adequate fertilization with K and Mg are required to ensure adequate quality of processing potatoes.

Soil K, Ca, Mg, S, and pH

Results of soil analyses for K, Ca, Mg, Sulfate-S, and pH are presented in Table 5. Spring soil samples were collected before fertilizer treatments were applied prior to planting and Fall soil samples were collected at the end of the growing season after tuber harvest.

Spring soil tests. In the Spring, the control plots had significantly lower soil Mg and S compared with all the rest of the plots to which fertilizer treatments were going to be applied. However, the differences were numerically small and unlikely to have affected treatment responses to the parameters measured in this experiment. The same is true for the significant linear increase in soil Mg in the plots that were going to receive increasing rates of polyhalite as their K source and no Ca, Mg, or S (treatments 3, 6, 5, and 2). The significant quadratic differences in soil K among these same groups of plots was numerically larger and this did have an effect (see the "Fall soil tests" section below). Soil pH was very uniform at the beginning of the experiment, with only 0.1 unit difference in the means for the groups of plots dedicated to each treatment.

Fall soil tests. In the Fall, the control treatment had significantly lower soil K, Mg, and S compared with the rest of the treatments considered collectively. The control also had significantly lower soil test K than all other treatments when it was compared to each of them individually, which was to be expected since it received no K and the others all received 400 lb K_2O/ac as either polyhalite, KCl, or various combinations of the two K sources. Differences in K source had no effect on fall soil test K. Treatment 7 (100% polyhalite K + gypsum + lime) had significantly greater soil K than Treatment 5 (75% polyhalite K and no other amendment), but this was not a treatment effect. It was due to the numerical difference in soil K before treatments were applied, because the change in soil K between spring and fall was similar for both treatments.

The only significant differences in fall soil test Ca were that treatment 8, which received 340 lb Ca/ac from gypsum, had higher soil Ca than the only two treatments (1 and 3) that received no Ca.

Fall soil Ca for the other treatments, which received between 170 and 340 lb Ca/ac, were intermediate.

Treatment 7, which received 103 lb Mg/ac from Epsom salts, had significantly greater soil test Mg in the fall than all other treatments. Treatments 2 and 4 also received 103 lb Mg/ac, one from polyhalite and one from Epsom salts, but they had similar soil Mg in the fall. The treatments with no Mg applied (1, 3, and 8) had the lowest fall soil Mg. Treatment 8 was significantly lower than all others and the control was significantly less than treatment 6 with 53 lb Mg/ac from polyhalite.

Treatments 1 and 3 with no S applied had the lowest soil test S in the Fall, and they were significantly lower than all other treatments except number 6, which had the next lowest S application. As the percentage of K applied as polyhalite increased, and therefore the S application rate, soil test S increased significantly. Treatments 2 and 4 received the largest amounts of S and had significantly higher levels of soil S in the Fall than all other treatments, including treatment 5 which received only 3 lbs S/ac less than treatment 4. Treatment 8 received only 2/3 as much S as treatment 5, but soil S was significantly greater than treatment 5 and all others except 2 and 4.

Treatment 7 had significantly higher pH in the Fall than all other treatments, reflecting the fact that it received pelletized lime as its Ca source. There was a slight decrease in soil pH as the polyhalite application rate increased, which was significant at the 10% level.

Changes between Spring and Fall. As you would expect, soil test changes between Spring and Fall generally followed the same pattern of differences among treatments described above in the "Fall soil tests" section, so in this section we will focus on the practical effects of these changes in terms of the adequacy soil test nutrient levels for potato production.

Results for the control show that when no K is applied, soil test K will decrease about 30 mg/kg soil for a total tuber yield of 390 cwt/ac. When 400 lbs K/ac was applied as polyhalite in treatment 2, there was a small decrease in soil K. All of the other treatments increased soil test K, suggesting that in the first year after application the K in polyhalite is less available than the K in KCl. However, only the 50% polyhalite/50% KCl treatment showed a significantly greater change in soil test K than 100% polyhalite.

Soil test K before fertilizer treatments were applied was in the medium to the lower end of the medium range for potatoes, at which recommendations call for application of 300-400 lbs K_2O/ac. Yield responses to the 400 lbs K_2O/ac. applied in this experiment are consistent with the accuracy of current University of Minnesota Extension recommendations. The relatively small end-of-season increases in soil K observed at this rate also show that higher K rates are required if the goal is to build up soil K reserves above the medium level.

Changes in soil test Ca were the only case where significant treatment differences occurred that did not also appear in the analysis of Fall soil test levels. The control treatment had a significantly smaller change in soil Ca compared with the rest of the treatments when they were considered collectively, and this change was significantly less than for treatments 5 and 8 when it was compared to each of them individually. As the amount of polyhalite applied increased, changes in soil Ca also increased, which was consistent with the Ca content of polyhalite. It should be noted

that soil Ca did increase for treatments 1 and 2, even though no Ca was applied to them. Although irrigation water was not tested for its Ca content, this was a likely cause of these increases.

Soil Ca was in the medium range across the entire experimental site before fertilizer treatments were applied. The general recommendation for vegetable crops is to apply 100 lbs Ca/ac at this soil test level. For the treatments receiving Ca, between 170 and 340 lbs Ca/ac were applied, so the increases in soil Ca were consistent with these rates being greater than the Ca needs of the current crop.

Soil Mg was in the low range across the entire experimental site before fertilizer treatments were applied. This was consistent with the very unusual occurrence of visual symptoms of Mg deficiency observed and photographed in plots of treatment 8, to which no Mg was applied in fertilizer applications. The control and the 100% K from KCl treatments also received no Mg. Although visual deficiency symptoms were not observed in these plots, it should be noted that nutrient deficiencies within plants and effects on growth occur well before the state of severe deficiency that results in visual symptoms.

In the treatments receiving Mg, rates of 50-100 lbs Mg were applied. General recommendations for vegetable crops are to apply 100 lbs Mg/ac when soil test Mg is <50 mg/kg soil, as it was at this site in the Spring. Only treatment 7, which received 103 lbs/ac Mg from Epsom salts had soil Mg levels above 50 mg/kg soil in the Fall. Treatment 4 also received 103 lbs Mg/ac from Epsom salts, and treatment 2 received the same Mg rate from polyhalite, but soil Mg for these treatments was still <50 mg/kg soil in the Fall. These results suggest that when soil Mg is very low, potatoes may require higher Mg rates than other vegetable crops.

Soil Mg did increase by 10-30 mg/kg soil for all treatments, including the control and 100% KCl treatments receiving no Mg. As with Ca, Mg in irrigation water was a likely cause of soil Mg increases in these treatments.

Soil test sulfate-S in the Spring was in the low range for vegetable crops. When S is <6 mg/kg soil, the recommendation for broadcast application is 20-30 lbs S/ac. For treatments receiving S, application rates were between 136 and 543 lbs S/ac. Despite these high rates, soil S increased by only 6-39 mg S/kg of soil. This could indicate that potatoes have a much greater S requirement than many other vegetable crops, although this conclusion must be qualified by the fact that substantial amounts of sulfate-S may have been leached below the 6-inch soil depth in the sandy soil at the experimental site. Sulfate-S would also have been incorporated into soil organic matter, which is the major reservoir for S in sandy soils.

The control and 100% K as KCl treatments received no S, but they were still able to maintain soil S at Spring levels. Spring levels were low, but these results suggest that S release from organic matter in this soil may have been sufficient to meet crop needs. As discussed in the first Results section, atmospheric deposition, rainwater, and irrigation water were negligible S sources at this site. For these treatments, overall soil S may have decreased due to depletion of organic S reserves, although measurements to validate this were not made in this experiment.

Soil pH decreased by 0.1 to 0.5 pH units during the growing season for all fertilizer treatments, except for treatment 7, which received pelletized lime. Soil pH increased by <0.1 unit in treatment 7, so the lime rate applied did not increase pH above the range recommended for potato production. This shows that lime can be used to supply Ca to potatoes, and even increase soil test Ca by over 90 mg/kg, without adverse effects on soil pH. As the rate of polyhalite increased, there was a significant linear increase at the 10% level in the pH changes that occurred. All of this change was between the zero and 50% polyhalite treatments and the greatest pH decrease was <0.2 pH units.

Petiole N, S, K, Mg, and Ca and SPAD readings
Results of petiole tissue analysis and analysis of SPAD readings were not available at the time of this report.

Tuber N, S, K, Mg, and Ca
Results of tuber chemical analysis were not available at the time of this report.

Conclusions: At the low soil test K level found at this experimental site, K fertilization was required for optimum yield and tuber size. The treatment receiving all of its K as polyhalite had the greatest total and marketable yields. Yields were significantly greater than two of the treatments receiving all of their K from KCl and numerically greater than the other. As the percentage of K applied as polyhalite increased, there were significant increases in tuber size. There were indications that tuber size differences were associated with application of other nutrients in addition to K, but there was no clear pattern in S, Ca, or Mg rates or sources showing which of those nutrients affected tuber size.

The only treatment effects on tuber quality were greater tuber dry matter and specific gravity for the control, and lower specific gravity for the 100% KCl + gypsum treatment than all but one of the other treatments receiving K.

Adequate K and Mg nutrition were required for light fry color and dark fry color were associated with higher glucose concentrations in the bud and stem ends of tubers. Differences in K source had no effect on either tuber glucose or fry color. The three treatments that did not receive Mg had the darkest fry color, indicating that Mg was also important for light fry color.

Soil testing showed that K, S, Ca, and Mg were all in the range where their application was required for optimum potato production. Changes in soil test levels between Spring and Fall indicated that polyhalite was as effective as other sources tested in supplying these nutrients.

Table 2. Effects of polyhalite and KCl (with or without Ca, Mg, and S) on Russet Burbank tuber yield and size distribution.

Fertilizer treatment[1]				Tuber yield										
Treatment #	K_2O lbs·ac^{-1} as polyhalite	K_2O lbs·ac^{-1} as KCl	Other amendments	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	0	None	62 a[2]	187 a	104	28 b	9 e	390 d	267 c	123	327 c	34 d	8 e
2	400	0	None	35 c	111 de	140	108 a	118 a	513 a	360 a	152	477 a	71 ab	44 ab
3	0	400	None	54 ab	159 b	159	84 a	35 de	490 abc	312 abc	178	436 ab	56 c	24 d
4	0	400	$MgSO_4$ + $CaSO_4$	38 c	101 e	134	124 a	101 ab	499 abc	343 ab	156	461 a	72 a	45 a
5	300	100	None	45 bc	138 c	140	105 a	77 bc	506 ab	343 ab	163	461 a	64 bc	36 abc
6	200	200	None	48 bc	137 c	148	115 a	62 cd	509 ab	344 ab	166	461 a	63 c	34 c
7	0	400	$MgSO_4$ + lime	52 ab	112 de	147	91 a	57 cd	459 bc	299 abc	160	407 b	64 abc	32 cd
8	0	400	$CaSO_4$	41 bc	124 cd	126	96 a	62 cd	450 c	282 c	168	408 b	63 c	35 bc
Overall treatment significance				*[3]	**	NS	**	**	**	++	NS	**	**	**
Treatment MSD (P < 0.1)				13	17	--	42	36	52	69	--	52	8	10
Contrasts	Control vs. others (1 vs. 2 - 8)			**	**	*	**	**	**	*	*	**	**	**
	Linear % polyhalite (3, 6, 5, 2)			*	**	NS	NS	**	NS	NS	NS	NS	**	**
	Quadratic % polyhalite (3, 6, 5, 2)			NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

[1]Polyhalite: 0-0-14.1-19S-3.6Mg-12.1Ca. KCl: (muriate of potash) 0-0-60. MgSO4 (Epsom salts): 0-0-0-12.9S-9.8Mg. $CaSO_4$ (gypsum): 0-0-0-17S-21Ca. Lime: 0-0-0-36Ca.

[2]Means followed by the same letter are not significantly different at $\alpha = 0.1$

[3]NS: not significant. ++, *, **: significant at 10%, 5%, and 1%, respectively.

Table 3. Effects of polyhalite and KCl (with or without Ca, Mg, and S) on tuber quality, dry matter percentage, specific gravity, plant stand, and the number of stems per plant.

Fertilizer treatment[1]				Tuber quality					Plant stand (%)	Number of stems per plant
Treatment #	K_2O lbs·ac^{-1} as polyhalite	K_2O lbs·ac^{-1} as KCl	Other amendments	Hollow heart	Brown center	Scab	Dry matter	Specific gravity		
				%						
1	0	0	None	0	0	0	21.2 a[2]	1.0765 a	94.4	3.4
2	400	0	None	0	0	0	19.7 ab	1.0683 bc	95.8	3.1
3	0	400	None	0	0	0	19.2 b	1.0678 cd	96.5	3.0
4	0	400	$MgSO_4$ + $CaSO_4$	0	0	0	18.8 b	1.0703 b	95.1	3.2
5	300	100	None	0	0	0	19.3 b	1.0696 bc	94.4	3.3
6	200	200	None	0	0	0	19.0 b	1.0698 bc	97.2	3.0
7	0	400	$MgSO_4$ + lime	0	0	0	18.7 b	1.0694 bc	97.2	3.5
8	0	400	$CaSO_4$	0	0	0	18.2 b	1.0661 d	100.0	2.9
Overall treatment significance				--	--	--	++[3]	**	NS	NS
Treatment MSD (P < 0.1)				--	--	--	1.8	0.0021	--	--
Contrasts	Control vs. others (1 vs. 2 - 8)			--	--	--	**	**	NS	NS
	Linear % polyhalite (3, 6, 5, 2)			--	--	--	NS	NS	NS	NS
	Quadratic % polyhalite (3, 6, 5, 2)			--	--	--	NS	++	NS	NS

[1]Polyhalite: 0-0-14.1-19S-3.6Mg-12.1Ca. KCl (muriate of potash): 0-0-60. MgSO4 (Epsom salts): 0-0-0-12.9S-9.8Mg. $CaSO_4$ (gypsum): 0-0-0-17S-21Ca. Lime: 0-0-0-36Ca.

[2]Means followed by the same letter are not significantly different at $\alpha = 0.1$

[3]NS: not significant. ++, *, **: significant at 10%, 5%, and 1%, respectively.

Table 4. Effects of polyhalite and KCl (with or without Ca, Mg, and S) on stem and bud end sugar concentrations, and fry color measured by two methods.

Fertilizer treatment[1]				Stem end		Bud end		Fry color	
Treatment #	K_2O lbs·ac^{-1} as polyhalite	K_2O lbs·ac^{-1} as KCl	Other amendments	Sucrose (mg/g)	Glucose (mg/g)	Sucrose (mg/g)	Glucose (mg/g)	Chip color 1 = lightest 5 = darkest	HunterLab score (higher = lighter)
1	0	0	None	0.095	3.735 ab[2]	0.651	1.051 a	4.00	43.2 c
2	400	0	None	0.143	3.687 ab	0.587	0.528 b	3.25	48.3 ab
3	0	400	None	0.054	3.129 bc	0.672	0.415 b	3.00	48.7 a
4	0	400	$MgSO_4$ + $CaSO_4$	0.093	3.377 bc	0.523	0.608 b	3.50	48.0 ab
5	300	100	None	0.140	3.331 bc	0.587	0.541 b	3.25	48.4 ab
6	200	200	None	0.176	3.468 ab	0.623	0.517 b	3.25	48.2 ab
7	0	400	$MgSO_4$ + lime	0.017	2.680 c	0.625	0.434 b	3.00	48.9 a
8	0	400	$CaSO_4$	0.075	4.176 a	0.638	0.524 b	3.75	46.9 b
Overall treatment significance				NS[3]	*	NS	*	*	**
Treatment MSD (P < 0.1)				--	0.734	--	0.345	0.54	1.7
Contrasts	Control vs. others (1 vs. 2 - 8)			NS	NS	NS	**	**	**
	Linear % polyhalite (3, 6, 5, 2)			NS	NS	NS	NS	NS	NS
	Quadratic % polyhalite (3, 6, 5, 2)			NS	NS	NS	NS	NS	NS

[1]Polyhalite: 0-0-14.1-19S-3.6Mg-12.1Ca. KCl (muriate of potash): 0-0-60. MgSO4 (Epsom salts): 0-0-0-12.9S-9.8Mg. $CaSO_4$ (gypsum): 0-0-0-17S-21Ca. Lime: 0-0-0-36Ca.

[2]Means followed by the same letter are not significantly different at $\alpha = 0.1$

[3]NS: not significant. ++, *, **: significant at 10%, 5%, and 1%, respectively.

Table 5. Effects of polyhalite and KCl (with or without Ca, Mg, and S) on soil test K, Ca, Mg and SO_4-S. Soil tests in the spring were taken before treatments were applied. Soil tests in the fall were taken after harvest.

Fertilizer treatment[1]				Soil test													
Treatment #	K_2O lbs·ac^{-1} as polyhalite	K_2O lbs·ac^{-1} as KCl	Other amendments	K Spring	K Fall	K difference	Ca Spring	Ca Fall	Ca difference	Mg Spring	Mg Fall	Mg difference	SO_4-S Spring	SO_4-S Fall	SO_4-S difference	pH Spring	pH Fall	pH difference
				(mg·kg^{-1})														
1	0	0	None	72 bc[2]	41 c	-32 c	207	251 b	44 c	29	41 cd	12 bc	4	6 e	2 e	5.0	4.75 bcd	-0.23 bc
2	400	0	None	99 a	95 ab	-4.5 bc	208	309 ab	102 abc	29	42 bc	13 b	5	43 a	38 ab	5.0	4.70 bcd	-0.28 bc
3	0	400	None	83 abc	100 ab	17 ab	210	249 b	39 c	29	40 cd	11 bc	5	6 e	2 e	5.0	4.85 b	-0.13 ab
4	0	400	$MgSO_4$ + $CaSO_4$	72 bc	86 ab	14 ab	227	307 ab	77 c	33	47 bc	14 b	4	44 a	39 a	5.1	4.60 d	-0.48 d
5	300	100	None	71 bc	81 b	10 ab	187	316 ab	128 ab	29	44 bc	15 b	5	29 c	24 c	5.0	4.65 cd	-0.30 c
6	200	200	None	67 c	94 ab	27 a	260	310 ab	50 c	35	48 b	14 b	5	19 d	14 d	5.1	4.78 bc	-0.3 c
7	0	400	$MgSO_4$ + lime	92 ab	111 a	19 ab	222	317 ab	94 abc	32	62 a	30 a	5	11 e	6 e	5.0	5.05 a	0.03 a
8	0	400	$CaSO_4$	75 abc	89 ab	14 ab	199	357 a	158 a	27	35 d	8 c	5	36 b	31 b	5.0	4.60 d	-0.35 cd
Overall treatment significance				++[3]	**	*	NS	++	*	NS	**	**	NS	**	**	NS	**	**
Treatment MSD (P < 0.1)				24	27	31	--	71	73	--	7	5	--	7	7	--	0.17	0.17
Contrasts	Control vs. others (1 vs. 2 - 8)			NS	**	**	NS	NS	*	++	NS	NS	*	**	**	NS	NS	NS
	Linear % polyhalite (3, 6, 5, 2)			NS	NS	NS	NS	NS	++	*	NS	NS	NS	**	**	NS	++	++
	Quadratic % polyhalite (3, 6, 5, 2)			**	NS	NS	NS	NS	NS	NS	++	NS	NS	++	++	NS	NS	NS

[1]Polyhalite: 0-0-14.1-19S-3.6Mg-12.1Ca. KCl (muriate of potash): 0-0-60. MgSO4 (Epsom salts): 0-0-0-12.9S-9.8Mg. $CaSO_4$ (gypsum): 0-0-0-17S-21Ca. Lime: 0-0-0-36Ca.

[2]Means followed by the same letter are not significantly different at $\alpha = 0.1$

[3]NS: not significant. ++, *, **: significant at 10%, 5%, and 1%, respectively.

Management of Colorado Potato Beetle in Minnesota and North Dakota – Annual Report 2016

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

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

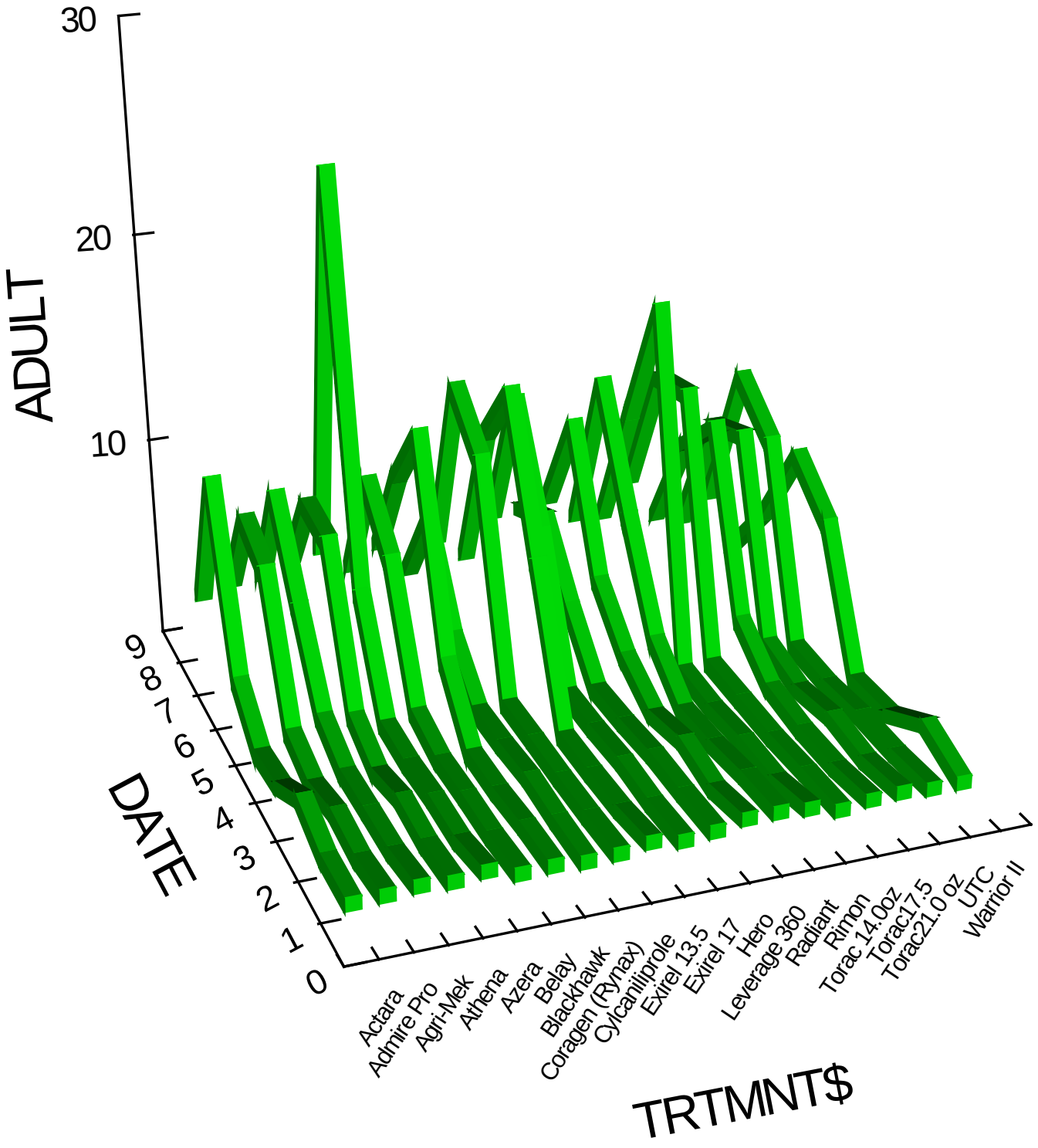
Plots were established at the UMN Sand Plains Research Farm in Becker, MN. Plots were 4 rows by 25 ft long and blocked north to south. Insecticides were applied to the center 2 rows with the outer rows left untreated treatments to allow CPB populations to build to ensure feeding pressure. Each treatment was replicated 4 times. Replicated treatments consisted of different rotated, foliar applications of insecticides (different modes of action). Published information and local experience was used to formulate regimes based on expected efficacy and cost. Efficacy was assessed by CPB population suppression and yield. Beetle populations and % defoliation were monitored weekly and applications made when the mean values in a set of treatment plots reached treatment threshold (30% defoliation pre-bloom or 50% egg hatch). Consequently, not all treatments were sprayed at the same date or as often through the season. Economic analyses of treatment costs (cost of insecticide application over a number of seasonal applications compared to protected yield) is still underway.

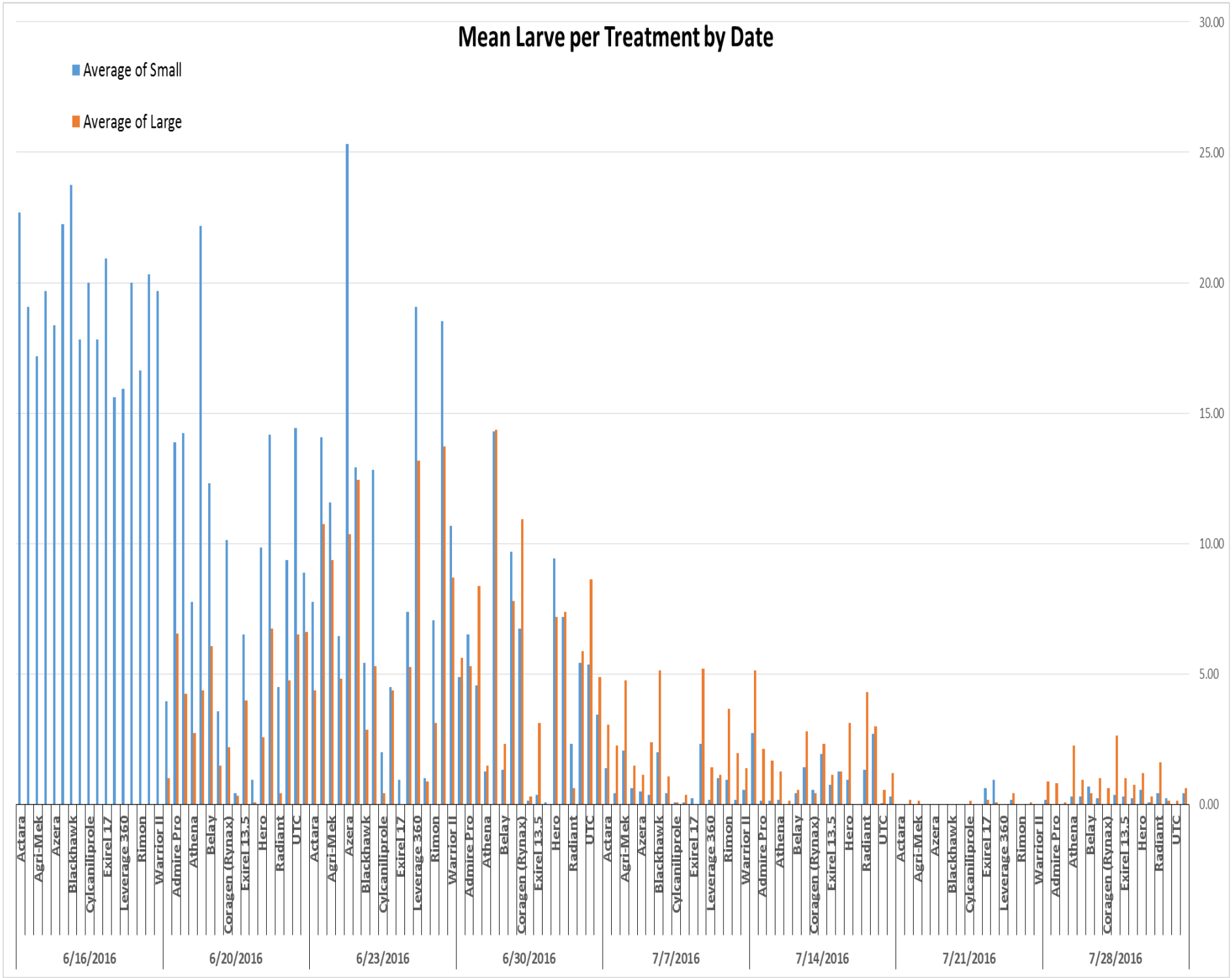
1st Foliar Treatment	**2nd Foliar Treatment**
Agri-Mek 0.15EC @ 16oz/ac	**Admire Pro 1.3 oz/ac**
Athena @ 17oz/ac	**Exirel @ 13.5oz/ac**
Blackhawk @ 3.5oz/ac	**Azera 3pt/ac**
Exirel @ 13.5oz/ac	**Corragen @5oz/ac**
Exirel @ 17oz/ac	**Agri-Mek 0.15EC @ 16oz/ac**
Rimon 0.83EC @ 12oz/ac	**Leverage 360 2.8oz/ac**
Radiant SC @ 8oz/ac	**Warrior II @1.92oz/ac**
Corragen @5oz/ac	**Blackhawk @ 3.5oz/ac**
Warrior II @1.92oz/ac	**Athena @ 17oz/ac**
Belay @12oz/ac	**Actara 3oz/ac**
Admire Pro @ 1.3 oz/ac	**Radiant SC @ 8oz/ac**
Leverage 360 @ 2.8oz/ac	**Exirel @ 17oz/ac**
Actara @ c3oz/ac	**Hero 10.3oz/ac**
Azera @c 3pt/ac	**Cyclaniliprole 15oz/ac**
Hero @c 10.3oz/ac	**Rimon 0.83EC @ 12oz/ac**
Cyclaniliprole @ 15oz/ac	**Belay @12oz/ac**
UTC	**UTC**

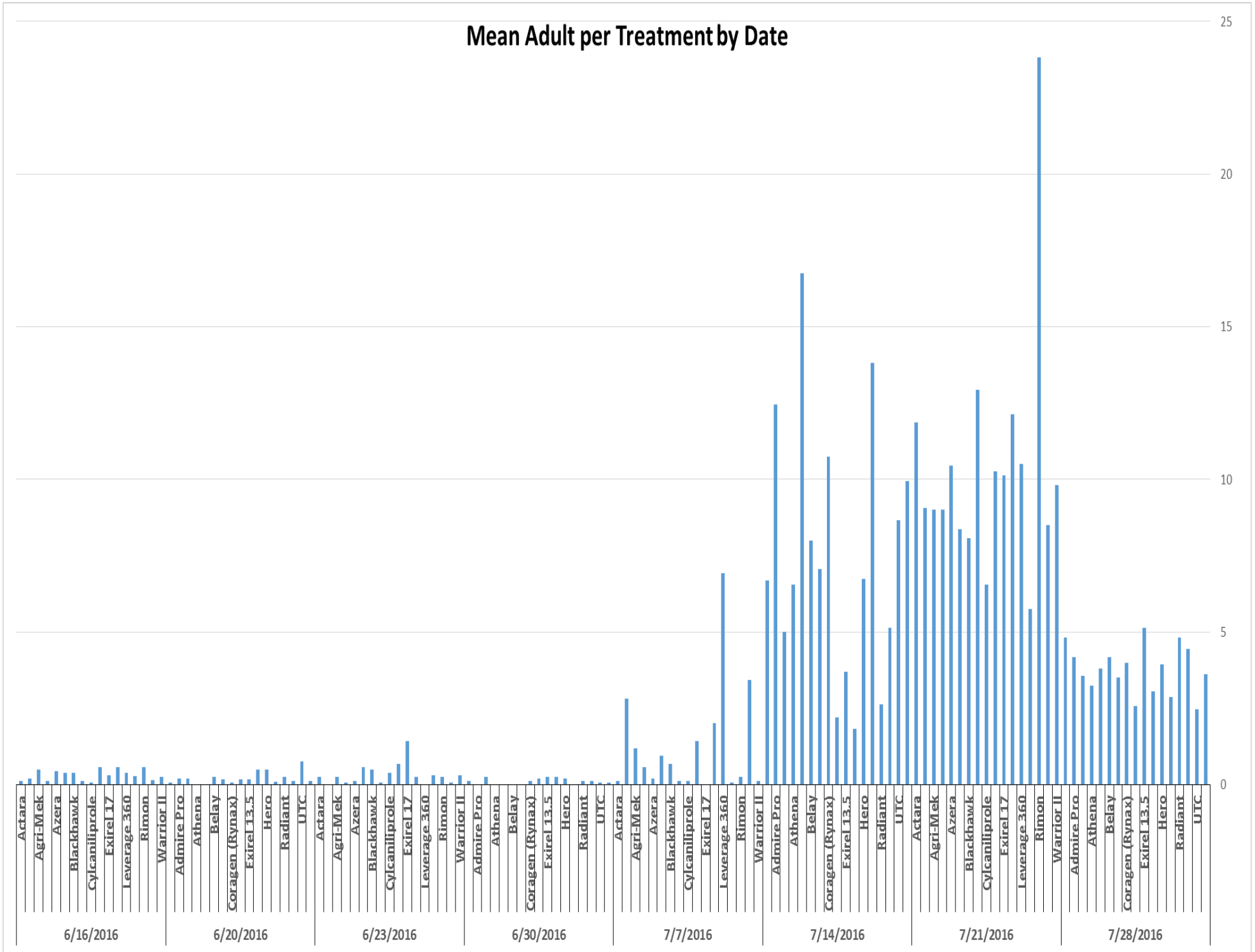
Populations were monitored weekly; CPB eggs, small and large larvae and adults counted weekly throughout the season. First insecticide applications were applied according to egg hatch thresholds (~25% egg hatch across the treatment plots). Secondary applications were timed according to defoliation thresholds. Defoliation was calculated by visual estimates of 4 plants per plot. Harvest yields were calculated from the middle 10ft of one treatment row.

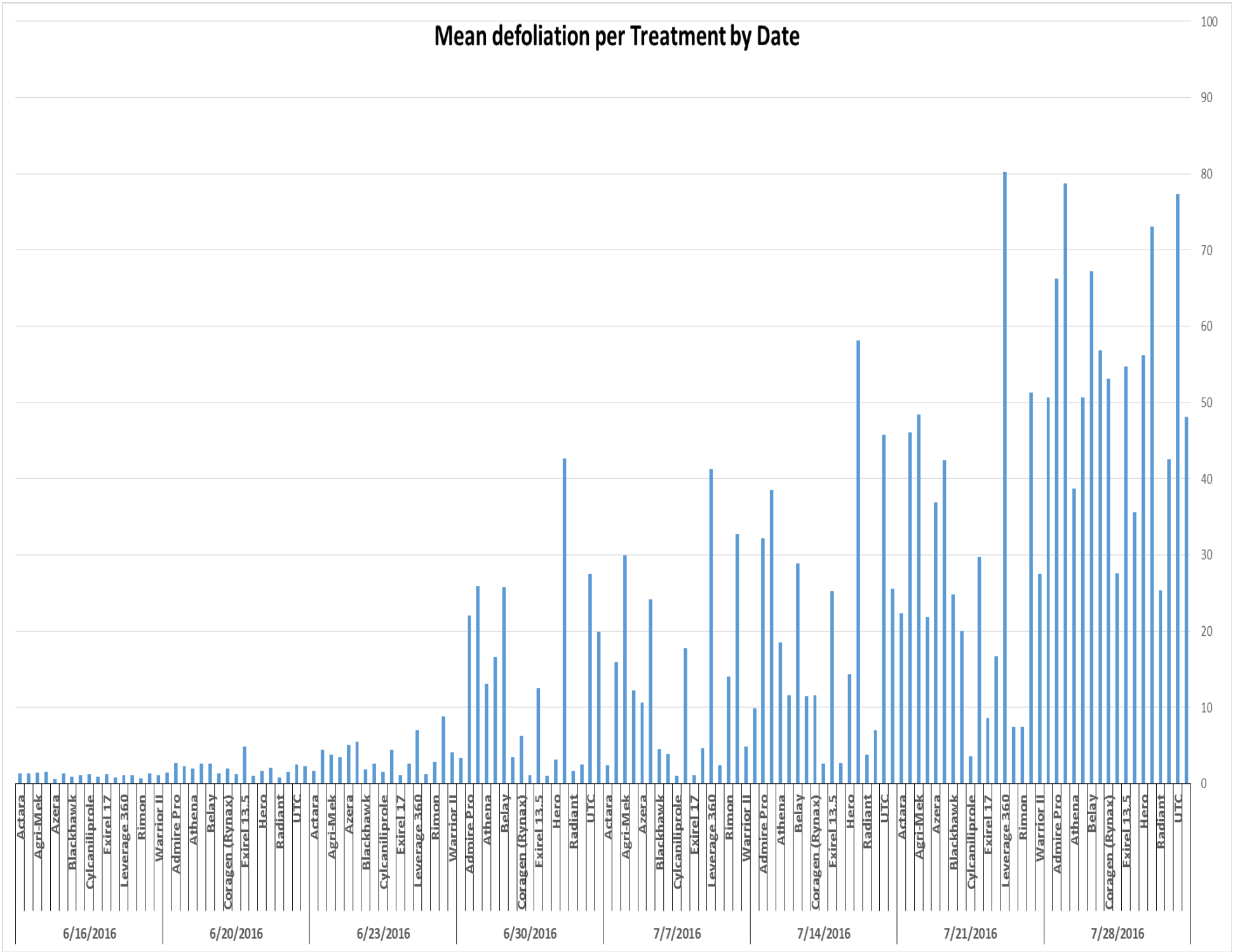
Seasonal population data do reflect treatment differences (see following graphs).

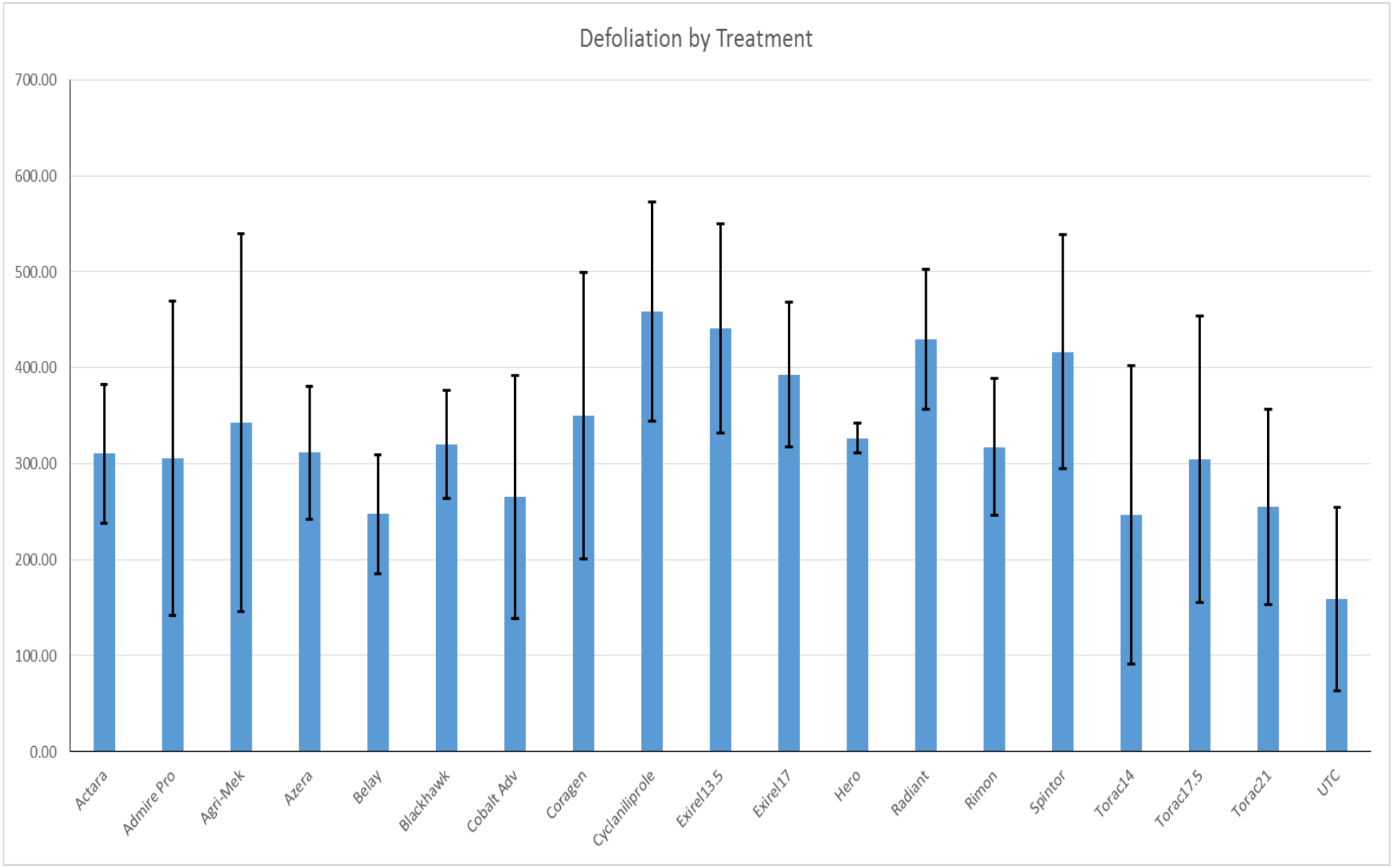
Although the data was highly variable, yields also showed significant treatment effects. Not surpirsingly, early season suppression of larvae seemed to be key in maximizing yields. The Cyclaniliprole, Exirel, Radiant and Spintor treatments (of various rates) had the highest yields. Also not surprisingly, given the trials were conducted in an area where Belay is experienceing increasing difficulties in suppressing CPB, it had the lowest of all chemically treated plots. Suppression by some newer chemistries, such as Agri-Mek and Torac, was variable in efficacy.




Mean Larve per Treatment by Date
Average of Small
Average of Large
30.00
25.00
20.00
15.00
10.00
5.00
0.00
Actara
Agri-Mek
Azera
Blackhawk
Cylcaniliprole
Exirel 17
Leverage 360
Rimon
Warrior II
Admire Pro
Athena
Belay
Coragen (Rynax)
Exirel 13.5
Hero
Radiant
UTC
6/16/2016
6/20/2016
6/23/2016
6/30/2016
7/7/2016
7/14/2016
7/21/2016
7/28/2016


Mean Adult per Treatment by Date
25
20
15
10
5
0
Actara
Agri-Mek
Azera
Blackhawk
Cylcaniliprole
Exirel 17
Leverage 360
Rimon
Warrior II
Admire Pro
Athena
Belay
Coragen (Rynax)
Exirel 13.5
Hero
Radiant
UTC
6/16/2016
6/20/2016
6/23/2016
6/30/2016
7/7/2016
7/14/2016
7/21/2016
7/28/2016


Mean defoliation per Treatment by Date
100
90
80
70
60
50
40
30
20
10
0
Actara
Agri-Mek
Azera
Blackhawk
Cylcaniliprole
Exirel 17
Leverage 360
Rimon
Warrior II
Admire Pro
Athena
Belay
Coragen (Rynax)
Exirel 13.5
Hero
Radiant
UTC
6/16/2016
6/20/2016
6/23/2016
6/30/2016
7/7/2016
7/14/2016
7/21/2016
7/28/2016



Percent Defoliation by Treatment. Vertical bars are 95% Confidence Limits, treatments whose bars do not overlap are significantly different. Yields in this figure contain some products in a neighboring trial and may not be included in statistical comparisons because of differing experimental design.

Product Comparisons

Larvae – There was a significant treatment effect in the ability of these products to suppress CPB larvae (P<0.001)The products demonstrating the best suppression of CPB larvae in this trial were Exirel (all rates) Cyclaniliprole, and Radiant. Larval suppression seen in Athena, Rimon, Actara and Corragen were not significantly different from the top three, but also did not differ from the next grouping (perhaps best referred to as the middle performers of this trial). Larval suppression in plots treated with Belay, Hero, Agri-Mek, and Warrior II were significantly lower than the top three products. Finally, Admire Pro and Leverage 360, whose larval suppression was not significantly lower than the middle performers was also not significantly better than Azera, the product with the lowest rates of larval CPB suppression.

Product	Active Ingredient (Insecticide Group)	Suppression of CPB Larvae (best suppression to least, products followed by the same letter are not significantly different)
Exirel	Cyantraniliprole (Diamides, 28)	A
Cyclaniliprole	Cyclaniliprole (Diamides, 28)	A
Radiant SC	Spinetoram (spinosyns, 5)	A
Athena	Bifenthrin (Pyrethroids, 3) Abamectin (Avermectins, 6)	AB
Rimon	Novaluron (Benzoyureas, 15)	AB
Actara	Thiomethoxam (Neonicotinoids, 4)	AB
Corragen	Chloantraniliprole (Diamides, 28)	AB
Blackhawk	Spinosad (Spinosyns, 5)	AB
Belay	Clothianidin (Neonicotinoids, 4)	B
Hero	Zeta-Cypermethrin & Bifenthrin (Pyrethroids)	B
Agri-Mek	Abamectin (Avermectins, 6)	B
Warrior II	Lambda-Cyhalothrin (Pyrethroids, 3)	B
Admire Pro	Imidacloprid (Neonicotinoids, 4)	BC
Leverage 360	Imidacloprid (Neonicotinoids, 4) & Beta-Cyfluthrin (Pyrethroids, 3)	BC
Azera	Azadirachtin (Unknown, UN) & Pyrethrins (Pyrethrins, 3A)	C

The performance of the top three is not surprising; in previous trials these products have consistently proven to be highly effective insecticides and have always been in the top performing treatments in CPB trials performed at Becker in the past 3 years. That Blackhawk seemed not perform as well as did radiant is surprising, these ai's in these two products are in the same mode of action and are usually similar in performance. Agri-Mek's lower suppression of larval CPB was also surprising as this too has generally been a top performer at this location. That Actara had better suppression of larvae than products containing Imidacloprid (Admire Pro or Leverage 360) or Clothianidin is understandable considering the higher levels of tolerance CPB populations in this region have to the these neonicotinoids; Thiomethoxam has less of a history of use in the area and consequently retains greater efficacy at this point.

Adults

There was a significant treatment effect in the ability of these products to suppress APB adults, although differences were not as marked as with larvae.

Cyclaniliprole, Radiant and Exirel all had greatest efficacy for suppressing adult CPB. Athena, Agri_Mek and Blackhawk, while not significantly different than the leading products in this trial also were not significantly different than the middle group, Belay, Actara, and Coragen. The suppression of CPB adults seen with Warrior II, Admire Pro, Hero and Azera was not significantly lower than the middle performers, but also not significantly better than the bottom performers, Rimon and Leverage 360.

The ability of Athena (a mixture of abamectin and a pyrethoird)to suppress CPB adults is due mostly to the efficacy of the active ingredient Abamectin. This is supported by the fact that Agri-Mek (abamectin) performed as well but pyrethroid based products did not.

With a few exceptions, these results were not surprising. The fact that the Synthetic Pyrethroids, Warrior II and Hero, still suppressed adult and larval CPB was not immediately expected given beetles in this area have had long exposure to this mode of action and have developed resistance. Often after a long period in the absence of selection pressure, resistant alleles may decrease in the population but it is anticipated that should this trial be replicated nest year, the efficacy of this mode of action will be greatly decreased.

Product	Active Ingredient (Insecticide Group)	Suppression of CPB Larvae (best suppression to least, products followed by the same letter are not significantly different)
Cyclaniliprole	Cyclaniliprole (Diamides, 28)	A
Radiant SC	Spinetoram (spinosyns, 5)	A
Exirel	Cyantraniliprole (Diamides, 28)	A
Athena	Bifenthrin (Pyrethroids, 3) Abamectin (Avermectins, 6)	AB
Agri-Mek	Abamectin (Avermectins, 6)	AB
Blackhawk	Spinosad (Spinosyns, 5)	AB
Belay	Clothianidin (Neonicotinoids, 4)	B
Actara	Thiomethoxam (Neonicotinoids, 4)	B
Corragen	Chloantraniliprole (Diamides, 28)	B
Warrior II	Lambda-Cyhalothrin (Pyrethroids, 3)	BC
Admire Pro	Imidacloprid (Neonicotinoids, 4)	BC
Hero	Zeta-Cypermethrin & Bifenthrin (Pyrethroids)	BC
Azera	Azadirachtin (Unknown, UN) & Pyrethrins (Pyrethrins, 3A)	BC
Rimon	Novaluron (Benzoyureas, 15)	C
Leverage 360	Imidacloprid (Neonicotinoids, 4) & Beta-Cyfluthrin (Pyrethroids, 3)	C

The fact there was a difference in efficacy in the two Imidacloprid products was also expected; Admire Pro has almost twice the Imidacloprid by volume and application and therefore it's greater suppression of CPB adults is understandable.

The poor performance of Rimon is due to the fact that it is a growth hormone and is ineffective against mature insect stages.

Yields – Yield data was extremely variable and comparisons between treatments for this preliminary trial year are not possible. The trial was designed to compare population levels only and yields were not a predesignated metric. The continuation of this project has been funded under a competitive MDA grant and yields and economic comparisons will be included in further work.

iii) Remote sensing of CPB Defoliation – funded from other sources

Insecticide treatment plots at the UMN Sand Plains Research Farm and at the UMN NWROC were again flown weekly in 2016, using a small unmanned aerial system (UAS) and imagery obtained from both visible (VIS) and near-infrared (NIR) cameras. The percent defoliation and CPB population was assessed weekly for each plot. Flights were conducted 40m above ground, between the hours of 10 a.m. and 2 p.m., ensuring the amount of reflected light was comparable across dates.

We used both VIS and NIR images in analysis but the following reports on the use of VIS data obtained from a GoPro camera. Individual images were obtained from the video using VLC Media player to capture TIFF images from video, resultant TIFF images were then stitched using AgiSoft PhotoScan (Agisoft LLC, St Petersburg, RU) into a single image of all the plots. Stitched image was uploaded into ArcGIS 10.3 and plot centers were described and bounded by polygons. Using polygons representing the plot centers, the stitched image was then clipped to produce a raster with only the plots to be analyzed. Supervised classification was used wherein the software is 'trained' to recognize areas of interest. Training data was obtained that represented both soil and vegetated areas and used in the maximum likelihood classification tool. Maximum likelihood image classification was conducted using plot centers clipped from the stitched image. All pixels were included in the classification, i.e., no values remained unclassified due to low probability. Resulting raster image displaying derived areas of vegetation and soil then converted to a polygon shapefile and intersected with the plot centers in order to retain plot numbers. Total area for soil was then calculated and then divided by the total plot area to calculate a percentage of area covered by soil (assumed to be defoliated areas). Calculated defoliation per plot was correlated with the ground-based defoliation estimates to estimate comparative accuracy of the method using the statistical software R v.3.2.2.

As in 2015, aerial estimates of defoliation in 2016 calculated from UAS visible imagery were at least as accurate as ground observations.

This project will complement an ongoing remote sensing of PVY project already being conducted collaboratively between my laboratory and that of Dr. Asunta Thompson of NDSU.

This project was partially supported by a Minnesota Dept. of Agriculture Crops Research Proposal. The results were so successful that we have submitted an additional proposal to develop techniques using commercially available equipment.

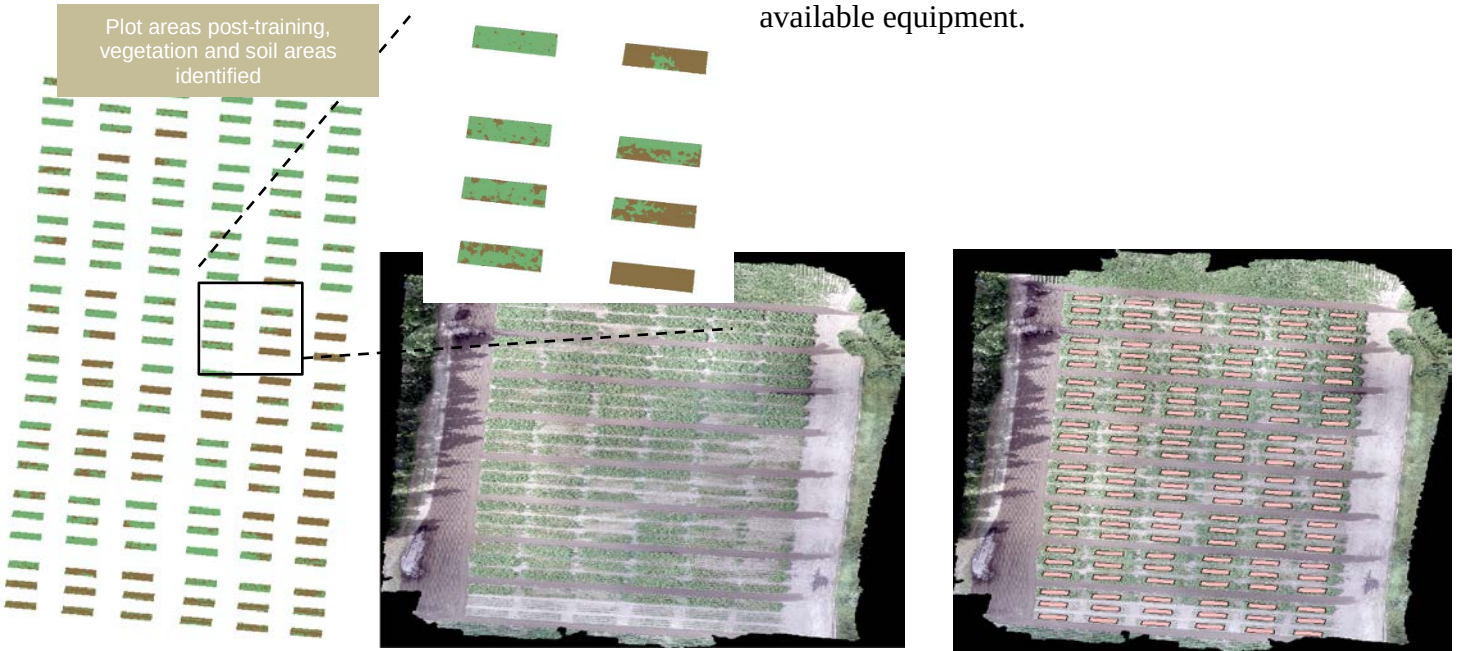


Image analysis is still ongoing, however the high resolution imagery does easily show individual plants and should provide insights into developing methods of developing a technology to assist in evaluating winter grow-out results.

iii) **Emergence patterns of CPB in ND & MN** Adult beetles were recovered from multiple locations in central MN. While spatial analysis is ongoing, it appears all areas are experiencing extended emergence of overwintering beetles, resulting in a much longer presence of immature stages. The latest ovewrwintering beetle was recovered at the Becker Sand Plains Research Farm on July 19, 2016. The emergence of overwintering CPB in the northern areas of MN and ND were extended as well. However, this was heavily influenced by climate as opposed to genetic predetermination of emergence period. There was little pattern or time to the emergence patterns seen in the Red River valley. While this work will continue in 2017, no support is being sought, it is funded under by a competitive grant from a separate agency.

Managing PVY Vectors, Annual Report 2016

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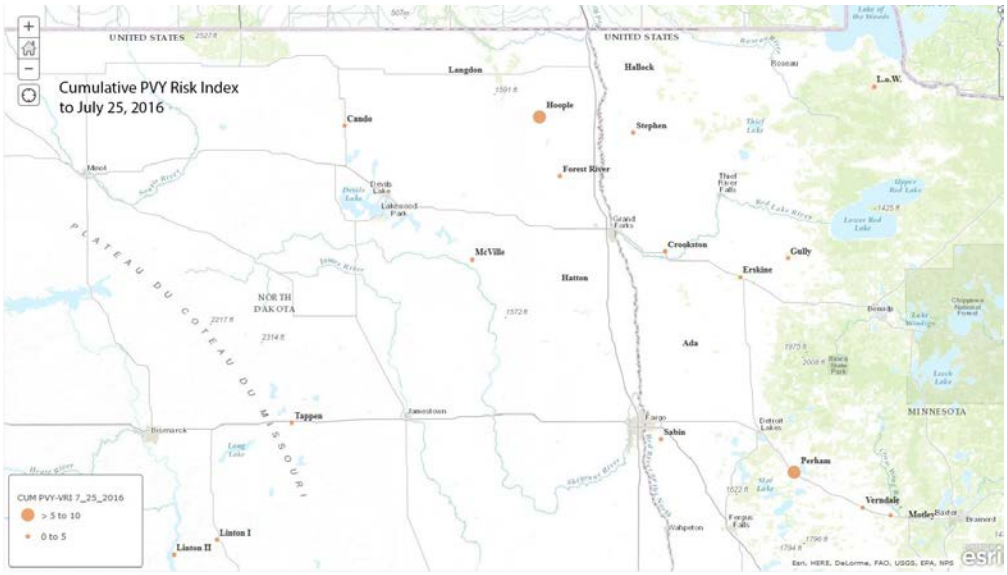
A) A network of 19 - 2m tall suction traps were established in the seed potato production areas of Minnesota and North Dakota, 17 of which were able to consistently provide data through the season. These traps consist of a fan drawing air down in through the trap and trapping the incoming aphids in a sample jar which is changed weekly. Sample jars are sorted, aphids identified to species and aphid population dynamics at sample locations are determined. Maps were prepared weekly showing these dynamics.

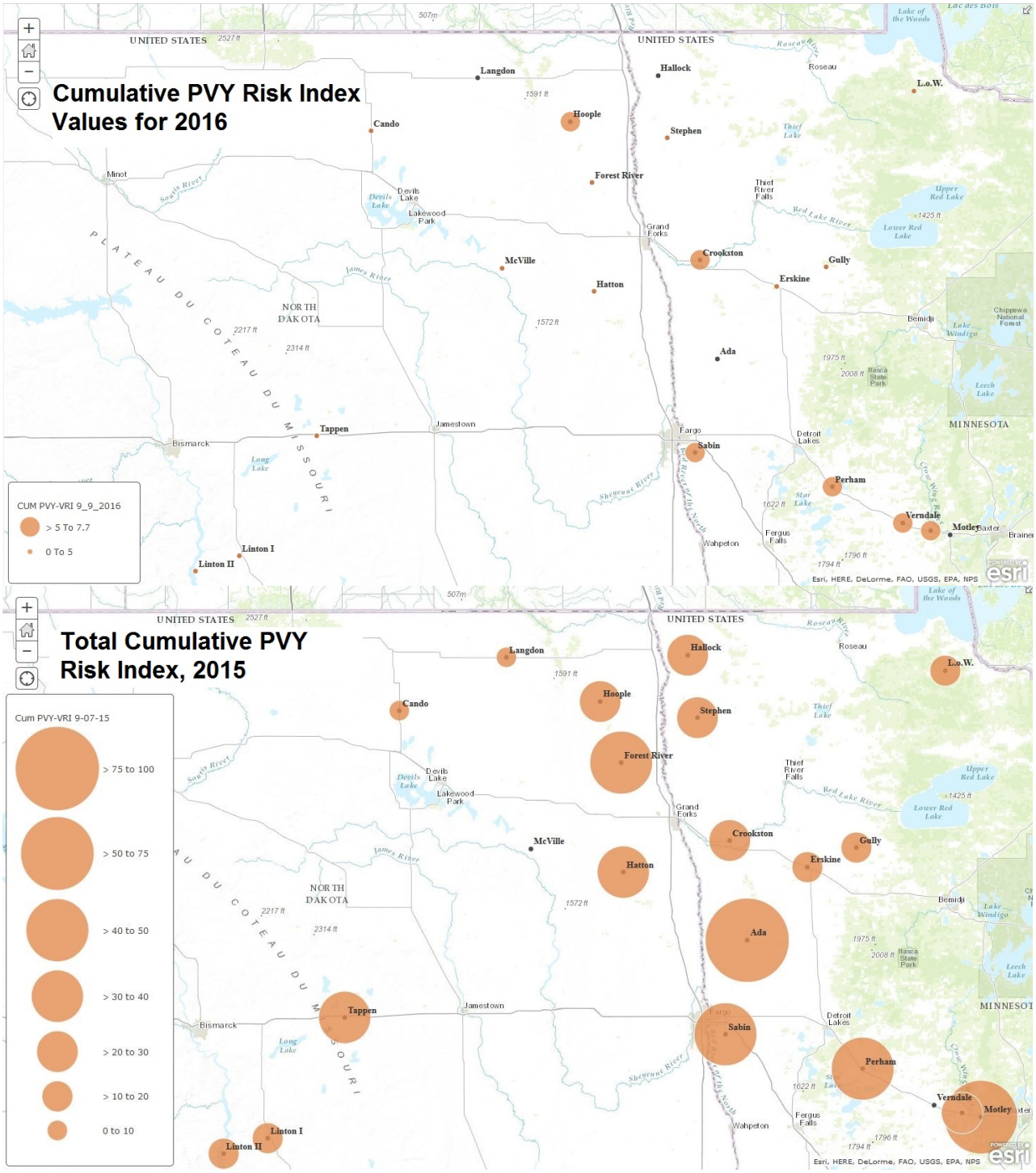


Aphid Alert suction trap locations, 2015.

In 2016, we continued including the PVY Vector Risk Index. This measurement standardized the amount of vector pressure being encountered at a trap location. All vectors are not created equally, some vector PVY more efficiently than others; therefore the same number of aphids of different species may not cause the same potential of PVY transmission to fields in the area. The relative efficiencies of aphid vectors to transmit PVY has been investigated and published, green peach aphid is the most efficient vector and the vector efficiency of other species is generally compared to it. We used values from the literature to calculate relative cumulative vector pressure at a location based on the relative efficiencies and numbers present (e.g. soybean aphid is 10% as efficient as green peach, so a catch of 5 soybean aphids and 1 green peach at a location would total a PVY Vector Index value of 1.5 for that location. We presented the cumulative yearly PVY Vector Index values and the total PVY Vector Index value from 2014 to provide producers with an insight into what vector pressure they were experiencing compared to last year.

In 2016, 4 traps were established at the MN Dept. of Agriculture winter grow-out site at Waialua HI. These traps are used to monitor for the presence of aphid virus vectors at the site; the absence of vectors ensures virus is not being transmitted to plants in the grow-out. These traps provide monitoring for the MN, MT, CO and ID programs, but basically provide a good overall representation of the aphid pressure

at the growout site. Aphid population information was made available to growers on two websites (aphidalert.blogspot.com and aphidalert.umn.edu), via NPPGA weekly email, linked to on the NDSU



Seasonal cumulative PVY Vector Risk Index for 2016 (upper map) and the total cumulative PVY Vector Risk Index for 2015 (bottom map). PVY Vector pressure was higher in 2015 and there were differences in PVY Vector Index values at most locations between the two years. The total cumulative values for the PVY Vector Risk Index in 2015 = 569.87, and in 2016 = .

Potato Extension webpage (http://www.ag.ndsu.edu/potatoextension), and posted on the AgDakota and Crops Consultants List Serves. Growers could make decisions on beginning oil treatments or targeted edge applications could be made based on the information obtained

from the regional monitoring system. Partial funding for this project was obtained from a Minnesota State Specialty Crops Block Grant in collaboration with the Minnesota Dept. of Agriculture and the Sugarbeet Research and Education Board (we established 3 sites to monitor Sugarbeet Root Aphid but they are in geographic locations that add to our regional picture of aphid vector distributions). Additional funding will be sought from other commodity groups to further expand the network if possible. Traps were established in early June and maintained until the seed field hosting the trap was vine-killed/harvested. At that point a field is no longer attractive to aphids.

Location (2015)	Location (2016)	PVY Vector Index 2015	PVY Vector Index 2016
Ada		93.04	
Cando	Cando	8.13	0.03
Crookston	Crookston	21.82	7.49
Erskine	Erskine	10.44	1.28
Forest River	Forest River	40.61	0.81
Gully	Gully	15.6	4.07
Hallock		22.05	
Hatton	Hatton	31.06	0.5
Hoople	Hoople	26.86	6.04
L.o.W.	L.o.W.	19.21	1.79
Langdon		8.43	
Linton I	Linton I	14.07	3.15
Linton II	Linton II	9.89	1.98
McVille	McVille	73.33	3.12
Motley		49.26	
Perham	Perham	44.42	7.14
Sabin	Sabin	20.31	6.19
Staples	Staples	25.66	7.05
Stephen	Stephen	35.68	1.14
	Tappen		3.13
	Verndale		7.62
Total PVY Risk		**569.87**	**62.53**

A total of only 496 vector species aphids, representing 16 potential PVY vector species, were recovered from traps in 2016. This is roughly 1/10 the number opf vectors recovered in 2015. Rather than the raw vector numbers at each location, the comparison of the risk of virus transmission is better represented by the PVY Vector Risk Index maps. The cumulative total values for the PVY Vector Index were much lower in 2016 than in 2015 (62.53 vs 569.87 respectively – again, roughly 1/10 the PVY Vector Risk Index value) but there were differences at individual sites (see above table).

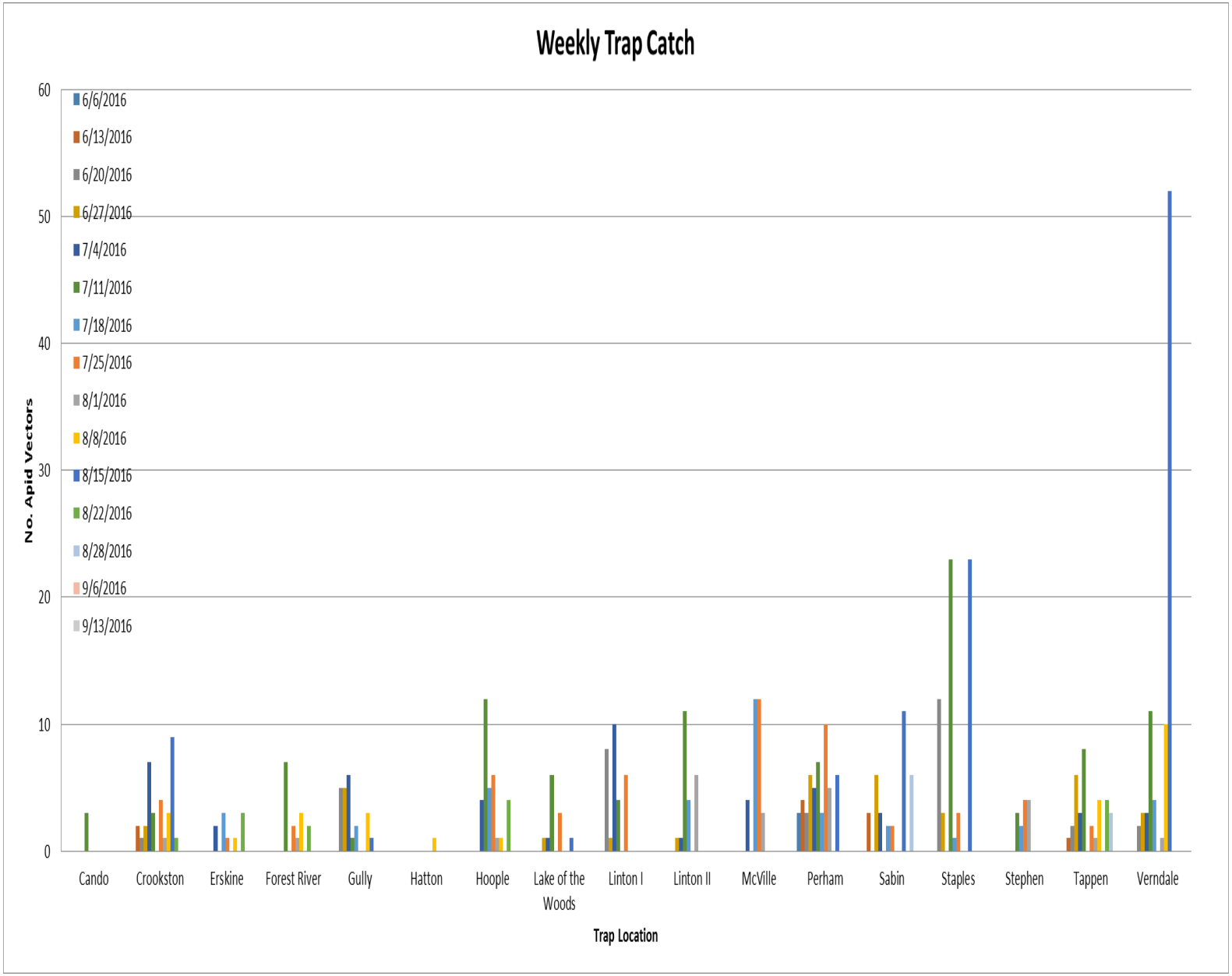
Again in 2016, the use of data from the Aphid Alert network was used to address the flight dynamics of sugarbeet root aphid. This demonstrated the potential application of the network to other cropping systems. In addition to providing information on sugarbeet root aphid, these extra traps provided a greater resolution to our regional estimation of all potato vector populations.

Predictive models of aphid arrival and distribution in MN and ND are currently being developed. This will facilitate a more timely application of management tactics. This work is ongoing.

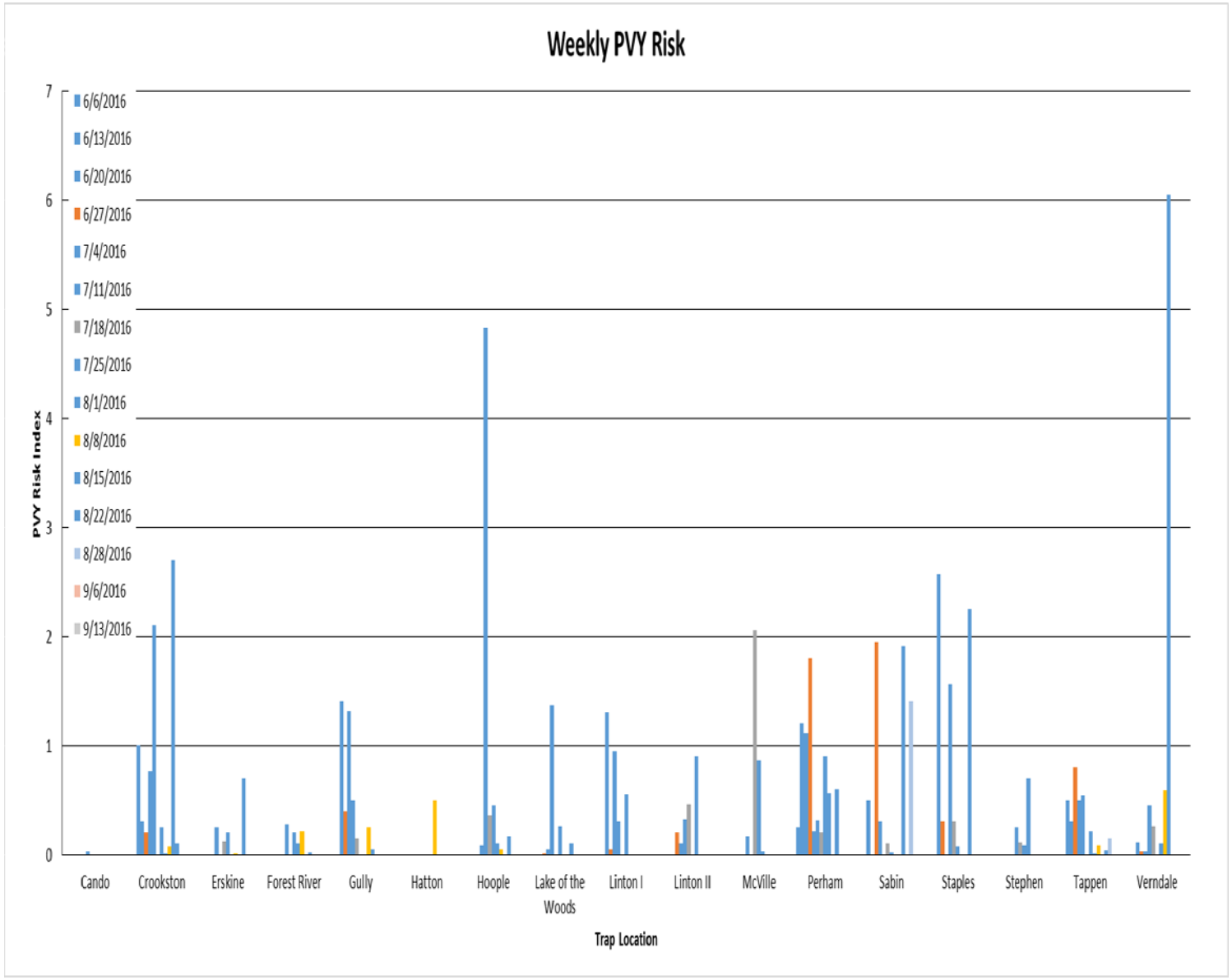
Results from the 2016 season winter test site indicate the within season transmission was not likely. Few aphids were caught and those that were recovered were not very effective vectors. Several green peach

aphids were recovered from one trap, but it was located on the high elevation slope to the east of the main growing area. Grap-hs and tables of capture data are appended at the end of this report.

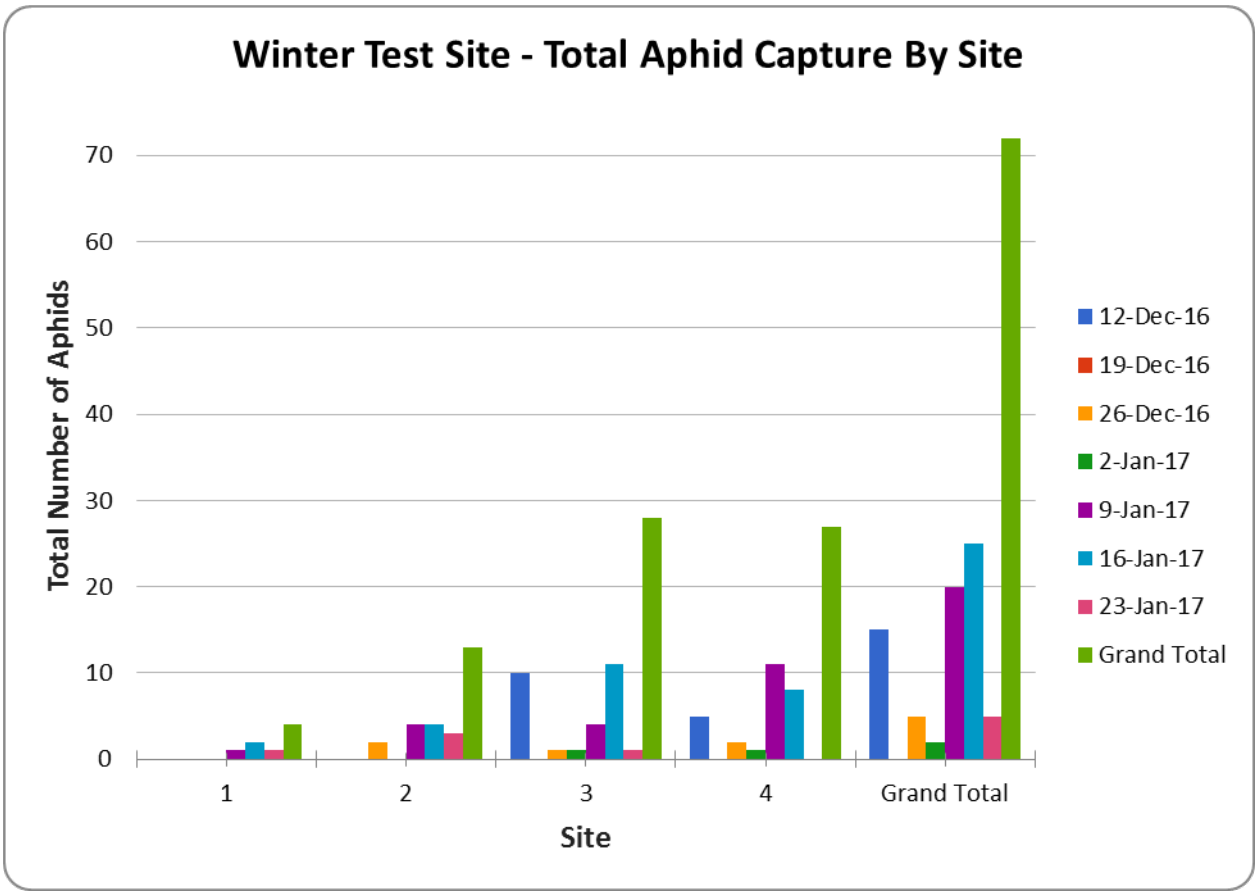
POST SCRIPT – Growout data from the 2016 season indicates higher than anticipated levels of PVY infection at several locations, especially given the low level of vector aphids. There are 3 potential explanations that may not be mutually exclusive. The very wet climatic conditions late in the season restricted harvest dates, meaning many of the discussed fields were harvested later, facilitating late season infection of PVY. In addition, populations of Colorado potato beetles (CPB) were unusually high in the Red River Valley in 2016. These beetles are known to preferentially feed on plants not infected by PVY and start feeding on the tops of canopies, where aphid vectors (both those that colonize potatoes and those that do not) generally alight to probe and assess the plant as a potential host. By feeding in the top of the canopy, CPB may have artificially changed the relative proportion of PVY infected plants in seed fields where they were prevalent. The last is the potential that CPB actively transmitted PVY, which is less probable than the previous two. While we infect plants in trials by hand using an abrasion technique, there is little support in the literature indicating that CPB can transmit PVY in meaningful numbers.

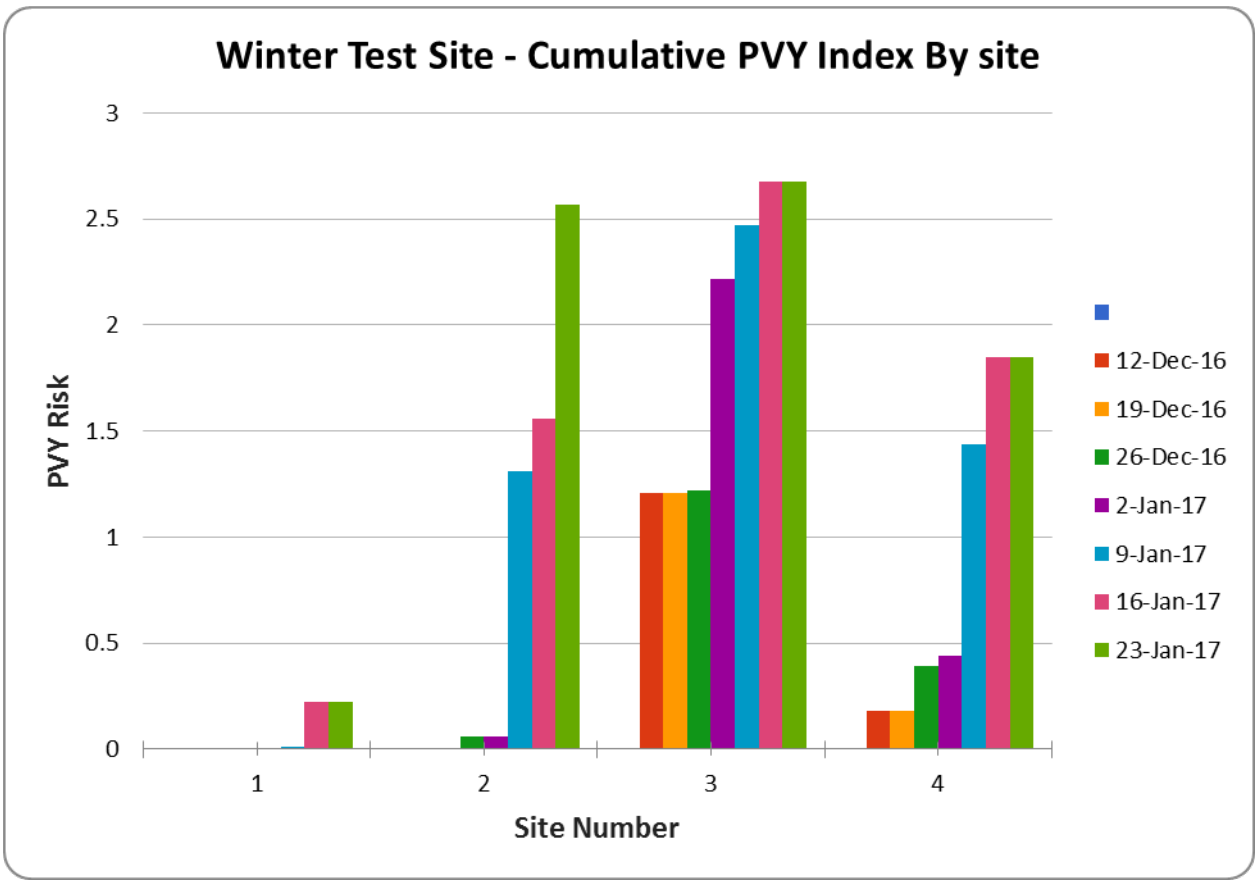


Seasonal trap catch by week and location



Seasonal PVY Risk Index by week and location


Winter Test Site - Total Aphid Capture By Site
Total Number of Aphids
70
60
50
40
30
20
10
0
1
2
3
4
Grand Total
Site
12-Dec-16
19-Dec-16
26-Dec-16
2-Jan-17
9-Jan-17
16-Jan-17
23-Jan-17
Grand Total


Winter Test Site - Cumulative PVY Index By site
PVY Risk
3
2.5
2
1.5
1
0.5
0
1
2
3
4
Site Number
12-Dec-16
19-Dec-16
26-Dec-16
2-Jan-17
9-Jan-17
16-Jan-17
23-Jan-17

Location	Week of	Green peach aphid	Soybean aphid	Bird cherry oat aphid	Corn leaf aphid	English grain aphid	Green bug	Potato aphid	Sunflower aphid	Thistle aphid	Turnip aphid	Cotton /melon aphid	Pea aphid	Cowpea aphid	Black bean aphid	Foxglove	Buckthorn aphid	Sugarb	Identified non-vector	Total # captured	Total V	PVY Risk Index
3	14-Dec-15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	14-Dec-15	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	0.2
2	28-Dec-15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	28-Dec-15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	28-Dec-15	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	3	0.3
1	28-Dec-15	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	3	0.3
2	21-Dec-15	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	3	0.3
4	21-Dec-15	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	3	0.3
3	21-Dec-15	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	5	0.5
3	4-Jan-16	0	0	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	8	7	0.7
4	4-Jan-16	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	4	3	0.3
2	4-Jan-16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0
1	4-Jan-16	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	1	0.1
2	11-Jan-16	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0.1
3	11-Jan-16	1	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	7	6	1.5
4	11-Jan-16	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	2	1	0.05
1	11-Jan-16	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0.1
2	18-Jan-16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	18-Jan-16	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	2	4	2	0.15
1	18-Jan-16	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	5	1	0.1
1	2-Feb-16	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	0.2
2	2-Feb-16	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1

Weekly trap catch at winter grow-out location.

Also funded from other sources - In an effort to acquire preliminary data for future project development, the grow out plots in Waialua, HI were flown and aerial imagery, both VISIBLE and NIR, were collected to ascertain if remote sensing could be used to assist in the identification of virus infected plants. This will hopefully lead to a cooperative project with the Minnesota Dept. of Agriculture.

Metam Sodium Control of Verticillium Wilt in High OM and Fine-Textured Soils
Submitted to MN Area II and NPPGA

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Executive Summary

Verticillium wilt, caused by *Verticillium dahliae* Kleb, is the principle pathogen involved in the early dying syndrome and is arguably the most economically damaging disease of potato in the USA when considering direct and indirect losses due to the disease and the cost of control. Soil fumigation with metam sodium is the primary means by which irrigated potato producers manage this disease. EPA estimates that 34 million pounds of the active ingredient metam sodium are applied by the potato industry each year for the control of *Verticillium* wilt at cost of nearly $200 million, not including the cost of application. Metam sodium recently has been re-registered by the Environmental Protection Agency (EPA), but with considerable restrictions placed on its use and the product is currently undergoing re-registration. The increased scrutiny by EPA and environmental groups on the application of metam sodium for soil-borne pathogen control increases the need to establish best management practices for sub-surface shank applications of this soil fumigant.

The purpose of the research proposed here is to fine-tune recommendations for shank applications of metam sodium based on soil propagule numbers of *V. dahliae,* soil temperature, injection depth and rate of chemical to improve disease control while also potentially reducing off-gassing of MITC and also reducing the amount of fumigant applied. An indirect result of this research will be an improvement in the sustainability of irrigated potato production. Previous research established parameters for proper fumigation of soils with a loamy sand texture and organic matter (OM) contents less than 1.3%. However, many potato production soils in North Dakota and Minnesota have a sandy loam to silt loam texture (a finer texture than our previous research) and OM contents of >2%. The proposed research will be directed at improving soil fumigation in these types of soils.

Research Objectives

1) Determine the efficacy of metam sodium based on rate, soil temperature and inoculum level of *V. dahliae* in irrigated sandy loam/silt loam soils with OM >2%.
2) Develop guidelines for sub-surface metam sodium applications at different soil temperatures that effectively control *V. dahliae* while also complying with more restrictive impending EPA mandates

Current Research

MN Area II and the NPPGA previously funded research on soil fumigation in 2010 and 2011. This research concentrated on developing effective metam sodium use strategies for improving efficacy in controlling *V. dahliae* populations in a low OM soil with a sandy texture (Pasche et al., 2014). The variables studied were metam sodium rate (0, 40, 50, 60, & 70 gal/a), depth of shank injection (two depths at 6” & 10” vs. single injection at 10”) and soil temperature at the time of application (39F vs 55-59F). In the light soil where these studies were conducted we found no rate response among the metam sodium rates used. A rate of 40 gal/a reduced Verticillium wilt and increased total and marketable yields to the same degree as rates of 50 to 70 gal/a. Control of Verticillium wilt was significantly better when metam sodium was applied at 39F compared to 55 or 59F. Finally, there was no significant difference in Verticillium wilt control

or yield of potatoes when metam sodium was injected at a single depth of 10” compared to traditional split applications at 6” & 10” (Pasche, et al., 2014). This research has dramatically changed the recommendations we make regarding how, what time, and the rate of metam sodium for Verticillium wilt control.

While it is apparent that the shank injection of metam sodium at cold soil temperatures (39F), at a single depth (10”) at a relatively low rate (40 gal/a) in light soils with relatively low OM will optimize Verticillium wilt control at the lowest possible cost to the grower, we were asked many times by potato growers if these application parameters are also ideal for fine textured soils with higher OM levels (>2%). These growers have asked if similar studies as those discussed here be performed on silt loam type soils with higher OM levels. A finer soil texture and higher OM levels may impede the movement of MITC gas through the soil profile thus reducing fumigation efficacy.

Materials and Methods

The first year of this two-year study was initiated in the fall of 2014. All of the treatments were established in a field in the Ponsford Prairie near Osage, MN in a field with 2.3% OM. The first fumigation was conducted on October 15, 2014 when the soil temperatures at the 6” depth were 54F and the second fumigation was conducted on November 5 when the soil temperatures were 38F at that depth. Site specific soil samples were taken before and after soil fumigation to determine metam sodium efficacy for each soil temperature at the time of application, metam sodium rate, and injection depth combination. The field was planted to Russet Burbank on April 29, 2015 and data such as Verticillium propagule reduction, stand, weekly wilt development, total and marketable yield, was collected throughout the season. The first year’s experiment was harvested on September 9-10, 2015. In the second year of the study, the experiment was conducted in a sandy loam silt soil with 2.8% OM. The experiment was fumigated on October 19 and November 11, 2015 when the soil temperature at the 6” depth was 56F and 41F, respectively. The experiment was planted on May 3, 2016 and harvested on September 18-20.

Results and Discussion

Levels of *V. dahliae* in the field were very high and averaged nearly 124 Verticillium propagules per gram (vppg) of soil in the non-fumigated plots which is >15-fold higher than the economic threshold for Russet Burbank (Table 1). Previous research by our group has demonstrated that high levels of Vd such as this cannot be completely ameliorated by soil fumigation (Pasche, et al. 2014; Taylor, et al. 2005). However, shank injection of metam sodium, regardless of injection depth, significantly reduced Vd propagules at both the 0-4” and 4-8” soil depths and all rates of the soil fumigant significantly reduced vppg although there was no rate response due to metam sodium (Table 1). In contrast to previous research, the level of Verticillium inoculum in soils fumigated with a split metam sodium application at depths, 6 and 10” resulted in a significantly lower level of propagules compared to fumigation at a single injection level of 10”. Soil temperature at the time of shank injection had no effect on metam sodium efficacy which is in direct contrast to previous research on sandy soils with low organic matter (Pasche, et al. 2014). In previous studies soil temperatures of 39F at the time of fumigation significantly improved metam sodium efficacy compared to temperatures of 55-59F. Improvement of metam sodium efficacy when injected at 38F compared to 54F was not evident in the silt loam soil type used in the current study.

In nearly all instances, metam sodium applications caused a positive reduction in Verticillium propagules (excluding the non-treated control) with only one exception (Table 2). Reductions of Verticillium propagules ranged from 12 to 77% in the 0-4” soil depth and from 39 to 93% in the 4-8” depth across all rates of metam sodium. However, the rate of metam sodium did not affect

the percent reduction of Verticillium inoculum (Table 2). Across all treatments, injection depth of metam sodium at two depths, 6 and 10", resulted in a significantly greater reduction in Verticillium propagules compared to a single injection depth of 10" with inoculum in the 0-4" soil profile, 69% vs 38% reduction, respectively (Table 2). Injection depth did not have a significant effect on the reduction of Verticillium inoculum in the 4-8" soil profile

Despite the high levels of Vd in the soil prior to soil fumigation, the shank injection of metam sodium significantly reduced Verticillium wilt at all rates compared to the non-fumigated control based on the area under the disease progress curve (AUDPC) and relative area under the disease progress curve (RAUDPC) (Table 3). However, soil temperature at the time of soil fumigation did not significantly affect efficacy. Interestingly, the injection of metam sodium at two depths of 6 and 10" significantly decreased Verticillium wilt compared to the non-fumigated control and was significantly better in controlling the disease when the fumigant was injected at a single 10" depth (Table 3). Once again, this suggests that splitting the injection of metam sodium when fumigating finer textured soils with >2% organic matter may improve efficacy of the fumigant.

Despite the high levels of Verticillium in the soil, soil fumigation with metam sodium significantly improved both total and marketable yields regardless of injection depth and rate of fumigant (Table 4). Percentages of tubers in each size category were also significantly increased, except in the <6 oz category, due to soil fumigation. There were no significant differences in yield parameters due to soil temperature at the time of soil fumigation. Additionally, there were no differences in the percentages of US No. 1 or US No. 2 potatoes due to soil fumigation (Tables 4 & 5). The percentages of total unusables was significantly reduced with the use of metam sodium compared to the non-fumigated control (Table 5).

The levels of *V. dahliae* were substantially lower in 2016 in non-fumigated control plots than they were the previous year averaging 23 vppg which is approximately 3-fold higher than the economic threshold for Russet Burbank (Table 6). Shank injection of metam sodium at both depths (dual injection at 6 & 10" vs 10" alone) significantly reduced Verticillium propagules, however, there were no difference in the levels of Vd between the injection depths (Table 6). Interestingly, in contrast to the previous year, the level of Verticillium inoculum was significantly lower when metam sodium was applied at 56F compared to 41F. Unfortunately, across metam sodium fumigation rates, 0 to 70 gal/a, the level of Verticillium propagules in fumigated plots after treatment were not significantly different than the non-fumigated control (Table 6).

When metam sodium was applied at 56F, the percent reduction of Verticillium inoculum in the 0-4" soil profile when the fumigant was injected at a single depth of 10" ranged from 83-89% and from 81-90% when injected at 6 and 10" (Table 7). Similarly, when metam sodium was applied the reductions in inoculum at the 4-8" depth ranged from 86 to 98% and 84-95% at the 10" and 6 and 10" injection depths, respectively. The percent reduction of Verticillium inoculum when metam sodium was injected at 41F was substantially lower than when the fumigant was injected at 56F, but these differences were not statistically significant (Table 7). Across all treatments, the percent reduction in Verticillium inoculum when metam sodium was injected at 56F ranged from 85 to 86% and only from 60-72% when injected at 41F, and these differences in inoculum reduction are statistically different (Table 7).

In 2016, metam sodium significantly reduced the development of Verticillium wilt compared to the non-fumigated control, however, there were no differences among rates of the fumigant (Table 8). All rates reduced the development Verticillium wilt similarly. As in previous years, there was no difference between shank injection depths and the efficacy of metam sodium in

controlling Verticillium wilt. A single injection depth of 10” controlled Verticillium wilt as well as a split application of 6 and 10” and the level of control was significantly better than the non-treated control. The temperature at which metam sodium was applied also had no effect on the development of Verticillium wilt (Table 8).

Soil fumigation with metam sodium significantly improved the total yield and marketable yield of Russet Burbank compared to the non-fumigated control (Table 9). However, there were no statistical difference in yield due to the rate of metam sodium applied. A rate of 40 gal/a produced total and marketable yield as high as higher rates of 50 to 70 gal/a (Table 9). There were also no significant differences in yield between the two methods of injection. Total and marketable yield of Russet Burbank grown in soil injected at a single depth of 10” yield similarly to soils injected with metam sodium at 6 and 10”. The temperature at the time of injection had no impact of total or marketable yield. However, tuber size (weight) was significantly higher in plots fumigated at 56F compared to 41F (Table 9). At 56F, the total percentage of tubers >10oz, 6-9oz, and >6 oz were significantly higher than those produced in soil fumigated at 41F. Concomitantly, in soil fumigated at 41F, the percentage of tubers less than 6oz was significantly higher than tubers produced in soil fumigated at 56F. In general, a similar trend was observed in the quality of those tubers. The grade analysis demonstrated that the percentage of US No. 1 potato tubers was significantly higher in the larger tubers when produced in soil fumigated at 56F compared to 41F (Table 10).

Summary

Results of the first year of this study suggest that the method by which a fine-textured soil with >2% organic matter is fumigated with metam sodium may be substantially different than what is recommended for coarse to medium textured sandy soils with <2% OM. In other words, with coarse textured soils, metam sodium fumigation at a single depth of 10” in relatively cold soils (<40F) will significantly improve efficacy. However, in finer textured soils, such as a silt loam, movement of metam sodium vertically and horizontally may be much slower suggesting that split applications at 6 and 10” may still be warranted to improve efficacy, particularly when soil populations of *V. dahliae* are extremely high, as they were in 2015 (124 vppg). Additionally, soil temperature at the time of fumigation may be less of a factor to improve efficacy in a finer textured silt loam soil compared to a sandy loam soil. It is interesting to note that in the previous studies we found there to be no rate response of metam sodium in low organic matter soils with a medium ‘sandy’ texture. In other words, a relatively low rate of 40 gal/a was as efficacious as higher rates of the soil fumigant. Based on a first year of this study, the same trend appears to be true for a finer textured soil with higher organic matter.

Results in the second year differed slightly from those in the first year, although there were many similarities. In both years of the study, the soil temperature at the time of metam sodium application did not affect disease development despite the fact that a significantly higher reduction of Verticillium soil populations occurred when soil was fumigated at 56F versus 41F. Although soil temperature at the time of fumigation had no effect on total or marketable yield, tubers produced in soil fumigated at warmer temperatures were larger than when fumigated at a colder temperature and had higher percentages of US No. 1’s. When these USDA grade size difference are applied to a French fry contract, they could result in a higher premium paid per hundredweight of potatoes.

The metam sodium rate used also had no impact on disease development and yield. A rate of 40 gal/a is as efficacious as any higher rate of the fumigant and is consistent with the first year of the study. Although there is some indication that splitting the metam sodium and injecting it at

6 and 10” depths will improve Verticillium reduction in the top soil profile (i.e., 0-4”), this increased efficacy in inoculum reduction did not improve disease control or yield of potato.

It is likely that any differences in the results we observed among treatments is due to the differences in Verticillium inoculum pressure between the two years. *V. dahliae* levels in 2015 were 5-fold higher than in 2016. As previously mentioned, the base level of inoculum in 2015 was so high that it likely negated much of the treatment effect we expect from soil fumigation. Therefore, in addition to knowing your soil type, as it pertains to level of organic matter and texture, it is recommended that soil testing be used to determine the level of Verticillium inoculum in those fields targeted for soil fumigation.

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Taylor, R. J., Pasche, J. S. and Gudmestad, N. C. 2005. Influence of tillage and method of metam sodium application on distribution and survival of *Verticillium dahliae* in the soil and the development of potato early dying disease. Am. J. Potato Res. 82:451-461.

Table 1. Verticillium propagules per gram of soil (Vppg) at two depths as impacted by metam sodium in 2015.

Injection Depth	Rate	Soil Temp.	Vppg					
			Fall 2014			Spring 2015		
			0-4"	4-8"	0-8"	0-4"	4-8"	0-8"
Control	0 gal / a	54 F	90.2	60.8	151.0	105.0	86.0	191.0
10 in	40 gal / a	54 F	77.8	59.0	136.8	47.0	10.0	57.0
10 in	50 gal / a	54 F	114.2	82.2	196.4	61.4	22.0	83.4
10 in	60 gal / a	54 F	91.8	76.8	168.6	55.8	30.2	86.0
10 in	70 gal / a	54 F	86.6	46.4	133.0	46.8	11.6	58.4
Control	0 gal / a	38 F	103.2	61.4	164.6	81.0	60.6	141.6
10 in	40 gal / a	38 F	68.4	39.0	107.4	39.0	11.4	50.4
10 in	50 gal / a	38 F	52.6	31.8	84.4	40.6	18.8	59.4
10 in	60 gal / a	38 F	89.6	55.2	144.8	34.4	6.4	40.8
10 in	70 gal / a	38 F	91.2	34.6	125.8	35.8	18.4	54.2
Control	0 gal / a	54 F	85.6	63.2	148.8	35.6	37.6	73.2
6 in +10 in	40 gal / a	54 F	71.8	67.6	139.4	25.0	9.6	34.6
6 in +10 in	50 gal / a	54 F	96.8	51.6	148.4	29.2	6.6	35.8
6 in +10 in	60 gal / a	54 F	95.8	61.8	157.6	22.6	9.8	32.4
6 in +10 in	70 gal / a	54 F	95.4	49.2	144.6	37.4	3.2	40.6
Control	0 gal / a	38 F	84.8	40.0	124.8	53.6	36.2	89.8
6 in +10 in	40 gal / a	38 F	80.4	40.4	120.8	22.2	7.0	29.2
6 in +10 in	50 gal / a	38 F	77.8	44.6	122.4	20.2	4.0	24.2
6 in +10 in	60 gal / a	38 F	67.4	32.6	100.0	22.2	8.6	30.8
6 in +10 in	70 gal / a	38 F	53.8	38.8	92.6	13.0	5.8	18.8
$LSD_{P = 0.05}$			NS	NS	NS	NS	32.4	72.7
Control			91.0	56.4	147.3	68.8	55.1	123.9
10 in			84.0	53.1	137.2	45.1	16.1	61.2
6 in +10 in			79.9	48.3	128.2	24.0	6.8	30.8
$LSD_{P = 0.05}$			NS	NS	NS	17.6	12.9	29.0
	0 gal / a		91.0	56.4	147.3	68.8	55.1	123.9
	40 gal / a		74.6	51.5	126.1	33.3	9.5	42.8
	50 gal / a		85.4	52.6	137.9	37.9	12.9	50.7
	60 gal / a		86.2	56.6	142.8	33.8	13.8	47.5
	70 gal / a		81.8	42.3	124.0	33.3	9.8	43.0
$LSD_{P = 0.05}$			NS	NS	NS	24.4	16.9	39.4
		54 F	90.6	61.9	152.5	46.6	22.7	69.2
		38 F	76.9	41.8	118.8	36.2	17.7	53.9
$LSD_{P = 0.05}$			NS	10.3	20.7	NS	NS	NS

Early = 1st Fumigation on 10/15/2014 Late = 2nd Fumigation on 11/5/2014

Table 2. Percent reduction of Verticillium propagules per gram of soil (Vppg) at two depths as impacted by metam sodium in 2015.

Injection Depth	Rate	Timing	Vppg			
			Percentage Reduction			
			0-4"	t Grouping	4-8"	t Grouping
Control	0 gal / a	54 F	-0.14	D	-0.40	D
10 in	40 gal / a	54 F	0.33	ABCD	0.83	A
10 in	50 gal / a	54 F	0.43	ABCD	0.74	A
10 in	60 gal / a	54 F	0.39	ABCD	0.59	A
10 in	70 gal / a	54 F	0.46	ABCD	0.70	A
Control	0 gal / a	38 F	0.12	BCD	-0.11	BCD
10 in	40 gal / a	38 F	0.25	ABCD	0.70	A
10 in	50 gal / a	38 F	-0.05	CD	0.42	ABC
10 in	60 gal / a	38 F	0.61	AB	0.85	A
10 in	70 gal / a	38 F	0.58	ABC	0.53	ABC
Control	0 gal / a	54 F	0.60	AB	0.39	ABCD
6 in +10 in	40 gal / a	54 F	0.67	AB	0.86	A
6 in +10 in	50 gal / a	54 F	0.68	AB	0.87	A
6 in +10 in	60 gal / a	54 F	0.77	A	0.84	A
6 in +10 in	70 gal / a	54 F	0.61	AB	0.93	A
Control	0 gal / a	38 F	0.37	ABCD	-0.23	CD
6 in +10 in	40 gal / a	38 F	0.72	AB	0.83	A
6 in +10 in	50 gal / a	38 F	0.71	AB	0.91	A
6 in +10 in	60 gal / a	38 F	0.65	AB	0.75	A
6 in +10 in	70 gal / a	38 F	0.76	A	0.83	A
$LSD_{P = 0.05}$			NS		NS	
Control			0.24	B	-0.09	B
10 in			0.38	B	0.67	A
6 in +10 in			0.69	A	0.85	A
$LSD_{P = 0.05}$			0.24		0.27	
	0 gal / a		0.24	B	-0.09	B
	40 gal / a		0.49	AB	0.80	A
	50 gal / a		0.44	AB	0.73	A
	60 gal / a		0.61	A	0.76	A
	70 gal / a		0.60	A	0.75	A
$LSD_{P = 0.05}$			NS		0.35	
		54 F	0.48	A	0.48	A
		38 F	0.47	A	0.47	A
$LSD_{P = 0.05}$			NS		NS	

Early = 1st Fumigation on 10/15/2014 Late = 2nd Fumigation on 11/5/2014

Table 3. Impact of metam sodium on Verticillium wilt development in 2015.

Injection Depth	Rate	Soil Temp.	Wilt (% Severity)								AUDPC	RAUDPC
			7/23	7/30	8/6	8/12	8/20	8/26	9/2	9/8		
Control	0 gal / a	54 F	1.10	2.46	6.99	45.96	56.96	89.45	99.57	100.00	960.5	0.20436
10 in	40 gal / a	54 F	0.29	0.53	5.13	11.79	14.90	41.18	82.60	98.42	961.04	0.20448
10 in	50 gal / a	54 F	0.42	0.49	3.98	20.55	21.78	51.14	88.92	98.25	646.35	0.13752
10 in	60 gal / a	54 F	1.28	0.58	4.19	21.51	21.50	46.63	77.50	100.00	282.61	0.06013
10 in	70 gal / a	54 F	0.23	0.42	3.81	15.05	18.03	30.36	66.94	91.63	1035.88	0.2204
Control	0 gal / a	38 F	2.36	2.01	13.33	53.97	83.71	97.17	100.00	100.00	1418.07	0.30172
10 in	40 gal / a	38 F	0.31	0.81	3.98	15.68	22.93	32.19	77.00	95.97	1140.14	0.24258
10 in	50 gal / a	38 F	0.23	0.65	3.75	11.23	17.90	37.29	71.89	89.36	1064.58	0.22651
10 in	60 gal / a	38 F	0.40	0.37	3.51	13.65	14.54	27.43	70.33	93.75	467.72	0.09951
10 in	70 gal / a	38 F	0.45	0.55	3.86	18.51	25.29	37.62	62.86	84.55	851.82	0.18124
Control	0 gal / a	54 F	1.63	1.16	11.71	34.29	34.80	84.82	100.00	100.00	1153.51	0.24543
6 in +10 in	40 gal / a	54 F	0.86	0.66	3.55	12.79	21.62	27.71	75.00	100.00	298.92	0.0636
6 in +10 in	50 gal / a	54 F	0.40	0.68	3.43	15.32	26.75	39.43	87.74	98.27	799.5	0.17011
6 in +10 in	60 gal / a	54 F	0.29	0.52	4.80	16.97	21.18	47.72	85.09	97.25	915.93	0.19488
6 in +10 in	70 gal / a	54 F	0.21	0.35	3.85	11.93	15.04	30.66	73.21	97.08	601.55	0.12799
Control	0 gal / a	38 F	0.34	1.07	4.80	16.70	17.93	73.33	98.00	100.00	735.27	0.15644
6 in +10 in	40 gal / a	38 F	0.27	0.41	3.14	17.81	17.15	38.99	83.13	96.25	612.32	0.13028
6 in +10 in	50 gal / a	38 F	0.35	0.37	2.43	11.17	15.03	24.72	38.25	75.05	477.58	0.10161
6 in +10 in	60 gal / a	38 F	0.19	0.29	2.43	10.54	12.24	23.22	59.70	86.31	476.77	0.10144
6 in +10 in	70 gal / a	38 F	0.21	0.38	3.88	17.06	16.13	26.83	62.73	89.43	452.9	0.09636
$LSD_{P = 0.05}$			0.32	0.31	1.56	5.90	7.96	12.37	12.56	3.81	492.57	0.10
Control			1.35	1.69	9.58	42.91	54.94	89.84	99.19	100.00	1096.54	0.23
10 in			0.45	0.55	4.02	15.63	19.84	37.06	73.42	94.35	799.61	0.17
6 in +10 in			0.35	0.46	3.47	14.88	18.12	34.02	70.60	93.20	577.93	0.12
$LSD_{P = 0.05}$			0.24	0.19	1.11	4.46	6.77	8.03	7.33	3.14	210.36	0.04
	0 gal / a		1.35	1.69	9.58	42.91	54.94	89.84	99.19	100.00	1096.54	0.23
	40 gal / a		0.44	0.61	3.98	14.63	18.99	36.59	79.91	98.03	750.11	0.16
	50 gal / a		0.35	0.54	3.45	15.02	20.00	37.90	70.22	89.42	747.00	0.16
	60 gal / a		0.73	0.51	4.33	17.23	21.11	44.48	76.82	97.36	599.87	0.13
	70 gal / a		0.28	0.40	3.59	15.25	17.56	30.52	66.92	90.62	640.04	0.14
$LSD_{P = 0.05}$			0.30	0.24	1.41	5.50	8.18	9.64	9.61	3.65	274.58	0.06
		54 F	0.66	0.78	5.02	20.17	23.25	46.87	83.82	98.43	781.60	0.17
		38 F	0.51	0.69	4.55	18.94	24.73	40.77	73.71	91.55	781.60	0.17
$LSD_{P = 0.05}$			NS	NS	NS	NS	NS	NS	6.96	2.47	NS	NS

Early = 1st Fumigation on 10/15/2014 Late = 2nd Fumigation on 11/5/2014

Table 4. Impact of metam sodium on potato yield and grade in 2015.

Injection Depth	Rate	Soil Temp.	Total Yield (cwt/a)	Market Yield (cwt/a)	Total >10 oz. (%)	Total 6 - 9 oz. (%)	Total >6 oz. (%)	Total 3 - 6 oz (%)	Specific Gravity
Control	0 gal / a	54 F	302.15	278.52	8.67	35.79	44.46	47.75	1.078
10 in	40 gal / a	54 F	443.02	422.51	23.48	42.67	66.15	29.21	1.083
10 in	50 gal / a	54 F	424.13	393.82	17.82	42.92	60.74	32.22	1.084
10 in	60 gal / a	54 F	402.79	374.45	12.35	44.99	57.34	35.52	1.085
10 in	70 gal / a	54 F	460.47	428.33	20.12	43.42	63.54	29.23	1.086
Control	0 gal / a	38 F	342.56	312.02	8.40	36.95	45.35	45.68	1.083
10 in	40 gal / a	38 F	431.92	395.43	23.85	38.16	62.01	29.21	1.084
10 in	50 gal / a	38 F	459.77	428.45	22.89	38.57	61.46	31.75	1.084
10 in	60 gal / a	38 F	465.29	420.48	18.31	38.99	57.30	33.02	1.087
10 in	70 gal / a	38 F	429.77	394.74	19.25	40.37	59.62	32.05	1.087
Control	0 gal / a	54 F	292.79	246.24	7.24	32.52	39.76	43.24	1.080
6 in +10 in	40 gal / a	54 F	404.59	376.08	16.11	41.59	57.70	35.02	1.085
6 in +10 in	50 gal / a	54 F	467.04	434.26	23.78	40.68	64.45	28.58	1.085
6 in +10 in	60 gal / a	54 F	424.54	393.53	21.08	39.63	60.71	31.91	1.085
6 in +10 in	70 gal / a	54 F	481.11	454.96	18.01	46.31	64.32	30.22	1.086
Control	0 gal / a	38 F	377.56	344.32	15.72	36.46	52.17	38.99	1.081
6 in +10 in	40 gal / a	38 F	487.33	464.07	23.12	43.44	66.56	28.66	1.088
6 in +10 in	50 gal / a	38 F	481.46	444.11	25.53	40.85	66.38	25.86	1.087
6 in +10 in	60 gal / a	38 F	512.33	482.30	24.83	42.66	67.49	26.65	1.087
6 in +10 in	70 gal / a	38 F	480.93	439.76	16.09	39.62	55.70	35.75	1.089
$LSD_{P=0.05}$			97.23	104.08	NS	NS	NS	NS	NS
Control			328.76	295.28	10.00	35.43	45.43	43.91	1.080
10 in			439.64	407.27	19.76	41.26	61.02	31.52	1.085
6 in +10 in			467.41	436.13	21.07	41.85	62.91	30.33	1.086
$LSD_{P=0.05}$			37.59	39.27	5.85	3.03	6.86	5.54	0.002
	0 gal / a		328.76	295.28	10.00	35.43	45.43	43.91	1.080
	40 gal / a		441.72	414.52	21.64	41.46	63.10	30.52	1.085
	50 gal / a		458.10	425.16	22.50	40.75	63.25	29.60	1.085
	60 gal / a		451.24	417.69	19.14	41.57	60.71	31.77	1.086
	70 gal / a		463.07	429.44	18.37	42.43	60.79	31.81	1.087
$LSD_{P=0.05}$			48.77	51.26	7.22	3.80	8.63	6.97	0.003
		54 F	410.26	380.27	16.87	41.05	57.92	34.29	1.083
		38 F	446.89	412.57	19.80	39.61	59.40	32.76	1.086
$LSD_{P=0.05}$			NS	NS	NS	NS	NS	NS	NS

Early = 1st Fumigation on 10/15/2014 Late = 2nd Fumigation on 11/5/2014

Table 5. Impact of metam sodium on potato yield and grade in 2015.

Injection Depth	Rate	Soil Temp.	>10 oz. (%)		6 - 9 oz. (%)		3 - 6 oz (%)		Unusables (%)			
			US No. 1	US No. 2	US No. 1	US No. 2	US No. 1	US No. 2	Total	Under-size	Hollow Heart	Other
Control	0 gal / a	54 F	7.85	0.82	33.34	2.46	43.50	4.26	7.79	7.40	0.00	0.40
10 in	40 gal / a	54 F	22.37	1.11	39.98	2.69	27.15	2.06	4.65	4.49	0.00	0.16
10 in	50 gal / a	54 F	17.05	0.77	40.61	2.31	30.29	1.94	7.04	4.97	1.93	0.15
10 in	60 gal / a	54 F	12.11	0.24	42.88	2.11	33.83	1.69	7.15	6.82	0.17	0.16
10 in	70 gal / a	54 F	19.05	1.08	41.90	1.52	27.62	1.61	7.23	4.74	2.25	0.24
Control	0 gal / a	38 F	8.10	0.30	34.98	1.97	43.69	1.99	8.98	8.04	0.65	0.29
10 in	40 gal / a	38 F	21.90	1.95	36.97	1.19	27.81	1.40	8.80	7.04	1.31	0.46
10 in	50 gal / a	38 F	21.79	1.10	36.50	2.08	29.85	1.90	6.81	5.65	0.88	0.28
10 in	60 gal / a	38 F	15.79	2.52	36.76	2.24	31.43	1.59	9.69	6.87	2.43	0.39
10 in	70 gal / a	38 F	16.33	2.92	37.92	2.46	30.09	1.96	8.33	4.70	3.26	0.37
Control	0 gal / a	54 F	6.84	0.40	29.99	2.54	41.33	1.91	17.01	14.27	0.00	2.74
6 in +10 in	40 gal / a	54 F	14.05	2.07	39.24	2.35	33.39	1.63	7.30	5.90	1.29	0.12
6 in +10 in	50 gal / a	54 F	20.46	3.32	38.76	1.92	26.91	1.68	6.98	4.98	1.47	0.53
6 in +10 in	60 gal / a	54 F	18.60	2.48	37.84	1.80	30.15	1.76	7.39	5.24	1.85	0.30
6 in +10 in	70 gal / a	54 F	17.03	0.98	44.09	2.22	28.21	2.02	5.45	5.15	0.00	0.30
Control	0 gal / a	38 F	14.29	1.43	34.42	2.04	36.95	2.04	8.84	7.35	1.39	0.10
6 in +10 in	40 gal / a	38 F	21.75	1.37	40.97	2.47	26.62	2.04	4.78	4.57	0.00	0.21
6 in +10 in	50 gal / a	38 F	23.84	1.70	38.34	2.51	24.50	1.37	7.76	4.47	2.99	0.30
6 in +10 in	60 gal / a	38 F	23.20	1.63	39.94	2.72	25.07	1.58	5.88	4.44	1.16	0.28
6 in +10 in	70 gal / a	38 F	15.77	0.32	37.90	1.72	34.08	1.67	8.56	6.91	0.40	1.26
$LSD_{P = 0.05}$			NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Control			9.27	0.74	33.18	2.25	41.36	2.55	10.65	9.26	0.51	0.88
10 in			18.30	1.46	39.19	2.07	29.76	1.77	7.46	5.66	1.53	0.27
6 in +10 in			19.34	1.73	39.63	2.21	28.61	1.72	6.76	5.21	1.14	0.41
$LSD_{P = 0.05}$			5.37	NS	2.93	NS	5.46	0.55	2.47	2.44	3.08	NS
	0 gal / a		9.27	0.74	33.18	2.25	41.36	2.55	10.65	9.26	0.51	0.88
	40 gal / a		20.02	1.62	39.29	2.18	28.74	1.78	6.38	5.50	0.65	0.24
	50 gal / a		20.78	1.72	38.55	2.20	27.88	1.72	7.15	5.02	1.82	0.31
	60 gal / a		17.43	1.72	39.35	2.22	30.12	1.65	7.52	5.84	1.40	0.28
	70 gal / a		17.04	1.32	40.45	1.98	30.00	1.81	7.39	5.37	1.48	0.54
$LSD_{P = 0.05}$			6.61	NS	3.65	NS	6.86	0.69	3.11	NS	NS	NS
		54 F	15.54	1.33	38.86	2.19	32.24	2.05	7.80	6.39	0.90	0.51
		38 F	18.27	1.52	37.47	2.14	31.01	1.75	7.84	6.00	1.45	0.39
$LSD_{P = 0.05}$			NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Early = 1st Fumigation on 10/15/2014 Late = 2nd Fumigation on 11/5/2014

Table 6. Verticillium propagules per gram of soil (Vppg) at two depths as impacted by metam sodium in 2016.

Injection Depth	Rate	Soil Temp.	Vppg					
			Fall 2015			Spring 2016		
			0-4"	4-8"	0-8"	0-4"	4-8"	0-8"
Control	0 gal / a	56 F	17.4	28.6	46.0	7.6	3.2	10.8
10 in	40 gal / a	56 F	20.2	20.8	41.0	3.2	1.8	5.0
10 in	50 gal / a	56 F	37.2	18.8	56.0	3.4	1.8	5.2
10 in	60 gal / a	56 F	40.4	19.2	59.6	4.2	0.8	5.0
10 in	70 gal / a	56 F	25.4	32.0	57.4	1.8	0.8	2.6
Control	0 gal / a	41 F	39.4	22.0	61.4	25.4	8.8	34.2
10 in	40 gal / a	41 F	19.0	25.0	44.0	11.2	1.0	12.2
10 in	50 gal / a	41 F	20.6	18.0	38.6	11.2	4.4	15.6
10 in	60 gal / a	41 F	30.4	13.6	44.0	16.8	3.2	20.0
10 in	70 gal / a	41 F	27.0	19.6	46.6	14.4	11.0	25.4
Control	0 gal / a	56 F	37.0	19.2	56.2	10.0	9.0	19.0
6 in +10 in	40 gal / a	56 F	29.0	20.6	49.6	3.8	4.0	7.8
6 in +10 in	50 gal / a	56 F	27.4	22.4	49.8	4.8	2.4	7.2
6 in +10 in	60 gal / a	56 F	41.0	19.0	60.0	4.0	3.0	7.0
6 in +10 in	70 gal / a	56 F	39.6	26.0	65.6	4.6	1.2	5.8
Control	0 gal / a	41 F	40.2	21.2	61.4	17.2	10.8	28.0
6 in +10 in	40 gal / a	41 F	46.2	25.2	71.4	20.6	3.2	23.8
6 in +10 in	50 gal / a	41 F	41.2	18.0	59.2	11.2	1.6	12.8
6 in +10 in	60 gal / a	41 F	35.8	13.6	49.4	9.4	1.2	10.6
6 in +10 in	70 gal / a	41 F	29.8	15.8	45.6	11.4	1.0	12.4
$LSD_{P = 0.05}$			NS	NS	NS	NS	NS	NS
Control			33.5	22.8	56.3	15.1	8.0	23.0
10 in			27.5	20.9	48.4	8.3	3.1	11.4
6 in +10 in			36.3	20.1	56.3	8.7	2.2	10.9
$LSD_{P = 0.05}$			NS	NS	NS	NS	3.8	8.5
	0 gal / a		33.5	22.8	56.3	15.1	8.0	23.0
	40 gal / a		28.6	22.9	51.5	9.7	2.5	12.2
	50 gal / a		31.6	19.3	50.9	7.7	2.6	10.2
	60 gal / a		36.9	16.4	53.3	8.6	2.1	10.7
	70 gal / a		30.5	23.4	53.8	8.1	3.5	11.6
$LSD_{P = 0.05}$			NS	NS	NS	NS	NS	NS
		56 F	31.5	22.7	54.1	4.7	2.8	7.5
		41 F	33.0	19.2	52.2	14.9	4.6	19.5
$LSD_{P = 0.05}$			NS	NS	NS	4.3	NS	6.0

Early = 1st Fumigation on 10/19/2015 Late = 2nd Fumigation on 11/11/2015

Table 7. Percent reduction of Verticillium propagules per gram of soil (Vppg) at two depths as impacted by metam sodium in 2016.

Injection Depth	Rate	Soil Temp.	Vppg			
			Percentage Reduction			
			0-4"	t Grouping	4-8"	t Grouping
Control	0 gal / a	56 F	0.51	AB	0.85	A
10 in	40 gal / a	56 F	0.83	A	0.91	A
10 in	50 gal / a	56 F	0.85	A	0.89	A
10 in	60 gal / a	56 F	0.84	A	0.86	A
10 in	70 gal / a	56 F	0.89	A	0.98	A
Control	0 gal / a	41 F	0.43	AB	0.62	A
10 in	40 gal / a	41 F	0.39	AB	0.97	A
10 in	50 gal / a	41 F	0.25	B	0.81	A
10 in	60 gal / a	41 F	0.49	AB	0.37	A
10 in	70 gal / a	41 F	0.47	AB	0.42	A
Control	0 gal / a	56 F	0.73	AB	0.58	A
6 in +10 in	40 gal / a	56 F	0.87	A	0.84	A
6 in +10 in	50 gal / a	56 F	0.81	AB	0.87	A
6 in +10 in	60 gal / a	56 F	0.90	A	0.82	A
6 in +10 in	70 gal / a	56 F	0.88	A	0.95	A
Control	0 gal / a	41 F	0.50	AB	0.39	A
6 in +10 in	40 gal / a	41 F	0.55	AB	0.83	A
6 in +10 in	50 gal / a	41 F	0.71	AB	0.89	A
6 in +10 in	60 gal / a	41 F	0.72	AB	0.91	A
6 in +10 in	70 gal / a	41 F	0.57	AB	0.94	A
$LSD_{P = 0.05}$			NS		NS	

			0-4"	t Grouping	4-8"	t Grouping	0-8"	t Grouping
Control			0.54	A	0.61	B	0.60	B
10 in			0.63	A	0.78	AB	0.71	AB
6 in +10 in			0.75	A	0.88	A	0.80	A
$LSD_{P = 0.05}$			NS		NS		NS	
	0 gal / a		0.54	A	0.61	A	0.60	A
	40 gal / a		0.66	A	0.89	A	0.76	A
	50 gal / a		0.66	A	0.87	A	0.74	A
	60 gal / a		0.74	A	0.74	A	0.76	A
	70 gal / a		0.70	A	0.82	A	0.76	A
$LSD_{P = 0.05}$			NS		NS		NS	
		56 F	0.81	A	0.86	A	0.85	A
		41 F	0.51	A	0.72	A	0.60	B
$LSD_{P = 0.05}$			NS		NS		0.11	

Early = 1st Fumigation on 10/19/2015 Late = 2nd Fumigation on 11/11/2015

Table 8. Impact of metam sodium on Verticillium wilt development in 2016.

Injection Depth	Rate	Soil Temp.	Wilt (% Severity)							AUDPC	RAUDPC
			7/21	7/28	8/4	8/15	8/24	9/1	9/9		
Control	0 gal / a	56 F	3.61	4.23	6.30	10.37	12.05	34.34	98.48	929.83	0.1860
10 in	40 gal / a	56 F	1.32	2.78	4.75	7.58	9.03	17.13	90.81	611.77	0.1224
10 in	50 gal / a	56 F	2.35	3.33	5.58	7.95	9.16	17.63	90.85	660.14	0.1320
10 in	60 gal / a	56 F	1.76	2.85	4.83	7.31	8.21	15.18	83.55	610.52	0.1221
10 in	70 gal / a	56 F	1.39	2.90	4.85	7.59	8.69	16.00	75.55	576.46	0.1153
Control	0 gal / a	41 F	2.95	3.85	6.15	9.61	11.76	38.44	97.71	612.75	0.1226
10 in	40 gal / a	41 F	1.68	3.20	4.68	7.55	8.55	18.80	93.96	705.79	0.1412
10 in	50 gal / a	41 F	1.96	3.20	4.58	7.84	9.29	20.85	96.95	600.09	0.1200
10 in	60 gal / a	41 F	1.98	3.13	5.08	7.11	9.34	22.90	93.93	707.83	0.1416
10 in	70 gal / a	41 F	2.41	2.85	4.55	7.44	8.92	19.22	90.90	592.54	0.1185
Control	0 gal / a	56 F	2.18	3.41	5.78	7.59	9.67	29.11	89.20	508.30	0.1017
6 in +10 in	40 gal / a	56 F	1.35	2.73	4.60	7.65	8.97	17.69	93.58	668.71	0.1337
6 in +10 in	50 gal / a	56 F	1.34	2.80	4.28	7.16	8.58	16.13	85.94	547.49	0.1095
6 in +10 in	60 gal / a	56 F	1.61	2.74	5.68	7.38	8.72	15.44	89.71	654.23	0.1309
6 in +10 in	70 gal / a	56 F	1.14	2.80	4.53	7.05	8.19	13.33	90.18	543.19	0.1086
Control	0 gal / a	41 F	2.70	3.70	6.20	10.10	14.72	36.94	98.43	1002.43	0.2005
6 in +10 in	40 gal / a	41 F	1.31	2.63	4.70	7.21	9.18	23.53	96.00	690.30	0.1381
6 in +10 in	50 gal / a	41 F	2.09	2.85	4.60	7.06	8.97	25.74	90.80	566.36	0.1133
6 in +10 in	60 gal / a	41 F	1.24	2.68	4.65	7.08	8.80	19.20	81.52	597.34	0.1195
6 in +10 in	70 gal / a	41 F	1.56	2.83	4.18	7.15	8.55	17.64	91.59	715.36	0.1431
$LSD_{P = 0.05}$			0.55	0.37	0.76	0.66	1.33	5.14	5.44	221.16	0.0442
Control			2.86	3.80	6.11	9.43	12.29	36.98	97.70	763.33	0.1500
10 in			1.86	3.03	4.85	7.52	8.88	18.48	88.41	633.14	0.1250
6 in +10 in			1.44	2.73	4.60	7.11	8.64	18.16	89.14	622.87	0.1250
$LSD_{P = 0.05}$			0.38	0.24	2.39	0.48	0.95	3.28	5.47	94.11	0.0188
	0 gal / a		2.86	3.80	6.11	9.43	12.29	36.98	97.70	763.33	0.1527
	40 gal / a		1.39	2.77	4.58	7.28	8.73	19.17	90.81	669.14	0.1338
	50 gal / a		1.93	3.04	4.74	7.39	8.89	19.27	89.07	593.52	0.1187
	60 gal / a		1.67	2.84	5.19	7.29	8.60	16.25	88.34	648.45	0.1297
	70 gal / a		1.62	2.85	4.64	7.29	8.77	17.79	87.25	615.67	0.1230
$LSD_{P = 0.05}$			0.50	0.31	0.50	0.63	1.23	4.08	6.80	121.01	0.0242
		56 F	1.80	3.03	5.08	7.72	9.14	19.67	88.54	631.07	0.1262
		41 F	1.99	3.09	4.93	7.76	9.76	23.31	92.13	679.08	0.1358
$LSD_{P = 0.05}$			NS	NS	NS	NS	NS	3.11	NS	NS	NS

Early = 1st Fumigation on 10/19/2015 Late = 2nd Fumigation on 11/11/2015

Table 9. Impact of metam sodium on potato yield and grade in 2016.

Injection Depth	Rate	Soil Temp.	Total Yield (cwt/a)	Market Yield (cwt/a)	Total >10 oz. (%)	Total 6 - 9 oz. (%)	Total >6 oz. (%)	Total 4 - 6 oz. (%)	Specific Gravity
Control	0 gal / a	56 F	430.58	300.43	7.75	26.80	34.55	35.25	1.081
10 in	40 gal / a	56 F	540.87	417.29	11.90	34.05	45.95	31.20	1.088
10 in	50 gal / a	56 F	526.28	399.73	8.50	34.35	42.85	33.25	1.086
10 in	60 gal / a	56 F	537.56	416.13	8.70	33.25	41.95	35.50	1.088
10 in	70 gal / a	56 F	555.76	437.03	12.10	34.65	46.75	31.80	1.081
Control	0 gal / a	41 F	483.84	356.64	4.55	27.45	32.00	41.70	1.081
10 in	40 gal / a	41 F	510.70	371.21	6.05	31.55	37.60	35.10	1.087
10 in	50 gal / a	41 F	514.95	381.27	8.45	27.70	36.15	38.05	1.083
10 in	60 gal / a	41 F	499.77	381.39	7.55	30.50	38.05	38.45	1.083
10 in	70 gal / a	41 F	501.40	376.75	5.00	29.40	34.40	40.85	1.085
Control	0 gal / a	56 F	450.41	331.72	4.60	30.75	35.35	38.25	1.083
6 in +10 in	40 gal / a	56 F	500.76	391.86	10.75	34.10	44.85	33.40	1.087
6 in +10 in	50 gal / a	56 F	521.34	402.78	7.35	35.85	43.20	34.15	1.083
6 in +10 in	60 gal / a	56 F	515.76	405.90	10.90	35.50	46.40	32.10	1.086
6 in +10 in	70 gal / a	56 F	521.34	406.89	8.25	34.50	42.75	35.25	1.084
Control	0 gal / a	41 F	482.97	347.95	8.50	32.05	40.55	31.45	1.079
6 in +10 in	40 gal / a	41 F	508.14	370.94	4.60	29.00	33.60	39.25	1.090
6 in +10 in	50 gal / a	41 F	495.87	373.36	6.40	30.50	36.90	38.45	1.083
6 in +10 in	60 gal / a	41 F	518.73	396.94	7.65	29.60	37.25	39.40	1.085
6 in +10 in	70 gal / a	41 F	501.40	382.95	8.20	30.40	38.60	37.50	1.080
$LSD_{P = 0.05}$			NS	57.88	NS	NS	5.97	NS	NS
Control			461.95	334.18	6.35	29.26	35.61	36.66	1.081
10 in			523.41	397.60	8.53	31.93	40.46	35.53	1.085
6 in +10 in			510.41	391.45	8.01	32.43	40.44	36.19	1.085
$LSD_{P = 0.05}$			22.93	23.48	NS	NS	NS	NS	0.003
	0 gal / a		461.95	334.18	6.35	29.26	35.61	36.66	1.081
	40 gal / a		515.12	387.82	8.33	32.18	40.50	34.74	1.088
	50 gal / a		514.61	389.28	7.68	32.10	39.78	35.98	1.084
	60 gal / a		517.95	400.09	8.70	32.21	40.91	36.36	1.085
	70 gal / a		519.97	400.90	8.39	32.24	40.63	36.35	1.082
$LSD_{P = 0.05}$			29.58	29.22	NS	NS	NS	NS	0.003
		56 F	510.06	390.97	9.08	33.38	42.46	34.02	1.084
		41 F	501.77	373.94	6.70	29.82	36.51	38.02	1.083
$LSD_{P = 0.05}$			NS	NS	1.92	1.96	3.15	2.08	NS

Early = 1st Fumigation on 10/19/2015 Late = 2nd Fumigation on 11/11/2015

Table 10. Impact of metam sodium on potato yield and grade in 2016.

Injection Depth	Rate	Soil Temp.	>10 oz. (%)		6 - 9 oz. (%)		4 - 6 oz (%)		Unusables (%)			
			US No. 1	US No. 2	US No. 1	US No. 2	US No. 1	US No. 2	Total	Under-size	Hollow Heart	Other
Control	0 gal / a	56 F	6.25	1.50	24.30	2.50	33.85	1.40	30.20	23.40	0.35	6.45
10 in	40 gal / a	56 F	11.25	0.65	32.75	1.30	30.40	0.80	22.85	21.00	0.40	1.45
10 in	50 gal / a	56 F	7.90	0.60	32.95	1.40	32.70	0.55	23.90	22.00	0.00	1.90
10 in	60 gal / a	56 F	7.90	0.80	31.90	1.35	33.90	1.60	22.55	21.35	0.50	0.70
10 in	70 gal / a	56 F	11.40	0.70	33.65	1.00	30.80	1.00	21.35	19.70	0.35	1.30
Control	0 gal / a	41 F	4.55	0.00	26.70	0.75	41.10	0.60	26.30	25.65	0.00	0.65
10 in	40 gal / a	41 F	5.40	0.65	30.45	1.10	34.10	1.00	27.35	26.25	0.00	1.10
10 in	50 gal / a	41 F	7.70	0.75	26.60	1.10	37.20	0.85	25.80	23.10	0.75	1.95
10 in	60 gal / a	41 F	6.95	0.60	29.45	1.05	37.35	1.10	23.60	22.35	0.25	1.00
10 in	70 gal / a	41 F	4.65	0.35	28.20	1.20	40.00	0.85	24.80	23.20	0.75	0.85
Control	0 gal / a	56 F	4.35	0.25	30.05	0.70	37.75	0.50	26.35	24.00	0.60	1.75
6 in +10 in	40 gal / a	56 F	9.65	1.10	32.50	1.60	32.40	1.00	21.75	20.55	0.30	0.90
6 in +10 in	50 gal / a	56 F	6.55	0.80	34.30	1.55	33.10	1.05	22.75	21.65	0.25	0.85
6 in +10 in	60 gal / a	56 F	9.80	1.10	33.65	1.85	31.40	0.70	21.55	20.15	0.85	0.55
6 in +10 in	70 gal / a	56 F	7.90	0.35	32.75	1.75	34.55	0.70	22.00	20.05	0.25	1.70
Control	0 gal / a	41 F	7.05	1.45	30.05	2.00	30.45	1.00	27.95	24.20	0.15	3.60
6 in +10 in	40 gal / a	41 F	4.00	0.60	27.80	1.20	38.55	0.70	27.00	26.25	0.00	0.75
6 in +10 in	50 gal / a	41 F	5.60	0.80	28.85	1.65	37.05	1.40	24.75	23.40	0.00	1.35
6 in +10 in	60 gal / a	41 F	7.55	0.10	29.00	0.60	38.80	0.60	23.40	22.50	0.20	0.70
6 in +10 in	70 gal / a	41 F	7.30	0.90	29.35	1.05	36.50	1.00	23.85	19.15	0.35	4.35
$LSD_{P=0.05}$			NS	NS	NS	NS	5.89	NS	NS	NS	NS	NS
Control			5.55	0.80	27.78	1.49	35.79	0.88	27.70	24.31	0.28	3.11
10 in			7.89	0.64	30.74	1.19	34.56	0.97	24.03	22.37	0.38	1.28
6 in +10 in			7.29	0.72	31.03	1.41	35.29	0.89	23.38	21.71	0.28	1.39
$LSD_{P=0.05}$			NS	NS	NS	NS	NS	NS	2.27	NS	NS	NS
	0 gal / a		5.55	0.80	27.78	1.49	35.79	0.88	27.70	24.31	0.28	3.11
	40 gal / a		7.58	0.75	30.88	1.30	33.86	0.88	24.74	23.51	0.18	1.05
	50 gal / a		6.94	0.74	30.68	1.43	35.01	0.96	24.30	22.54	0.25	1.51
	60 gal / a		8.05	0.65	31.00	1.21	35.36	1.00	22.78	21.59	0.45	0.74
	70 gal / a		7.81	0.58	30.99	1.25	35.46	0.89	23.00	20.53	0.43	2.05
$LSD_{P=0.05}$			NS	NS	NS	NS	NS	NS	2.76	NS	NS	NS
		56 F	8.30	0.79	31.88	1.50	33.09	0.93	23.53	21.39	0.39	1.76
		41 F	6.08	0.62	28.65	1.17	37.11	0.91	25.48	23.61	0.25	1.63
$LSD_{P=0.05}$			1.82	NS	2.06	NS	2.10	NS	NS	NS	NS	NS

Early = 1st Fumigation on 10/19/2015 Late = 2nd Fumigation on 11/11/2015

Minimizing Phytotoxicity and Quantify Efficacy of Phosphorous Acid
Submitted to the MN Area II and NPPGA

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Executive Summary

Phosphorous acid is commonly used as a method to reduce pink rot of potatoes in storage. Some of the challenges of using this product are that it burns leaves when foliar applied. Data indicate that this foliar damage can be reduced by adjuvants, but injury is still too high for grower acceptance. Additional data indicate that foliar treatments likely increase the amount of phosphites in tubers. This study evaluated the effects of various phosphorous acid products on plant injury, but no significant injury was observed in 2015 or 2016. Another study found differences in timing and rates of phosphorous acid treatments applied foliar on Russet Burbank. From these studies, the data suggestions that multiple applications of 5-7 pt/a of phosphoric acid with one application occurring during bulking will provide the least injury and best protection from pink rot.

Research Objectives

1) Determine how injury can be reduced with foliar phosphorous acid treatments
2) Quantify the amount of phosphonic acid needed in tubers to provide disease protection by application rate and timing

Current Research

Injury Study

Previous work on phosphorous acid has examined the effectiveness of adding surfactants to phosphorous acid to reduce foliar injury. It was found that silicone surfactants were able to reduce injury when tank mixed with 4.2 lb ai/a phosphorous acid (5 pt/a Phostrol), but not at 8.4 lb ai/a phosphorous acid (10 pt/a Phostrol).

In a study in 2015, Reveille and Phostrol were applied at various rates to test for injury differences with and without Silkin (Table 1). Phostrol at 5 and 10 pt/a has 4.2 and 8.4 lb ai/a phosphorous acid, respectively. Reveille was applied at 5, 8, and 16 pt/a which represents 2.4, 4.2, and 8.4 lb ai/a phosphorous acid, respectively. Treatments were applied on July 14, 2015 with a 9-foot handheld boom pressurized with CO_2 and calibrated to deliver 10 gal/a. Plots were rated for visual injury symptoms and estimated for biomass loss on 20 and 27 July and 11 August (1, 2 and 4 weeks after treatment). There were no significant differences in crop injury or biomass loss.

In 2016 a study was established at Inkster, ND with Russet Burbank potatoes. Phostrol was studied at different rates (5, 7.5 and 10 pt/a) with and without the adjuvant Silkin (0.25, 0.13 and 0.06 % v/v) (Table 2). Plots were planted on May 19, 2016 with 36 in rows and 12 in within-row spacing. Treatments were made on July 26, 2016 with a 9-foot handheld boom pressurized with CO_2 and calibrated to deliver 15 gal/a. Plots were rated for visual injury symptoms and estimated for biomass loss on August 10th and 19th. There were no significant differences in crop injury or biomass loss.

One of the challenges working with this product is the inconsistent results. The environment, plant health, or timing before the next irrigation may affect phosphorus acid injury.

Rate Study

A trial was established near Park Rapids, MN in 2015 in a commercial planted Russet Burbank field that would not receive any phosphorous acid treatments during the season. A second study was established near Inkster, ND in 2016 in a research location. Each study utilized a randomized complete block design with 4 replicates and plots measuring 12 x 30 ft. Of the 12 treatments, treatments 1 to 10 were the same both years; however, treatments 11 and 12 differed between years (Tables 3 and 4). The first foliar treatments were applied approximately 2 to 3 weeks after emergence, before row closure. Plants in plots were visually evaluated for injury and biomass loss. Harvest was completed on September 25, 2015 and on September 29, 2015 by digging 25 row feet with a small plot harvester. In 2015, one row was harvested and in 2016 two rows were harvested (50 row feet). All tubers were subsequently graded into <4, 4-6, 6-10, 10-14, and >14 oz size categories (Tables 5 and 6).

There was little injury expressed in these studies. No more than 7% visual crop injury was noted. Differences in data were found for pink rot challenge inoculations and graded yield. However, tears were separated because of differences between year each. Pink rot control differed between treatments (Tables 3 and 4). Treatments 1 through 7 were used to determine if an early treatment of phosphorous acid could be applied at high rates with a ground sprayer to reduce injury and provide sufficient control of pink rot in storage. In 2015, the severity of pink rot declined as the rate increased from 5 to 20 pt/a, but rates higher than 20 pt/a caused less control of pink rot than 20 pt/a. Multiple treatments of phosphorous acid were more effective than a single early treatment, except for treatment 11 which had 10 pt/a of Phostrol applied on 18 and 25 June. When Phostrol was applied in multiple treatments and had at least one treatment applied on or after July 9th, pink rot control was the best. In 2016, pink rot severity was less than 2015. The early treatments on July 6 were similar to the non-treated, except 15 and 30 pt/a had a reduced severity comparted to the non-treated control. Two treatments, Phostrol applied at 7 pt/a three times and Phostrol applied at 10 pt/a followed by two treatments of 5 pt/a had complete control of pink rot. It appears that Phostrol applied at 7 pt/a three times had one of the lowest pink rot severity measurement in both years.

There were differences in graded yield, but differences were somewhat inconsistent between treatments (Tables 5 and 6). The non-treated check had the highest numerical yield in 2015, but not in 2016. The 3 applications of 7 pt/a Phostrol (treatment 8) had a similar yield to the non-treated check in 2015, but was the numerically highest yield in 2016. The treatment of 3 application of 7 pt/a Phostrol was the highest yielding treatment in both years. Most other meaningful parameters measured in 2016 were not significant. More differences existed in 2015 between graded yield measurement. This could be explained because only 25 row feet was harvested and there could be more variability in the data than in 2016.

Early treatments of phorphorous acid at 15 pt/a is an effective way load tubers with phosphites and not risk plant injury. Multiple treatments of phosphorous acid at 5 to 7 pt/a with a surfactant/silicone seem to be most effective at keeping injury minimized and providing the best protection from pink rot. Laboratory data on phosphonic acid concentrations is still be conducted.

Table 1. Phosphorous acid injury treatments applied at Lisbon, ND in 2015.

Treatment		Rate
1	Non-treated	0
2	Reveille	5 pt/a
3	Phostrol	5 pt/a
4	Reveille	8 pt/a
5	Phostrol	10 pt/a
6	Reveille	16 pt/z
7	Phostrol + Silkin	10 pt/a + 0.06% v/v
8	Phostrol + Silkin	10 pt/a + 0.13% v/v
9	Phostrol + Silkin	10 pt/a + 0.25% v/v
10	Reveille + Silkin	16 pt/a + 0.06% v/v
11	Reveille + Silkin	16 pt/a + 0.13% v/v
12	Reveille + Silkin	16 pt/a + 0.25% v/v
13	Sysstem-Ready + Agrobest Liquid + Micro-Mix	2.5 qt/a + 1 gal/a + 1 qt/a
14	Sysstem-K + Sysstem-Cal + Micro-Mix DL	1 qt/a + 2 qt/a + 1 qt/a

Table 2. Phosphorous acid injury treatments applied at Inkster, ND in 2016.

Treatment		Rate
1	Non-treated	0
2	Phostrol	10 pt/a
3	Phostrol	7.5 pt/a
4	Phostrol	5 pt/a
5	Phostrol + Silkin	10 pt/a + 0.25 % v/v
6	Phostrol + Silkin	7.5 pt/a + 0.25 % v/v
7	Phostrol + Silkin	5 pt/a + 0.25 % v/v
8	Phostrol + Silkin	10 pt/a + 0.13 % v/v
9	Phostrol + Silkin	7.5 pt/a + 0.13 % v/v
10	Phostrol + Silkin	5 pt/a + 0.13 % v/v
11	Phostrol + Silkin	10 pt/a + 0.06 % v/v
12	Phostrol + Silkin	7.5 pt/a + 0.06 % v/v
13	Phostrol + Silkin	5 pt/a + 0.06 % v/v

Table 3. Treatments applied near Park Rapids, MN in 2015. Severity of pink rot on Russet Burbank tubers tested shown by depth in millimeter (mm). Least significant difference determined at P=0.05.

Treatment		Rate (pt/a)	Treatment date	Pink rot severity
				(penetration depth in mm)
1	Non-treated	0	--	26.6
2	Phostrol	5	18-Jun	23.1
3	Phostrol	10	18-Jun	20.4
4	Phostrol	15	18-Jun	16.0
5	Phostrol	20	18-Jun	11.8
6	Phostrol	25	18-Jun	16.5
7	Phostrol	30	18-Jun	22.2
8	Phostrol	7	9-Jul	1.4
	Phostrol	7	16-Jul	
	Phostrol	7	23-Jul	
9	Phostrol	5	9-Jul	0
	Phostrol	5	16-Jul	
	Phostrol	5	23-Jul	
	Phostrol	5	30-Jul	
10	Phostrol	10	9-Jul	0.6
	Phostrol	10	23-Jul	
11	Phostrol	10	18-Jun	13.0
	Phostrol	10	25-Jun	
12	Phostrol	10	18-Jun	2.9
	Phostrol	10	25-Jun	
	Phostrol	10	9-Jul	
	LSD (±=0.05)			*7.6*

Table 4. Treatments applied near Inkster, ND in 2016. Severity of pink rot on Russet Burbank tubers tested shown by depth in millimeter (mm). Least significant difference determined at P=0.05.

Treatment		Rate (pt/a)	Treatment date	Pink rot severity
				(penetration depth in mm)
1	Non-treated	0	--	6.27
2	Phostrol	5	6-Jul	5.43
3	Phostrol	10	6-Jul	6.50
4	Phostrol	15	6-Jul	4.84
5	Phostrol	20	6-Jul	5.43
6	Phostrol	25	6-Jul	5.30
7	Phostrol	30	6-Jul	4.76
8	Phostrol	7	6-Jul	0
	Phostrol	7	15-Jul	
	Phostrol	7	22-Jul	
9	Phostrol	5	6-Jul	5.36
	Phostrol	5	15-Jul	
	Phostrol	5	22-Jul	
	Phostrol	5	26-Jul	
10	Phostrol	10	22-Jul	3.29
	Phostrol	10	26-Jul	
11	Phostrol	10	15-Jul	0
	Phostrol	5	22-Jul	
	Phostrol	5	26-Jul	
12	Phostrol	3	15-Jul	4.79
	Phostrol	3	22-Jul	
	Phostrol	3	26-Jul	
	Phostrol	3	10-Aug	
	Phostrol	3	19-Aug	
	Phostrol	3	25-Aug	
	LSD (±=0.05)			1.07

Table 5. Graded yield of Russet Burbank potato after receiving foliar phosphorous acid treatments near Park Rapids, MN 2015. Least significant difference determined at P=0.05, ns=not significant.

	Treatment	Rate (pt/a)	Treatment Date	<4 oz	4-6 oz	6-10 oz	10-14 oz	> 14 oz	Total	Total marketable	#1s > 4 oz	#2s > 4 oz	> 6 oz	> 10 oz
									cwt/a				%	
1	Non-treated	0		52	99	218	89	53	511	460	433	26	71	28
2	Phostrol	5	18-Jun	54	96	176	79	60	467	413	391	22	68	30
3	Phostrol	10	18-Jun	59	123	209	72	33	496	438	424	14	63	21
4	Phostrol	15	18-Jun	49	103	191	87	37	469	420	400	20	67	27
5	Phostrol	20	18-Jun	55	100	194	80	37	466	411	405	7	67	25
6	Phostrol	25	18-Jun	62	117	174	84	32	468	407	391	16	62	25
7	Phostrol	30	18-Jun	51	104	223	80	43	502	452	422	30	69	25
8	Phostrol	7	9-Jul	57	123	214	96	20	510	454	438	16	65	23
	Phostrol	7	16-Jul											
	Phostrol	7	23-Jul											
9	Phostrol	5	9-Jul	61	113	170	68	39	450	392	369	23	61	23
	Phostrol	5	16-Jul											
	Phostrol	5	23-Jul											
	Phostrol	5	30-Jul											
10	Phostrol	10	9-Jul	66	112	188	62	26	453	388	373	14	61	19
	Phostrol	10	23-Jul											
11	Phostrol	10	18-Jun	58	113	203	91	39	503	445	437	8	66	26
	Phostrol	10	25-Jun											
12	Phostrol	10	18-Jun	62	111	204	71	27	475	414	395	19	64	21
	Phostrol	10	25-Jun											
	Phostrol	10	9-Jul											
	LSD (±=0.05)			*ns*	*ns*	*31.1*	*ns*	*ns*	*40.8*	*42.6*	*44.8*	*ns*	*ns*	*ns*

Table 6. Graded yield of Russet Burbank potato after receiving foliar phosphorous acid treatments near Inkster, ND 2016. Least significant difference determined at P=0.05, ns=not significant.

	Treatment	Rate (pt/a)	Treatment Date	<4 oz	4-6 oz	6-10 oz	10-14 oz	> 14 oz	Total	Total marketable	#1s > 4 oz	#2s > 4 oz	> 6 oz	> 10 oz
				cwt/a									%	
1	Non-treated	0		79	121	170	66	25	461	382	274	108	57	20
2	Phostrol	5	6-Jul	86	107	152	51	35	431	346	280	65	55	20
3	Phostrol	10	6-Jul	94	132	151	58	20	455	361	299	62	50	17
4	Phostrol	15	6-Jul	89	123	172	45	26	455	366	288	78	53	16
5	Phostrol	20	6-Jul	82	104	165	57	31	439	357	277	81	58	20
6	Phostrol	25	6-Jul	132	128	159	42	7	469	337	265	72	45	11
7	Phostrol	30	6-Jul	87	137	159	70	23	476	389	299	90	53	20
8	Phostrol	7	6-Jul	98	138	171	53	25	484	386	280	106	52	16
	Phostrol	7	15-Jul											
	Phostrol	7	22-Jul											
9	Phostrol	5	6-Jul	102	131	155	56	15	460	358	291	67	49	15
	Phostrol	5	15-Jul											
	Phostrol	5	22-Jul											
	Phostrol	5	26-Jul											
10	Phostrol	10	22-Jul	111	128	152	66	25	482	371	280	91	50	19
	Phostrol	10	26-Jul											
11	Phostrol	10	15-Jul	85	120	147	75	36	463	378	281	97	56	24
	Phostrol	5	22-Jul											
	Phostrol	5	26-Jul											
12	Phostrol	3	15-Jul	108	122	158	51	24	464	356	302	54	51	17
	Phostrol	3	22-Jul											
	Phostrol	3	26-Jul											
	Phostrol	3	10-Aug											
	Phostrol	3	19-Aug											
	Phostrol	3	25-Aug											
	LSD (±=0.05)			*30*	*ns*	*ns*	*ns*	*ns*	*38*	*ns*	*ns*	*39*	*ns*	*ns*

Title: Nitrogen fertilizer use and expression of key enzymes associated with reducing sugar accumulation in potato tubers during storage.

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Summary: Nitrogen fertilizer is used routinely in potato cultivation to maximize yield. However, it also affects the processing and storage quality through changes in sugar, free amino acid and protein concentrations in potato tubers. Altered key enzymes expression at bud and stem end of the tubers may have a significant effect on tuber reducing sugar accumulation during storage. For optimum growth, development and yield of potatoes, carbon and nitrogen metabolism need to be coordinated.

In the present study three contrasting cultivars were evaluated for their N assimilation into soluble protein content and expression of key enzyme acid invertase and total reducing sugar level. All three cultivars had high soluble protein content and low basal acid invertase at the bud end and consequently low reducing sugar level at harvest. Basal acid invertase enzyme in the stem end of Russet Burbank tubers increased with increasing N fertilizer level but was not affected by N fertilizer in the stem end of Dakota Russet and Easton tubers. The expression of acid invertase inhibitor protein which regulates acid invertase enzyme activity had slightly different response to N rate. Total acid invertase activity reflects the amount of inhibitor protein was higher at lower N rate. Data suggest that high N fertilizer use may affect the processing quality positively or negatively, depending on cultivar. The expression of acid invertase and its regulatory protein in commercial cultivars under higher N rates need to be further explored to gain better understanding.

Rationale: Potatoes are an important staple food worldwide and Minnesota ranked 7th in U.S. for potato production. In Minnesota, nearly 70% of this crop is processed for 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. High levels of N fertilization complicate the problem by producing physiologically immature tubers (Shewry et al. 2001). N fertilization is known to affect free amino acid concentrations in potato tubers and acrylamide forming potential (Halford et al. 2011).

Providing crops with adequate levels of nutrients ensures the best yield possible. Soil-plant atmosphere system inefficiencies prevent complete utilization of N, leaving residual N in the soil. Nutrient use efficiency of potato plants is relatively low with less than 70% of N fertilizer being recovered by plants. As a result, farmers apply relatively high rates of N fertilizers as security. Rising fertilizer prices have prompted growers to be more conservative with their N applications, but the risks of not applying enough N to maintain potato yield and quality can be substantial. Commercial potato production is especially prone to environmental contamination, in combination with high N fertilizer and irrigation resulting in the leaching of nitrate (Sharifi et al. 2007). Balancing economic yield, tuber quality during long term storage with environmental concerns is often challenging.
Excessive loss of nitrate from the potato root zone is a serious environmental problem (Richards et al. 1990). The consequences of heavy N fertilization have led policy makers and society in search of mitigating options.

Nutrient efficiency estimation has been used commonly to assess the plant's potential to absorb and utilize nutrients for biomass production. Excessive available N in plant stimulates top growth and delays tuber formation and maturity. Nitrogen use efficiency decreased curvilinearly with increasing crop N supply. Nitrogen use efficiency was reported lower for early-maturing cultivars compared to mid-season and late-maturing cultivars (Zebarth et al. 2004). N fertilization influences tuber sugar content and

chip color by interfering with tuber chemical maturation (Eppendorfer et al. 1996, Kumar et al. 2004, and Elmore et al. 2007). Studies have shown a close association of key enzymes with reducing sugar (RS) accumulation (Sowokinos 1990 and Nursten 2005)). Change in carbohydrate metabolizing enzymes expression in response to N status may have significant effects in tuber RS accumulation during storage. Studies have been conducted to assess the effect of N rate on economic yield and RS of various commercial cultivars. N best management practices (BMPs) have been developed for optimum yield and reduced environmental losses (Zebarth and Rosen 2007). However, the physiological basis of nitrogen use in various cultivars is poorly understood. Cultivars differ more in terms of N uptake than in utilization. That could be related to the activity of key enzymes. Systematic studies are lacking on the effect of N fertilization rate on expression of various enzymes related to carbohydrate metabolism in potato tubers which directly influence tuber quality during storage.

Cultivars that are more efficient at capturing soil N during the growing season can make maximum use of added N fertilizer. Cultivars with high N use efficiency will decrease N leaching and denitrification losses and produce chemically mature tubers. Chemically mature tubers will maintain the processing quality during long term storage.

Material and methods: To gain a better understanding of nitrogen use by potato plant, three commercial potato cultivars (Russet Burbank, Dakota Russet and Easton) having a wide variation in their reducing sugar accumulating potential or Cold-Induced Sweetening (CIS) resistance were selected.

In the year 2015, all the cultivars were planted at Sand Plain Research farm, Becker, MN in Hubbard loamy sandy soil. A randomized complete block design with four replicated was used. Five N rate (120, 180, 240, 300 and 360 kg/ha) were used. All the potatoes were harvest in early November, suberized for three weeks at room temperature.

A 2.5 gram fresh tuber tissue was collected from the bud and stem end of the tuber. The tissue was ground with HEPES extraction buffer pH 7.5. The crude extract was centrifuged and supernatant was stored at -80°C for biochemical analysis. All the steps were conducted on ice.

Soluble protein content was determined using the dye-binding method of Bradford (1976) and expressed as mg per g FW. Microplate based method developed in our lab was used for acid invertase activity (Gupta, SK 2017) determination. Enzyme activity was expressed as units (mmols Glc formed per hour) per mg protein. Total reducing sugars were determined by the DNS method as described by Lindsay (1973). The concentration of sugar was expressed as mg per gram fresh weight.

Results: The three cultivars showed differential response to N rate in terms of total soluble protein concentrations, expression of key enzyme acid invertase related to RS accumulation and its regulatory protein and ultimately the RS accumulation at harvest.

1. **Effect of N rate on cellular soluble protein concentration:** All the three cultivars showed significantly higher soluble protein content at the bud end of the tuber. Cultivar response to N rate differed. Russet Burbank showed a linear increase in cellular soluble protein content in response to N rate increase. Whereas CIS resistant cultivars Dakota Russet and Easton had no significant increase.

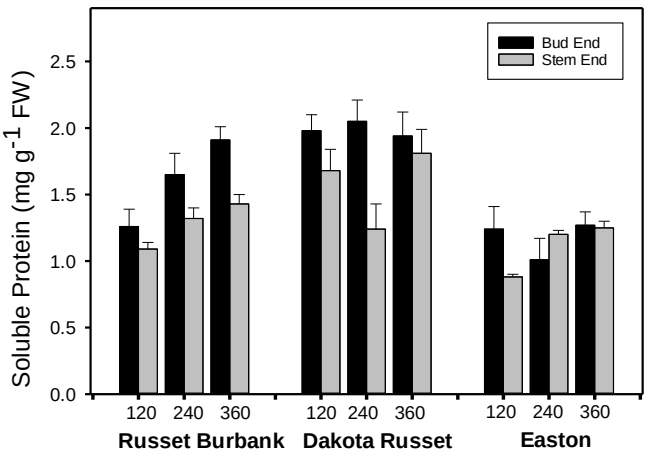

Figure 1: Soluble protein concentration at bud and stem end of the tuber at harvest. Data represents 3 replicates ±SE.

2. Effect of N rate on Acid Invertase enzyme activity: Acid invertase (AcInv) enzyme activity in the presence of its inhibitor protein is shown in Fig. (2). All the three cultivars had higher acid invertase enzyme activity at the stem end. The CIS sensitive cultivar Russet Burbank had a 3-5 fold higher enzyme activity. Cultivars with CIS resistance (Dakota Russet and Easton) had lower acid invertase activity. Dakota Russet had the lowest acid invertase activity with less than three units (class A), which did not increase with increasing in N rate. Easton had acid invertase activity around six units mg^{-1} protein, which did not increase significantly in response to N rate increase.

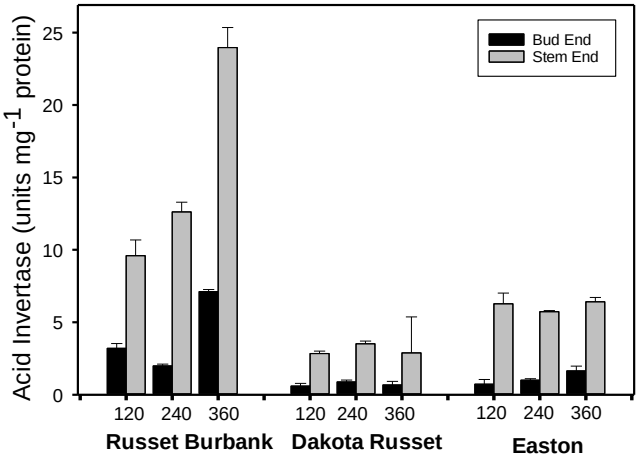

Figure 2: Basal acid invertase enzyme activity (in presence of inhibitor protein) at bud and stem end of the tuber at harvest. Data represents 3 replicates +SE.

3. Effect of N rate on reducing sugars (RS): Reducing sugar concentration (Fig. 3) showed significant differences between the CIS sensitive cultivar Russet Burbank and CIS resistant cultivars Dakota Russet and Easton. Dakota Russet recorded the lowest RS levels. All the cultivars had higher RS levels in stem end at harvest. The increase in N rate showed no clear effect in terms of RS at harvest. The stem end of Easton recorded a slight decrease in RS concentration in response to higher N rate.

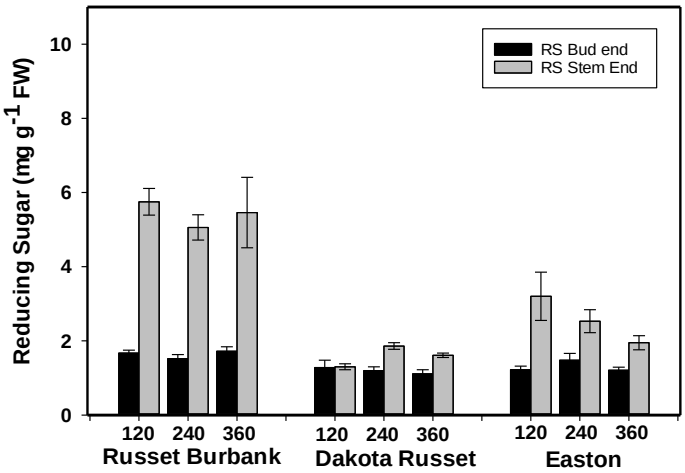

Figure 3: Reducing sugar (RS) concentration at bud and stem end of the tuber at harvest. Data represents 3 replicates ±SE.

Discussion: The response to N fertilizer for soluble protein content, RS and enzyme activity was cultivar-specific. Irrespective of the cultivar and N rate, soluble protein content at bud end of the tuber was high (Fig 1). This represents high metabolic activity of key starch synthesizing enzymes (Liu et al. 2016). Muttucumaru et al. (2013) reported substantial increase in asparagine and total free amino acid in response to increasing N fertilization. A high concentration of free amino acids may lead to their incorporation in various cellular proteins including the proteins involved in starch synthesis or degradation. The increase in soluble protein concentration is clearly reflected in low reducing sugar levels at bud end of the tuber (Fig 3). This indicates possibly higher levels of starch synthesizing enzymes like AGPase, Branching enzymes and Granule Bound Sucrose synthase.

N supply has been reported to affect the sugar concentration and interconversion of simple sugars and complex carbohydrates such as fructans (Halford et al. 2011). However, previous studies have not reported a consistent trend in term of N rate and RS accumulation. Muttucumaru et al. (2013) reported inconsistent increase or decrease in glucose concentration with increase N fertilizer. Amerein et al.

(2003) reported no significant effect of N fertilization on RS. Dr. Rosen's lab recorded decreased RS in response to higher N fertilization in Russet Burbank and Alpine Russet (personal communication). In the present study, Easton had lower RS levels with increasing N rate. The other two cultivars (Russet Burbank and Dakota Russet) had inconsistent RS levels in response to N rate (Fig 3) at harvest. The effect of N fertilization on RS accumulation depends on cultivar, growing conditions, and chemical maturity of the tubers. Growing conditions and nutrient status of the plant influence expression of several key enzymes.

Our data showed higher AcInv enzyme activity at the stem end in all three cultivars at harvest. These results are consistent with the results reported by Liu et al. (2016). Liu et al. (2016) reported increased expression of acid invertase gene at the stem end in response to higher N fertilizer. This could possibly be due to translocation of sugars from source to sink and phloem unloading. Basal AcInv enzyme expression increased in Russet Burbank with high N rate (Fig 2). The increase level of AcInv enzyme could possibly lead to higher incidence of stem-end defects during long term storage. Cultivars Dakota Russet and Easton with known CIS resistance demonstrated inconsistent expression of AcInv enzyme activity. The effect of increase AcInv enzyme activity at harvest needs to be evaluated during storage.

Several studies have shown that lower levels of AcInv relates with the low levels of reducing sugar accumulation (McKenzie et al. 2013; Liu et al., 2011, 2013; Ou et al. 2013; Zhang et al. 2013). Clones with high levels of basal AcInv activity accumulated high levels of reducing sugars. It is not surprising that in the current study the effect of acid invertase was not found to be proportional to RS at harvest. In a study involving 198 genetically diverse clones and cultivar, Gupta (2017) reported acceptable range of RS and high AcInv enzyme activity (class C clones) at harvest. Class C clones accumulated high levels of RS during storage. AcInv activity increases during long term storage (Matsuura-Endo 2004; Sin'Kevich et al. 2008). Therefore, the effect of increased enzyme expression in response to N rate at harvest will be seen after storage. The increase in AcInv activity during long term storage depends on AcInv enzyme level at harvest, genotype, storage temperature and the amount of inhibitor protein present.

Our preliminary data showed differential expression of acid invertase inhibitor protein in response to N rate. Not much research has been done on AcInv enzyme regulatory inhibitor protein. Expression of AcInv enzyme and its inhibitor protein in response to N rate needs to be further explored during long term storage. Knowledge of physiological responses at the proteome level will aid the subsequent development of functional molecular markers for future targeted breeding and selection of desirable cultivars with high N uses efficiency and high CIS resistance.

Conclusion:

Higher N levels increased expression of key enzymes like acid invertase, which is related to RS accumulation. The effect was evident in Russet Burbank but not in Dakota Russet or Easton at harvest. The increased level of AcInv at harvest may adversely affect the processing quality during storage. A previous study has shown that cultivars with high AcInv enzyme activity at harvest tends to accumulate high levels of RS during storage and lose processing quality (Gupta 2017). Management practices for N fertilizer use have been developed to maximize economic yield. Our study indicates the emphasis should be on cultivar and its optimum N use to get best processing quality during storage. There is a need to evaluate commercial cultivars for both optimum yield and best storage quality for process. Cultivars with high N utilization efficiency may reduce fertilizer cost and nitrate leaching to ground water.

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Acknowledgement:
The research funding from Northern Plains Potato Grower Association (NPPGA) and Cavendish Farms is gratefully acknowledged. The tubers analyzed in this study were part of a grant funded by NIFA SCRI to reduce acrylamide in processed potatoes.

Nitrogen and Irrigation Management Strategies for Potato Production to Reduce Nitrate Leaching

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ABSTRACT: The expansion of intensive, irrigated agriculture in Central Minnesota has led to concerns regarding potential increases in non-point source pollution to surficial aquifers. With a goal to improve drinking water quality in this region, which is commonly impaired by nitrate-N, renewed interest has been placed on the role of nitrogen (N) and irrigation (IRR) best management practice to meet environmental and agronomic goals. Precision agriculture methods such as remote spectral and soil moisture sensing are promising methods to reach these multiple objectives. A plot-scale field experiment was conducted in 2016 at the Sand Plains Research Farm in Becker, MN to evaluate the effect of conventional and adaptive management for IRR and N strategies on tuber yield, quality, and nitrate-N leaching for irrigated potatoes grown on coarse-textured soils. Management strategies for IRR included two treatments: (1) conventional checkbook, and (2) deficit irrigation monitored by soil moisture sensors. Six N-treatments were imposed including (1) 40 lb N/ac control treatment, (2) split-applied urea treatments of 160 lb N/ac, (4) and of 240 lb N/ac, (3) controlled-release polymer coated urea (PCU) treatments of 160 lb N/ac, (5) and of 240 lb N/ac, (6) and split-applied urea applied at a variable-rate based on weekly remote sensing of crop nitrogen stress. Overall, N-treatments had a significant effect on total and marketable yield, while IRR did not. Neither N nor IRR had a significant effect on calculated nitrate leaching load; however, a significant difference in nitrate-N concentration between control and fertilized N-treatments was found. Additionally, remote spectral sensing was able to identify significant plant-N deficiencies on a timely basis; as a result, the variable rate treatment (6) received 20 lb N/ac less than the comparable split-applied urea treatment (4) without a significant difference in tuber yield or quality.

INTRODUCTION

As a crop with high nitrogen [N] requirement and low tolerance for water stress, potato yield and quality are highly dependent upon adequate supply of fertilizer-N and supplemental irrigation [IRR] when grown on soils with low fertility and available water holding capacity. In addition, shallow rooting systems of the potato crop and high drainage rates in coarse-textured soils lead to the potential for precipitation-driven leaching of nitrate-N out of the root zone and into surficial groundwater systems. Management of IRR and N necessarily have reciprocal impacts; management of N impacts crop growth, which in turn vary crop water requirements, and management of IRR drives deep percolation of nitrate-N. Conventional management strategies for IRR and N still have relatively low nitrogen and water use efficiencies, leaving the potential for adaptive precision agriculture management of N and IRR to improve agronomic and environmental outcomes. Utilizing remote sensing based crop N-stress measurements and in-field soil moisture measurements are two such methods for managing N and IRR, respectively.

The primary objectives of this study were to (i) determine the response on tuber yield and quality to conventional and adaptive N and IRR management methods, (ii) evaluate the effectiveness of multispectral remote sensing based variable rate N-management on agronomic and environmental, (iii) determine the impact of IRR and N management on nitrate-N leaching.

MATERIALS & METHODS

Study Site

Plot-scale field experiments were conducted in 2016 at the University of Minnesota Sand Plain Research Farm (°23'N, 95°53'W) in Becker, MN. The soils located in the field studied are predominantly Hubbard loamy sand, with significant areas of Hubbard-Nymore loamy sand and Sverdrup sandy loam (Figure 1); these soils are rapidly drained and have relatively low available water holding capacity [AWHC] with 2.8, 2.3 and 3.0 inches of AWHC in the 24-inches, respectively. Soil samples were collected prior to planting from the top 6-inches of the soil profile, and analyzed for the following chemical properties: water pH – 5.9; organic matter - 1.8%; Bray P1 - 34 ppm; ammonium acetate extractable K, Ca, and Mg - 136, 793, and 125 ppm, respectively; Ca-phosphate extractable SO_4-S - 1 ppm; and DTPA extractable Zn, Cu, Fe, and Mn – 1.4, 0.6, 34.7, and 10.8 ppm, respectively. Soil samples were collected from the top 24-inches of the soil profile to determine pre-planting inorganic-N concentration, and analyzed conductimetrically (Carlson 1986, Carlson *et al*. 1990). Concentrations of $NH_4^+ + NO_3^-$ was 2.2 ppm.

Experimental Design

This study has a randomized complete block design with a split-plot restriction on randomization and four replicates. Irrigation rate and timing was the whole plot treatment (with two treatments) and nitrogen rate, source, and timing as the sub-plot treatment (with six treatments). Each replicate was separated by a 50 ft buffer of rye and irrigation blocks within replicates are separated by a 30 ft buffer alley. Experimental plots are 21 ft wide (7 x 3 ft rows) and 20 ft long with an additional 5 ft buffer for plots located at the edge of the irrigation block. A 10 ft buffer separates split-plots within whole plots that are co-located in the same set of 7 rows. Russet Burbank was selected as the variety of potato within this study because of its widespread use in production across the state. Whole "B" seeds were planted on 22 April 2016 with a one-foot spacing between seeds. Vines were killed with a mechanical flail mower on 14 September 2016 and tubers were mechanically harvested on 30 September 2016. Tubers were sorted into size classes (0-3 oz, 3-6 oz, 6-10 oz, 10-14 oz, and >14 oz) and graded (US No. 1 and No. 2). Subsamples were randomly collected after sorting to analyze tuber quality and specific gravity. Cultural practices, apart from those explicitly listed here, were conducted by the staff at the Sand Plains Research Farm and follow the standard practices for the region.

Irrigation treatments used were (1) modified checkbook method (see Wright, 2002 and Steele et al., 2010) and (2) deficit method monitored by soil moisture sensors. Irrigation at the Sand Plains Research Farm was applied using a solid-set sprinkler system and normally conducted with a modified checkbook method: using a fixed irrigation scheduled for a given field, depth of application on a given date determined by accumulated water deficit since the previous irrigation event. Irrigation was managed with an effective rooting depth of 18-inches and during the period of peak water consumption, a maximum allowable soil water deficit was set at 30% or 0.6-inch deficit. Irrigation was typically scheduled Monday, Thursday, and Saturday for the field in which this study was located. Each standard irrigation event was designed to refill the soil profile completely for IRR-treatment (1), and was typically a depth of 1/2". Regular irrigation began on 20 June 2016 and concluded on 25 August 2016. Irrigation treatments are paired (i.e. applied simultaneously) due to logistical constraints, with the only difference between treatments being sprinkler nozzle size; nozzles for IRR-treatment (2) were designed to apply 15% less water than

those for IRR-treatment (1). The objective for IRR-treatment (2) was to maintain a maximum deficit of 50% available water holding capacity, which is greater than the threshold of 65% AWHC typically used as an irrigation set point to avoid water stress in potatoes (Shock et al. 2007). The level of soil moisture deficit was measured with Watermark soil moisture tension sensors (Irrometer Company – Riverside, CA) permanently installed at 6- and 18-inch depths, portable TDR-300 unit with 8-inch waveguides (Spectrum Technologies – Aurora, IL), and gravimetric water content of soil samples collected with 7/8" OD soil probe at 0- to 12-inch depth taken from within plots.

Nitrogen treatments used in this study include (1) 40 lb N/ac control treatment, (2) split-applied urea treatments of 160 lb N/ac, (4) and of 240 lb N/ac, (3) controlled-release polymer coated urea (PCU) treatments of 160 lb N/ac, (5) and of 240 lb N/ac, (6) and split-applied urea applied at a variable-rate based on weekly remote sensing of crop nitrogen stress. Fertilizer at planting was diammonium phosphate applied uniformly to all N-treatments at a rate of 40 lb N/ac. Emergence fertilizer was urea for treatments (2), (4), and (6) and Environmentally Smart Nitrogen (Agrium Inc. – Calgary, AB) for treatments (3), and (5) at various rates (Table 2). Nitrogen treatments (2) and (4) received four scheduled post-hilling applications of 28 UAN in the form of simulated fertigation on a 1- to 2-week basis; three post-hilling fertilizer applications in the form of 28 UAN were applied to N-treatment (6) based on the results of remote sensing indices.

Table 2. Rate and timing of Nitrogen (N) fertilizer treatments

		Planting	Emergence	---------- Post-Emergence ----------				
		April 22	June 1	June 23	July 14	July 21	July 27	Total
Nitrogen		---------- lbs N ac^{-1} ----------						
1	Control	40 DAP	-	-	-	-	-	40
2	160 Urea	40 DAP	60 Urea	15 UAN	15 UAN	15 UAN	15 UAN	160
3	160 ESN	40 DAP	120 ESN	-	-	-	-	160
4	240 Urea	40 DAP	120 Urea	20 UAN	20 UAN	20 UAN	20 UAN	240
5	240 ESN	40 DAP	200 ESN	-	-	-	-	240
6	Var. Rate	40 DAP	120 Urea	-	20 UAN	20 UAN	20 UAN	220

Multi-spectral remote sensing data was collected on a weekly basis using CROPSCAN MSR-16R (CROPSCAN Inc. – Rochester, MN) which collects reflectance data at 16 narrowband wavelengths (460, 510, 560, 610, 660, 680, 710, 720, 740, 760, 810, 870, 950, 1320, 1500, and 1720 nm). Remote sensing data was collected on a weekly basis on 10 dates between 21 June 2016 and 24 August 2016. 4 subsamples were collected from each plot at a height of 6 feet, giving a diameter of view of approximately 3 feet. Using the methods of Nigon et al. (2014) and Nigon et al. (2015), relative crop N-deficits were determined using nitrogen sufficiency indices (NSIs), with N-treatment (5) used as the well fertilized reference. Spectral indices used in this study were the MERIS Terrestrial Chlorophyll Index (MTCI), Green Ratio Vegetation Index (GRVI), and Simple Ratio 8 (SR8), which were among the best performing index as identified by Nigon et al. (2015) (Table 1). If statistical analysis indicated a significant difference for 2 out of the 3 spectral indices where N-treatment 6 (i.e. variable-rate) was less N-treatment 5 (i.e. sufficient nitrogen), post-hilling fertilizer was applied to N-treatment 6 at a rate no greater than 20 lbs N/acre.

Table 1. Nitrogen Sufficiency Indices

Index		Formula[†]	Source	Calculation
MERIS Terrestrial Chlorophyll Index	MTCI	$\frac{R_{751}-R_{713}}{R_{713}-R_{676}}$	Dash and Curran (2004)	$\frac{\frac{(R_{760}+R_{740})}{2}-R_{710}}{R_{710}-R_{680}}$
Simple Ratio 8	SR8	$\frac{R_{857}}{R_{554}\times R_{704}}$	Datt (1998)	$\frac{R_{870}}{R_{560}\times R_{710}}$
Green Ratio Vegetation Index	GRVI	$\frac{R_{NIR}}{R_G}$	Sripada et al. (2006)	$\frac{R_{760}+R_{810}}{R_{510}+R_{560}}$

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

Temperature and accumulated precipitation and irrigation measurements were collected at hourly increments using in-field weather stations (Spectrum Technologies – Aurora, IL). Additionally, measurements of solar radiation, precipitation, relative humidity, temperature, and wind speed were collected at hourly increments from a weather station located at the Sand Plains Research Farm, but not located within the field this study was located in. Calculations of reference and crop evapotranspiration were based on measurements from this weather station and conducted using the methods of ASCE Manual 70 for tall-reference crop with mean crop coefficient (Jensen and Allen 2016).

Water quality below the root zone was measured with suction-cup lysimeters using the methods of Venterea *et al.* (2011). Monitoring equipment was installed in row 3 of each experimental plot on 4 May 2016 and water sampling was conducted on weekly to twice-weekly basis with 25 samples collected between 18 May 2016 and 6 October 2016. Samples were stored frozen and analyzed conductimetrically for nitrate-N concentrations using a Wescan N analyzer (Carlson *et al.* 1990). Interpolated daily values of nitrate-N concentration was calculated for each sub-plot, and N-leaching loads was calculated for each sub-plot by multiplying the calculated value of percolation from the water balance method of Errebhi *et al*. (1998) by the interpolated nitrate-N concentration value.

Statistical Analysis

Tuber yield and quality data were analyzed using PROC MIXED in SAS Studio Version 3.5 (SAS Institute Inc. – Cary, NC). Main effects specified in the model statement were IRR-treatment and N-treatment, with an interaction effect also specified. Random effects specified were replicate and IRR-treatment nested within replicate. Degrees of freedom were estimated with the Satterthwaite method.

NSI values were analyzed using repeated-measures in PROC MIXED. Main effects specified in the model statement were IRR-treatment, N-treatment, and Date with all interaction effects specified. Random effects specified were replicate, IRR-treatment nested within replicate, and N-treatment nested within IRR-treatment*replicate. Degrees of freedom were estimated with the Satterthwaite method.

Nitrate-N leaching concentrations were analyzed using repeated-measures in PROC GLIMMIX, with nobound, method = MSPL options, and lognormal response variable distribution. Main effects specified in the model statement were IRR-treatment, N-treatment, Date, with all

interaction effects included. Random effects specified include replicate, IRR-treatment nested in replicate, and N-treatment nested in IRR-treatment*replicate. An additional random effect statement was included to specify an R-side covariance structure for Date using the heterogeneous auto-regressive method for observations on experimental units of N-treatment nested in IRR-treatment*replicate.

Non-orthogonal contrast statements were included to test *a priori* hypotheses in N-treatment and interactions between IRR-treatment and N-treatment (Table 3). Least square means were calculated for main effects and their interactions, and *post hoc* pairwise multiple comparisons was specified using a difference statement. Means for treatments were placed into letter groups using the PDMIX800 macro (Saxton 1998), using a protected Fischer Least Significant Difference test ($\alpha = 0.05$) without p-value correction.

Table 3. Non-orthogonal contrasts used for *a priori* hypothesis testing on main and interaction effects for Nitrogen treatments

Contrast	Control	160 Urea	160 ESN	240 Urea	240 ESN	Var. Rate
Control	-5	+1	+1	+1	+1	+1
Rate	0	-1	-1	+1	+1	0
Source	0	-1	+1	-1	+1	0
Var. Rate	0	0	0	-1	-1	2

RESULTS & DISCUSSION

Water Balance

Irrigation treatments had a cumulative difference of 1.4 inches of irrigation applied, resulting in a 4 % overall difference between IRR-treatment (1) and (2) in cumulative precipitation and irrigation (Table 4). Above average precipitation was observed in July and August, reducing the need for supplemental irrigation and limiting the ability to impose irrigation treatments as designed. As a result of above average precipitation, leaching of water below the root zone was large; however, percolation was reduced in IRR-treatment (1) by 1.3 inches, equivalent to a 7 % reduction. Calculated soil moisture deficit in the root zone remained low, and differences between IRR-treatments on a monthly basis were small.

Tuber Yield and Quality

Significant differences in total yield, marketable yield, and size distribution of tubers in response to N-treatment were observed (Table 5). The variance in the response for these three measures is mostly attributed to differences between control and fertilized treatment; however, N-rate had a significant effect for total yield and marketable yield. The treatments with the highest mean value of total and marketable yield were N-treatments (4) and (6) at IRR-treatment (1). A significant interaction effect on total and marketable yield was found for I x Rate, suggesting that N supplied by irrigation water was critical for growth in N-treatments with low rate and excessive irrigation was detrimental to growth at high-N rates by leading to leaching N-losses. The ratio of misshapen tubers was found to significantly vary as a result of N-source, with urea-based treatments (i.e. N-treatments (2) and (4)) having greater misshapen tubers than PCU-based treatments (i.e. N-treatments (3) and (5)). The variable rate treatment (i.e. N-treatment (6)) was not found to be significantly different in yield and quality response than either of the existing best management practices for N-application (i.e. N-treatments (4) and (5)), although 20 lb N/ac less was applied to

this treatment. Incidence of hollow heart internal defects was significantly greater for IRR-treatment (2) than (1). Specific gravity had no significant response to either IRR- or N-treatments.

Table 4. Summary of Irrigation treatments and field water balance

	April	May	June	July	Aug.	Sept.	Total
	Input†						
	---------- inches ----------						
Irrigation‡	Irrigation [I]						
1 Deficit	0.0	0.0	2.4	2.2	1.9	0.00	6.5
2 Checkbook	0.0	0.0	2.7	2.9	2.3	0.00	7.8
	Precipitation [P] ‡						
	2.3	3.7	2.8	7.3	5.7	4.7	26.6
	[avg]	[avg]	[dry]	[wet]	[wet]	[wet]	[wet]
Irrigation	P + I						
1 Deficit	2.3	3.7	5.2	9.5	7.6	4.7	33.0
2 Checkbook	2.3	3.7	5.5	10.1	8.0	4.7	34.4
	---------- % ----------						
Difference	0	0	-6	-6	-4	0	-4
	Output						
	---------- inches ----------						
	Evapotranspiration [ET]						
	0.2	1.7	4.4	4.6	3.0	1.2	15.1
Irrigation	Leaching [L]						
1 Deficit	2.2	2.1	0.9	5.0	4.4	3.4	18.1
2 Checkbook	2.2	2.1	1.0	5.9	4.8	3.4	19.4
	---------- % ----------						
Difference	0	0	-11	-14	-8	0	-7
	Soil Moisture						
	---------- % ----------						
Irrigation	Root Zone Deficit [D_{RZ}]						
1 Deficit	1	22	19	11	7	7	11
2 Checkbook	1	22	15	8	6	7	10

† – See text for complete explanation of I, P, ET, L, and D_{RZ} measurements and calculations

‡ – [wet], [dry], [avg] respectively indicate precipitation totals above the 70th percentile, below the 30th percentile, and between the 30th and 70th percentile of the period-of-record; data from the gridded database for Becker, MN of the MN DNR Climatology Working Group

Nitrate Leaching

Cumulative nitrate leaching loads were not significantly different for either IRR- or N-treatments, and were relatively low overall (Table 6). Lack of statistical significance most likely does not indicate a true lack of difference between treatments, but rather a lack of statistical power to detect treatment differences due to the high variance within treatments and errors introduced in the calculation procedure. Statistical analysis of soil water nitrate-N concentrations, using repeated measures analysis with temporally correlated error structures, indicates a significant difference between the control and fertilized N-treatments (Table 6). Overall, these data suggest that differences in N-leaching are marginal when best management practices for N-fertilization are used and further improvements in reducing N-leaching may be difficult to obtain with fine tuning of N-management.

Remote Sensing

Nitrogen sufficiency index values were found to be significant for the N-treatment by Date interaction and pairwise multiple comparison procedures identified significant excess or deficiency in N relative to the reference N-treatment (Table 5). Each of the three spectral indices evaluated were able to detect significant N-stress or N-excess on each given date for at least one of the N-treatments. Depending on the spectral index used, differences in NSI of approximately 3%-units were found to be significant differences in the statistical models, indicating that boundaries of 97 and 103 % NSI are appropriate first order approximations for nitrogen excess or deficiency, relative to the well fertilized reference.

With respect to the variable-rate treatment (i.e. N-treatment (6)), SR8 detected significant deficiencies on 6 dates, while GRVI and MTCI only detected stress on 2 and 3 dates, respectively. The minor differences between the statistical significance of GRVI, MTCI, and SR8 for a given N-treatment on a given date were found, suggest that consideration of NSI values from multiple spectral indices may be appropriate method for decision making.

Additionally, this remote sensing approach appears to be able to not only detect the primary response due to N-fertilizer management, but also able to resolve spatial heterogeneities within a given management regime. For example, on the first sampling date, 21 June 2016, N-stress was detected in N-treatment (4) but was not detected in N-treatment (6) even though these two treatments had received identical fertilizer application at this point in time.

CONCLUSION AND FUTURE RESEARCH

Overall, results of this study suggest IRR- and N-treatments have important effects on tuber yield, quality, and nitrate-N leaching, influencing the economic and environmental outcomes from potato production. The N-management strategies evaluated in this study generally produced an increase in total and marketable yield as N-rate increased, based on the mean values and the N-rate contrast test. The control treatment had the lowest total yield, and the target fertilizer rate based on observed yield response is between 160 and 240 lbs N/ac. Differences in nitrate-N leaching load were not significant, but the nitrate-N concentration in the control treatment was significantly less than the fertilized treatments. Additionally, variable rate N-treatments reduced N-fertilizer application based on remote sensing of N-stress, without significant differences in yield response, highlighting this practice as an effective management strategy to reduce fertilizer input costs and maintain maximum yield.

Future work for this study will include analysis of petiole N-content, and relative chlorophylls measurements made with SPAD-502 meter (Spectrum Technologies – Aurora, IL) as well as leaf area index measured with LAI-2000 (Li-Cor Biosciences, Inc., Lincoln, NE) to remote measurements of crop growth and N-status. Additionally, nitrogen use efficiency metrics will be calculated based on measurements of N-content in tuber and vine samples. Accuracy of soil water balance methods will be determined based on comparison to measurements of soil water content collected in this study. Finally, data from this study will be further utilized to calibrate and validate the biophysical simulation model EPIC.

Table 5. Tuber Yield, Quality, and Nitrate Leaching

				Total Yield		Marketable Yield		Tubers > 6 oz		Misshapen Tubers	Hollow Heart		Specific Gravity	Nitrate Leaching	Nitrate Concentration
Irrigation		**Nitrogen**		---------- cwt acre^{-1} ----------				---------- % ----------						lbs NO_3^- acre^{-1}	ppm NO_3^-
1	Deficit	1	Control	449.5	†D	402.5	C	52.6	C	37.0	0.0	B	1.075	15.7	2.40
1	Deficit	2	160 Urea	611.6	BC	568.0	B	69.3	B	43.1	2.4	AB	1.077	22.5	5.16
1	Deficit	3	160 ESN	603.5	C	569.0	B	74.3	AB	39.6	1.1	AB	1.077	17.6	4.05
1	Deficit	4	240 Urea	675.4	A	634.9	A	76.4	A	44.8	1.1	AB	1.077	24.3	5.37
1	Deficit	5	240 ESN	654.8	ABC	612.2	AB	76.3	A	37.2	0.0	B	1.076	21.1	4.71
1	Deficit	6	Var. Rate	670.6	A	630.7	A	76.4	A	41.1	1.0	AB	1.078	17.3	4.32
2	Checkbook	1	Control	476.8	D	444.1	C	57.7	C	41.0	0.0	B	1.075	22.9	3.59
2	Checkbook	2	160 Urea	649.6	ABC	609.6	AB	74.3	AB	44.2	2.0	AB	1.077	20.9	4.07
2	Checkbook	3	160 ESN	634.9	ABC	604.2	AB	78.2	A	33.9	1.1	AB	1.076	20.6	4.20
2	Checkbook	4	240 Urea	660.7	AB	621.1	AB	75.4	AB	40.0	0.0	B	1.081	24.0	4.80
2	Checkbook	5	240 ESN	628.9	ABC	592.4	AB	77.0	AB	33.3	4.1	A	1.076	26.9	4.28
2	Checkbook	6	Var. Rate	648.2	ABC	616.8	AB	77.7	A	39.1	3.2	AB	1.077	23.3	4.77
Main Effect		**Irrigation [I]**		‡ –		–		–		–	*		–	–	–
Main Effect		**Nitrogen [N]**		***		***		***		–	–		–	–	–
Contrast§		Control		***		***		***		–	–		–	–	*
Contrast		Rate		*		*		–		–	–		–	–	–
Contrast		Source		–		–		–		**	–		–	–	–
Contrast		Var. Rate		–		–		–		–	–		–	–	–
Interaction		**I x N**		–		–		–		–	–		–	–	–
Contrast		I x Control		–		–		–		–	–		–	–	–
Contrast		I x Rate		*		*		–		–	–		–	–	–
Contrast		I x Source		–		–		–		–	–		–	–	–
Contrast		I x Var. Rate		–		–		–		–	–		–	–	–

Main Effect	**Date [D]**	*
Interaction	**D x I**	
Interaction	**D x N**	+
Interaction	**D x I x N**	

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

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

§ Non-orthogonal and *a priori* contrasts, as specified in Table ###

Table 6. Treatment means and significance for CROPSCAN Nitrogen Sufficiency Indices response

		6/21/16		6/29/16		7/6/16		7/12/16		7/18/16		7/25/16		8/1/16		8/10/16		8/16/16		8/24/16	
	Nitrogen	**MTCI**																			
1	Control	78.5†	–	76.7	–	69.3	–	63.7	–	61.1	–	54.4	–	48.8	–	44.7	–	42.3	–	54.6	–
2	160 Urea	92.4	–	101.0		92.9	–	84.3	–	87.0	–	87.3	–	92.1	–	92.1	–	88.0	–	82.9	–
3	160 ESN	95.5	–	100.1		95.6	–	90.7	–	91.5	–	88.2	–	85.7	–	83.1	–	78.6	–	78.0	–
4	240 Urea	94.1	–	104.1	+	100		94.3	–	97.3		102.0		104.0	+	107.1	+	106.8	+	108.2	+
6	Var. Rate	97.8		101.4		97.9		93.0	–	93.6	–	96.0	–	101.4		103.0		102.3		101.3	
5	*Reference*	*3.262*		*3.407*		*3.361*		*3.475*		*3.263*		*3.058*		*3.257*		*2.978*		*2.693*		*2.097*	
	Nitrogen	**SR8**																			
1	Control	73.4	–	76.2	–	64	–	54.7	–	53.4	–	47.8	–	40.9	–	41.6	–	45.9	–	74.6	–
2	160 Urea	89.5	–	102.0		87.5	–	76.3	–	79.6	–	83.2	–	85.5	–	89.1	–	84.6	–	82.1	–
3	160 ESN	91.3	–	100.2		91.6	–	85.0	–	86.0	–	83.9	–	78.5	–	76.9	–	74.9	–	77.5	–
4	240 Urea	91.1	–	106.6	+	98.0		89.9	–	92.3	–	101.0		100.2		108.1	+	107.5	+	107.1	+
6	Var. Rate	95.8	–	100.5		94.9	–	88.3	–	89.1	–	94.5	–	99.5		104.3		101.9		100.6	
5	*Reference*	*0.531*		*0.540*		*0.498*		*0.510*		*0.480*		*0.453*		*0.509*		*0.444*		*0.387*		*0.327*	
	Nitrogen	**GRVI**																			
1	Control	82.4	–	80.5	–	76.4	–	71.3	–	68.7	–	61.9	–	58.5	–	54.9	–	52.1	–	55.0	–
2	160 Urea	94.6	–	101.1		94.6	–	87.8	–	89.6	–	90.6	–	95.1	–	94.4	–	90.9	–	86.7	–
3	160 ESN	97.8		100.3		96.2	–	92.4	–	93.8	–	91.8	–	90.4	–	88.0	–	84.1	–	82.1	–
4	240 Urea	95.9	–	103.6	+	99.9		95.9	–	97.6		102.9	+	102.5		105.0	+	105.2	+	106.3	+
6	Var. Rate	98.7		100.5		98.1		94.7	–	94.6	–	97.3		100.9		102.9		102.0		101.2	
5	*Reference*	*9.432*		*9.804*		*9.716*		*9.701*		*9.904*		*9.306*		*9.625*		*8.726*		*8.169*		*6.736*	

† Values followed by – or + are significantly less than or greater than, respectively, the well fertilized reference treatment (i.e. N-treatment 5) using the Fischer Least Significant Difference procedure for protected *post–hoc* multiple comparison at α=0.05

ACKNOWLEDGEMENTS
This project was supported with funding from the Minnesota Area II and Northern Plains Potato Growers Associations, and the Minnesota Department of Agriculture.

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Potato Breeding and Cultivar Development for the Northern Plains
2016 Summary

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Potato is one of the most important horticultural crops produced in North Dakota, Minnesota, and the Northern Plains. The NDSU potato breeding program participates in germplasm enhancement efforts, breeding, selection of superior genotypes, evaluation, and development of improved potato cultivars, for producers and the potato industry in North Dakota, Minnesota, and beyond. Via conventional breeding efforts, the potato improvement team focuses on advancements including durable and long-term pest and stress resistances, improved nutrient and water-use efficiency, enhanced quality and nutritional attributes, combined with high yield potential, to address producer, industry, and consumer needs.

In order to meet the challenges of the NPPGA/MN Area II potato producers and our associated industry, the following research objectives were established for 2016:

1. Develop potato (*Solanum tuberosum* Group Tuberosum L.) cultivars for the Northern Plains, via traditional hybridization, that are genetically superior for yield, disease/pest resistance, and quality attributes.
2. Identify and introgress into adapted potato germplasm, genetic resistance to major and emerging biotic (disease, insect, and nematode pests) and abiotic (cold sweetening resistance, sugar end resistance, amongst others) stressors causing economic losses and/or limiting potato production in the Northern Plains.
3. Identify and develop improved germplasm with enhanced quality attributes for adoption by potato producers, industry, and consumers.

Ninety-five parents were used for hybridizing in 2016; 1139 flower clusters were pollinated, with 217 families created. Sixty percent of the new families had late blight resistance breeding, 48% Colorado Potato Beetle Resistance Breeding, 14 % Verticillium Wilt resistance breeding, 14% PVY resistance breeding, and 3% of hybrids had resistance breeding to Corky Ringspot Disease.

In 2016, seed production, including the seedling nursery, was moved to Baker, MN; 21,606 seedlings, representing 211 families, were evaluated; 430 selections were retained. Unselected seedling tubers were shared with the breeding programs in Colorado, Idaho, Maine, Oregon, and Texas; unselected seedling tubers received from cooperating programs were grown at Larimore ND. Maintenance and increase lots included 187 second, 48 third year, and 219 fourth year and older selection; 70 second year, 30 third year, and 155 fourth year and older, selections were retained.

Yield and evaluation trials were grown at eight locations in North Dakota and Minnesota, five irrigated (Inkster, Larimore, Oakes, Park Rapids, and Williston) and three non-irrigated locations (Crystal, Grand Forks, and Hoople). The fresh market trials at Crystal (fresh, prefresh and North Central Regional non-irrigated) were abandoned after heavy rains and hail in June and beyond

resulted in seed piece decay and extremely poor stands. Twenty-four entries were grown in the chip trial at Hoople, including 15 advancing selections from the NDSU program, and nine standard chipping cultivars. ND7519-1, ND7799c-1, ND102917C-1, ND102922C-3, and ND113394CAB-2 were standouts. The National Chip Breeders Trial (NCPT), with the goals to rapidly identify and develop clones to replace Atlantic for southern production areas, and Snowden from storage, initiated by the USPB and regional chip processors, had 97 entries in the unreplicated trial (eight from NDSU), and 40 in the replicated trial. ND5255-59, ND102858CB-2, ND102921C-3, ND113278-3, and ND102642C-2 had excellent chip color in the initial chipping following grading. Trials at the NPPGA Research Farm south of Grand Forks included the Colorado Potato Beetle defoliation studies, family evaluation and the single replicate selection study. An additional trial was conducted with Dr. Darrin Haagenson's project at the USDA-ARS Potato Worksite assessing foliar and tuber glycoalkaloids of materials

One trial was grown at Inkster, the metribuzin screening trial, conducted in collaboration with Dr. Harlene Hatterman-Valenti's program; there were 26 entries. Advancing selections AND00272-1R, ND8068-5Russ, ND8305-1, and ND092355CR-2Russ exhibit sensitivity based on foliar injury and yield reductions. Eighteen selections and commercially acceptable cultivars were grown in the Oakes trial that included both processing (10) and fresh market (8) genotypes.

Thirty-six advancing selections and industry standards were included in the Larimore Processing Trial. Standouts included ND8068-5Russ, ND050032-4Russ, ND060735-4Russ, ND113065-1Russ, ND113065-2Russ, ND113100-1Russ, and Dakota Russet. Please see Tables 1-3 below for specific research results, including summary tables of agronomic attributes, yield and grade, and quality assessments including fry color. (Results from additional trials supported by this funding will be published in the Valley Potato Grower magazine, posted on-line at the NDSU Potato Breeding Program website, etc.) The preliminary processing trial had 88 entries. The NFPT (National French Fry Processing Trial) is an industry driven trial with evaluations in WA, ID, ND, WI and ME. There were 46 genotypes evaluated (five lines from NDSU). One hundred eighty-seven out-of-state selections were made from seedling tubers shared by the Idaho, Maine, and Texas potato breeding programs. Maintenance plots of second (130), third (20), and fourth (3) year and older clones selected from previous year's out-of-state seedlings were also produced; 19 selections will continue. Fifteen advancing selections were compared to nine industry standard chip clones in the irrigated chip trial. Standouts included ND7519-1 and ND7799c-1. The preliminary chip trial was also grown at Larimore due to space constraints; 68 entries were included as a way to evaluated clones with limited seed more rapidly, and efficiently determine what early selections should continue. The North Central Regional Potato Variety Trial (NCRPVT) has a fresh market focus. Thirty entries from the programs in MI, MN, ND, WI, and Fredericton, NB, were included, many with uniquely colored skin and flesh. NDSU submissions included ND6002-1R, ND79982-1R, ATND99331-2PintoY, ND7834-2P, ND6961-21PY, and ND7818-1Y. Our program also participated with a group from the Pacific Northwest led by Dr. Chuck Brown looking at tuber glycoalkaloid stability/variability across northern/western production locals.

A processing trial with 16 entries, including 3 NDSU advancing selections, was grown at Park Rapids, in collaboration with RDO/LambWeston. A common scab screening trial was conducted; 68 genotypes were evaluated. The Verticillium screening trial was also conducted at Park Rapids. Twenty-five selections and industry standards were included in the replicated trial. DNA from green stems is extracted and colony forming units determined, in addition to determination of yield and grade for the two treatments (fumigation, non-fumigation).

Certified seed of advancing selections ND6002-1R, ND8068-5Russ, ND050032-4Russ, ND7132-1R, ND7519-1R, ND7799c-1, ND8314-1R and WND8625-2Russ for evaluation purposes was produced under MTA by certified seed producers in several states. Additionally, Dakota Russet and Dakota Ruby were widely grown by process and fresh-pack growers, respectively. Dakota Trailblazer is also finding a niche.

ND8068-5Russ, our very early dual-purpose russet, and ND7799c-1, a high yielding chip processing selection will be considered for release in 2017. ND7519-1 and ND6002-1R will be presented to the pre-release committee in March 2017. Please see photos and attribute summaries following the Larimore Processing Trial tables below.

The NDSU potato breeding program is supported by Dick (Richard) Nilles (NPPGA/MN Area II funding). Leah Krabbenhoft defended her thesis on starch attributes in NDSU potato breeding program germplasm during fall semester. That work was supported by North Dakota Specialty Crop Block grant funding (Thompson, Raatz and Simsek). Several manuscripts are planned from these results. Currently, five graduate students are working with the potato breeding program. James Bjerke is characterizing late blight resistance present in the NDSU potato breeding program (Thompson/Secor). Steffen Falde is working on the potential for remote sensing PVY; his work is supported by North Dakota Specialty Crop Block Grant funding (Thompson/MacRae). Razi Ibrahim is evaluating the metribuzin sensitivity model for appropriateness for northern plains production conditions (Hatterman-Valenti/Thompson); preliminary work suggests that a new model equation will be necessary to more accurately assess sensitivity. Blake Greiner is screening NDSU potato germplasm for resistance to *Dickeya* and *Pectobacterium* species, and developing a rapid screening technique for plant diagnostic laboratories (Secor/Thompson). His work is supported by North Dakota Specialty Crop Block Grant funding. Sanzida Rahman joined our program in January 2017. She is building on the PVY remote sensing work, comparing reflectance data for PVY and nitrogen deficiency, in order to be sure that we can ascertain differences in widely grown potato cultivars in our area; her work is also supported by North Dakota Specialty Crop Block Grant funding (Thompson/MacRae).

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

Table 1. Agronomic and quality evaluations for advanced processing selections and cultivars, full season, Larimore, ND, 2016.

Clone	% Stand	Vine Size[1]	Vine Maturity[2]	Stems per Plant	Specific Gravity[3]	% Hollow Heart[4]	Black-spot Bruise[5]
1. AND97279-5Russ	99	4.0	3.5	2.1	1.0991	0	3.7
2. ND8068-5Russ	93	1.0	1.0	2.0	1.0896	1	3.6
3. ND050032-4Russ	95	4.0	2.5	1.7	1.0945	3	2.9
4. ND060735-4Russ	94	3.3	2.5	1.7	1.0935	20	2.7
5. ND070927-2Russ	98	1.8	1.0	2.3	1.0915	0	2.2
6. ND081764B-4Russ	79	3.0	3.5	1.2	1.0867	0	3.2
7. ND091933ABCR-2Russ	96	3.0	1.8	2.5	1.0812	19	3.9
8. ND091933ABCR-7Russ	95	2.8	1.3	2.2	1.0850	23	3.0
9. ND091938BR-2Russ	83	4.3	3.3	1.8	1.0909	5	2.4
10. ND091997BT-3Russ	90	3.0	1.5	2.5	1.0944	3	2.2
11. ND092007R-2Russ	91	3.8	1.6	2.2	1.0858	9	3.3
12. ND092019C-4Russ	96	1.5	1.0	2.3	1.0976	0	2.6
13. ND092024CR-1Russ	91	3.0	1.0	2.1	1.0875	10	3.0
14. ND102647-3Russ	96	2.0	1.4	2.2	1.0898	8	2.2
15. ND102687AB-1Russ	81	4.0	3.5	1.8	1.0995	20	4.0
16. ND102719B-1Russ	86	4.3	3.8	1.6	1.0949	8	3.4
17. ND102721b-1Russ	88	2.0	2.8	1.9	1.0986	0	2.1
19. ND113065CB-1Russ	94	3.3	2.0	1.7	1.0797	3	3.5
20. ND113065CB-2Russ	94	3.5	1.8	2.1	1.0798	3	3.0
21. ND113100-1Russ	96	4.3	2.3	2.5	1.0853	1	2.2
22. ND113174B-2Russ	93	4.8	3.8	2.0	1.1033	3	3.6
23. ND113224C-3Russ	96	2.5	1.1	2.2	1.1062	0	3.5
24. ND113330-1Russ	90	1.3	1.1	1.8	1.0762	0	3.2
25. Proprietary	98	4.0	2.3	2.0	1.0833	3	1.7
26. WND8524-2Russ	86	1.8	1.5	1.4	1.0825	0	4.0
27. WND8625-2Russ	86	3.5	1.8	1.9	1.0844	1	2.7
28. Alpine Russet	95	3.8	3.5	1.7	1.0862	1	3.0
29. Bannock Russet	90	4.5	3.5	2.4	1.0934	5	2.7
30. Dakota Russet	91	3.5	3.5	1.5	1.0944	4	2.4
31. Dakota Trailblazer	94	4.8	4.0	1.4	1.1074	6	2.4
32. Ranger Russet	96	3.5	2.8	1.9	1.0994	1	4.0
33. Russet Burbank	95	5.0	3.5	2.2	1.0886	19	2.3
34. Russet Norkotah	88	3.0	1.6	1.9	1.0811	9	3.4
35. Shepody	89	3.3	2.6	1.7	1.0810	1	2.5
36. Umatilla Russet	94	3.5	3.0	2.1	1.0826	0	2.9
Mean	92	3.3	2.4	2.0	1.0901	5	2.9
LSD ($\propto$=0.05)	9	0.9	0.9	0.6	0.0083	7	1.1

[1] Vine size – scale 1-5, 1 = small, 5 = large.
[2] Vine maturity – scale 1-5, 1 = early, 5 = late.
[3] Determined using weight-in-air, weight-in-water method.
[4] Hollow heart includes brown center.
[5] Blackspot bruise determined by the abrasive peel method, scale 1-5, 1=none, 5=severe.

Table 2. Yield and grade for advanced processing selections and cultivars, full season, Larimore, ND, 2016.

Clone	Total Yield Cwt./A	US No. 1 Cwt./A	US No. 1 %	0-4 oz. %	4-6 oz. %	6-12 oz. %	>12 oz. %	US No. 2 %	Culls %
1. AND97279-5Russ	301	190	61	34	38	12	11	0	5
2. ND8068-5Russ	221	166	75	16	37	19	19	4	5
3. ND050032-4Russ	322	233	72	15	37	17	18	0	13
4. ND060735-4Russ	304	236	77	17	39	18	20	1	5
5. ND070927-2Russ	339	219	64	29	43	16	5	0	6
6. ND081764B-4Russ	301	253	84	14	52	22	10	0	1
7. ND091933ABCR-2Russ	335	223	66	28	40	14	11	2	4
8. ND091933ABCR-7Russ	352	229	68	30	44	16	8	2	0
9. ND091938BR-2Russ	294	233	78	12	40	19	20	4	5
10. ND091997BT-3Russ	316	206	63	36	43	14	7	0	1
11. ND092007R-2Russ	244	180	72	25	45	18	11	0	2
12. ND092019C-4Russ	223	116	52	41	37	11	4	0	7
13. ND092024CR-1Russ	224	149	67	28	45	13	8	1	4
14. ND102647-3Russ	233	126	53	45	40	10	3	1	0
15. ND102687AB-1Russ	219	189	85	9	34	17	33	5	1
16. ND102719B-1Russ	261	217	83	7	23	12	48	1	9
17. ND102721b-1Russ	187	114	60	35	38	14	7	1	4
19. ND113065CB-1Russ	231	179	74	23	35	14	25	2	1
20. ND113065CB-2Russ	288	249	86	14	38	15	33	1	0
21. ND113100-1Russ	301	223	74	15	32	17	25	2	9
22. ND113174B-2Russ	298	207	68	20	39	15	13	4	8
23. ND113224C-3Russ	332	196	59	20	35	13	11	0	21
24. ND113330-1Russ	192	143	73	24	42	16	15	0	2
25. Proprietary	319	194	61	36	42	14	5	2	1
26. WND8524-2Russ	157	120	74	26	44	18	12	0	0
27. WND8625-2Russ	199	153	77	20	40	18	19	2	1
28. Alpine Russet	304	227	70	21	37	14	20	1	7
29. Bannock Russet	227	151	64	27	38	12	13	0	10
30. Dakota Russet	335	275	82	12	31	15	36	0	6
31. Dakota Trailblazer	268	215	80	13	38	17	24	2	5
32. Ranger Russet	372	239	63	15	29	13	21	1	21
33. Russet Burbank	480	242	50	9	21	9	19	0	41
34. Russet Norkotah	255	197	74	18	37	16	21	0	7
35. Shepody	247	168	66	20	33	17	16	6	8
36. Umatilla Russet	239	99	39	47	29	7	3	0	14
Mean	278	194	69	23	38	15	17	1	7
LSD ($\propto$=0.05)	75	67	10	10	8	5	11	2	7

Table 3. Shatter bruise potential and French fry evaluations following harvest and after 8 weeks storage at 45F, full season trial, Larimore, ND, 2016.

Clone	Shatter Bruise[1]	Fry Color[2]	Stem-end Color	% Sugar End[3]	Fry Color[2]	Stem-end Color	% Sugar End[3]
		Field Fry			Following 8 wks. at 45F		
1. AND97279-5Russ	2.2	0.5	1.3	58	0.5	2.5	100
2. ND8068-5Russ	2.4	0.5	1.0	67	0.9	2.1	67
3. ND050032-4Russ	2.1	0.4	1.4	58	0.4	0.8	42
4. ND060735-4Russ	1.9	0.4	0.4	0	0.4	0.4	0
5. ND070927-2Russ	2.5	0.5	0.7	17	0.5	0.9	50
6. ND081764B-4Russ	2.5	0.6	0.8	33	0.8	2.6	59
7. ND091933ABCR-2Russ	2.7	0.4	0.5	8	0.4	0.7	34
8. ND091933ABCR-7Russ	2.5	0.2	0.2	0	0.4	0.5	17
9. ND091938BR-2Russ	2.8	0.5	0.9	59	1.0	1.7	50
10. ND091997BT-3Russ	2.5	1.4	2.0	42	1.9	2.4	34
11. ND092007R-2Russ	2.4	1.1	2.1	58	1.6	2.7	50
12. ND092019C-4Russ	2.8	2.0	2.7	33	1.2	2.5	56
13. ND092024CR-1Russ	2.8	1.8	2.0	17	1.9	2.8	42
14. ND102647-3Russ	2.1	0.4	1.0	50	0.4	1.6	67
15. ND102687AB-1Russ	2.3	0.8	2.5	84	0.8	2.3	84
16. ND102719B-1Russ	2.2	0.6	1.0	33	0.5	1.4	50
17. ND102721b-1Russ	2.4	0.3	0.5	8	0.4	0.5	25
19. ND113065CB-1Russ	1.7	2.0	2.3	17	3.1	3.8	25
20. ND113065CB-2Russ	1.9	2.1	2.2	8	3.1	3.4	8
21. ND113100-1Russ	2.5	0.7	1.5	67	0.9	1.7	59
22. ND113174B-2Russ	2.0	0.7	2.4	42	1.1	1.6	34
23. ND113224C-3Russ	2.7	1.0	1.8	67	0.9	2.5	84
24. ND113330-1Russ	2.8	1.8	2.1	25	1.2	2.7	67
25. Proprietary	2.6	0.6	1.3	67	0.8	1.4	67
26. WND8524-2Russ	2.4	1.8	2.0	8	2.7	2.7	0
27. WND8625-2Russ	2.2	1.0	1.1	17	1.4	1.8	33
28. Alpine Russet	2.3	1.0	1.0	0	1.1	1.7	42
29. Bannock Russet	1.9	0.6	0.8	34	0.9	1.4	42
30. Dakota Russet	2.4	0.3	0.5	8	0.5	0.6	8
31. Dakota Trailblazer	2.3	0.8	1.0	17	0.9	1.2	34
32. Ranger Russet	2.2	0.7	1.5	67	0.9	1.7	42
33. Russet Burbank	2.1	0.9	3.0	83	1.5	2.7	50
34. Russet Norkotah	1.9	2.1	2.6	25	3.5	3.5	0
35. Shepody	2.8	0.7	1.1	50	2.3	2.5	8
36. Umatilla Russet	1.8	1.1	1.4	25	0.8	1.5	67
Mean	2.3	0.9	1.4	36	1.2	1.9	42
LSD ($\propto$=0.05)	0.8	0.5	0.7	41	0.8	0.8	45

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

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

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

Promising selections for release consideration.

ND8068-5Russ

- ND2667-9Russ x ND4233-1Russ
- Medium vine size
- Very early vine maturity
- Medium to high yield potential
- Dual-purpose
- High specific gravity
- Pre-harvest irrigation and bruise prevention strategies should be employed to mitigate blackspot
- Good storability with low sugar accumulation and excellent frozen processing quality after 7 months storage
- Russet Norkotah fertility regime

ND7799c-1

- Dakota Pearl x NY115
- Medium vine size
- Medium-late maturity
- High yield potential
  - Nice tuber type and tuber size profile
- Medium to high specific gravity (1.086 average)
- Chips from 42F storage

ND6002-1R

- NorDonna x Bison
- Medium sized vine
- Medium maturity
- Medium yield potential
- Round, smooth, bright red tubers with smooth eyes and bright white flesh
- Medium specific gravity
- Some silver scurf noted.

ND7519-1

- ND3828-15 x W1353
- Medium sized vine
- Medium-late maturity
- High yield potential
- High specific gravity (+1.090 average in ND)
- Chips from 42F storage

Stability of Verticillium Resistance in French Fry Potato Cultivars
Submitted to MN Area II Potato Growers

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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. Despite decades of research to control VW, this disease continues to be a recurrent problem for potato production throughout the country. It can result in yield losses of up to 50% and is currently controlled by fumigation. In addition to its cost, fumigation is undesirable due to its environmental impacts. Additionally, based on questions and discussions with the potato industry, many growers perceive that fumigation is still required when they are growing VW resistant cultivars such as Bannock Russet, Alturas, or Dakota Trailblazer. The development of cultivars with higher levels of resistance would provide a longer term solution for the control of VW and full characterization of the stability of current levels of VW resistance in cultivars under higher inoculum levels to address the concerns of potato growers is warranted.

Current and Previous Research

We have established in previous research that *V. dahliae* colonization in potato stems can be quantified efficiently with PCR techniques (Pasche, et al. 2013). We also demonstrated that potato cultivars with reportedly high levels of Verticillium wilt resistance are colonized by the pathogen at different levels and that some cultivars develop high levels of inoculum within the vascular tissue of the potato stems late in the season (Pasche, et al. 2014). We also demonstrated that potato cultivars that have been named and released with reportedly high levels of Vertcillium resistance, based solely on visual disease assessments, may not be as resistant to Verticillium wilt as once believed. Current research has demonstrated that some of these cultivars may succumb to Verticillium wilt under controlled conditions if planted in soil with high levels of *V. dahliae* (>200 vppg), soil levels of the pathogen that are not unusual in our potato production region due to relatively short rotations and the lack of vine desiccation that allows the pathogen to increase its reproduction.

Research Objectives

1. Determine the yield of VW resistant cultivars under field conditions when grown in soils that are fumigated with metam sodium or left non-fumigated.
2. Determine the level of inoculum returned to the soil in the stems of Verticillium resistant cultivars grown under fumigated and non-fumigated soil.

Research Plan

The field trial will be conducted under conditions typical of commercial potato production under overhead sprinkler irrigation in west central Minnesota including cultivation, standard fungicide, insecticide, and herbicide regimes. The field used for this trial will be one with an initial *V. dahliae* level of >40 verticillium propagules per gram of soil, prior to fumigation with metam sodium. Replicated strips of fumigated and non-fumigated will be used to plant potato cultivars such as Russet Burbank (susceptible check), Dakota Russet, Ranger Russet, Bannock Russet, Premier Russet, Alpine Russet,

Dakota Trailblazer, and Clearwater Russet. We will use approximately 8-10 cultivars with varying reported levels of resistance to *V. dahliae*. We will also add additional soil inoculum of *V. dahliae* in an attempt to increase the soil levels of the pathogen to determine if increased levels of this pathogen affects the expression of disease resistance.

The field experiment will be arranged in a split-plot design with soil populations of *V. dahliae* blocked by cultivar with four replications planted at 0.3 m seed spacing in two 6.1 m rows, 0.9 m apart.

Disease severity will be determined at approximately 7 to 10 day intervals by estimating the percentage of the canopy with wilted / senescent foliage. Wilt severity was transformed to area under the wilt progress curve (AUWPC) following to the method outlined by Shaner and Finney (1977) and AUWPC values were normalized by dividing them by the total area of the graph and the resulting relative area under the wilt progress curve (RAUWPC) was used to compare treatments. Potato stems at the end of the season will be sampled within each treatment and assayed to determine *V. dahliae* populations using quantitative PCR. Total yield and marketable yield will be determined at the end of the growing season.

Results

The addition of Verticillium inoculum to the hill significantly increased the level of soil inoculum the potato cultivars were exposed to (Table 1), however, it did not substantially increase the severity of Verticillium wilt or negatively affect yield in most cultivars (Table 2).

Table 1. Verticillium propagules per gram (VPPG) in the hill and in the furrow in Vapam- treated and non-treated soil. Soil inoculum was either resident inoculum or added to the hill through soil infestation prior to planting.

Treatment	VPPG Hill	VPPG Furrow	Mean
No Vapam-Inoculated	40.0a	41.0a	40.5a
No Vapam	23.5b	18.0b	20.7b
Vapam	12.5c	10.5c	11.5c

There were significant differences among potato cultivars and their susceptibility Verticillium wilt. Cultivars such as Dakota Trailblazer, Ranger Russet, Clearwater Russet, Bannock Russet, and Alturas expressed significantly less Verticillium wilt than the control cultivar Russet Burbank (Table 2). Cultivars such as Dakota Trailblazer, Alturas, Bannock Russet, and Clearwater Russet were found to be highly resistant to Verticillium wilt and the application of soil fumigants such as metam sodium (Vapam) did not significantly increase yield.

These studies will be repeated and expanded in 2017 with financial support of the ND Specialty Crop Block Grant system.

References

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Table 2. Impact of Potato Cultivar and Genetic Resistance to Verticillium Wilt on the Use of Metam Sodium (Vapam) on the Expression of Verticillium Wilt and Yield

Cultivar	Treatment	Emergence (%)	Wilt (% Severity)								AUDPC	RAUDPC	Yield (cwt/a)
		6/20	7/19	7/26	8/2	8/9	8/16	8/22	8/31	9/7			
Alpine Russet	Non vapam	93.33	0.03	2.06	4.38	4.00	6.44	9.19	13.63	71.38	542.71	0.11	506.07
Alpine Russet	Non vapam-inoculated	90.00	0.03	2.00	3.81	3.75	5.94	8.31	13.38	74.44	535.52	0.11	517.60
Alpine Russet	Vapam	90.00	0.02	2.44	3.75	3.81	6.25	7.38	13.75	64.94	503.28	0.10	547.69
Alturas Russet	Non vapam	89.17	0.00	1.97	3.31	3.88	5.38	6.50	8.75	40.00	357.78	0.07	617.96
Alturas Russet	Non vapam-inoculated	90.00	0.02	1.63	3.00	3.50	5.63	6.38	9.13	42.63	363.50	0.07	574.52
Alturas Russet	Vapam	95.00	0.00	1.50	3.06	3.44	5.38	6.19	8.25	31.94	315.13	0.06	601.09
Bannock Russet	Non vapam	88.33	0.04	1.56	2.88	3.31	5.00	6.44	8.88	39.69	345.09	0.07	467.84
Bannock Russet	Non vapam-inoculated	89.17	0.03	1.63	2.81	3.19	5.13	5.94	8.94	43.56	355.28	0.07	519.54
Bannock Russet	Vapam	90.83	0.02	2.25	3.44	3.75	4.56	6.13	9.38	43.63	369.41	0.07	474.27
Clearwater Russet	Non vapam	89.17	0.04	2.00	3.88	4.13	5.94	7.31	11.88	60.00	468.57	0.09	504.85
Clearwater Russet	Non vapam-inoculated	87.50	0.06	2.03	4.00	5.38	7.19	8.81	13.81	66.06	534.59	0.11	499.76
Clearwater Russet	Vapam	86.67	0.04	1.91	4.19	4.75	5.50	7.00	10.31	49.19	418.97	0.08	525.00
Dakota Russet	Non vapam	82.50	0.05	1.50	5.06	5.19	6.19	8.56	12.69	67.88	525.93	0.11	471.48
Dakota Russet	Non vapam-inoculated	84.17	0.06	1.78	5.25	5.25	6.81	10.13	15.13	70.00	572.41	0.11	435.56
Dakota Russet	Vapam	79.17	0.03	2.28	5.88	5.06	5.81	9.06	12.69	69.13	541.81	0.11	440.41
Dakota Trailblazer	Non vapam	85.83	0.04	1.19	2.88	3.38	4.75	7.13	10.94	54.50	414.76	0.08	451.22
Dakota Trailblazer	Non vapam-inoculated	91.67	0.03	1.44	3.06	4.06	4.75	7.00	10.75	57.69	431.33	0.09	444.17
Dakota Trailblazer	Vapam	88.33	0.02	1.31	2.56	3.31	4.06	5.88	8.69	38.44	324.88	0.06	496.00
Ranger Russet	Non vapam	95.00	0.08	3.13	6.13	4.88	6.56	8.25	11.31	60.81	507.01	0.10	536.89
Ranger Russet	Non vapam-inoculated	91.67	0.12	2.94	5.81	5.38	7.31	8.13	11.38	62.50	517.51	0.10	512.62
Ranger Russet	Vapam	96.67	0.06	2.81	6.13	5.56	6.06	7.44	10.50	51.81	462.23	0.09	508.13
Russet Burbank	Non vapam	90.83	0.03	1.88	4.19	4.56	6.31	8.06	14.06	75.63	553.17	0.11	530.10
Russet Burbank	Non vapam-inoculated	90.83	0.04	2.00	4.19	5.13	7.06	8.25	14.19	77.69	572.53	0.11	545.63
Russet Burbank	Vapam	89.17	0.04	2.94	4.13	5.19	6.25	7.56	12.25	61.44	496.28	0.10	566.14
$LSD_{P = 0.05}$		NS	0.04	0.44	0.53	0.56	0.60	0.70	1.55	5.43	59.85	0.01	43.54

Main effects (*P* value)	Emergence(%)	W1	W2	W3	W4	W5	W6	W7	W8	AUDPC	RAUDPC	Yield
Treatment	0.99	0.05	0.05	0.50	0.12	0.00	0.00	0.06	0.00	0.0007	0.0007	0.27
Cultivar	0.00	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Trt*Cul	0.91	0.89	0.11	0.31	0.15	0.34	0.02	0.91	0.89	0.679	0.679	0.08

Cultivar	Emergence(%)	W1	W2	W3	W4	W5	W6	W7	W8	AUDPC	RAUDPC	Yield (cwt/a)
Alpine Russet	91.11a	0.03b	2.17b	3.98b	3.85b	6.20ab	8.29b	13.58a	70.25a	527.17ab	0.11ab	523.78bc
Alturas Russet	91.38a	0.01b	1.70bc	3.13c	3.60b	5.45bc	6.35c	8.71c	38.18c	345.47c	0.07c	597.85a
Bannock Russet	89.44ab	0.03b	1.81bc	3.04c	3.41b	4.90cd	6.16c	9.06c	42.29c	356.59c	0.07c	487.21cd
Clearwater Russet	87.77ab	0.05ab	1.98b	4.02b	4.75a	6.21ab	7.71b	12.0ab	58.42ab	474.04b	0.09b	509.87bc
Dakota Russet	81.94b	0.05ab	1.85bc	5.39a	5.17a	6.27ab	9.25a	13.5a	69.00a	546.71a	0.11ab	449.15d
Dakota Trailblazer	88.61ab	0.03b	1.31c	2.83c	3.58b	4.52d	6.66c	10.12bc	50.21bc	390.32c	0.08c	463.79d
Ranger Russet	94.45a	0.08a	2.96a	6.02a	5.27a	6.65a	7.93b	11.06abc	58.38ab	495.58ab	0.10ab	519.21bc
Russet Burbank	90.27a	0.04b	2.27b	4.17b	4.96a	6.54a	7.95b	13.5a	71.58a	540.65ab	0.11ab	547.28b

Treatment	Emergence(%)	W1	W2	W3	W4	W5	W6	W7	W8	AUDPC	RAUDPC	Yield (cwt/a)
Vapam	89.47	0.03	2.18	4.14	4.35	5.48	7.08	10.73	51.31	429.00	0.09	519.84
Non vapam	89.27	0.04	1.91	4.08	4.16	5.82	7.68	11.52	58.73	464.38	0.09	510.80
Non vapam - inoculated	89.37	0.05	1.93	3.99	4.45	6.23	7.87	12.09	61.80	485.33	0.10	506.17

Starter Fertilizer. Harlene Hatterman-Valenti and Collin Auwarter.

Field research was conducted in 2016 at the Northern Plains Potato Grower's Association non-irrigated research site near Grand Forks, ND to evaluate starter fertilizer on Red Lasoda potatoes. Potatoes were planted on June 8, with the starter fertilizer applied on both sides of the seed piece in the furrow. Potatoes were maintained through the season with typical grower standard practices when needed. Potatoes were harvested on October 24 and graded for yield. Treatments were applied on two rows (A & B). Each row consisted of 20 row ft with seed pieces planted 12 inches apart and rows were 36 inches apart. The 'B' rows was harvested in the field, weighed, and then discarded. The 'A' row was graded for yield. Although total and marketable yields did not statistically differ due to the limited number of degrees of freedom in the error term and the variability of potato, treatment 4 (10-34-0 @ 25 gal/a + WC139 @ 5 gal/a) and treatment 8 (10-34-0 @ 23 gal/a + WC139 @ 5 gal/a + WC246 @ 1 qt/a) increased marketable by approximately 12 cwt/a and total yield by approximately 8 cwt/a compared to 10-34-0 @ 30 gal/a. More importantly treatment 2 had the greatest yield for tubers > 12 oz (165 cwt/a), a negative characteristic for the red potato fresh market. Treatments 4 and 8 on the other hand produced more tubers in the creamer market, a potentially positive characteristic.

Crop Code				SOLTU	SOLTU	SOLTU	SOLTU	SOLTU	SOLTU	SOLTU
Crop Name				Potato	Potato	Potato	Potato	Potato	Potato	Potato
Crop Variety				Red Lasoda	Red Lasoda	Red Lasoda	Red Lasoda	Red Lasoda	Red Lasoda	Red Lasoda
Description				B ROW	A ROW	A ROW	A ROW	A ROW	A ROW	A ROW
Part Rated				TUBER C	TUBER C	TUBER C	TUBER C	TUBER C	TUBER C	TUBER C
Rating Date				10-24-2016	10-24-2016	10-24-2016	10-24-2016	10-24-2016	10-24-2016	10-24-2016
Rating Type					Total	Total	0-4 oz	4-6 oz	6-12 oz	>12 oz
Rating Unit				lb/row	lb/row	#/row	CWT/A	CWT/A	CWT/A	CWT/A
Number of Subsamples				1	1	1	1	1	1	1
Days After First/Last Applic.				129 129	129 129	129 129	129 129	129 129	129 129	129 129
Trt-Eval Interval				114 DA-A	114 DA-A	114 DA-A	114 DA-A	114 DA-A	114 DA-A	114 DA-A
Plant-Eval Interval				129 DP-1	129 DP-1	129 DP-1	129 DP-1	129 DP-1	129 DP-1	129 DP-1
Days After Emergence				111 DE	111 DE	111 DE	111 DE	111 DE	111 DE	111 DE
Trt No.	Treatment Name	Rate	Rate Unit	Appl Code	1	2	3	4	5	6	7
1	Untreated Check				40.20 b	31.433 b	78.3 b	22.3475021 a	83.878 a	45.773 a	76.198 b
2	10-34-0	30	gal/a	A	52.48 a	46.688 a	107.0 a	26.7025021 a	94.028 a	53.103 a	165.110 a
3	10-34-0	29.75	gal/a	A	52.63 a	45.138 a	114.5 a	28.9725027 a	107.130 a	62.868 a	128.720 ab
	WC 246	1	qt/a	A							
4	10-34-0	25	gal/a	A	52.80 a	48.318 a	116.0 a	30.8900025 a	110.230 a	64.048 a	145.620 a
	WC 139	5	gal/a	A							
5	10-34-0	23	gal/a	A	54.03 a	46.438 a	110.8 a	29.0850020 a	91.395 a	63.843 a	152.813 a
	WC 139	7	gal/a	A							
6	10-34-0	30	gal/a	A	49.65 a	44.515 a	116.0 a	33.9725032 a	105.020 a	56.878 a	127.288 ab
	CHS Unlocked	4	fl oz/a	A							
7	10-34-0	29.75	gal/a	A	53.08 a	45.433 a	111.8 a	31.4250043 a	97.068 a	57.538 a	143.815 a
	WC 246	1	qt/a	A							
	CHS Unlocked	4	fl oz/a	A							
8	10-34-0	23	gal/a	A	53.13 a	48.470 a	118.0 a	32.0250047 a	105.440 a	64.740 a	149.670 a
	WC 139	5	gal/a	A							
	WC 246	1	qt/a	A							
LSD (P=.05)					7.021	7.3447	19.32	10.62210475	20.9686	14.2875	46.6567
Standard Deviation					4.774	4.9938	13.13	7.22207905	14.2568	9.7142	31.7224
CV					9.36	11.21	12.05	24.54	14.36	16.58	23.3
Bartlett's X2					11.795	10.888	3.617	13.765	5.094	2.517	5.972
P(Bartlett's X2)					0.107	0.144	0.823	0.056	0.649	0.926	0.543
Replicate F					1.256	1.831	1.551	2.317	1.500	0.775	2.450
Replicate Prob(F)					0.3148	0.1725	0.2308	0.1049	0.2436	0.5209	0.0919
Treatment F					3.623	4.832	3.874	1.001	1.643	1.889	2.939
Treatment Prob(F)					0.0102	0.0023	0.0074	0.4577	0.1782	0.1226	0.0261

Means followed by same letter do not significantly differ (P=.05, Student-Newman-Keuls)
Mean comparisons performed only when AOV Treatment P(F) is significant at mean comparison OSL.

Part Rated
TUBER = tuber
C = Crop is Part Rated
Rating Unit
% = percent
Plant-Eval Interval
129 DP-1 = 1 6-6-2016

Table 1. continued

Crop Variety				Red Lasoda	Red Lasoda	Red Lasoda	Red Lasoda	Red Lasoda	Red Lasoda	Red Lasoda
Description				A ROW	A ROW	A ROW	A ROW	A ROW	A ROW	A ROW
Part Rated				TUBER C	TUBER C	TUBER C	TUBER C	TUBER C	TUBER C	TUBER C
Rating Date				10-24-2016	10-24-2016	10-24-2016	10-24-2016	10-24-2016	10-24-2016	10-24-2016
Rating Type				Total	> 4 oz	0-4 oz	4-6 oz	6-12 oz	> 12 oz	> 4 oz
Rating Unit				CWT/A	CWT/A	#/row	#/row	#/row	#/row	#/row
Days After First/Last Applic.				129 129	129 129	129 129	129 129	129 129	129 129	129 129
Trt-Eval Interval				114 DA-A	114 DA-A	114 DA-A	114 DA-A	114 DA-A	114 DA-A	114 DA-A
Plant-Eval Interval				129 DP-1	129 DP-1	129 DP-1	129 DP-1	129 DP-1	129 DP-1	129 DP-1
Days After Emergence				111 DE	111 DE	111 DE	111 DE	111 DE	111 DE	111 DE
Trt No.	Treatment Name	Rate	Rate Unit	Appl Code	8	9	10	11	12	13	14
1	Untreated Check				228.193 b	205.845 b	23.0 b	29.3 a	13.3 a	12.8 b	55.3 b
2	10-34-0	30	gal/a	A	338.940 a	312.238 a	34.0 ab	32.3 a	14.8 a	26.0 a	73.0 a
3	10-34-0	29.75	gal/a	A	327.690 a	298.720 a	38.3 ab	37.0 a	17.5 a	21.8 a	76.3 a
	WC 246	1	qt/a	A							
4	10-34-0	25	gal/a	A	350.785 a	319.895 a	37.3 ab	37.5 a	17.8 a	23.5 a	78.8 a
	WC 139	5	gal/a	A							
5	10-34-0	23	gal/a	A	337.140 a	308.055 a	38.3 ab	29.5 a	17.3 a	25.8 a	72.5 a
	WC 139	7	gal/a	A							
6	10-34-0	30	gal/a	A	323.163 a	289.188 a	42.3 a	36.8 a	15.8 a	21.3 a	73.8 a
	CHS Unlocked	4	fl oz/a	A							
7	10-34-0	29.75	gal/a	A	329.845 a	298.423 a	39.5 ab	32.8 a	15.8 a	23.8 a	72.3 a
	WC 246	1	qt/a	A							
	CHS Unlocked	4	fl oz/a	A							
8	10-34-0	23	gal/a	A	351.878 a	319.853 a	40.5 a	36.0 a	18.0 a	23.5 a	77.5 a
	WC 139	5	gal/a	A							
	WC 246	1	qt/a	A							
LSD (P=.05)					53.3269	50.2050	10.98	7.34	4.15	7.22	12.49
Standard Deviation					36.2575	34.1349	7.46	4.99	2.82	4.91	8.49
CV					11.21	11.61	20.38	14.72	17.37	22.04	11.73
Bartlett's X2					10.87	10.05	10.134	4.104	4.752	4.153	12.691
P(Bartlett's X2)					0.144	0.186	0.181	0.768	0.69	0.762	0.08
Treatment Prob(F)					0.0023	0.0025	0.0426	0.1320	0.2540	0.0269	0.0242

Crop Variety				Red Lasoda
Description				A ROW
Part Rated				TUBER C
Rating Date				10-24-2016
Rating Type				> 4 oz
Rating Unit				%
Days After First/Last Applic.				129 129
Trt-Eval Interval				114 DA-A
Plant-Eval Interval				129 DP-1
Days After Emergence				111 DE
Trt No.	Treatment Name	Rate	Rate Unit	Appl Code	15
1	Untreated Check				70.9075083 a
2	10-34-0	30	gal/a	A	68.2450096 a
3	10-34-0	29.75	gal/a	A	66.7150030 a
	WC 246	1	qt/a	A	
4	10-34-0	25	gal/a	A	68.4025108 a
	WC 139	5	gal/a	A	
5	10-34-0	23	gal/a	A	65.6425084 a
	WC 139	7	gal/a	A	
6	10-34-0	30	gal/a	A	63.4425074 a
	CHS Unlocked	4	fl oz/a	A	
7	10-34-0	29.75	gal/a	A	64.9775074 a
	WC 246	1	qt/a	A	
	CHS Unlocked	4	fl oz/a	A	
8	10-34-0	23	gal/a	A	65.5775059 a
	WC 139	5	gal/a	A	
	WC 246	1	qt/a	A	
LSD (P=.05)					7.03542970
Standard Deviation					4.78346205
CV					7.17
Bartlett's X2					9.617
P(Bartlett's X2)					0.211
Treatment Prob(F)					0.4763

Starter Fertilizer. Harlene Hatterman-Valenti and Collin Auwarter.

Field research was conducted in 2016 at the Northern Plains Potato Grower's Association irrigated research site near Inkster, ND to evaluate starter fertilizer on Russet Burbank potatoes. Potatoes were planted on June 8, with the starter fertilizer applied on both sides of the seed piece in the furrow. Potatoes were maintained through the season with typical grower standard practices when needed. Potatoes were harvested on October 13 and graded for yield. Treatments were applied on two rows (A & B). Each row consisted of 20 row ft with seed pieces planted 12 inches apart and rows were 36 inches apart. The 'B' rows was harvested in the field, weighed, and then discarded. The 'A' row was graded for yield.

Although total and marketable yields did not statistically differ due to the limited number of degrees of freedom in the error term and the variability of potato, treatment 4 (10-34-0 @ 25 gal/a + WC139 @ 5 gal/a) increased marketable and total yield by approximately 20 cwt/a compared to 10-34-0 @ 30 gal/a.

Table 1. Starter fertilizer grade and yield.

Crop Code					SOLTU	SOLTU	SOLTU	SOLTU	SOLTU	SOLTU
Crop Name					Potato	Potato	Potato	Potato	Potato	Potato
Crop Variety					Russet Burbank	Russet Burbank	Russet Burbank	Russet Burbank	Russet Burbank	Russet Burbank
Description					B ROW	A ROW	A ROW	A ROW	A ROW	A ROW
Part Rated					TUBER C	TUBER C	TUBER C	TUBER C	TUBER C	TUBER C
Rating Date					10-13-2016	10-13-2016	10-13-2016	10-13-2016	10-13-2016	10-13-2016
Rating Type						Total	Total	0-4 oz	4-6 oz	6-12 oz
Rating Unit					lb/row	lb/row	#/row	CWT/A	CWT/A	CWT/A
Number of Subsamples					1	1	1	1	1	1
Days After First/Last Applic.					129 129	129 129	129 129	129 129	129 129	129 129
Trt-Eval Interval					114 DA-A	114 DA-A	114 DA-A	114 DA-A	114 DA-A	114 DA-A
Plant-Eval Interval					129 DP-1	129 DP-1	129 DP-1	129 DP-1	129 DP-1	129 DP-1
Days After Emergence					111 DE	111 DE	111 DE	111 DE	111 DE	111 DE
Trt No.	Treatment Name	Rate	Rate Unit	Appl Code	1	2	3	4	5	6
1	Untreated Check				69.28 a	53.468 a	130.0 a	41.793 a	75.1425093 a	185.095 a
2	10-34-0	30	gal/a	A	68.70 a	64.713 a	152.3 a	49.040 a	59.9850066 a	235.373 a
3	10-34-0	29.75	gal/a	A	68.55 a	62.210 a	143.3 a	43.413 a	67.9275047 a	210.360 a
	WC 246	1	qt/a	A						
4	10-34-0	25	gal/a	A	70.85 a	67.248 a	153.0 a	47.698 a	71.5125041 a	233.173 a
	WC 139	5	gal/a	A						
5	10-34-0	23	gal/a	A	67.75 a	63.595 a	141.3 a	42.893 a	59.4650061 a	219.843 a
	WC 139	7	gal/a	A						
6	10-34-0	30	gal/a	A	64.73 a	54.910 a	131.0 a	43.095 a	58.4450055 a	198.280 a
	CHS Unlocked	4	fl oz/a	A						
7	10-34-0	29.75	gal/a	A	70.25 a	57.730 a	131.0 a	47.733 a	64.9800099 a	172.118 a
	WC 246	1	qt/a	A						
	CHS Unlocked	4	fl oz/a	A						
8	10-34-0	23	gal/a	A	70.45 a	65.695 a	156.0 a	60.170 a	67.5200034 a	217.223 a
	WC 139	5	gal/a	A						
	WC 246	1	qt/a	A						
LSD (P=.05)					16.335	15.2674	35.21	19.0487	25.67003316	70.4084
Standard Deviation					11.106	10.3805	23.94	12.9514	17.45332320	47.8714
CV					16.14	16.96	16.83	27.57	26.6	22.91
Bartlett's X2					8.664	8.135	5.98	8.628	10.827	7.993
P(Bartlett's X2)					0.278	0.321	0.542	0.28	0.146	0.333
Treatment Prob(F)					0.9955	0.4630	0.5907	0.5568	0.8383	0.5413

Means followed by same letter do not significantly differ (P=.05, Student-Newman-Keuls)
Mean comparisons performed only when AOV Treatment P(F) is significant at mean comparison OSL.

Part Rated
TUBER = tuber
LEAF = foliage
C = Crop is Part Rated

Rating Unit
% = percent

Plant-Eval Interval
129 DP-1 = 1 6-6-2016
38 DP-1 = 1 6-6-2016

Table 1 cont.

Crop Variety					Russet Burbank	Russet Burbank	Russet Burbank	Russet Burbank	Russet Burbank	Russet Burbank
Description					A ROW	A ROW	A ROW	A ROW	A ROW	A ROW
Part Rated					TUBER C	TUBER C	TUBER C	TUBER C	TUBER C	TUBER C
Rating Date					10-13-2016	10-13-2016	10-13-2016	10-13-2016	10-13-2016	10-13-2016
Rating Type					>12 oz	Total	> 4 oz	0-4 oz	4-6 oz	6-12 oz
Rating Unit					CWT/A	CWT/A	CWT/A	#/row	#/row	#/row
Days After First/Last Applic.					129 129	129 129	129 129	129 129	129 129	129 129
Trt-Eval Interval					114 DA-A	114 DA-A	114 DA-A	114 DA-A	114 DA-A	114 DA-A
Plant-Eval Interval					129 DP-1	129 DP-1	129 DP-1	129 DP-1	129 DP-1	129 DP-1
Days After Emergence					111 DE	111 DE	111 DE	111 DE	111 DE	111 DE
Trt No.	Treatment Name	Rate	Unit	Appl Code	7	8	9	10	11	12
1	Untreated Check				86.135 a	388.163 a	346.370 a	37.0 a	32.3 a	48.5 a
2	10-34-0	30	gal/a	A	125.410 a	469.803 a	420.768 a	46.5 a	26.8 a	61.0 a
3	10-34-0	29.75	gal/a	A	129.933 a	451.633 a	408.218 a	41.8 a	30.0 a	54.8 a
	WC 246	1	qt/a	A						
4	10-34-0	25	gal/a	A	135.833 a	488.218 a	440.515 a	42.0 a	31.5 a	60.5 a
	WC 139	5	gal/a	A						
5	10-34-0	23	gal/a	A	139.495 a	461.693 a	418.803 a	37.3 a	26.5 a	57.0 a
	WC 139	7	gal/a	A						
6	10-34-0	30	gal/a	A	98.805 a	398.623 a	355.528 a	38.8 a	25.8 a	52.3 a
	CHS Unlocked	4	fl oz/a	A						
7	10-34-0	29.75	gal/a	A	134.290 a	419.120 a	371.385 a	39.8 a	28.5 a	44.0 a
	WC 246	1	qt/a	A						
	CHS Unlocked	4	fl oz/a	A						
8	10-34-0	23	gal/a	A	132.030 a	476.940 a	416.773 a	52.3 a	30.0 a	56.0 a
	WC 139	5	gal/a	A						
	WC 246	1	qt/a	A						
LSD (P=.05)					80.2254	110.8445	106.8853	16.38	11.19	17.44
Standard Deviation					54.5461	75.3644	72.6724	11.14	7.61	11.86
CV					44.44	16.96	18.29	26.58	26.31	21.85
Bartlett's X2					3.361	8.131	7.879	7.926	10.302	7.2
P(Bartlett's X2)					0.85	0.321	0.343	0.339	0.172	0.408
Treatment Prob(F)					0.8184	0.4628	0.5193	0.5468	0.8893	0.4803

Table 1. continued

Crop Variety					Russet Burbank	Russet Burbank	Russet Burbank	Russet Burbank
Description					A ROW	A ROW	A ROW	A ROW
Part Rated					TUBER C	TUBER C	TUBER C	LEAF C
Rating Date					10-13-2016	10-13-2016	10-13-2016	7-14-2016
Rating Type					> 12 oz	> 4 oz	> 4 oz	Row Closure
Rating Unit					#/row	#/row	%	%
Days After First/Last Applic.					129 129	129 129	129 129	38 38
Trt-Eval Interval					114 DA-A	114 DA-A	114 DA-A	129 DA-A
Plant-Eval Interval					129 DP-1	129 DP-1	129 DP-1	38 DP-1
Days After Emergence					111 DE	111 DE	111 DE	20 DE-
Trt No.	Treatment Name	Rate	Unit	Appl Code	13	14	15	16
1	Untreated Check				12.3 a	93.0 a	72.2925030 a	82.5 a
2	10-34-0	30	gal/a	A	18.0 a	105.8 a	69.5825112 a	68.8 a
3	10-34-0	29.75	gal/a	A	16.8 a	101.5 a	70.5975107 a	93.8 a
	WC 246	1	qt/a	A				
4	10-34-0	25	gal/a	A	19.0 a	111.0 a	72.7750088 a	70.0 a
	WC 139	5	gal/a	A				
5	10-34-0	23	gal/a	A	20.5 a	104.0 a	73.6475064 a	65.0 a
	WC 139	7	gal/a	A				
6	10-34-0	30	gal/a	A	14.3 a	92.3 a	70.4425043 a	55.0 a
	CHS Unlocked	4	fl oz/a	A				
7	10-34-0	29.75	gal/a	A	18.8 a	91.3 a	69.8875039 a	77.5 a
	WC 246	1	qt/a	A				
	CHS Unlocked	4	fl oz/a	A				
8	10-34-0	23	gal/a	A	17.8 a	103.8 a	67.0450049 a	70.0 a
	WC 139	5	gal/a	A				
	WC 246	1	qt/a	A				
LSD (P=.05)					10.43	23.40	6.54670495	33.64
Standard Deviation					7.09	15.91	4.45117280	22.87
CV					41.35	15.86	6.29	31.41
Bartlett's X2					3.516	9.579	2.65	8.077
P(Bartlett's X2)					0.834	0.214	0.915	0.326
Treatment Prob(F)					0.7661	0.5684	0.5323	0.4255

The Use of Chlorophyll Meters for Nitrogen Management in Potatoes

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Summary

Nitrogen lost from the soil by leaching and volatilization, which is caused by mismatches between N availability and crop N needs, is both economically and environmentally costly. One approach to better matching N availability to crop N requirements is to measure the crop's leaf chlorophyll concentration and fertilize accordingly. Instant-read chlorophyll meters provide a simple and efficient means to do this, but such meters provide only a relative index of chlorophyll concentration that is not linearly related to chlorophyll concentration. Previous research has found the relationship between leaf chlorophyll concentration and the readings produced by two kinds of chlorophyll meters (Chlorophyll SPAD Meters by Konica Minolta and Chlorophyll Concentration Meters by Apogee Instruments) for multiple crop species, but potatoes are not among the crops for which such conversions are available. The objectives of this study were (1) to evaluate the effectiveness of chlorophyll-meter based N management in potatoes and (2) to establish relationships between chlorophyll meter readings and leaf chlorophyll concentration in two cultivars of potato – Russet Burbank and Red Norland. For each cultivar, four N treatments were applied to each of four blocks in a randomized complete block design: (1) a check treatment receiving no N at emergence (40 $lbs \cdot ac^{-1}$ N total); (2) a treatment receiving 120 $lbs \cdot ac^{-1}$ N as Environmentally Smart Nitrogen (ESN; Agrium, Inc.) at emergence (160 $lbs \cdot ac^{-1}$ N total); (3) a treatment receiving 260 $lbs \cdot ac^{-1}$ N as ESN at emergence (300 $lbs \cdot ac^{-1}$ N total); and (4) a treatment receiving 120 $lbs \cdot ac^{-1}$ N as ESN at emergence with subsequent applications of 20 $lbs \cdot ac^{-1}$ N as 28% UAN as needed, based on readings from a SPAD-502 chlorophyll meter. UAN was applied three times to each cultivar, giving this treatment 220 $lbs \cdot ac^{-1}$ N in total. Leaves were collected at six times throughout the season, and SPAD-502 readings, MC-100 Chlorophyll Concentration Meter readings, and chlorophyll concentrations based on DMSO extraction and spectrophotometry were determined for the same location on each leaf. Tuber yield, size, and quality were determined after harvest. In Russet Burbank, the treatment receiving UAN based on SPAD-502 readings had numerically greater total and marketable yield than the treatment receiving 260 $lbs \cdot ac^{-1}$ N as ESN at emergence, despite receiving 80 $lbs \cdot ac^{-1}$ less N. However, its tuber size distribution shifted toward tubers under 6 ounces and away from tubers over 10 ounces. In Red Norland, total yield and size distributions were simply functions of total N application rate. Tuber dry matter content increased with N rate in Russet Burbank, but decreased with N rate in Red Norland. Specific gravity showed similar trends. The difference in the effect of chlorophyll-meter-based UAN applications between the two cultivars may be due to the developmental stage each cultivar was in when fertilized; Russet Burbank has a longer time to tuber maturity than Red Norland. Readings from both chlorophyll meters were strongly related to chlorophyll concentration, and even more strongly related to each other. Red Norland leaves had slightly higher meter readings at any given chlorophyll concentration than Russet Burbank leaves, possibly due to their higher anthocyanin content.

Background

Nitrogen (N) is one of the most abundantly applied elements in crop production, with over 100 million tons applied worldwide annually. However, because matching the timing of N application and release with crop N needs is difficult, much N is lost from the soil by leaching and volatilization before the crop can take it up. The application of N that crops do not take up is both economically and environmentally costly.

One promising approach for better adapting an N fertilization regime with plant requirements is to measure leaf chlorophyll concentration to determine the plant's N needs and fertilize accordingly.

Instant-read chlorophyll meters quickly provide indices of chlorophyll concentration without a need for specialized chemicals, equipment, or training. The two leading lines of instant-read meters for measuring leaf chlorophyll concentration are Chlorophyll Meter SPAD meters (Konica Minolta, Inc.) and Chlorophyll Concentration Meters (Apogee Instruments). Both meters estimate leaf chlorophyll concentration by measuring the transmission of red and near infrared light through leaf tissues, and both output indices of chlorophyll concentration that are positively but not linearly related to actual chlorophyll concentration. The relationship between the index value and chlorophyll concentration depends on the crop species, and sometimes the cultivar. Previous research has generated equations for converting chlorophyll meter readings to chlorophyll concentrations in multiple crops, but to date, no such equations have been generated for potatoes (Parry et al., 2014)

To assess the effectiveness of chlorophyll-meter-based N management in potatoes, we applied four treatments to plots planted with potatoes: (1) no N applied beyond 40 $lbs \cdot ac^{-1}$ applied to all plots at planting, (2) 120 $lbs \cdot ac^{-1}$ N as Environmentally Smart Nitrogen (ESN; Agrium, Inc.) applied at shoot emergence, (3) 260 $lbs \cdot ac^{-1}$ N applied as ESN at shoot emergence, and (4) 120 $lbs \cdot ac^{-1}$ N applied as ESN at emergence plus multiple, light applications of 28% UAN with application timing determined by chlorophyll meter readings (using a Chlorophyll Meter SPAD-502).

We tested these treatments on both Russet Burbank and Red Norland potatoes, both because these cultivars are widely grown and because Red Norland typically has a darker green leaf than Russet Burbank, allowing us to quickly get a sense of the range in the relationships between chlorophyll meter readings and chlorophyll concentration in potatoes. Leaf chlorophyll content was measured at six times throughout the summer for plants in each plot using the SPAD-502, an MC-100 Chlorophyll Concentration Meter, and spectrophotometry of chlorophyll extracted from leaf tissues in DMSO. The three measurements were plotted against each other and equations were fitted to each relationship to determine how each instrument's readings related to chlorophyll concentration and to each other.

Methods

Study design

The study was conducted in 2016 at the Sand Plain Research Farm in Becker, MN, on a Hubbard loamy sand soil. The previous crop was rye. We employed a split-plot randomized complete block design with four blocks. Whole plots were defined by the potato cultivar, which was either Russet Burbank or Red Norland. Whole plots were divided into subplots based on four N treatments: (1) a check treatment receiving no N after planting (40 $lbs \cdot ac^{-1}$ N total), (2) a treatment receiving 120 $lbs \cdot ac^{-1}$ N as ESN at emergence (160 $lbs \cdot ac^{-1}$ N total), (3) a treatment receiving 260 $lbs \cdot ac^{-1}$ N at emergence (300 $lbs \cdot ac^{-1}$ N total), and (4) a treatment receiving 120 $lbs \cdot ac^{-1}$ N as ESN at emergence plus 60 $lbs \cdot ac^{-1}$ N as 28% UAN in three subsequent applications (220 $lbs \cdot ac^{-1}$ N total). A summary of the treatments is presented in Table 1.

Soil sampling

Soil samples to a depth of six inches were collected on March 28 and analyzed for Bray P, NH_4-Ac extractable K, Ca, and Mg, DTPA-extractable Fe, Mn, Zn, and Cu, $Ca(H_2PO_2)_2$/Ba-extractable SO_4-S, hot-water-extractable B, organic matter based on loss on ignition, and water pH. Soil samples to a depth of two feet were collected on April 11, dried for 48 hours at 95°F, and extracted in 2N KCl. The extract was analyzed for NO_3-N concentration using a Wescan nitrogen analyzer. Soil samples to a depth of 2 feet were collected on April 11, 2016. All samples were analyzed for NO_3-N concentration. Initial soil characteristics are presented in Table 2.

Planting

Tubers were planted on May 16. Russet Burbank whole "B" seed tubers were planted with 1-foot spacing within rows. Red Norland whole "B" tubers were planted with 9-inch spacing within rows. Rows were spaced 3 feet apart for both cultivars. Subplots were 20 feet long and 21 feet (seven rows) wide. The subplots within each block were planted adjacent to each other, with 8-foot alleyways between blocks, along which irrigation lines were placed (with 50-foot spacing between lines). Within each subplot, the row adjacent to the irrigation alley was used as a buffer. End-of-year tuber harvests were collected from the fourth and fifth rows from the alley. The first and last tuber in each harvest row was replaced with either Russet Burbank (in the Red Norland plots) or Chieftain (in the Russet Burbank plots). The sixth row from the alley was designated for petiole samples, chlorophyll meter measurements, and leaf tissue samples to determine chlorophyll content.

At row opening, 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 as a blend of DAP (18-46-0), MOP (0-0-60), SulPoMag (0-0-22-20S-10Mg), BluMin (0-0-0-0.5S-1Zn), and Boron 15 (0-0-0-15).

Emergence N and posthilling UAN applications

Environmentally Smart Nitrogen (ESN) was hand-applied to plots per N treatment on June 1, shortly after shoot emergence. The rows were then hilled. Plots receiving the ESN/UAN treatment (treatment 4) received 20 lbs/ac N as UAN on July 14 (both cultivars), July 27 (Red Norland), August 1 (both cultivars), and August 4 (Russet Burbank). Application timing was based on SPAD readings. Relative crop N-deficits were determined using nitrogen sufficiency indicies (NSIs); if the NSI ratio between N-treatment 4 (i.e. variable-rate) with N-treatment 3 (i.e. sufficient nitrogen) fell below 0.95, post-hilling fertilizer was applied to N-treatment 4 at a rate of 20 lbs N/acre.

Chlorophyll meters and chlorophyll concentration

Leaflet sampling for chlorophyll concentration measurements was conducted on June 27, July 12, July 19, July 25, August 2, and August 9. Relative indices of leaf chlorophyll concentration were taken using a Chlorophyll Meter SPAD-502 (Konica Minolta) and an MC-100 Chlorophyll Concentration Meter (Apogee Instruments). The SPAD-502 measures the transmission of red (λ = 650 nm) and near infrared (λ = 940 nm) wavelengths through a circular area of leaf tissue about 6 mm^2. The MC-100 measures the transmission of slightly different wavelengths (λ = 653 and 931 nm) through a larger area of leaf tissue (70 mm^2).

On each chlorophyll sampling date, ten leaflet samples per plot – the terminal leaflet of the fourth or fifth leaf from the shoot tip - were collected from the field, placed on ice, and taken to a controlled-light environment inside a building at the research station. SPAD-502 readings and MC-100 readings were taken from the same spot on each sampled leaflet.

A 90 mm^2 disk was then punched from the same spot and placed in 10 mL DMSO and kept at 65°C until the disc was transparent, indicating that virtually all of the chlorophyll was in solution. A 3 mL aliquot of the chlorophyll solution was transferred to an analysis cell to measure light absorbance at 665.1 nm and 649.1 nm. Chlorophyll a and b concentrations were determined using the equations developed by Wellburn (1994) for DMSO:

Chlorophyll a ($\mu g \cdot ml^{-1}$) = $12.47 * A_{665.1nm} - 3.62 * A_{649.1nm}$

Chlorophyll b ($\mu g \cdot ml^{-1}$) = $125.06 * A_{649.1nm} - 6.5 * A_{665.1nm}$

These concentrations were used to find the total chlorophyll concentration in $\mu mol \cdot m^{-2}$.

Harvest

Tubers were harvested on September 20 and sorted by size and USDA grade about two weeks later. Russet Burbank tubers were sorted by weight, while Red Norland tubers were sorted by diameter. Representative 25-tuber subsamples were collected for each plot, and stored at 48°F for six weeks.

They were then assessed for the prevalences of hollow heart, brown center, and scab, and their dry matter content and specific gravity were determined.

Data analysis

Because Russet Burbank and Red Norland are very different cultivars grown for very different purposes, we were not interested in testing for cultivar or cultivar-by-N-treatment effects. Consequently, data for the two cultivars were analyzed separately.

Yield and tuber quality data were analyzed with SAS 9.4m3® software (copyright 2015, SAS Institute, Inc.) using the GLM procedure with N treatment and block as categorical effect variables. Pairwise comparisons were made using a Waller-Duncan post-hoc comparison with a threshold k ratio of 50 (alpha = 0.10). Post-hoc comparisons are only reported where the effect of N treatment in the total model was at least marginally statistically significant ($P < 0.10$).

Chlorophyll concentration and chlorophyll meter readings were analyzed as functions of N treatment, sampling date, and their interaction in a repeated-measures analysis using the MIXED procedure, with block as a random effect, sampling date as the repeated-measure variable, and plot (within cultivar) as the subject. The covariance matrix structure was selected based on the adjusted Akaike's information criterion (AICC), with a spatial power structure [SP(POW)(date)] preferred to an autoregressive structure [AR(1)], which was preferred to a compound symmetrical structure (CS), which was preferred to an unstructured matrix (UN), when AICC scores were similar and the G matrix was positive definite for the preferred structure.

Chlorophyll concentration was plotted as functions of SPAD-502 readings and MC-100 readings, and SPAD-502 readings were plotted as a function of MC-100 readings, using SigmaPlot Version 12.3 (Systat Software, San Jose, CA). The software was then used to fit the data with curves using equations of the form: $y = y_0 + a * e^{b*x}$

Results and discussion

Tuber yield

Tuber yield results for Russet Burbank are presented in Table 3. Total and marketable yields were significantly lower in the zero-N check treatment (treatment 1) than in any of the three treatments receiving N after planting, which did not differ significantly from each other in terms of either measure. The N-fertilized treatments had significantly higher yields of U.S. No. 1 tubers and numerically lower yields of U.S. No. 2 tubers than the check treatment. They also had greater percentages of yield in tubers over six or ten ounces, with the treatment receiving 260 $lbs \cdot ac^{-1}$ N (treatment 3) having significantly greater percentages in each of these categories than the other fertilized treatments (treatments 2 and 4). The treatment receiving 120 $lbs \cdot ac^{-1}$ N as ESN at emergence plus UAN as needed later in the season had the highest total and marketable yields, though its yields were not statistically significantly greater than those of the other fertilized treatments. Compared to the treatment receiving 120 $lbs \cdot ac^{-1}$ N as ESN at emergence without UAN (treatment 2), the ESN/UAN treatment had an increased yield of 3- to 6-ounce tubers, but had very similar yields in all other size classes.

Tuber yield results for Red Norland are presented in Table 4. N treatment affected neither total yield nor the percentage of yield in tubers over 2 ¼" in diameter. Total yield increased with total N application rate, whether or not a portion of the N was applied as UAN in fertigation. Unlike total yield, yields in three of the size classes were significantly related to N treatment. The treatment receiving 260 $lbs \cdot ac^{-1}$ N at emergence (treatment 3) had the highest yield of tubers in the largest size class (over 3" in diameter), though its yield in this class was not significantly greater than that of the treatment receiving 120 $lbs \cdot ac^{-1}$ N ESN at emergence with subsequent applications of UAN (treatment 4). The zero-N check treatment (treatment 1) had significantly lower yields than the other treatments in both this size class and in tubers between 2 ¼" and 2 ½". It had higher yields of tubers under 1 ¾"

than either treatment receiving ESN at emergence without subsequent UAN applications (treatments 2 and 3).

The fact that the ESN/UAN treatment had relatively high yield but small tubers in Russet Burbank, while it had the expected tuber yield and size distribution for its total N rate in Red Norland, may be due to the developmental stages the two cultivars were in when the UAN was applied. Red Norland has a much shorter growing season than Russet Burbank. The UAN applications may have been delivered and utilized during the tuber bulking and maturation phases for Red Norland, but during the initiation/retention and bulking phases for Russet Burbank. The expected result of this would be that the ESN/UAN treatment in Red Norland would have similar numbers of tubers to the treatment receiving the same rate of ESN without UAN (treatment 2), but those tubers would be larger. In Russet Burbank, however, the ESN/UAN treatment would retain more initiated tubers than the treatment receiving only ESN at the same rate, and those excess retained tubers may not be fully bulked before harvest. This may also explain why the ESN/UAN treatment had a numerically greater yield of U.S. No. 2 tubers, but not U.S. No. 1 tubers, than the treatment receiving 120 $lbs \cdot ac^{-1}$ N as ESN at emergence without UAN.

Tuber quality

Tuber quality results for both cultivars are presented in Table 5. Hollow heart and brown center were not detected in Red Norland tubers, and the prevalences of these disorders and scab were unrelated to N treatment in both cultivars.

Russet Burbank tuber dry matter content tended to increase, while Red Norland tuber dry matter content tended to decrease, as the application rate of N increased. The results for tuber specific gravity generally paralleled those for tuber dry matter in each cultivar, but the effect of N treatment on specific gravity was not significant ($P > 0.1$) in Russet Burbank, while it was highly significant ($P < 0.01$) in Red Norland.

Like the results for yield, the results for tuber dry matter and specific gravity may indicate that Russet Burbank, unlike Red Norland, had not finished maturing its tubers at harvest time, and that the more heavily-fertilized plants, which were still bulking their tubers, had less mature tubers than those receiving less N.

Chlorophyll meters

The effect of N treatment on chlorophyll concentration, SPAD-502 reading, and MC-100 reading in each cultivar over time are presented in Figure 1. In Russet Burbank, leaf chlorophyll concentration decreased for all treatments between the first sampling date (June 27) and the second (July 12). Chlorophyll concentration changed more gradually over the remainder of the season. In general, chlorophyll concentration declined further in the zero-N check treatment (treatment 1) after July 12 and either showed no directional trend or increased slightly in the remaining treatments, with greater increases in leaf chlorophyll concentration as N application rate increased. The chlorophyll concentration of the treatment receiving ESN with supplemental UAN (treatment 4) approached that of the treatment receiving a high rate of ESN at emergence (treatment 3) on the last sampling date (August 9).

The trends were similar for Red Norland, except that chlorophyll concentrations decreased through the third sampling date (July 19) and increased for all treatments receiving ESN at emergence (treatments 2-4) between the last two sampling dates (August 2 and 9). The chlorophyll concentration in the treatment receiving ESN with supplemental UAN (treatment 4) did not approach that of the treatment receiving a high rate of ESN at emergence (treatment 3), unlike in Russet Burbank. Chlorophyll concentrations were higher in Red Norland than Russet Burbank on the first two sampling dates. For the remainder of the season, Red Norland had similar leaf chlorophyll concentrations to Russet Burbank.

Results for both chlorophyll meters were qualitatively similar to those for chlorophyll concentration, except that, while Red Norland chlorophyll concentrations declined rapidly through the third sampling date, the rapid decline in both SPAD-502 readings and CM-100 readings stopped after the second sampling date. In addition, the chlorophyll meter readings of the treatment receiving ESN with supplemental UAN (treatment 4) began to approach that of the treatment receiving a high rate of ESN at emergence (treatment 3) on the last sampling date (August 9) in Red Norland, which did not happen with chlorophyll concentration. The trend toward convergence of meter readings between the two treatments began with the second-to-last sampling date (August 2) in Russet Burbank, a week earlier than the same trend in chlorophyll concentration.

The relationships between leaf chlorophyll concentration and each chlorophyll meter's readings are presented in Figure 2. SPAD-502 and MC-100 readings were strongly correlated with chlorophyll concentrations in both Russet Burbank and Red Norland (R^2 = 0.89 – 0.90 in each case). For both the SPAD-502 and the MC-100, chlorophyll meter readings corresponding to any given chlorophyll concentration tended to be higher for Red Norland than for Russet Burbank, with the difference between the two cultivars increasing at higher concentrations. It is possible that red anthocyanins in Red Norland leaves slightly inflate the chlorophyll concentration estimates of the meters. An effect of anthocyanin pigments on chlorophyll meter readings has been observed previously in tomato plants (Hlavinka et al., 2013).

SPAD-502 readings and MC-100 readings were even more strongly correlated with each other in each cultivar (R^2 = 0.98 in each case) than either reading was with chlorophyll concentration, indicating that our measurements of leaf chlorophyll concentration were less accurate than the readings from either meter. Unlike the relationships between each meter's readings and chlorophyll concentration, the relationship between the two meter's readings was not cultivar-dependent. This was expected, since any factor that creates cultivar-specific differences in apparent chlorophyll concentration with one meter will have the same effect on the other meter, but perhaps not on spectrophotometer readings performed on an extract.

Conclusions

In Russet Burbank, the application of ESN at emergence with later applications of UAN based on SPAD-502 meter readings produced slightly larger total and marketable yields, with less N, than the application of far more ESN at emergence without UAN. This improved N efficiency (in terms of marketable yield per pound of N applied) did not come at a cost in terms of tuber quality, though it did result in a shift in the tuber size distribution toward smaller tubers. Red Norland tuber yield was much less responsive to N treatment than Russet Burbank yield. In terms of both yield and tuber quality, this cultivar responded to N application rate in a way that was seemingly unrelated to the form (ESN or UAN) of N applied. The greater impact of SPAD-502-based UAN fertilization on N efficiency in Russet Burbank than Red Norland may be a result of the shorter time to tuber maturity for Red Norland. The more N a Russet Burbank plot received, the lower its tubers' dry matter content and specific gravity were, indicating incomplete maturation. The increased yield in the treatment receiving UAN relative to the treatment receiving the same rate of ESN without UAN was observed almost entirely in 3- to 6-ounce tubers, possibly indicating that this treatment had not fully bulked its tubers before harvest.

Red Norland plants had higher meter readings for a given chlorophyll concentration than Russet Burbank plants did, possibly because of red anthocyanin pigments in Red Norland leaves. The readings of the two meters were more strongly correlated with each other than either was to extraction-based chlorophyll concentration measurements, although their readings were still strongly correlated with chlorophyll concentration.

References

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Table 1. Nitrogen treatments applied to Russet Burbank and Red Norland potatoes grown at the Sand Plain Research Farm in Becker, MN, in 2016.

Treatment	Total N applied ($lbs \cdot ac^{-1}$)	N applied post-planting[1] ($lbs \cdot ac^{-1}$)
1	40	None
2	160	120 $lbs \cdot ac^{-1}$ N as ESN at emergence
3	300	260 $lbs \cdot ac^{-1}$ N as ESN at emergence
4	220	120 $lbs \cdot ac^{-1}$ N as ESN at emergence + 60 lbs·ac-1 N as 28%UAN post-hilling[2]

[1]ESN: 44-0-0. UAN: 28-0-0.

[2]Three applications of 20 $lbs \cdot ac^{-1}$ N as 28% UAN, with timing based on SPAD readings

Table 2. Initial soil characteristics of the study site at the beginning of the season (April 11 for NO_3-N; March 28 for all other characteristics) at the Sand Plain Research Farm in Becker, MN, in 2016.

0 - 2 feet	0 - 6 inches											
Primary macronutrients			Secondary macronutrients			Micronutrients					Other characteristics	
NO_3-N	Bray P	K	SO_4-S	Ca	Mg	Zn	Fe	Mn	Cu	B	Organic matter	pH
ppm											%	
1.56 - 4.08	27 - 36	93 - 146	1	747 - 827	119 - 133	1.11 - 1.13	25.7 - 28.7	8.4 - 11.9	0.50	0.22 - 0.23	1.6 - 1.7	6.0 - 6.2

Table 3. Effect of N treatment on tuber yield, size, and grade for Russet Burbank potato plants grown at the Sand Plain Research Farm in Becker, MN, in 2016. Values within the same column that have a letter in common are not significantly different from each other (i.e. P > 0.05). Letters are only included where the P-value of the effect of N treatment is less than 0.10.

Treatment	Total N applied (lbs·ac^{-1})	N applied post-planting[1] (lbs·ac^{-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	40	None	112	205 a	107 b	8 c	3 c	435 b	232 b	203	323 b	27 c	2 c
2	160	120 lbs·ac^{-1} N as ESN at emergence	106	158 b	184 a	55 b	13 bc	516 a	374 a	142	410 a	48 b	13 b
3	300	260 lbs·ac^{-1} N as ESN at emergence	86	123 c	178 a	90 a	38 a	515 a	379 a	135	428 a	59 a	25 a
4	220	120 lbs·ac^{-1} N as ESN at emergence + UAN post-hilling[2]	108	183 ab	182 a	59 b	15 b	548 a	373 a	175	439 a	47 b	14 b
Treatment significance (P-value)			0.2155	**0.0029**	**0.0014**	**0.0010**	**0.0008**	**0.0079**	**0.0066**	0.1147	**0.0105**	**0.0005**	**0.0005**
Treatment MSD (P < 0.1)			--	29	27	24	10	47	68	57	55	9	6

[1]ESN: 44-0-0. UAN: 28-0-0.

[2]Three applications of 20 lbs·ac^{-1} N as 28% UAN, with timing based on SPAD readings

Table 4. Effect of N treatment on tuber yield and size for Red Norland potato plants grown at the Sand Plain Research Farm in Becker, MN, in 2016. Values within the same column that have a letter in common are not significantly different from each other (i.e. P > 0.05). Letters are only included where the P-value of the effect of N treatment is less than 0.10.

Treatment	Total N applied (lbs·ac^{-1})	N applied post-planting[1] (lbs·ac^{-1})	Tuber Yield						
			0 to 1 3/4"	1 3/4" to 2 1/4"	2 1/4" to 2 1/2"	2 1/2" to 3"	> 3"	Total yield	> 2 1/4"
			cwt · ac^{-1}						%
1	40	None	14 a	65	139 a	244	34 c	495	84
2	160	120 lbs·ac^{-1} N as ESN at emergence	9 c	58	104 b	268	86 b	526	87
3	300	260 lbs·ac^{-1} N as ESN at emergence	11 b	60	99 b	245	120 a	535	86
4	220	120 lbs·ac^{-1} N as ESN at emergence + UAN post-hilling[2]	13 a	59	100 b	252	105 ab	530	86
Treatment significance (P-value)			**0.0046**	0.8054	**0.0328**	0.6975	**0.0010**	0.6821	0.3931
Treatment MSD (P < 0.1)			2	--	25	--	26	--	--

[1]ESN: 44-0-0. UAN: 28-0-0.

[2]Three applications of 20 lbs·ac^{-1} N as 28% UAN, with timing based on SPAD readings

Table 5. Effect of N treatment on tuber quality for Russet Burbank and Red Norland potato plants grown at the Sand Plain Research Farm in Becker, MN, in 2016. Values within the same column that have a letter in common are not significantly different from each other (i.e. P > 0.05). Letters are only included where the P-value of the effect of N treatment is less than 0.10.

Cultivar	Treatment	Total N applied (lbs·ac^{-1})	N applied post-planting[1] (lbs·ac^{-1})	Tuber Quality				
				Hollow Heart	Brown Center	Scab	Dry matter	Specific Gravity
				%				
Russet Burbank	1	40	None	1.0	1.0	3.0	20.7 b	1.0767
	2	160	120 lbs·ac^{-1} N as ESN at emergence	2.4	2.4	0.0	21.9 ab	1.0772
	3	300	260 lbs·ac^{-1} N as ESN at emergence	1.1	1.1	0.0	22.5 a	1.0814
	4	220	120 lbs·ac^{-1} N as ESN at emergence + UAN post-hilling[2]	0.0	0.0	1.0	22.2 a	1.0812
	Treatment significance (P-value)			0.4998	0.4998	0.6214	*0.0654*	0.2078
	Treatment MSD (P < 0.1)			--	--	--	1.2	--
Red Norland	1	40	None	0.0	0.0	35.9	17.8 a	1.0620 a
	2	160	120 lbs·ac^{-1} N as ESN at emergence	0.0	0.0	5.0	17.1 ab	1.0604 a
	3	300	260 lbs·ac^{-1} N as ESN at emergence	0.0	0.0	18.2	16.0 b	1.0546 b
	4	220	120 lbs·ac^{-1} N as ESN at emergence + UAN post-hilling[2]	0.0	0.0	16.0	16.5 ab	1.0596 a
	Treatment significance (P-value)			--	--	0.3326	*0.0927*	**0.0033**
	Treatment MSD (P < 0.1)			--	--	--	1.3	0.0027

[1]ESN: 44-0-0. UAN: 28-0-0.

[2]Three applications of 20 lbs·ac^{-1} N as 28% UAN, with timing based on SPAD readings

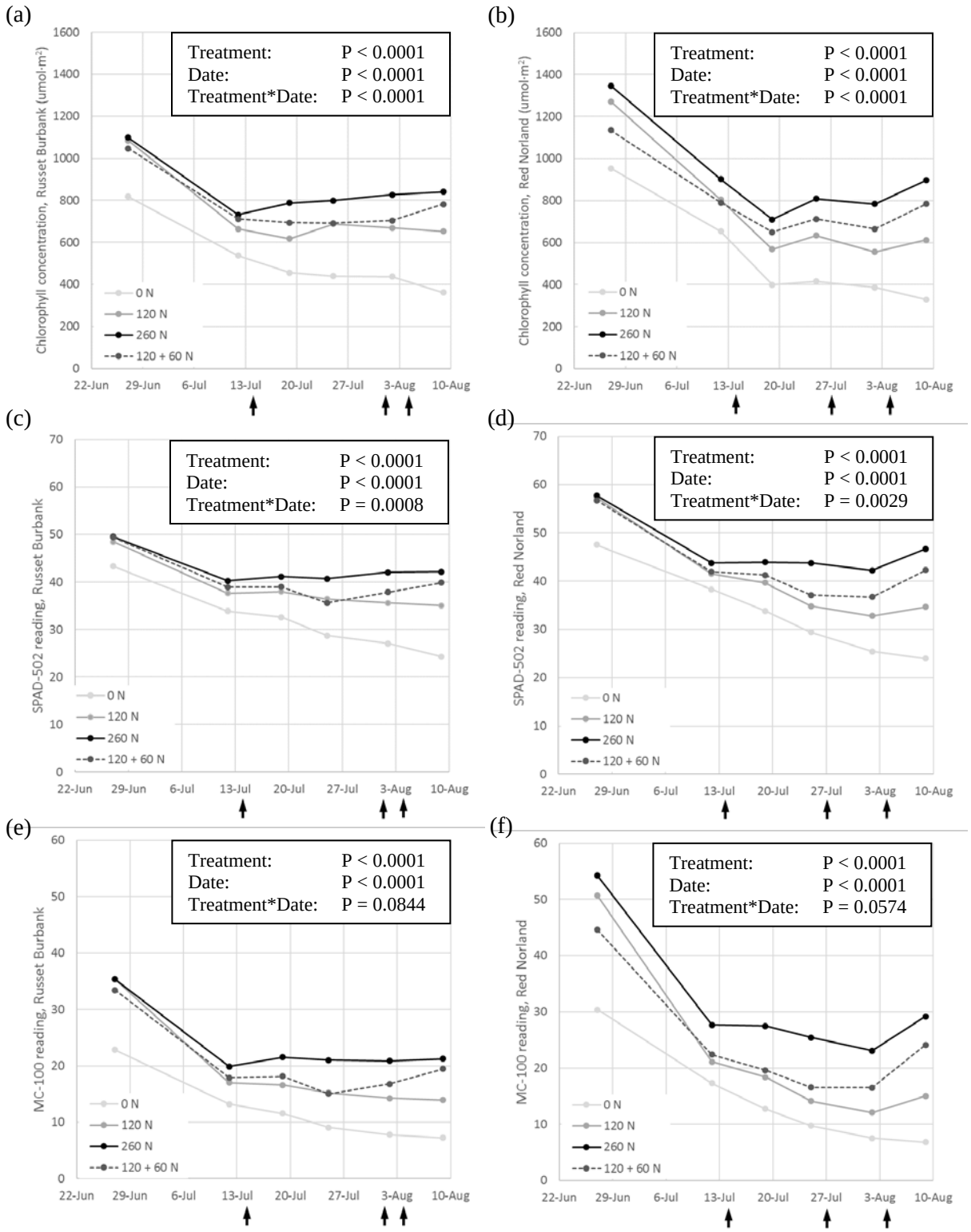

Figure 1. Mean leaf chlorophyll concentrations (a and b), SPAD-502 chlorophyll meter readings (c and d), and MC-100 chlorophyll meter readings (e and f) at six time points throughout the growing season for each N treatment applied to Russet Burbank (a, c, and e) and Red Norland (b, d, and f) potato plants grown at that Sand Plain Research Farm in Becker, MN, in 2016. Arrows indicate times when 20 lbs·ac^{-1} N were applied as 28% UAN.

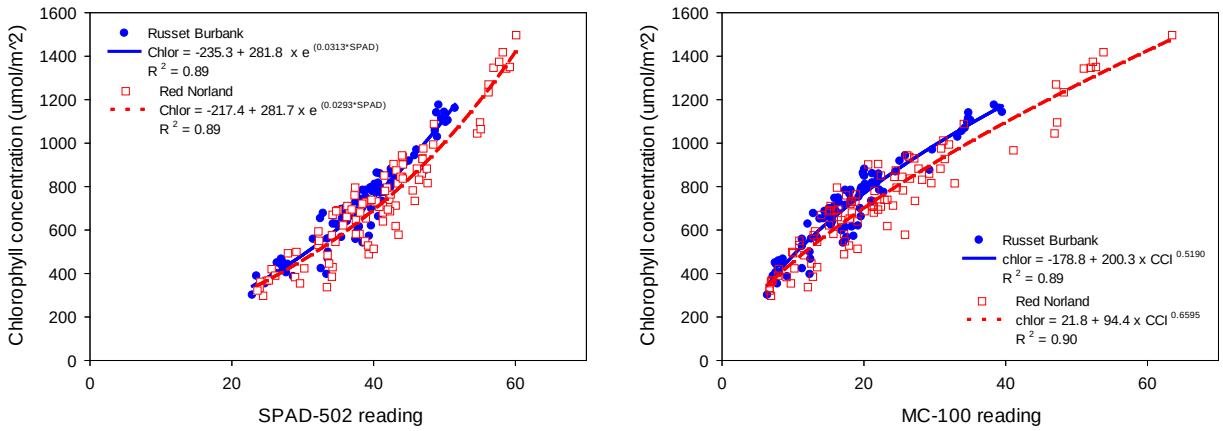

Figure 2. Leaf chlorophyll concentration as a function of (a) SPAD-502 chlorophyll meter reading and (b) MC-100 chlorophyll meter reading in Russet Burbank (blue) and Red Norland (red) potato plants grown at the Sand Plain Research Farm in Becker, MN, in 2016.

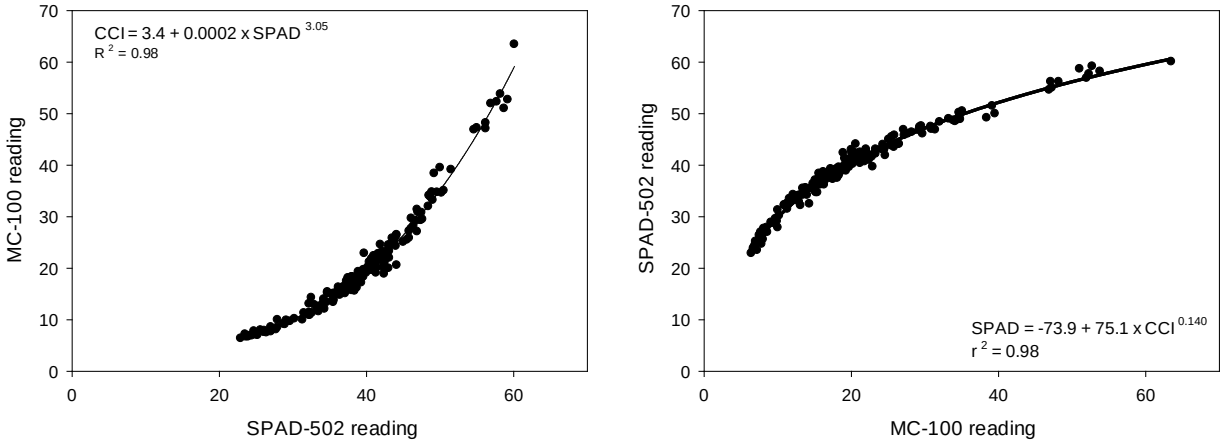

Figure 3. MC-100 chlorophyll meter reading as a function of SPAD-502 chlorophyll meter reading (a) and vice-versa (b) for Russet Burbank and Red Norland potato plants grown at the Sand Plain Research Farm in Becker, MN, in 2016. The relationships were not cultivar-dependent; combined data for both cultivars are shown.

Winfield Desiccation. Harlene Haterman-Valenti and Collin Auwarter.
Field research was conducted in 2016 at the Northern Plains Potato Grower's non-irrigated research site near Grand Forks, ND to evaluated different surfactants added to Reglone (diquat) on Red Lasoda potatoes. Potatoes were planted on June 8 and maintained through the season with typical grower standard practices when needed. Two ratings were done on the leaf and stem 3 and 10 DAA. Application information using a CO2 back pack sprayer is provided below. Plants were starting to senesce when the desiccant was applied. However, the application of reglone with an adjuvant hastened necrosis by three days after application and by 10 days after application, reglone + preference and reglone + AG16134 had at least 95% of the leaf and stem material dead.

Date:	9/12/16	
Sprayer:	GPA:	20
	PSI:	40
	Nozzle:	8002 FF
Air Temp:	59F	
Rel. Humidity:	78%	
Wind (MPH):	8	
Cloud Cover:	90%	
Soil Moisture:	Above Normal	

Trt No.	Treatment Name	Rate	Rate Unit	Appl Code	1	2	3	4
	Crop Code				SOLTU	SOLTU	SOLTU	SOLTU
	Crop Variety				Red Lasoda	Red Lasoda	Red Lasoda	Red Lasoda
	Part Rated				LEAF C	STEM C	LEAF C	STEM C
	Rating Date				9-15-2016	9-15-2016	9-22-2016	9-22-2016
	Rating Type				Necrosis	Necrosis	Necrosis	Necrosis
	Rating Unit				%	%	%	%
	Number of Subsamples				1	1	1	1
	Days After First/Last Applic.				3 3	3 3	10 10	10 10
	Trt-Eval Interval				3 DA-A	3 DA-A	10 DA-A	10 DA-A
	Plant-Eval Interval				99 DP-1	99 DP-1	106 DP-1	106 DP-1
1	Untreated Check				23.3 b	5.0 b	73.3 b	40.0 b
2	Reglone	1	pt/a	A	58.3 a	21.7 a	93.3 a	83.3 a
3	Reglone	1	pt/a	A	75.0 a	28.3 a	96.7 a	95.0 a
	Preference	0.25	% v/v	A				
4	Reglone	1	pt/a	A	60.0 a	18.3 a	95.0 a	88.3 a
	AG16133	0.25	% v/v	A				
5	Reglone	1	pt/a	A	63.3 a	26.7 a	93.3 a	83.3 a
	AG16134	0.25	% v/v	A				
6	Reglone	1	pt/a	A	68.3 a	28.3 a	100.0 a	95.0 a
	AG16131	0.25	% v/v	A				
7	Reglone	1	pt/a	A	65.0 a	25.0 a	100.0 a	90.0 a
	AG8050	6.4	fl oz/a	A				
8	Reglone	1	pt/a	A	63.3 a	26.7 a	93.3 a	86.7 a
	AG13064	4	fl oz/a	A				
9	Reglone	1	pt/a	A	60.0 a	26.7 a	98.3 a	86.7 a
	AG14039	6.4	fl oz/a	A				
10	Reglone	1	pt/a	A	61.7 a	28.3 a	100.0 a	91.7 a
	Supurb HC	0.5	pt/a	A				
	InterLock	2	fl oz/a	A				
	LSD (P=.05)				15.25	9.64	10.49	12.40
	Standard Deviation				8.89	5.62	6.12	7.23
	CV				14.86	23.91	6.48	8.6
	Bartlett's X2				15.972	4.046	7.805	6.15
	P(Bartlett's X2)				0.067	0.853	0.253	0.63
	Replicate F				7.124	7.364	1.693	2.489
	Replicate Prob(F)				0.0053	0.0046	0.2120	0.1111
	Treatment F				7.130	5.012	5.010	14.723
	Treatment Prob(F)				0.0002	0.0018	0.0018	0.0001

Means followed by same letter do not significantly differ (P=.05, Student-Newman-Keuls)
Mean comparisons performed only when AOV Treatment P(F) is significant at mean comparison OSL.

Part Rated
LEAF = leaf
STEM = stem
C = Crop is Part Rated
Rating Unit
% = percent
Plant-Eval Interval
99 DP-1 = 1 6-8-2016