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Research Summary 2011
Potato Pathology & Genomics

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1. Understanding the Molecular Basis of Tuber Disease Resistance

Transgenic 'Russet Burbank' is made foliar resistant to late blight disease by the *RB* gene [Fig 1a, (Bradeen et al. 2009)]. We have tested tubers of 'Russet Burbank' +*RB* transgenic lines for enhanced tuber resistance to late blight and identified two lines with improved resistance (Fig 1b). Interestingly, these tubers have very high levels of the *RB* transcript (i.e., the *RB* gene is turned on "higher" in these tubers), but, as the tuber ages in storage, both *RB* transcript levels and tuber blight resistance decline.

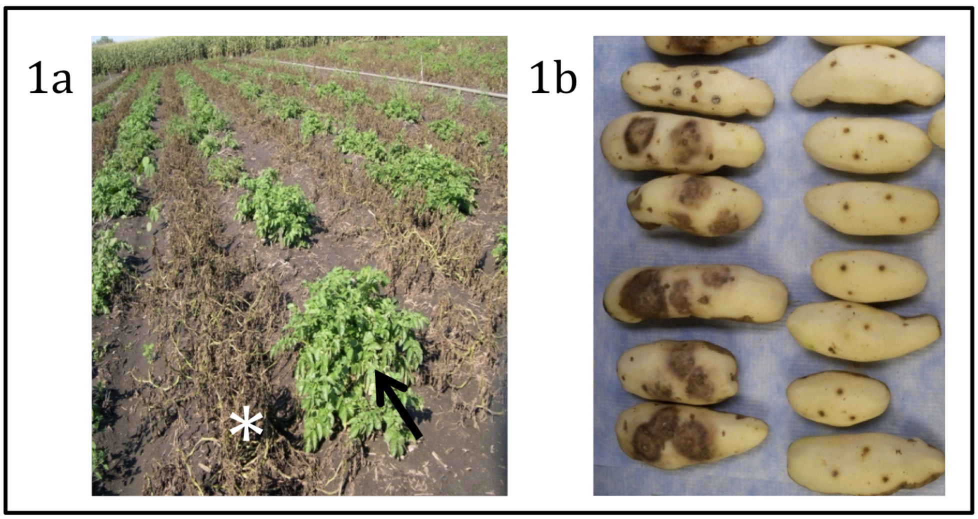


Figure 1. The *RB* gene imparts late blight resistance to transgenic potato. (1a) A photograph of our Rosemount U-More Park late blight nursery. This field received no fungicides and was inoculated with the late blight pathogen (*Phytophthora infestans*). While non-transgenic potato (star) was destroyed by late blight, transgenic potato with the *RB* gene (arrow) remained disease free and healthy. (1b) 'Russet Burbank' tubers were wounded and inoculated with the late blight pathogen. Tubers on the left are non-transgenic 'Russet Burbank'. Tubers on the right are transgenic 'Russet Burbank' with the *RB* gene. Tuber blight developed only in the non-transgenic line. (Note that 'dots' on the transgenic tubers are wounding sites—not tuber blight.) Tuber resistance correlates with *RB* gene transcription: the 'higher' the gene is turned 'on', the better the resistance.

In 2011, using "next generation" high throughput sequencing, we studied what genes are activated in the potato tuber in response to the late blight pathogen. Our experiment includes 42 samples, representing both transgenic and non-transgenic 'Russet Burbank' tubers prior to infection and at 24hrs and 48hrs post infection with the late blight pathogen (Fig 2). For reference, our samples also include 6 foliar samples challenged with the late blight pathogen.

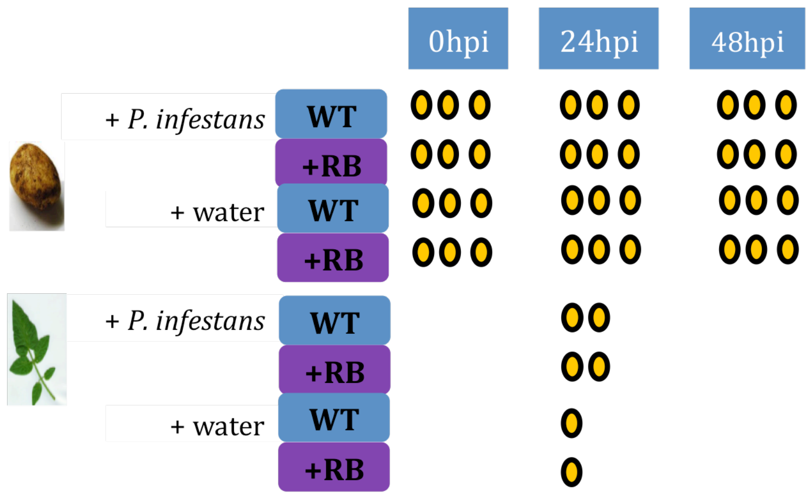


Figure 2. Sample scheme for RNA sequencing effort. This project emphasizes tuber samples infected with the late blight pathogen (*P. infestans*). Tubers of tuber blight susceptible non-transformed 'Russet Burbank' (WT) and tuber blight resistant transgenic 'Russet Burbank' (+RB) were sampled 0, 24, and 48 hours after inoculation. Tubers inoculated with water, a negative control, were also included. Finally, for comparison, foliage of 'Russet Burbank' with and without the *RB* gene was sampled at 24 hours after inoculation with the late blight pathogen and water. Note that we used multiple replicates for each treatment to achieve appropriate statistical robustness.

RNA was extracted from each sample and submitted for RNA sequencing at the University of Minnesota. Over 540 million RNA seq reads (data points) were generated. Each of these reads corresponds to gene transcription. Genes that are turned up 'higher' are represented by more reads. To figure out which gene is represented by each read, we anchored the reads to the potato genome reference sequence, which was released in the summer of 2011 (Consortium 2011). Then, we compared gene expression patterns between non-transgenic 'Russet Burbank' and the *RB* transgenic lines at each time point.

Our analyses indicate that enhanced tuber resistance is due to "pre-priming" of defense response pathways; transgenic (*+RB*) tubers have higher levels of defense gene transcripts even before the pathogen attacks (Fig 3). This means that the tuber—at all times—has already partially activated defense responses, and, when a pathogen does attack, it is better prepared to mount a successful defense.

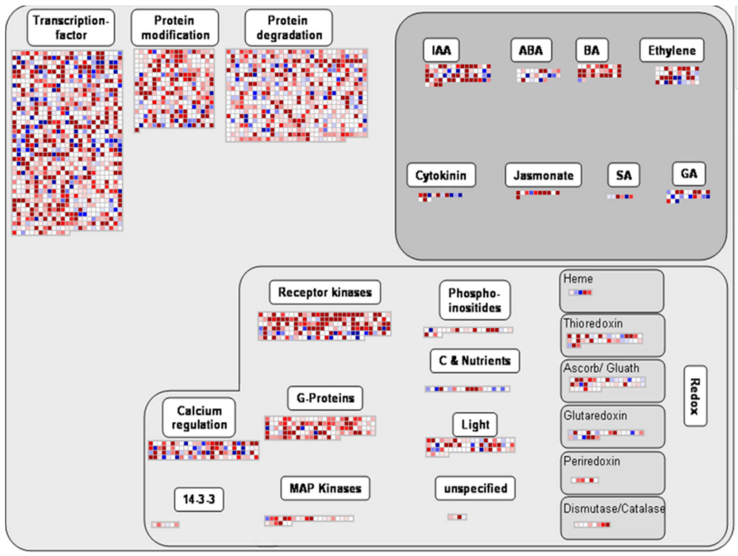


Figure 3. Tubers of transgenic 'Russet Burbank' carrying the *RB* gene have 'pre-primed' disease defense relative to tubers of non-transgenic 'Russet Burbank'. Summarized are RNA sequencing data from tubers 24 hours after inoculation with the late blight pathogen (*P. infestans*). RNA sequencing reads were mapped to potato genes and assigned to functional categories. Shown are functional categories with known impact on plant disease resistance. Within each category, red squares indicate a specific gene that is transcribed more in transgenic (*+RB*) than non-transgenic 'Russet Burbank' tubers. Blue boxes indicate specific genes that are transcribed more in non-transgenic lines. White boxes indicate genes for which transcription is similar in non-transgenic and transgenic lines. Importantly, most genes involved in defense responses are up-regulated in the transgenic lines. In other words, the *RB* gene prepares the tuber for defense, resulting in more rapid response to the pathogen.

Importantly, **we hypothesize that the defense response pathways will be similar regardless of the pathogen**. Thus, our findings using this late blight system may apply to other diseases as well and our *+RB* transgenic line may be better able to resist all tuber pathogens. Additionally, we are identifying specific genes that are "pre-primed" in this system; these may serve as molecular markers for screening of non-transgenic potato germplasm to identify lines with a natural propensity for a "pre-primed" defense response system.

2. Using DNA Sequence-based Analyses to Find New Disease Resistance Genes

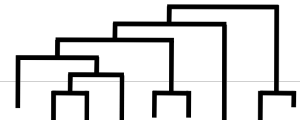
Most plant disease resistance genes share specific structures at the DNA sequence level. This allows us to use genome sequences to find resistance genes and to use molecular techniques to isolate DNA fragments that encode for resistance—even from species for which the genome has not been sequenced. The potato genome has been sequenced (Consortium 2011), revealing approximately 400 disease resistance genes! But none the genomes of the 200 wild potato species have been. Using a combination of DNA sequence analyses and molecular techniques, we are now isolating DNA fragments containing disease resistance genes from wild potato species and more distant relatives to potato. In 2011, we completed the generation of an R gene library for the wild potato *Solanum bulbocastanum.* This is a disease resistant species from Mexico and was the original source of the *RB* late blight resistance gene described above (Song et al. 2003). Our *S. bulbocastanum* library represents 97 distinct disease resistance genes and this is the largest R gene library ever generated in any *Solanum* species.

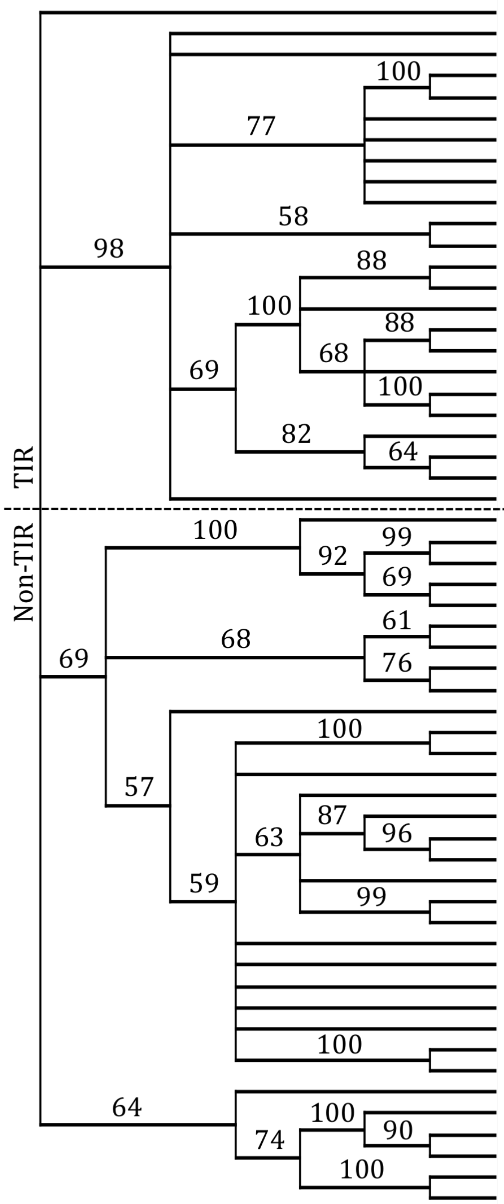
We used our *S. bulbocastanum* R gene library as the starting point to develop an analytical framework that combines nearly 800 disease resistance gene sequences from across the genus *Solanum* and even other Solanaceous plants such as tobacco and pepper. We call our framework the "SolaR80" system [Fig 4, (Quirin et al. In Press)]. **The SolaR80 system allow visualization of resistance gene distribution patterns across *Solanum* species and facilitates evolutionary studies aimed at finding resistance genes with new functions.** For example, we have discovered that one disease resistance gene family (SolaR80.1) is greatly expanded in the wild potato *S. bulbocastanum.* This expansion, in turn, may have allowed some gene copies to mutate and evolve in response to different pathogens. We find evidence for this in the pattern of DNA sequence variation. Thus, this gene family has likely acquired new function in *S. bulbocastanum.*

Using next generation sequencing, we now plant to catalog disease resistance genes from a broad array of *Solanum* species, with particular emphasis on potato species with breeding potential for potato improvement. As sequences are identified, they will be integrated into the SolaR80 framework and appropriate evolutionary analyses will be pursued. To date, more than 800 sequences have been generated and integrated into the SolaR80 framework, identifying 56 distinct disease resistance gene families. Importantly, our research confirms that these gene families are predominantly conserved across potato species, meaning that structural information garnered from the sequencing of the potato genome can be utilized to access allelic diversity found in its wild relatives.

Figure 4. The SolaR80 System provides a framework for visualizing R gene distribution patterns across *Solanum* species. Approximately 800 R gene sequences from Solanaceous species were assigned to 56 "SolaR80" diversity bins on the basis of DNA sequence homology (designated as SolaR80.1 to SolaR80.56). Evolutionary relationships amongst these groups were determined and their distribution was plotted as a function of species relationships. ▶

Resistance Gene Analogs





	S. bulbocastanum	*S. tuberosum*	*S. phureja*	*S. demissum*	*S. lycopersicum*	*S. habrochaites*	*S. caripense*	*S. melongena*	*S. aculeatissimum*	Cloned R Genes (+ Homologs)
Apaf1										
SolaR80.42							1			
SolaR80.11					3					
SolaR80.7	1				5					
SolaR80.12	1									
SolaR80.10					3					
SolaR80.1	36				3					
SolaR80.5	9							1		
SolaR80.25					2					
SolaR80.56								1		
SolaR80.2	18									
SolaR80.4	9									
SolaR80.38		1								
SolaR80.36							4			(+1)
SolaR80.37					1					NL27
SolaR80.26							6			(+7)
SolaR80.35							3			N (+14)
SolaR80.6		1			9					
SolaR80.53	1						1			
SolaR80.34							4			NL25
SolaR80.3	9	2			3	1				*Gro1 1,2,4,5* (+12)
SolaR80.20		1								*Z2* (+9)
SolaR80.39		1								
SolaR80.9	5									
SolaR80.17					6					
SolaR80.32					1					
SolaR80.14	1	1	1	13	2					(+55)
SolaR80.8								2		
SolaR80.24		1		16	3	1	7			*I2, IC 1, IC 2, R3a* (+91)
SolaR80.47	1									
SolaR80.50									1	
SolaR80.15			3		5	1		2		
SolaR80.13	2				12					*RB,* B149, T118 (+35)
SolaR80.27									1	*Rpi vnt1,2,3;tm2* (+50)
SolaR80.51						1				*R2* (+40)
SolaR80.41	3									
SolaR80.22					1					(+2)
SolaR80.19						1				*Sw5a,b,c,d,e* (+13)
SolaR80.52										*Prf, Pto* (+6)
SolaR80.29							12			*R1* (+77)
SolaR80.30							2			
SolaR80.48										*Hero* (+4)
SolaR80.46	1								7	*Mi1 1, Rpi-blb2* (+28)
SolaR80.28										(+1)
SolaR80.49								1	1	
SolaR80.31					2					
SolaR80.23					1					
SolaR80.40										*Rx, Rx2, GPA2* (+25)
SolaR80.55								2		
SolaR80.43									1	
SolaR80.44										*Bs2*
SolaR80.54										(+1)
SolaR80.21						1				
SolaR80.33		2								
SolaR80.16		1			7	1				
SolaR80.18					3	1				
SolaR80.45					1					

3. Shifting the Potato Endophyte 'Community' Towards Enhanced Disease Resistance (collaboration with Professor Linda Kinkel and Dr. Brett Arenz, UM Dept Plant Pathology)

Plants are known to harbor bacteria and fungi that live *inside* leaves, stems, and other plant structures. Sometimes these *endophytes* have no impact on the plant at all. But endophytes might also have negative or positive effects on plant health. For example, endophytes might produce toxins or "steal" nutrients, negatively impact plant growth. Conversely, endophytes might produce antimicrobial compounds that have no direct effect on the plant but can fight off potential pathogens. Because potato is asexually propagated, the potential exists for manipulation of the endophyte community in one generation (e.g., the seed tuber generation) with impact on the subsequent generation (e.g., production season). **We hypothesize that the potato endophyte community can be manipulated to favor microbes that improve plant health, reducing the impact of diseases on potato production.**

To test this hypothesis, in 2011 we conducted a small scale trial aimed at determining the degree to which the endophytic community in potato varies (Fig 5). Dale Steevens, William Mack, and Jon Gilley (R.D. Offutt) kindly provided us with 'Russet Burbank' potato seed tubers that were grown in a common MT field in 2009 but in different ND and MN fields in 2010. We reason that if the growing environment influenced the potato endophyte community, then all tubers from 2009 would have had a characteristic "MT" endophyte community that would have shifted in 2010 to a "ND" and a "MN" endophyte community.

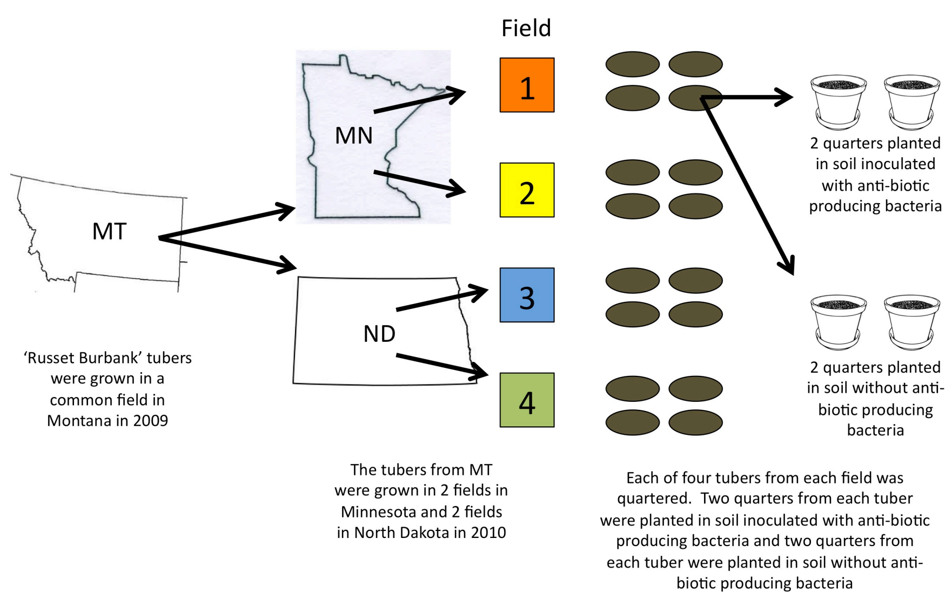


Figure 5. Endophyte sampling experimental plan.

In phase one of this project, we isolated DNA from tubers grown in ND and MN. This DNA was used for sequencing the bacterial endophyte community. Each tuber sample yielded approximately 3,000 bacterial DNA sequences. Phylogenetic analysis revealed that most of these belong to the bacterial genus *Blastomonas.* This genus is a known common endophyte and its prominence in our tuber samples confirms our experimental approach. Thus, we conclude that next generation sequencing is an effective strategy to examine the composition and plasticity of the potato tuber endophyte community. This phase of our research serves as a “proof-of-concept” test.

In phase two of this project, we planted the ND and MN tubers in pots containing soil from Becker. The soil comes from a field with a history of rye-potato rotation. Each of the ND and MN tubers was quartered and two quarters were planted in pots containing the Becker soil without amendment and two quarters were planted in pots containing the Becker soil amended with a bacterium known to produce antibiotics. This bacterium is a relative of the potato scab pathogen, but does not produce disease. It was initially isolated and studied by Dr. Linda Kinkel (UM Plant Pathology), a collaborator on this project. All pots were grown outside in St. Paul during the summer of 2011. Samples from the resulting potato tubers and from the soil itself were stored for subsequent analyses

In coming months, we will generate DNA sequence from the daughter tubers and compare fungal and bacterial populations based on (1) state and field of origin (e.g., Fig 5, MN vs. ND, Field 1 vs. 2 vs. 3 vs. 4) and (2) amendment with or without anti-biotic producing bacteria (Fig 5). A primary outcome of this effort will be determination of the plasticity of the potato tuber endophyte community: **Do tubers from MN vs. ND differ in their endophyte communities? Does amendment with anti-biotic producing bacteria alter the endophyte communities?** Pending the answers to these questions, downstream research will likely include field testing of potato tubers amended with the anti-biotic producing bacteria to determine if disease incidence (e.g., scab) is reduced.

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Marketing Potential
of Advanced Breeding Clones

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Using a scale based on a the harvest sucrose-rating (SR) and its glucose-forming-potential (GFP) in storage (Sowokinos, 1987), ninety-one of the most promising potato clones were evaluated for chipping, fry and/or fresh market utilization potential .

The purpose of this information is intended to (1) assist the potato breeder in correctly marketing their new breeding selections and (2) to aid in the identification of promising genotypes for future crosses. Marketing suggestions are based on sugar content and processing characteristics as described previously by Sowokinos and Preston (1988).

Storage and processing evaluations were conducted at the U.S. Department of Agriculture (USDA) Potato Research Worksite in East Grand Forks, MN. For acceptable chip color, two genetic requirements must be met. First, the potato line should be capable of reducing its SR value to 1.0 mg sucrose/g tuber FW by harvest or less. Secondly, the potato line should demonstrate a low GFP in storage (i.e., 0.25 mg glucose/g tuber FW or less for chips and 1.0 mg glucose/g tuber FW for fries). Meeting these genetic requirements should yield a color code (CC) of 2 or higher. Higher levels of glucose lead to the production of unacceptable dark brown to black pigmented chips or French fries (CC of 3 - 5)after the raw product is cooked in oil at a high temperature. This study is funded, in part, by the Northern Plains Potato Growers Association.

Results

Breeding programs nationwide provide the advanced breeding clones used in this study. Along with control varieties, the sugar content and processing quality of all clones directly from 9^{o} C (48.2^{o} F) storage were evaluated. In addition to harvest analysis, clones were evaluated following 3 and 7 months in storage. Potatoes with a glucose content of 0.25 mg/g or less should yield acceptable colored potato chips. This amount of glucose is equivalent to 0.025 % on a FW weight basis and represents chips giving an Agtron value of 60 or higher. Clones with glucose levels of 1.0 mg/g to 1.3 mg/g are still acceptable for French fry quality, although lower levels are generally desired. Potatoes with higher levels of glucose are destined for fresh market utilization.

A summary of results for the 2009-2010 storage season are presented in Table 1.

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Sowokinos, J.R., 1987. Variations in glucose forming potential (GFP) between potato clones. Amer. Potato J. 64:459

Sowokinos, J. R., and D. A. Preston, 1988, Maintenance of potato processing quality by chemical maturity monitoring (CMM) Minn. Ag Expt. Station Bulletin, 586-1988(Item No. AD-SB-3441), pp 11

Table 1. 2009 -2010 Marketing-potential of advanced potato breeding clones stored at 9^{o} C (48.2^{o} F) for 3 and 7 months.   Clones are aligned in order of decreasing Color Code (CC) values following 7 months in storage.

VARIETY	Color	Code	Agtron	Agtron	**Marketing**		**Potential**
	3 Month	**7 Month**	**3 Month**	**7 Month**	**Chip**	**Fries**	**Fresh**
MN 00467-4	1	1	68	69	x	x	x
ND 7799C-1	1	1	66	69	x	x	x
IVORY CRISP	2	1	64	68	x	x	x
ND 8-14	1	1	69	67	x	x	x
BNC 49-2	2	1	62	66	x	x	x
B 2492-7	2	1	60	66	x	x	x
W 7124-9	1	1	66	66	x	x	x
W 2438-3Y	1	1	65	66	x	x	x
NY 139	2	1	63	66	x	x	x
MN 02696	1	1	67	66	x	x	x
ND 7818-1Y	2	1	64	66	x	x	x
B 2634-13	1	1	67	65	x	x	x
B 2634-3	2	1	62	65	x	x	x
YUKON GEM	2	1	64	65	x	x	x
FV 13567-7	1	1	65	65	x	x	x

SPORT 860	1	1	67	65	x	x	x
DAKOTA CRISP	2	1	62	65	x	x	x
W 2717-5	1	1	66	65	x	x	x
W 2978-3	1	1	67	65	x	x	x
MSJ 147-1	2	1	60	65	x	x	x
MSL 292-A	1	1	67	65	x	x	x
CV 1396-4	2	2	62	64	x	x	x
SNOWDEN	2	2	64	64	x	x	x
W 2324-1	2	2	59	64	x	x	x
ND 8304-2	1	2	69	64	x	x	x
ND 7192-1	2	2	62	64	x	x	x
ND 8-14	1	2	68	63	x	x	x
CLEARWATER RUSS	2	2	58	63	x	x	x
NORVALLEY	1	2	66	63	x	x	x
COTX02377-1W	2	2	64	63	x	x	x
UMATILLA	2	2	57	63	x	x	x
W 2982-1	1	2	65	63	x	x	x
NY 138	2	2	64	63	x	x	x
NY 140	2	2	64	63	x	x	x
MSJ 126-9Y	2	2	64	63	x	x	x
ND 8307C-3	2	2	63	63	x	x	x
ND 7560C-4	1	2	68	63	x	x	x
AOND 95249-1RUSS	2	2	57	63	x	x	x
CO 97087-2RU	2	2	59	62	x	x	x
A 98345-1	2	2	59	62	x	x	x
DAKOTA PEARL	1	2	66	62	x	x	x
W 5015-12	2	2	64	62	x	x	x
MSK 061-4	2	2	63	62	x	x	x
MSN 191-2Y	1	2	66	62	x	x	x
AOND 95292-3RUSS	2	2	60	62	x	x	x
PREMIER RUSSET	2	2	63	61	x	x	x
ALPINE RUSSET	2	2	58	61	x	x	x
A 96814-65lB	2	2	62	61	x	x	x
MN 18747 LW/W	2	2	63	61	x	x	x
W 3186-2	1	2	66	61	x	x	x
ND 8068-5RUS	2	2	64	61	x	x	x
ND 860-2-8	2	2	64	61	x	x	x
MSH 228-6	2	2	61	61	x	x	x
ND 8331CB-3	2	2	62	61	x	x	x
ND 8456-1	2	2	64	61	x	x	x

ND 5255-59	1	2	66	60	x	x	x
AC 99375-1RU	2	2	60	59	x	x	x
CO 99100-1RU	3	2	54	58		x	x
A00324-1	3	2	48	58		x	x
ATLANTIC	2	2	60	58		x	x
W 2310-3	1	2	66	57		x	x
MSQ 070-1	1	2	67	57		x	x
MSR 061-1	2	2	62	57		x	x
DAKOTA DIAMOND	2	2	60	57		x	x
AOMN 03178	2	2	60	56		x	x
CO 99053-3RU	3	2	52	55		x	x
RUSS BURBANK	2	2	55	56		x	x
MN 15620	2	2	61	55		x	x
WV 4992-1	3	2	54	55		x	x
CVO 1238-3	2	2	58	55		x	x
W 6234-4 RUSS	2	2	59	55		x	x
TX 03196-1W	2	2	56	54			x
AOMN 03178-2RU	3	2	53	54			x
ND 5775-3	1	2	65	54			x
ND 7511C-1	2	2	61	54			x
CO 98368-2RU	3	2	49	54			x
AOMN 041101-01LW	2	2	58	54			x
YUKON GOLD	3	3	52	52			x
ND 8305-1	2	3	62	52			x
W 2683-2 RUSS	3	3	50	52			x
CO 98067-7RU	2	3	58	51			x
A97066-42IB	3	3	48	51			x
SHEPODY	3	3	51	51			x
MN 02-419	4	4	49	50			x
NORLAND	4	4	51	50			x
RED PONTIAC	4	4	48	49			x
MN 02419	4	4	52	49			x
CO 99053-4 RU	4	4	50	48			x
WV 5888-2	5	5	48	48			x
CU 99279-1	5	5	47	46			x
WV 5843-6	5	5	47	44			x

Effect of Application Method, Soil Temperature and Rate of Metam Sodium on The Control of Verticillium Wilt

Submitted to MN Area II and NPPGA

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Executive Summary

Verticillium wilt, caused by *Verticillium dahliae*, 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. Approximately 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 has been recently re-registered by the Environmental Protection Agency (EPA) but with considerable restrictions placed on its use. Metam sodium is currently applied to the soil through irrigation water (water-run) or sub-surface applied via shanks. However, the most recent buffer zone requirements proposed by the EPA may effectively force growers to abandon water-run applications, this shift will result in increased pressure of Verticillium wilt unless best management practices for sub-surface shank applications of metam sodium are established. 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* and soil temperature to improve disease control while also potentially reducing the amount of the fumigant applied which will in turn improve sustainability of irrigated potato production.

Introduction

Verticillium dahliae infects the water conducting tissues of many plant species, including the potato (*Solanum tuberosum* L.), causing a disease known as *Verticillium* wilt. This pathogen is also the principle component of the early dying complex. The fungus survives in the soil as microsclerotia which allow the pathogen to survive long periods of time in the absence of a suitable plant host. The application of metam sodium to the soil kills the microsclerotia and is the primary means by which the potato industry controls this disease. The economic threshold for densities of *V. dahliae* in soil for susceptible cultivars such as Russet Burbank is 8 vppg (Nicot and Rouse, 1987), which is not a very high level of the pathogen. However, we know from previous research performed in Minnesota that soil densities after multiple potato crops can easily exceed 200 vppg (Taylor et al., 2005). These levels of *V. dahliae* make soil fumigation less effective especially when you consider studies in which places metam sodium efficacy at approximately 72% (Taylor et al., 2005).

There are a number of reasons why the efficiency of metam sodium applications to control Verticillium wilt are variable, and at times, quite poor. Previous research has indicated that *V. dahliae* is concentrated within the top 12 inches of the soil (Hamm et al. 2003) and more recently within the top 4 inches (Taylor et al. 2005). However, fumigation trials have not been conducted to factor in the *V. dahliae* concentration data in conjunction with the impending EPA mandates and the collective impacts on efficacy and other related disease problems (Hamm et al. 2003). Sub-surface metam sodium applications made too close to the soil surface will lead to increased volatilization, while applications made too deep will result in a sub-lethal dose of metam sodium reaching the area where the majority of *V. dahliae* is located. Improper applications will result in greater yield loss due to *V. dahliae* and increase the potential for other costly and deleterious effects. Unless effective guidelines for shank applications of metam sodium are established, as proposed in the research described here, an unintended consequence of the buffer zones implemented by the EPA may be increased losses due to potato early dying/Verticillium wilt. Additionally, increased scrutiny placed upon the potato crop for sustainability dictates that guidelines for the proper application of metam sodium based on soil propagule numbers and soil temperature at the time of application provides an additional rationale for the research proposed here.

Research Objectives

1) Determine the efficacy of metam sodium based on rate, soil temperature, injection depth and inoculum level of *V. dahliae*.
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

Research Plan

A replicated fumigation trial utilizing a split-split plot design was established in a commercial Russet Burbank field near Perham, Minnesota in cooperation with the RD Offutt, Company. Metam sodium was shanked into the soil using a commercial applicator on two dates to achieve different soil temperatures; September 29 and November 5, 2010. Soil temperatures at the 6” depth on those dates were 59F and 39F, respectively. Metam sodium was injected at two depths 6+10 and 10 inches only. Rates of metam sodium applied included 0, 40, 50, 60, and 70 gallons per acre. Procedures specific to each research objective are summarized below.

Prior to fumigation, two-hundred individual plots were geo-referenced and soil was sampled to a depth of 0-4 and 4-8 inches to establish pre-fumigation *V. dahliae* inoculum levels. Soil was sampled again prior to potato planting to determine the effect of metam sodium fumigation on soil populations of *V. dahliae.* Soil samples were sent to Pest Pros in Wisconsin for commercial processing. *V. dahliae* levels were determined in the pre-fumigation soil samples from December, 2010 through January, 2011. Levels of *V. dahliae* from post-fumigation soil sampling were determined in June-July, 2011.

The experiment was planted on May 3, 2011. Potato plants were evaluated for Verticillium wilt symptom development weekly beginning the end of July. Weekly wilt severity values were converted to the relative area under the wilt progress curve (RAUWPC) to facilitate data analysis and to more easily compare treatments. Individual plots were harvested on September 14 to determine yield and grade.

Results

Unfortunately, levels of *V. dahliae* in soil samples taken prior to fumigation, and determined during the winter months, were substantially lower than levels found in the soil samples taken post-fumigation, suggesting that fumigation with metam sodium increased levels of the pathogen. However, Pest Pros staff members indicate that it is not unusual for them to have lower vppg values in soil samples tested during the winter than in the summer. Unfortunately, all soil samples were discarded after testing and, therefore, cannot be re-tested. Soil samples for the 2012 trial will be tested simultaneously during the summer months to eliminate this potential problem.

Despite these difficulties, data from soil testing reveal some interesting results when examining the post-fumigation soil sampling performed on May 12. As previously stated, the economic threshold for densities of *V. dahliae* in soil for susceptible cultivars such as Russet Burbank is 8 vppg (Nicot and Rouse, 1987). Based on the post-fumigation soil tests, levels of *V. dahliae* left in the soil after fumigation ranged from 1.5 to 7-fold over the economic threshold

(Table 1). Injection depth had no effect on metam sodium efficacy based on residual levels of *V. dahliae* in the soil. It is also apparent from the data that soil levels of *V. dahliae* were quite variable since there was no statistically significant reduction in levels of the pathogen regardless of the rate of metam sodium used despite consistent reduction in soil levels at each rate. Metam sodium only reduced levels of *V. dahliae* 30-37%, substantially less than the 72% reduction we observed in previous studies (Taylor, et al., 2005). Perhaps most surprising was that late fumigation, when soil temperatures were 39F, resulted in significantly lower levels of *V. dahliae* compared to levels of the pathogen remaining in the soil after metam sodium was applied at 59F.

Weekly wilt severity data reveal similar trends. As noted previously, metam injection depth did not significantly impact the development of Verticillium wilt over the course of the growing season (Table 2). However, the rate of metam sodium used did have a significant effect on the development of wilt symptoms. Plots in which metam sodium was applied at 70 gal/a had significantly less wilt than plots treated with 40 gal/a. This is likely due to the extremely high levels of *V. dahliae* in the soil of the field in which we performed the experiment. Once again, it was surprising to observe that late fumigation in cold soil (39F) resulted in significantly less Verticillium wilt than in plots fumigated when soils were warmer (59F). Unfortunately, none of the differences in Verticillium wilt development we observed resulted in an increase of total or marketable yields (Table 3).

Further statistical analysis provides additional insights as to the impact of soil fumigation on *V. dahliae* levels in the soil stratum and the impacts of the pathogen at various depths on the development of wilt and subsequent yield. It is interesting to find that the levels of *V. dahliae* at 4-8" is more highly correlated with wilt severity observed on September 9 than the levels of the pathogen in the 0-4" depth (Table 4, Figure 1). This is interesting because the levels of *V. dahliae* in the 0-4" depth are 2 to14-fold higher than in the 4-8" depth (Table 1). Likewise, the levels of *V. dahliae* in the 4-8" stratum are more highly correlated with RAUWPC values than levels of the pathogen in the 0-4" depth (Table 4, Figure 2), which supports the statistical finding that total and marketable yields are more highly correlated with *V. dahliae* levels in the lower stratum (4-8") than in the higher stratum (0-4") (Table 4, Figure 3 & 4).

<u>Summary and Conclusions</u>

Results of this trial provide additional insights into the impact of *V. dahliae* and the development of wilt in a potato crop. Although levels of the pathogen were not controlled as well with metam sodium as we expected, the results reported here provide valuable information that may allow us to improve the efficacy of this very important and expensive crop production and disease management tactic. Interestingly, and counter to previously published studies, metam sodium application during colder soil temperatures significantly improved efficacy of the chemical in reducing *V. dahliae* levels. This suggests that there may be more off-gassing of metam sodium at the higher temperatures which likely had a negative effect on the efficacy of the soil fumigant than we anticipated.

Perhaps more interesting is the observation that levels of *V. dahliae* in the lower soil stratum (4-8") appear to be more important than levels of the pathogen in the upper soil levels, despite being substantially lower. Levels of *V. dahliae* at 4-8" were more highly correlated with wilt severity before harvest, total wilt development (RAUWPC) and total and marketable yields. Thus, it appears more attention needs to be given the management and reduction of these *V. dahliae* populations. This can be done by either improving metam sodium injection methodology, the rate of metam sodium used, the temperature of the soil at the time of injection, or a combination of all of these factors. Further studies on this are warranted and a similar experiment has been initiated for the 2012 growing season.

Literature Cited

Hamm, P. B., Ingham, R. E., Jaeger, J. R., Swanson, W. H., and Volker, K. C. 2003. Soil fumigant effects on three genera of potential soilborne pathogenic fungi and their effect on potato yield in the Columbia Basin of Oregon. Plant Disease 87:1449-1456.

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Taylor, Raymond J., Pasche, Julie S. and Gudmestad, Neil 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.

Treatment	Injection Depth	Rate	Timing	Vppg 9/28/10 0-4"	Vppg 9/28/10 4-8"	Vppg 9/28/10 0-8"	Vppg 5/12/11 0-4"	Vppg 5/12/11 4-8"	Vppg 5/12/11 0-8"
801	Control	0 gal / a	Control	8.2	3.8	12.0	36.8	17.2	54.0
802	10 in	40 gal / a	Early	7.0	2.2	9.2	36.8	14.2	51.0
803	10 in	50 gal / a	Early	10.6	5.0	15.6	28.8	7.2	36.0
804	10 in	60 gal / a	Early	15.0	4.6	19.6	29.8	5.6	35.4
805	10 in	70 gal / a	Early	8.8	2.8	11.6	38.4	10.0	48.4
806	Control	0 gal / a	Control	4.4	7.0	11.4	21.8	11.6	33.4
807	10 in	40 gal / a	Late	9.4	10.6	20.0	27.6	4.2	31.8
808	10 in	50 gal / a	Late	4.8	3.6	8.4	14.4	1.2	15.6
809	10 in	60 gal / a	Late	3.6	5.6	9.2	9.4	2.6	12.0
810	10 in	70 gal / a	Late	10.8	7.0	17.8	14.6	2.4	17.0
811	Control	0 gal / a	Control	10.2	3.6	13.8	43.2	10.4	53.6
812	6 in +10 in	40 gal / a	Early	7.6	2.0	9.6	23.2	4.6	27.8
813	6 in +10 in	50 gal / a	Early	7.4	3.6	11.0	23.8	5.8	29.6
814	6 in +10 in	60 gal / a	Early	12.4	3.0	15.4	23.6	4.0	27.6
815	6 in +10 in	70 gal / a	Early	7.8	1.8	9.6	26.2	5.6	31.8
816	Control	0 gal / a	Control	13.4	4.4	17.8	33.4	17.4	50.8
817	6 in +10 in	40 gal / a	Late	12.8	4.8	17.6	21.0	2.2	23.2
818	6 in +10 in	50 gal / a	Late	18.4	4.4	22.8	23.8	5.4	29.2
819	6 in +10 in	60 gal / a	Late	13.8	4.2	18.0	20.8	3.6	24.4
820	6 in +10 in	70 gal / a	Late	12.4	3.4	15.8	16.6	5.6	22.2
$LSD_{P = 0.05}$ (interaction of main effects)				NS	NS	*	NS	NS	NS
	Control			9.1	4.7	13.8	33.8	14.2	48.0
	10 in			8.8	5.2	13.9	25.0	5.9	30.9
	6 in +10 in			11.6	3.4	15.0	22.4	4.6	27.0
$LSD_{P = 0.05}$				2.7	1.6	NS	NS	NS	NS
		0 gal / a		9.1	4.7	13.8	33.8	14.2	48.0
		40 gal / a		9.2	4.9	14.1	27.2	6.3	33.5
		50 gal / a		10.3	4.2	14.5	22.7	4.9	27.6
		60 gal / a		11.2	4.4	15.6	20.9	4.0	24.9
		70 gal / a		10.0	3.8	13.7	24.0	5.9	29.9
$LSD_{P = 0.05}$				NS	NS	NS	NS	NS	NS
			Control	9.1	4.7	13.8	33.8	14.2	48.0
			Early	9.6	3.1	12.7	28.8	7.1	36.0
			Late	10.8	5.5	16.2	18.5	3.4	21.9
$LSD_{P = 0.05}$				NS	NS	3.3	5.5	2.8	7.2

Early = 1st Fumigation on 9/29/10; Late = 2nd Fumigation on 11/5/10

At pre-fumigation (9/28/10), significant rate X timing interactions were observed at 0-4", 4-8" and 0-8".

At pre-fumigation (9/28/10), significant injection depth X timing interactions were observed at 0-4" and 0-8".

At post-fumigation(5/12/11), significant injection depth X timing interactions were observed at 0-4", 4-8" and 0-8".

Table 2. Impact of metam sodium on Verticillium wilt development.

Trt	Injection Depth	Rate	Timing	Wilt (% Severity)							AUWPC	RAUWPC
				7/28	8/3	8/10	8/17	8/23	8/31	9/9		
801	Control	0 gal / a	Control	1.0	9.4	16.8	15.9	47.0	79.5	97.6	1744.1	0.406
802	10 in	40 gal / a	Early	2.7	7.3	8.3	15.0	44.5	76.0	93.8	1608.9	0.374
803	10 in	50 gal / a	Early	3.3	7.2	10.9	20.4	40.0	75.5	89.2	1603.3	0.373
804	10 in	60 gal / a	Early	5.5	7.9	9.5	14.7	41.0	65.0	89.0	1485.7	0.346
805	10 in	70 gal / a	Early	0.4	2.9	6.0	8.6	24.9	50.0	87.2	1119.1	0.260
806	Control	0 gal / a	Control	4.8	10.8	13.0	32.0	59.5	82.5	96.6	1959.3	0.456
807	10 in	40 gal / a	Late	4.0	6.9	10.9	19.5	43.0	70.0	90.1	1577.4	0.367
808	10 in	50 gal / a	Late	2.5	5.6	6.7	9.9	19.2	45.0	78.0	1029.3	0.239
809	10 in	60 gal / a	Late	2.6	8.5	8.6	9.1	23.0	45.5	82.2	1107.3	0.258
810	10 in	70 gal / a	Late	1.0	4.8	6.1	10.8	31.2	62.5	87.6	1303.5	0.303
811	Control	0 gal / a	Control	2.9	4.6	14.2	21.2	47.5	74.4	93.9	1679.9	0.391
812	6 in +10 in	40 gal / a	Early	1.5	5.7	13.3	18.7	30.5	59.5	86.1	1371.5	0.319
813	6 in +10 in	50 gal / a	Early	4.4	8.8	20.8	16.6	44.3	62.0	89.3	1574.6	0.366
814	6 in +10 in	60 gal / a	Early	2.2	5.5	9.7	11.7	28.0	58.0	89.6	1287.7	0.299
815	6 in +10 in	70 gal / a	Early	2.2	4.8	6.7	8.7	35.2	57.8	91.4	1173.8	0.273
816	Control	0 gal / a	Control	3.4	10.2	20.9	21.2	46.5	78.5	97.1	1803.1	0.419
817	6 in +10 in	40 gal / a	Late	2.5	4.4	9.2	9.7	24.2	57.5	84.0	1207.2	0.281
818	6 in +10 in	50 gal / a	Late	0.6	1.9	4.5	4.7	17.7	41.0	74.2	889.1	0.207
819	6 in +10 in	60 gal / a	Late	2.9	5.5	19.0	10.3	27.0	58.5	87.0	1326.2	0.308
820	6 in +10 in	70 gal / a	Late	2.6	4.1	7.3	7.3	22.5	44.0	72.5	998.4	0.232
$LSD_{P=0.05}$ (interaction)				NS	NS	NS	NS	NS	*	NS	NS	NS
	Control			3.0	8.8	16.2	22.6	50.1	78.7	96.3	1796.6	0.418
	10 in			2.8	6.4	8.4	13.5	33.4	61.2	87.1	1354.3	0.315
	6 in +10 in			2.4	5.1	11.4	11.0	28.6	54.7	84.2	1228.5	0.286
$LSD_{P=0.05}$				NS	NS	NS	NS	NS	6.0	NS	NS	NS
		0 gal / a		3.0	8.8	16.2	22.6	50.1	78.7	96.3	1796.6	0.418
		40 gal / a		2.7	6.1	10.4	15.7	35.6	65.8	88.5	1441.2	0.335
		50 gal / a		2.7	5.9	10.7	12.9	30.3	55.9	82.7	1274.1	0.296
		60 gal / a		3.3	6.9	11.7	11.5	29.8	56.8	87.0	1301.7	0.303
		70 gal / a		1.5	4.1	6.5	8.8	28.3	53.5	84.5	1148.7	0.267
$LSD_{P=0.05}$				NS	NS	NS	NS	NS	7.3	NS	184.3	0.043
			Control	3.0	8.8	16.2	22.6	50.1	78.7	84.4	1796.6	0.418
			Early	2.8	6.3	10.7	14.4	36.1	63.0	90.0	1403.1	0.326
			Late	2.3	5.2	9.0	10.2	26.0	53.0	87.3	1179.8	0.274
$LSD_{P=0.05}$				NS	NS	NS	4.6	5.9	6.0	NS	150.5	0.035

Early = 1st Fumigation on 9/29/10; Late = 2nd Fumigation on 11/5/10

AUWPC = area under the wilt progress curve; RAUWPC = relative area under the wilt progress curve

A significant interaction of main effects of rate X timing was observed on 8/10, 8/23, 8/31 as well as with AUWPC and RAUWPC.

A significant interaction of main effects of injection X timing was observed on 9/9.

Table 3. Impact of metam sodium on potato yield and grade.

Trt	Injection Depth	Rate	Timing	Total Yield (cwt/a)	Market Yield (cwt/a)	10 oz. & over (%)			6 - 9 oz. (%)			>6 oz. (%)	2 in/4 oz (%)		Total Smalls (%)	Unusables (%)		
						US No. 1	US No. 2	Total	US No. 1	US No. 2	Total	Total	US No. 1	US No. 2		Total	Undersize	Other
801	Control	0 gal / a	Control	413.1	316.9	4.1	0.6	4.7	24.4	3.2	27.6	32.3	41.5	3.2	44.7	23.1	16.2	6.9
802	10 in	40 gal / a	Early	428.1	337.5	5.6	0.6	6.2	25.2	1.8	26.9	33.2	43.9	1.8	45.7	21.2	17.4	3.8
803	10 in	50 gal / a	Early	449.0	352.2	4.3	0.3	4.6	24.9	2.6	27.5	32.1	44.3	2.0	46.3	21.5	17.3	4.3
804	10 in	60 gal / a	Early	460.3	393.8	4.9	0.6	5.5	28.7	2.1	30.8	36.3	47.8	1.3	49.1	14.6	13.0	1.6
805	10 in	70 gal / a	Early	470.0	384.5	6.5	1.2	7.7	28.5	2.9	31.4	39.1	41.1	1.6	42.7	18.2	14.5	3.7
806	Control	0 gal / a	Control	451.7	339.1	3.3	0.2	3.5	22.8	1.8	24.5	28.0	45.1	2.0	47.1	24.9	18.8	6.1
807	10 in	40 gal / a	Late	459.6	380.5	6.1	0.6	6.6	28.9	1.6	30.6	37.2	44.0	1.6	45.7	17.2	14.7	2.5
808	10 in	50 gal / a	Late	470.7	390.8	9.3	1.5	10.8	28.3	1.9	30.2	41.0	40.4	1.6	42.0	17.0	15.2	1.7
809	10 in	60 gal / a	Late	456.6	358.7	6.4	1.5	7.9	24.9	3.1	27.9	35.8	40.1	2.6	42.8	21.4	16.8	4.7
810	10 in	70 gal / a	Late	456.5	383.1	6.9	0.6	7.5	28.1	2.0	30.1	37.6	44.5	1.8	46.3	16.1	13.1	2.9
811	Control	0 gal / a	Control	458.5	350.3	3.6	0.1	3.7	20.5	1.9	22.4	26.1	48.1	2.3	50.3	23.6	19.6	4.0
812	6 in +10 in	40 gal / a	Early	475.5	375.4	5.9	0.5	6.4	24.5	1.7	26.2	32.6	44.6	1.7	46.2	21.2	18.6	2.6
813	6 in +10 in	50 gal / a	Early	481.3	375.2	3.5	0.7	4.2	21.2	1.7	22.8	27.0	49.0	2.0	51.0	22.1	17.7	4.3
814	6 in +10 in	60 gal / a	Early	465.9	367.6	6.3	0.5	6.8	22.3	2.4	24.7	31.5	45.3	2.1	47.4	21.1	17.6	3.5
815	6 in +10 in	70 gal / a	Early	479.1	374.3	5.2	0.2	5.4	22.9	2.5	25.4	30.8	46.1	1.4	47.5	21.7	18.0	3.7
816	Control	0 gal / a	Control	388.9	282.3	3.1	0.6	3.7	19.0	3.9	22.8	26.5	43.4	2.7	46.1	27.4	22.3	5.0
817	6 in +10 in	40 gal / a	Late	464.5	372.5	6.9	0.8	7.7	25.3	1.2	26.5	34.2	44.4	1.6	46.0	19.8	17.1	2.7
818	6 in +10 in	50 gal / a	Late	453.8	367.4	4.5	0.7	5.3	24.4	1.6	26.0	31.3	48.2	1.3	49.5	19.2	17.9	1.3
819	6 in +10 in	60 gal / a	Late	444.2	360.0	6.8	8.2	15.1	24.1	1.7	25.8	40.9	45.7	1.9	47.6	18.9	15.9	3.1
820	6 in +10 in	70 gal / a	Late	443.6	370.3	11.2	0.1	11.3	26.2	1.8	28.0	39.3	43.0	1.2	44.2	16.5	15.3	1.2
$LSD_{P = 0.05}$ (interaction of 3 main effects				NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
	Control			428.1	322.1	3.5	0.4	3.9	21.7	2.7	24.3	28.2	44.5	2.5	47.1	24.7	19.2	5.5
	10 in			456.4	372.6	6.2	0.9	7.1	27.2	2.2	29.4	36.5	43.3	1.8	45.1	18.4	15.3	3.1
	6 in +10 in			463.5	370.3	6.3	1.5	7.8	23.9	1.8	25.7	33.4	45.8	1.6	47.4	20.1	17.3	2.8
$LSD_{P = 0.05}$				NS	NS	NS	NS	NS	3.0	NS	3.1	NS	NS	NS	NS	NS	NS	NS
		0 gal / a		428.1	322.1	3.5	0.4	3.9	21.7	2.7	24.3	28.2	44.5	2.5	47.1	24.7	19.2	5.5
		40 gal / a		456.9	366.5	6.1	0.6	6.7	26.0	1.6	27.5	34.3	44.2	1.7	45.9	19.9	17.0	2.9
		50 gal / a		463.7	371.4	5.4	0.8	6.2	24.7	1.9	26.6	32.8	45.5	1.7	47.2	19.9	17.0	2.9
		60 gal / a		456.8	370.0	6.1	2.7	8.8	25.0	2.3	27.3	36.1	44.7	2.0	46.7	19.0	15.8	3.2
		70 gal / a		462.3	378.1	7.4	0.5	8.0	26.4	2.3	28.7	36.7	43.7	1.5	45.2	18.1	15.3	2.9
$LSD_{P = 0.05}$				NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
			Control	428.1	322.1	3.5	0.4	3.9	21.7	2.7	24.3	28.2	44.5	2.5	47.1	24.7	19.2	5.5
			Early	463.7	370.1	5.3	0.6	5.9	24.8	2.2	27.0	32.8	45.2	1.7	47.0	20.2	16.8	3.4
			Late	456.2	372.9	7.3	1.8	9.0	26.3	1.9	28.1	37.2	43.8	1.7	45.5	18.3	15.8	2.5
$LSD_{P = 0.05}$				NS	NS	1.6	NS	3.0	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Early = 1st Fumigation on 9/29/10; Late = 2nd Fumigation on 11/5/10

A significant interaction of main effects of injection X timing was observed in total yield.

Table 4. Relationship between percent wilt on three dates, relative area under the wilt progress curve (RAUWPC), total and market yield to Verticillium propagules per gram of soil (Vppg).

		Vppg			Total yield	Market yield
		0-4 in	4-8 in	0-8 in		
August 23	r	0.5344	0.6671	0.6200		
	P	0.0152	0.0013	0.0035		
August 31	r	0.5746	0.6851	0.6544		
	P	0.0081	0.0009	0.0017		
September 9	r	0.6114	0.6684	0.6735		
	P	0.0042	0.0013	0.0011		
RAUWPC	r	0.5130	0.6691	0.6061	-0.4505	-0.6127
	P	0.0207	0.0013	0.0046	0.0462	0.0041
Total yield	r	-0.3229	-0.7410	-0.5023		
	P	0.1650	0.0002	0.024		
Market yield	r	-0.3951	-0.8248	-0.5838		
	P	0.0847	<0.0001	0.0069		

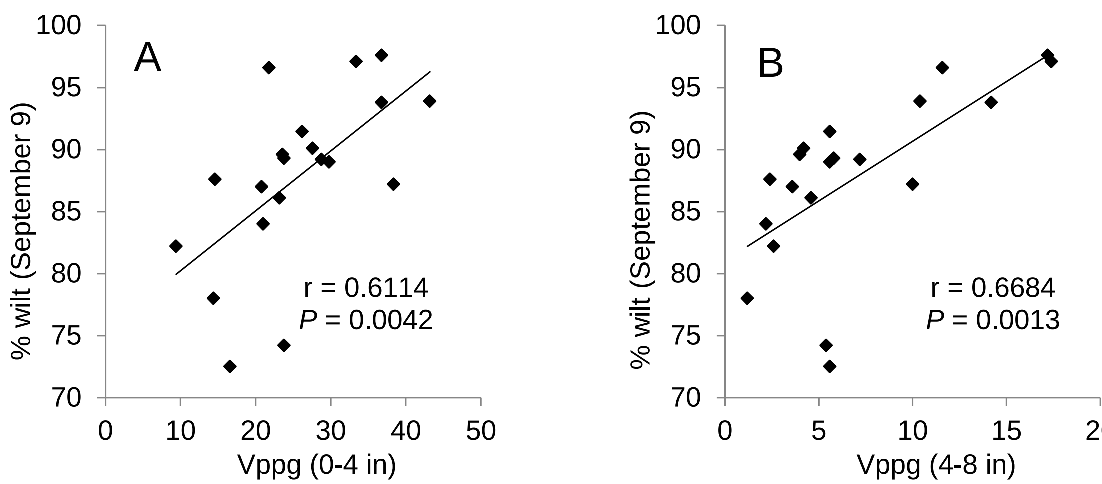

Figure 1. Relationship between percent Verticillium wilt on September 9 and Verticillium propagules per gram (Vppg) of soil post-fumigation at 0-4 inches (A) and 4-8 inches (B).

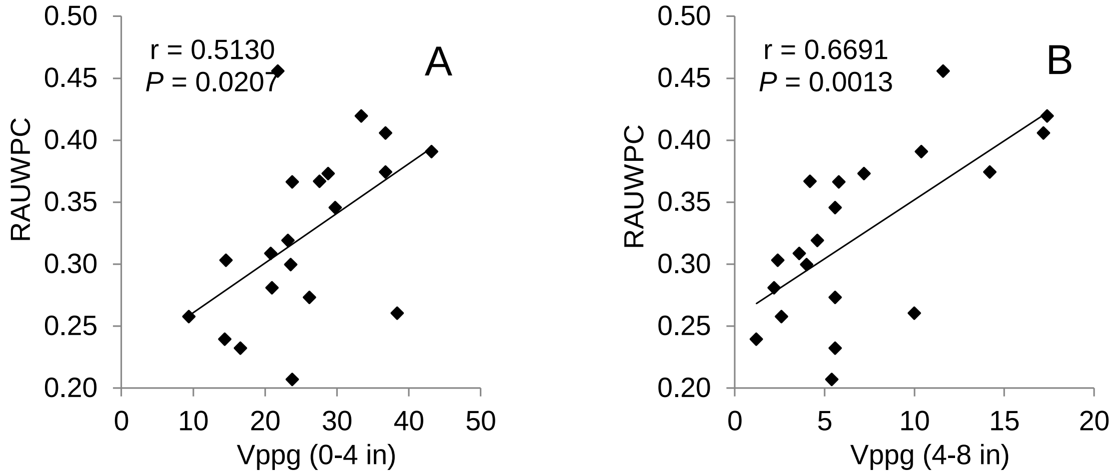

Figure 2. Relationship between relative area under the wilt progress curve (RAUWPC) and Verticillium propagules per gram (Vppg) of soil post-fumigation at 0-4 inches (A) and 4-8 inches (B).

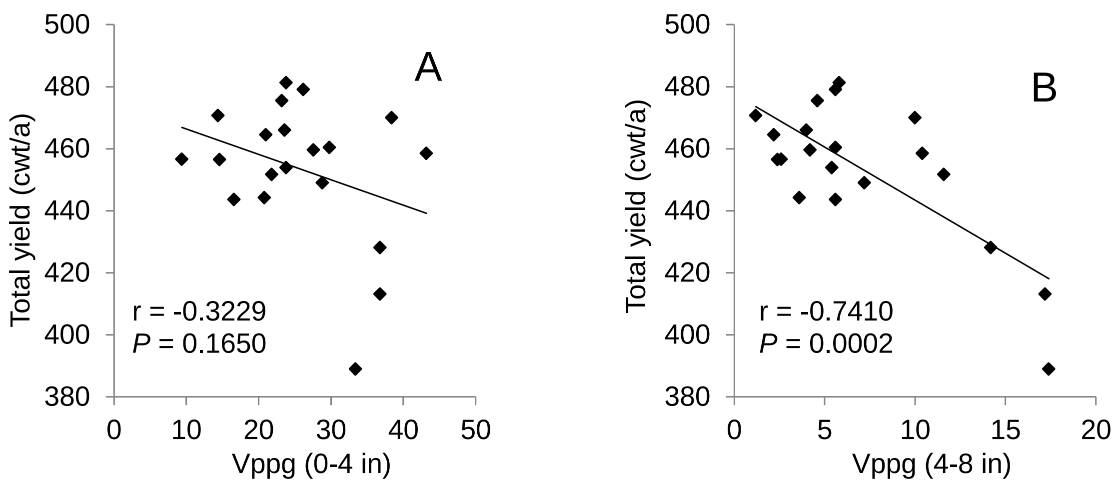

Figure 3. Relationship between total yield (cwt/a) and Verticillium propagules per gram (Vppg) of soil post-fumigation at 0-4 inches (A) and 4-8 inches (B).

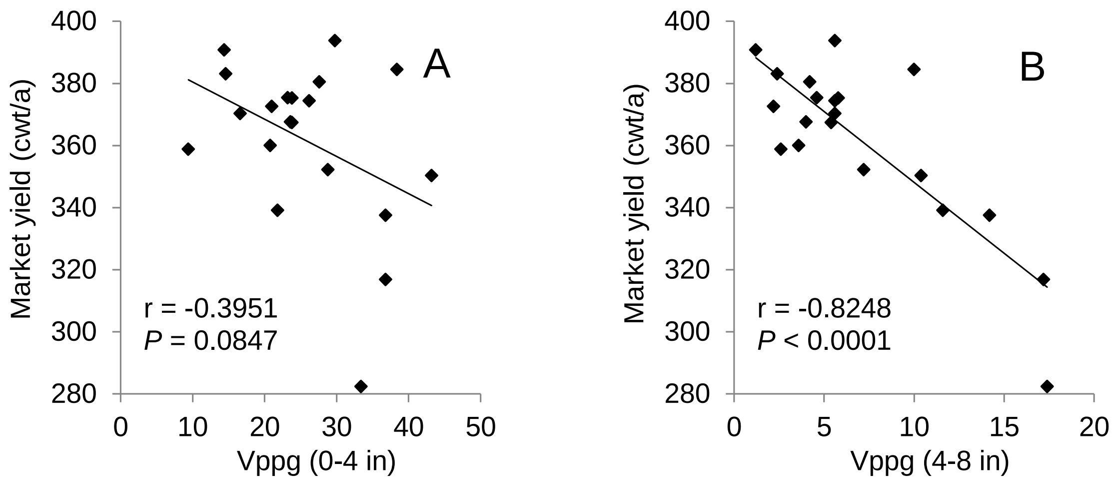

Figure 4. Relationship between market yield (cwt/a) and Verticillium propagules per gram (Vppg) of soil post-fumigation at 0-4 inches (A) and 4-8 inches (B).

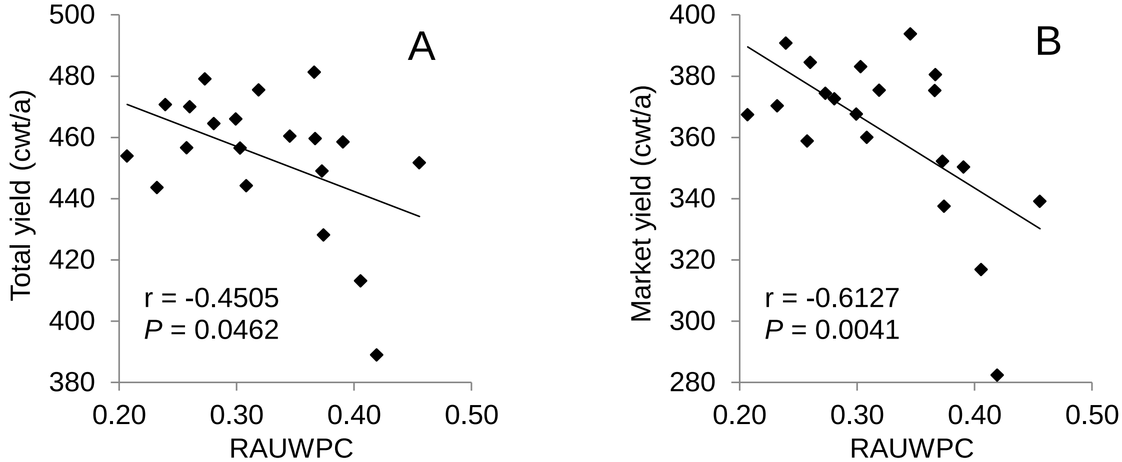

Figure 5. Relationship between total yield (cwt/a) (A) market yield (cwt/a) (B) and relative area under the wilt progress curve (RAUWPC).

Title: Potential Management of Powdery Scab and Mop Top Virus Using an Integration of Soil Fumigation and Genetic Resistance

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Executive Summary:

Soilborne diseases of potato are generally regarded as the one of the most serious economic constraints facing the potato industry when disease losses are coupled with the cost of control. The principle soil borne pathogens affecting potato are *Verticillium dahliae, Colletotrichum coccodes, Rhizoctonia solani,* and most recently *Spongospora subterranea,* the cause of powdery scab. The powdery scab pathogen is also the vector of potato mop top virus (PMTV), an important tuber necrosis virus recently detected in North Dakota for the first time in 2010 (David, et al., 2010). Powdery scab was first reported in North Dakota in 1997 (Draper, et al., 1997) and has since emerged as one of the most important soil borne diseases of potato in the region.

Rationale:

A number of important soilborne pathogens affect potato development and tuber quality. Among the most important of these diseases is powdery scab, caused by *Spongospora subterranea*, The powdery scab pathogen forms galls on the roots of infected plants which can girdle the roots and compromise their function in water and nutrient uptake. However, the tuber lesion phase of this disease is the most recognizable since infected tubers are unmarketable. When the powdery scab pathogen carries the mop top virus (PMTV) and transmits it to potato plants, the resulting tuber necrosis exacerbates the yield loss potential from this pathogen causing a disease the potato industry in the United Kingdom refers to as 'spraing'. The occurrence of spraing in several French fry processing fields in North Dakota caused significant economic hardship for one grower but the threat to other growers in the region is real. A survey of potato soils in the state have identified two additional farms that have powdery scab fungus present on the farm that is infected with PMTV.

At current time, the only method of controlling powdery scab in potato is to avoid it. The methods to determine the presence and concentration of important soil borne potato pathogens have historically been costly, time-consuming, and in the case of powdery scab, nonexistent. The development of a multiplex real-time PCR method in my research laboratory capable of detecting and quantifying soil inocula of three soilborne pathogens has assisted growers in making management decisions. The NPPGA supported this research in previous years and, as a result, growers are testing soils before planting in order to avoid planting potatoes into soils with high levels of powdery scab. The red growers in MN and ND have been particularly supportive of this testing method.

Unfortunately, many potato soils in our region are already contaminated with high levels of powdery scab and, in some cases, PMTV also exists. There are currently no disease management strategies available for these producers. Research proposed here would provide short and intermediate control strategies for potato producers already faced with serious powdery scab and mop top disease problems.

The goal of the research proposed here is to investigate the ability of chloropicrin fumigation to reduce soil levels of *S. subterranea*, We have established three field trials in which several rates of chloropicrin were applied during the fall of 2010, two in MN and one in ND. We will establish another chloropicrin fumigation trial in ND in a field with mop top virus infestation. Within these trials we will determine the level of soil borne inoculum reduction of the powdery scab pathogen and we will screen a wide variety of potato varieties and germplasm for resistance to powdery scab and mop top virus.

Research Objectives:

1) Determine the degree of *S. subterranea* soil inoculum reduction that can be achieved using chloropicrin soil fumigation.
2) Screen red, white, and russet-skinned potato varieties for their susceptibility to powdery scab and mop top virus.

Research Plan:

Two field trials were established in two fields with a history of potato production and with known infestations of powdery scab. One field trial was also established in which the powdery scab infestation was infected with PMTV. These fields will be treated with three rates of broadcast chloropicrin (0, 87.5 & 175 lb a.i./a) and four rates of in-row chloropicrin (0, 100, 137.5 & 175 lb a.i./a) in a replicated, randomized block design. Within each of these fumigation rates and methods of application seven French fry russet cultivars (Russet Burbank, Russet Norkotah, Ranger Russet, Umatilla Russet, Alpine Russet, Bannock Russet, and Dakota Trailblazer), three white cultivars (Ivory Crisp, Shepody, and Kennebec), three red cultivars (Red Lasoda, Red Pontiac, and Red Norland) and one yellow cultivar (Yukon Gold) were planted. The goal in this experiment was to assess whether or not chloropicrin would reduce powdery scab incidence and severity on each of these cultivars and to determine if any reductions in disease would also result in a reduction of tuber necrosis caused by PMTV.

In the second set of experiments we assessed susceptibility to powdery scab and susceptibility to mop top virus in potato cultivars, advanced clones, and breeding selections representing every market class. Eighty eight cultivars and advanced clones were assessed for susceptibility to tuber necrosis caused by PMTV. These trials were planted on May 24-25, 2011, and harvested on October 5-6. Varietal susceptibility to powdery scab was assessed by determining the severity of galls that form on roots and the severity of tuber lesion development. Mop top susceptibility was determined by the degree of internal tuber necrosis that developed in potato tubers and was assessed post-harvest.

Results:

We detected wide variability in susceptibility of potato cultivars and germplasm to both powdery scab and PMTV.

The use of chloropicrin soil fumigation did not significantly reduce powdery scab incidence or severity on potato tubers, although there were some numerical reductions at the higher use rates (Figure 1). As expected, potato cultivars such as Russet Burbank, Russet Norkotah, Ranger Russet, Umatilla Russet, Alpine Russet and Bannock Russet did not develop powdery scab lesions on potato tubers (Figure 2). Russet skinned cultivars tend to resist tuber infection by *S. subterranea*. Interestingly, powdery scab lesions were observed on the russet cultivar Dakota Trailblazer.

Tuber necrosis caused by PMTV also varied among cultivars (Figure 3A). Russet skinned cultivars tended to have a lower incidence than white or red-skinned cultivars. Soil fumigation with chloropicrin did not affect the incidence of mop top tuber necrosis among the cultivars we evaluated (Figure 3B). It is interesting to note that among the standard cultivars included in both trials that the overall incidence of tuber necrosis in the fumigation trial (Figure 3) was substantially lower than that observed in the cultivar screening trial (Tables 1-4).

Wide variation in the incidence of tuber necrosis caused by PMTV was observed among all cultivars and selections in each market class in the screening trial (Tables 1-4). Tuber necrosis ranged from zero in some cultivars to over 45% in some advanced breeding selections.

PMTV caused tuber necrosis was not observed among red-skinned cultivars Red Pontiac and Puyehue and a number of advanced selections (Table 1). As a group, russet-skinned cultivars tended to have a lower incidence of tuber necrosis caused by PMTV (Table 2). It is interesting to note that in these trials, Russet Burbank did not develop any observable tuber necrosis from PMTV which is surprising since the field in which this field study was conducted had a field infection rate of >14% in this cultivar. White-skinned cultivars also appeared to be much more susceptible, as a group, compared to yellow-skinned cultivars although there was substantial variability in tuber necrosis observed among clones in both market classes (Tables 3 & 4). No PMTV tuber necrosis was observed in Shepody, Kennebec, Yukon Gold, Puren, and several advanced breeding selections (Tables 3 & 4).

Based on these data, we believe we can use field trials to develop reliable susceptibility rankings for potato cultivars and provide growers with useful disease management information by having growers avoid the most susceptible cultivars. Furthermore, we believe we can begin to develop PMTV resistant germplasm that can be utilized in further breeding strategies.

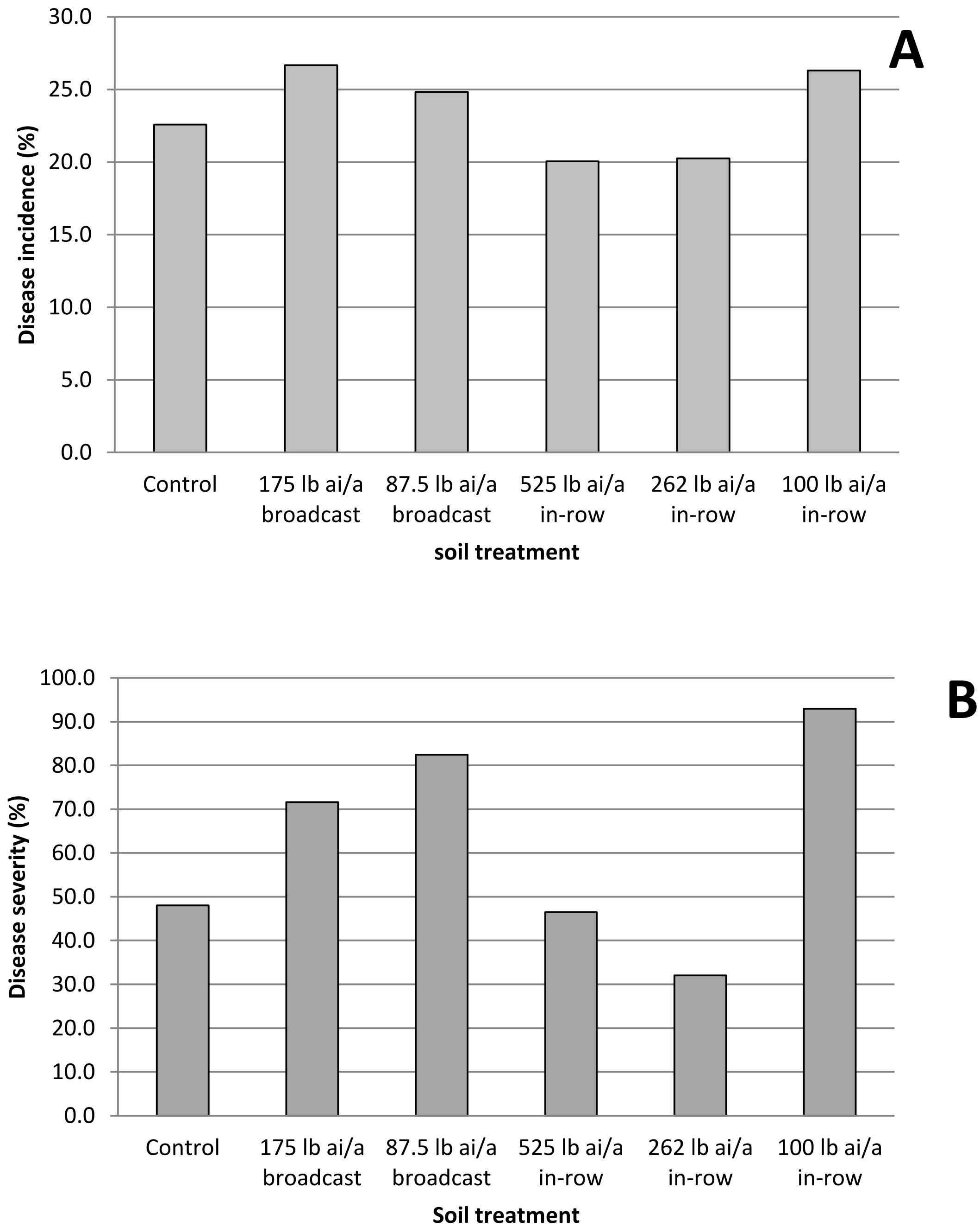

Figure 1. Average of the powdery scab tuber incidence (A) and severity (B) from chloropicrin soil fumigation trial at Larimore, ND in fall 2010 by soil treatment.

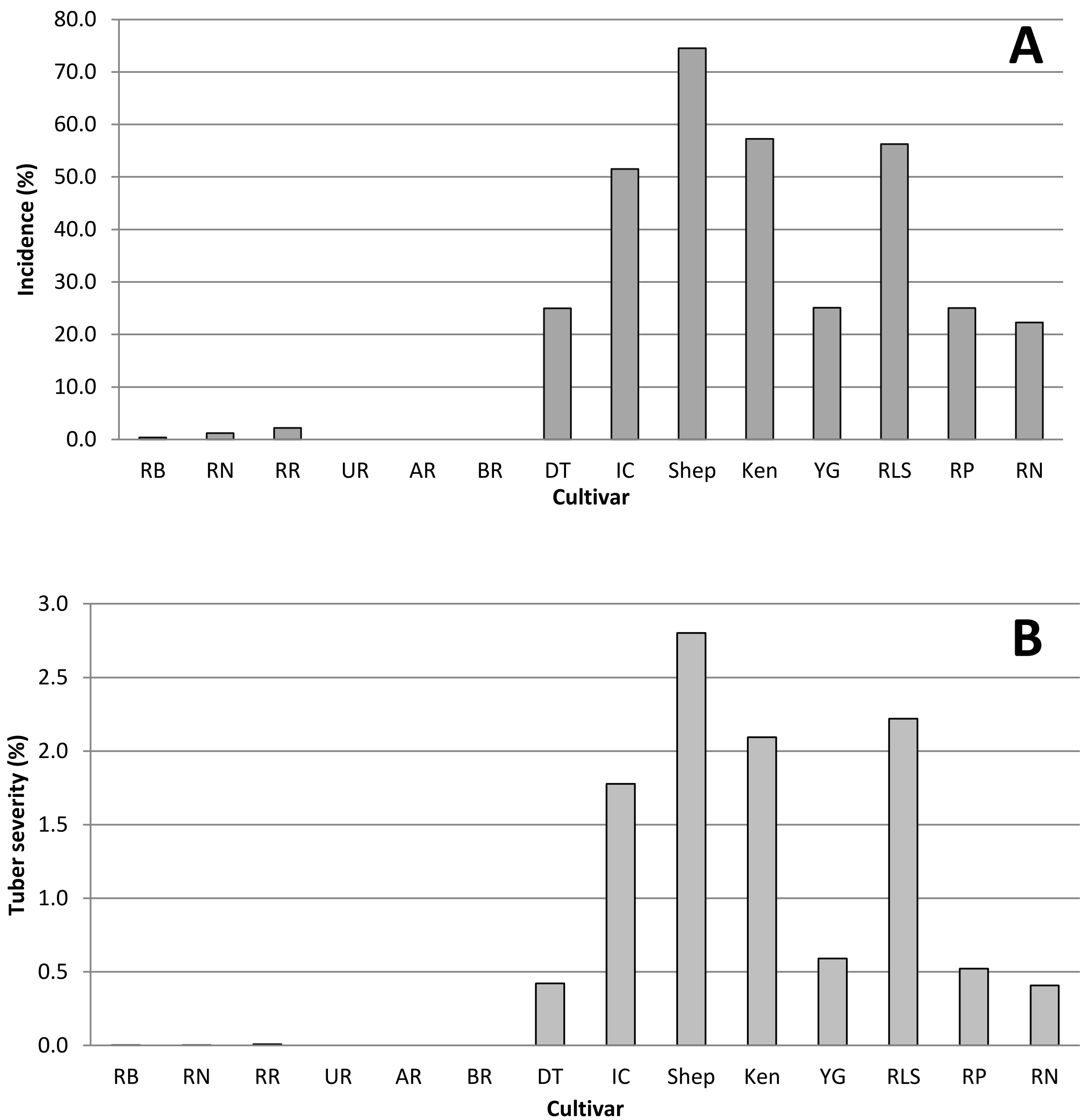

Figure 2. Average of the powdery scab tuber incidence (A) and severity (B) from chloropicrin soil fumigation trial at Larimore, ND in fall 2010 by Cultivar. RB: Russet Burbank, RN: Russet Norkotah, RR: Ranger Russet, UR: Umatilla Russet, AR: Alpine Russet, BR: Bannock Russet, DT: Dakota Trailblazer, IC: Ivory Crisp, Shep: Shepody, Ken: Kennebec, YG: Yukon Gold, RLS: Red LaSoda, RP: Red Pontiac, RN: Red Norland.

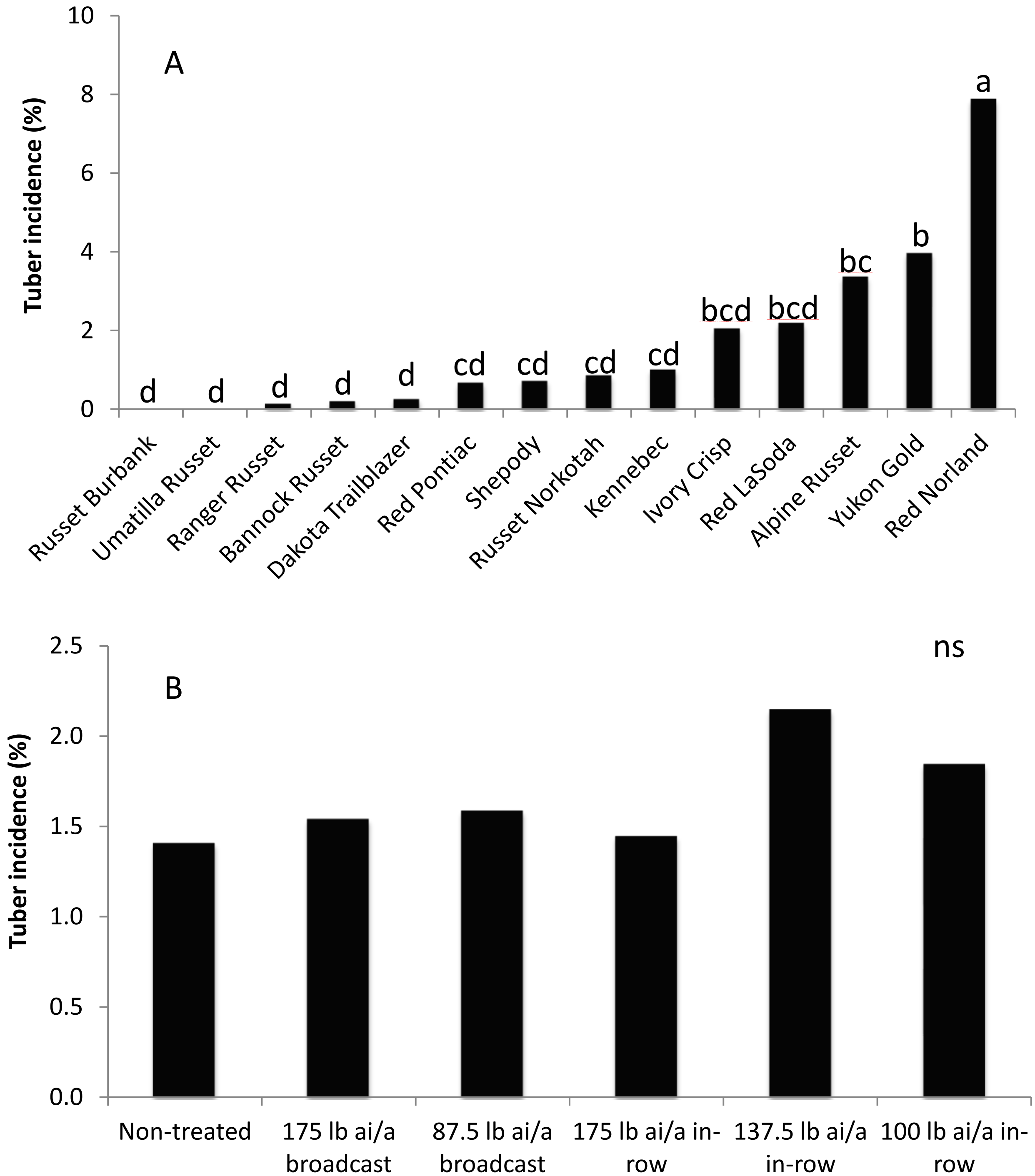

Figure 3. PMTV lesion incidence among cultivars (A) and chloropicrin treatments (B).

Table 1. PMTV tuber lesion incidence (%) of several cultivars / selections with red skin-type.

Cultivar / Selection	Tuber incidence (%)
Red Pontiac	0.0 cde
R 91129-11	0.0 cde
R 90160-5	0.0 cde
RA 89044-45	0.0 cde
RA 20-6	0.0 cde
Puyehue	0.0 cde
T10-12	0.0 cde
ND4659-5R	1.7 cde
R 90070-8	2.3 cde
RC 72-35	2.7 cde
ATND98459-1RY	3.7 cde
ND8555-8R	6.0 cde
ND060733b-4RY	8.0 cde
R90213-6	10.3 cde
Viking	11.3 cde
Patagonia	11.7 cde
ND8058-11R	17.0 bcde
Red LaSoda	19.0 bcde
ND050167C-3R	20.0 bcde
Red Norland	20.3 bcde
ND028842b-1RY	20.3 bcde
Dakota Jewel	20.7 bcde
R90134-6	20.7 bcde
Dark Red Norland	21.0 bcde
AND00272-1R	23.3 abcd
ND060728-5R	24.3 abcd
RA 90213-60	28.0 abc
SPA 161	38.3 ab
ND8314-1R	45.3 a

Table 2. PMTV tuber lesion incidence (%) of several cultivars / selections with russet skin-type.

Cultivar / Selection	Tuber incidence (%)
Russet Burbank	0.0 c
Russet Norkotah	0.0 c
Ranger Russet	0.0 c
Umatilla	0.0 c
Alpine	0.0 c
Bannock	0.0 c
Dakota Trailblazer	0.0 c
ND060766b-4Russ	0.0 c
ND060796AB-1Russ	0.0 c
AND01804-3Russ	0.0 c
ND049546b-10Russ	0.0 c
ND049289-1Russ	0.0 c
ND049423b-1Russ	0.0 c
ND8413-7Russ	0.0 c
ND050105C-1Russ	2.7 bc
ND8068-5Russ	2.7 bc
ND6400C-1Russ	2.7 bc
ND050082Cb-2Russ	5.0 bc
ND059769Ab-1Russ	6.0 b
ND8229-3	6.0 b
ND060742C-1Russ	11.7 a

Table 3. PMTV tuber lesion incidence (%) of several cultivars / selections with white skin-type.

Cultivar / Selection	Tuber incidence (%)	
Shepody	0.0	c
Kennebec	0.0	c
W2717-5	0.0	c
NY-138	0.0	c
ND8559-20	0.0	c
ND8331Cb-3	0.0	c
ND7550C-1	1.3	c
Lamoka	2.0	bc
ND6956b-13	2.0	bc
CO 95051-7W	2.3	bc
RA 151-24	2.3	bc
Ivory Crisp	2.7	bc
ND8331Cb-2	2.7	bc
ND8307C-3	4.7	bc
ND060835C-4	5.7	bc
NY-139	6.7	bc
MSL-292A	8.7	bc
R65A-70	8.7	bc
Snowden	10.3	bc
ND7519-1	13.0	bc
ND8304-2	14.3	bc
Nicolet	14.7	bc
ND060847CB-1	14.7	bc
ND060715B-15	17.3	b
ND060601CAB-2	35.0	a

Table 4. PMTV tuber lesion incidence (%) of several cultivars / selections with yellow skin-type.

Cultivar / Selection	Tuber incidence (%)
Yukon Gold	0.0
RA 16-5	0.0
RC 06-109	0.0
RA 517-123	0.0
R 91007-5	0.0
Puren	0.0
RA 148-48	0.0
RA 519-50	2.3
R 89045-35	2.3
R 87009-28	3.7
RA 362-54	4.7
Yagana	9.0
RA 82-4	11.3

Literature Cited:

David, N., Mallik, I., Crosslin, J.M. and Gudmestad, N.C. 2010. First report of *Mop Top virus* in North Dakota. Plant Dis. 94:1506.

Draper, M.A., Secor, G.A. and Gudmestad, N.C. 1997. First report of potato powdery scab caused by *Spongospora subterranea f.sp. subterranea*, in North Dakota. Plant Dis. 81:693.

Nutrisphere-2011. Harlene Hatterman-Valenti and CollinAuwarter.

This study was conducted at the Northern Plains Potato Grower's Association Irrigation Research site near Inkster, ND to evaluate Urea with Nutrisphere against Urea using grower standard practices. The study was conducted on sandy loam soil with 3.5% O.M., 6.5 pH, and 12 lbs. of N. Soybeans were grown during 2010. Plots were 4 rows by 25 ft arranged in a randomized complete block design with four replicates. Seed pieces (2 oz) were planted on 36 inch rows and 12 inch spacing on June 9. Treatments were hilled June 29. Fertilizer applications were done prior to planting (June 9), @ planting (10-34-0 starter), hilling, July 18, and July 29. The goal for nitrogen for the year was 230 lbs/a. Potatoes were machine harvested October 27 and graded November 15.

Trt	Trt		Rate	App		Running
No	Name	Rate	Unit	Code	Date	N
1	Soil					12
	Broadcast	26	lb		5/26	38
	46-0-0	33	lb	A	6/9	71
	10-34-0	29	lb	B	6/9	100
	46-0-0	50	lb	C	6/29	150
	46-0-0	50	lb	D	7/18	200
	46-0-0	30	lb	E	7/29	230
2	Soil					12
	Broadcast	26	lb		5/26	38
	46-0-0	18	lb	A	6/9	56
	10-34-0	29	lb	B	6/9	85
	46-0-0	37	lb	C	6/29	122
	46-0-0	37	lb	D	7/18	159
	46-0-0	37	lb	E	7/29	196
3	Soil					12
	Broadcast	26	lb		5/26	38
	NUT	163	lb	A	6/9	201
	10-34-0	29	lb	B	6/9	230
4	Soil					12
	Broadcast	26	lb		5/26	38
	NUT	98	lb	A	6/9	136
	10-34-0	29	lb	B	6/9	165
	NUT	65	lb	C	6/29	230
5	Soil					12
	Broadcast	26	lb		5/26	38
	NUT	129	lb	A	6/9	167
	10-34-0	29	lb	B	6/9	196
6	Soil					12
	Broadcast	26	lb		5/26	38
	NUT	77	lb	A	6/9	115
	10-34-0	29	lb	B	6/9	144
	NUT	51	lb	C	6/29	195
7	Soil					12
	Broadcast	26	lb		5/26	38
	ESN	163	lb	A	6/9	201
	10-34-0	29	lb	B	6/9	230
8	Soil					12
	Broadcast	26	lb		5/26	38
	46-0-0	34	lb	A	6/9	72
	10-34-0	29	lb	B	6/9	101
	ESN	129	lb	C	6/29	230

Trt	------------------------Yield in 25 feet-------------------					--CWT/A--					
No	Total	<4oz	4-6oz	6-12oz	>12oz	Total	<4oz	4-6oz	6-12oz	>12oz	>4oz
1	77.07a	16.9a	17.74a	26.44a	15.97a	447.65a	98.21a	103.06a	153.58a	92.78a	349.44a
2	78.37a	15.32a	17.80a	26.10a	19.13a	455.23a	89.03a	103.44a	151.59a	111.16a	366.20a
3	69.90a	16.58a	13.88a	22.66a	16.77a	406.00a	96.30a	80.64a	131.64a	97.41a	309.69a
4	71.45a	18.04a	18.18a	22.97a	12.24a	415.01a	104.82a	105.62a	133.45a	71.09a	310.18a
5	73.39a	17.84a	18.08a	25.29a	12.16a	426.28a	103.65a	105.01a	146.93a	70.67a	322.62a
6	70.36a	17.33a	17.08a	23.22a	12.71a	408.70a	100.69a	99.24a	134.90a	73.86a	308.01a
7	69.06a	17.97a	15.25a	21.09a	14.73a	401.13a	104.42a	88.60a	122.50a	85.60a	296.71a
8	73.10a	14.20a	14.85a	24.35a	19.69a	424.59a	82.48a	86.25a	141.45a	114.40a	342.12a
LSD (P=.05)	8.19	4.27	3.58	4.44	5.99	47.59	24.78	20.77	25.77	34.8	46.87

Trt	-----------------Tuber Counts in 25 feet-----------------					% Tubers
No	Total	<4oz	4-6oz	6-12oz	>12oz	>4oz
1	247.4a	116.2a	57.0a	54.9a	19.3a	53.19a
2	243.3a	108.2a	57.0a	54.2a	23.9a	55.85a
3	230.5a	118.0a	44.5a	47.5a	20.5a	49.64a
4	251.1a	128.4a	58.4a	48.6a	15.7a	48.87a
5	250.8a	124.0a	58.5a	52.7a	15.6a	50.47a
6	240.6a	121.3a	54.8a	48.7a	15.8a	49.35a
7	237.3a	126.3a	48.7a	44.1a	18.2a	47.05a
8	222.7a	101.0a	47.2a	50.8a	23.7a	55.41a
LSD (P=.05)	35.55	28.29	11.57	9.07	6.79	7.21

All treatments had total yields > 400 CWT/A. The greatest total yield occurred with treatment 2 or 85% (196 LB N) standard practice with 455 CWT/A, followed by 100% growers standard practice (trt 1) with 448 CWT/A. The greatest total yield with Nutrisphere was 85% side-dress at hilling (trt 5) with 426 CWT/A. Nutrisphere applied at 100% side-dressed had 406 CWT/A. Results suggest that a single Nutrisphere application could be used instead of multiple in-season nitrogen applications.

Adjuvants for potato desiccation with Rely. Harlene Hatterman-Valenti and Collin Auwarter. Field research was conducted at the Northern Plains Potato Grower's Association Research site near Grand Forks, ND to evaluate the use of adjuvants with Rely in Red Norland potato. Potatoes were planted July 14 and harvested November 1. Delayed planting was inevitable due to the wet spring/summer. Plots were 4 rows by 20 ft arranged in a randomized complete block design with three replicates. Seed pieces (2 oz) were planted on 36 inch rows and 12 inch spacing. Treatments were applied on September 19 to the middle 2 rows.

Date:		9/19/11
Treatment:		A
Sprayer:	GPA:	20
	PSI:	40
	Nozzle:	8002
Air Temperature (F):		73
Relative Humidity (%):		29
Wind (MPH):		9
Soil Moisture:		Adequate
Cloud Cover (%):		50

Treatments 4 DAA showed little differences in leaf necrosis and no difference in stem necrosis. At 7 DAA, the treatment where Rely was applied alone had the greatest necrosis to both leaves and stems (40 and 17%), which was significantly different the other treatments. Similar results were seen at 16 DAA as the leaves had 90% and stems had 80% necrosis. All other treatments had between 70-83% leaf necrosis and 50-72% stem necrosis.

				Leaves	Stems	Leaves	Stems	Leaves	Stems
Trt	Trt		Rate	------4 DAA------		------7 DAA------		-----16 DAA------	
No	Name	Rate	Unit	-----------------------% Desiccated---------------------					
1	Unt			0 b	0 b	0 c	0 c	0 c	0 c
2	Rely	3	pt/a	18 a	5 a	40 a	40 a	90 a	80 a
3	Rely	3	pt/a	15 a	5 a	27 b	10 b	75 ab	57 ab
	Class Act NG	2.5	% v/v						
	InterLock	4	floz/a						
4	Rely	3	pt/a	15 a	5 a	25 b	10 b	83 ab	72 ab
	AG8034	2	% v/v						
	InterLock	4	floz/a						
5	Rely	3	pt/a	10 ab	5 a	23 b	10 b	72 b	58 ab
	AG 08050	0.5	% v/v						
6	Rely	3	pt/a	12 ab	5 a	22 b	10 b	75 ab	55 ab
	Superb HC	0.5	% v/v						
	InterLock	4	floz/a						
7	Rely	3	pt/a	15 a	5 a	27 b	10 b	75 ab	50 b
	AG 10055	1	pt/a						
8	Rely	3	pt/a	13 a	5 a	22 b	10 b	78 ab	62 ab
	Destiny HC	0.5	% v/v						
	InterLock	4	floz/a						
9	Rely	3	pt/a	10 ab	5 a	23 b	10 b	70 b	53 ab
	Inergy	0.5	% v/v						
			LSD (P=.05)	8.8	0	7.6	1.7	11.3	17.5

Effect of cover crop and control method on weed control in dryland potato. Grant H. Mehring, Harlene Hatterman-Valenti, Collin Auwarter, Bob Smith, and Blaine Schatz.

An experiment was conducted at the Carrington Research and Extension Center to evaluate alternative weed control methods for organic and low external input potato production. Cover crop, kill technique of the cover crop, and potato variety were the three factors investigated (Table 1). A randomized complete block with four replicates was the experimental design. The research commenced with the tilling of the previous barley crop following harvest in 2010 and came to a close with potato harvest in 2011 (Table 2). Cover crops were planted with a grain drill at the rates of 135 lbs/acre triticale, 120 lbs/acre rye, and 30 lbs/acre hairy vetch. Cover crop desiccation was performed with 22 fl oz/acre Roundup Weathermax, disk-till, or roller-crimping. Two ounce potato seed was planted with 36 inch row spacing and 12 inch plant spacing using a two row Iron Age potato planter. Treatments were evaluated for overall weed control using a visual scale from 0-100% three times throughout the season at 12, 28, and 46 days after planting. To further evaluate weed control weed density and weight inside a one foot quadrat were taken. Plots were cultivated once at 12 days after planting and due to wet conditions and potato row closure could not be cultivated again at 28 days as desired. Potatoes were harvested then graded in Fargo, ND.

Table 1. Treatments in the factorial arrangement.

Cover Crop	Kill	Potato variety
Triticale	Disk-till	Red Norland
Rye	Roller-crimp	Red Pontiac
Hairy vetch	Herbicide	
Rye/hairy vetch		
No cover crop		

Table 2. Schedule of field operations.

	Date	
Field operation	2010	2011
Cover crop planting	August 27	-
Burn-down herbicide of cover crop	-	June 6
Disk-till and roller-crimping termination of cover crop	-	June 29
Potato planting	-	June 30
Potato harvest	-	October 18, 20

Results: The dry weight biomass accumulation for all four cover crop treatments was adequate for weed suppression with cover crops (Table 3). With the late potato planting cover crops grew until June 29th, partly accounting for the very high biomass accumulation. Biomass for the no cover crop treatment came from the weed biomass present at collection. Weed control was at 85% or above for every treatment except the weedy check (Table 4). Roller-crimping recorded the lowest weed control for each cover crop. Weed density and weed weight were low throughout almost all treatments. Overall there was very little weed pressure throughout the experiment. Marketable yields were large enough to be considered acceptable but not exceptional (Table 5).

Table 3. Average dry weight biomass for cover crop treatments.

Treatment	Dry weight
	-------kg·ha^{-1}-------
Hairy vetch	7661
Rye/hairy vetch	7603
Triticale	7415
Rye	4539
No cover crop	1286

Table 4. Effect of cover crop, kill, and variety treatments on total weed control, weed density, and weed weight.

Cover crop	Kill	Potato variety	Weed control	Weed density	Weed weight
			----%----	-density/ft^2-	-----g-----
Triticale	Disk-till	Red Norland	90	2	0.4
Triticale	Disk-till	Red Pontiac	90	1	1.6
Triticale	Roller-crimp	Red Norland	89	0	0.0
Triticale	Roller-crimp	Red Pontiac	89	0	0.0
Triticale	Herbicide	Red Norland	94	0	0.8
Triticale	Herbicide	Red Pontiac	94	0	0.4
Rye	Disk-till	Red Norland	93	0	0.3
Rye	Disk-till	Red Pontiac	93	0	0.3
Rye	Roller-crimp	Red Norland	90	0	0.0
Rye	Roller-crimp	Red Pontiac	90	0	0.3
Rye	Herbicide	Red Norland	95	0	0.3
Rye	Herbicide	Red Pontiac	95	0	0.9
Hairy vetch	Disk-till	Red Norland	96	0	0.8
Hairy vetch	Disk-till	Red Pontiac	96	0	0.2
Hairy vetch	Roller-crimp	Red Norland	85	0	10.7
Hairy vetch	Roller-crimp	Red Pontiac	85	0	1.6
Hairy vetch	Herbicide	Red Norland	94	0	0.1
Hairy vetch	Herbicide	Red Pontiac	94	0	0.6
Rye/hairy vetch	Disk-till	Red Norland	92	0	1.2
Rye/hairy vetch	Disk-till	Red Pontiac	92	0	0.0
Rye/hairy vetch	Roller-crimp	Red Norland	89	0	3.1
Rye/hairy vetch	Roller-crimp	Red Pontiac	89	0	1.5
Rye/hairy vetch	Herbicide	Red Norland	94	1	1.0
Rye/hairy vetch	Herbicide	Red Pontiac	94	0	0.0
No cover crop	Disk-till	Red Norland	89	0	1.6
No cover crop	Disk-till	Red Pontiac	89	0	17.1
No cover crop	Weedy check	Red Norland	54	0	0.1
No cover crop	Weedy check	Red Pontiac	54	0	37.4
No cover crop	Herbicide	Red Norland	93	0	0.2
No cover crop	Herbicide	Red Pontiac	93	0	0.0

Table 5. Effect of cover crop, kill, and variety treatments on total and marketable potato yield.

Cover crop	Kill	Potato variety	Total yield	Total marketable yield
			---CWT/A---	------CWT/A------
Triticale	Disk-till	Red Norland	195	139
Triticale	Disk-till	Red Pontiac	211	153
Triticale	Roller-crimp	Red Norland	94	48
Triticale	Roller-crimp	Red Pontiac	139	81
Triticale	Herbicide	Red Norland	153	97
Triticale	Herbicide	Red Pontiac	166	110
Rye	Disk-till	Red Norland	154	101
Rye	Disk-till	Red Pontiac	136	90
Rye	Roller-crimp	Red Norland	90	55
Rye	Roller-crimp	Red Pontiac	105	63
Rye	Herbicide	Red Norland	141	92
Rye	Herbicide	Red Pontiac	166	112
Hairy vetch	Disk-till	Red Norland	192	134
Hairy vetch	Disk-till	Red Pontiac	226	166
Hairy vetch	Roller-crimp	Red Norland	48	25
Hairy vetch	Roller-crimp	Red Pontiac	70	40
Hairy vetch	Herbicide	Red Norland	209	149
Hairy vetch	Herbicide	Red Pontiac	239	174
Rye/hairy vetch	Disk-till	Red Norland	174	119
Rye/hairy vetch	Disk-till	Red Pontiac	225	163
Rye/hairy vetch	Roller-crimp	Red Norland	78	49
Rye/hairy vetch	Roller-crimp	Red Pontiac	136	75
Rye/hairy vetch	Herbicide	Red Norland	122	66
Rye/hairy vetch	Herbicide	Red Pontiac	186	111
No cover crop	Disk-till	Red Norland	186	118
No cover crop	Disk-till	Red Pontiac	264	196
No cover crop	Weedy check	Red Norland	153	103
No cover crop	Weedy check	Red Pontiac	176	124
No cover crop	Herbicide	Red Norland	182	133
No cover crop	Herbicide	Red Pontiac	236	174

Effect of cover crop and control method on weed control in irrigated potato. Grant H. Mehring, Harlene Hatterman-Valenti, Collin Auwarter, Bob Smith, and Blaine Schatz.

An experiment was conducted at the Carrington Research and Extension Center to evaluate alternative weed control methods for organic and low external input potato production. Cover crop, kill technique of the cover crop, and potato variety were the three factors investigated (Table 1). A randomized complete block with four replicates was the experimental design. The research commenced with the tilling of the previous barley crop following harvest in 2010 and came to a close with potato harvest in 2011 (Table 2). Cover crops were planted with a grain drill at the rates of 135 lbs/acre triticale, 120 lbs/acre rye, and 30 lbs/acre hairy vetch. Cover crop desiccation was performed with 22 fl oz/acre Roundup Weathermax, disk-till, or roto-till. Two ounce potato seed was planted with 36 inch row spacing and 12 inch plant spacing using a two row Iron Age potato planter. Treatments were evaluated for overall weed control using a visual scale from 0-100% three times throughout the season at 13, 26, and 42 days after planting. To further evaluate weed control weed density and weight inside a one foot quadrat were taken. Plots were cultivated at 13 and 23 days after planting. Potatoes were harvested then graded in Fargo, ND.

Table 1. Treatments in the factorial arrangement.

Cover Crop	Kill	Potato variety
Triticale	Disk-till	Yukon Gold
Rye	Roto-till	Russet Norkotah
Hairy vetch	Herbicide	
Rye/hairy vetch		
No cover crop		

Table 2. Schedule of field operations.

	Date	
Field operation	2010	2011
Cover crop planting	August 27	-
Burn-down herbicide of cover crop	-	June 3
Disk-till and roto-till termination of cover crop	-	June 15
Potato planting	-	June 16
Potato harvest	-	October 13

Results: The dry weight biomass accumulations for hairy vetch and rye/hairy vetch cover crop treatments were adequate for weed suppression with cover crops (Table 3). Triticale and rye biomasses were lower than desired for weed control with cover crops. Biomass for the no cover crop treatment came from the weed biomass present at collection. Weed control was excellent and similar throughout every treatment besides the weedy check (Table 4). The weedy check averaged 80% weed control, which remains adequate despite being lower than the other treatments. Weed density and weed weight were negligible throughout all treatments. Overall there was very little weed pressure throughout the experiment. Marketable yields were large enough to be considered acceptable but not exceptional (Table 5).

Table 3. Average dry weight biomass for cover crop treatments.

Treatment	Dry weight
	-------kg·ha^{-1}-------
Hairy vetch	3996
Rye/hairy vetch	3580
Triticale	1850
Rye	1671
No cover crop	54

Table 4. Effect of cover crop, kill, and variety treatments on total weed control, weed density, and weed weight.

Cover crop	Kill	Potato variety	Weed control	Weed density	Weed weight
			----%----	-density/ft^2-	-----g-----
Triticale	Disk-till	Russet Norkotah	94	0	0.00
Triticale	Disk-till	Yukon Gold	94	0	0.00
Triticale	Roto-till	Russet Norkotah	96	0	0.00
Triticale	Roto-till	Yukon Gold	96	0	0.00
Triticale	Herbicide	Russet Norkotah	97	1	0.00
Triticale	Herbicide	Yukon Gold	97	0	0.00
Rye	Disk-till	Russet Norkotah	96	0	0.00
Rye	Disk-till	Yukon Gold	96	0	0.00
Rye	Roto-till	Russet Norkotah	97	0	0.00
Rye	Roto-till	Yukon Gold	97	0	0.00
Rye	Herbicide	Russet Norkotah	97	0	0.00
Rye	Herbicide	Yukon Gold	97	0	0.00
Hairy vetch	Disk-till	Russet Norkotah	96	0	0.00
Hairy vetch	Disk-till	Yukon Gold	96	0	0.00
Hairy vetch	Roto-till	Russet Norkotah	97	1	0.83
Hairy vetch	Roto-till	Yukon Gold	97	0	0.00
Hairy vetch	Herbicide	Russet Norkotah	94	0	0.00
Hairy vetch	Herbicide	Yukon Gold	94	1	0.33
Rye/hairy vetch	Disk-till	Russet Norkotah	95	0	0.00
Rye/hairy vetch	Disk-till	Yukon Gold	95	0	0.00
Rye/hairy vetch	Roto-till	Russet Norkotah	96	0	0.00
Rye/hairy vetch	Roto-till	Yukon Gold	96	0	0.00
Rye/hairy vetch	Herbicide	Russet Norkotah	94	0	0.00
Rye/hairy vetch	Herbicide	Yukon Gold	94	0	0.00
No cover crop	Disk-till	Russet Norkotah	94	0	0.42
No cover crop	Disk-till	Yukon Gold	94	0	0.00
No cover crop	Weedy check	Russet Norkotah	80	1	0.42
No cover crop	Weedy check	Yukon Gold	80	0	0.00
No cover crop	Herbicide	Russet Norkotah	97	0	0.08
No cover crop	Herbicide	Yukon Gold	97	0	0.00

Table 5. Effect of cover crop, kill, and variety treatments on total and marketable potato yield.

Cover crop	Kill	Potato variety	Total yield	Total marketable yield
			---CWT/A---	------CWT/A------
Triticale	Disk-till	Yukon Gold	163	133
Triticale	Disk-till	Russet Norkotah	265	230
Triticale	Roto-till	Yukon Gold	206	173
Triticale	Roto-till	Russet Norkotah	293	259
Triticale	Herbicide	Yukon Gold	182	140
Triticale	Herbicide	Russet Norkotah	312	255
Rye	Disk-till	Yukon Gold	128	99
Rye	Disk-till	Russet Norkotah	289	232
Rye	Roto-till	Yukon Gold	181	148
Rye	Roto-till	Russet Norkotah	227	199
Rye	Herbicide	Yukon Gold	132	102
Rye	Herbicide	Russet Norkotah	308	270
Hairy vetch	Disk-till	Yukon Gold	201	154
Hairy vetch	Disk-till	Russet Norkotah	303	260
Hairy vetch	Roto-till	Yukon Gold	163	127
Hairy vetch	Roto-till	Russet Norkotah	258	219
Hairy vetch	Herbicide	Yukon Gold	152	128
Hairy vetch	Herbicide	Russet Norkotah	272	233
Rye/hairy vetch	Disk-till	Yukon Gold	198	154
Rye/hairy vetch	Disk-till	Russet Norkotah	217	166
Rye/hairy vetch	Roto-till	Yukon Gold	208	172
Rye/hairy vetch	Roto-till	Russet Norkotah	327	290
Rye/hairy vetch	Herbicide	Yukon Gold	196	162
Rye/hairy vetch	Herbicide	Russet Norkotah	298	264
No cover crop	Disk-till	Yukon Gold	237	193
No cover crop	Disk-till	Russet Norkotah	321	278
No cover crop	Weedy check	Yukon Gold	209	172
No cover crop	Weedy check	Russet Norkotah	332	304
No cover crop	Herbicide	Yukon Gold	203	164
No cover crop	Herbicide	Russet Norkotah	317	262

<u>Combinations of diquat and pyraflufen-ethyl for potato desiccation</u>. Harlene Hatterman-Valenti and Collin Auwarter.

Field research was conducted at the Northern Plains Potato Grower's Association Research site near Grand Forks, ND to evaluate the use of diquat plus pyraflufen-ethyl combinations as a desiccant in Red Norland potato. A nonionic surfactant (Preference), was added to each application at a rate of 0.25% v/v. Potatoes were planted July 14 and harvested November 1. Delayed planting was inevitable due to the wet spring/summer. Plots were 4 rows by 20 ft arranged in a randomized complete block design with three replicates. Seed pieces (2 oz) were planted on 36 inch rows and 12 inch spacing. Treatments were applied on September 19 (A) and September 26 (B) to the middle two rows.

Date:		9/19/11	9/26/11
Treatment:		A	B
Sprayer:	GPA:	20	20
	PSI:	40	40
	Nozzle:	8002	8002
Air Temperature (F):		73	57
Relative Humidity (%):		29	75
Wind (MPH):		9	5
Soil Moisture:		Adequate	Adequate
Cloud Cover (%):		50	50

Treatments at 4 DAA showed little differences for leaf necrosis and no difference for stem necrosis when pyraflufen-ethyl (ET) was added with diquat. However, treatments with 0.50 lb/A diquat showed greater leaf necrosis than 0.25 and 0.375 lb/A diquat treatments. At 7 DAA, similar results were observed for both leaf and stem necrosis. At 16 DAA "A" and 9 DAA "B", treatments that were reapplied 1 wk after initial application, had significantly greater leaf necrosis than treatments applied once. Diquat at 0.50 lb/A plus 0.0012 lb/A pyraflufen-ethyl had 98% leaf necrosis when applied twice and 78% leaf necrosis when applied once. Diquat at 0.25 lb/A plus 0.0012 lb/A pyraflufen-ethyl showed no significant difference for necrosis of leaves (97%) or stems (90%) compared to 0.25 lb/A diquat alone.

Yields did not show any significant differences. The greatest total yield, marketable yield (> 4 oz), and tuber number occurred with the untreated (144 cwt/A, 69 cwt/A, and 104 tubers/20 row ft, respectively). Since the potatoes never reached maturity, necrosis was more difficult and generally simulated grower practices to obtain tubers at specific size categories. Only 22-28% of the tubers were greater than 4 oz, which was similar for all treatments.

					Leaves	Stems	Leaves	Stems	Leaves	Stems
Trt	Trt		Rate		--------4 DAAA-------		-------7 DAAA--------		--16 DAAA & 9 DAAB--	
No	Name	Rate	Unit	Time	--------------------------% Desiccated---------------------------					
1	Unt				0 b	0 b	0 b	0 b	0 e	0 e
2	Diquat	1	pt/a	AB	15 a	5 a	25 a	10 ab	97 a	90 a
	ET	0.75	floz/a							
	Preference	0.25	% v/v							
3	Diquat	1	pt/a	AB	15 a	5 a	25 a	10 ab	93 a	85 a
	Preference	0.25	% v/v							
4	Diquat	1.5	pt/a	AB	20 a	5 a	38 a	17 a	98 a	92 a
	ET	0.75	floz/a							
	Preference	0.25	% v/v							
5	Diquat	1.5	pt/a	AB	17 a	5 a	32 a	12 ab	95 a	88 a
	Preference	0.25	% v/v							
6	Diquat	2	pt/a	A	17 a	5 a	25 a	12 ab	78 b	70 b
	ET	0.75	floz/a							
	Preference	0.25	% v/v							
7	Diquat	2	pt/a	A	22 a	5 a	33 a	13 ab	77 b	70 b
	Preference	0.25	% v/v							
8	Diquat	1	pt/a	A	22 a	5 a	35 a	13 ab	80 b	68 b
	ET	2.75	floz/a							
	Preference	0.25	% v/v							
				LSD (P=.05)	8.9	0	17.3	8.5	7.5	11.1

<u>Red Lasoda daughter tuber injury from simulated glyphosate drift</u>. Harlene Hatterman-Valenti and Collin Auwarter.

This study was conducted at the Northern Plains Potato Growers Non-Irrigation Research site near Grand Forks, ND to evaluate Red Lasoda seed potatoes that had glyphosate drift during previous season. Simulated glyphosate drift was applied at 3 different growth stages in 2010; tuber initiation (A) early tuber bulking (B), and late tuber bulking (C) with a modified ATV sprayer. Roundup Weathermax with 4.5 pounds acid equivalent per gallon glyphosate and AMS at 4 pounds/100 gallons were used in this trial. Twenty tubers were saved in storage until one seed piece per tuber was planted July 5, 2011. Potatoes were machine harvested November 1 and graded November 15.

Trt	Trt		Rate	App	Total	<4oz	4-6oz	6-10oz	>10oz	>4oz	Total	<4oz	4-6oz	6-10oz	>10oz	>4oz
No	Name	Rate	Unit	Code	------------------cwt/a---------------------						-------Tuber count in 20 feet-------					Tuber %
1	Untreated				170a	43ab	80a	29ab	18ab	128a	88a	45ab	31a	9a	3ab	50a
2*	GLY	.2	lb ae/a	A	140abc	52a	57ab	18abc	13ab	88abc	88a	57a	24a	5ab	2ab	35ab
3*	GLY	.1	lb ae/a	A	151ab	47a	58ab	22abc	24ab	104ab	85a	52a	23ab	6ab	4ab	39ab
4*	GLY	.05	lb ae/a	A	180a	42ab	73a	35a	30ab	138a	94a	51a	28a	10a	6a	47a
5*	GLY	.2	lb ae/a	B	38d	14b	14b	5c	6b	24c	25b	18b	5b	1b	1b	20b
6*	GLY	.1	lb ae/a	B	112a-d	29ab	43ab	20abc	19ab	82abc	58ab	33ab	16ab	6ab	3ab	42ab
7*	GLY	.05	lb ae/a	B	139abc	33ab	50ab	22abc	35a	106ab	66ab	36ab	18ab	6ab	6a	45a
8*	GLY	.2	lb ae/a	C	50cd	13b	14b	10bc	14ab	38bc	28b	18b	5b	3b	2ab	35ab
9*	GLY	.1	lb ae/a	C	91a-d	23ab	42ab	16abc	10ab	68abc	51ab	29ab	15ab	5ab	2ab	39ab
10*	GLY	.05	lb ae/a	C	66bcd	28ab	15b	8c	14ab	37bc	51ab	41ab	6b	2b	3ab	20b
*AMS added			LSD (P=.05)		61	19	30	13	16	47	32	21	12	4	3	16

The highest total yield treatment occurred when glyphosate was applied at the tuber initiation stage at the 0.05 lb ae/a rate with 180 cwt/a, followed by the untreated with 170 cwt/a. The lowest yielding treatments resulted from 0.2 lb at the early and late tuber bulking stage with 38 and 50 cwt/a, respectively. The late tuber bulking stage had 3 of the 4 lowest yielding treatments. Tuber counts indicated that increased glyphosate uptake into the seed tubers resulted in lower tuber set. Tuber counts from the untreated and tuber initiation stage averaged between 85 and 94, respectively, while tuber counts from the early and late tuber bulking stages ranged from 25 to 66.

Red Norland daughter tuber injury from simulated glyphosate drift. Harlene Hatterman-Valenti and Collin Auwarter.

This study was conducted at the Northern Plains Potato Growers Non-Irrigation Research site near Grand Forks, ND to evaluate Red Norland seed potatoes that had glyphosate drift during previous season. Simulated glyphosate drift was applied at 3 different growth stages in 2010; tuber initiation (A) early tuber bulking (B), and late tuber bulking (C) with a modified ATV sprayer. Roundup Weathermax with 4.5 pounds acid equivalent per gallon glyphosate and AMS at 4 pounds/100 gallons were used in this trial. Twenty tubers were saved in storage until one seed piece per tuber was planted July 5, 2011. Potatoes were machine harvested November 1 and graded November 15.

Trt	Trt		Rate	App	Total	<4oz	4-6oz	6-10oz	>10oz	>4oz	Total	<4oz	4-6oz	6-10oz	>10oz	>4oz
No	Name	Rate	Unit	Code	----------------------------cwt/a----------------------------						---------------Tuber count in 20 feet-------------					Tuber %
1	Untreated				112a	43abc	48a	13a	7a	69a	68a	43ab	20a	4a	1a	37a
2*	GLY	.2	lb ae/a	A	25c	15c	8bc	0b	1a	10bc	23bc	20bc	4bc	0b	1a	17bc
3*	GLY	.1	lb ae/a	A	106a	58a	39ab	7ab	2a	48abc	78a	59a	17ab	2ab	1a	23abc
4*	GLY	.05	lb ae/a	A	110a	56ab	41ab	10ab	2a	54ab	76a	54a	18a	3ab	1a	28ab
5*	GLY	.2	lb ae/a	B	19c	14c	4c	1ab	0a	5c	17c	15c	2c	1ab	0a	7c
6*	GLY	.1	lb ae/a	B	34bc	20c	8bc	6ab	0a	14bc	27bc	22bc	4bc	2ab	0a	15bc
7*	GLY	.05	lb ae/a	B	41bc	29bc	9bc	3ab	0a	12bc	44abc	39abc	4bc	1ab	0a	9bc
8*	GLY	.2	lb ae/a	C	73abc	43abc	23abc	5ab	1a	30abc	62a	51a	9abc	2ab	1a	17bc
9*	GLY	.1	lb ae/a	C	59abc	39abc	18abc	2ab	0a	19bc	54ab	46a	8abc	1ab	0a	14bc
10*	GLY	.05	lb ae/a	C	88ab	56ab	27abc	5ab	0a	32abc	73a	60a	11abc	2ab	0a	17bc
*AMS added		LSD (P=.05)			41	19	22	8	5	28	26	18	9	2	1	12

There were only 3 treatments that yielded over 100 cwt/a, untreated (112), 0.05 lb at the tuber initiation stage (110) and 0.1 lb at the tuber initiation stage (106). All other treatments had total yields under 88 cwt/a. Early tuber bulking stage treatments had significantly lower yields than the other stages, with 0.2 lb resulting in only 19 cwt/a. Tuber counts indicated that increased glyphosate uptake into the seed tubers during the early tuber bulking stage resulted in lower tuber set. Tuber counts from the untreated averaged 68 tubers in 20 ft or approximately 3.5 tubers/plant if all seed pieces emerged, while tuber counts from the early tuber bulking stage averaged 29 tubers in 20 ft or approximatley 1.5 tubers/plant if all seed pieces emerged.

Sangre daughter tuber injury from simulated glyphosate drift. Harlene Hatterman-Valenti and Collin Auwarter.

This study was conducted at the Northern Plains Potato Growers Non-Irrigation Research site near Grand Forks, ND to evaluate Red Lasoda seed potatoes that had glyphosate drift during previous season. Simulated glyphosate drift was applied at 3 different growth stages in 2010; tuber initiation (A) early tuber bulking (B), and late tuber bulking (C) with a modified ATV sprayer. Roundup Weathermax with 4.5 pounds acid equivalent per gallon glyphosate and AMS at 4 pounds/100 gallons were used in this trial. Twenty tubers were saved in storage until one seed piece per tuber was planted July 5, 2011. Potatoes were machine harvested November 1 and graded November 15.

Trt	Trt		Rate	App	Total	<4oz	4-6oz	6-10oz	>10oz	>4oz	Total	<4oz	4-6oz	6-10oz	>10oz	>4oz
No	Name	Rate	Unit	Code	------------------cwt/a---------------------						-------Tuber count in 20 feet-------					Tuber %
1	Untreated				172 a	64 a	64 a	29 a	16 a	108 a	102 a	66 a	25 a	8 a	3 a	35 a
2*	GLY	.2	lb ae/a	A	152 ab	56 a	65 a	17 ab	14 a	96 a	94 a	60 a	26 a	5 ab	2 a	36 a
3*	GLY	.1	lb ae/a	A	150 ab	59 a	63 a	18 ab	11 a	92 a	92 a	60 a	25 a	6 ab	2 a	35 a
4*	GLY	.05	lb ae/a	A	159 ab	66 a	57 a	19 ab	17 a	92 a	100 a	69 a	23 a	5 ab	3 a	30 a
5*	GLY	.2	lb ae/a	B	23 c	10 c	8 b	3 b	1 a	13 b	17 c	13 c	3 b	1 b	.3 a	12 ab
6*	GLY	.1	lb ae/a	B	67 bc	25 bc	26 ab	9 b	7 a	42 ab	43 bc	29 bc	10 ab	3 b	1 a	23 ab
7*	GLY	.05	lb ae/a	B	124 ab	46 ab	54 a	18 a	6 a	79 a	80 ab	51 ab	22 a	6 ab	1 a	35 a
8*	GLY	.2	lb ae/a	C	22 c	11 c	6 b	4 b	1 a	11 b	16 c	12 c	2 b	1 b	.3 a	6 b
9*	GLY	.1	lb ae/a	C	23 c	10 c	9 b	2 b	3 a	13 b	19 c	15 c	4 b	1 b	1 a	19 ab
10*	GLY	.05	lb ae/a	C	100 abc	35 abc	41 ab	14 ab	10 a	65 ab	63 abc	41 abc	16 ab	4 ab	2 a	34 a
*AMS added		LSD (P=.05)			61	19	30	13	62.5	20.8	29.8	11.6	10.5	44.4	33.3	21.7

The highest total yielding treatment was the untreated with 172 cwt/a. Yield from treatments where glyphosate was applied to plants at the tuber initiation stage regardless of the rate yielded well compared to the early and late tuber bulking stages. Both yield and tuber counts were smaller at the 0.2 and 0.1 lb rates at the early and late tuber bulking stages. Results suggest that more glyphosate is moved into the tubers the later in the season the glyphosate drift occurred.

<u>Reflex, Boundary, and Dual Magnum efficacy in Russet Burbank potato</u>. Harlene Hatterman-Valenti and Collin Auwarter.

This study was conducted at the Northern Plains Potato Growers Irrigation Research site near Inkster, ND to evaluate the efficacy of Boundary, Reflex and Dual Magnum for weed control in Russet Burbank potatoes. Soybeans were grown in 2010. Plots were 4 rows by 20 ft arranged in a randomized complete block design with four replicates. Seed pieces (2 oz) were planted on 36 inch rows and 12 inch spacing on June 3, 2011. Treatments were applied on June 24 (same day as hilling) to the middle 2 rows. Crop injury and weed control were evaluated 5, 17, and 24 DAA. All potatoes were emerged as hiller didn't throw soil to cover. Primarily common lambsquarters (COLQ) at 2/sq ft was seen in border rows. Potatoes were machine harvested October 27 and graded November 15.

Date:		6/24/11
Treatment:		PRE
Sprayer:	GPA:	20
	PSI:	40
	Nozzle:	8002
Air Temperature (F):		71
Relative Humidity (%):		63
Wind (MPH):		7
Soil Moisture:		Adequate
Cloud Cover (%):		100

Potato injury was the main factor in this trial as all potatoes were emerged at application. All treatments showed injury especially the ones with Reflex which had significantly greater injury. Injury ratings at 24 DAA were unacceptable with Reflex + Boundary at 40%, while Reflex + Boundary was 31% and Reflex alone was 19%. Weed control was very good. At 5 DAA, all treatments with Reflex had >90% COLQ control. Redroot pigweed (RRPW) pressure was low in this trial. At 24 DAA, Boundary + Reflex provided 96% COLQ control followed by Reflex + Dual Magnum with 93% control. Reflex alone had 90% COLQ control at 24 DAA.

				COLQ	RRPW	GRFT	Injury	COLQ	RRPW	GRFT	Injury	COLQ	RRPW	GRFT	Injury
Trt	Trt		Rate	----------------5 DAA----------------				----------------17 DAA---------------				----------------24 DAA---------------			
No	Name	Rate	Unit	---------% Control---------			%	---------% Control---------			%	---------% Control---------			%
1	Unt			0 b	0 b	0 b	0 d	0 c	0 b	0 b	0 d	0 b	0 b	0 b	0 c
2	Reflex	1	pt/a	90 a	98 a	100 a	28 c	90 b	98 a	100 a	23 c	90 a	98 a	100 a	19 b
3	Boundary	1.5	pt/a	88 a	95 a	99 a	6 d	91 b	93 a	100 a	6 d	91 a	94 a	100 a	3 c
4	Dual Magnum	2	pt/a	88 a	96 a	100 a	8 d	88 b	94 a	100 a	6 d	89 a	94 a	100 a	3 c
5	Reflex	1	pt/a	94 a	99 a	100 a	66 a	94 ab	99 a	100 a	49 a	93 a	100 a	100 a	40 a
	Dual Magnum	2	pt/a												
6	Reflex	1	pt/a	94 a	99 a	100 a	49 b	98 a	100 a	100 a	36 b	96 a	99 a	100 a	31 a
	Boundary	1.5	pt/a												
		LCD (P=.05)		6	9	2	10	5	7	2	10	6	7	0	11

Overall yield showed little differences. The untreated had the greatest total yield at 446 cwt/a, all other treatments were set back from the early injury. The two treatments with the lowest yields were the tank-mixes, Reflex + Boundary at 327 cwt/a, and Reflex + Dual Magnum at 348 cwt/a. Marketable yield (>4 oz) mimicked total yield results with the untreated having a marketable yield of 335 cwt/a. The lowest marketable yielding treatments were Reflex + Boundary with 197 cwt/a, and Reflex + Dual Magnum with 225 cwt/a.

Evaluating potential herbicide carryover in Russet Burbank potatoes. Harlene Hatterman-Valenti and Collin Auwarter.

This study was conducted at the Northern Plains Potato Growers Irrigation Research site near Inkster, ND to evaluate simulated herbicide carryover in Russet Burbank potatoes. Soybeans were grown in 2010. Plots were 4 rows by 20 ft arranged in a randomized complete block design with four replicates. 4 herbicides were included in this trial; Accent (nicosulfuron), Stinger (clopyralid), Beyond (imazamox), and FirstRate (cloransulam). The 2011 North Dakota Weed Control Guide was used for the base rate with applications at 1/8, 1/16, and 1/32 the medium use rate, on June 6 and immediate incorporation. Seed pieces (2 oz) were planted on 36 inch rows and 12 inch spacing on June 20, 2011. Potatoes were machine harvested October 27 and graded November 15.

Date:		6/9/11
Treatment:		PRE
Sprayer:	GPA:	20
	PSI:	40
	Nozzle:	8002
Air Temperature (F):		58
Relative Humidity (%):		57
Wind (MPH):		5
Soil Moisture:		Adequate
Cloud Cover (%):		25

Some herbicides can cause both foliar and tuber injury symptoms. However, some plants in all treatments and the untreated showed symptoms of glyphosate uptake the year before, making injury evaluations difficult. By mid-season, all plants appeared normal and grew uniformly without cupped leaves, fiddle-neck stems or yellow, chlorotic foliage. Yield and grading data mimicked mid-season evaluations with few differences.

Trt	Trt		Rate	Total	<4oz	4-6oz	6-12oz	>12oz	>4oz
No	Name	Rate	Unit	--------------------cwt/a--------------------					
1	Untreated			516a	110a	118a	169a	119ab	406a
2	Accent	.156	oz/a	506a	100a	130a	178a	99ab	406a
3	Accent	.078	oz/a	495a	93a	100a	171a	131ab	401a
4	Accent	.039	oz/a	493a	108a	125a	179a	80b	384a
5	Stinger	.325	floz/a	494a	105a	114a	176a	98ab	389a
6	Stinger	.163	floz/a	510a	99a	112a	209a	90b	410a
7	Stinger	.081	floz/a	481a	103a	119a	171a	87b	377a
8	Beyond	.375	floz/a	506a	106a	113a	169a	118ab	400a
9	Beyond	.188	floz/a	525a	81a	115a	207a	121ab	444a
10	Beyond	.094	floz/a	521a	90a	113a	186a	133ab	431a
11	FirstRate	.075	oz/a	513a	72a	100a	172a	169a	441a
12	FirstRate	.038	oz/a	501a	87a	103a	188a	123ab	414a
13	FirstRate	.019	oz/a	475a	80a	112a	174a	108ab	394a
			LSD (P=.05)	57.8	22	23.4	42.4	44.2	59.4

Trt	Trt		Rate	Total	<4oz	4-6oz	6-12oz	>12oz	>4oz
No	Name	Rate	Unit	--------Tuber counts in 20 feet-------					% Tubers
1	Untreated			221a	101a	51a	49a	20ab	55a
2	Accent	.156	oz/a	217a	93a	57a	51a	17ab	58a
3	Accent	.078	oz/a	203a	88a	43a	49a	23ab	57a
4	Accent	.039	oz/a	223a	102a	56a	52a	14b	54a
5	Stinger	.325	floz/a	217a	100a	50a	50a	17ab	54a
6	Stinger	.163	floz/a	219a	93a	50a	60a	17ab	58a
7	Stinger	.081	floz/a	215a	98a	53a	49a	15ab	54a
8	Beyond	.375	floz/a	215a	99a	50a	48a	19ab	54a
9	Beyond	.188	floz/a	205a	75a	50a	59a	21ab	63a
10	Beyond	.094	floz/a	205a	93a	50a	52a	21ab	60a
11	FirstRate	.075	oz/a	192a	71a	44a	49a	27a	63a
12	FirstRate	.038	oz/a	205a	85a	45a	54a	21ab	58a
13	FirstRate	.019	oz/a	191a	75a	49a	50a	17ab	61a
			LSD (P=.05)	23.4	19.2	10.4	11.5	6.9	6.3

Solida efficacy in Russet Burbank potatoes. Harlene Hatterman-Valenti and Collin Auwarter.
This study was conducted at the Northern Plains Potato Growers Irrigation Research site near Inkster, ND to evaluate weed control, efficacy, and selectivity of Solida when applied PRE and early POST to Russet Burbank potatoes. Soybeans were grown in 2010. Plots were 4 rows by 20 ft arranged in a randomized complete block design with four replicates. Seed pieces (2 oz) were planted on 36 inch rows and 12 inch spacing on June 3, 2011. Treatments were applied on June 24 (A), same day as hilling and July 7 (B) to the middle 2 rows. Crop injury and weed control were evaluated 5, 17, and 24 DAA "A". All potatoes were emerged as hiller didn't throw soil to cover. Common lambsquarters (COLQ) was the most prevalent weed (2/sq ft), followed by redroot pigweed (RRPW) and green foxtail (GRFT). Potatoes were machine harvested October 27 and graded November 15.

Date:		6/24/11	7/11/11
Treatment:		PRE	POST
Sprayer:	GPA:	20	20
	PSI:	40	40
	Nozzle:	8002	8002
Air Temperature (F):		71	73
Relative Humidity (%):		63	62
Wind (MPH):		7	9
Soil Moisture:		Adequate	Adequate
Cloud Cover (%):		100	25

Weed control was good throughout the trial. All PRE treatments, (Solida at 0.0117, 0.0234, and 0.047 lb ai/a, and Matrix at 0.0234 lb ai/a) provided between 91 and 93% COLQ control at 5 DAAA. At 24 DAA "A" and 7 DAA "B", all POST treatments provided 95% COLQ control, while Solida at 0.0234 lb ai/a provided 91% control and Matrix at 0.234 lb ai/a provided 89% control.

					COLQ	RRPW	GRFT	Injury	COLQ	RRPW	GRFT	Injury	COLQ	RRPW	GRFT	Injury
Trt	Trt		Rate	App	---------------5 DAA----------------				--------------17 DAA------------				-------24 DAAA & 7 DAAB-------			
No	Name	Rate	Unit	Code	---------% Control---------			%	---------% Control----			%	---------% Control------			%
1	Unt				0 b	0 b	0 b	0 a	0 c	0 b	0 c	0 c	0 c	0 c	0 b	0 a
2	Solida	0.0117	lb ai/a	A	91 a	99 a	100 a	0 a	86 b	93 a	100 a	0 c	89 b	90 b	95 a	0 a
3	Solida	0.0234	lb ai/a	A	93 a	100 a	100 a	0 a	91 a	95 a	94 b	0 c	91 ab	95 ab	94 a	0 a
4	Solida	0.047	lb ai/a	A	91 a	100 a	99 a	0 a	93 a	99 a	95 b	0 c	93 ab	98 a	98 a	0 a
5	Matrix	0.0234	lb ai/a	A	91 a	100 a	99 a	0 a	89 ab	94 a	99 a	0 c	89 b	95 ab	99 a	0 a
6	Solida	0.0117	lb ai/a	B									95 a	95 ab	98 a	0 a
	Preference	0.25	% v/v	B												
7	Solida	0.0234	lb ai/a	B									95 a	95 ab	100 a	0 a
	Preference	0.25	% v/v	B												
8	Solida	0.047	lb ai/a	B									95 a	95 ab	96 a	0 a
	Preference	0.25	% v/v	B												
9	Matrix	0.0234	lb ai/a	B									95 a	95 ab	95 a	0 a
	Preference	0.25	% v/v	B												
LCD (P=.05)					4	1	2	0	3	6	3	0	3	4	5	0

Yields varied little. Matrix at 0.234 lb ai/a POST and Solida at 0.0234 lb ai/a POST were the only two treatments that had total yields >500 cwt/a. The lowest yielding treatments were Matrix at 0.234 lb ai/a with a total yield of 410 cwt/a and the untreated at 434 cwt/a.

Establishing a Resistance Management Program for Neonicotinoid Insensitive Colorado Potato Beetle in Minnesota and North Dakota

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Executive Summary – This is a new project designed to take the first steps necessary in establishing a resistance management program for neonicotinoid insensitive Colorado Potato Beetles (CPB) in Minnesota and North Dakota. This project can be expanded to incorporate developing management techniques as they become available in the future.

Procedures – Plots were established at the UMN Sand Plains Research Farm at Becker (Becker), MN and at the UMN Northwest Research & Outreach Center (NWROC). CPB populations in plots were monitored weekly. Population parameters (mean no. beetles/plant, beetle stage, mortality, etc.), defoliation levels and yields were assessed in each plot.

Products tested included a number of currently registered products and several relatively new modes of action such as Cyazypyr, Tolfenpyrad, and Spinosyn insecticides.

In addition, while sampling CPB at chemical treatment locations, area populations of CPB were collected and tested for neonicotinoid insensitivity. Testing consisted of comparing LD_{50} values of collected beetles to those of the susceptible population. Populations were sent to Michigan State University for testing against their susceptible populations.

Results & Discussion – Plots were established at both UMN's Sand Plain Research Farm in Becker, MN and at the Northwest Research & Outreach Center (NWROC) at Crookston, MN. Becker plots were plants with Russet Burbank (kindly supplied by Frank Kasowski) and NWROC plots were planted with Red Norkota (kindly supplied by Lonnie Spokley). Weather played an important role in yields in 2011, delaying planting in Crookston and inducing slow growth through June because of low temperatures and impacting tubers in July because of high temperatures. There was, however, no significant difference in the emergence of plants in plots at either location. Colorado Potato Beetle populations were high at the Becker location and extremely low at the Crookston location. Populations at the NWROC would not support beetle trials and so all results are from Becker plots. Both seed treatments and foliar treatments were conducted; CPB populations, defoliation and yields were monitored and analyzed.

CPB seed treatments – Seven separate seed treatments were tested at Becker, they are labeled on the graphs as:

1. MN: Admire Pro In-furrow (@ 7 fl.oz product/ac) [**ADMIRE PRO IF**]
2. HGW86 20 SC (Cyazypyr, DuPont) (@ 0.47 fl.oz. product / 100lb seed) & Cruiser 5FS (@ 0.12 fl.oz. product / 100lb seed) as a seed treatments [**HGW86 & Cruiser ST**] or [**Cyazypyr 20SC & Cruiser ST** on yield graphs**]**
3. HGW 20SC (Cyazypyr, DuPont) (@ 150 gm ai/ha) in-furrow [**HGW86 20SC IF 150**] or [**Cyaypyr 20SC IF 150** on yield graphs**]**
4. HGW 20SC (Cyazypyr, DuPont) (@ 200 gm ai/ha) in-furrow [**HGW86 20SC IF 200**] or [**Cyazypyr 20SC IF 200** on yield graphs**]**
5. HGW 20SC (Cyazypyr, DuPont) (@ 0.47 fl.oz. product / 100lb seed) as a seed treatment [**HGW86 ST 0.47**] or [**Cyazypyr ST 0.47** on yield graphs**]**
6. HGW 20SC (Cyazypyr, DuPont) (@ 0.62 fl.oz. product / 100lb seed) as a seed treatment [**HGW86 ST 0.62**] or [**Cyazypyr ST 0.62** on yield graphs**]**
7. Untreated Control [**UTC**]

Defoliation dynamics – Not unexpectedly, there was no difference in the defoliation in any plot until June 28, when higher numbers of larvae began to appear and inflict serious defoliation. At this point, the UTC plots started to suffer significantly more defoliation than did any of the treatment plots. There was no statistical difference in any of the treatments at any date; while the mean defoliation appears higher in the **HGW86 & Cruiser ST** plots seem higher June 23, this difference is not statistically significant and is likely the result of the amount of variation in the data as populations of CPB become established in the plots. It was determined that all of the seed treatments tested provided control of early season defoliation, and there were no differences in the level of control provided.

It is apparent that comparative defoliation becomes more similar at the beginning of August (Aug 03). This is a reflection of the establishment of summer adults on the plants which feed considerable more than do the spring emerging adults. Because this was a seed treatment trial, the summer adults were not treated. In hindsight, all plots should have received a treatment of Spinosad to end beetle feeding and cease the experiment. It was concluded that none of the seed treatments tested provide control of summer adult beetles emerging in late July / early August. It is expected that foliar rescue treatments will be necessary to control these insects.

Conclusions – all Cyazypyr treatments were as effective at suppressing defoliation as was Admire Pro. Until summer adults colonized plots, all insecticide soil treatments suppressed defoliation significantly better than not treating.

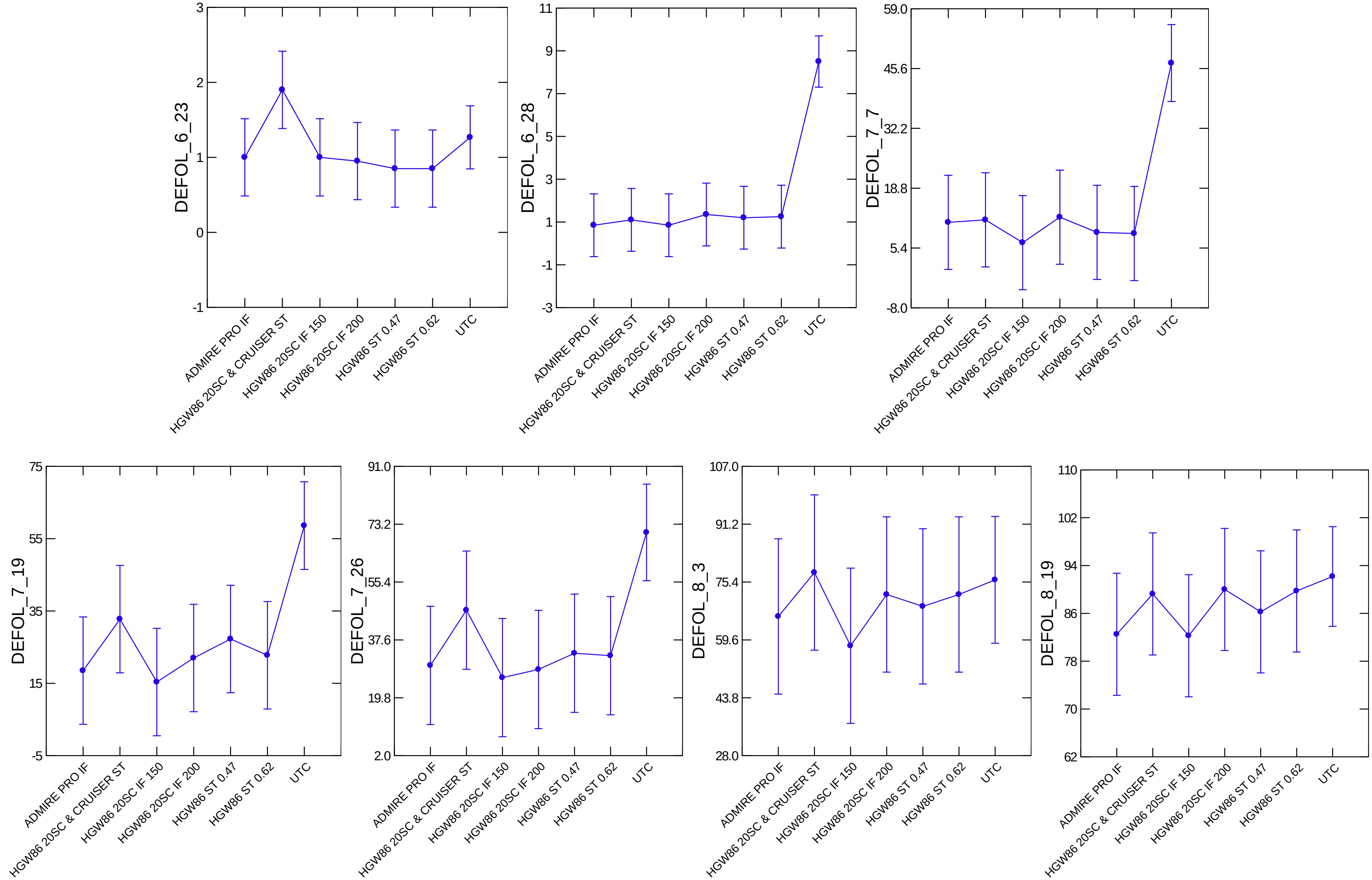

Figure 1. Mean comparative Colorado Potato Beetle defoliation ratings between seed treatments at Becker, MN, 2011. Dates are indicated on Y-axis. Vertical lines are 96% confidence intervals, overlapping CI's indicate no significant difference in the means.

CPB population dynamics – Adults: There were no significant differences in the number of adult CPB in any plot until the July 19 sample date (Fig. 2). June was exceptionally cold and wet in 2011 and populations of CPB adults were slow to emerge and become established on plants. Until July 19, the number of beetles per plant remained very low, between 0 and 1. This had changed drastically by the July 19 sample date, adult CPB had established in significantly higher numbers on plants in the UTC plots than on plants in the chemically treated plots. This pattern was short-lived, however, with equal numbers of beetles in all plots on July 26. As previously noted, the length of protection provided by the seed treatments had run its course by the beginning of August and, while there was significant variation in the number between plots, even of the same treatment, number of beetles were not significantly different in plots for the rest of the summer. The number of CPB in the **UTC** plots on Aug 03 are significantly lower than in the **HGW86 20SC IF 150** plots, but may have been a reflection of the active nature of CPB movement between plants.

Larvae: There were significantly more larvae per plant in the **ADMIRE PRO IF** plots than in either the **HGW86 ST 0.47** or the **UTC** plots (Fig. 3). It should be noted that the number of larvae per plant in any plot were still very low. While there was not a significant difference in the number of adults in these plots at this time, it must be remembered that weekly population counts are a ‘glimpse through a window in time’ at that population. Through the previous time period, adults could well have laid eggs on these plants, which hatch and result in the larval populations we witnessed. In any case, by the following week, the number of larvae in the **UTC** plots was significantly higher than any of the chemically treated plots. The variation in larvae per plant in all plots increased to the point where there were no further significant differences between any treatment plot for the rest of the season.

Conclusions – All Cyazypyr (HGW86) treatments were as effective in suppressing both adult and larval CPB as was Admire Pro. Further trials are necessary to further differentiate between the two compounds. None of the insecticide treatments provided season-long suppression of beetle numbers and all will require some form of foliar treatment. In late June and early July, all insecticide treatments suppressed larvae and adult (respectively) CPB populations significantly better than not treating. It is strongly recommended not to follow a neonicotinyl seed treatment with a foliar application of the same mode of action to prevent facilitating the development of resistance.

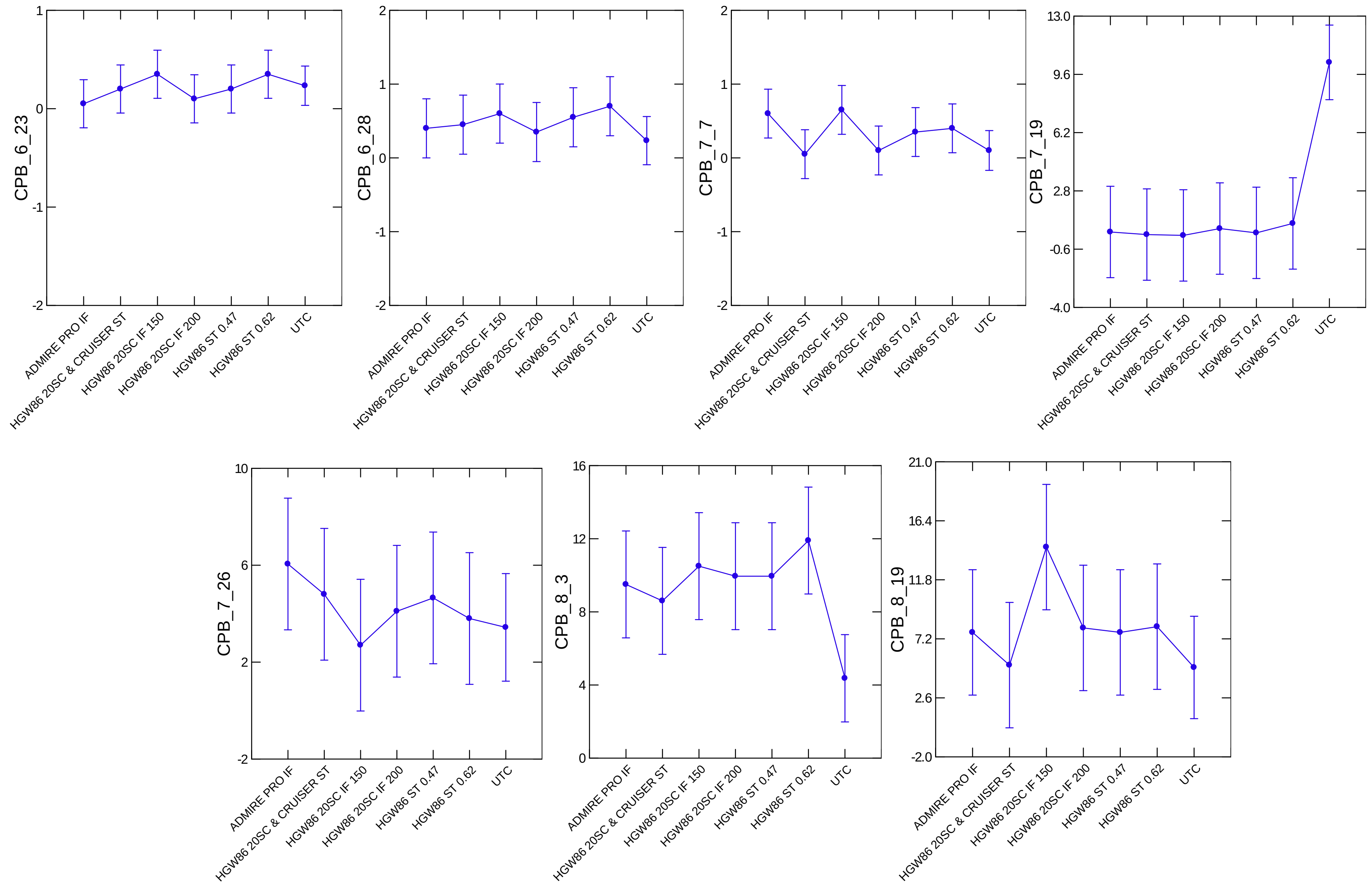

Figure 2. Mean no. of adult Colorado Potato Beetle in seed treatment plots at Becker, MN, 2011. Dates are on Y-axis. Vertical lines are 96% confidence intervals, overlapping CI's indicate no significant difference in the means.

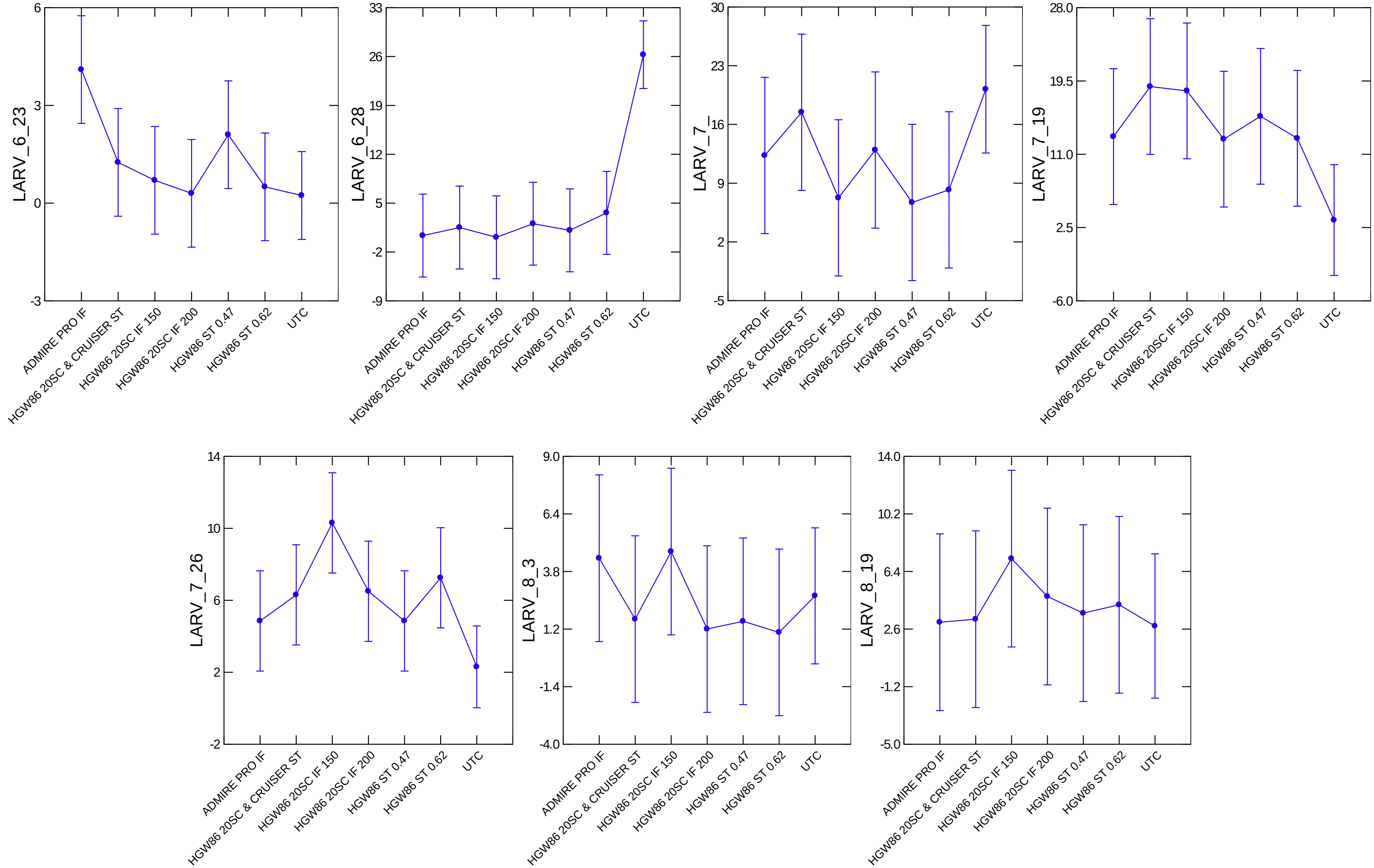

Figure 3. Mean no. of larval Colorado Potato Beetle Beetle in seed treatment plots at Becker, MN, 2011. Dates are on Y-axis. Vertical lines are 96% confidence intervals, overlapping CI's indicate no significant difference in the means.

CPB seed treatment yields – Yields were extremely low for both seed treatments and foliar treatments at Becker. A combination of an unseasonably cold and wet June, followed by a hot July and early vine kill all contributed to low yields in all plots. However, what is important in this trial is the comparative yields. There was no significant difference in the yields between any chemically treated plot. There was no significant difference between the yields from the **UTC** plots and the yields from the **ADMIRE PRO IF, Cyazypyr 20SC & Cruiser ST, Cyazypyr 20SC IF 150,** and **Cyazypyr 20SC IF 150** plots. Yields from the **Cyazypyr ST 0.62** and the **Cyazypyr 20SC IF 200** plots were significantly higher than those from the **UTC** plots. From these data it seems that the highest rate of seed Cyazypyr seed treatment and the highest rate of Cyazypyr in-furrow treatment provide the best treatment of CPB.

The variance in the population data caused by the failure to control summer adult CPB feeding made it difficult to differentiate between other seed treatments and **UTC** plots. We plan to repeat these comparisons and use applications of Spinosyn insecides to control the summer beetle populations, thereby obtaining a better estimate of the efficacy of these insecticide treatments.

In any case, it should be noted again that all seed treatments and in-furrow treatments do not provide sufficient protection against feeding damage by summer adult CPB.

Conclusions – Yield trials indicate Cyazypyr (HGW86) appears to show promise as either a seed or an in-furrow treatment to control CPB. It is at least as effective as Admire Pro, further trials are necessary to completely compare the efficacies of the two compounds. As it has a different mode of action, it may well provide a good alternative to neonicotinyl insecticides as at-plant treatments and be a good fit into a resistance management program.

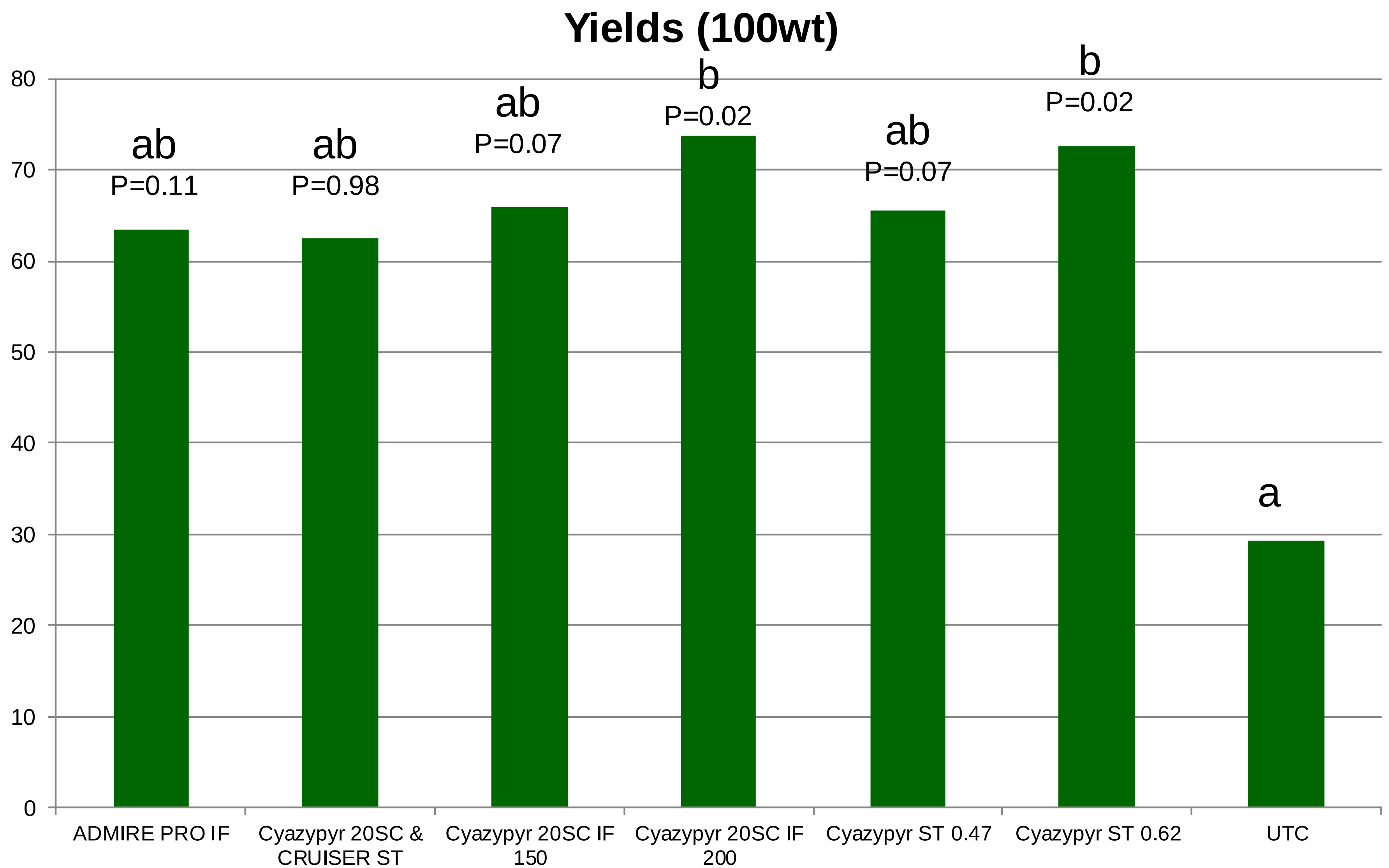

Figure 4. Mean yields of plots from seed treatments for controlling Colorado Potato Beetle at Becker, MN. Variance due to weather and late season populations made differentiation of means difficult. Bars topped by different letters are significantly different.

CPB foliar treatment yields - The foliar treatments included:

1. Blackhawk (Spinosad A & D, Dow AgroScience), 1 application
2. Blackhawk (Spinosad A & D, Dow AgroScience), 2 applications
3. Leverage (imidacloprid and ß-cyfluthrin, Bayer Crop Sci.) @ 2.8 fl.oz./ac
4. Untreated Control (UTC)
5. Tolfenpyrad (Nichino Amer. INC.) @ 14 fl.oz.ac
6. Tolfenpyrad (Nichino Amer. INC.) @ 21 fl.oz./ac

Weekly population data is not reported for CPB foliar trials. The foliar trials provided good suppression of CPB. Yields in this trial were higher than those in the seed treatment / in-furrow trials for a number of reasons. Suppression of CPB populations (both adults and larvae), while not lasting through the entire season, was longer than that of the seed and in-furrow treatments. Vines were also not killed early. The nature of the trial, and the continued low CPB population prevented the need for early vine kill. Consequently, these plots were able to gain late season bulking, so important in potato yield.

Both rates of **Tolfenpyrad** (an unregistered, pyrazole insecticide) and the plots treated with **Leverage** yielded significantly higher than did the **UTC** plots**.** There was no significant difference in the yields of either **Tolfenpyrad** treatment, **Leverage**, or 2 applications of **Blackhawk**. In addition, both rates of **Tolfenpyrad** yielded significantly higher than did 1 application of **Blackhawk**.

Conclusions – Tolfenpyrad shows considerable promise as a foliar treatment for the control of CPB. Leverage, as a neonicotinyl insecticide, should be avoided as a foliar following the use of a neonicotinyl as a seed treatment to avoid facilitating the development of resistance in CPB to this group of insecticides. Most of these foliar insecticides would provide good control of either spring or summer adults as well as of larvae.

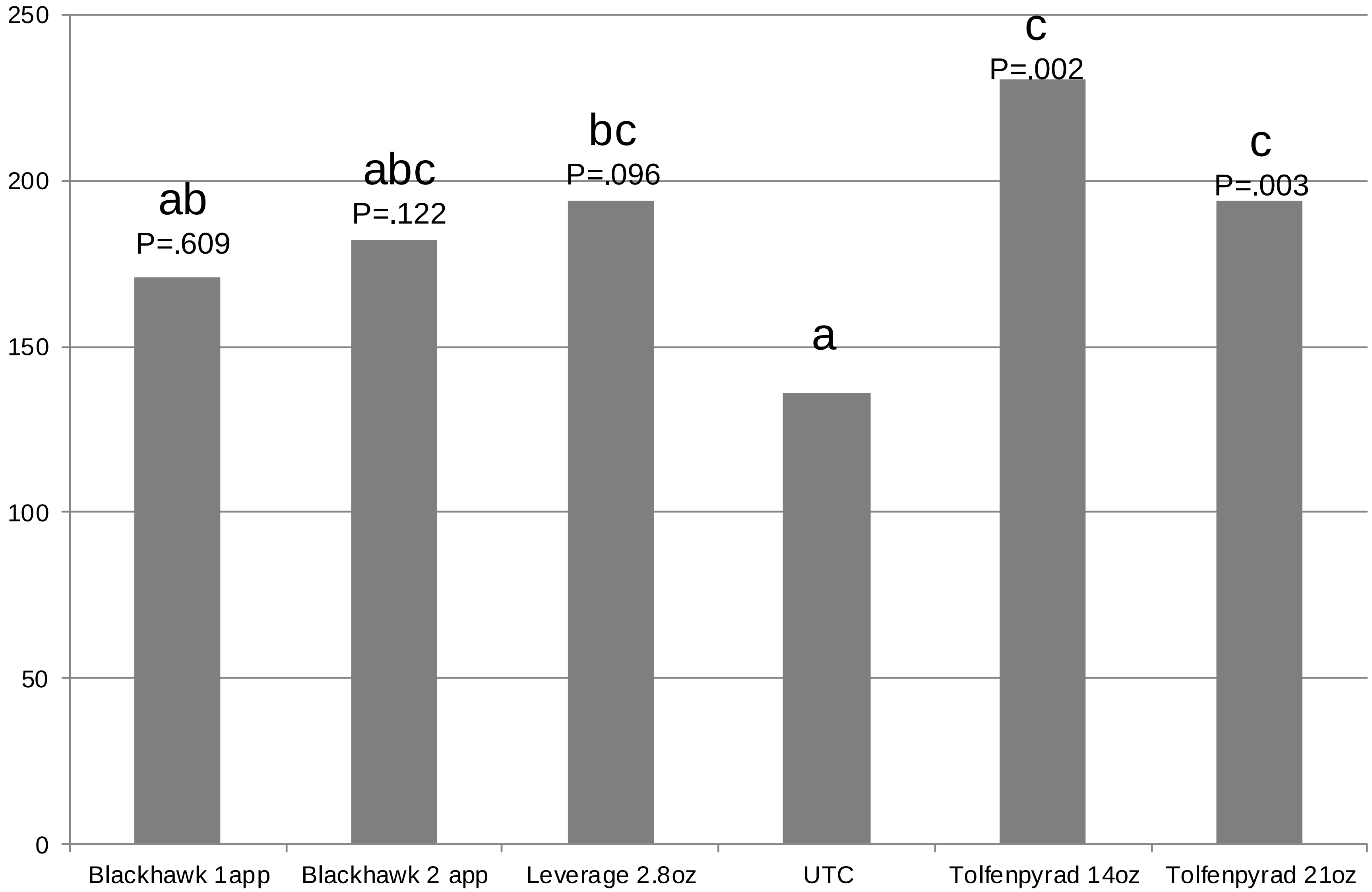

Figure 5. Mean yields from foliar treatment plots for controlling Colorado Potato Beetle at Becker, MN. Bars topped with different letters are significantly different ($\alpha = 0.05$). Yields are in 100wt. Bars topped by different letters are significantly different.

CPB neonicotinyl resistance – CPB adults were collected from 3 locations in MN early in the growing season in Minnesota. UMN personnel collected samples from Becker, Growers and RDO staff collected samples from Perham and Long Prairie. Beetles were prepared and shipped to the potato entomology lab at Univ. of Michigan, where they were assessed for susceptibility to the neonicotinyl insecticides, imidacloprid (e.g. Admire) and thiamethoxam (e.g. Actara, Platinum). In an additional sample, the University of Wisconsin was forwarded a small sample from Becker, MN which they evaluated (referred to as Becker2 sample). The amount of insecticide required to kill 50% of the sampled population was compared to the amount required to kill 50% of a population of CPB know to be susceptible to neonicotinyl insecticides. The rates could then be compared using Probit Analysis. What is presented is comparative susceptibilities of the two population. When it is said the sampled individuals are 4X less susceptible, it means it took 4 times the amount of insecticide to kill the sampled population than the known susceptible population.

The development of resistance to neonicotinyl insecticides in CPB seems to follow a similar pattern in different regions. Decreasing susceptibility to Imidacloprid is generally seen first followed by a lowered susceptibility to other neonicotinyls, such as thiamethoxam and others.

Decreased susceptibility to neonicotinyl insecticides varies in the 3 different sampled regions of MN (Fig. 6). Becker populations showed a minor level of resistance to imidacloprid (a mean of 4X that of the susceptible population) and were still relatively susceptible to thiamethoxam (mean of 1.3X). The smaller population tested by the Univ. of Wisconsin. Showed a much higher rate of resistance to imidacloprid (mean of 10.4X) but this may be explained by the smaller sample size or timing of sample. Long Prairie demonstrated low minor levels of resistance to imidacloprid (mean of 3.5X) and populations from this location were borderline minor resistant to thiamethoxam (mean of 2.4X). Populations of CPB from Perham showed the least susceptibility to either neonicotinyl insecticide but 'resistance levels' would be categorized as low to medium (mean of 8X for imidacloprid, 2.5X for thiamethoxam).

Conclusions – The current rates of CPB resistance to neonicotinyl insecticides in the three sampled areas of MN are what would be categorized as minor to low. However, it should be noted the levels of resistance can escalate rapidly. The number of MN and ND areas that can be annually tested by the U. Michigan lab is limited. It would be advantageous to establish a local mechanism of assessing resistance levels. In addition, to delay the future onset of resistance, it is recommended that potato producers alternate their insecticide modes of action, definitely not following a neonicotinyl seed treatment with a neonicotinyl foliar application.

Location	Insecticide	LD_{50} (mg/individual)	Resistance (X less susceptibility)
Becker (450 beetles)	Imidacloprid Thiomethoxam	0.473 0.102 (.087-.122)	**4 X** **1.3 X**
Perham (400 beetles)	Imidacloprid Thiomethoxam	0.904 (.63-1.228) 0.198	**8 X** **2.5 X**
Long Prairie (400 beetles)	Imidacloprid Thiomethoxam	0.399 (.189-.585) .193 (.164-.224)	**3.5 X** **2.4 X**
NJ Susceptible Population	Imidacloprid Thiomethoxam	0.115 (.068-.156) 0.082	**NA** **NA**
Becker2 (U.W.) (74 beetles)	Imidacloprid Thiomethoxam	1.19	**10.4 X**

Figure 6. Mean resistance levels of Colorado potato beetle sampled from 3 locations in MN. The Becker2 sample was tested at the Univ. of Wisconsin, all other samples were tested at the Univ. of Michigan. Level of resistance are calculated as the comparative amount of insecticide necessary to kill 50% of the sampled population compared to the amount necessary to kill a population known to be completely susceptible to the insecticide. It is generally considered that: ***susceptible*** **= 0X-3X**, ***minor*** = **3X-5X**, ***low*** **= 5X to 10X**, ***medium*** **= 10X-40X**, ***high*** **= 40X-160X**, ***extremely high*** **>160X**). Shen JL and Wu YD, *Insecticide Resistance in Cotton Bollworm and its Management* (in Chinese). China Agricultural Press, Beijing, China, pp. 259–280 (1995).

CPB colonization – A staggered edge was created at Becker, MN. A ‘stepped’ edge, with steps increasing at 10m lengths (so rows started 1m, 24m, 48m, and 72m from the field edge (Fig. 7). The step are not planted into potatoes was planted into rye. The hypothesis was that rye slows the movement and colonization of CPB into potato fields. Newly active CPB adults were gathered early in the season from around the field edge, marked with DayGlo fingernail polish, and each color released at one of the ‘steps’ (Fig. 7). This marking does impair flight, most beetles were marked on the elytra (wing covers) which prevented them from opening. After spring emergence, however, adults generally do not fly but orient and move into potato fields by walking. Marked beetles were highly visible in both the rye crop and in the potato foliage. Almost all beetles were accounted for after 72 hours indicating there was little mortality from the nail polish over this period. In addition, given the rate at which beetles moved into the potato fields, this marking does not impair their ground movement.

Figure 7. The staggered planted edge created at Becker, MN and the 4 different colored marked CPB adults released along the margin at the base of each ‘step’.

Movement into the field was measured 24, 48 and 72 hours later. Initial plans were to monitor movement weekly but this was unnecessary. Released CPB adults reached the step furthest from the edge within 48 hours. There was no need to statistically analyze the results; beetles were not slowed in any way by having to cross the rye.

Conclusions – border crops of rye less than 72m did not hinder movement of CPB and colonization of fields. Border crops are likely of little use in preventing or slowing the colonization of fields by CPB. On perhaps the only positive note from this trial, DayGlo nail polish marks beetles well enough for them to be visible from several feet away, both in the rye cover or in the potato foliage. Beetles marked in this manner do not seem to suffer significant mortality in the first 72 hrs. This may be an aid in future research.

Use of Remote Sensing Techniques to Evaluate Water and Nitrogen Stress in Irrigated Russet Burbank and Alpine Russet Potato

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ABSTRACT: A field experiment was conducted in 2010 and 2011 at the Sand Plain Research Farm (Becker, MN) to evaluate the ability of canopy level hyperspectral (in the visible & near-infrared spectrum) and thermal imagery to detect nitrogen (N) and water stress in a potato crop. Additionally, the effects of irrigation, N management (i.e., rate and timing of N applications, use of a soil surfactant), and variety were evaluated based on differences in tuber yield, tuber quality, and crop N uptake. Treatment variables included: two irrigation regimes (unstressed and stressed), five N management strategies (30 lbs ac^{-1} control [starter only], 160 lbs ac^{-1} with post-emergence N split-applied, 240 lbs ac^{-1} with post-emergence N split-applied, 240 lbs ac^{-1} with post-emergence N split-applied + soil surfactant, and 240 lbs ac^{-1} with all post-emergence N applied at once [early]), and two varieties (Russet Burbank [RB] and Alpine Russet [AR]). Total yield was greater for the 240 lb ac^{-1} rate with post-emergence N split-applied than for the 240 lb ac^{-1} rate with post-emergence N applied early in both years. Overall, total and marketable tuber yields increased with increasing N rate, and when post-emergence N was split-applied. Total tuber yield was similar for both varieties, but marketable tuber yield was significantly affected by variety in both years – AR had higher marketable yields than RB. RB had better emergence rates than AR, although this did not result in lower total tuber yields for AR. In general, higher N rates with the RB variety resulted in a higher incidence of hollow heart. In general, AR had better frying quality and lower glucose (stem end) than RB. Increasing N rate resulted in better frying quality, and surprisingly, water stressed plots had slightly better chip color and AGT scores than unstressed plots. There were mixed results between 2010 and 2011 for specific gravity among the treatment variables. Overall, petiole nitrate measurements tended to estimate N deficiency sooner with higher accuracy than relative chlorophyll measurements. Linear regression was used to determine the relationship between image data and N stress within a particular plot. Preliminary results from 2010 indicate that there are very good relationships between N stress and percent reflectance. However, these relationships changed throughout the growing season and with differences in variety (e.g., the best method to predict N stress early in the season might not be the best later in the season for a given variety). Thermal images were also able to detect water stress, but more research will be needed on data interpretation before either hyperspectral or thermal imagery can be used by growers on a practical scale to help manage water and N applications.

INTRODUCTION

Potato yield and quality are highly dependent on an adequate supply of nitrogen (N) and water; however, excessive N uptake can result in reduced tuber yield and quality. Furthermore, the naturally shallow and poorly developed root system of the potato plant, coupled with a high N requirement and sensitivity to water stress on coarse-textured soils increases the risk for nitrate (NO_3-N) leaching. To optimize N uptake and minimize environmental losses, many growers apply post-emergent N fertilizer in split applications implemented with precise irrigation management. To help decide when to apply N and water inputs, growers take tissue samples or use sensors to take point measurements that are indicative of the N or water stress of the crop. However, spatial variability often exists within fields because of differences in soil characteristics or landscape position, and a few point measurements are not likely to be an accurate representation of the entire field. Hyperspectral (HS) and thermal aerial imagery is an effective research tool that can be used to develop new techniques to detect N and/or water stress in a crop because of its ability to detect spatial and temporal variability. Modified N and/or water stress methodologies might then be applied to active sensors to optimize the efficiency of variable rate application.

Russet Burbank (RB) is the most popular processing potato in the upper Midwest and Alpine Russet (AR) is a relatively new variety that is resistant to most external and internal defects and has similar yields to RB. Controlled studies are needed to indentify AR response to N and water management under Minnesota conditions. Additionally, soil surfactants applied at emergence are thought to allow increased and more uniform water infiltration to the hill. This would enable growers to be more efficient with their watering which would potentially reduce nitrate leaching.

The objectives of this study were to: (i) determine tuber yield and tuber quality differences based on the main effects and interactions of irrigation, N management, and variety, (ii) evaluate the effectiveness of split applications of post-emergence N and the use of a soil surfactant on crop N uptake, (iii) evaluate the ability of canopy level HS (in the visible & near-infrared spectrum) and thermal imagery to detect N and water stress in a potato crop, and (iv) distinguish between N deficiency stress and water deficiency stress using canopy level HS and thermal imagery.

MATERIALS & METHODS

Study Site

Field experiments were conducted over two years (2010-2011) at the University of Minnesota Sand Plain Research Farm (45°23’N, 95°53’W) near Becker, MN. The soil at this location is classified as an excessively drained Hubbard loamy sand formed in glacial outwash. The available water holding capacity in the top 48” of soil is 3.9”. During the growing season (April – September), the 30-year average temperature and rainfall are 62° F and 21.7”, respectively.

Representative soil samples from the upper 6” were taken prior to planting for routine soil analysis. Selected soil chemical properties for 2010 were: water pH - 6.8; organic matter - 1.5%; Bray P1 - 30 ppm; ammonium acetate extractable K, Ca, and Mg - 101, 847, and 166 ppm, respectively; Ca-phosphate extractable SO_4-S - 6 ppm; and DTPA extractable Zn, Cu, Fe, and Mn - 0.9, 0.4, 15.0, and 4.0 ppm, respectively. Selected soil chemical properties for 2011 were: water pH - 6.2; organic matter - 2.0%; Bray P1 - 44 ppm; ammonium acetate extractable K, Ca, and Mg – 109, 875, and 146 ppm, respectively; Ca-phosphate extractable SO_4-S - 3 ppm; and DTPA extractable Zn, Cu, Fe, and Mn – 1.5, 0.7, 38.1, and 11.0 ppm, respectively. To determine pre-plant soil inorganic N, soil samples from the upper 24” were collected from each whole plot on 23 March and 6 April in 2010 and 2011, respectively. The samples were air-dried, ground to pass a 2-mm sieve, and conductimetrically analyzed for KCl extractable NO_3-N and NH_4-N using a Wescan N analyzer. The average concentration of pre-plant soil inorganic N (NH_4-N + NO_3-N) was 1.7 ppm for 2010 and 0.9 ppm for 2011.

Experimental Design

Each year, the experiment was set up as a randomized complete block design with a split-split plot restriction on randomization (four replications). The whole plot treatment was irrigation rate (unstressed and stressed). Irrigation was applied with an overhead sprinkler system – irrigation rate for the unstressed treatment was scheduled according to the checkbook method, and the stressed treatment was irrigated at about 80% of that rate. The sub plot treatment was N fertilizer management strategy, which included variable rates of total N fertilizer and variable timings of post-emergence N (Table 1). Of the five N fertilizer management strategies, there were three N rates: 30, 160, and 240 lbs N ac^{-1} (N management strategy 1, 2, 3, 4, and 5, respectively). N management strategy 4 had the same rate and timing as strategy 3, however, it was treated with a soil surfactant (IrrigAid Gold®) which was applied with a backpack sprayer at a rate of 4 quarts ac^{-1} on 24 May and 27 May in 2010 and 2011, respectively, to determine the effects of the surfactant on plant N uptake. The planting and emergence N source was diammonium phosphate and urea, respectively, for both years. Post-emergence N was split-applied four times by hand as a 1:1 mixture of urea/ammonium nitrate (UAN) and five times by spray boom and tractor as 28% UAN solution in 2010 and 2011, respectively. All post-emergence N was watered in immediately by irrigation. The sub-sub plot treatment consisted of two potato varieties, Russet Burbank (RB) and Alpine Russet (AR).

Table 1: N fertilizer management strategies.

	N Fertilizer Management Strategy	Timing of Application			Total N
		Planting	Emergence	Post Hill UAN	
		------------------------------	lbs N ac^{-1}	------------------------------	
1	Low N (control) -- 30 lbs ac^{-1}	30	0	0	30
2	Medium N split -- 160 lbs ac^{-1}	30	70	15 (*4)	160
3	High N split -- 240 lbs ac^{-1}	30	110	25 (*4)	240
4	High N split (+ surfactant) -- 240 lbs ac^{-1}	30	110	25 (*4)	240
5	High N early -- 240 lbs ac^{-1}	30	110	100	240

For both years, whole “B” seed and cut “A” seed were used for the RB and AR varieties, respectively. Seed was hand planted in furrows with 36” row spacing and approximately 12” spacing between seed pieces within rows. Planting dates were 16 April and 29 April in 2010 and 2011, respectively. The previous crop in both years was non-irrigated cereal rye. Each plot consisted of seven 45’ rows, and only the fourth and fifth rows from the alley were considered for harvest. Rows were mechanically hilled at plant emergence. Chemicals were applied as needed during the season for the control of pests, disease, and weeds according to standard practices in the region.

Field Data Collection

A weather station (constructed by Apogee Inst.) was installed at the field site to measure canopy temperature, air temperature, relative humidity, vapor pressure, vapor pressure deficit, solar & net radiation, wind speed & direction, boundary layer heat conductance, and precipitation.

Soil matric tension was measured with granular matrix soil moisture sensors (Watermark Model 200, Irrometer Co., Riverside, CA) in and below the root zone. Sensors were placed in several plots, which included both irrigation treatments, both varieties, and N management strategies 3 and 4 for both years (one or two replications). The sensors were packed with moist soil during installation to ensure good sensor to soil contact.

Infrared radiometers were used to measure ground-based canopy temperature (Apogee Inst., Model SI-111). Each radiometer was mounted to a pole at the end of the fifth row from the alley about 6’ off the ground, and was aimed at a 45° angle to the crop canopy. Measurements were taken every second and were averaged and recorded every half hour.

Stand and stem counts were performed in early June for both 2010 and 2011. Field measurements were taken five times throughout the growing season each year and included tissue samples (petioles and leaflets), relative chlorophyll (Minolta SPAD-502, Spectrum Technologies, Plainfield, IL), leaf area index (LAI-2000, LI-COR Biosciences, Inc., Lincoln, NE [Serial no. PCA 0353]), and multispectral reflectance (MSR16R Cropscan, Serial no. 249).

Twenty leaf samples (petiole + leaflets) were randomly selected and picked (each sample was the fourth leaf from the apex of the shoot) in the fifth row from the alley in each treatment plot. Relative chlorophyll was immediately measured at a central point on the terminal leaflet between the midrib and leaf margin. The 20 measurements from each plot were averaged to represent a single value for each treatment plot and were recorded. Immediately following relative chlorophyll measurements on each leaf, leaflets were stripped from the petiole and both tissue samples were separately saved for analysis. Tissue samples were oven-dried at 140°F, weighed for dry matter yield, and ground with a Wiley mill to pass a 20 mesh screen. Total N in ground samples was determined with a combustion analyzer. Nitrate-nitrogen (NO_3-N) was extracted from 0.1 g ground tissue with 20 mL nanopure water (once extracted, samples were kept frozen until analysis).

Vines were manually harvested and weighed from a 10’ length of each of the two harvest rows 147 DAP and 138 DAP in 2010 and 2011, respectively (10 September and 14 September in 2010 and 2011, respectively). Vine samples were collected, oven-dried at 140°F, weighed for dry matter yield, and ground with a Wiley mill to pass a 20 mesh screen. Total N in ground samples was determined with a combustion analyzer. Tubers were mechanically harvested from the two harvest rows 165 DAP and 146

DAP in 2010 and 2011, respectively (28 September and 22 September in 2010 and 2011, respectively). Tubers were sorted to determine marketable tuber yield and size class distribution; subsamples were then randomly selected to be analyzed for tuber quality, specific gravity, N uptake, and sugar content.

Aerial Image Acquisition

Aerial hyperspectral and thermal remotely sensed images were acquired with an AISA Eagle Visible-Near Infrared HS imaging sensor (SPECIM, Spectral Imaging, Ltd., Oulu, Finland) and a FLIR Systems ThermaCam SC640, respectively, by the Center for Advanced Land Management Information Technologies (CALMIT) from the University of Nebraska-Lincoln, USA. The plane flew over the plots on 1 July (76 DAP) and 6 August (112 DAP) in 2010 and on 6 July (68 DAP) and 29 July (91 DAP) in 2011 and captured imagery with a spatial resolution of 1.0 m (3.3') and 0.75 m (2.5') for the hyperspectral and thermal imagery, respectively. The AISA Eagle is a complete pushbroom system, consisting of a hyperspectral sensor head, a miniature GPS/INS sensor, and a data acquisition unit in a rugged PC with a display unit and power supply. It has a 1,000 pixel swath width and was configured to capture imagery in 63 bands covering a spectral range from 392 to 982 nm, with band widths ranging from 8.8 nm to 9.6 nm (spectral resolution of 2.3 nm). The thermal imagery was acquired in the spectral range of 7,500 nm to 13,000 nm.

Image Processing

A post processing software package, CaliGeo, was used for radiometric correction (using NIST traceable calibrations) and rectification (using a C-Migits III GPS/INS unit manufactured by Systron Donner Inertial Division, Walnut Creek, CA, USA). Geographic coordinates of plot corners were acquired with a GPS unit (0.3 m accuracy), and in-house geo-referencing was completed to minimize the image distortion.

ENVI software (Version 4.8, Exelis, Inc.) was used for all hyperspectral and thermal image processing. Regions of Interest (ROIs) were created for every treatment plot on each image date. A narrowband NDVI image was created and a minimum threshold value was applied to the image using the *Band Threshold to ROI* in the "ROI Tool" window to automatically select the pixels to be included within each ROI. The pixels included in each of the ROIs were used for all subsequent analysis. The *Band Math* tool was used to record the formulas for all the indices and derivative bands used in the HS analysis.

Statistical Analysis

Data were analyzed using PROC MIXED (SAS Institute Inc., 2008) with replicates considered as a random effect. Pairwise comparisons of the least square means were made using the pdiff statement in SAS to compare treatment means (alpha = 0.1).

RESULTS & DISCUSSION

Weather

Average daily air temperature and cumulative water for both 2010 and 2011 are shown in Figures 1 and 2, respectively. In general, June and early July were warmer in 2011 than in 2010. Cumulative water at harvest was 3.8" and 5.2" greater in the unstressed plots than in the stressed plots for 2010 and 2011, respectively. The cumulative water at harvest was approximately 10" greater in 2010 than in 2011. This can be attributed to two main factors: (1) there was a shorter growing season in 2011 due to a later planting date and an early frost, and (2) there were very dry conditions in August 2011 (on 1 August 2011, cumulative water was at approximately the same quantity as it was at 1 August 2010).

Tuber Yield

Statistical analysis across both years has not yet been completed – instead analysis was done separately for each year. Also, the treatment means for the interactions are not included, but the levels of significance are displayed in Tables 2 & 3.

In 2010, irrigation differences did not significantly affect total yield, marketable yield, or any of the tuber size classes (Table 2), although the unstressed treatment resulted in numerically higher total and marketable yields. The effect of nitrogen management was significant for total yield, marketable yield, and all tuber size classes, except for the 3-6 oz size class. Among N management strategies, the 240 lb ac^{-1} rate with post-emergence N split-applied + soil surfactant had the highest numerical total and marketable yields. With similar N management, there was not a statistical difference in total or marketable yields when a soil surfactant was used (between N management strategies 3 and 4). However, total yield for the 240 lb ac^{-1} rate with post-emergence N split-applied + soil surfactant was significantly higher than the 240 lb ac^{-1} rate with post-emergence N applied early (N management strategies 4 and 5, respectively). Overall, total and marketable tuber yields increased with increasing N rate, and when post-emergence N was split-applied. Differences in variety did not affect total tuber yield, but did significantly affect marketable yield and all tuber size classes (with AR showing higher marketable yields than RB) – marketable yield for RB and AR were 437 CWT ac^{-1} and 494 CWT ac^{-1}, respectively. AR had higher yields in the larger tuber size classes, and RB had higher yields in the smaller tuber size classes – this is the reason for the highly significant effect for tubers greater than 10 oz. for differences in variety. There were no significant effects on total yield for any of the interactions, but there was a significant effect on marketable yield for the interaction between N management strategy and variety.

In 2011, irrigation differences significantly affected total yield, marketable yield, and all tuber size classes, except for the 3-6 oz size class (Table 3). Total yield for the unstressed and stressed treatments were 487 CWT ac^{-1} and 397 CWT ac^{-1}, respectively, and marketable yield for the unstressed and stressed treatments were 413 CWT ac^{-1} and 308 CWT ac^{-1}, respectively. There was a highly significant effect of irrigation on size distribution – there were 44.7% and 29.9% of tubers greater than 6 oz. for the unstressed and stressed treatments, respectively. N management significantly affected total yield, marketable yield, and all tuber size classes. Among N management strategies, the 240 lb ac^{-1} rate with post-emergence N split-applied (N management strategy 3) had the highest numerical total and marketable yields, but there was no significant statistical difference between the 160 lb ac^{-1} rate and the 240 lb ac^{-1} rate that had post-emergence N split-applied (N management strategies 2, 3, & 4). As in 2010, the use of a soil surfactant did not significantly affect tuber yields when similar N management was used. However, the 240 lb ac^{-1} rate with post-emergence N applied early (N management strategy 5) had statistically lower total and marketable yields than the N management strategies with post-emergence N split-applied at 160 and 240 lbs ac^{-1} (N management strategies 2, 3, & 4), but did have significantly higher total and marketable yields than the 30 lb ac^{-1} rate (N management strategy 1 [control]). Although there was a highly significant effect of N on percent of tubers greater than 6 oz., there were no statistical differences between timing of post-emergence N for the N management strategies with 240 lb ac^{-1} rates (N management strategies 3, 4, & 5 – ranged from 41.8%-44.7% of tubers greater than 6 oz.). There was, however, differences between N rates – the 30 lb ac^{-1} rate, 160 lb ac^{-1} rate, and 240 lb ac^{-1} rates had 17.9%, 36.3%, and 43.7% (average) of tubers greater than 170 g. The variety differences did not affect total yield, but did affect marketable yield – marketable yields for AR were significantly higher than those for RB. The AR variety had higher yields in the larger tuber size classes, and the RB variety had higher yields in the smaller tuber size classes – this was similar to 2010. There was no significant effect on total and marketable tuber yields for any of the interactions.

Although statistical analysis for both years together has not yet been run, it will surely trigger a significant response – total yield was about 90 CWT ac^{-1} higher in 2010 than in 2011. The low yields in 2011 can likely be attributed to: (1) a relatively cool spring (Figure 1), (2) a very hot July (warm temperatures at night are not conducive for tuber bulking), (3) a dry period through the month of August (Figure 2), and (4) an early freeze (the 16 September freeze made for a much shorter growing season in 2011).

Tuber Quality & Stand/Stem Count

Statistical analysis across both years has not yet been completed – instead analysis was done separately for each year. Laboratory analysis for the 2011 six month frying quality has not started, and therefore, is not included in the table. Also, the treatment means for the interactions are not included, but the levels of significance are displayed in Tables 4 & 5. Frying quality is not discussed in detail, but the treatment means and level of significance of the variables are included in the tables. In general, AR had better frying quality and lower glucose (stem end) than RB. Increasing N rate resulted in better frying quality, and surprisingly, water stressed plots had slightly better chip color and AGT scores than unstressed plots (Tables 4 & 5).

In 2010, the effects of irrigation and N management were non-significant for both stand and stem populations (Table 4). There was a significant response by variety, however; RB had higher emergence rates and number of stems per plant than AR. Although AR had less stems per plant and a lower emergence rate, it produced higher yields. The effects of N management and variety were highly significant for percent hollow heart – the high N rates had a greater incidence of hollow heart, as did the RB variety. The effects of irrigation and N management were both non-significant for specific gravity, however, the effect of variety was highly significant – RB had an overall higher specific gravity than AR.

In 2011, the effects of N management and variety were significant for stem populations (Table 5). The low N rate had lower amount of stems per plant than the medium and high rates, and RB had more stems per plant than the AR. RB also had higher emergence rates than AR, but AR produced higher yields than RB, which is consistent with 2010 data. RB had a significantly higher rate of hollow heart than AR, which was also consistent with 2010. Unlike 2010, the effect of variety was non-significant for specific gravity, and the effects of irrigation and N management were both highly significant. The water stressed treatment had a higher specific gravity than the unstressed treatment, and the medium and high N rates with split applications of post-emergence N had a higher specific gravity than both the high N with post-emergence N applied early and the low N rate (N fertilizer management strategies 5 and 1, respectively).

Tissue Samples & Relative Chlorophyll

Tissue sample data includes petiole NO_3-N, leaf total N, and SPAD relative chlorophyll at various growth stages for 2010 and 2011 (Tables 6 & 7, respectively). Complete laboratory analysis of leaf N for 2011 has not been finished, and therefore, is not discussed.

In 2010, irrigation differences did not significantly affect petiole NO_3-N, leaf N, or relative chlorophyll, except on the 6/15 sampling date – the stressed plots had higher petiole NO_3-N and leaf N concentrations than the unstressed plots on this date (Table 6). N management significantly affected petiole NO_3-N, leaf N, and relative chlorophyll for every sampling date. The statistical differences between N management strategies for the different methods to estimate N uptake (i.e., petiole NO_3-N, leaf N, and SPAD relative chlorophyll) followed similar general trends over the course of the growing season. However, as the growing season progressed, petiole NO_3-N tended to estimate N deficiency the quickest, and relative chlorophyll measurements tended to estimate N deficiency the slowest and with the lowest accuracy – this is based on the assumption that the split applications of post-emergence fertilizer maintain N sufficiency throughout the growing season better than post-emergence N applied early (e.g., the 240 lb ac^{-1} rate with post-emergence N applied early is expected to have higher N uptake at early sampling dates, but the N management strategies that have post-emergence N split-applied are expected to show higher N uptake at the mid to late sampling dates). To further explain the comparison between the different methods for estimation of N uptake, consider the 7/13 sampling date: each method showed no significant differences between the two N management strategies with 240 lb ac^{-1} rates and split applications of post-emergence N (N management strategies 3 & 4). However, petiole NO_3-N and leaf N each showed a significant difference from the 240 lb ac^{-1} rate with post-emergence N applied early (N management strategy 5), whereas relative chlorophyll measurements showed no significant difference for these comparisons. Furthermore, relative chlorophyll measurements showed a significantly lower value for the 160 lb ac^{-1} rate with post-emergence N split-applied (N management strategy 2) than for the 240 lb ac^{-1} rate with post-emergence N split-applied (N management strategies 3 & 4), whereas petiole NO_3-N and leaf N showed higher values for the 160 lb ac^{-1} rate with post-emergence N split-applied (only petiole NO_3-N showed a *significant* difference). For the purposes of this study, the relationship between the different estimations of N uptake as the growing season progresses is important to recognize. This is because aerial imagery primarily senses entire potato leaves, and is not able to pick up subtle changes in petiole reflectance. Differences in variety significantly affected petiole NO_3-N, leaf N, and relative chlorophyll on most of the sampling dates. Leaf N was higher for AR than for RB on every sampling date, and petiole NO_3-N was higher for AR than for RB in every sampling date except 6/15. Unlike petiole NO_3-N and leaf N, relative chlorophyll was higher for RB at every sampling date except 8/5; however, the relationship between the two varieties on this date was not statistically significant.

In 2011, irrigation differences did not significantly affect relative chlorophyll, and irrigation only significantly affected petiole NO_3-N on the 8/11 sampling date – the unstressed plots had higher petiole NO_3-N concentrations than the stressed plots on this date (Table 7). N management significantly affected petiole NO_3-N and relative chlorophyll for every sampling date. As in 2010, the 240 lb ac^{-1} rate with post-emergence N applied early showed the highest N uptake at the early sampling dates, but the N management strategies with post-emergence N split-applied began to show higher N uptake at the mid to late sampling dates. As in 2010, the 2011 petiole NO_3-N and relative chlorophyll measurements for the main effect of N management followed similar general trends over the course of the growing season. The petiole NO_3-N concentrations tended to be more sensitive than relative chlorophyll measurements in showing differences among N management strategies; petiole NO_3-N concentrations were also able to show differences at earlier sampling dates. Differences in variety significantly affected petiole NO_3-N and relative chlorophyll on most of the sampling dates in the early and middle part of the growing season. Similar to 2010, petiole NO_3-N and relative chlorophyll were not in agreement with each other for the differences in variety. Contrary to 2010, however, petiole NO_3-N was higher for RB than for AR and relative chlorophyll was higher for AR than for RB during the middle sampling dates. The conflicting results for differences in variety between 2010 and 2011 are surprising, and are currently unexplained.

Hyperspectral Image Analysis

To compare the relationship between image data and field measurements for each variety and flyover date, linear regression analysis was used. For the reflectance and derivative reflectance, the coefficient of determination (r^2) was recorded and plotted as a function of wavelength to determine the wavelengths that were best correlated with leaf N or petiole NO_3-N in the tissue samples. Leaf N was used because it is a good indicator of the *current* N status of the plant. However, because it does not respond as rapidly as petiole NO_3-N to N fertilization, it is not as good a predictor of the *future* N status of the plant. Low N and/or NO_3-N concentrations were assumed to be reflective of N deficient potato plants.

Spectral analysis has only been completed for the 2010 season. The wavelengths that had the reflectance values best correlated to leaf total N for RB on the 1 July 2010 flyover were the visible wavelengths from about 510 nm – 630 nm, the red-edge wavelengths around 700 nm, and the near-infrared wavelengths from about 760 nm – 920 nm (Figure 4). The best correlated derivative reflectance values were much more scattered, and occurred around 500 nm (blue wavelengths) and 700 nm (red-edge wavelengths). The r^2 values from the derivative reflectance at the red-edge wavelengths are greater than any r^2 values from the reflectance (the r^2 values across all wavelengths peak at 0.85 and 0.80 for the derivative reflectance and the reflectance, respectively). Similar procedures were performed for each tissue sample, variety, and flyover date – all results were compared to determine the best wavelengths to detect N stress in potatoes.

The indices used for evaluation in the preliminary analysis were selected based on two criteria: (1) their popularity/success from previous literature and (2) indices that used wavelengths with consistently high r^2 values for the relationship between tissue N and reflectance/derivative reflectance (as described in the preceding paragraph). There were eight narrowband indices evaluated (Table 2), as well as the reflectance and derivative reflectance for all wavelengths.

The r^2 values that represent the indices or wavelengths that best predicted N stress for each scenario are shaded in Table 3. Based on the preliminary analysis, a different index or wavelength was found to best predict N stress for each scenario (for the purposes of this analysis, a “scenario” is hereafter defined as any one combination of the three variables considered in the linear regression [i.e., flyover date/growth stage, tissue sample used in linear regression, and variety]). In general, leaf total N had a better relationship with reflectance and/or index values than petiole NO_3-N, RB had a better relationship than AR, and the 1 July flyover date had a better relationship than the 6 August flyover date. The SR8 index performed best in three out of four scenarios for the 6 August flyover; however, it did not perform best for any scenario on the 1 July flyover. Analysis of variance and means separation for these relationships are in progress.

The highest overall r^2 value was from the relationship between derivative reflectance at 751 nm and leaf total N for RB on the 1 July flyover date (the image of the derivative reflectance at 751 nm is shown in Figure 4). The pixels with the lowest derivative reflectance values are displayed in Figure 4 as being blue or green in color, and the higher derivative reflectance values are displayed as being red, orange, and yellow. The plots with low N rates can be easily seen because of their dark grey color. The plots that had the 240 lb ac^{-1} rates with post-emergence N applied early tended to have the highest derivative reflectance on this date. This makes sense, because on this date, only two applications of post-emergent N were applied to the split-applied N treatments – therefore, the 240 lb ac^{-1} rate with N applied early actually had a greater amount of N applied on 1 July.

Thermal Image Analysis

Although processing and statistical analysis for most of the thermal imagery is in progress, visual differences in temperature are obvious in the unprocessed thermal image (Figure 5). Canopy temperature was extracted from the pixels within each treatment plot of the thermal imagery using similar methods as the HS imagery. Weather data (humidity, air temperature, etc.) was used to calculate the Crop Water Stress Index (CWSI). On 1 July 2010, CWSI increased with increasing water stress, but differences were only significant for AR (data not shown). Further processing and analysis is in progress.

Soil Matric Tension

In 2010, the soil matric tension for the stressed plots stayed relatively consistent from 15 June through the end of the growing season (Figure 6a); the major peaks occurred just before each of the flyovers (1 July and 6 August) in which the irrigation was withheld for a few days. The matric tension for the unstressed plots was less than 20 kPa throughout the entire season.

In 2011, the soil matric tension for the stressed plots stayed relatively consistent through the months of June and July, although the matric tension during this time was lower than it was in 2010, indicating wetter conditions (Figure 6b). During this time, there was one small peak (climaxing at around 70 kPa) before the 6 July flyover, but there is no obvious peak at the time of the second flyover on 26 July. In the month of August and through the remainder of the growing season, the stressed plots became drastically more stressed – the soil matric tension was consistently over 120 kPa, and reached as high as 170 kPa. The matric tension for the unstressed plots was usually always below 20 kPa through July, then during August and September it reached as high as 30 kPa at times. The extremely dry soil conditions towards the end of the growing season are the primary reason for the significant responses of tuber yield for water stress.

CONCLUSIONS & FUTURE RESEARCH:

There are thousands of potential methodologies that can be used to process and analyze the large amount of data contained within a single HS image. Some of this information is useful for detecting crop stress, some is not. In addition, the image processing and analysis steps take a fair amount of time – because of this, it can be days to weeks after image acquisition before potential implementation by the end user (the grower). After detection of a crop's nutrient or water status, a grower must make management decisions regarding inputs within hours in order to operate at optimum efficiencies. The relatively long time before potential implementation of image data for N sidedress by the grower, coupled together with its high acquisition costs, presently makes aerial imagery impractical as a primary means to make management decisions for variable rate crop inputs. In the future, there is potential to use satellites to obtain imagery from large areas at low costs and quick revisit times (e.g., if a satellite is able to obtain imagery over any particular field every few days, growers can be more precise in their timing of sidedress N applications). Improvement in these aspects, coupled with more efficient processing techniques may help to facilitate the potential of remote sensing as a primary means for making variable rate management decisions.

Because imagery contains spatially dependant information over large areas, it is a great research tool for determining which image processing methodologies are most useful at a given growth stage or for a given variety – the analysis of the 2010 image data showed that a different analysis method (e.g., vegetation index) was “best” for predicting N stress depending on the crop growth stage, the potato variety, and the tissue sample used as a reference. If researchers can precisely determine the effects of these factors and effectively determine calibrations for variable rate N sidedress applications for a given N stress level (based on reflectance), active sensors (e.g., Crop Circle, GreenSeeker) can be further developed to be able to account for variations in crop species, yield potential, growth stage, and/or variety in order to optimize the accuracy and precision of remote sensing for variable rate application. From a practical standpoint, active sensors are desirable because they emit their own energy to detect reflectance, and measurements are more consistent between different irradiance levels (e.g., cloudy vs. sunny, night vs. day). In contrast, *passive sensors* (e.g., cameras used to acquire aerial imagery) detect natural radiation that is reflected by the crop canopy, which will result in variability of measurements between different irradiance levels. Unfortunately, using ground-based sensors (such as Crop Circle or GreenSeeker) make it difficult to detect field variability when the canopy has already closed; however, there is potential to mount sensors to irrigation pivots that can sense the crop canopy and make real-time adjustments to fertilizer and/or irrigation application rates.

Processing of the 2011 imagery has just been initiated. Comprehensive analysis of many broadband and narrowband indices for both years will be completed, followed by a correlation with total leaf N, petiole NO_3-N, relative chlorophyll, and leaf area index. The derivative reflectance showed positive results in 2010, so this will also be completed for the 2011 imagery and its effects and trends will be evaluated more closely to find its potential use in detecting N stress in potatoes. Finally, the image data will be compared to ground measurements (from Cropscan) in order to evaluate differences. Processing and analysis of thermal imagery will also continue in order to detect water stress.

Figure 1: Average daily air temperature during the 2010 and 2011 growing seasons at the Sand Plain Research Farm, Becker, MN. Planting was 16 April and 29 April in 2010 and 2011, respectively.

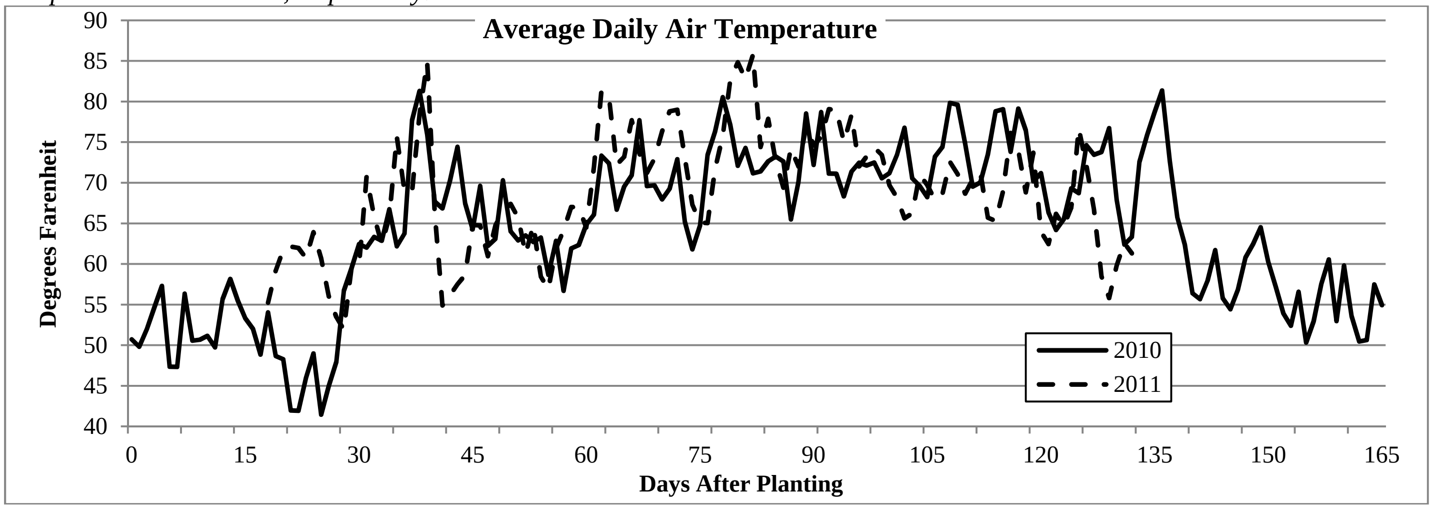


Figure 2: Cumulative rainfall + irrigation by irrigation treatment and year at the Sand Plain Research Farm, Becker, MN. Planting was 16 April and 29 April in 2010 and 2011, respectively. E = emergence; VK = vine kill.

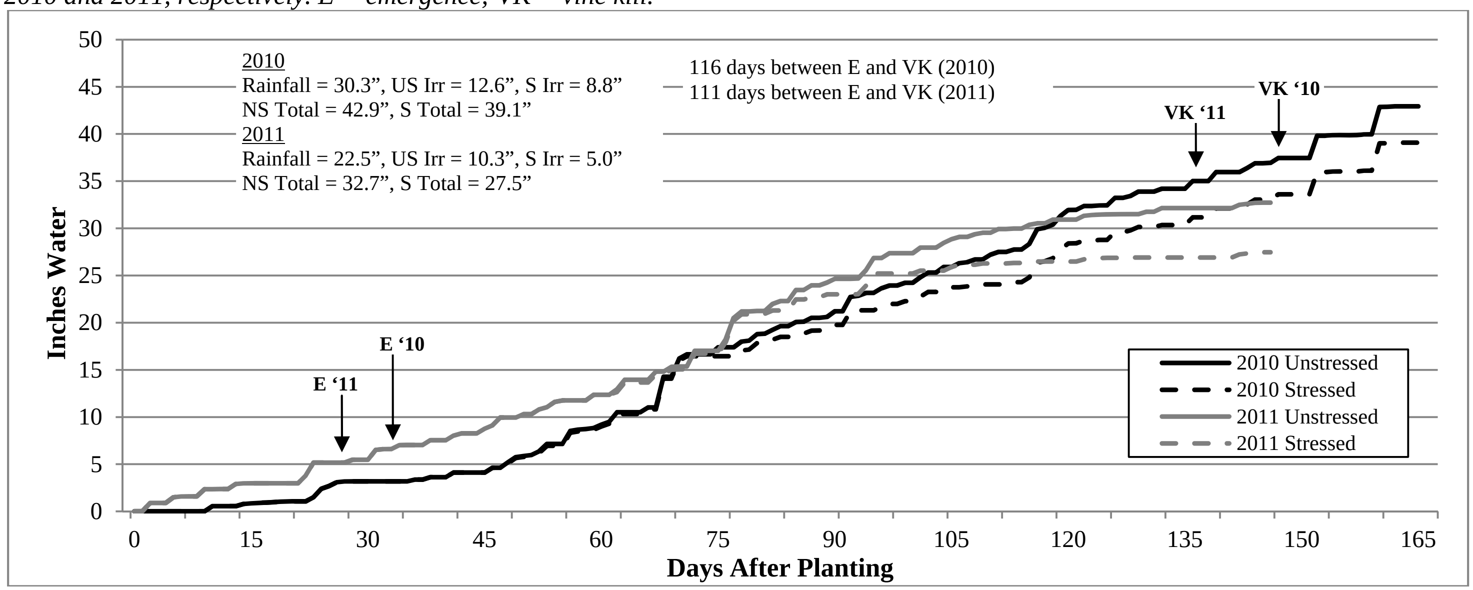


Table 2: Treatment means and significance of 2010 tuber yield and size distribution for the main effects of irrigation, nitrogen management strategy, and variety, as well as level of significance for the interactions.

Sources of Variation	Tuber Size Class										
	0-3 oz	3-6 oz	6-10 oz	10-14 oz	>14 oz	Total Yield	#1 > 3 oz	#2 > 3 oz	Total Marketable	> 6oz	> 10 oz
	CWT A^{-1}									%	
Irrigation											
Unstressed	56.8	165.0	199.0	77.9	34.2	533.0	386.3	90.0	476.2	57.3	20.4
Stressed	57.6	172.6	188.2	66.7	26.6	511.7	381.9	72.2	454.1	53.6	17.2
	NS[1]	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
N Management Strategy											
1 Low N (control) -- 30 lbs ac^{-1}	82.5a[2]	186.2a	128.4b	28.7b	4.2c	430.0d	278.4c	69.2b	347.6c	36.7b	7.3b
2 Medium N split -- 160 lbs ac^{-1}	55.5b	161.6b	207.3a	75.8a	30.4b	530.6c	400.9b	74.2b	475.1b	58.6a	19.6a
3 High N split -- 240 lbs ac^{-1}	51.2bc	165.1ab	205.4a	85.4a	45.2a	552.2ab	399.2b	101.9a	501.1a	60.4a	23.2a
4 High N split (+ surfactant) -- 240 lbs ac^{-1}	49.8bc	166.3ab	215.5a	88.3a	41.7ab	561.7a	410.3b	101.6a	511.9a	61.4a	23.0a
5 High N early -- 240 lbs ac^{-1}	47.1c	164.9ab	211.4a	83.4a	30.6b	537.4bc	431.7a	58.6b	490.3ab	60.1a	20.8a
	**	NS	**	**	**	**	**	**	**	**	**
Variety											
Russet Burbank	81.9	210.6	175.6	39.6	10.9	518.5	343.2	93.4	436.6	42.2	9.2
Alpine Russet	32.5	127.1	211.6	105.1	50.0	526.2	425.0	68.8	493.8	68.6	28.4
	**	**	**	**	**	NS	**	**	**	**	**
Interactions											
Irrigation x Variety	NS	++	++	**	**	NS	NS	NS	NS	++	**
N x Irrigation	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
N x Variety	**	NS	**	++	**	NS	++	**	**	NS	*
N x Irrigation x Variety	NS	*	*	NS	NS	NS	NS	NS	NS	*	NS

[1]Statistical significance: NS = non-significant; ++, *, ** = significant at 10%, 5%, and 1%, respectively.
[2]Treatment means with the same letter are not statistically different (alpha = 0.1).

Table 3: Treatment means and significance of 2011 tuber yield and size distribution for the main effects of irrigation, nitrogen management strategy, and variety, as well as level of significance for the interactions.

Sources of Variation	Tuber Size Class										
	0-3 oz	3-6 oz	6-10 oz	10-14 oz	>14 oz	Total Yield	#1 > 3 oz	#2 > 3 oz	Total Marketable	> 6oz	> 10 oz
	CWT A^{-1}									%	
Irrigation											
Unstressed	74.1	191.0	156.7	50.6	14.2	486.7	327.5	85.1	412.6	44.3	12.7
Stressed	89.6	185.4	103.4	17.1	1.9	397.4	282.6	25.3	307.9	29.9	4.6
	*[1]	NS	**	**	**	**	++	**	**	**	**
N Management Strategy											
1 Low N (control) -- 30 lbs ac^{-1}	102.0a[2]	186.0b	60.7c	5.3c	0.1b	354.1c	162.6b	89.5a	252.1c	17.9c	1.4c
2 Medium N split -- 160 lbs ac^{-1}	80.2b	216.3a	137.2b	31.1b	7.5a	472.2b	338.6a	53.5b	392.0a	36.3b	7.7b
3 High N split -- 240 lbs ac^{-1}	74.0b	183.4bc	160.9a	44.2a	11.0a	473.5b	349.8a	49.8b	399.5a	44.6a	11.0a
4 High N split (+ surfactant) -- 240 lbs ac^{-1}	79.9b	187.5b	146.7ab	44.4a	10.9a	469.4b	337.2a	52.3b	389.4a	41.8a	11.1a
5 High N early -- 240 lbs ac^{-1}	73.2b	168.1c	144.8b	44.3a	10.9a	441.2a	337.0a	31.0c	368.0b	44.7a	12.0a
	**	**	**	**	**	**	**	**	**	**	**
Variety											
Russet Burbank	104.6	206.1	106.0	19.4	2.5	438.7	293.4	40.7	334.1	27.7	4.5
Alpine Russet	59.1	170.3	154.1	48.3	13.6	445.4	316.7	69.7	386.4	46.5	12.8
	**	**	**	**	**	NS	**	**	**	**	**
Interactions											
Irrigation x Variety	NS	**	NS	**	**	NS	NS	NS	NS	**	**
N x Irrigation	NS	**	NS	*	**	NS	NS	**	NS	NS	++
N x Variety	NS	**	NS	**	**	NS	*	**	NS	++	**
N x Irrigation x Variety	NS	NS	NS	**	**	NS	NS	NS	NS	NS	**

[1]Statistical significance: NS = non-significant; ++, *, ** = significant at 10%, 5%, and 1%, respectively.
[2]Treatment means with the same letter are not statistically different (alpha = 0.1).

Table 4: Treatment means and significance of 2010 tuber quality for the main effects of irrigation, nitrogen management strategy, and variety, as well as level of significance for the interactions.

Sources of Variation	Tuber Quality		Zero Month Frying Quality							
			Stem				Bud			
	Hollow Heart (%)	Specific Gravity	Chip Color	AGT Score	Sucrose ($mg\ g^{-1}$)	Glucose ($mg\ g^{-1}$)	Chip Color	AGT Score	Sucrose ($mg\ g^{-1}$)	Glucose ($mg\ g^{-1}$)
Irrigation										
Unstressed	1.80	1.075	3.30	46.9	1.44	2.98	2.53	54.6	2.60	0.37
Stressed	1.00	1.073	3.20	48.0	1.59	3.00	2.30	55.3	2.64	0.38
	NS[1]	NS	++	*	NS	NS	++	NS	NS	NS
N Management Strategy										
1 Low N (control) -- 30 lbs ac^{-1}	0.00b[2]	1.075	3.50	44.1b	2.00a	4.13a	2.94a	50.9b	3.22a	0.60a
2 Medium N split -- 160 lbs ac^{-1}	0.00b	1.074	3.13	48.5a	1.50b	2.63b	2.19b	56.5a	2.48b	0.49ab
3 High N split -- 240 lbs ac^{-1}	2.25a	1.073	3.13	48.5a	1.29b	2.76b	2.38b	55.6a	2.45b	0.22c
4 High N split (+ surfactant) -- 240 lbs ac^{-1}	2.25a	1.073	3.25	48.3a	1.22b	2.83b	2.25b	56.5a	2.31b	0.21c
5 High N early -- 240 lbs ac^{-1}	2.50a	1.075	3.25	47.9a	1.57b	2.60b	2.31b	55.2a	2.62b	0.34bc
	**	NS	NS	*	*	**	**	**	*	**
Variety										
Russet Burbank	2.80	1.076	3.35	46.2	1.14	3.56	2.43	54.7	1.94	0.30
Alpine Russet	0.00	1.072	3.15	48.7	1.89	2.42	2.40	55.2	3.30	0.44
	**	**	*	**	**	**	NS	NS	**	*
Interactions										
Irrigation x Variety	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
N x Irrigation	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
N x Variety	**	NS	NS	NS	++	NS	NS	NS	**	NS
N x Irrigation x Variety	NS	NS	NS	NS	NS	NS	*	NS	NS	NS

Sources of Variation	Six Month Frying Quality								Stand/Stem Count	
	Stem				Bud					
	Chip Color	AGT Score	Sucrose ($mg\ g^{-1}$)	Glucose ($mg\ g^{-1}$)	Chip Color	AGT Score	Sucrose ($mg\ g^{-1}$)	Glucose ($mg\ g^{-1}$)	Stand	Stems per Plant
Irrigation										
Unstressed	4.18	36.8	0.84	5.46	3.68	43.1	1.62	0.97	96.5	3.17
Stressed	4.25	36.2	1.01	5.01	3.63	43.2	1.76	0.93	95.9	3.12
	NS[1]	NS	NS	NS	NS	NS	NS	NS	NS	NS
N Management Strategy										
1 Low N (control) -- 30 lbs ac^{-1}	4.56a[2]	34.1b	0.97	6.56a	4.00a	39.9c	1.71	1.36a	96.8	3.27
2 Medium N split -- 160 lbs ac^{-1}	4.19b	36.9a	0.89	5.26b	3.88ab	42.4b	1.68	1.00b	96.1	3.18
3 High N split -- 240 lbs ac^{-1}	4.00b	37.3a	0.91	4.65b	3.44c	44.8a	1.74	0.61c	96.0	3.06
4 High N split (+ surfactant) -- 240 lbs ac^{-1}	4.13b	36.4a	0.93	4.72b	3.31c	44.9a	1.68	0.82bc	95.2	3.10
5 High N early -- 240 lbs ac^{-1}	4.19b	37.7a	0.94	4.96b	3.63bc	43.8ab	1.63	0.97b	96.9	3.10
	*	*	NS	**	**	**	NS	*	NS	NS
Variety										
Russet Burbank	4.20	36.4	0.50	5.62	3.48	44.6	1.44	0.59	98.7	3.69
Alpine Russet	4.23	36.6	1.36	4.85	3.83	41.7	1.94	1.32	93.7	2.60
	NS	NS	**	**	**	**	**	**	**	**
Interactions										
Irrigation x Variety	NS	NS	NS	NS	*	*	NS	NS	NS	NS
N x Irrigation	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
N x Variety	NS	*	*	NS	NS	NS	NS	NS	NS	NS
N x Irrigation x Variety	NS	NS	*	NS	NS	NS	NS	NS	NS	*

[1]Statistical significance: NS = non-significant; ++, *, ** = significant at 10%, 5%, and 1%, respectively.

[2]Treatment means with the same letter are not statistically different (alpha = 0.1).

Table 5: Treatment means and significance of 2011 tuber quality for the main effects of irrigation, nitrogen management strategy, and variety, as well as level of significance for the interactions.

Sources of Variation	---- Tuber Quality ----		Zero Month Frying Quality								Stand & Stem Count	
			Stem				Bud					
	Hollow Heart (%)	Specific Gravity	Chip Color	AGT Score	Sucrose (mg g^{-1})	Glucose (mg g^{-1})	Chip Color	AGT Score	Sucrose (mg g^{-1})	Glucose (mg g^{-1})	Stand	Stems per Plant
Irrigation												
Unstressed	2.10	1.076	3.03	48.9	0.75	3.73	2.85	51.9	1.87	0.52	95.6	3.63
Stressed	0.30	1.080	2.83	50.8	1.72	2.47	2.43	54.6	2.26	0.44	95.1	3.79
	NS[1]	**	NS	NS	**	**	++	++	**	NS	NS	NS
N Management Strategy												
1 Low N (control) -- 30 lbs ac^{-1}	0.0	1.073c[2]	3.13a	47.6a	1.64a	4.50a	3.00a	49.2d	2.58a	0.79a	95.5	3.39b
2 Medium N split -- 160 lbs ac^{-1}	0.5	1.078ab	3.00a	48.4a	1.43a	3.31b	2.69b	53.4c	2.13b	0.38b	95.5	3.74a
3 High N split -- 240 lbs ac^{-1}	2.5	1.081a	2.94ab	51.1b	1.10b	2.26cd	2.38c	55.4a	1.94bc	0.41b	95.3	3.74a
4 High N split (+ surfactant) -- 240 lbs ac^{-1}	2.5	1.079ab	2.88ab	51.1b	1.00b	2.46cd	2.50bc	54.7ab	1.68c	0.33b	94.5	3.72a
5 High N early -- 240 lbs ac^{-1}	0.5	1.078b	2.69b	51.2b	1.02b	2.98bc	2.63bc	53.7bc	1.99b	0.49b	95.9	3.94a
	NS	**	++	**	**	**	*	**	**	**	NS	++
Variety												
Russet Burbank	2.30	1.079	3.13	48.0	1.05	3.90	2.68	52.8	1.57	0.41	99.2	4.18
Alpine Russet	0.10	1.077	2.73	51.8	1.43	2.31	2.60	53.7	2.55	0.55	91.5	3.23
	*	NS	**	**	**	**	NS	NS	**	*	**	**
Interactions												
Irrigation x Variety	++	NS	NS	NS	*	NS	NS	NS	NS	NS	NS	NS
N x Irrigation	NS	NS	NS	NS	++	++	NS	NS	NS	NS	NS	NS
N x Variety	NS	NS	NS	NS	++	NS	++	NS	**	NS	NS	NS
N x Irrigation x Variety	NS	NS	NS	NS	++	NS	NS	NS	NS	NS	NS	NS

[1]Statistical significance: NS = non-significant; ++, *, ** = significant at 10%, 5%, and 1%, respectively.

[2]Treatment means with the same letter are not statistically different (alpha = 0.1).

Table 6: Treatment means and significance of 2010 petiole NO_3-N, leaf total N, and SPAD relative chlorophyll for the main effects of irrigation, nitrogen management strategy, and variety, as well as level of significance for the interactions.

Sources of Variation	Petiole NO_3-N (ppm)				Leaf N (%)				SPAD Relative Chlorophyll			
	6/15/2010	7/1/2010	7/13/2010	8/5/2010	6/15/2010	7/1/2010	7/13/2010	8/5/2010	6/15/2010	7/1/2010	7/13/2010	8/5/2010
Irrigation												
Unstressed	10421	2600	1998	1548	5.49	3.94	3.74	3.76	39.2	35.8	34.2	31.7
Stressed	12161	2595	2205	1583	5.69	3.91	3.83	3.60	39.4	35.7	34.6	32.2
	*[1]	NS	NS	NS	++	NS	NS	NS	NS	NS	NS	NS
N Management Strategy												
1 Low N (control) -- 30 lbs ac^{-1}	1765c[2]	337d	266d	181c	4.15c	3.12d	3.01c	2.93d	36.4c	28.2d	25.1c	22.0d
2 Medium N split -- 160 lbs ac^{-1}	12414b	2132c	2088b	1555b	5.74b	3.96c	3.87b	3.75b	39.6b	36.3c	35.1b	32.9b
3 High N split -- 240 lbs ac^{-1}	12877b	3105b	3451a	2995a	5.73b	4.11b	4.19a	4.23a	40.0ab	37.5b	37.4a	37.0a
4 High N split (+ surfactant) -- 240 lbs ac^{-1}	12678b	2803bc	3526a	2639a	5.84b	4.06bc	4.07a	4.13a	39.7ab	37.9ab	37.5a	36.8a
5 High N early -- 240 lbs ac^{-1}	16722a	4610a	1178c	457c	6.49a	4.36a	3.79b	3.37c	40.8a	38.7a	36.9a	31.1c
	**	**	**	**	**	**	**	**	**	**	**	**
Variety												
Russet Burbank	11081	3397	2432	2219	5.64	4.24	3.91	3.94	37.3	34.5	33.8	32.4
Alpine Russet	11501	1798	1771	911	5.54	3.61	3.67	3.42	41.3	37.0	35.1	31.5
	NS	*	**	**	**	**	**	**	**	**	**	NS
Interactions												
Irrigation x Variety	++	*	NS	NS	NS	NS	NS	NS	NS	*	NS	NS
N x Irrigation	NS	NS	NS	NS	NS	NS	NS	*	NS	NS	NS	++
N x Variety	NS	**	**	**	NS	NS	**	NS	**	NS	NS	**
N x Irrigation x Variety	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

[1]Statistical significance: NS = non-significant; ++, *, ** = significant at 10%, 5%, and 1%, respectively.
[2]Treatment means with the same letter are not statistically different (alpha = 0.1).

Table 7: Treatment means and significance of 2011 petiole NO_3-N, leaf total N, and SPAD relative chlorophyll for the main effects of irrigation, nitrogen management strategy, and variety, as well as level of significance for the interactions.

Sources of Variation	Petiole NO_3-N (ppm)					SPAD Relative Chlorophyll				
	6/23/2011	7/7/2011	7/19/2011	7/28/2011	8/11/2011	6/23/2011	7/7/2011	7/19/2011	7/28/2011	8/11/2011
Irrigation										
Unstressed	11654	3553	4623	2493	2392	37.3	35.7	34.5	34.0	33.0
Stressed	12549	2966	3432	2813	1038	37.5	35.0	34.1	33.4	29.6
	NS[1]	NS	NS	NS	**	NS	NS	NS	NS	NS
N Management Strategy										
1 Low N (control) -- 30 lbs ac^{-1}	841d[2]	262d	261c	84c	82d	33.6c	28.9d	27.3c	29.1c	22.1d
2 Medium N split -- 160 lbs ac^{-1}	10895c	1349c	2053b	1370b	969c	37.8b	34.3c	33.8b	34.6ab	30.2c
3 High N split -- 240 lbs ac^{-1}	15018b	3958b	5970a	4512a	3889a	38.7a	37.2b	37.0a	36.5a	36.0a
4 High N split (+ surfactant) -- 240 lbs ac^{-1}	15158b	4243b	5693a	4729a	3139b	38.4ab	38.0ab	36.6a	33.2b	35.8a
5 High N early -- 240 lbs ac^{-1}	18595a	6485a	6161a	2570b	495cd	38.6ab	38.5a	36.9a	35.1ab	32.4b
	**	**	**	**	**	**	**	**	**	**
Variety										
Russet Burbank	11948	3851	4881	3263	1695	36.1	34.5	33.2	33.1	31.3
Alpine Russet	12255	2668	3174	2043	1734	38.7	36.3	35.4	34.3	31.3
	NS	**	**	**	NS	**	**	**	NS	NS
Interactions										
Irrigation x Variety	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
N x Irrigation	NS	NS	NS	NS	**	NS	NS	NS	NS	**
N x Variety	NS	NS	*	*	NS	**	**	NS	NS	**
N x Irrigation x Variety	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

[1]Statistical significance: NS = non-significant; ++, *, ** = significant at 10%, 5%, and 1%, respectively.
[2]Treatment means with the same letter are not statistically different (alpha = 0.1).

Figure 3: Coefficient of determination (r^2) plotted versus wavelength for the relationship between leaf total N and canopy reflectance as well as leaf total N and derivative reflectance at all AISA Eagle wavelengths for the Russet Burbank variety on the 1 July 2010 flyover.

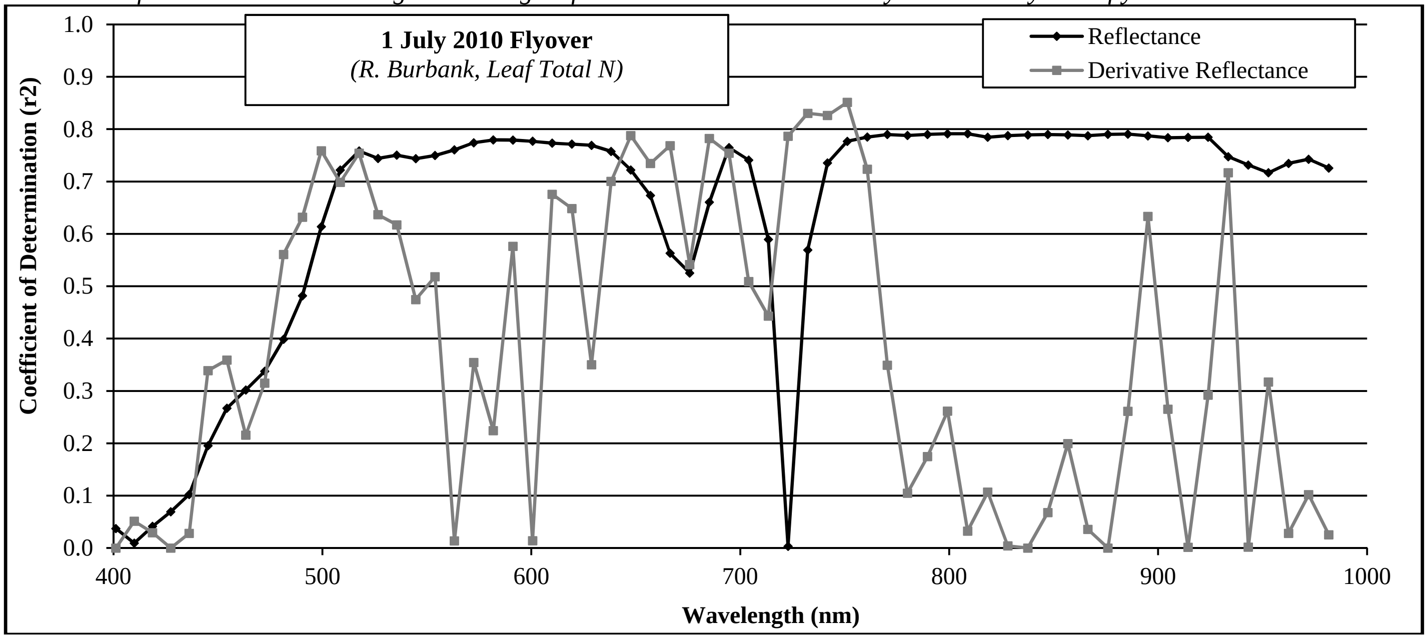


Table 8: Published indices evaluated in the preliminary analysis.

Index	Equation	Reference
GNDVI	(R801 - R550)/(R801 + R550)	Daughtry et al. (2000)
NDI1	(R780 - R710)/(R780 - R680)	Datt (1999)
NDVI	(R800 - R680)/(R800 + R680)	Lichtenthaler et al. (1996)
OSAVI	(1 + 0.16)(R800 - R670)/(R800 + R670 + 0.16)	Rondeaux et al. (1996)
SR8	R860/(R550 * R708)	Datt (1998)
TCARI	3 * [(R700-R670) - 0.2 * (R700-R550) * (R700/R670)]	Haboudane et al. (2002)
TCARI(705, 750)	3 * [(R750-R705) - 0.2 * (R750-R550) * (R750/R705)]	Wu et al. (2008)
TCARI/OSAVI	TCARI/OSAVI	Haboudane et al. (2002)

Table 9: Coefficient of determination (r^2) values of tested indices/wavelengths for each tissue sample, variety, and flyover date from 2010 hyperspectral imagery; shaded boxes highlight the r^2 value of the best performing index for each scenario.

Index	Petiole NO_3-N		Leaf Total N	
	RB	AR	RB	AR
1 July 2010				
SR8	0.69	0.46	0.79	0.74
NDI1	0.64	0.41	0.82	**0.80**
TCARI (R751)	**0.73**	0.52	0.77	0.70
Slope at 509nm	0.53	0.39	0.70	0.55
Derivative (751nm)	0.69	0.48	**0.85**	0.80
Derivative (761nm)	0.59	**0.54**	0.72	0.73
6 August 2010				
SR8	**0.63**	0.52	**0.68**	**0.72**
NDI1	0.49	0.39	0.58	0.63
TCARI (R751)	0.02	0.09	0.07	0.01
Derivative (509nm)	0.45	**0.54**	0.31	0.71
Derivative (751nm)	0.38	0.33	0.48	0.51
Derivative (761nm)	0.47	0.37	0.54	0.50

Figure 4: Derivative reflectance image at 751 nm on 1 July 2010. The labels on the left refer to the N management strategies in the plots furthest to the left. (Note: the variety sub-sub plot is included in each N management strategy sub plot)

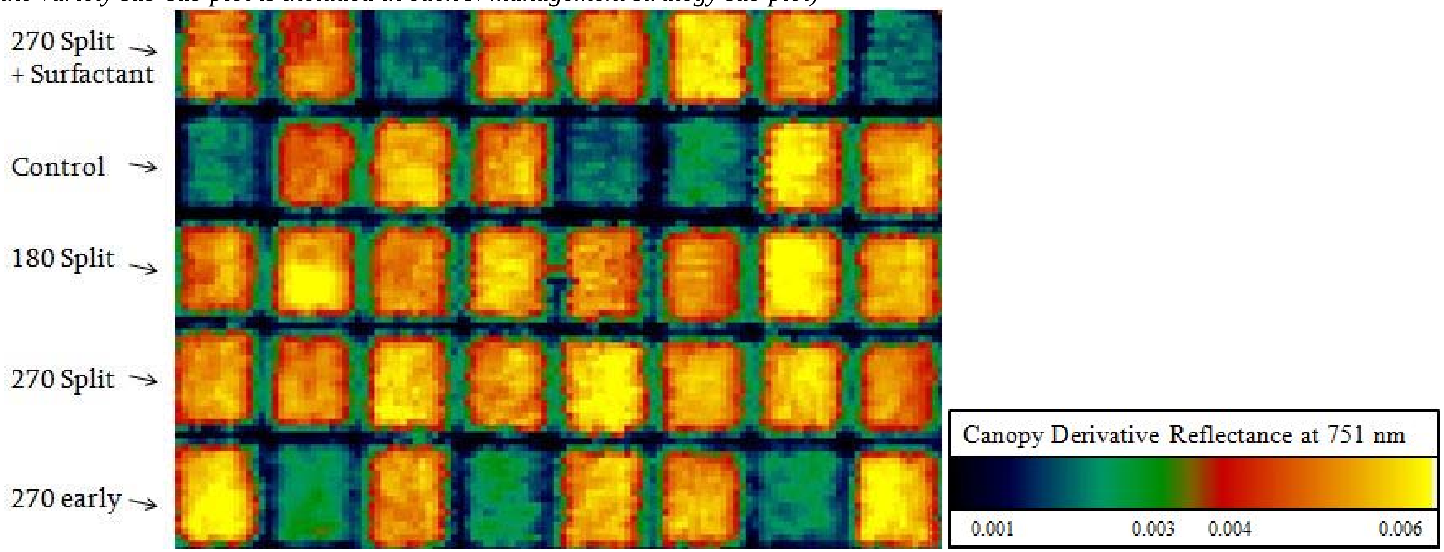


Figure 5: Thermal image 6 August 2010. The labels and dashed boxes refer to the whole plot irrigation treatments (blue = unstressed, red = stressed). (Note: the N sub plots and the variety sub-sub plots are included in each irrigation whole plot)

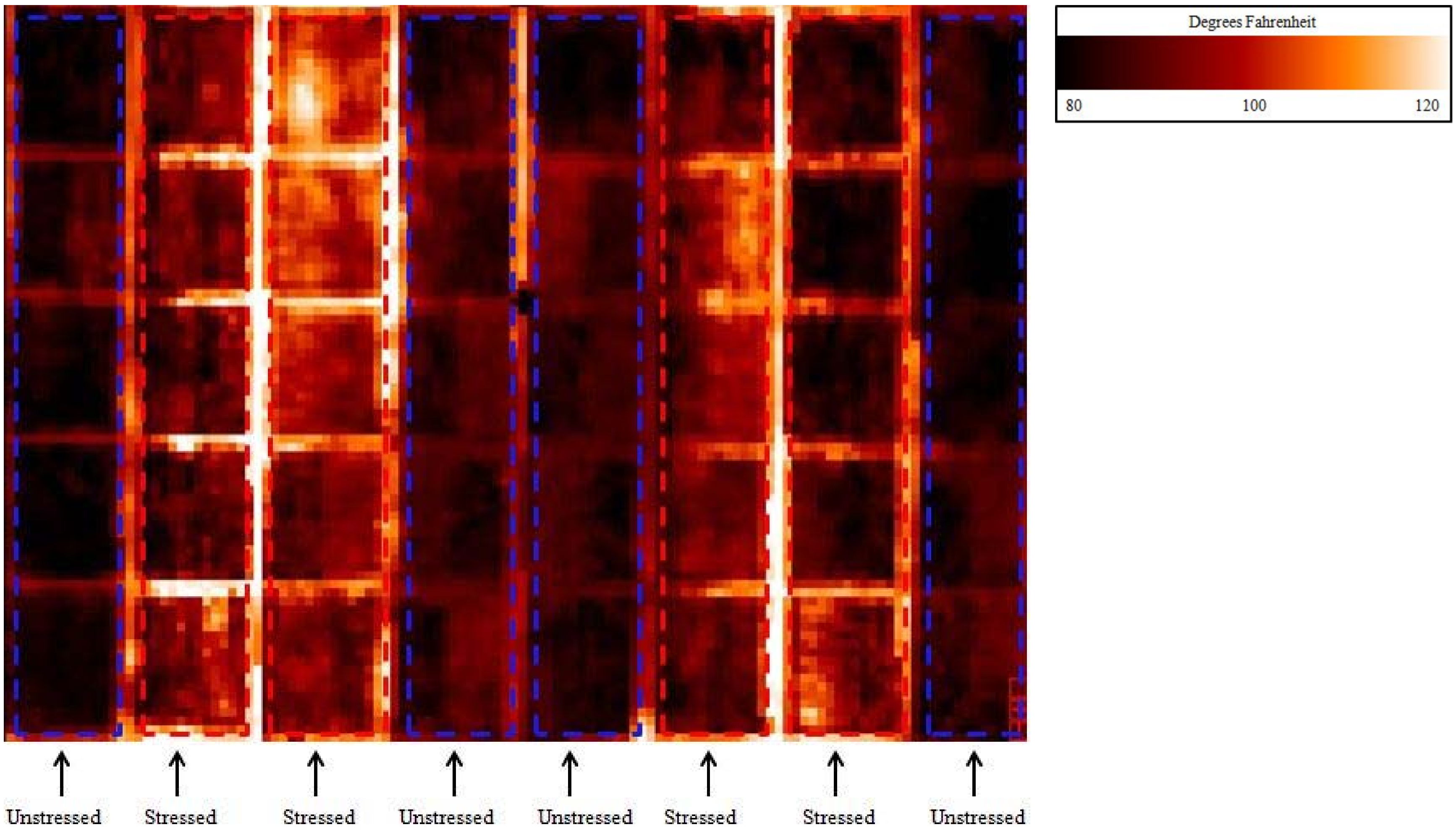
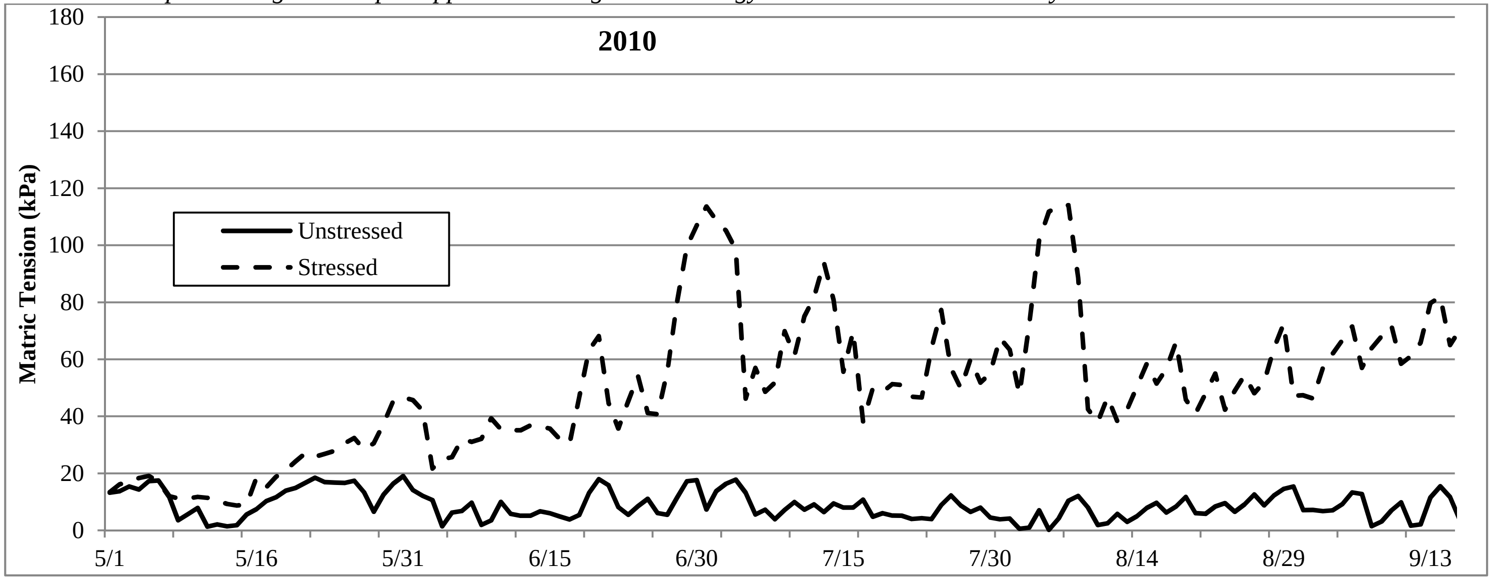
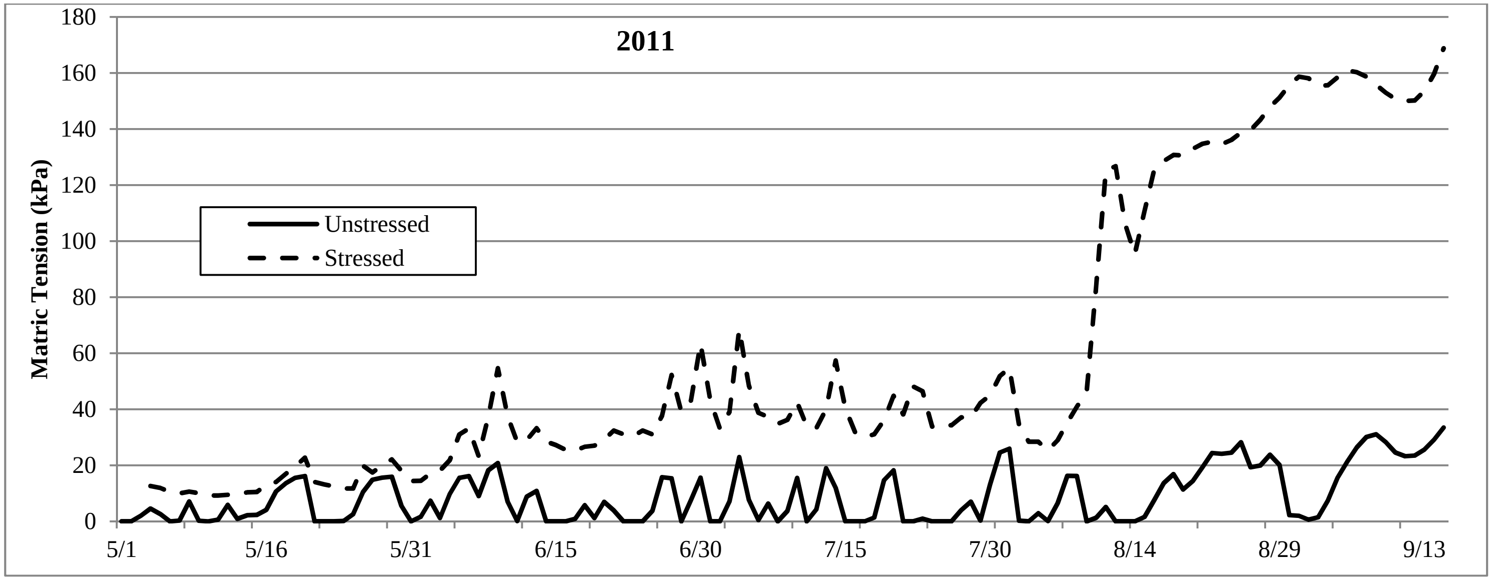


Figure 6a, 6b: Effect of water stress on soil matric tension in the root zone through the 2010 and 2011 growing season (5a and 5b, respectively). Data is from the 240 lb ac^{-1} rate with post-emergence N split-applied N management strategy and Russet Burbank variety.

6a:



6b:



Comparison of Dealer Grade ESN and Airboom Damaged ESN Used as Nitrogen Sources in Irrigated Potato Production

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Summary: A field experiment was conducted at the Sand Plain Research Farm in Becker, MN to evaluate differences in N release rates and tuber yield and quality between dealer grade ESN and damaged ESN collected from airboom deflector plates. Airboom ESN lost 23% of its weight during a 24 hour water test while dealer grade ESN lost 12% of its weight. Four N treatments were examined, all of which included the equivalent of 30 lb N/A in a starter blend. There of 240 lb N/A using different N sources. The was a starter only control and three treatments that received a total of 240 lb N/A, which included: 1) 105 lb N/A from urea applied at emergence + 105 lb N/A from UAN split between 5 post-hilling applications, 2) 210 lb N/A from airboom damaged ESN applied at emergence [ESN(A)], and 3) 210 lb N/A from dealer grade ESN applied at emergence [ESN(C)]. Nitrogen release was more rapid from the airboom damaged ESN source than from the dealer grade ESN source. The difference was greatest in the first three days, when ESN(A) released 36% of its N and ESN(C) released 17%. This difference gradually narrowed until 77 days after planting, when both ESN sources had released 97.7% of their N. The two ESN sources had nearly identical total and marketable yields and similar size distribution. Tuber yield and size were not significantly different than the conventional fertilizer treatment with the same N rate from urea + UAN. There was a trend for ESN(C) to have more tubers greater than 10 oz in size than ESN(A) and urea + UAN, which may have accounted for it having significantly greater incidence of hollow heart and brown center. ESN(A) had significantly greater petiole nitrate-N concentrations than ESN(C) on the first sampling date on June 20, probably due to its more rapid N release. The two ESN sources had similar nitrate-N concentrations during the remainder of the growing season. The conventional urea + UAN treatment also had significantly greater petiole nitrate-N than ESN(C) on the first sampling date. It had significantly lower concentrations than both ESN sources for the second date on June 28, but was similar to them on the last two dates. Leaching rainfall in 2011 occurred after most of the N was released from either ESN source, which likely explains the lack of yield differences in this study between the two sources.

Background: This study is a continuation of research conducted over a seven-year period on enhanced efficiency N fertilizers – primarily polymer coated urea. While plot research results have been quite positive with ESN, a polymer coated controlled release N fertilizer manufactured by Agrium, responses from on-farm grower trials are sometimes less favorable. One possible reason for these differences is increased abrasion of the ESN polymer coating in grower trials, particularly when the product is applied with air boom spreaders. Abrasion damage to prills results in faster N release (up to 56% release after 24 h in laboratory water tests), negating some of the enhanced efficiency benefits. In this current potato response study, we compared ESN collected from the deflector plates of an airboom spreader [ESN(A)] to the dealer grade ESN that we have used in earlier trials [ESN(C)]. This was the second year of field research comparing these ESN sources of differing quality.

The objectives of this study were, under field conditions, to: 1) compare N release rates from dealer grade ESN with ESN collected from an air boom spreader on potato yield and quality, and 2) compare the effects of these ESN sources on potato yield and quality.

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, 6.3; organic matter, 2.1%; Bray P1, 71 ppm; ammonium acetate extractable K, Ca, and Mg, 172, 795, and 145 ppm, respectively; Ca-phosphate extractable SO_4-S, 3.5 ppm; hot water extractable B, 0.3; and DTPA extractable Zn, Cu, Fe, and Mn, 1.9, 1.1, 36.5, and 10.5 ppm, respectively. Extractable nitrate-N and ammonium-N in the top 2 ft of soil were 7.1 and 13.8 lb/A, respectively.

Prior to planting, 250 lb/A 0-0-60 and 250 lb/A 0-0-22 were broadcast and incorporated with a moldboard plow. Four, 20-ft rows were planted for each plot with the middle two rows used for sampling and harvest. Whole "B" seed of Russet Burbank potatoes were hand planted in furrows on May 3, 2011. 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 was applied in-furrow 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.

There were four N fertilizer treatments as described in Table 1 below. All treatments received 30 lb N/A in a starter blend. There was a starter only control and three treatments that received a total of 240 lb N/A using different N sources. One of these received a combination of urea and UAN to supply the majority of their N. The other two received most of their N from ESN. These treatments had equivalent total N and ESN rates, but the ESN sources were different. ESN(A) had air boom damage to the coating based on the 24 hour water test where prills lost 23% of their weight and ESN(C) was a dealer grade control that had not passed through the deflector plates of an air boom spreader and lost 12% of their weight during the 24 hour water test.

The 30-lb N/A application at planting as MAP and ammonium sulfate was banded 3 inches to each side and 2 inches below the seed piece using a metered, drop fed applicator. For all treatments, the banded fertilizer at planting included 130 lb P_2O_5/A, 181 lb K_2O/A, 20 lb Mg/A, 46 lb S/A, 3.3 lb B/A, and 5.6 lb Zn/A applied as a blend of monoammonium phosphate, ammonium sulfate, potassium chloride, potassium magnesium sulfate, boric acid, and zinc oxide. Emergence N applications were supplied as urea and ESN and mechanically incorporated during hilling. Post-hilling N was applied over the row with a tractor-mounted sprayer as a 28% UAN solution in 25 gal of water/A. The tractor traveled in the irrigation alleys to prevent damage to the crop. Irrigation was applied immediately following application of UAN to simulate fertigation with an overhead irrigation system. Emergence fertilizer was applied on May 25 and post-hilling N was applied on June 9, June 27, July 11, July 20, and July 28.

Measured amounts of ESN(A) and ESN(C) fertilizer were placed in plastic mesh bags and buried at the same depth as emergence fertilizer placement on May 11. Bags were removed on May 14, May 18, May 25, June 2, June 8, June 15, June 30, July 23, Aug 21, and Sept 11. Remaining amounts of fertilizer were measured on each date to track N release over time. Plant stands were measured on June 2 and stem number per plant on June 8. Petiole samples were collected from the 4th leaf from the terminal on four dates:

June 20, June 28, July 11, and July 26. Petioles were analyzed for nitrate-N on a dry weight basis.

Vines were harvested on Sept 23 from two, 10-ft sections of row, followed by mechanically beating the vines over the entire plot area. Plots were machine harvested on Sept 29 and total tuber yield and graded yield were measured. Sub-samples of vines and tubers were collected to determine moisture percentage and N concentrations, which were then used to calculate N uptake and distribution within the plant (Note: all the data for N uptake were not available at the time of this report and therefore will be presented at a later time). Tuber sub-samples were also used to determine tuber specific gravity and the incidence of hollow heart, brown center, and scab.

Table 1. Nitrogen treatments tested on irrigated Russet Burbank potatoes.

Trtmt #	----------------------------------- N timing -----------------------------------			
	Planting	Emergence/Hilling	Post-hilling[1]	Total N
	--------------------- N sources[2] and N rates (lb N/A) ---------------------			
1	30 MAP+AS	0	0	30
2	30 MAP+AS	105 Urea	105 UAN	240
3	30 MAP+AS	210 ESN(A)	0	240
4	30 MAP+AS	210 ESN(C)	0	240

[1]Post-hilling N was applied 5 times at 8-18 day intervals.
[2]MAP = monoammonium phosphate (10-50-0), AS = ammonium sulfate (21-0-=0), Urea = 46-0-0, UAN = urea and ammonium nitrate (28-0-0), ESN(A) = Environmentally Smart Nitrogen (airboom damaged) (44-0-0), ESN(C) = Environmentally Smart Nitrogen (dealer grade control) (44-0-0).

Results

Nitrogen release from ESN: Release curves of N from the two ESN fertilizer sources are presented in Fig. 1. N release was more rapid from the airboom damaged source [ESN(A)] than from the dealer grade control source [ESN(C)], indicating that abrasion of the polymer coating does occur during the process of controlled release fertilizer application with airboom spreaders. The difference in N release was greatest in the first three days following application, when ESN(A) released 36% of its N and ESN(C) released 17%. Maximum N uptake by Russet Burbank potatoes generally occurs between 40 and 80 days after planting. ESN(A) released about 70% of its N by day 40 (18 days after application) and 95% by day 80 (58 days after application). ESN(C) had released about 55% of its N by day 40, but by day 80 it had released nearly as much N (about 93%) as ESN(A). N release from the two sources converged 95 days after planting at 97.7%. N release from both ESN sources was consistent with the period of greatest N demand for Russet Burbank potatoes, but the faster N release from ESN(A) could result in greater N losses if leaching rainfall occurred early in the growing season. Differences in N release were less than those observed in a similar experiment in 2010, when ESN(A) released 60% of its N in the first eight days following application and ESN(C) released only 12%. This was consistent with differences in N release after 24 h in laboratory water tests between the two years, which showed greater damage to the ESN collected from airboom spreaders collected in 2010 than in 2012.

Tuber yield and size distribution: Table 2 shows the effects of N source and ESN quality on tuber yield and size distribution. As expected, the treatment that received only 30 lb N/A from MAP at planting had significantly lower total and marketable yields, and a significantly greater proportion of tubers less than 6 oz in size, than the three treatments receiving total N rates of 240 lb/A. The two ESN treatments had numerically greater total and marketable yields than the conventional urea + UAN treatment, due to greater yields of tubers larger than 6 oz, but none of these differences were statistically significant. The airboom damaged [ESN(A)] and dealer grade control [ESN(C)] sources of ESN had nearly identical total and marketable yields and similar size distribution. ESN(C) tended to have more large tubers (greater than 10 oz), but the difference was not significant. The absence of significant yield differences between the two ESN sources was similar to results in 2010, although last year yields for ESN(C) were numerically 8.5% greater than ESN(A) yields.

Tuber Quality and Tuber Dry Matter: The dealer grade ESN(C) had significantly greater incidence of hollow heart and brown center than any of the other treatments (Table 3). This may have been due to ESN(C) having the numerically highest percentage of tubers in the greater than 10 oz size class (Table 2). Incidence of scab was low for all treatments (Table 3). The 30 lb N/A control treatment had significantly lower specific gravity than all of the other treatments. It also had the lowest tuber dry matter percentage, but this difference was not significant. Specific gravity and tuber dry matter were similar for the two ESN treatments and the conventional urea + UAN treatment.

Petiole Nitrate-N Concentrations: The 30 lb N/A control treatment had significantly lower petiole nitrate-N concentrations than the three treatments receiving 240 lb N/A on all four sampling dates (Table 4). ESN(A) had significantly greater nitrate-N concentrations than ESN(C) on the first sampling date. This was consistent with the slightly greater N release on this date, which was 62 days after planting, from the airboom damaged ESN than from the dealer grade control (Fig. 1). The conventional urea + UAN treatment also had significantly greater petiole nitrate-N than ESN(C) on the first sampling date. The two ESN sources had similar nitrate-N concentrations on the last three sampling dates, which was consistent with their similar yields (Table 2). The conventional urea + UAN treatment had significantly lower nitrate-N concentrations than either of the ESN treatments on the second sampling date. This was the only instance where any of the 240 lb N/A treatments were below the recommended sufficiency range. One of the post-hilling applications of UAN was the day before the second sampling date, so the full effect of this N application had probably not taken place at the time these petioles were collected. On the last two sampling dates, the urea + UAN treatment had petiole nitrate-N concentrations that were similar to the two ESN treatments.

Conclusions

Nitrogen release was more rapid from the airboom damaged ESN(A) source than from the dealer grade ESN(C) source, although the difference was less than found in a similar experiment in 2010. The difference was greatest in the first three days, when ESN(A) released 36% of its N and ESN(C) released 17%. At 95 days after planting, the two ESN sources had released the same amount of N (97.7%). Faster N release from ESN(A) increased the potential for N losses if leaching rainfall occurred early in the growing season. However in 2011, most of the significant leaching occurred later in the growing season. More rapid N release probably accounted for significantly higher petiole nitrate-N concentrations for ESN(A) than ESN(C) on the first sampling date on June 20, but nitrate-N concentrations were similar the rest of the growing season and there were no significant differences between the two ESN sources in total or marketable tuber yield. Total and marketable yield with ESN were similar to yields for the conventional urea + UAN nitrogen source. ESN(C) had significantly greater incidence of hollow heart and brown center than all the other treatments. This was probably due to a higher proportion of tubers greater than 10 oz in size, although it wasn't significantly higher than ESN(A) or urea + UAN.

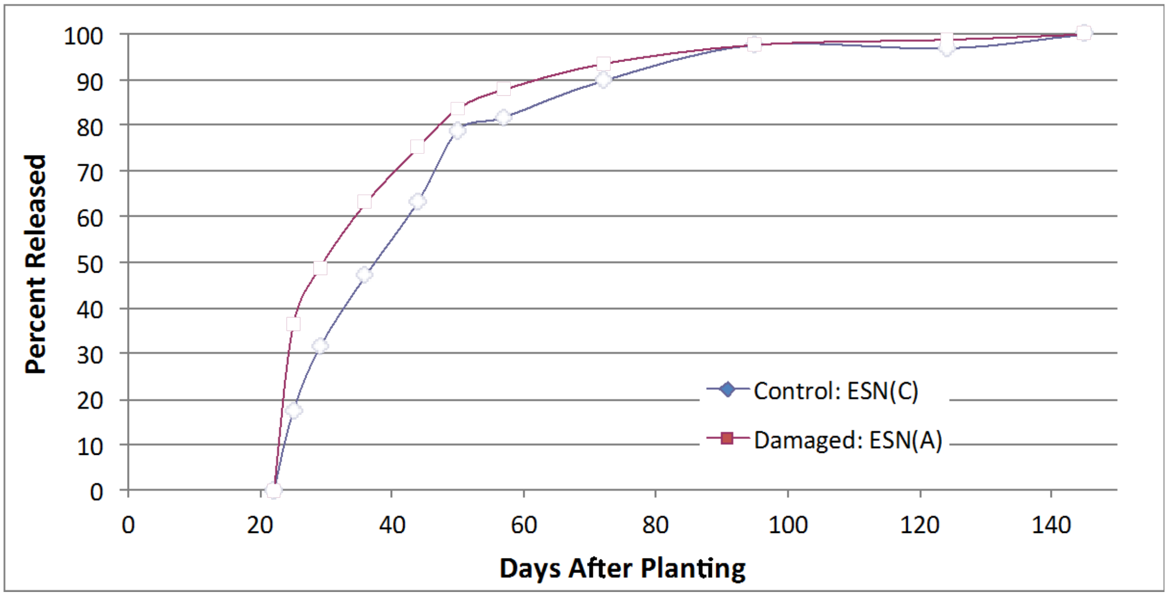

Fig. 1. Nitrogen release from Dealer Grade Control and Airboom Damaged ESN fertilizers applied at emergence.

Table 2. Effect of nitrogen source and quality of ESN fertilizer on Russet Burbank tuber yield and size distribution

Nitrogen Treatments				Tuber Yield										
Trtmt #	N Source[1]	N Rate	N Timing[2]	0-3 oz	3-6 oz	6-10 oz	10-14 oz	>14 oz	Total	#1 > 3 oz	#2 > 3 oz	Total Marketable	> 6 oz	> 10 oz
		lb N / A	P, E, PH	---------- cwt / A ----------									------ % ------	
1	MAP+AS	30	30, 0, 0	141.0	231.1	56.6	1.1	0.0	429.8	232.2	56.6	288.8	12.9	0.3
2	MAP+AS, Urea, UAN	240	30, 105, 105	100.1	217.9	129.2	36.6	9.3	493.0	313.6	79.3	392.9	35.5	9.3
3	MAP+AS, ESN(A)	240	30, 210, 0	101.2	200.4	162.8	38.0	11.6	514.1	315.8	97.1	412.8	41.2	9.6
4	MAP+AS, ESN(C)	240	30, 210, 0	102.4	208.3	139.4	50.5	14.4	515.0	315.9	96.7	412.6	39.6	12.6
Significance[3]				**	NS	*	**	*	*	*	++	**	*	**
LSD (0.10)				17.6	--	65.1	21.7	6.6	45.9	59.6	30.7	45.6	13.7	4.5

[1]MAP = monoammonium phosphate (10-50-0), AS = ammonium sulfate (21-0-0), Urea = 46-0-0, UAN = urea and ammonium nitrate (28-0-0), ESN(A) = Environmentally Smart Nitrogen (air boom damaged) (44-0-0), ESN(C) = Environmentally Smart Nitrogen dealer grade control) (44-0-0).

[2]P = planting, E = emergence/hilling, PH = post-hilling (5 applications).

[3]NS = Non significant; ++, *, ** = Significant at 10%, 5%, and 1%, respectively.

Table 3. Effect of nitrogen source and quality of ESN fertilizer on Russet Burbank tuber yield and size distribution.

Nitrogen Treatments				Tuber Quality				Tuber Dry Matter
Trtmt #	N Source[1]	N Rate	N Timing[2]	Specific Gravity	Hollow Heart	Brown Center	Scab	
		lb N / A	P, E, PH		%			
1	MAP+AS	30	30, 0, 0	1.0758	0.0	0.0	0.0	19.95
2	MAP+AS, Urea, UAN	240	30, 105, 105	1.0807	6.0	8.0	0.0	21.43
3	MAP+AS, ESN(A)	240	30, 210, 0	1.0830	6.0	6.0	0.0	21.74
4	MAP+AS, ESN(C)	240	30, 210, 0	1.0799	19.0	19.0	3.0	21.09
			Significance[3]	*	*	*	NS	NS
			LSD (0.10)	0.0041	8.5	8.3	--	--

[1]MAP = monoammonium phosphate (10-50-0), AS = ammonium sulfate (21-0-0), Urea = 46-0-0, UAN = urea and ammonium nitrate (28-0-0), ESN(A) = Environmentally Smart Nitrogen (air boom damaged) (44-0-0), ESN(C) = Environmentally Smart Nitrogen dealer grade control) (44-0-0).
[2]P = planting, E = emergence/hilling, PH = post-hilling (5 applications).
[3]NS = Non significant; ++, *, ** = Significant at 10%, 5%, and 1%, respectively.

Table 4. Effect of nitrogen source and quality of ESN fertilizer on petiole nitrate-N on four sampling dates.

Nitrogen Treatments				Petiole Nitrate-N			
Trtmt #	N Source[1]	N Rate	N Timing[2]	20-Jun	28-Jun	11-Jul	26-Jul
		lb N / A	P, E, PH	ppm			
1	MAP+AS	30	30, 0, 0	4415	689	333	112
2	MAP+AS, Urea, UAN	240	30, 105, 105	23114	8795	10829	7303
3	MAP+AS, ESN(A)	240	30, 210, 0	23555	14044	10579	7022
4	MAP+AS, ESN(C)	240	30, 210, 0	19549	14070	12438	6683
			Significance[3]	**	**	**	**
			LSD (0.10)	1644	1948	1781	771

[1]MAP = monoammonium phosphate (10-50-0), AS = ammonium sulfate (21-0-0), Urea = 46-0-0, UAN = urea and ammonium nitrate (28-0-0), ESN(A) = Environmentally Smart Nitrogen (air boom damaged) (44-0-0), ESN(C) = Environmentally Smart Nitrogen dealer grade control) (44-0-0).
[2]P = planting, E = emergence/hilling, PH = post-hilling (5 applications).
[3]NS = Non significant; ++, *, ** = Significant at 10%, 5%, and 1%, respectively.

Evaluation of Nitrogen Rate and Variety on Tuber Yield and Quality: Effects on Sugars and Acrylamide

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Summary: Since the discovery of acrylamide in fried potato products a decade ago, reducing the amount of acrylamide in fried potato products has become a priority of the potato industry. Acrylamide content can potentially be reduced by minimizing the abundance of acrylamide precursors (reducing sugars and the amino acid asparagine) in mature raw tubers through methods including selective breeding and nitrogen management in the field. A field experiment was conducted at the Sand Plain Research Farm in Becker, Minnesota, to evaluate the effect of potato variety and nitrogen fertilization regime on petiole nitrate content, yield, tuber quality, tuber sucrose and glucose content, and the acrylamide content of fried potato products. Three frying varieties (Russet Burbank, Alpine Russet, and Dakota Trailblazer) and two chipping varieties (Snowden and Ivory Crisp) were grown under five nitrogen fertilization regimes (30 lbs N/A as MAP and ammonium sulfate for all treatments at planting, plus 0, 90, 150, 210, or 270 lbs N/A as ESN at emergence). As expected, higher-nitrogen treatments resulted in higher petiole nitrate content. Higher-nitrogen treatments also tended to have smaller yields of small (0- to 3-ounce) tubers and larger yields of large (10-ounce and above) tubers, but maximum total yield was achieved for all varieties when 150 or 210 lbs N/A was applied as ESN. Higher-nitrogen treatments tended to have higher incidences of hollow heart and brown center, probably due to their larger percentages of large tubers. Sucrose content did not respond to nitrogen regime, but glucose content tended to decline as the amount of nitrogen applied increased. The abundances of both sugars varied significantly among varieties, but were not correlated with each other. The acrylamide content in fried products is currently being measured, but the results collected to date suggest that both nitrogen management and selective breeding have good potential to reduce the acrylamide content of fried potato products.

Background:

The discovery of the neurotoxin and possible carcinogen acrylamide in fried potato products has prompted new research into methods for reducing the acrylamide content of such products. Acrylamide is formed during the frying process from two precursors: the amino acid asparagine and reducing sugars (such as sucrose and glucose). If the concentrations of these precursors can be reduced, the final acrylamide concentration in fried potato projects should also be diminished.

The concentrations of sucrose and glucose in potato tubers are influenced by both genetic factors and environmental factors, including growth conditions in the field, tuber storage conditions, and processing methods. In the field, nitrogen management can influence tuber maturation and, consequently, the concentrations of sucrose and glucose found in tubers.

The objective of this study is to determine whether potato variety (genetics) and nitrogen fertilization regime (an aspect of the growing environment) influence the concentrations of sucrose and glucose in mature tubers and acrylamide in fried potato products. Measurements of acrylamide concentrations are currently in progress and are not available at the time of this report. We also evaluated the effect of nitrogen fertilization regime and potato variety on petiole nitrate content, tuber yield, whole-plant traits (percent stand and stems per plant), and tuber quality (prevalence of hollow heart, brown center, and scab, plus tuber specific gravity and percent dry matter).

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, 5.8-6.0; organic matter, 2.0-2.2%; Bray P1, 31-46 ppm; ammonium acetate extractable K, Ca, and Mg, 100-119, 785-863, and 138-148 ppm, respectively; Ca-phosphate extractable SO_4-S, 2-5 ppm; hot water extractable B, 0.2-0.3; and DTPA extractable Zn, Cu, Fe, and Mn, 1.3-1.7, 0.6-0.8, 41.0-44.2, and 11.4-13.2 ppm, respectively. Extractable nitrate-N and ammonium-N in the top 2 ft of soil were 4.9-6.6 and 11.8-19.9 lb/A, respectively.

Three frying varieties (Russet Burbank, Alpine Russet, and Dakota Trailblazer) and two chipping varieties (Snowden and Ivory Crisp) were studied. Prior to planting, 250 lb/A 0-0-60 and 250 lb/A 0-0-22 were broadcast and incorporated with a moldboard plow in all plots. Four, 20-ft rows were planted for each plot, with the middle 18 feet of the middle two rows used for sampling and harvest. Whole “B” seed of Russet Burbank, and cut “A” seed of Snowden, Alpine Russet, Dakota Trailblazer, and Ivory Crisp were hand planted in furrows on May 3, 2011. Row spacing was 12 inches within each row and 36 inches between rows. Each treatment was replicated four times for each variety in a randomized complete block design. Belay insecticide was applied in-furrow 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.

Each cultivar was subjected to 5 nitrogen fertilizer treatments, described in Table 1 below, which differed in total nitrogen fertilization rate due to differences in the amount of Environmentally Smart Nitrogen (Agrium, Inc.; referred to hereafter as ESN) applied at emergence. A complete factorial arrangement was used with cultivar and N fertilizer treatment as main effects. At planting, fertilizer was banded 3 inches to each side and 2 inches below the seed piece, including 30 lbs N/A, 130 lbs P_2O_5/A, 181 lbs K_2O/A, 46 lbs S/A, 20 lbs Mg/A, 3.3 lbs B/A, and 5.6 lbs Zn/A, applied as a blend of monoammonium phosphate (MAP), potassium chloride, potassium magnesium sulfate, ammonium sulfate (AMS), boric acid, and zinc oxide. Emergence N applications as ESN were applied on May 25 and mechanically incorporated during hilling.

Plant stands were measured on June 6 and stem number per plant on June 14. Petiole samples were collected from the fourth leaf from the terminal on four dates: June 20, June 28, July 11, and July 26. Petioles were analyzed for nitrate-N on a dry weight basis. The vines of the chipping varieties were mechanically beaten on September 15 and those of the frying varieties on September 23. The plots were machine harvested on September 29, and total tuber yield and graded yield were measured. Tuber sub-samples were also collected and used to determine the incidence of hollow heart, brown center, and scab, and tuber dry matter and specific gravity. Additional sub-samples were collected for tuber analysis after frying. Whole-tuber sucrose and glucose contents were determined for all five varieties. For the chipping varieties (Snowden and Ivory Crisp), chip color and

AGT score were also determined. Fry tests conducted shortly after harvest are reported here. Additional fry tests will be made after six months of storage at about 45˚ F and reported at a later date, along with the acrylamide results.

Table 1. Nitrogen treatments tested on five processing potato varieties.

Trtmt #	-------------------------- N timing --------------------------		
	Planting	Emergence/Hilling	Total N
	------------- N sources[1] and N rates (lb N/A) -------------		
1	30 MAP + AMS	0	30
2	30 MAP + AMS	90 ESN	120
3	30 MAP + AMS	150 ESN	180
4	30 MAP + AMS	210 ESN	240
5	30 MAP + AMS	270 ESN	300

[1]MAP = monoammonium phosphate (11-52-0); AMS = ammonium sulfate (21-0-0-22); ESN = Environmentally Smart Nitrogen (44-0-0).

Results:

Petiole Nitrate:

Petiole nitrate increased significantly with increasing application of ESN for all combinations of variety and testing date (Tables 2 – 6).

Petiole nitrate also varied significantly among varieties in all four sampling periods, but the rank-order of the five varieties changed over time. On June 20, Alpine Russet plants had significantly higher petiole nitrate than all other varieties, and on June 28, the same variety still had significantly higher nitrate than Russet Burbank or Snowden plants. On both July 11 and July 26, Russet Burbank plants had significantly higher petiole nitrate than any other variety, while Ivory Crisp plants had significantly lower nitrate than Snowden or Dakota Trailblazer (but not Alpine Russet).

Different lines had generally parallel responses to increasing nitrogen fertilization. However, for the July samples, there was a marginally significant tendency for different varieties to show different responses to fertilization. The lowest-nitrate varieties (Alpine Russet and Ivory Crisp) showed weaker responses to differences in the rate of nitrogen application than the other varieties at lower rates of nitrogen (between 30 and 180 lbs N/A) and stronger responses at higher rates of nitrogen (between 180 and 300 lbs N/A).

Tuber Yield:

Tuber size categories for the chipping varieties (Snowden and Ivory Crisp) are discussed both in terms of weight (to allow comparison with the frying varieties) and tuber mean diameter (which is more relevant to the chipping process).

Russet Burbank: The control treatment, which received no nitrogen at emergence and 30 lbs N/A in total, had significantly more small (0- to 3-ounce) tubers than any of the

ESN-fertilized treatments, but tended to have fewer tubers in the two largest-size classes (Table 7). This treatment had lower total yield than the treatments receiving 180 and 240 lbs N/A, and lower marketable yield than any fertilized treatment. The control also had lower percentages of tubers over 6 ounces and 10 ounces than any other treatment.

In contrast, the treatment receiving the largest amount of ESN at emergence (300 lbs total N/A) had significantly fewer 0- to 3-ounce tubers than the treatments receiving 120 and 180 lbs N/A, and significantly more 10- to 14-ounce tubers over 14 ounces than the treatments receiving 120 and 180 lbs N/A. This treatment had a significantly higher percentage of tubers over 6 ounces than the treatment receiving 120 lbs N/A and a higher percentage of tubers over 10 ounces than any other treatment.

The treatments receiving 120, 180, and 240 lbs N/A had insignificantly higher yields of 3- to 6-ounce tubers than the control treatment or the treatment receiving 300 lbs N/A. Because 3- to 6-ounce tubers represented the largest size class in terms of yield, these three treatments also had the higher total yield and marketable yield. However, no treatment produced significantly more yield than the treatment receiving 300 lbs N/A for any but the smallest size class, nor for total yield or marketable yield.

Number 2 tubers represented a moderate proportion of total marketable yield for Russet Burbank, accounting for 16% (at 120 lbs N/A) to 28% (at 300 lbs N/A) of marketable yield.

Alpine Russet: The control treatment had relatively high yields of tubers in the two smallest size classes (0 to 3 ounces and 3 to 6 ounces), but the difference was only significant for the control compared to the treatment receiving 300 lbs N/A, and only for 3- to 6-ounce tubers (Table 8). For 6- to 10-ounce and 10- to 14-ounce tubers, the control had significantly lower yield than any treatment except the one receiving 300 lbs N/A. For tubers over 14 ounces, the control had lower yield than any of the ESN-fertilized treatments. It also had a lower yield of #1 tubers and total marketable potatoes than any ESN-fertilized treatment. It had a higher yield of #2 tubers than any fertilized treatment except the one receiving 120 lbs N/A. The control treatment had smaller percentages of tubers over 6 ounces and tubers over 10 ounces than any of the ESN-fertilized treatments.

The treatment receiving 300 lbs N/A had a greater yield of tubers over 14 ounces than any other treatment, and a significantly greater percentage of this treatment's yield was in tubers over 10 ounces than for the treatments receiving 120 and 180 lbs N/A. In all tuber size classes but the largest one, tuber yield was greater for treatments receiving 120 to 240 lbs N/A. Indeed, the treatment receiving 180 lbs N/A produced a significantly greater yield of 6- to 10-ounce tubers, #1 tubers, and total marketable tubers than the treatment receiving 300 lbs N/A.

Alpine Russet potatoes had relatively high yields of #2 tubers compared to #1 tubers in this study, with #2 tubers accounting for 20% (at 180 lbs N/A) to 47% (at 30 lbs N/A) of total marketable yield.

Dakota trailblazer: The control treatment had a significantly lower yield of 0- to 3-ounce tubers than the treatments receiving 180 and 300 lbs N/A, more 3- to 6-ounce tubers than the treatment receiving 300 lbs N/A, and fewer 6- to 10-ounce tubers than the treatment receiving 180 lbs N/A (Table 9). It had lower yield than any ESN-fertilized treatment for 10- to 14-ounce tubers, total yield, #1 tubers, and total marketable yield, and lower yield of tubers over 14 ounces than any ESN-fertilized treatment except the one receiving 180 lbs N/A. A smaller percentage of the control treatment's yield was accounted for by tubers over 6 ounces or tubers over 10 ounces than for any of the ESN-fertilized treatments.

The treatment receiving 300 lbs N/A had a significantly higher yield of 0- to 3-ounce tubers than the treatment receiving 120 lbs N/A, but a lower yield of 3- to 6-ounce tubers than the treatments receiving 180 and 240 lbs N/A. It had a lower yield of 6- to 10-ounce tubers than the treatment receiving 180 lbs N/A, but a higher yield of tubers over 14 ounces than any treatment except the treatment receiving 240 lbs N/A. A larger percentage of yield for this treatment included tubers over 10 ounces than for the treatments receiving 120 and 180 lbs N/A. However, it had a significantly lower yield of 6- to 10-ounce tubers, total yield, yield of #1 tubers, and total marketable yield than the treatment receiving 180 lbs N/A.

Less than 1% of marketable yield of Dakota Trailblazer was represented by #2 potatoes for any treatment.

Snowden: The control treatment had a significantly lower yield of 0- to 3-ounce (0- to 2.25-inch-diameter) tubers than the treatment receiving 300 lbs N/A, and significantly lower yield than any fertilized treatment for 6- to 10-ounce (2.75- to 3.25-inch) tubers, total yield, #1 tubers, and total marketable yield (Table 10). It also had a significantly lower yield of 10- to 14-ounce (3.25- to 3.75-inch) tubers than the treatments receiving 180, 240, and 300 lbs N/A, and a lower yield of tubers over 14 ounces (3.75 inches) than the treatments receiving 240 and 200 lbs N/A. A smaller percentage of its yield included tubers over 6 ounces (2.75 inches) than any ESN-fertilized treatment, and a smaller percentage of its yield included tubers over 10 ounces (3.25 inches) than any treatment except the one receiving 120 lbs N/A.

The treatment receiving 300 lbs N/A had a significantly greater yield of 10- to 14-ounce (3.25- to 3.75-inch) tubers than any other treatment, and greater yields of 0- to 3-ounce (0- to 2.25-inch) tubers and tubers over 14 ounces (3.75 inches) than any treatment except the one receiving 240 lbs N/A. A larger percentage of its yield included tubers over 10 ounces (3.25 inches) than was seen in any other treatment, and it also had a greater percentage of its yield in tubers over 6 ounces (2.75 inches) than did the treatment receiving 120 lbs N/A. Total yield, yield of #1 tubers, and total marketable yield did not differ significantly among ESN-fertilized treatments.

Number 2 tubers accounted for less than 1% of marketable yield of Snowden potatoes for all treatments.

Ivory Crisp: The control treatment had significantly lower yield than any ESN-fertilized treatment for 6- to 10-ounce (2.75- to 3.25-inch-diameter) tubers, total yield, #1 tubers, and total marketable yield (Table 11). It also had lower yields than any treatment except the one receiving 120 lbs N/A for 10- to 14-ounce (3.25- to 3.75-inch) tubers and tubers over 14 ounces (3.75 inches). Tubers over 6 ounces (2.75 inches) accounted for a smaller percentage of yield for the control than for any ESN-fertilized treatment, and tubers over 10 ounces (3.25 inches) accounted for a smaller percentage of yield than for any treatment except the one receiving 120 lbs N/A.

The treatment receiving 300 lbs N/A had a significantly lower yield of 3- to 6-ounce (2.25- to 2.75-inch) tubers than any other treatment except the one receiving 240 lbs N/A, and a lower yield of 6- to 10-ounce tubers than any other ESN-fertilized treatment except the one receiving 180 lbs N/A. It had a greater yield of tubers over 14 ounces (3.75 inches) than the treatment receiving 120 lbs N/A. A greater percentage of this treatment's yield was in tubers over 10 ounces (3.25 inches) than for any other treatment.

The treatment receiving 240 lbs N/A had a significantly higher yield of 6- to 10-ounce (2.75- to 3.25-inch) tubers than any other treatment. It also had the greatest total yield, yield of #1 tubers, and total marketable yield, though its total yield was not significantly greater than the yield for the treatment receiving 180 lbs N/A, and for #1 tubers and marketable yield, the yield was only statistically significantly greater than the yield for the treatment receiving 120 lbs N/A.

Less than 1% of marketable Ivory Crisp tubers were #2 tubers for any treatment.

Marketable yield, all varieties: For all varieties combined, the treatment receiving 180 lbs total N/A had significantly greater marketable yield and yield of # 1 tubers than the treatments receiving 120 or 300 lbs total N/A. All treatments that received ESN at emergence had significantly higher yield than the control treatment (30 lbs total N/A).

Pooling all nitrogen treatments, for both #1 potatoes considered alone and total marketable yield (#1 and #2 potatoes combined), Dakota Trailblazer had significantly higher yield than any other variety, while Alpine Russet had significantly lower yield than any other variety, and Russet Burbank had lower yield than any variety except Alpine Russet. Alpine Russet had significantly greater yield of #2 potatoes than any other variety, and Russet Burbank had a greater yield of #2 potatoes than any variety except Alpine Russet. These trends were also seen in all five nitrogen treatments taken separately, though not all of the differences were statistically significant.

Plant vigor, tuber quality, frying quality:

Frying quality analysis (chip color and AGT score) was only performed for the chipping varieties (Snowden and Ivory Crisp).

Plant vigor, all varieties: Percent stand differed significantly among the five potato varieties used in this study. Alpine Russet (with 61.4% stand) had significantly lower percent stand than any other variety, and Ivory Crisp (with 88.4% stand) had significantly lower percent stand than any variety other than Alpine Russet. The other three varieties all had over 98.5% stand. The low stand for Alpine Russet was likely due to dry rot.

The varieties also differed significantly in their numbers of stems per plant. Snowden (with 5.0 stems per plant) had significantly more than any other variety. Russet Burbank (with 4.5 stems) had significantly more than any variety but Snowden. Ivory Crisp (3.6 stems) and Alpine Russet (3.5 stems) had significantly more stems per plant than Dakota Trailblazer (2.7 stems).

Fertilizer treatment did not significantly affect percent stand or the number of stems per plant when all varieties were considered together, nor did the effect of fertilizer treatment on these traits vary significantly from variety to variety.

Within any given variety, percent stand and the number of stems per plant were generally not significantly different among fertilizer treatments, with three exceptions. In Dakota Trailblazer plants (Table 14), the treatment receiving 120 lbs N/A had significantly lower percent stand than all other treatments, including the control (30 lbs N/A). In Russet Burbank plants, the control treatment had significantly more stems per plant than any ESN-fertilized treatment but the one receiving 120 lbs N/A. In Ivory Crisp plants (Table 16), the treatment receiving 300 lbs N/A had significantly fewer stems per plant than the control treatment or the treatment receiving 180 lbs N/A. The treatment that received 180 lbs N/A also had significantly more stems per plant than the treatments receiving 120 and 240 lbs N/A.

Russet Burbank tuber quality: The treatments receiving 240 and 300 lbs N/A had significantly higher incidences of hollow heart and brown center than the control treatment or the treatment receiving 120 lbs N/A (Table 12). The treatment receiving 240 lbs N/A also had significantly higher incidences of both flaws than the treatment receiving 180 lbs N/A.

Tubers from the control treatment (30 lbs N/A) had a significantly lower average specific gravity than tubers from any of the ESN-fertilized treatments. Tubers from the treatment receiving 240 lbs N/A also had lower specific gravity than those from the treatment receiving 120 lbs N/A.

Nitrogen had no significant effect on the incidence of scab (which was consistently low), or tuber percent dry matter in Russet Burbank potatoes.

Alpine Russet tuber quality: There were no significant effects of nitrogen treatment on tuber quality for Alpine Russet potatoes in this study (Table 13). Hollow heart and brown center tended to increase with increasing application of ESN, but these flaws were rare for all five treatments. Scab was entirely absent from this variety.

Dakota Trailblazer tuber quality: The treatment receiving 240 lbs N/A had significantly more hollow heart and brown center than any other treatment, and the treatment receiving 300 lbs N/A had these flaws in a significantly greater percentage of tubers than did the control treatment (30 lbs N/A; Table 14).

The treatment receiving 180 lbs N/A had a significantly higher percentage of dry matter than the treatments receiving 120 and 300 lbs N/A. The treatment receiving 300 lbs N/A had a significantly lower percentage of dry matter than any other treatment.

Fertilizer treatment had no significant effect on the incidence of scab (which was rare in all treatments) or on tuber specific gravity.

Snowden tuber quality and tuber frying quality: Tubers in the control treatment (30 lbs N/A) had a significantly lower percentage of dry matter than tubers in the treatments receiving 180 and 300 lbs N/A (Table 15). There were no other significant effects of fertilizer treatment on tuber quality, though hollow heart and brown center tended to be more common in treatments receiving more ESN at emergence, and the prevalence of scab ranged from 0% to 12%. There were also no significant differences in whole-tuber frying quality from treatment to treatment.

Ivory Crisp tuber quality and tuber frying quality: Tuber specific gravity tended to increase with increasing application of ESN (Table 16). The control treatment (30 lbs N/A) had lower tuber specific gravity than any of the ESN-fertilized treatments, and the treatment receiving 120 lbs N/A had significantly lower tuber specific gravity than the treatment receiving 300 lbs N/A.

Tuber percent dry matter also increased with increasing ESN application. The control had significantly lower percent dry matter than any ESN-fertilized treatment. The treatments receiving 120 and 180 lbs N/A had significantly lower percent dry matter than the treatment receiving 300 lbs N/A, and the treatment receiving 120 lbs N/A also had significantly lower percent dry matter than the one receiving 240 lbs N/A.

There were no significant effects of nitrogen treatment on hollow heart or brown center (which were rare in this variety), or on scab, though the prevalence of scab ranged from 9% to 20%. There were also no significant effects of nitrogen treatment on whole-tuber frying quality.

Tuber quality, all varieties: Nitrogen treatment had a significant effect on all tuber quality traits but percent scab. Hollow heart and brown center tended to be increasingly prevalent as nitrogen application increased. The percentage of dry matter and the specific gravity of tubers also tended to increase with increasing nitrogen application.

All tuber quality traits varied significantly among the five varieties. Dakota Trailblazer had significantly higher incidences of hollow heart and brown center than any other variety, and Russet Burbank had significantly higher incidences of these flaws than any variety but Dakota Trailblazer. The remaining three varieties had these flaws in less than 3% of their tubers. Ivory Crisp had a significantly higher prevalence of scab than any other variety, and Snowden had significantly more scab than Alpine Russet.

For both dry mass and specific gravity, the varieties ranked as follows: Dakota Trailblazer > Snowden > Ivory Crisp > Russet Burbank > Alpine Russet. For specific gravity, the difference between Snowden and Ivory Crisp was not significant, but all other differences were significant. The response of tuber dry matter to nitrogen treatment also varied significantly with variety. Dry matter peaked in the treatment receiving 180 total lbs N/A for Dakota Trailblazer, increased consistently with increasing application of nitrogen for Snowden and Ivory Crisp, and did not respond in any simple way to nitrogen treatment for Russet Burbank and Alpine Russet.

<u>Whole-tuber sugar content:</u>

For the experimental population as a whole (all varieties considered), sucrose content varied significantly among varieties, but not among nitrogen treatments, and the effect of nitrogen treatment on sucrose content did not depend significantly on variety. Alpine Russet and Dakota Trailblazer had significantly more sucrose than the other three varieties, and Ivory Crisp had significantly lower sucrose content than any other variety.

Glucose content was affected by both the nitrogen treatment applied and the variety analyzed, and the effect of nitrogen treatment on glucose content depended on variety. For all varieties combined, glucose content declined with increasing application of nitrogen. The control treatment (30 lbs N/A) had significantly higher glucose content than any ESN-fertilized treatment, and the treatment receiving 120 lbs N/A had significantly lower glucose content than the treatment receiving 300 lbs N/A. The two chipping varieties (Snowden and Ivory Crisp) had significantly lower glucose content than any of the three frying varieties. Among the three frying varieties, Russet Burbank had the highest glucose content, followed by Alpine Russet, then Dakota Trailblazer, with each difference being statistically significant.

The rank-order of the varieties based on the content of each sugar was similar (Alpine Russet > Dakota Trailblazer > Snowden > Ivory Crisp; Russet Burbank was second-lowest in sucrose but highest in glucose). However, the relationship between sucrose content and sucrose content was very weak across varieties. A linear regression analysis showed that sucrose content could only explain 8.2% of the variation in glucose content for all varieties and treatments combined, and only 1.6% to 27.6% of the variation for any single nitrogen treatment.

Within individual varieties, nitrogen treatment only influenced whole-tuber sucrose content in Snowden (Table 15), in which the control treatment had higher sucrose content than the treatments receiving 180 and 300 lbs N/A, and the treatment receiving 300 lbs N/A had significantly lower sucrose content than the one receiving 120 lbs N/A. Glucose content was at least marginally significantly related to nitrogen treatment in all varieties except Russet Burbank (Tables 12-16).

For Alpine Russet tubers, glucose content declined with increasing application of ESN (Table 13). The control treatment had significantly higher glucose content than the treatments receiving 180, 240 and 300 lbs N/A; the treatment receiving 120 lbs N/A had higher glucose content than the treatments receiving 240 and 300 lbs N/A; and the treatment receiving 180 lbs N/A had higher glucose content than the treatment receiving 300 lbs N/A.

For Dakota Trailblazer tubers, the treatment receiving 120 lbs N/A had significantly higher glucose content than one receiving 240 lbs N/A or the control treatment (Table 14).

For Snowden tubers, the control treatment and the treatment receiving 120 lbs N/A had significantly higher glucose than the treatments receiving 180 and 300 lbs N/A.

For Ivory Crisp tubers, the control treatment had significantly higher glucose content than any of the ESN-fertilized treatments (Table 15).

Conclusions:

The nitrate concentration of petioles increased with increasing nitrogen fertilization rate, as expected. Varieties had different petiole nitrate concentrations, but the rank-order of varieties by petiole nitrate was not consistent over time, suggesting that varieties either take up nitrate or transfer nitrate from above-ground shoots to tubers at different rates from each other throughout the season. Late in the season, the varieties with the lowest mean petiole nitrate (Alpine Russet and Ivory Crisp) showed a weaker response to nitrogen fertilization rate than the other varieties at low rates (< 180 lbs N/A), but a stronger response at high rates (> 180 lbs N/A). This may have occurred because petiole nitrate for these varieties was quite low at 180 lbs N/A, leaving little room for further response below that rate, but great potential for a response to additional nitrogen above that rate, though it is not clear why petiole nitrate was low for these varieties at 180 lbs N/A.

Percent stand and stems per plant were generally not related to fertilization regime, and two of the exceptions (Dakota Trailblazer for stand and Ivory Crisp for stems per plant) showed relationships between these traits and nitrogen fertilization regime that are difficult to explain biologically. The third exception (Russet Burbank) tended to exhibit a decrease in stems per plant with increasing nitrogen application.

Both traits were much more strongly related to variety. In particular, the Alpine Russet plants had poor mean stand in 2011 (61.4%), probably as a result of dry rot. While the Ivory Crisp plants fared much better, their mean stand (88.4%) was still substantially below that of the remaining three varieties (all over 98.5%). Alpine Russet also had an unusually high proportion of #2 potatoes. This variety has generally performed better at this site than it did in 2011, so its poor performance in this year may be due to unusual weather conditions.

Treatments with greater amounts of ESN applied generally had smaller yields of very small tubers (0 to 3 ounces) and larger yields of very large tubers (over 14 ounces) than treatments with less ESN. However, this did not translate into greater total marketable yield, which was actually maximized for each variety at one of the intermediate levels of ESN application (180 or 240 lbs total N/A). There was also a tendency for higher-nitrogen treatments to have higher incidences of hollow heart and brown center, presumably because very large tubers are more prone to these particular flaws. More heavily-fertilized plants also produced tubers with higher dry matter content for three of the five varieties (Alpine Russet, Snowden, and Ivory Crisp), but for one variety (Dakota Trailblazer), peak dry matter content was found with intermediate fertilizer application (180 lbs N/A).

Sucrose content varied significantly among varieties, but was not significantly influenced by the amount of nitrogen fertilization. This suggests that lower tuber sucrose content can be achieved through potato breeding efforts, but not through nitrogen management in the field.

Glucose content also varied significantly among varieties, but it was also significantly influenced by nitrogen fertilization regime, and the effect of nitrogen fertilization on glucose content differed between different varieties. Overall, tubers had lower glucose content if they were more heavily fertilized. The one clear exception to this general rule (Dakota Trailblazer) showed a relationship between nitrogen treatment and glucose content that was difficult to explain biologically. Based on these results, both plant breeding and nitrogen management show good potential for minimizing glucose content in potatoes.

Sucrose content and glucose content did not co-vary significantly among the five varieties, consistent with the findings of earlier research in Switzerland. Thus, decreasing the content of one sugar through selective breeding may not substantially decrease the content of the other. Because glucose is more efficient than sucrose is at participating in the reaction that generates acrylamide, breeding efforts and the selection of varieties for planting should focus more attention on reducing glucose.

Among the nitrogen treatments tested under the conditions of this study, the treatment receiving 180 lb N/A (30 lbs N/A as MAP and AMS at planting and 150 lbs N/A as ESN at emergence) appeared to offer the highest marketable yield for most varieties, while resulting in a relatively low prevalence of hollow heart and brown center and low glucose content.

Table 2. Effect of nitrogen rate from ESN fertilizer on nitrate content in petioles of Russet Burbank potato plants.

Nitrogen Treatments				NO_3-N, ppm			
Trtmt #	N Source	N Rate	N Timing[1]				
		lb N / A	PP, P, E, PH	June 20	June 28	July 11	July 26
1	MAP + AMS	30	30, 0	4415 c	689 e	333 e	112 e
2	MAP + AMS, ESN	120	30, 90	14864 b	5353 d	2919 d	1600 d
3	MAP + AMS, ESN	180	30, 150	17714 a	10181 c	7442 c	4367 c
4	MAP + AMS, ESN	240	30, 210	19549 a	14070 b	12438 b	6683 b
5	MAP + AMS, ESN	300	30, 270	19893 a	17249 a	15501 a	9377 a
			Significance[2]	**	**	**	**
			LSD (0.10)	2638	2177	1776	1313

[1]MAP = monoammonium phosphate; AMS = ammonium sulfate; ESN = Environmentally Smart Nitrogen.

[2]P = planting; E = emergence/hilling.

[3]NS = non-significant; ++ = significant at 10%; * = significant at 5%; ** = significant at 1%.

Treatments that have the same letter within a column are not significantly different from each other.

Table 3. Effect of nitrogen rate from ESN fertilizer on nitrate content in petioles of Alpine Russet potato plants.

Nitrogen Treatments				NO_3-N, ppm			
Trtmt #	N Source	N Rate	N Timing[1]				
		lb N / A	PP, P, E, PH	June 20	June 28	July 11	July 26
1	MAP + AMS	30	30, 0	10197 b	1423 c	181 d	206 c
2	MAP + AMS, ESN	120	30, 90	20449 a	10819 b	2417 c	781 c
3	MAP + AMS, ESN	180	30, 150	21559 a	12151 b	3032 c	1329 c
4	MAP + AMS, ESN	240	30, 210	21206 a	19265 a	9571 b	3834 b
5	MAP + AMS, ESN	300	30, 270	22655 a	19594 a	14510 a	9299 a
			Significance[2]	*	**	**	**
			LSD (0.10)	5769	5653	1369	1199

[1]MAP = monoammonium phosphate; AMS = ammonium sulfate; ESN = Environmentally Smart Nitrogen.

[2]P = planting; E = emergence/hilling.

[3]NS = non-significant; ++ = significant at 10%; * = significant at 5%; ** = significant at 1%.

Treatments that have the same letter within a column are not significantly different from each other.

Table 4. Effect of nitrogen rate from ESN fertilizer on nitrate content in petioles of Dakota Trailblazer potato plants.

Nitrogen Treatments				NO_3-N, ppm			
Trtmt #	N Source	N Rate	N Timing[1]				
		lb N / A	PP, P, E, PH	June 20	June 28	July 11	July 26
1	MAP + AMS	30	30, 0	8011 c	981 d	379 e	194 d
2	MAP + AMS, ESN	120	30, 90	17102 b	7813 c	3301 d	1092 cd
3	MAP + AMS, ESN	180	30, 150	18381 ab	10133 c	7121 c	2682 c
4	MAP + AMS, ESN	240	30, 210	20606 a	16080 b	9954 b	5071 b
5	MAP + AMS, ESN	300	30, 270	21556 a	20186 a	12828 a	7515 a
			Significance[2]	**	**	**	**
			LSD (0.10)	3181	3594	1081	1652

[1]MAP = monoammonium phosphate; AMS = ammonium sulfate; ESN = Environmentally Smart Nitrogen.

[2]P = planting; E = emergence/hilling.

[3]NS = non-significant; ++ = significant at 10%; * = significant at 5%; ** = significant at 1%.

Treatments that have the same letter within a column are not significantly different from each other.

Table 5. Effect of nitrogen rate from ESN fertilizer on nitrate content in petioles of Snowden potato plants.

Nitrogen Treatments				NO_3-N, ppm			
Trtmt #	N Source	N Rate	N Timing[1]				
		lb N / A	PP, P, E, PH	June 20	June 28	July 11	July 26
1	MAP + AMS	30	30, 0	3556 c	573 d	260 e	306 d
2	MAP + AMS, ESN	120	30, 90	15618 b	6535 c	2766 d	1490 c
3	MAP + AMS, ESN	180	30, 150	20797 a	11989 b	6237 c	2561 b
4	MAP + AMS, ESN	240	30, 210	22039 a	16424 a	10604 b	6679 a
5	MAP + AMS, ESN	300	30, 270	20957 a	18960 a	14041 a	7535 a
			Significance[2]	**	**	**	**
			LSD (0.10)	3843	2691	1907	1003

[1]MAP = monoammonium phosphate; AMS = ammonium sulfate; ESN = Environmentally Smart Nitrogen.

[2]P = planting; E = emergence/hilling.

[3]NS = non-significant; ++ = significant at 10%; * = significant at 5%; ** = significant at 1%.

Treatments that have the same letter within a column are not significantly different from each other.

Table 6. Effect of nitrogen rate from ESN fertilizer on nitrate content in petioles of Ivory Crisp potato plants.

Nitrogen Treatments				NO_3-N, ppm			
Trtmt #	N Source	N Rate	N Timing[1]				
		lb N / A	PP, P, E, PH	June 20	June 28	July 11	July 26
1	MAP + AMS	30	30, 0	4032 c	346 d	160 d	100 c
2	MAP + AMS, ESN	120	30, 90	16220 b	5157 c	937 d	275 c
3	MAP + AMS, ESN	180	30, 150	19321 ab	9918 b	4265 c	1721 bc
4	MAP + AMS, ESN	240	30, 210	21115 a	16604 a	8705 b	3536 b
5	MAP + AMS, ESN	300	30, 270	22467 a	16943 a	14872 a	7478 a
			Significance[2]	**	**	**	**
			LSD (0.10)	3467.4	3370	2654	2134

[1]MAP = monoammonium phosphate; AMS = ammonium sulfate; ESN = Environmentally Smart Nitrogen.

[2]P = planting; E = emergence/hilling.

[3]NS = non-significant; ++ = significant at 10%; * = significant at 5%; ** = significant at 1%.

Treatments that have the same letter within a column are not significantly different from each other.

Table 7. Effect of nitrogen rate from ESN fertilizer on Russet Burbank tuber yield and size distribution.

Nitrogen Treatments				Tuber Yield										
Trtmt #	N Source[1]	N Rate	N Timing[2]	0-3 oz	3-6 oz	6-10 oz	10-14 oz	> 14 oz	Total	# 1 > 3 oz	# 2 > 3 oz	Total marketable	> 6 oz	> 10 oz
		lb N / A	P, E	cwt / A									%	
1	MAP + AMS	30	30, 0	141.0 a	231.1	56.6	1.1 c	0.0 c	429.8 b	232.2	56.6	288.8 b	12.9 c	0.3 c
2	MAP + AMS, ESN	120	30, 90	112.2 b	234.3	135.5	7.6 c	5.0 bc	494.6 ab	320.2	62.1	382.4 a	30.2 b	2.6 c
3	MAP + AMS, ESN	180	30, 150	107.2 b	243.7	143.7	38.4 b	10.0 bc	543.0 a	363.2	72.6	435.8 a	35.4 ab	8.9 b
4	MAP + AMS, ESN	240	30, 210	102.4 bc	208.3	139.4	50.5 ab	14.4 ab	515.0 a	315.9	96.7	412.6 a	39.6 ab	12.6 b
5	MAP + AMS, ESN	300	30, 270	82.0 c	177.3	148.2	68.7 a	25.3 a	501.5 ab	304.0	115.5	419.5 a	48.1 a	19.3 a
			Significance[3]	*	NS	NS	**	*	++	NS	NS	*	**	**
			LSD (0.10)	24.8	--	--	20.7	12.7	77.2	--	--	79.1	14.3	6.3

[1]MAP = monoammonium phosphate (11-46-0); AMS = ammonium sulfate (21-0-0-22); ESN = Environmentally Smart Nitrogen (44-0-0).

[2]P = planting; E = emergence/hilling.

[3]NS = non-significant; ++ = significant at 10%; * = significant at 5%; ** = significant at 1%.

Treatments that have the same letter within a column are not significantly different from each other.

Table 8. Effect of nitrogen rate from ESN fertilizer on Alpine Russet tuber yield and size distribution.

Nitrogen Treatments				Tuber Yield										
Trtmt #	N Source[1]	N Rate	N Timing[2]	0-3 oz	3-6 oz	6-10 oz	10-14 oz	> 14 oz	Total	# 1 > 3 oz	# 2 > 3 oz	Total marketable	> 6 oz	> 10 oz
		lb N / A	P, E	cwt / A									%	
1	MAP + AMS	30	30, 0	51.3	168.4 a	82.7 c	34.1 b	1.6 c	338.1 c	154.3 c	132.5 a	286.8 c	37.1 b	11.5 c
2	MAP + AMS, ESN	120	30, 90	42.5	150.5 a	140.1 ab	66.5 a	30.3 b	429.8 ab	293.6 ab	93.7 ab	387.3 ab	55.8 a	23.4 b
3	MAP + AMS, ESN	180	30, 150	50.7	150.3 a	154.1 a	75.7 a	42.5 b	473.3 a	339.7 a	82.9 b	422.5 a	57.8 a	25.2 b
4	MAP + AMS, ESN	240	30, 210	53.8	123.4 ab	128.8 ab	79.7 a	41.9 b	427.6 ab	286.4 b	87.4 b	373.8 ab	59.9 a	29.6 ab
5	MAP + AMS, ESN	300	30, 270	40.6	96.6 b	113.9 bc	56.5 ab	76.7 a	384.3 bc	266.7 b	77.0 b	343.7 b	64.7 a	35.1 a
			Significance[3]	NS	++	*	*	**	*	**	++	**	**	**
			LSD (0.10)	--	46.5	32.1	23.2	24.4	59.9	51.8	39.2	50.3	10.6	9.6

[1]MAP = monoammonium phosphate (11-46-0); AMS = ammonium sulfate (21-0-0-22); ESN = Environmentally Smart Nitrogen (44-0-0).

[2]P = planting; E = emergence/hilling.

[3]NS = non-significant; ++ = significant at 10%; * = significant at 5%; ** = significant at 1%.

Treatments that have the same letter within a column are not significantly different from each other.

Table 9. Effect of nitrogen rate from ESN fertilizer on Dakota Trailblazer tuber yield and size distribution.

Nitrogen Treatments				Tuber Yield										
Trtmt #	N Source[1]	N Rate	N Timing[2]	0-3 oz	3-6 oz	6-10 oz	10-14 oz	> 14 oz	Total	# 1 > 3 oz	# 2 > 3 oz	Total marketable	> 6 oz	> 10 oz
		lb N / A	P, E	cwt / A									%	
1	MAP + AMS	30	30, 0	20.6 bc	162.7 a	213.6 bc	26.1 b	0.9 c	424.0 c	399.8 c	3.6	403.3 c	56.2 c	6.1 c
2	MAP + AMS, ESN	120	30, 90	19.5 c	121.9 bc	260.3 ab	88.8 a	21.7 b	512.1 ab	491.2 ab	1.4	492.6 ab	72.4 a	21.5 b
3	MAP + AMS, ESN	180	30, 150	29.1 a	135.4 ab	272.9 a	97.3 a	12.4 bc	547.0 a	516.4 a	1.4	517.8 a	69.8 ab	19.9 b
4	MAP + AMS, ESN	240	30, 210	27.8 ab	159.6 ab	196.1 c	115.9 a	24.4 ab	523.8 ab	496.0 ab	0.0	496.0 ab	64.1 b	26.2 ab
5	MAP + AMS, ESN	300	30, 270	32.1 a	94.1 c	213.4 bc	114.7 a	44.3 a	498.7 b	465.7 b	1.0	466.6 b	74.7 a	32.0 a
			Significance[3]	*	*	++	**	*	**	**	NS	**	**	**
			LSD (0.10)	7.7	38.6	57.2	27.8	20.1	41.9	46.0	--	46.2	7.1	6.6

[1]MAP = monoammonium phosphate (11-46-0); AMS = ammonium sulfate (21-0-0-22); ESN = Environmentally Smart Nitrogen (44-0-0).

[2]P = planting; E = emergence/hilling.

[3]NS = non-significant; ++ = significant at 10%; * = significant at 5%; ** = significant at 1%.

Treatments that have the same letter within a column are not significantly different from each other.

Table 10. Effect of nitrogen rate from ESN fertilizer on Snowden tuber yield and size distribution.

Nitrogen Treatments				Tuber Yield										
Trtmt #	N Source[1]	N Rate	N Timing[2]	0-3 oz 0-2.25"	3-6 oz 2.25-2.75"	6-10 oz 2.75-3.25"	10-14 oz 3.25-3.75"	> 14 oz > 3.75"	Total	# 1, > 3 oz > 2.25"	# 2, > 3 oz > 2.25"	Total marketable	> 6 oz > 2.75"	> 10 oz > 3.25"
		lb N / A	P, E	cwt / A									%	
1	MAP + AMS	30	30, 0	76.1 bc	240.7	81.2 b	12.1 d	1.8 c	411.9 b	335.7 b	0.0	335.7 b	23.0 c	3.3 d
2	MAP + AMS, ESN	120	30, 90	72.8 c	275.8	164.8 a	25.2 cd	1.6 c	540.3 a	467.5 a	0.0	467.5 a	35.2 b	4.9 cd
3	MAP + AMS, ESN	180	30, 150	75.3 bc	243.8	203.2 a	32.5 c	5.1 bc	559.9 a	484.6 a	0.0	484.6 a	43.1 ab	6.7 c
4	MAP + AMS, ESN	240	30, 210	90.3 ab	231.5	181.2 a	48.3 b	13.3 ab	564.6 a	474.3 a	0.0	474.3 a	43.2 a	10.9 b
5	MAP + AMS, ESN	300	30, 270	96.4 a	210.7	173.1 a	64.9 a	16.9 a	562.0 a	464.0 a	1.6	465.6 a	44.9 a	14.5 a
			Significance[3]	*	NS	**	**	*	**	**	NS	**	**	**
			LSD (0.10)	16.0	--	47.5	14.8	8.9	53.1	53.2	--	53.5	8.0	2.6

[1]MAP = monoammonium phosphate (11-46-0); AMS = ammonium sulfate (21-0-0-22); ESN = Environmentally Smart Nitrogen (44-0-0).

[2]P = planting; E = emergence/hilling.

[3]NS = non-significant; ++ = significant at 10%; * = significant at 5%; ** = significant at 1%.

Treatments that have the same letter within a column are not significantly different from each other.

Table 11. Effect of nitrogen rate from ESN fertilizer on Ivory Crisp tuber yield and size distribution.

Nitrogen Treatments				Tuber Yield										
Trtmt #	N Source[1]	N Rate	N Timing[2]	0-3 oz 0-2.25"	3-6 oz 2.25-2.75"	6-10 oz 2.75-3.25"	10-14 oz 3.25-3.75"	> 14 oz > 3.75"	Total	# 1 > 3 oz	# 2 > 3 oz	Total marketable	> 6 oz	> 10 oz
		lb N / A	P, E	cwt / A									%	
1	MAP + AMS	30	30, 0	41.6	147.1 a	135.6 d	36.2 c	7.6 c	368.1 c	326.4 c	0.0	326.4 c	47.8 b	11.4 c
2	MAP + AMS, ESN	120	30, 90	30.4	125.7 ab	215.4 b	80.2 bc	18.4 bc	470.1 b	438.9 b	0.8	439.7 b	66.1 a	20.0 bc
3	MAP + AMS, ESN	180	30, 150	33.6	137.2 ab	185.2 bc	108.7 ab	40.1 ab	504.8 ab	470.7 ab	0.5	471.2 ab	65.9 a	28.9 b
4	MAP + AMS, ESN	240	30, 210	26.4	118.4 bc	254.8 a	104.9 ab	41.5 ab	546.1 a	516.7 a	2.9	519.6 a	73.5 a	26.6 b
5	MAP + AMS, ESN	300	30, 270	25.5	89.9 c	176.9 c	128.6 a	67.0 a	487.9 b	461.6 ab	0.8	462.4 ab	76.3 a	40.2 a
			Significance[3]	NS	*	**	*	*	**	**	NS	**	**	**
			LSD (0.10)	--	28.7	35.3	47.4	30.6	53.3	59.6	--	59.7	11.0	10.6

[1]MAP = monoammonium phosphate (11-46-0); AMS = ammonium sulfate (21-0-0-22); ESN = Environmentally Smart Nitrogen (44-0-0).

[2]P = planting; E = emergence/hilling.

[3]NS = non-significant; ++ = significant at 10%; * = significant at 5%; ** = significant at 1%.

Treatments that have the same letter within a column are not significantly different from each other.

Table 12. Effect of nitrogen rate from ESN fertilizer on Russet Burbank stand, tuber quality, dry matter, and sugar levels.

Nitrogen Treatments				Stand	Stems per plant	Hollow Heart	Brown Center	Scab	Specific Gravity	Tuber Dry Matter	Whole Tuber Sugar Levels	
Trtmt #	Nitrogen Source[1]	Nitrogen Rate	Nitrogen Timing[2]									
		lb N/A	P, E	%		%	%	%		%	Sucrose	Glucose
1	MAP + AMS	30	30, 0	100.0	5.2 a	0.0 c	0.0 c	0.0	1.0758 c	20.0	0.936	2.397
2	MAP + AMS, ESN	120	30, 90	100.0	4.5 ab	3.0 c	2.0 c	0.0	1.0839 a	19.7	0.778	1.488
3	MAP + AMS, ESN	180	30, 150	99.3	4.4 b	6.3 bc	6.3 bc	0.0	1.0823 ab	21.0	0.832	1.365
4	MAP + AMS, ESN	240	30, 210	100.0	4.1 b	19.0 a	19.0 a	3.0	1.0799 b	21.1	0.946	1.762
5	MAP + AMS, ESN	300	30, 270	99.3	4.3 b	18.3 ab	18.3 ab	0.0	1.0831 ab	20.8	1.239	1.557
			Significance[3]	NS	++	*	++	NS	**	NS	NS	NS
			LSD (0.10)	--	0.8	12.7	12.4	--	0.0037	--	--	--

[1]MAP = monoammonium phosphate (11-46-0); AMS = ammonium sulfate (21-0-0-22); ESN = Environmentally Smart Nitrogen (44-0-0).

[2]P = planting; E = emergence/hilling.

[3]NS = non-significant; ++ = significant at 10%; * = significant at 5%; ** = significant at 1%.
Treatments that have the same letter within a column are not significantly different from each other.

Table 13. Effect of nitrogen rate from ESN fertilizer on Alpine Russet stand, tuber quality, dry matter, and sugar levels.

Nitrogen Treatments				Stand	Stems per plant	Hollow Heart	Brown Center	Scab	Specific Gravity	Tuber Dry Matter	Whole Tuber Sugar Levels	
Trtmt #	Nitrogen Source[1]	Nitrogen Rate	Nitrogen Timing[2]									
		lb N/A	P, E	%		%	%	%		%	Sucrose	Glucose
1	MAP + AMS	30	30, 0	61.8	3.4	0.0	0.0	0.0	1.0802	17.6	1.519	2.368 a
2	MAP + AMS, ESN	120	30, 90	61.8	3.5	0.0	0.0	0.0	1.0725	19.5	1.501	1.856 b
3	MAP + AMS, ESN	180	30, 150	67.4	3.5	2.0	2.0	0.0	1.0758	20.0	1.461	1.504 bc
4	MAP + AMS, ESN	240	30, 210	63.9	3.7	2.0	2.0	0.0	1.0765	19.8	1.343	1.238 c
5	MAP + AMS, ESN	300	30, 270	52.1	3.6	3.3	4.3	0.0	1.0798	20.7	1.493	0.734 d
			Significance[3]	NS	NS	NS	NS	--	NS	NS	NS	**
			LSD (0.10)	--	--	--	--	--	--	--	--	0.437

[1]MAP = monoammonium phosphate (11-46-0); AMS = ammonium sulfate (21-0-0-22); ESN = Environmentally Smart Nitrogen (44-0-0).

[2]P = planting; E = emergence/hilling.

[3]NS = non-significant; ++ = significant at 10%; * = significant at 5%; ** = significant at 1%.
Treatments that have the same letter within a column are not significantly different from each other.

Table 14. Effect of nitrogen rate from ESN fertilizer on Dakota Trailblazer stand, tuber quality, dry matter, and sugar levels.

Nitrogen Treatments				Stand	Stems per plant	Hollow Heart	Brown Center	Scab	Specific Gravity	Tuber Dry Matter	Whole Tuber Sugar Levels	
Trtmt #	Nitrogen Source[1]	Nitrogen Rate	Nitrogen Timing[2]									
		lb N/A	P, E	%		%	%	%		%	Sucrose	Glucose
1	MAP + AMS	30	30, 0	99.3 a	2.6	4.3 c	4.3 c	0.0	1.0985	26.6 ab	1.452	0.307 b
2	MAP + AMS, ESN	120	30, 90	95.8 b	2.5	11.0 bc	11.0 bc	4.3	1.1074	26.3 b	1.347	0.608 a
3	MAP + AMS, ESN	180	30, 150	100.0 a	2.9	15.0 bc	15.0 bc	0.0	1.1045	27.3 a	1.392	0.413 ab
4	MAP + AMS, ESN	240	30, 210	99.3 a	2.8	37.8 a	37.8 a	0.0	1.1057	26.7 ab	1.502	0.249 b
5	MAP + AMS, ESN	300	30, 270	99.3 a	2.8	22.3 b	22.3 b	0.0	1.1020	24.9 c	1.379	0.475 ab
			Significance[3]	++	NS	**	**	NS	NS	**	NS	++
			LSD (0.10)	2.8	--	14.2	14.2	--	--	1.0177	--	0.262

[1]MAP = monoammonium phosphate (11-46-0); AMS = ammonium sulfate (21-0-0-22); ESN = Environmentally Smart Nitrogen (44-0-0).

[2]P = planting; E = emergence/hilling.

[3]NS = non-significant; ++ = significant at 10%; * = significant at 5%; ** = significant at 1%.
Treatments that have the same letter within a column are not significantly different from each other.

Table 15. Effect of nitrogen rate from ESN fertilizer on Snowden stand, tuber quality, dry matter, frying quality, and sugar levels.

Nitrogen Treatments				Stand	Stems per plant	Hollow Heart	Brown Center	Scab	Specific Gravity	Tuber Dry Matter	Whole Tuber Frying Quality		Whole Tuber Sugar Levels	
Trtmt #	Nitrogen Source[1]	Nitrogen Rate	Nitrogen Timing[2]											
		lb N/A	P, E	%		%	%	%		%	Chip Color	AGT Score	Sucrose	Glucose
1	MAP + AMS	30	30, 0	100.0	5.3	0.0	0.0	1.0	1.0835	20.8 b	2.0	57.25	1.178 a	0.285 a
2	MAP + AMS, ESN	120	30, 90	100.0	5.0	0.0	0.0	12.0	1.0875	22.2 ab	2.0	57.75	1.134 ab	0.300 a
3	MAP + AMS, ESN	180	30, 150	99.3	5.2	3.0	4.0	1.0	1.0893	22.8 a	2.0	58.75	0.953 bc	0.163 b
4	MAP + AMS, ESN	240	30, 210	100.0	4.8	3.0	3.0	0.0	1.0871	22.4 ab	2.0	57.75	1.051 abc	0.218 ab
5	MAP + AMS, ESN	300	30, 270	99.3	5.0	6.0	6.0	4.3	1.0922	23.5 a	2.3	58.25	0.914 c	0.122 b
			Significance[3]	NS	NS	NS	NS	NS	NS	++	NS	NS	++	++
			LSD (0.10)	--	--	--	--	--	--	1.6343	--	--	0.2046	0.121

[1]MAP = monoammonium phosphate (11-46-0); AMS = ammonium sulfate (21-0-0-22); ESN = Environmentally Smart Nitrogen (44-0-0).

[2]P = planting; E = emergence/hilling.

[3]NS = non-significant; ++ = significant at 10%; * = significant at 5%; ** = significant at 1%.

Treatments that have the same letter within a column are not significantly different from each other.

Table 16. Effect of nitrogen rate from ESN fertilizer on Ivory Crisp stand, tuber quality, dry matter, frying quality, and sugar levels.

Nitrogen Treatments				Stand	Stems per plant	Hollow Heart	Brown Center	Scab	Specific Gravity	Tuber Dry Matter	Whole Tuber Frying Quality		Whole Tuber Sugar Levels	
Trtmt #	Nitrogen Source[1]	Nitrogen Rate	Nitrogen Timing[2]											
		lb N/A	P, E	%		%	%	%		%	Chip Color	AGT Score	Sucrose	Glucose
1	MAP + AMS	30	30, 0	88.2	3.7 ab	0.0	0.0	18.8	1.0758 c	18.9 d	2.3	56.00	0.479	0.444 a
2	MAP + AMS, ESN	120	30, 90	90.3	3.5 bc	1.0	1.0	9.0	1.0851 b	20.9 c	2.0	58.50	0.610	0.211 b
3	MAP + AMS, ESN	180	30, 150	86.7	4.0 a	1.0	1.0	20.0	1.0864 ab	21.1 bc	2.0	58.00	0.759	0.153 b
4	MAP + AMS, ESN	240	30, 210	88.2	3.5 bc	1.0	2.0	17.0	1.0880 ab	22.1 ab	2.3	58.00	0.811	0.143 b
5	MAP + AMS, ESN	300	30, 270	88.9	3.4 c	1.0	1.0	18.0	1.0894 a	22.5 a	2.0	58.25	0.721	0.181 b
			Significance[3]	NS	**	NS	NS	NS	**	**	NS	NS	NS	**
			LSD (0.10)	--	0.3	--	--	--	0.0038	1.1	--	--	--	0.081

[1]MAP = monoammonium phosphate (11-46-0); AMS = ammonium sulfate (21-0-0-22); ESN = Environmentally Smart Nitrogen (44-0-0).

[2]P = planting; E = emergence/hilling.

[3]NS = non-significant; ++ = significant at 10%; * = significant at 5%; ** = significant at 1%.

Treatments that have the same letter within a column are not significantly different from each other.

Response of Irrigated Potatoes to Two Controlled Release Fertilizers and a Soil Amendment Designed to Improve Fertilizer Efficiency

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Summary: A field experiment was conducted at the Sand Plain Research Farm in Becker, MN to evaluate alternative methods of improving N use efficiency in irrigated potato production. Treatments compared differences in N release rates and tuber yield and quality between the two controlled release fertilizers ESN and Duration. The effects of the soil amendment SoilBuilder AF on potato yield and quality was also compared with conventional N fertilizer practices. A total of 18 treatments were examined, all of which included the equivalent of 30 lb N/A in a starter blend. There was a starter only control, 11 treaments that received a total N rate of 240 lb N/A, and six treatments that received a total N rate of 170 lb N/A. The 240 lb N/A treatments included (all rates in lb N/A): 105 urea at emergence + 105 UAN post-hilling; 210 from urea, ESN, or Duration preplant; 105 ESN + 105 Duration preplant; 105 Duration preplant + 105 urea at emergence; 210 from ESN or Duration at emergence; 105 urea + 105 ESN at emergence; 105 urea + 105 Duration at emergence; and 105 ESN + 105 Duration at emergence. The 170 lb N/A treatments included: 70 urea at emergence + 70 UAN post-hilling (three treatments); 140 ESN at emergence; 140 Duration preplant; and 70 ESN + 70 Duration preplant. The three 70 urea + 70 UAN treatments included one with SoilBuilder AF at two qt/A, one with SoilBuilder at 4 qt/A, and one with no SoilBuilder. N release from ESN was more rapid than N release from the thicker-coated Duration. At crop emergence 30 days after planting, ESN applied preplant had released over 50% of its N and preplant Duration had released less than 5%. Duration applied at emergence released 15% of its N by 80 days after planting compared with nearly 90% from emergence applied ESN. There were no significant yield differences between ESN and Duration when they were applied at the same rates and timing. Delayed N release from Duration may have been compensated for by greater N leaching losses from ESN. There were also no significant yield differences between preplant and emergence application timing for either of the controlled release fertilizers. Compared with the conventional N fertilizer treatment of urea at emergence + UAN post-hilling, both ESN and Duration produced equivalent yields when they were used as the major N source. However, numerically highest marketable yields were obtained with 50% ESN (105 lb N/A) and 50% Duration (105 lb N/A) applied at emergence. When the total N rate was 170 lb/A marketable yields were actually significantly greater for preplant Duration than for urea + UAN, probably due to leaching losses from the conventional treatment. The soil amendment SoilBuilder AF had no effect on tuber yield at either of the applied rates. Amounts of residual nitrate-N remaining in the upper two ft of soil after harvest were greatest for treatments that included Duration, so the delayed N release from Duration increases the potential for leaching losses of N after the crop is harvested, suggesting the need for a cover crop following harvest.

Background: Studies with controlled release N fertilizer have been conducted for the past seven years using ESN, a polymer coated urea product manufactured by Agrium. While results have been promising and adoption by growers has occurred, N release in grower trials has been much faster than in the research trials. After extensive analysis in 2009 using a 24 hour water test to determine ESN prill damage, it was found that abrasion of the coating (and hence damage) became greater with each step of handling. ESN collected after going through an air boom spreader had the highest N release rate of up to 56% after 24 hours. Field research in 2010 also showed that damage to the polymer coating from air boom spreaders resulted in a faster release of N from the prill than desired. One possible way to overcome this problem is to use a slightly thicker coating that is not as susceptible to damage. A product called "Duration", also manufactured by Agrium, may be one that can substitute for ESN. However because of the thicker coating, release characteristics will be slower than ESN. A slower release may necessitate a preplant application rather than a sidedress application at emergence, which has been found to be the most efficient application timing for ESN.

AMS (Advanced Microbial Solutions, LLC) has developed products derived from manure fermentation containing complex organic compounds and various microbial organisms. Use of these products may have the potential to reduce commercial fertilizer application and at the same time provide other benefits for crop growth. One AMS product is SoilBuilder AF, described as a fertilizer catalyst designed to improve fertilizer efficiency and enhance soil structure.

The overall goal of this research was to evaluate alternative methods of improving N use efficiency in irrigated potato production. Specific objectives included: 1) Compare the effects of ESN with Duration on potato yield and quality, and 2) compare the effects of the soil amendment SoilBuilder AF with conventional N fertilizer practices on potato yield and quality.

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, 6.3; organic matter, 2.1%; Bray P1, 71 ppm; ammonium acetate extractable K, Ca, and Mg, 172, 795, and 145 ppm, respectively; Ca-phosphate extractable SO_4-S, 3.5 ppm; hot water extractable B, 0.3; and DTPA extractable Zn, Cu, Fe, and Mn, 1.9, 1.1, 36.5, and 10.5 ppm, respectively. Extractable nitrate-N and ammonium-N in the top 2 ft of soil were 7.1 and 13.8 lb/A, respectively.

Prior to planting, 250 lb/A 0-0-60 and 250 lb/A 0-0-22 were broadcast and incorporated with a moldboard plow. Four, 20-ft rows were planted for each plot with the middle two rows used for sampling and harvest. Whole "B" seed of Russet Burbank potatoes were hand planted in furrows on April 19, 2011. 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 was applied in-furrow 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.

There were 18 N fertilizer/soil amendment treatments as described in Table 1 below. There were 16 N treatments with different N sources, rates, and application timing, and two treatments with different rates of SoilBuilder AF (Advanced Microbial Solutions, LLC) used in conjunction with identical N management (conventional N sources, rates, and timing).

Preplant urea, ESN, and Duration fertilizer were applied one day before planting on April 18 and incorporated with a field cultivator. The 30-lb N/A application at planting as MAP and ammonium sulfate was banded 3 inches to each side and 2 inches below the seed piece using a metered, drop fed applicator. For all treatments, banded fertilizer at planting included 130 lb P_2O_5/A, 181 lb K_2O/A, 20 lb Mg/A, 46 lb S/A, 3.3 lb B/A, and 5.6 lb Zn/A applied as a blend of monoammonium phosphate, ammonium sulfate, potassium chloride, potassium magnesium sulfate, boric acid, and zinc oxide. Emergence N applications were supplied as urea, ESN, and Duration and mechanically incorporated during hilling. Post-hilling N was applied over the row with a tractor-mounted sprayer as a 28% UAN solution in 25 gal of water/A. The tractor traveled in the irrigation alleys to prevent damage to the crop. Irrigation was applied immediately following application of UAN to simulate fertigation with an overhead irrigation system. Emergence fertilizer was applied on May 19 and post-hilling N was applied on June 9, June 27, July 11, July 20, and July 28.

SoilBuilder AF was applied at planting and emergence with a hand sprayer in 25 gal of water/A at the 1 or 2 qt/A rates described in Table 1. Application at planting was in-furrow before row closure. At emergence it was applied to the shoulder of the existing hill and mechanically incorporated during hilling along with the sidedressed urea. Post-hilling application at the 1 qt/A rate involved blending SoilBuilder AF with 28% UAN solution and applying it through the tractor mounted sprayer on the first post-hilling N date using the procedures described in the previous paragraph.

A WatchDog weather station from Spectrum Technologies was used to monitor rainfall, air temperature, soil moisture, and soil temperature. Two pairs of soil moisture and temperature sensors were installed at different times in two locations. One pair was installed in a plot of Trtmt #10, which received a preplant application of 210 lb N/A from Duration. These probes were placed in the planting hill two inches below the soil surface soon after planting. The second pair was installed in a plot of Trtmt #12, which received 210 lb N/A from Duration at emergence. These probes were installed at emergence and initially placed at the same depth as the first pair of probes, two inches below the soil surface. Both sets of probes were then buried deeper by the tillage involved in hilling, and they were all four inches below the surface of the hill for the remainder of the growing season.

Measured amounts of ESN and Duration fertilizer were placed in plastic mesh bags and buried at the depth of fertilizer placement when both the preplant and emergence applications were made. Bags from the preplant group were removed on April 27, May 6, May 20, May 31, June 13, June 27, July 18, Aug 16, Sept 1, Sept 14, and Oct 14. Bags from the emergence group were removed on May 24, May 31, June 8, June 20, July 5, July 18, Aug 2, Aug 25, Sept 14, and Oct 14. Remaining amounts of fertilizer were measured for each date to track N release over time. Plant stands were measured on June 2 and stem number per plant on June 8. Petiole samples were collected from the 4th leaf from the terminal on four dates: June 14, June 28, July 11, and July 25. Petioles were analyzed for nitrate-N on a dry weight basis.

Vines were harvested on Sept 14 from two, 10-ft sections of row, followed by mechanically beating the vines over the entire plot area. Plots were machine harvested on Sept 21 and total tuber yield and graded yield were measured. Sub-samples of vines and tubers were collected to determine moisture percentage and N concentrations, which were then used to calculate N uptake and distribution within the plant (Note: all the data for N uptake were not available at the time of this report and therefore will be presented at a later time). Tuber sub-samples were also used to determine tuber specific gravity and the incidence of hollow heart, brown center, and scab. Soil samples were collected from the 0-2 ft depth on Oct 12 and Oct 13 to measure residual inorganic N (nitrate-N and ammonium-N).

Table 1. Nitrogen/soil amendment treatments tested on irrigated Russet Burbank potatoes.

Trtmt #	------------------------- N and soil amendment timing ---------------------------				
	Preplant	Planting	Emergence/Hilling	Post-hilling[1]	Total N + total SBAF
	------------------------ N sources[2], N rates (lb N/A), SBAF[3] (qt/A) ----------------------				
1	0	30 MAP+AS	0	0	30
2	0	30 MAP+AS	70 Urea	70 UAN	170
3	0	30 MAP+AS	105 Urea	105 UAN	240
4	210 Urea	30 MAP+AS	0	0	240
5	0	30 MAP+AS	140 ESN	0	170
6	0	30 MAP+AS	210 ESN	0	240
7	0	30 MAP+AS	105 Urea + 105 ESN	0	240
8	210 ESN	30 MAP+AS	0	0	240
9	140 Duration	30 MAP+AS	0	0	170
10	210 Duration	30 MAP+AS	0	0	240
11	105 Duration	30 MAP+AS	105 Urea	0	240
12	0	30 MAP+AS	210 Duration	0	240
13	70 ESN + 70 Duration	30 MAP+AS	0	0	170
14	105 ESN + 105 Duration	30 MAP+AS	0	0	240
15	0	30 MAP+AS	105 ESN + 105 Duration	0	240
16	0	30 MAP+AS	105 Urea + 105 Duration	0	240
17	0	30 MAP+AS +2 qt SBAF	70 Urea +1 qt SBAF	70 UAN +1qt SBAF	170 +4 qt SBAF
18	0	30 MAP+AS +1 qt SBAF	70 Urea +1 qt SBAF	70 UAN	170 +2 qt SBAF

[1]Post-hilling N was applied 5 times at 8-18 day intervals.
[2]MAP = monoammonium phosphate (10-50-0), AS = ammonium sulfate (21-0-0), Urea = 46-0-0, UAN = urea and ammonium nitrate (28-0-0), ESN = Environmentally Smart Nitrogen (44-0-0), Duration = 43-0-0.
[3]SBAF = SoilBuilder AF (Advanced Microbial Solutions).

Results

Weather: Rainfall and irrigation for the 2011 growing season are provided in Fig. 1, soil moisture in Fig. 2, and soil and air temperature in Fig. 3. Between April 19 and September 14 (from planting to vine kill), approximately 23.9 inches of rainfall was supplemented with 10.7 inches of irrigation for a total of 34.6 inches of water. There were eight leaching events (greater than 1 inch of water) during the growing season. None of these leaching events occurred early in the season before emergence. Rainfall and irrigation maintained adequate soil moisture during most of the growing season, although there were several intervals of saturated soil conditions later in the season.

Nitrogen release from ESN and Duration: Release curves of N from preplant and emergence applications of the two controlled release fertilizers are presented in Fig. 4. As expected, N release from ESN was more rapid than N release from the thicker-coated Duration. At the time of crop emergence (30 days after planting), ESN applied preplant had released over 50% of its N and preplant Duration had released less than 5%. Duration applied preplant did not release 50% of its N until about 105 days after planting. Maximum N uptake rates by Russet Burbank potatoes generally occur between 40 and 80 days after planting. Preplant ESN had released 95% of its N by 80 days, but preplant Duration had released less than 30%. Under 2011 growing conditions, N release from Duration appeared to be too slow to support maximum growth even when it was applied preplant. Although as discussed below, weather conditions (cool temperatures in the spring and excessive rainfall in July), may have resulted in a positive yield response to the slower N release with Duration. For ESN, preplant application probably resulted in greater than desired early-season N release. Preplant ESN had released about 75% of its N before the onset of the rapid growth phase at 40 days after planting, which could result in excessive N losses in a year with high early-season rainfall.

When Duration was applied at emergence, only about 15% of its N had been released by the end of the rapid growth phase at 80 days after planting. ESN applied at emergence had released a little less than 40% of its N by the beginning of the rapid growth phase at 40 days after planting and nearly 90% by 80 days. Delayed release of N from Duration increased the potential for leaching losses of residual N in the fall after the end of the growing season and in the spring of the following year before the beginning of the next growing season. For both preplant and emergence applied Duration, 26% of its N had not been released at the time of vine killing on Sept 14.

Tuber Yield: As expected, the 30 lb N/A control (Trtmt #1) had significantly lower total and marketable yields than all of the other treatments (Table 2). Trtmt #15, which had most of its N applied as a combination of ESN and Duration at emergence and a total N rate of 240 lb/A, had the greatest total yield of 551.9 cwt/A. Two other 240 lb N/A treatments had statistically equivalent total yields (#3, urea at emergence and UAN post-hilling) and #10 (Duration preplant), and a third (#8, ESN preplant) was 1.6 cwt/A short of being equivalent. Trtmt #15 also had the greatest marketable yield, but #3, 8, 9, and 10 were statistically equivalent. Trtmt #9 had most of its N applied as Duration preplant and a total N rate of 170 lb/A. This group of high-yielding treatments included all three of the major N sources (urea/UAN, ESN, and Duration) used in the study, indicating that all three sources were capable of producing comparable yields. The high yields for the Duration treatments contrasted with the N release curves in Fig.4, which suggested that N release from Duration may have been too slow for maximum yield. The positive response to Duration in 2011 may have been due to delayed N uptake and leaching rains which occurred during tuber bulking in July.

Three pairs of treatments compared ESN and Duration when they were applied at the same rates and timing: #6 vs. 12 (emergence), 8 vs.10 (preplant), and 7 vs. 16 (in combination with urea at emergence). There were no significant differences in total or marketable yield between the two controlled release N sources in any of these comparisons. This also contrasted with the N release curves for the two sources (Fig. 4), since N release from ESN seemed to be better matched with the maximum growth and N uptake period between 40 and 80 days after planting than N release from Duration. One factor in the comparable performance of Duration may have been leaching losses of some of the earlier released N from ESN (see leaching events in Fig. 1). Duration treatments could have been restricted by N for part of the growing season, but benefited from greater N release during later growth periods. These results also show that use of Duration is very effective in reducing nitrate leaching during the growing season.

When urea (Trtmt #4) was applied preplant at the same N rate as ESN (Trtmt #8) and Duration (Trtmt #10), both total and marketable yield were significantly less for urea. This is likely due to leaching losses of N with early application of urea. If emergence applications of ESN and Duration (Trtmts # 6 and 12) are compared with the same N application rate from urea at emergence + UAN post-hilling (Trtmt #3), total and marketable yields were numerically greater with urea/UAN, although the differences were not statistically significant. The preceding N source comparisons were all at a total N rate of 240 lb/A. If urea at emergence + UAN post-hilling (Trtmt #2) are compared with the same N rate from ESN at emergence (Trtmt #5), both at a total N rate of 170 lb/A, there were no yield differences between the two N sources.

Four of the five highest-yielding treatments received 240 lb N/A, suggesting that this was the optimum total N rate under the growing conditions of 2011. However, there was variability in the optimum N rate for the three major N sources. There were four pairs of treatments that compared total N rates of 240 lb/A and 170 lb/A from the same N sources with the same application timing (#2 vs. 3, 5 vs. 6, 9 vs. 10, and 13 vs. 14). For the conventional fertilizer treatment of urea at emergence and UAN post-hilling, both total and marketable yields were greatest at 240 lb N/A. Preplant Duration also had significantly greater total yields at 240 lb N/A, but marketable yields were the same at both N rates. For ESN at emergence and ESN + Duration preplant, both total and marketable yields were equivalent at the two N rates. These results suggest that leaching losses may have occurred with the urea/UAN treatments, leading to a greater N requirement for this N source compared with the controlled release N sources.

Five pairs of treatments compared preplant with emergence application timing for the three major N sources: #3 vs. 4 (urea/UAN), #6 vs. 8 (ESN), #10 vs. 12 (Duration), #14 vs. 15 (equal parts ESN + Duration), and #11 vs. 16 (equal parts Duration preplant + urea at emergence vs. equal parts Duration + urea at emergence). Total N rate for all of these treatments was 240 lb/A. Both total and marketable yields were significantly greater when urea was applied at emergence and UAN post-hilling, compared with the same amount of N from urea applied preplant. This is consistent with possible N leaching losses from urea applied preplant. Application timing had no significant effects on yield for ESN or Duration when they were applied alone as the major N source. However, both total and marketable yields were numerically greater when these controlled release fertilizers were applied preplant rather than at emergence, suggesting that earlier application may be beneficial. Results were different when ESN and Duration were applied in combination. In this case, both total and marketable yield were significantly greater when they were applied at emergence rather than preplant. For the comparison where an emergence application of urea was combined with either a preplant or emergence application of Duration, both total and marketable yield were nearly identical for the two treatments. So in this case, application timing of Duration had no effect. The reason for these differences is unclear. Fig. 4 might predict a greater response from Duration applied preplant, due to greater N release during the critical growth period from 40 to 80 days.

The soil amendment SoilBuilder AF had no effect on tuber yield at either of the applied rates. Trtmt #2 and the two SoilBuilder treatments (#17, high rate and #18, low rate) had identical N sources, rates, and timing (MAP+ammonium sulfate/urea/UAN, planting/emergence/post-hilling, 170 lb total N/A), but there were no significant differences among them in total or marketable yield.

Tuber Size: Comparisons between the N sources ESN and Duration at the same rates across different application timings (Trtmts #6 and 12, #8 and 10, #7 and 16) found a consistent trend for Duration to have a greater yield of tubers in the non-marketable 0-3 oz size. ESN tended to have higher percentages of its yield in the greater than 6 oz and greater than 10 oz categories, although the difference was only significant for the greater than 6 oz size in the comparison where the two N sources were applied at emergence. There was also a strong trend for Duration applied at emergence (Trtmt #12) to have lower percentages of its yield in the greater than 6 oz and greater than 10 oz categories than the treatment with urea/UAN applied at emergence/post-hilling (Trtmt #3). This urea/UAN treatment had similar percentages in these size categories to ESN applied at emergence (Trtmt #6). This comparison was made at total N rate of 240 lb/A. When urea/UAN was compared with ESN at the same application timing, but a total N rate of 170 lb/A, there was a strong trend for urea/UAN (Trtmt #2) to have higher percentages of its yield in the greater than 6 oz and greater than 10 oz categories than ESN (Trtmt #5). Total yields were similar, since ESN had numerically greater yields in the 3-6 oz size. When preplant application of urea and the two controlled release N sources were compared at a total N rate of 240 lb/A (Trtmts #4, 8, and 10), urea had significantly lower yield in the 6-10 oz size and numerically lower yield in the 10-14 oz size than both ESN and Duration. These size differences accounted for its significantly lower total and marketable yields. When a combination of ESN + Duration was used as the major N source (Trtmts 13, 14, and 15) total N rate had no effect on tuber size, but application timing had significant effects. Emergence application resulted in significantly greater yields of both 6-10 oz and 10-14 oz tubers. These differences accounted for significantly greater total and marketable yields with emergence application.

The 30 lb N/A control treatment had much lower percentages of tubers greater than 6 oz and 10 oz in size than all of the other treatments and most of the differences were significant. Non-marketable tubers in the 0-3 oz category made up 28% of total yield. Tuber size differences between the 170 lb N/A and 240 lb N/A treatments varied with N source. For urea/UAN at 170 and 240 lb N/A (Trtmts #2 and 3), there were no significant differences in any of the tuber size categories. The significantly greater total and marketable yield at the higher N rate was primarily due to numerically greater yield in the 3-6 oz size. The lower N rate actually had numerically higher percentages of its yield in both the greater than 6 oz and greater than 10 oz categories. For ESN (Trtmts #5 and 6) there were also no significant differences in any of the tuber size categories, but for this N source the higher N rate had numerically higher percentages of its yield in both the greater than 6 oz and greater than 10 oz categories. There were also no significant differences in any of the tuber size categories between the two N rates of Duration (Trtmts #9 and 10). The high N rate had significantly greater total yield, but not marketable yield, which is explained by its numerically greater yield in the non-marketable 0-3 oz size. For the two rates of ESN + Duration (Trtmts #13 and 14), there were no significant differences in any of the tuber size categories and no consistent trends.

The two treatments that received the soil amendment SoilBuilder AF (#17, high rate and #18, low rate) had a significantly lower percentage of tubers greater than 6 oz in size than Trtmt #2, which received the same N source, rate, and timing. There was also a strong trend for the SoilBuilder AF treatments to have a lower proportion of tubers greater than 10 oz in size (53% and 44% less). The two SoilBuilder AF rates were not significantly different, although the higher rate had a numerically lower proportion of tubers greater than 10 oz in size (15% less).

Tuber Quality, Stand Count, and Stems per Plant: Nitrogen source, rate, and timing, and application of the soil amendment SoilBuilder AF, had no significant effects on specific gravity, brown center, scab, or plant stand (Table 3). Incidence of hollow heart ranged from 0 to 14% and the two highest treatments, UAN at 240 lb N/A and ESN at emergence (Trtmt #3 and 6) were significantly greater than the two lowest, 30 lb N/A and SoilBuilder at 170 lb N/A (Trtmt #1 and 18). Hollow heart is usually more prevalent in large tubers, so the 0% rate in the 30 lb N/A control (Trtmt #1) was consistent with it having the smallest tuber size (Table 2). That appeared to be the only consistent effect of N treatment or soil amendment on hollow heart. The number of stems per plant ranged from 2.55 to 3.25. The four highest treatments (#9, 13, 14, and 18) were significantly greater than the four lowest (#1, 2, 9, and 16), but there weren't any consistent effects of N treatment or soil amendment on stems per plant.

Petiole Nitrate-N Concentrations: Nitrogen source, rate, and timing had significant effects on nitrate-N concentrations in petioles (Table 4). As expected, increasing the N application rate increased most measurements of nitrate-N. The 30 lb N/A control treatment had significantly lower petiole nitrate-N concentrations than most of the other treatments on all four sampling dates. It was always numerically lower than all of the other treatments. The effect of N rate can also be seen by looking at the four pairs of treatments that compared total N rates of 240 lb/A and 170 lb/A from the same N sources with the same application timing (#2 vs. 3, 5 vs. 6, 9 vs. 10, and 13 vs. 14). For all of these paired treatments, nitrate-N on the third and fourth sampling dates was always significantly greater for the 240 lb N/A rate. On the first sampling date the urea/UAN source produced similar concentrations at both N rates, but for all other comparisons on the first two dates the high N rate produced either significantly or numerically greater nitrate-N concentrations in petioles.

Three pairs of treatments compared the N sources ESN and Duration when they were applied at the same rates and timing: #6 vs. 12 (emergence), 8 vs.10 (preplant), and 7 vs. 16 (in combination with urea at emergence). For all three comparisons, the ESN treatments had significantly higher nitrate-N concentrations on the first three sampling dates than the Duration treatments, except for July 11 when ESN and Duration were statistically the same for the pair of preplant treatments. On the fourth sampling date, the Duration treatments had significantly higher nitrate-N concentrations than the ESN treatments for all three pairs of treatments. These results are consistent with the slower N release measured for Duration than for ESN (Fig. 2). When the N source urea (Trtmt #4) was applied preplant at the same N rate as ESN (Trtmt #8) and Duration (Trtmt #10), nitrate-N concentrations for the urea treatment were similar to ESN on the first sampling date, and significantly lower than ESN on the third date, and numerically lower on the second and fourth dates. As discussed in the "Tuber Yield" section, this may have been due to leaching losses of N with early application of urea. Compared with preplant

Duration, the preplant urea treatment had significantly greater nitrate-N concentrations on the first sampling date, numerically greater concentrations on the second date, and significantly lower concentrations on the third and fourth dates. This was consistent with both the potential for N leaching losses from urea and delayed N release from Duration.

Comparison of the emergence applications of ESN and Duration (Trtmts #6 and 12) with urea at emergence + UAN post-hilling (Trtmt #3), evaluates the three major N sources at the same N application rate of 240 lb/A and similar but not identical timing. On the first sampling date, petiole nitrate-N concentrations for urea/UAN were similar to ESN and significantly greater than Duration; on the second date, urea/UAN was significantly less than ESN and numerically greater than Duration; on the third date, urea/UAN was significantly greater than both ESN and Duration; and on the fourth date, urea/UAN was significantly greater than ESN and significantly less than Duration. A similar comparison between urea at emergence + UAN post-hilling (Trtmt #2) and ESN at emergence (Trtmt #5), at a total N rate of 170 lb/A, found the exactly the same pattern of significant differences in nitrate-N concentrations between the two N sources on all four sampling dates. These combined results suggest that urea at emergence + UAN post-hilling was slightly more effective than ESN at emergence in maintaining season long nitrate-N concentrations in petioles and considerably more effective than Duration. For Duration applied at emergence, petiole nitrate-N reached its highest concentration on the fourth sampling date and it probably maintained higher concentrations than urea/UAN and ESN for the remainder of the season.

Preplant and emergence application timing for the two controlled release N sources at the same N rate can be evaluated by comparing the following pairs of treatments: #6 vs. 8 (ESN), #10 vs. 12 (Duration), and #11 vs. 16 (equal parts Duration preplant + urea at emergence vs. equal parts Duration + urea at emergence). For ESN, preplant application produced numerically higher nitrate-N concentrations on the first date and emergence application produced significantly higher concentrations on the second and fourth dates; concentrations were similar on the third date. These results suggest that emergence application of ESN has a more positive overall effect on petiole nitrate-N than preplant application. When Duration was applied alone, preplant application produced numerically greater nitrate-N concentrations on the first two sampling dates and significantly greater nitrate-N on the third date; emergence application produced significantly greater concentrations on the fourth date. When the main N source was preplant or emergence Duration applied in combination with urea at emergence, preplant Duration produced numerically greater nitrate-N concentration on the first three sampling dates; concentrations were similar for emergence and preplant on the fourth date. These results suggest that preplant application of Duration has a more positive overall effect on petiole nitrate-N than emergence application. When Duration was applied at emergence (Trtmt #12) the slow N release (Fig. 4) resulted in high petiole nitrate-N late in the season.

Trtmt #14 and Trtmt #15 compare preplant and emergence application of equal parts ESN + Duration at the same total N rate. Preplant application produced significantly greater nitrate-N concentrations on the first date and numerically greater concentrations on the third date. Concentrations were similar on the second date and emergence application produced numerically greater concentrations on the fourth date. These results may indicate that preplant application of

ESN + Duration has a more positive overall effect on petiole nitrate-N than emergence application.

Trtmt #3 and Trtmt #4 compare preplant application of urea with emergence urea + post-hilling UAN at the same N rates. Preplant urea produced significantly greater nitrate-N concentrations on the first date, concentrations were similar on the second date, and the emergence/post-hilling treatment produced significantly greater concentrations on the third and fourth dates (4-5 times greater). These results confirm previous research showing that the emergence urea + post-hilling UAN timing of N application is more efficient than preplant urea.

The two treatments that received the soil amendment SoilBuilder AF (#17, high rate and #18, low rate) had significantly greater petiole nitrate-N concentrations on the fourth sampling date than Trtmt #2, which received the same N source, rate, and timing. This suggests the possibility of a positive SoilBuilder AF effect on N efficiency later in the growing season. There was no significant difference between the two SoilBuilder AF rates, although the low rate was numerically 17% higher. There were no significant differences in petiole nitrate-N among these three treatments on any of the other sampling dates, although on the second date the low rate was numerically the highest.

Petiole nitrate-N concentrations were generally low for most treatments, especially on the first three sampling dates. On the first date, all treatments were below the critical level of 17000 ppm. Preplant urea (Trtmt #4), urea + ESN applied at emergence (Trtmt #7), and ESN at emergence (Trtmt #8) were close to the sufficiency level, but the control and the three treatments that received Duration alone as their major N source (Trtmts #9, 10, and 12) were very low. All treatments were very low on the second sampling date, except for urea + ESN at emergence (Trtmt #7). Most treatments were also very low on the third sampling date, except for Trtmt #3, which received the high rate of UAN post-hilling. On the fourth sampling date, nine of the 18 treatments were within the sufficiency range of 6000 to 9000 ppm. All of these treatments either received post-hilling N from UAN or used Duration as one of their major N sources.

Cool temperatures early in the growing season probably reduced growth and limited N uptake, and excessive rainfall in July probably resulted in greater than normal N leaching for a number of treatments. These factors may have combined to cause the generally low petiole nitrate-N concentrations, as well as tuber yields in 2011 that were about 200 cwt below yields achieved at this location in top-yielding years.

Residual Soil N: Amounts of residual nitrate-N in the upper 2 ft of soil after harvest are presented in Table 5. Soil samples for these measurements were collected one month after vine kill. Six of the seven treatments with the greatest amounts of residual nitrate-N, and seven of the top nine, received at least part of their N from Duration. This is consistent with the slow rate of N release measured for Duration (Fig. 4). Trtmts #10 and 12, which received the highest rates of N from Duration (210 lb N/A), had the greatest amounts of residual nitrate-N and they were significantly greater than all of the other treatments. The other six Duration treatments in the group with the greatest amounts of residual nitrate-N received either 105 or 140 lb N/A from Duration. As expected, the 30 lb N/A control (Trtmt #1) had the lowest amount of residual nitrate-N in the soil after harvest. It was significantly lower than all of the other treatments.

Treatment #13, which received 70 lb N/A from Duration, had one of the lower amounts of residual nitrate-N. This may have been due to the fact that it was one of the treatments that received the lower total N rate of 170 lb N/A. Trtmts #3, 17, and 18 were similarly low and they also received a total of 170 lb N/A. This group included the SoilBuilder AF treatments and the treatment that had the same N sources, rates, and timing, so SoilBuilder AF had no effect on residual nitrate-N.

Inorganic N that remains in the soil after harvest is subject to leaching losses in the fall and spring, so the delayed N release from Duration increases the probability of N leaching. The amounts of residual soil N measured in the soil after harvest may actually underestimate the leaching potential. The final samples for measurement of N release from ESN and Duration were collected the day after fall soil sampling. N release from ESN was complete, but over 21% of the N from both the preplant and emergence applications of Duration had not been released.

Conclusions

N release from ESN was much more rapid than N release from the thicker-coated Duration, but there were no significant yield differences between ESN and Duration when they were applied at the same rates and timing. Delayed N release from Duration may have been compensated for by greater N leaching losses from ESN. There were also no significant yield differences between preplant and emergence application timing for either of the controlled release fertilizers. Compared with the conventional N fertilizer treatment of urea at emergence + UAN post-hilling, both ESN and Duration produced equivalent yields when they were used as the major N source. Numerically, highest marketable yields were obtained with 50% ESN (105 lb N/A) and 50% Duration (105 lb N/A) applied at emergence. When the total N rate was 170 lb/A, marketable yields were actually significantly greater for preplant Duration than for urea + UAN. This was probably due to greater leaching losses from the conventional treatment. There was a consistent trend for ESN to produce larger tuber size than Duration applied at the same rates and timing, although most of the differences were not significant. The soil amendment SoilBuilder AF had no effect on tuber yield at either of the applied rates. Both rates of SoilBuilder AF had a significantly lower percentage of tubers greater than 6 oz in size than the comparable N treatment with no SoilBuilder AF. When ESN and Duration were applied at the same rates and timing, ESN produced significantly higher petiole nitrate-N concentrations on the first three sampling dates than Duration in all but one of the comparisons. On the fourth sampling date, Duration consistently produced significantly higher nitrate-N concentrations than ESN. These results were consistent with the slower N release measured for Duration. Residual nitrate-N remaining in the soil after harvest was greatest for treatments that included Duration, so the delayed N release from Duration increases the potential for leaching losses of N in the fall and early spring before the beginning of the next growing season and suggests the need for a cover crop following harvest if this N source is used.

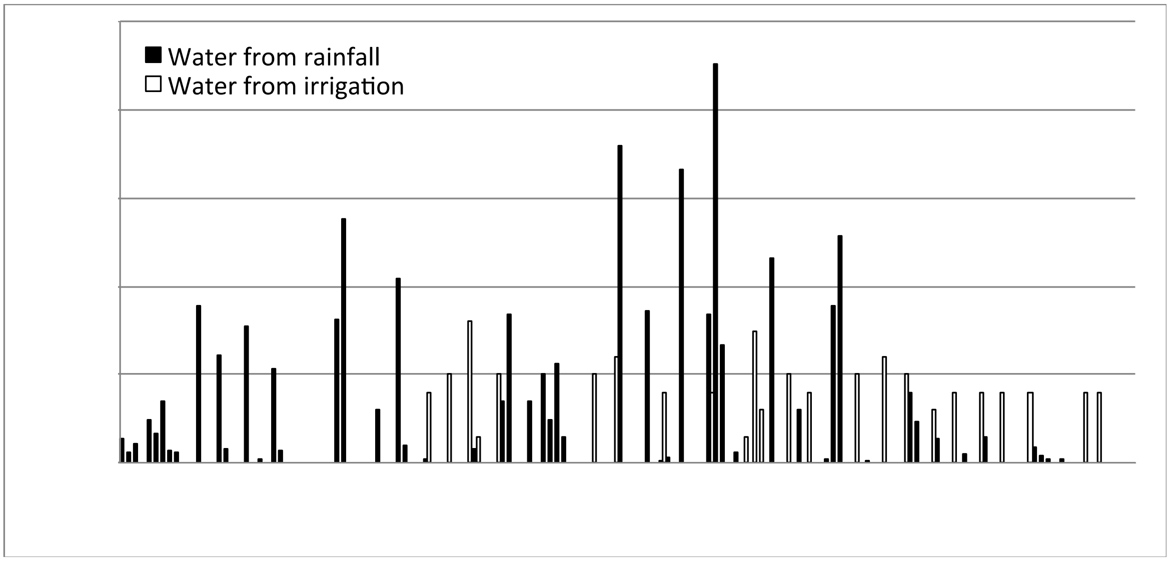

Fig. 1. Rainfall and irrigation amounts during the 2011 growing season.

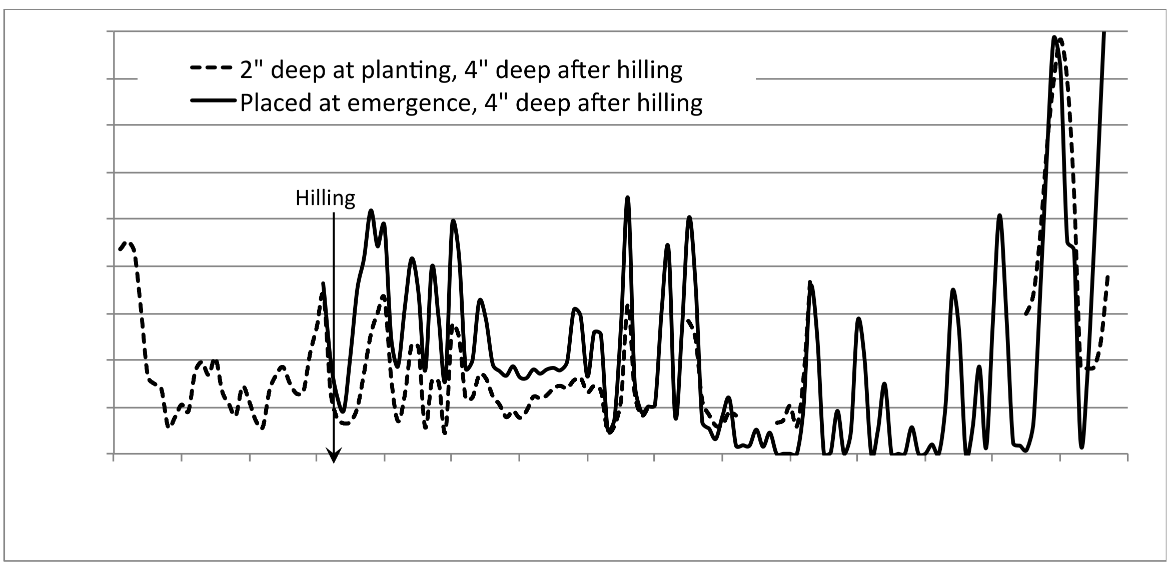

Fig. 2. Soil moisture at two field locations during the 2011 growing season.

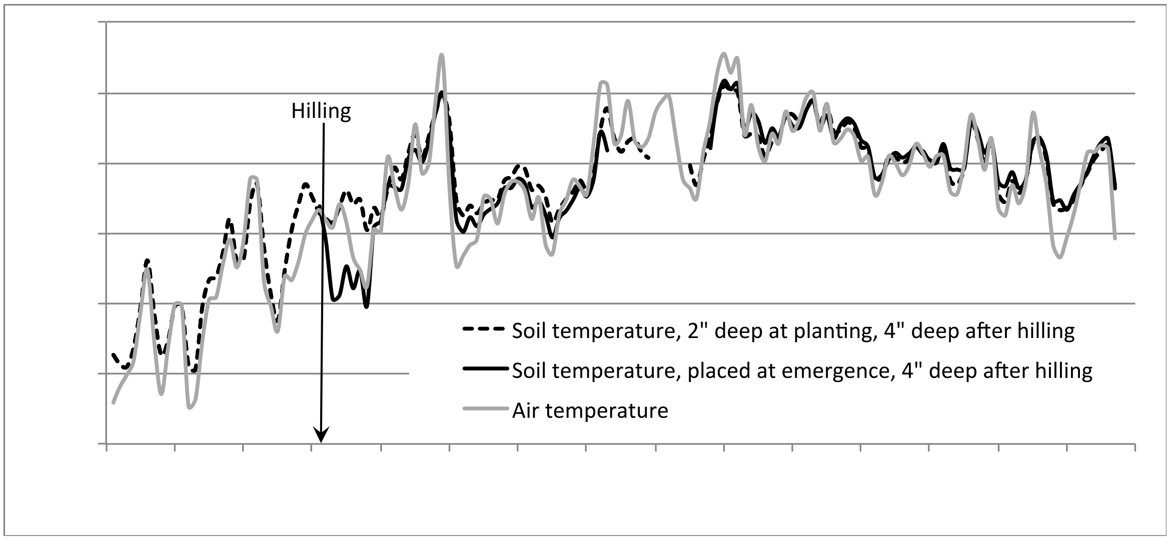

Fig. 3. Soil temperature at two field locations and air temperature during the 2011 growing season.

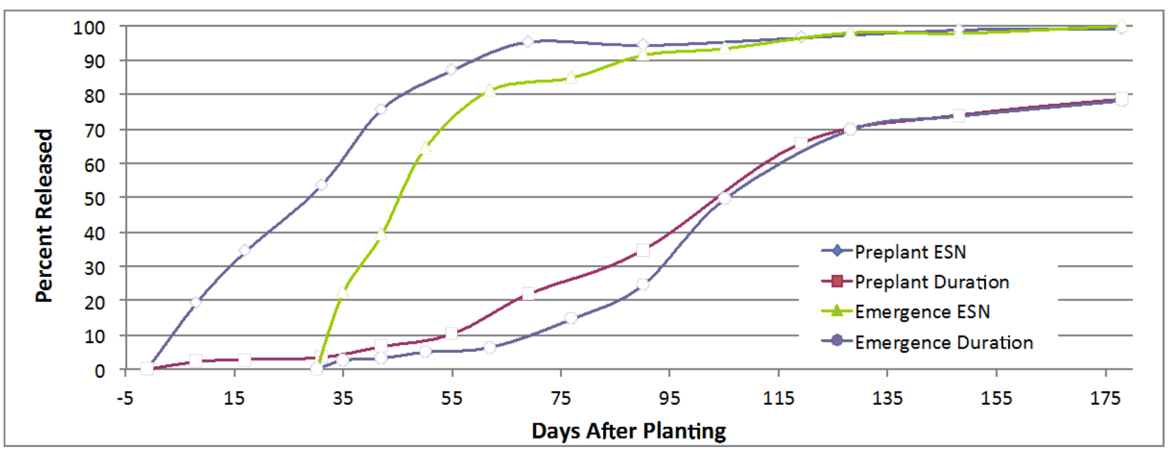

Fig. 4. Nitrogen release from ESN and Duration controlled release fertilizers applied preplant or at potato emergence.

Table 2. Effect of nitrogen source, rate, and timing, and soil amendment with SBAF[1], on Russet Burbank tuber yield and size distribution.

Nitrogen & Soil Amendment Treatments				Tuber Yield										
Trtmt #	N Source[2]	N Rate	N & SBAF Timing[3]	0-3 oz	3-6 oz	6-10 oz	10-14 oz	>14 oz	Total	#1 > 3 oz	#2 > 3 oz	Total Marketable	> 6 oz	> 10 oz
		lb N / A	PP, P, E, PH	cwt / A									%	
1	MAP+AS	30	0, 30, 0, 0	96.5	213.0	36.6	1.8	0.0	347.9	189.8	61.6	251.4	11.1	0.5
2	MAP+AS, Urea, UAN	170	0, 30, 70, 70	102.5	171.1	131.4	59.4	16.5	481.0	298.2	80.3	378.5	42.4	15.4
3	MAP+AS, Urea, UAN	240	0, 30, 105, 105	108.8	208.9	136.5	54.7	19.1	528.0	325.4	93.7	419.2	39.1	13.6
4	Urea, MAP+AS	240	210, 30, 0, 0	101.9	190.7	110.3	46.6	20.3	469.8	294.7	73.2	367.8	37.4	13.9
5	MAP+AS, ESN	170	0, 30, 140, 0	96.2	209.5	134.0	34.0	14.5	488.2	320.0	72.0	392.0	37.5	10.0
6	MAP+AS, ESN	240	0, 30, 210, 0	98.6	193.8	137.2	56.7	11.3	497.7	340.4	58.7	399.1	40.4	13.4
7	MAP+AS, Urea+ESN	240	0, 30, 105+105, 0	100.8	174.2	132.5	48.0	28.6	484.2	322.3	61.1	383.4	42.6	15.5
8	ESN, MAP+AS	240	210, 30, 0, 0	94.4	197.5	156.2	53.0	13.2	514.3	329.4	90.6	419.9	43.4	12.9
9	Duration, MAP+AS	170	140, 30, 0, 0	74.2	215.7	150.2	43.9	12.3	496.2	313.2	108.8	422.0	41.7	11.4
10	Duration, MAP+AS	240	210, 30, 0, 0	114.4	209.7	140.2	56.4	15.6	536.3	260.1	161.8	421.9	39.0	13.1
11	Duration, MAP+AS, Urea	240	105, 30, 105, 0	109.0	205.9	121.0	37.6	14.2	487.7	290.3	88.4	378.7	34.8	10.1
12	MAP+AS, Duration	240	0, 30, 210, 0	109.1	237.2	121.8	32.3	5.9	506.1	240.9	156.1	397.1	31.3	7.4
13	ESN+Duration, MAP+AS	170	70+70, 30, 0, 0	114.5	214.2	116.0	33.9	22.5	501.0	313.0	73.6	386.5	34.0	10.6
14	ESN+Duration, MAP+AS	240	105+105,30,0,0	109.8	214.5	114.4	37.5	17.8	494.0	285.1	99.1	384.2	34.1	11.1
15	MAP+AS, ESN+Duration	240	0,30,105+105,0	104.8	218.9	148.6	65.0	14.6	551.9	298.0	149.1	447.0	41.2	14.3
16	MAP+AS, Urea+Duration	240	0,30,105+105,0	110.2	206.3	118.1	43.6	11.6	489.8	279.1	100.5	379.6	34.8	10.9
17	MAP+AS+2qt. SBAF, Urea+1qt SBAF, UAN+1qt SBAF	170 +4qt SBAF	0, 30+2qt, 70+1qt, 70+1qt	102.4	216.3	122.1	32.4	2.5	475.7	303.2	70.1	373.3	32.9	7.3
18	MAP+AS+1qt SBAF, Urea+1qt SBAF, UAN	170 +2qt SBAF	0, 30+1qt., 70+1qt, 70	134.6	196.4	113.4	34.8	6.9	486.1	267.4	84.1	351.5	32.0	8.6
			Significance[4]	NS	NS	**	**	NS	**	**	**	**	**	*
			LSD (0.10)	--	--	24.5	26.7	--	36.0	36.8	30.2	40.9	9.1	8.6

[1]SoilBuilder AF (Advanced Microbial Solutions).
[2]MAP = monoammonium phosphate (10-50-0), AS = ammonium sulfate (21-0-0), Urea = 46-0-0, UAN = urea and ammonium nitrate (28-0-0), ESN = Environmentally Smart Nitrogen (44-0-0), Duration = 43-0-0, SBAF = SoilBuilder AF.
[3]PP = preplant, P = planting, E = emergence/hilling, PH = post-hilling (5 applications).
[4]NS = Non significant; ++, *, ** = Significant at 10%, 5%, and 1%, respectively.

Table 3. Effect of nitrogen source, rate, and timing, and soil amendment with SBAF[1], on Russet Burbank tuber quality, plant stand, and number of stems per plant.

Nitrogen & Soil Amendment Treatments				Tuber Quality				Plant Stand	# of Stems per Plant
Trtmt #	N Source[2]	N Rate	N & SBAF Timing[3]	Specific Gravity	Hollow Heart	Brown Center	Scab		
		lb N / A	PP, P, E, PH		---------------------- % ----------------------				
1	MAP+AS	30	0, 30, 0, 0	1.0735	0.0	0.0	5.0	100.0	2.78
2	MAP+AS, Urea, UAN	170	0, 30, 70, 70	1.0725	5.0	5.0	0.0	100.0	2.63
3	MAP+AS, Urea, UAN	240	0, 30, 105, 105	1.0755	14.0	12.0	3.0	100.0	2.88
4	Urea, MAP+AS	240	210, 30, 0, 0	1.0729	8.3	6.2	1.0	99.3	2.90
5	MAP+AS, ESN	170	0, 30, 140, 0	1.0765	8.0	7.0	0.0	100.0	2.85
6	MAP+AS, ESN	240	0, 30, 210, 0	1.0726	12.1	9.0	0.0	100.0	2.85
7	MAP+AS, Urea+ESN	240	0, 30, 105+105, 0	1.0740	11.0	12.0	2.0	99.3	2.95
8	ESN, MAP+AS	240	210, 30, 0, 0	1.0759	4.0	3.0	3.0	100.0	2.98
9	Duration, MAP+AS	170	140, 30, 0, 0	1.0733	5.0	0.0	1.9	100.0	2.55
10	Duration, MAP+AS	240	210, 30, 0, 0	1.0784	8.0	7.0	1.0	100.0	3.25
11	Duration, MAP+AS, Urea	240	105, 30, 105, 0	1.0721	10.0	9.0	0.0	100.0	2.95
12	MAP+AS, Duration	240	0, 30, 210, 0	1.0718	5.9	4.0	0.0	100.0	2.90
13	ESN+Duration, MAP+AS	170	70+70, 30, 0, 0	1.0783	3.9	3.9	4.0	100.0	3.23
14	ESN+Duration, MAP+AS	240	105+105,30,0,0	1.0733	12.0	9.0	4.0	100.0	3.25
15	MAP+AS, ESN+Duration	240	0,30,105+105,0	1.0766	10.9	9.0	4.0	99.3	2.88
16	MAP+AS, Urea+Duration	240	0,30,105+105,0	1.0716	5.0	5.0	0.0	100.0	2.63
17	MAP+AS+2qt. SBAF, Urea+1qt SBAF, UAN+1qt SBAF	170 +4qt SBAF	0, 30+2qt, 70+1qt, 70+1qt	1.0741	3.0	3.0	5.0	100.0	2.83
18	MAP+AS+1qt SBAF, Urea+1qt SBAF, UAN	170 +2qt SBAF	0, 30+1qt., 70+1qt, 70	1.0731	1.0	1.0	0.0	100.0	3.25
			Significance[4]	NS	*	NS	NS	NS	*
			LSD (0.10)	--	11.1	--	--	--	0.41

[1]SoilBuilder AF (Advanced Microbial Solutions).
[2]MAP = monoammonium phosphate (10-50-0), AS = ammonium sulfate (21-0-0), Urea = 46-0-0, UAN = urea and ammonium nitrate (28-0-0), ESN = Environmentally Smart Nitrogen (44-0-0), Duration = 43-0-0, SBAF = SoilBuilder AF.
[3]PP = preplant, P = planting, E = emergence/hilling, PH = post-hilling (5 applications).
[4]NS = Non significant; ++, *, ** = Significant at 10%, 5%, and 1%, respectively.

Table 4. Effect of nitrogen source, rate, and timing, and soil amendment with SBAF[1], on petiole nitrate-N on four sampling dates.

Nitrogen & Soil Amendment Treatments				Petiole Nitrate - N			
Trtmt #	N Source[2]	N Rate lb N / A	N & SBAF Timing[3] PP, P, E, PH	14-Jun	28-Jun	11-Jul	25-Jul
				ppm			
1	MAP+AS	30	0, 30, 0, 0	2476	412	96	142
2	MAP+AS, Urea, UAN	170	0, 30, 70, 70	12938	2388	5486	3914
3	MAP+AS, Urea, UAN	240	0, 30, 105, 105	12927	4014	9865	7271
4	Urea, MAP+AS	240	210, 30, 0, 0	15234	4659	2422	1567
5	MAP+AS, ESN	170	0, 30, 140, 0	12476	5661	3346	1567
6	MAP+AS, ESN	240	0, 30, 210, 0	14065	9170	5879	4103
7	MAP+AS, Urea+ESN	240	0, 30, 105+105, 0	16206	11879	6135	2997
8	ESN, MAP+AS	240	210, 30, 0, 0	15939	6337	5228	2680
9	Duration, MAP+AS	170	140, 30, 0, 0	4165	1172	2321	3568
10	Duration, MAP+AS	240	210, 30, 0, 0	6445	2494	5985	9069
11	Duration, MAP+AS, Urea	240	105, 30, 105, 0	14489	4095	4772	5459
12	MAP+AS, Duration	240	0, 30, 210, 0	4749	1455	3539	12342
13	ESN+Duration, MAP+AS	170	70+70, 30, 0, 0	8974	2505	2107	3647
14	ESN+Duration, MAP+AS	240	105+105,30,0,0	14501	3546	5951	6732
15	MAP+AS, ESN+Duration	240	0,30,105+105,0	11501	3585	4530	7814
16	MAP+AS, Urea+Duration	240	0,30,105+105,0	12581	2882	3083	5853
17	MAP+AS+2qt. SBAF, Urea+1qt SBAF, UAN+1qt SBAF	170 +4qt SBAF	0, 30+2qt, 70+1qt, 70+1qt	14270	1643	5611	5750
18	MAP+AS+1qt SBAF, Urea+1qt SBAF, UAN	170 +2qt SBAF	0, 30+1qt., 70+1qt, 70	12594	3073	5770	6725
			Significance[4]	**	**	**	**
			LSD (0.10)	2022	2292	1755	1696

[1]SoilBuilder AF (Advanced Microbial Solutions).

[2]MAP = monoammonium phosphate (10-50-0), AS = ammonium sulfate (21-0-0), Urea = 46-0-0, UAN = urea and ammonium nitrate (28-0-0), ESN = Environmentally Smart Nitrogen (44-0-0), Duration = 43-0-0, SBAF = SoilBuilder AF.

[3]PP = preplant, P = planting, E = emergence/hilling, PH = post-hilling (5 applications).

[4]NS = Non significant; ++, *, ** = Significant at 10%, 5%, and 1%, respectively.

Table 5. Effect of nitrogen source, rate, and timing, and soil amendment with SBAF1, on residual nitrate-N in the upper 2 ft of soil after harvest.

Nitrogen & Soil Amendment Treatments				Residual
Trtmt #	N Source[2]	N Rate	N & SBAF Timing[3]	NO_3-N
		lb N / A	PP, P, E, PH	lb N / A
1	MAP+AS	30	0, 30, 0, 0	23.2
2	MAP+AS, Urea, UAN	170	0, 30, 70, 70	36.7
3	MAP+AS, Urea, UAN	240	0, 30, 105, 105	34.1
4	Urea, MAP+AS	240	210, 30, 0, 0	32.5
5	MAP+AS, ESN	170	0, 30, 140, 0	34.4
6	MAP+AS, ESN	240	0, 30, 210, 0	35.1
7	MAP+AS, Urea+ESN	240	0, 30, 105+105, 0	44.1
8	ESN, MAP+AS	240	210, 30, 0, 0	37.6
9	Duration, MAP+AS	170	140, 30, 0, 0	37.0
10	Duration, MAP+AS	240	210, 30, 0, 0	57.7
11	Duration, MAP+AS, Urea	240	105, 30, 105, 0	44.5
12	MAP+AS, Duration	240	0, 30, 210, 0	52.5
13	ESN+Duration, MAP+AS	170	70+70, 30, 0, 0	32.0
14	ESN+Duration, MAP+AS	240	105+105,30,0,0	43.1
15	MAP+AS, ESN+Duration	240	0,30,105+105,0	43.9
16	MAP+AS, Urea+Duration	240	0,30,105+105,0	41.2
17	MAP+AS+2qt. SBAF, Urea+1qt SBAF, UAN+1qt SBAF	170 +4qt SBAF	0, 30+2qt, 70+1qt, 70+1qt	32.1
18	MAP+AS+1qt SBAF, Urea+1qt SBAF, UAN	170 +2qt SBAF	0, 30+1qt., 70+1qt, 70	32.3
			Significance[4]	**
			LSD (0.10)	7.2

[1]SoilBuilder AF (Advanced Microbial Solutions).
[2]MAP = monoammonium phosphate (10-50-0), AS = ammonium sulfate (21-0-0), Urea = 46-0-0, UAN = urea and a
ESN = Environmentally Smart Nitrogen (44-0-0), Duration = 43-0-0, SBAF = SoilBuilder AF.
[3]PP = preplant, P = planting, E = emergence/hilling, PH = post-hilling (5 applications).
[4]NS = Non significant; ++, *, ** = Significant at 10%, 5%, and 1%, respectively.

Project Title: Potato Breeding and Genetics University of Minnesota
Project leader: Dr. Christian A. Thill

Research Scientist: Jeffrey L. Miller
Assistant Scientist: Kristen John

OBJECTIVES OF THIS RESEARCH
The objective of this research is to develop and release potato varieties adapted to Minnesota and North Dakota. Selection will emphasize lines having superior yield, quality, and host plant resistance to biotic and abiotic stress.

GOALS OF THIS RESEARCH
Breeding efforts focus on state and regional needs as identified by growers at research prioritization meetings.

1. French fry processing lines that fry from the field, fry from 48F or below, have specific gravity >1.085.
2. Fresh market red skin, white flesh lines that retain color at harvest and after storage and do not skin.
3. Potato chipping lines with white skin and white flesh that chip directly from the field and after long term storage without accumulating reducing sugars, and specific gravity > 1.085.
4. Fresh market red skin, yellow flesh lines that retain color at harvest and storage and do not skin.

SELECTIONS FOR RELEASE IN 2012
MN18747 A 80-day maturity, blocky long white, white skin potato for the FF field processing & fresh market.
MN02616R/Y A red skin yellow flesh potato for the fresh market.
MN99380-1Y A white skin yellow flesh potato for chip and fresh market.

SUMMARY
Research emphasized the development, evaluation and release of potato varieties with improved yield, quality, and resistance to biotic and abiotic stress. We field evaluated 53,000 single-hill generation (SH) seedlings from 200 families. New hybrid crosses focused on priority traits determined by Minnesota (MN) and North Dakota (ND) growers in French fry processing, fresh market russet and red skin, and potato chip processing markets. Combined we selected 650 SH lines for these markets. Among SH populations we continue studying environmental influence on selection efficiency. As example, variation in red skin color and degree of color fading is observed across locations; influencing selection decisions. A new, short-season northern MN site with peat soils was added for developing early maturing fresh reds. We observe improved red skin color when growing on peat soils and selected 157 SH clones with bright red color. Conversely, red skin color fades on sandy soils; the predominant soil type in commercial central MN regions. Concern arises though if SH selection occurs in commercial regions due to line contamination with viral pathogens; which, hinders our ability to replant and reevaluate them due to yield and quality declines. The northern seed site facilitates production of virus free seed for subsequent evaluation on sandy soils. We selected 157 SH and 50 generation 1 (G1) red lines for testing on-farm in sandy soils in 2012. Growing for processing also predominates in central MN and we selected 100 SH fry, and 238 SH chip lines. SH selections fill the breeding pipeline for subsequent evaluation over years across MN environments. We continued evaluation of 450 generation 2 (G2) through G3, G4, and G5 or greater lines in MN and ND for yield, grade, internal and external physiological defects, and processing quality at harvest and from low temperature storage. Host plant resistance to common scab, late blight, and viral pathogens was also determined. Promising lines include MN02419Rus, MN18747, and MN02467Rus/Y for fry processing; MN03178-2Rus and MN02467Rus/Y for fresh russet; MN96072-4R/W, MN99460-14R/W, MN03505-3R/W, MN03021-1R/W, MN03027-1R/W, MN06030-1R/W, MN02616R/Y, and MN96013-1 for fresh red; MN02696, MN00467-4, MN02574, MN03339-4, MN02588, and MN99380-1Y for chips; MN02586Y, and MN04844-07Y for fresh

yellow markets. We released MN15620 (MonDak Gold) to growers in 2010. Commercial testing continues exploiting its long-storage fry potential and as a roasted restaurant product. MN18747, MN02419Rus, MN02467Rus/Y, and MonDak Gold are fry lines with low acrylamide (less than 200ppb). Cultivar Russet Burbank had greater than 1000ppb acrylamide. Acrylamide is a known carcinogen found in processed food products, and is a major concern to the industry. Chip potato line MN99380-1Y was selected for fast-track expansion by the US Potato Board due to its high yield and superior quality, and will be grown at 11 US locations in 2012. The red skin yellow flesh line MN02616R/Y is being expanded for commercialization and varietal release in 2012. These clones are maintained in tissue culture as virus free; seed was produced for stakeholder testing.

BREEDING YIELD & QUALITY TRIALS

Yield, Grade and Quality Evaluations – Selections advancing are compared to commercial cultivars in field trials at irrigated and non-irrigated locations in MN and ND. Plant maturity, yield, grade, and quality information are collected at harvest. Data for the following attributes are collected – US #1 marketable and size distribution yield, percentage of U.S. #1 yield and graded defect weights (malformed tubers, severe growth cracking, etc.), specific gravity, incidence and type of internal and external defects, and processing color. A comprehensive storage/processing/temperature profile (40 & 45F direct and reconditioning) for chip and French fry potato types is performed. Following harvest at each varietal evaluation site, clones are graded and packaged into samples for storage @ 1, 3, 5, 7 & 9 months. At each time point physiological defects, both, internal (hollow heart, internal brown center, vascular discoloration), and external (bruise, skin color) are determined. Additional processing characteristics include FF length distribution, and characterization for sugar end and dark ends. Red-skinned selections are evaluated for color and skin sloughing at harvest and storage.

Crosses sown 2011: 200

Single Hill Population: 4,000@UMORE Park, 19,000@Nesson Valley (Russet only population), 30,000@PLWR

Single Hill (G0) Selections: 31@UMORE Park, 80@Nesson Valley, 539@ PLWR

	UMORE	*Nesson*	*PLWR*	*Total*
Russet	16	71	100	187
Red	2	6	157	165
Chip	13	1	238	252
Yellow	0	0	40	40
Other		2	4	6
Total	31	80	539	

First Year (G1) Selections: 135@Becker, 135@Nesson Valley

Second Year (G2) Selections: 100@Becker, 100@Nesson Valley, All 3 Disease Trials

G2 Red Family selection at PLWR
In 2010 168 red selections from 40 families was made. 2011 selections among the 168 yielded 49 G2 selections.

Third year (G3) Selections: 43@Becker, and Nesson Valley, All 3 Disease Trials

Fourth Year (G4) selections: 44@Becker and Nesson Valley, All 3 Disease Trials

Fifth Year and greater Selections: 17@Becker, 23@Nesson Valley, All 3 Disease Trials

Strip-trial at Nesson Valley;
Eight breeding lines were grown in 200-hill, 2-row strip plots to determine commercial handling and adaptation. Processing lines are being evaluated bi-monthly by Ag World Support Systems for grade and quality. Red lines are stored at USDA and are being evaluated monthly for storage quality.

Processing	MonDak Gold
Russet Fresh	MN02467Y
Red Fresh	MN02616R/Y, MN19298R/Y
Chip	MN00467-4, MN03339-4, MN02588,

Yellow MN02586Y

DISEASE RESISTANCE BREEDING

Disease screening for foliar and tuber late blight, common scab, PVY and PLRV resistance and PVY symptom expression, are performed on all selections from the 2nd clonal generation.

Late blight resistance: The primary focus of this research is to develop new potato varieties and parental germplasm resistant to late blight. Breeding lines are evaluated 3x for % late blight infection after inoculation. Selections will be made advancing the most resistant lines. This work is done at UMORE Park, Rosemount, MN.

Lines evaluated include: MN Breeding lines, NCR lines, National late blight lines, US Potato Board Chip Breeders Trial lines. N=590 clones

Common scab resistance: The primary focus of this research is to develop new potato varieties and parental germplasm resistant to common scab. Common scab is a soil-borne disease, which causes significant economic loss by adversely affecting tuber quality with lesions on the tuber periderm. Breeding lines are evaluated for disease incidence (% coverage) and disease severity (surface, raised, and pitted scab; individual or coalesced lesions). This work is done at the Sand Plains Research Farm in Becker, MN.

Lines evaluated include: MN Breeding lines, NCR lines, National C. Scab lines, US Potato Board Chip Breeders Trial lines. N=575 clones

PVY resistance and PVY symptom expression: The primary focus of this research is to develop new potato varieties and parental germplasm resistant to PVY. Additionally this research explores the symptom expression of PVY and its relationship to variety. PVY is a viral plant disease that reduces potato plant productivity, marketability, and seed quality. This work is done at UMORE Park, Rosemount, MN.

Lines evaluated include: MN Breeding lines, NCR lines, National breeding lines, US Potato Board Chip Breeders Trial lines, and Flynn MS. Research PVY resistance lines. N=564 clones

SEED

G1 & G2 Seed production; MDA; UM at PLWR

Tissue culture transplant seedlings, Pre nuclear seed, and G1 seed from lines produced G1 and G2 seed.

Processing	MN02419, MN18747, MonDak Gold
Russet Fresh	MN02467Y
Red Fresh	MN03021-1R, MN02616R/Y
Chip	MN00467-4, MN02574, MN03339-4, MN02588, MN99380-1Y
Yellow	MN02586Y, MN04844-07Y

Prenuclear and G1 Hybrid crosses seed; MDA, UM greenhouse, PLWR

Pre nuclear seed of 200 families from 2010 winter crosses was produced in isolated UM greenhouses under MDA guidelines. Lines were grown in 5 pot sizes (second year study) to determine production efficiency.

Additionally the 159 families were transplanted to PLWR@ 150 seedlings / family and selected.

		# of Families Planted	*# of Families Selected*	*# of Clones Selected*
Russet		28	24	100
Red		59	41	157
Chip		54	47	238
yellow		13	11	40
Other		5	3	4

Pre nuclear; Valley Tissue Culture

MonDak Gold MN18747 MN02616R/Y
MN99380-1Y MN04844-07Y

Seed Trials

MN02616R/Y	PLWR	G1
MonDak Gold	Enander Farms	G1
MN02616R/Y	K. Mason	Prenuclear
MN04844-07Y	K. Mason	Prenuclear
MN02586Y	R. Schmidt	G1
MN99380-1	R. Schmidt	G1
MN18747	J. Dagen	G2
MN02616R/Y	J. Dagen	G2

Commercial Trials

MN18747 L. Ryman G2 (flooding)
8 MN lines Tri-Campbell Farms G2

TRANSITIONING TO VIRUS FREE

Processing

MN02419Rus Lt Russet skin, white flesh, long shape FF processing line from 45F

Russet Fresh

MN03178-2Rus Blocky russet, white flesh, FF processing

Red Fresh

MN96072-4R/W Red skin, white flesh, Fresh
MN99460-14R/WRed skin, white flesh, Fresh
ATMN03505-3R/W Red skin, white flesh, Fresh; storage red
MN03021-1R/W Red skin, white flesh, Fresh; storage red
MN03027-1R/W Red skin, white flesh, Fresh; storage red
MN06030-1R/W Red skin, white flesh, Fresh; small uniform size, large B market

Chip

MN02696 White skin, white flesh, Chip potato with CIS resistance from 42F

Yellow

MN96013-1R/Y Red skin, yellow flesh, Fresh

POTATO VIRUS ERADICATION STRATEGIES TO ADVANCE MN BREEDING LINES

The primary focus of this laboratory research is continued development of strategies for eradicating virus from potato breeding lines. Viral infection is a major constraint to the production of high yielding potatoes and virus can be transmitted from generation to generation through seed tubers. Cryotherapy is an *in vitro* technique recently found to eliminate virus from vegetatively propagated plant shoots. Current virus eradication methods in potato are costly and time-consuming factors that minimize the number of clones subjected to virus eradication methods. Potato breeders maintain vegetatively many clones with valuable breeding traits; frequently these clones are infected with one or more viruses. A less expensive, less time consuming procedure for virus eradication would benefit both the research community and the potato industry:

1. Breeders could deploy new varieties with expediency avoiding time consuming protocols (up to 18 months) and high costs (ca. $3-5K / clone) due to limitations imposed by current methods;
2. Lower virus in breeding populations would result in higher quality performance trials;
3. Germplasm lacking virus reduces the risk of moving novel potato diseases across the US while sharing germplasm for national trials.

The goal of this project is to determine the effectiveness, reliability, and efficiency of cryotherapy as a means of eliminating virus from potato.

NEW GRANTS INITIATIVES

North Dakota/ Montana Specialty Crop Block Grant Program: $100,000 (UM $20,000) for research on MonDak Gold, pre nuclear seed production of MonDak Gold, and storage quality and market testing of MonDak Gold and other UM breeding lines. *Thill / Bergman*

MDA US Farm Bill Grants Funds: $100,000 for research on MN02616R/Y, pre nuclear seed production of MN02616R/Y, and storage quality and market testing of MN02616R/Y lines. *Thill / PLWR (Spring 2012)*

USDA/ARS/NPC Potato grants:
National common scab *(December 2011)*
National late blight *(December 2011)*
Cryotherapy *(December 2011)*

EXTENSION / COMMUNICATION:

MN Area II: Reporting conference & field @ Becker
NPPGA: Reporting conference / Expo & field/shed @ Twilight tour
MONDAK: MonDak Irrigation Tour & MonDak Ag Open @ Nesson Valley field

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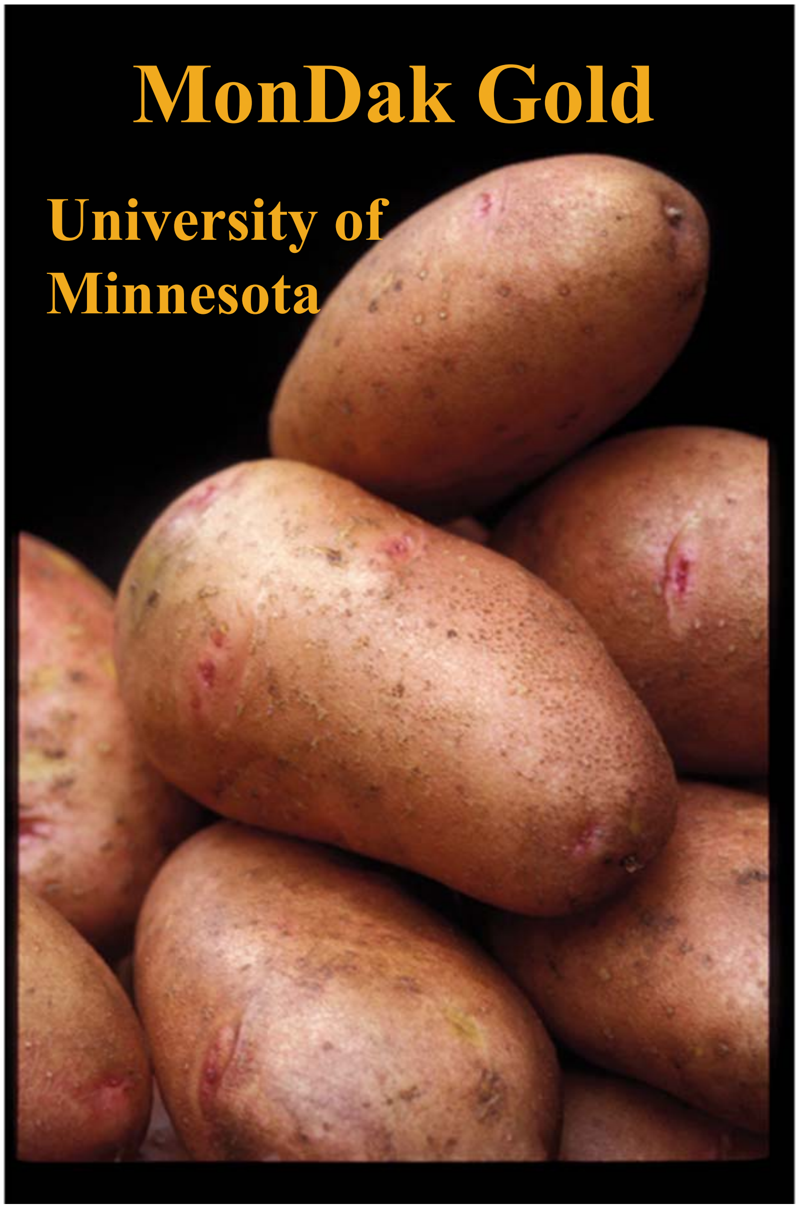
NOTES:


MonDak Gold
University of Minnesota

INVEST IN GOLD

MonDak Gold

(LOW ACRYLAMIDE (< 150ppb, USPB Fry trials), **GOLDEN Fries)**

Incentives for production: The tubers of MonDak Gold have a uniform shape with a smooth skin and light yellow flesh; >92% of the tubers are US No. 1. French fry processing color is excellent from 45F. Tuber set averages 10 tubers/plant with >60% over 6oz. Specific gravity of MonDak Gold ranges 1.080 - 1.085. Smaller tubers may be marketed for fresh market due to their light yellow flesh.

Strengths: MonDak Gold has a smooth red to pink color skin, light yellow flesh, oblong tuber shape, and excellent cooking qualities that make it suitable for French fry processing and tablestock use. MonDak Gold has low acrylamide and frys late from storage. Internal quality is excellent. MonDak Gold is resistant to PVY and PLRV, and has moderate field tolerance to CPB, and Verticillium wilt.

Culinary Quality: MonDak Gold can be used for processing into fries, fresh market baking, mashing, roasting, and microwave cooking.
Seed availability: Virus-free tissue culture plantlets of MonDak Gold are available from the University of Minnesota Potato Breeding program. Tissue culture plantlets are available from the MN. Dept. of Agr. Seed Potato Certification, **www.mnseedpotato.org**

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Potato Research Team
This potato research is a collaborative effort of the potato research programs at the University of Minnesota and the NDSU Williston Research Extension Center; with assistance from the Williston Area Ag. Diversification Group, Spud Viking Consulting, and the Northern Plains Potato Growers Association. These organizations work together conducting potato research and varietal testing for developing cultivars for specific markets and adapted to the MonDak and Northern Plains region.


University of Minnesota
Potato Breeding and Genetics
Potato Seedling MN 02616 R/Y

MN02616R/Y

Parentage: Minnesota Family #149 x OP

Developers: University of Minnesota, Minnesota Agricultural Experiment Station.

Strengths: MN02616R/Y is a seedling selected by C. Thill having a smooth uniform round to oval shape with dark red skin, deep yellow flesh, and excellent internal quality. Its use is for the Fresh market as baked, boiled, salad, fried or grilled.

Incentives for production: The tubers of MN02616R/Y have a uniform round to oval shape with dark red skin and deep yellow flesh. Culinary characteristics are excellent. Tuber set averages 13 tubers/plant and 43% > 6oz. and a large proportion of of the tubers are US No. 1. MN02616R/Y specific gravity ranges from 1.066 - 1.076. Internal quality is excellent.

Excellent culinary quality

Morphological Characteristics:

Plant: Dark green foliage; vine has an erect to spreading growth habit, medium to tall in height; intermediate stemmy to leafy foliage providing full canopy cover over the bed. Vigor is excellent.

Tubers: Dark red skin, deep yellow flesh, round to oval uniform tuber shape with shallow eyes, and excellent internal quality.

Flower: Red violet.

Agronomic Characteristics:

Foliage: Dark green foliage with medium to large leaflets.

Maturity: Medium to full season.

Yield: Medium to high yield.

Specific gravity: Moderate to low.

Storability: Medium dormancy (January - February).

Culinary quality: MN02616R/Y when prepared for Fresh market use as baked, boiled, salad, fried or grilled - its golden flesh makes appealing culinary products.

Disease reaction: MN02616R/Y expresses normal symptoms of PVY and PLRV, susceptible to common scab and late blight.

Seed availability: Virus-free tissue culture plantlets of MN02616R/Y are available from the University of Minnesota Potato Breeding program as are small amounts of seed. Tissue culture plantlets are available from the Minnesota Department of Agriculture, Seed Potato Certification, **www.mnseedpotato.org**.

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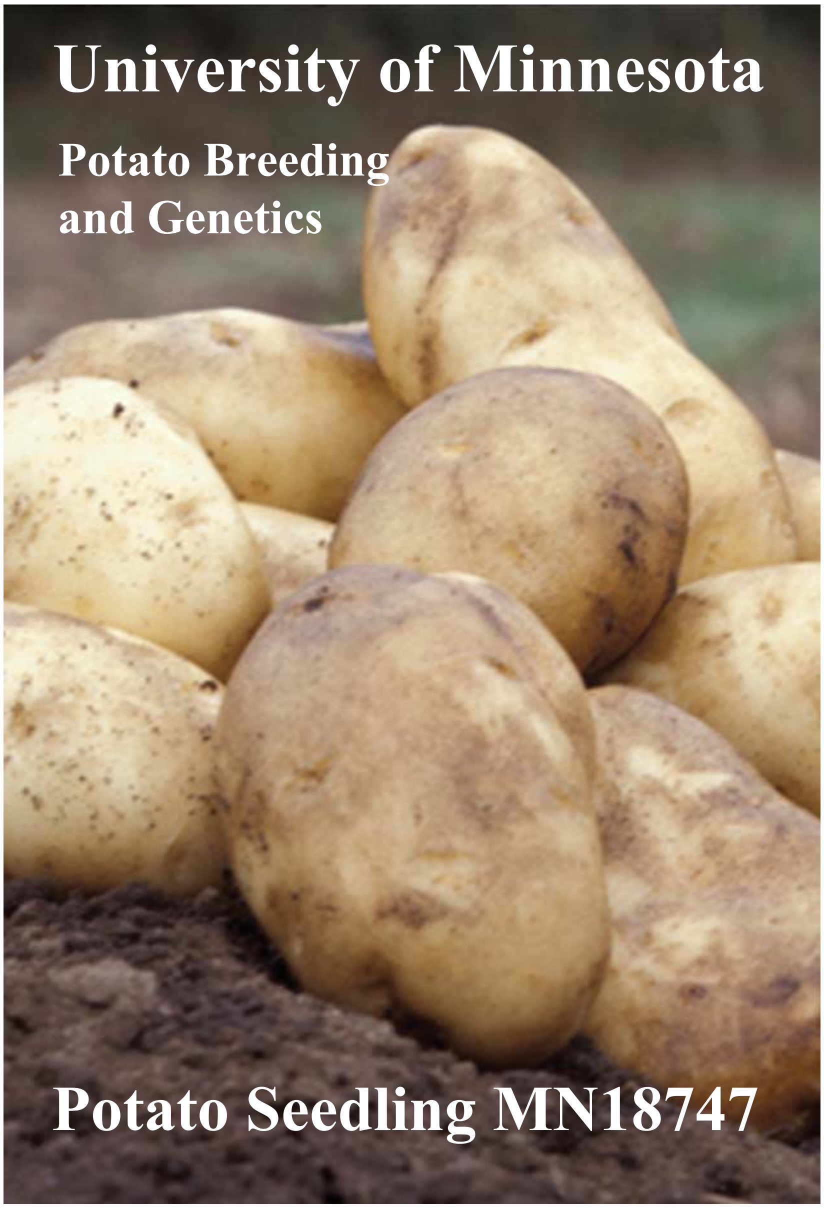
North Central Potato Breeding Team

The North Central Potato Breeding Team is a cooperative effort of the potato research programs at Michigan State University, the University of Minnesota, North Dakota State University, and the University of Wisconsin. The four states work together conducting breeding and genetic research, disease and pest resistance screening, develop improved cultivars, and enhance germplasm with the potato industry in the North Central Region. Teams of researchers from the four cooperating institutions apply conventional and molecular breeding strategies to develop and test improved cultivars for specific markets.


University of Minnesota
Potato Breeding
and Genetics
Potato Seedling MN18747

MN18747

Parentage: ND 2264-7 x MN 47.82-6 (MN 14489)
Developers: University of Minnesota, Minnesota Agricultural Experiment Station.
Strengths: MN18747 is a seedling selected by C. Thill having a bright white skin color, white flesh, and blocky to oblong uniform tubers. Its use is for early French fry processing, it has low acrylamide formation, and excellent internal quality. MN18747 expresses normal symptoms of PVY, and is resistant to common scab.
Incentives for production: The tubers of MN18747 have a uniform blocky shape with a smooth bright skin and white flesh. Tuber set averages 7 tubers/plant with >55% early harvest and >80% late harvest over 6oz. Early French fry processing color is excellent as is from 48F storage. Specific gravity of MN18747 is 1.080.

(LOW ACRYLAMIDE (<150ppb USPB national testing), **EARLY)**

Morphological Characteristics:

Plant: Dark green foliage; intermediate to stemmy erect vine and tall in height, large oblong leaflets that provide good bed cover. Vigor is excellent.
Tubers: The tubers are smooth, white color skin, white flesh, and a blocky-oblong uniform tuber shape. MN18747 has excellent internal quality.
Flower: Flowers are red violet with prominent white tips that fade to white.

Agronomic Characteristics:

Foliage: Dark green foliage with large oblong leaflets.
Maturity: Medium to early bulking.
Yield: Tubers bulk early and yield it moderate to high in Minnesota irrigated.
Specific Gravity: Moderate, ranging from 1.077 to 1.081 in Minnesota irrigated.
Storability: Medium dormancy, i.e. slight sprouting at 5 months.
Culinary Quality: MN18747 tubers can be used for fresh market baking, mashing, and microwave cooking and for processing into French fries.
Diseases reaction: Normal symptoms of PVY and PLRV infection, resistant to common scab, susceptibility to CPB, Verticillium wilt, and late blight.
Seed availability: Virus-free tissue culture plantlets of MN18747 are available from the University of Minnesota Potato Breeding program as are small amounts of seed. Tissue culture plantlets are available from the Minnesota Department of Agriculture, Seed Potato Certification, **www.mnseedpotato.org**.

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University of Minnesota
Potato Breeding and Genetics
Potato Seedling MN99380-1Y

MN99380-1Y

Parentage: Atlantic x MSA091-1
Developers: University of Minnesota, Minnesota Agricultural Experiment Station.
Strengths: MN99380-1Y is a seedling selected in 1999 having white skin, yellow flesh, smooth uniform tubers, and excellent internal quality. Yield is high. Tubers have moderate specific gravity and good culinary characteristics.
MN99380-1Y has low glucose content and chips acceptably from the field and from cold storage.
Incentives for production: The tubers of MN99380-1Y have a uniform shape with a smooth white skin and yellow flesh. Yield is high with ~ 95% US No.1; and tuber set averages 10 tubers/plant. Attractive chips result after field harvest and late into the storage season.

Morphological Characteristics:

Plant: Light to medium green foliage; semi-erect vine medium in height; closed canopy with small to medium size leaflets.
Tubers: The tubers are smooth and uniform; white skinned, yellow flesh, and round to oval shape. Internal quality is excellent.
Flower: Pale red violet with prominent white tips - fades to white. Male and female fertile; fruit production is evident in the field.

Agronomic Characteristics:

Foliage: Light to medium green.
Maturity: Medium.
Yield: High yield under irrigated conditions.
Specific gravity: Moderate range 1.078 to 1.085.
Storability: Short to medium dormancy.
Diseases reaction: Low incidence of pink rot, susceptible to Verticillium wilt, CPB, slight resistance to common scab and late blight, Hollow heart is rare.
Seed availability: Virus-free tissue culture plantlets of MN99380-1Y are available from the University of Minnesota Potato Breeding program as are small amounts of seed. Tissue culture plantlets are available from the Minnesota Department of Agriculture, Seed Potato Certification, **www.mnseedpotato.org**.

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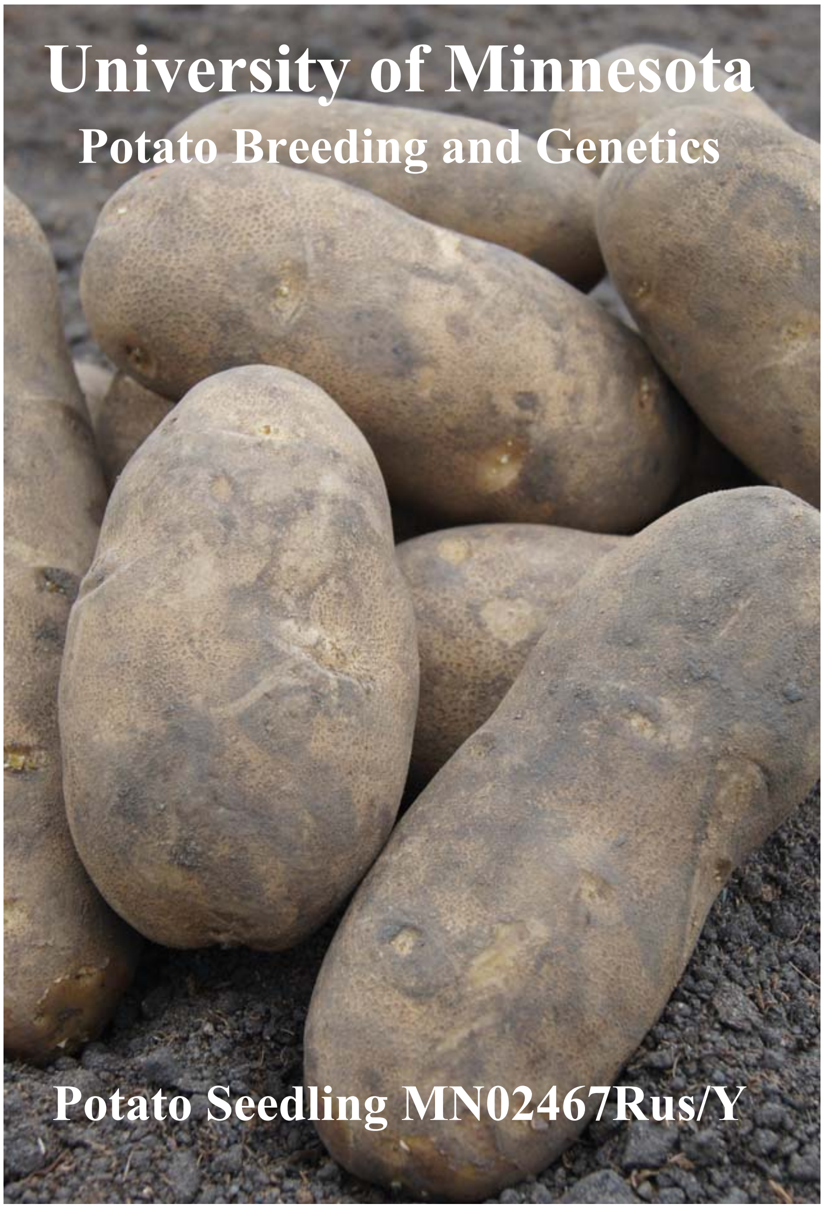
University of Minnesota
Potato Breeding and Genetics
Potato Seedling MN02467Rus/Y

MN02467Rus/Y

Parentage: MN Family #51 x (OP)

Developers: University of Minnesota, Minnesota Agricultural Experiment Station.

Strengths: MN02467Rus/Y is a seedling selected by C. Thill having a smooth russet skin, uniform oblong tuber shape with shallow eyes, yellow flesh, and excellent French fry quality. Its use is for both French fry processing and Fresh market.

Incentives for production: The tubers of MN02467Rus/Y have a uniform shape with a russet skin and yellow flesh. Tuber set averages 8 tubers per plant and 64% over 6oz. and >95% of the tubers are US No. 1. MN02467Rus/Y specific gravity ranges from 1.080 – 1.084. Early French fry processing color is excellent as is from 48F storage. Internal quality is good to excellent; some Hollow heart noted.

LOW ACRYLAMIDE (<225ppb, USPB national testing)

Morphological Characteristics:

Plant: Medium to dark green foliage; tall semi-erect vine; intermediate to full canopy with large oblong leaflets providing good bed cover. Vigor is excellent.

Tubers: Russet skin, yellow flesh, oblong uniform tuber shape with shallow eyes, and excellent internal quality. Some hollow heart noted similar to Russet Burbank.

Flower: Red violet with white tips.

Agronomic Characteristics:

Foliage: Medium to dark green foliage with large oblong leaflets.

Maturity: Full season.

Yield: Medium yield, slightly less than Russet Burbank.

Specific gravity: Moderate to high, 1.080 in Minnesota irrigated and 1.084 in Nesson Valley irrigated (Williston, ND).

Storability: Medium long dormancy.

Culinary quality: MN02467Rus/Y tubers can be used for Fresh market baking, and for processing into French fries giving a nice golden colored French fry.

Disease reaction: MN02467Rus/Y expresses normal symptoms of PVY and PLRV, susceptible to common scab and late blight.

Seed availability: Virus-free tissue culture plantlets of MN02467Rus/Y are available from the University of Minnesota Potato Breeding program as are small amounts of seed. Tissue culture plantlets are available from the Minnesota Department of Agriculture, Seed Potato Certification, **www.mnseedpotato.org**.

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Potato Breeding and Cultivar Development for the Northern Plains
North Dakota State University
2011 Summary

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Potato is the most important vegetable and horticultural crop grown in North Dakota. Potatoes were planted on about 84,000 acres (33,994 ha) in 2011 (NASS 2011); total acreage harvested was approximately 77,000 (31,161 ha). The average yield was reported 235 cwt./acre (138.8 t per ha). Production was reduced by approximately 16% from 2010. Lost production was primarily due to wet conditions at planting and in June. In 2011, 49% of acres eligible for certification by the North Dakota State Seed Department were planted to cultivars developed by the NDSU potato breeding program. The NDSU potato breeding program conducted research trials and seed maintenance/increase at eleven locations in ND and MN in 2011. In 2012, ND8229-3, a dual-purpose russet selection, may be considered for release; it offers producers sugar end and Verticillium wilt resistance, in addition to outstanding French fry/frozen processing and tablestock properties. ND4659-5R, ND5002-3R and ND8555-8R are beautiful red-skinned selections for the tablestock market should also be considered for release. Large scale evaluation of three advancing chip processing selections, ND7519-1, ND8304-2, and ND8305-1, are planned for 2012.

NDSU potato cultivar releases have traditionally been widely adapted and adopted, significantly impacting production in North Dakota and Minnesota, the Northern Plains, but also throughout North America. As a leader in potato breeding, selection, and cultivar development, the aim of the NDSU potato breeding program is to identify and release superior, multi-purpose cultivars that are high yielding, possess multiple resistances to diseases, insect and other pests and stresses, have excellent processing and/or culinary quality, and that are adapted to production in North Dakota, Minnesota, and the Northern Plains. The potato improvement team emphasizes disease, insect pest and stress resistance, including late blight, cold-sweetening, Colorado potato beetle, *Verticillium* wilt, pink rot and *Pythium* leak, silver scurf, sugar end, *Fusarium* dry rot, and aphid resistance breeding. In order to develop durable long-term resistance to these pests and stresses, breeding efforts include germplasm enhancement, incorporating resistance and improved quality attributes through the use of wild species, wild species hybrids, and the use of released cultivars and advanced germplasm from breeding programs around the globe. Our breeding, evaluation, and screening efforts are successful because of the cooperative and interdisciplinary efforts amongst the NDSU potato improvement team, the North Dakota State Seed Department (NDSSD) and Minnesota Department of Agriculture, and with potato producers, research and industry personnel in ND, MN, the Northern Plains, and across North America.

In order to address the needs of potato producers and the potato industry, we have established the following research objectives:
1) Develop potato (*Solanum tuberosum* Group Tuberosum L.) cultivars for North Dakota and Minnesota, the Northern Plains, and beyond, using traditional hybridization that are genetically superior for yield, market-limiting traits, and processing quality.

2) Identify and introgress into adapted potato germplasm, genetic resistance to major disease, insect, and nematode pests causing economic losses in potato production in North Dakota, Minnesota, and the Northern Plains.

3) Identify and develop enhanced germplasm with resistance to environmental stresses and improved quality characteristics for adoption by consumers and the potato industry.

The NDSU potato improvement team conducts breeding, selection, and cultivar development efforts, focusing on traits important to our industry, including high yield, durable disease and insect pest resistance, and improved quality attributes, such as cold processing ability (both chip and frozen products), and sugar end resistance. Germplasm enhancement and dedicated crossing blocks are used in hybridizing efforts to develop resistance to pests and stresses, and in improving quality attributes. In 2011, 544 families were created using 154 parental genotypes. Of these families, 321 (59%) included late blight resistance breeding, 256 (47%) Colorado potato beetle (CPB) resistance breeding, and 199 (37%) chip processing and 99 (18%) frozen processing with cold sweetening resistance breeding. Two hundred forty families from botanical seed (TPS) were grown in the summer greenhouse crop. Of these families, 174 (73%) included late blight resistance breeding, 55 (23%) CPB resistance breeding, 57 (24%) aphid resistance breeding, 5 (2%) *Verticillium* wilt resistance breeding. Harvest of the summer crop is finished, and nearly complete for the fall crop; with the summer and fall crops combined more than 102,000 individual seedlings were planted in the greenhouse. The new greenhouse facility is allowing a crop in just over two months, with larger seedling tubers produced and more set per individual genotype.

In 2011, in the field at Langdon, ND, 84,680 seedlings, representing 518 families, were evaluated; 804 selections were retained, accounting for just under one percent. Unselected seedling tubers from cooperating programs in Idaho, Texas and Maine were grown at Larimore, ND. Unselected seedling tubers, totaling 45,702 tubers, were shared with the breeding programs in ID (21, 243), ME (7,826), CO (10,023), and TX (20,558). In 2011, 851 second, 167 third year, and 381 fourth year and older selections, were produced in maintenance and increase lots at Absaraka, ND, and Baker, MN.

Yield and evaluation trials were grown at nine locations in North Dakota and Minnesota, seven irrigated (Larimore, Oakes, Inkster, Williston, Perham (2) and Sebeka) and three non-irrigated locations (Hoople, Crystal and Valley City). Thirty-two entries were grown in the chip trial at Hoople, including 22 advancing selections from the NDSU program, four lines from Frito-Lay, and six standard chipping cultivars. In the preliminary chip trial 92 entries were grown; chip and quality evaluations will be used to more efficiently determine what to maintain and promote, and what genotypes to drop. A new trial in 2010 was the National Chip Breeders Trial (NCBT) 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. In 2011, 167 entries were included in the unreplicated NCBT and 36 in the replicated trial. At Crystal, 38 entries were grown in the fresh market trial, including 29 advancing selections and nine named cultivars. In the preliminary fresh market trial 30 entries were evaluated, including 25 advanced selections and five industry standards. The Crystal site was badly compromised by the wet June, thus making it difficult to accurately assess yield and quality attributes. Twenty selections and commercially acceptable cultivars were grown in the Oakes processing trial, 20 in the Larimore processing trial, and 22 in the Williston processing trial. Several selections early in the evaluation process demonstrate good yield and frozen processing potential. The preliminary processing trial at Larimore had 80 entries, including six check genotypes. Similar to the preliminary chip processing trial, this trial will be used to more efficiently determine selections to proceed with and those to drop from further consideration based upon frozen processing quality attributes. A new trial in 2011 is the NFPT. Similar to the NCBT, this is an industry driven trial directed by the USPB and processing companies, with evaluations in WA, ID, ND and also WI. There were 81 clones evaluated at all four locations, and sugar, asparagine and acrylamide levels are analyzed following various storage regimen. One hundred fifty-four clones selected from out-of-state seedlings in 2010 and prior were grown in maintenance plots; about a dozen processing and specialty genotypes were retained, including the exceptionally high yielding selection with processing potential and widely publicized AFND4405-1Russ. Additionally at Larimore, the NDSU potato breeding program cooperated with Simplot Plant Sciences in conducting three trials evaluating improved lines of Ranger Russet, Russet Burbank and Atlantic. Trials at Inkster ranged from the chip processing yield trial with 30 entries (including six industry standards and four FritoLay clones), evaluation of genotypes for resistance to Verticillium wilt in collaboration with Dr. Neil Gudmestad and Julie Pasche (21 clones across market types, rather than frozen processing focus), and cultural management trials including work with a foliarly applied nutritional product, and the acrylamide trial (a sister trial to Dr. Carl Rosen's in Minnesota, but supported by a North Dakota Specialty Crop Block Grant). A processing trial was grown at Perham, a collaboration with RDO/Lamb-Weston. A second trial at Perham evaluated a nutritional supplement applied as a seed piece treatment and foliarly; this was a collaboration with Tobkins. Two additional new trials in 2011 were organic trials at Sebeka and Valley City, with 24 and 22 entries, respectively. The focus was specialty types, and also included genotypes with late blight and/or Colorado potato beetle resistance. Four entries from NDSU were evaluated in the North Central Regional Potato Variety Trial (NCRPVT), including ND8555-8R and AND00272-1R, bright red skinned selections suitable for the fresh market, and ND8068-5Russ and ND8229-3, both dual-purpose russets. NCRPVT locations are Crystal (fresh market), Hoople (chip processing), Larimore (frozen processing), and Inkster (fresh market, chip and frozen processing). Our efforts continue to identify processing (both chip and frozen) germplasm that will reliably and consistently process from long term cold storage. As we grade, chip processing selections are sampled, 'field chipped', stored at 42F and 38F (5.5C and 3.3C) for eight weeks, while a fourth set is evaluated the following June from 42F storage. Frozen processing selections are evaluated after grading and from 45F (7.2C) storage for eight weeks and again the following June. All trial entries are evaluated for blackspot and shatter bruise potential.

In 2011, Dr. Gary Secor's program evaluated seedling families using a detached leaf assay in the greenhouse. Resistant selections are retained for field evaluations in 2012. Collaborative field trials for late blight foliar and tuber evaluations with Dr. Secor were lost due to wet planting conditions at Prosper. Similarly, the bacterial ring rot trial with Dr. Neil Gudmestad's program at Prosper was also lost. Two Colorado potato beetle resistance screening trials at Glyndon conducted in collaboration with Dr. Deirdre Prischmann-Voldseth also succumbed to seed piece decay after planting due to saturated soils. Sucrose rating, invertase/ugpase analysis, and serial chipping of chip and frozen processing selections is conducted by Marty Glynn (USDA-ARS) at the USDA-ARS Potato Worksite in East Grand Forks, MN. We also submitted entries in many cooperative trials with various producers, industry, and research groups across North America. As in 2011, trial results will be reported in articles in the Valley Potato Grower magazine.

The most promising advancing red fresh market selections include ND4659-5R, ND8555-8R, AND00272-1R, ND6002-1R and ND7132-1R. Dual-purpose russet selections, ND8229-3, ND8068-5Russ and several hybrids between Dakota Trialblazer and ND8229-3 possess excellent appearance, yield, and processing qualities. ND7519-1, ND8304-2, and ND8305-1, advancing chip processing selections, possess excellent appearance and cold sweetening resistance. These selections are summarized in the graphics below.

Goals for 2012 include developing improved germplasm with the goal of potato cultivar releases for ND, MN, the Northern Plains and beyond, using traditional hybridization, and utilizing early generation selection techniques such as marker assisted selection and greenhouse screening procedures when possible in order to more rapidly identify genetically superior genotypes. Our efforts will focus on the needs of our producer and potato industry stakeholders, including incorporation of resistance to major insect, disease and nematode pests, and to environmental stresses, with an emphasis on improved quality attributes. Working with the NDSSD and MN Department of Agriculture, we will strive to improve our seed increase efforts in order to produce high quality certified seed. We are grateful for the opportunity to conduct cooperative and interdisciplinary research with members of the NDSU potato improvement team, the USDA-ARS programs in Fargo and East Grand Forks, and the North Central and other potato research programs across the globe. Our heartfelt thanks to our grower, industry, and research cooperators in North Dakota, Minnesota, and beyond. We are grateful for the support and cooperation in providing resources of land, certified seed, research funds, and equipment.

ND8229-3

- Marcy x AH66-4
- Medium maturity
- Medium vine size
- High yield potential
- Good storability and excellent fry color from 45F storage. Suitable for the fresh market too.
- High specific gravity
- Resistance to sugar ends and Verticillium wilt
- Tolerant of metribuzin applications

ND8068-5Russ

- ND2667-9Russ x ND4233-1Russ
- Medium vine size
- Very early vine maturity
- Medium to high yield potential
- Dual-purpose
- High specific gravity
- Good storability with low sugar accumulation and excellent frozen processing quality after 7 months storage

ND4659-5R

- NorDonna x ND2842-3R
- Suited for the fresh market
- Medium vine with red-purple flowers
- Medium maturity
- Medium yield potential
- Bright red, round, smooth tubers with white flesh and shallow eyes
- Medium specific gravity
- No outstanding disease or pest susceptibilities
- Stores well

ND8555-8R

- ND7188-4R x ND5256-7R
- Suited for the fresh market
- Medium maturity
- Medium-large vine size
- High yield potential
- Bright red, round, smooth tubers with white flesh and shallow eyes
- Very uniform tuber size profile
- Medium specific gravity
- Stores well

AND00272-1R

- MN17922 x A92653-6R
- Suited for the fresh market
- Medium vine with red-purple flowers
- Medium-late maturity
- Medium yield potential
- Bright red, round to oval, tubers with white flesh, shallow eyes and smooth tuber type.
- Low to medium specific gravity
- No outstanding disease or pest susceptibilities
- Stores well

ND6002-1R

- NorDonna x Bison
- Medium sized vine
- Medium-late vine maturity
- Medium yield potential
- Round, smooth, bright red tubers with smooth eyes and bright white flesh
- Low to medium specific gravity
- Early in evaluation process

ND7132-1R

- ND5002-3R x ND5438-1R
- Medium maturity
- Medium yield potential
- Bright red skinned, oval to oblong tubers with white flesh
- Early in evaluation process

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

ND8304-2

- ND860-2 x ND7083-1
- Medium early maturity
- Small to medium sized vine
- Medium yield potential
  - Nice tuber type, smaller size profile
- High specific gravity
- Chips from 42F storage
  - Excellent cold chipping selection

ND8305-1

- ND2471-8 x White Pearl
- Medium maturity
- Medium sized vine
- Medium yield potential
  - Nice tuber type, smaller size profile
- High specific gravity
- Chips from 42F storage
  - Excellent cold chipping selection

ND7799c-1

- Dakota Pearl x Dakota Diamond
- 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

ATND98459-1RY

- ATD252-5R x T4845
- Medium to large vine size
- Medium maturity
- High yield potential
- Round, smooth, red tubers with shallow eyes and yellow flesh
- Medium to high specific gravity

ND7834-2P

- NorDonna x ND5554-1R
- Medium vine size
- Medium maturity
- Medium to high yield potential
- Oval and blocky tubers, smooth, dark purple (blue) color, with very shallow eyes and marbled flesh
- Medium to high specific gravity

ND7818-1Y

- Morene x Marcy
- Medium vine size
- Medium maturity
- Medium to high yield potential
- Oval, smooth, yellow skinned tubers with yellow flesh
- Medium to high specific gravity
- Excellent cold chipping selection
- 'European' type

ATND99331-2 PintoY

- Inca Gold x COA94019-5R
- Large and vigorous vine
- Medium maturity
- High yield potential
- Specific gravity is low (avg. 1.070 across ND locations)
- Suited for the specialty tablestock market with bright yellow flesh. Excellent steamed, boiled, mashed, in soups, stews and potato salad. Makes light yellow colored lefse.