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Marketing Potential
of Advanced Breeding Clones

Martin Glynn
USDA/ARS
Potato Research Worksite
East Grand Forks, Mn

Dr. Joe Sowokinos, Professor Emeritus
Department of Horticultural Science
University of Minnesota, St Paul, MN

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

Methods:
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 equal to or less than 1.0 mg sucrose/g FW tuber by harvest. Secondly, the potato line should demonstrate a low GFP in storage which is a function of the basal activity of acid invertase. This study is funded, in part, by the Northern Plains Potato Growers Association. 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 0.50 mg/g FW tuber or less should yield acceptable colored potato chips. This amount of glucose is equivalent to 0.050% on a FW weight basis and represents chips giving an Agtron value of 60 or higher. Clones with glucose levels up to 1.3 mg/g are still acceptable for french fry quality, although lower levels are generally desired. For French fries, Agtron values generally range from 45 to 59. Potatoes with lower Agtron values (below 45) are destined for fresh market utilization. High levels of glucose lead to the production of unacceptable dark brown to black pigmented chips or fries after the raw product is cooked in oil at a high temperature.

Results:
A summary of results for the 2010-2011 storage season is presented in Table 1.

References:
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 1-11

Table 1. 2010 -2011 Marketing-potential of advanced potato breeding clones stored at 9^o C (48^o F) for 3 and 7 months. Clones are aligned in order of decreasing Agtron values following 7 months in storage.

CLONE	SOURCE	Desired Chip Atron Value 55 Or Above		Market on Potential Atron Based Values		
		3 Mo's AGT	7 Mo's. AGT	Chips	Fries	Fresh
W 2310-3	WI	64	66	X	X	X
W 7124-9	WI	68	66	X	X	X
SPORT 860	ND	63	66	X	X	X
MSJ 126-9Y	MI	65	66	X	X	X
MSQ 086-3	MI	66	66	X	X	X
SNOWDEN	WI	70	65	X	X	X
W 2978-3	WI	64	65	X	X	X
NY 145	NY	67	65	X	X	X
NDTX 059979-1W	ND/TX	68	65	X	X	X
AO 0188-3C(5099-6128)	ID/OR	63	65	X	X	X
MSJ 147-1	MI	64	65	X	X	X
DAKOTA PEARL	ND	66	65	X	X	X
MSP 459-5	MI	66	65	X	X	X
MSR 061-1	MI	61	65	X	X	X
CO 00188-4W	CO/OR	67	65	X	X	X
W 2717-5	WI	66	63	X	X	X
W 2324-1	WI	62	63	X	X	X
W 6360-1rus	WI	62	63	X	X	X
NORVALLEY	ND	64	63	X	X	X
NY 138	NY	66	63	X	X	X
COTX 02377-1W	CO/OR/TX	60	63	X	X	X
ND 8-14	ND	68	63	X	X	X
ND 8331CB-2	ND	65	63	X	X	X
ND 8456-1	ND	62	63	X	X	X
ND 8304-2	ND	68	63	X	X	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

Neil C. Gudmestad and Raymond J. Taylor
Departments of Plant Pathology
North Dakota State University

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; October 1 and November 3, 2011. Soil temperatures at the 6" depth on those dates were 50F 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.* All soil samples were sent to Pest Pros in Wisconsin for commercial processing at the same time. Levels of *V. dahliae* from post-fumigation soil sampling were determined in June-July, 2012.

The experiment was planted on April 26, 2012. 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 20 to determine yield and grade.

Results

Mean *V. dahliae* levels in control plots ranged from approximately 25 to 41 vppg (Table 1) which is approximately 3-5X the economic threshold for many potato varieties. 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 below threshold to approximately 3.5X 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, however, metam sodium did substantially reduce the levels of *V. dahliae* across the experiment. The mean level of V. dahliae in non-treated plots was 33 vppg and across all rates of metam sodium, levels of the wilt pathogen were 16.6 vppg when injected at a single depth of 10" and 18.6 vppg when injected at 6" and 10". However, all rates of metam sodium used significantly reduced the level of V. dahliae in the soil, although there were no statistical differences among rates (Table 1). In other words, plots treated with a 70 gal/a rate of metam sodium did not reduce Verticillium levels significantly more than 40 gal/a, although the general trend was that vppg were reduced with incrementally higher rates of soil fumigant. As we found in 2011, 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 50F.

Weekly wilt severity data reveal similar trends. Metam sodium injection depth had a significant impact on the development of Verticillium wilt over the course of the growing season (Table 2). We observed a significant reduction in the development of Verticillium wilt over the course of the growing season, as evidenced by the relative area under the wilt progress curve (RAUWPC), regardless of injection depth, however, a single injection depth of 10" had significantly less wilt development compared to the split injection depths of 6" and 10". Similiarly, the rate of metam sodium used had 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 any other rate of the fumigant. 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 (50F).

Total yield was significantly increased regardless of injection depth of metam sodium although the rate of soil fumigant did not significantly increase total yield (Table 3). As noted with the reduction of Verticillium soil inoculum and with the development of wilt symptoms, total yield of plots fumigated late when soil temperatures were 39F were significantly higher than when soils were fumigated when warmer, at 50F. Unfortunately, none of the differences in Verticillium wilt development we observed resulted in an increase of marketable yield in any treatment combination (Table 3).

Further statistical analysis provided 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. In the 2011 experiment we found that the levels of *V. dahliae* at 4-8" are more highly correlated with wilt severity than the levels of the pathogen in the 0-4" depth despite the fact that the levels of *V. dahliae* in the 0-4" depth are 2 to14-fold higher than in the 4-8" depth. This was not necessarily the case with results obtained in the 2012 experiment. For example, the total wilt observed on September 5 was more robustly correlated with the levels of *V. dahliae* in the 0-4" depth compared to the 4-8" depth (Figure 1). However, the wilt observed on August 21 and 28 was more robustly correlated with the level of the pathogen in the 4-8" soil stratum (Table 4), which likely contributed to the progression of wilt, as expressed as RAUWPC, was more highly correlated with the level of Verticillium in the 4-8" depth compared to the 0-4" depth (Figure 2) which is in agreement with the data from the 2011 experiment. In contrast, total and marketable yield were more robustly correlated with the level of Verticillium in the 0-4" depth compared to the 4-8" depth (Figure 3 & 4). Not surprisingly, there was a very high degree of correlation between wilt progression and total and marketable yield (Figure 5).

Summary and Conclusions

Results of this trial provide additional insights into the impact of *V. dahliae* and the development of wilt in a potato crop. In contrast to the experiment conducted in 2011, *V. dahliae* levels were controlled very well with metam sodium in the 2012 experiment. The results reported here provide valuable information that we believe will improve the efficacy of metam sodium application and improve the level of disease management obtained from this tactic. Interestingly, and counter to previously published studies, metam sodium application during colder soil temperatures (39F) 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 despite being shank injected, which very likely has a negative effect on the efficacy of the soil fumigant. We also have two years of data that clearly demonstrate that a single injection depth at 10” is at least as effective as injection at two depths (i.e., 2011 data) and can result in significantly better disease control as noted in 2012.

Perhaps more interesting is the observation that levels of *V. dahliae* in the lower soil stratum (4-8”) appear to be as important as those 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 in 2011 and very similar to the correlation values observed in 2012. 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.

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.

Nicot, P.C. and Rouse, D.I. 1987. Relationship between soil inoculum density of *Verticillium dahliae* and systemic colonization of potato stems in commercial fields over time. Phytopathology 77:1346-1355.

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					
				9/30/11			4/5/12		
				0-4"	4-8"	0-8"	0-4"	4-8"	0-8"
801	Control	0 gal / a	Early	12.4	9.0	21.4	20.6	17.4	38.0
802	10 in	40 gal / a	Early	8.8	7.0	15.8	11.0	3.6	14.6
803	10 in	50 gal / a	Early	15.8	6.0	21.8	11.4	2.2	13.6
804	10 in	60 gal / a	Early	16.8	11.0	27.8	9.2	0.8	10.0
805	10 in	70 gal / a	Early	15.4	9.6	25.0	11.6	2.8	14.4
806	Control	0 gal / a	Late	14.2	11.0	25.2	14.0	13.8	27.8
807	10 in	40 gal / a	Late	15.2	9.8	25.0	9.4	2.4	11.8
808	10 in	50 gal / a	Late	21.4	16.2	37.6	14.0	5.6	19.6
809	10 in	60 gal / a	Late	15.8	7.2	23.0	6.6	3.6	10.2
810	10 in	70 gal / a	Late	14.2	14.2	28.4	4.0	2.4	6.4
811	Control	0 gal / a	Early	18.8	12.4	31.2	15.0	10.1	25.1
812	6 in +10 in	40 gal / a	Early	16.4	11.4	27.8	21.4	6.8	28.2
813	6 in +10 in	50 gal / a	Early	17.6	17.4	35.0	13.4	5.0	18.4
814	6 in +10 in	60 gal / a	Early	18.4	16.0	34.4	17.4	9.2	26.6
815	6 in +10 in	70 gal / a	Early	19.4	13.8	33.2	15.6	2.2	17.8
816	Control	0 gal / a	Late	20.8	10.4	31.2	25.8	15.2	41.0
817	6 in +10 in	40 gal / a	Late	14.6	7.6	22.2	7.8	1.8	9.6
818	6 in +10 in	50 gal / a	Late	17.2	12.2	29.4	4.4	1.2	5.6
819	6 in +10 in	60 gal / a	Late	14.6	6.0	20.6	5.8	2.0	7.8
820	6 in +10 in	70 gal / a	Late	14.4	5.8	20.2	3.8	1.8	5.6
$LSD_{P=0.05}$				NS	6.8	10.6	7.1	4.1	9.0
	Control			16.6	10.7	27.3	18.9	14.1	33.0
	10 in			15.0	10.1	25.1	11.2	5.5	16.6
	6 in +10 in			17.2	11.3	28.5	13.0	5.5	18.6
$LSD_{P=0.05}$				NS	NS	3.4	NS	NS	NS
		0 gal / a		16.6	10.7	27.3	18.9	14.1	33.0
		40 gal / a		13.8	9.0	22.7	12.4	3.7	16.1
		50 gal / a		18.0	13.0	31.0	10.8	3.5	14.3
		60 gal / a		16.4	10.1	26.5	9.8	3.9	13.7
		70 gal / a		15.9	10.9	26.7	8.8	2.3	11.1
$LSD_{P=0.05}$				NS	NS	NS	3.5	2.1	4.6
			Control	16.6	10.7	27.3	18.9	14.1	33.0
			Early	16.0	11.4	27.3	14.7	6.0	20.7
			Late	16.2	10.0	26.3	9.6	5.0	14.5
$LSD_{P=0.05}$				NS	NS	NS	2.2	NS	2.9

Early = 1st Fumigation on 10-1-11 Late = 2nd Fumigation on 11-3-11

Significant interactions were observed in the 9-30-11 sampling
InjectionDepth*Timing at 4-8", 0-8"

Significant interactions were observed in the 4-5-12
InjectionDepth*Rate at 4-8"
InjectionDepth*Timing at 0-8"
Rate*Timing at 0-4", 0-8"
InjectionDepth*Rate*Timing at 0-4", 4-8", 0-8"

Table 2. Impact of metam sodium on Verticillium wilt development

Treatment	Injection Depth	Rate	Timing	Wilt (% Severity)									AUWPC	RAUWPC
				7/13	7/25	7/31	8/7	8/14	8/21	8/28	9/5	9/10		
801	Control	0 gal / a	Early	0.7	2.0	3.4	5.2	14.7	35.5	67.0	95.9	98.7	1926.2	0.275
802	10 in	40 gal / a	Early	0.2	1.5	1.8	1.6	2.6	5.6	24.0	59.5	81.5	938.3	0.134
803	10 in	50 gal / a	Early	0.5	2.9	1.9	1.6	4.6	4.4	12.1	38.2	63.0	666.0	0.095
804	10 in	60 gal / a	Early	0.8	1.8	2.1	1.9	2.4	3.7	15.9	44.5	69.5	734.4	0.105
805	10 in	70 gal / a	Early	0.4	1.1	1.5	1.4	1.9	2.9	14.4	44.1	75.6	640.8	0.092
806	Control	0 gal / a	Late	1.4	3.0	8.2	14.2	24.2	44.0	86.0	96.3	98.4	2287.4	0.327
807	10 in	40 gal / a	Late	1.0	2.1	3.0	2.4	2.8	3.8	7.9	21.3	47.0	462.4	0.066
808	10 in	50 gal / a	Late	0.4	1.0	1.1	1.5	2.2	5.1	20.0	48.5	71.9	786.6	0.112
809	10 in	60 gal / a	Late	0.2	1.5	1.4	1.4	1.2	1.8	6.0	22.0	45.0	390.1	0.056
810	10 in	70 gal / a	Late	0.6	1.0	2.2	1.2	1.7	2.8	8.5	18.0	40.0	380.3	0.054
811	Control	0 gal / a	Early	0.5	4.6	7.6	11.2	23.7	46.5	82.5	97.9	99.4	2270.1	0.324
812	6 in +10 in	40 gal / a	Early	0.7	2.6	3.8	6.0	11.7	25.0	57.0	85.0	92.5	1656.1	0.237
813	6 in +10 in	50 gal / a	Early	0.5	2.6	4.1	5.5	7.9	13.7	36.0	73.0	89.0	1294.0	0.185
814	6 in +10 in	60 gal / a	Early	1.5	5.4	4.5	6.1	9.4	20.2	50.0	82.0	90.3	1567.2	0.224
815	6 in +10 in	70 gal / a	Early	0.4	2.7	3.4	4.7	5.9	9.3	29.0	66.7	88.1	1139.6	0.163
816	Control	0 gal / a	Late	1.7	1.8	2.7	6.9	16.4	34.5	61.2	88.1	97.7	1826.4	0.261
817	6 in +10 in	40 gal / a	Late	0.7	2.1	2.1	1.6	1.5	1.9	4.0	10.7	37.5	292.9	0.042
818	6 in +10 in	50 gal / a	Late	0.4	1.0	1.4	1.2	1.7	1.8	5.8	16.7	41.0	339.3	0.048
819	6 in +10 in	60 gal / a	Late	0.7	4.3	3.7	2.3	2.0	3.0	15.0	33.4	54.0	631.4	0.090
820	6 in +10 in	70 gal / a	Late	0.4	0.3	0.3	0.2	0.5	0.7	3.0	9.5	31.0	201.0	0.029
LSD$_{P\ =\ 0.05}$				NS	2.4	2.8	4.0	6.9	12.1	14.4	14.6	12.7	347.1	0.050
	Control			1.0	2.8	5.4	9.4	19.8	40.9	74.2	94.6	98.6	2077.5	0.297
	10 in			0.5	1.6	1.9	1.6	2.4	3.8	13.6	36.9	61.6	624.8	0.089
	6 in +10 in			0.7	2.6	2.9	3.4	5.1	9.4	25.0	47.1	65.4	890.2	0.127
LSD$_{P\ =\ 0.05}$				NS	1.0	1.2	1.7	2.9	4.9	6.1	6.0	NS	145.1	0.021
		0 gal / a		1.0	2.8	5.4	9.4	19.8	40.9	74.2	94.6	98.6	2077.5	0.297
		40 gal / a		0.6	2.1	2.7	2.9	4.7	9.1	23.2	44.1	64.6	837.4	0.120
		50 gal / a		0.4	1.9	2.1	2.4	4.1	6.2	18.5	44.1	66.2	771.5	0.110
		60 gal / a		0.8	3.2	2.9	2.9	3.8	7.2	21.7	45.5	64.7	830.8	0.119
		70 gal / a		0.4	1.3	1.8	1.9	2.5	3.9	13.7	34.3	58.4	590.4	0.084
LSD$_{P\ =\ 0.05}$				NS	1.2	NS	NS	NS	NS	NS	7.3	NS	177.7	0.025
			Control	1.0	2.8	5.4	9.4	19.8	40.9	74.2	94.6	98.6	2077.5	0.297
			Early	0.6	2.7	3.4	4.5	8.5	17.1	39.0	68.9	84.8	1283.3	0.183
			Late	0.7	1.8	2.6	3.3	5.4	9.9	21.7	36.5	56.4	759.8	0.109
LSD$_{P\ =\ 0.05}$				NS	0.8	0.9	1.3	2.3	3.8	4.7	4.6	4.0	112.4	0.016

Early = 1st Fumigation on 10-1-11 Late = 2nd Fumigation on 11-3-11

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

Significant interactions w ere observed in Wilt Severity as follow s
InjectionDepth*Rate on 7-25, 9-5, 9-10
InjectionDepth*Timing on 7-31, 8-7, 8-14, 8-21, 8-28, 9-5, 9-10
Rate*Timing on 8-28, 9-5, 9-10
InjectionDepth*Rate*Timing on 9-5, 9-10
A significant interaction of main effects InjectionDepth*Timing and Rate*Timing also w as observed w ith AUWPC and RAUWPC

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	Early	462.2	372.1	11.2	2.0	13.1	27.2	8.0	35.2	48.3	25.3	6.9	32.2	19.5	8.6	10.9
802	10 in	40 gal / a	Early	535.4	463.9	14.3	3.3	17.6	30.7	5.9	36.6	54.2	25.0	7.3	32.3	13.5	6.2	7.3
803	10 in	50 gal / a	Early	564.4	516.5	21.4	5.3	26.7	34.5	5.0	39.5	66.2	22.2	3.1	25.3	8.5	3.9	4.6
804	10 in	60 gal / a	Early	550.9	492.7	19.6	2.0	21.5	35.1	3.7	38.9	60.4	25.0	4.0	29.0	10.6	5.9	4.7
805	10 in	70 gal / a	Early	534.4	480.7	19.4	7.1	26.5	27.0	9.9	36.8	63.3	18.4	6.9	25.3	11.4	4.7	6.7
806	Control	0 gal / a	Late	518.3	434.6	11.9	1.2	13.1	34.6	3.8	38.5	51.6	27.8	4.5	32.3	16.2	7.2	9.0
807	10 in	40 gal / a	Late	581.0	527.4	23.9	2.7	26.6	33.2	4.3	37.5	64.1	22.6	4.0	26.6	9.3	5.4	3.9
808	10 in	50 gal / a	Late	559.6	486.6	19.9	6.4	26.4	26.9	8.1	35.0	61.3	18.2	7.3	25.5	13.2	5.7	7.5
809	10 in	60 gal / a	Late	601.2	555.7	25.8	3.9	29.7	32.6	4.0	36.6	66.3	22.9	3.2	26.1	7.6	4.2	3.4
810	10 in	70 gal / a	Late	620.7	570.5	19.2	3.1	22.3	33.1	7.8	40.9	63.1	24.1	4.7	28.8	8.1	4.8	3.3
811	Control	0 gal / a	Early	480.1	389.9	11.1	2.1	13.3	29.6	4.6	34.2	47.5	28.7	5.2	33.9	18.7	7.9	10.8
812	6 in +10 in	40 gal / a	Early	553.5	491.2	15.4	2.3	17.7	37.1	4.4	41.4	59.2	26.1	3.4	29.5	11.3	5.6	5.7
813	6 in +10 in	50 gal / a	Early	561.4	484.2	18.8	3.5	22.3	31.1	5.7	36.8	59.1	21.9	5.2	27.1	13.8	5.4	8.5
814	6 in +10 in	60 gal / a	Early	524.6	427.9	13.4	2.1	15.5	29.2	3.9	33.2	48.7	27.3	5.1	32.4	18.9	6.2	12.7
815	6 in +10 in	70 gal / a	Early	525.1	452.5	15.4	3.7	19.2	30.9	4.4	35.3	54.5	27.5	4.2	31.7	13.9	6.6	7.2
816	Control	0 gal / a	Late	480.4	362.0	10.8	1.8	12.6	27.6	5.8	33.4	46.0	23.5	5.7	29.2	24.8	9.3	15.4
817	6 in +10 in	40 gal / a	Late	601.2	540.0	21.1	3.1	24.2	36.9	4.3	41.2	65.4	20.7	3.5	24.2	10.4	5.7	4.8
818	6 in +10 in	50 gal / a	Late	632.7	574.0	22.1	5.3	27.4	29.6	8.8	38.3	65.7	19.9	5.1	25.0	9.3	5.2	4.0
819	6 in +10 in	60 gal / a	Late	596.4	548.4	27.1	3.3	30.4	31.4	5.4	36.9	67.2	20.8	3.9	24.7	8.1	5.0	3.1
820	6 in +10 in	70 gal / a	Late	597.8	539.2	26.8	3.3	30.1	29.2	7.7	37.0	67.0	18.2	4.8	23.1	9.9	4.9	5.0
$LSD_{P=0.05}$				42.7	103.0	10.2	2.9	11.1	NS	NS	NS	11.5	NS	NS	NS	6.3	2.6	6.4
	Control			485.2	389.7	11.2	1.8	13.0	29.8	5.6	35.3	48.3	26.3	5.6	31.9	19.8	8.2	11.6
	10 in			568.9	513.8	20.5	4.0	24.5	32.0	5.8	37.8	62.3	22.6	5.0	27.5	10.2	5.1	5.1
	6 in +10 in			574.1	507.2	20.0	3.3	23.3	31.9	5.6	37.5	60.9	22.8	4.4	27.2	11.9	5.6	6.4
$LSD_{P=0.05}$				17.5	NS	NS	1.1	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
		0 gal / a		485.2	389.7	11.2	1.8	13.0	29.8	5.6	35.3	48.3	26.3	5.6	31.9	19.8	8.2	11.6
		40 gal / a		567.8	505.6	18.7	2.9	21.5	34.5	4.7	39.2	60.7	23.6	4.5	28.2	11.1	5.7	5.4
		50 gal / a		579.5	515.3	20.6	5.1	25.7	30.5	6.9	37.4	63.1	20.6	5.2	25.7	11.2	5.0	6.1
		60 gal / a		568.3	506.2	21.5	2.8	24.3	32.1	4.3	36.4	60.7	24.0	4.1	28.1	11.3	5.3	5.9
		70 gal / a		570.4	515.0	20.3	3.9	24.2	30.5	7.1	37.6	61.8	22.6	4.9	27.5	10.7	5.3	5.4
$LSD_{P=0.05}$				NS	NS	NS	1.3	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
			Early	529.1	455.9	15.8	3.1	19.0	31.5	5.3	36.8	55.8	25.1	5.0	30.1	14.1	6.2	8.0
			Late	578.9	513.8	20.9	3.4	24.3	31.5	6.0	37.5	61.8	21.9	4.7	26.5	11.7	5.7	5.9
$LSD_{P=0.05}$				13.6	32.3	3.0	NS	3.3	NS	NS	NS	3.5	NS	NS	2.7	2.3	NS	NS

Early = 1st Fumigation on 10-1-11 Late = 2nd Fumigation on 11-3-11

Significant interactions w ere observed
Rate*Timing: 10 oz. and over (Total)
InjectionDepth*Timing: >6 oz. (Total)

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 21	r	0.7222	0.8957	0.8498		
	P	0.0003	<0.0001	<0.0001		
August 28	r	0.7613	0.8770	0.8636		
	P	<0.0001	<0.0001	<0.0001		
September 5	r	0.8588	0.8158	0.8910		
	P	<0.0001	0.0002	<0.0001		
RAUWPC	r	0.8026	0.8618	0.8803	-0.8504	-0.8722
	P	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Total yield	r	-0.8371	-0.7959	-0.8688		
	P	<0.0001	<0.0001	<0.0001		
Market yield	r	-0.8618	-0.8422	-0.9054		
	P	<0.0001	<0.0001	<0.0001		

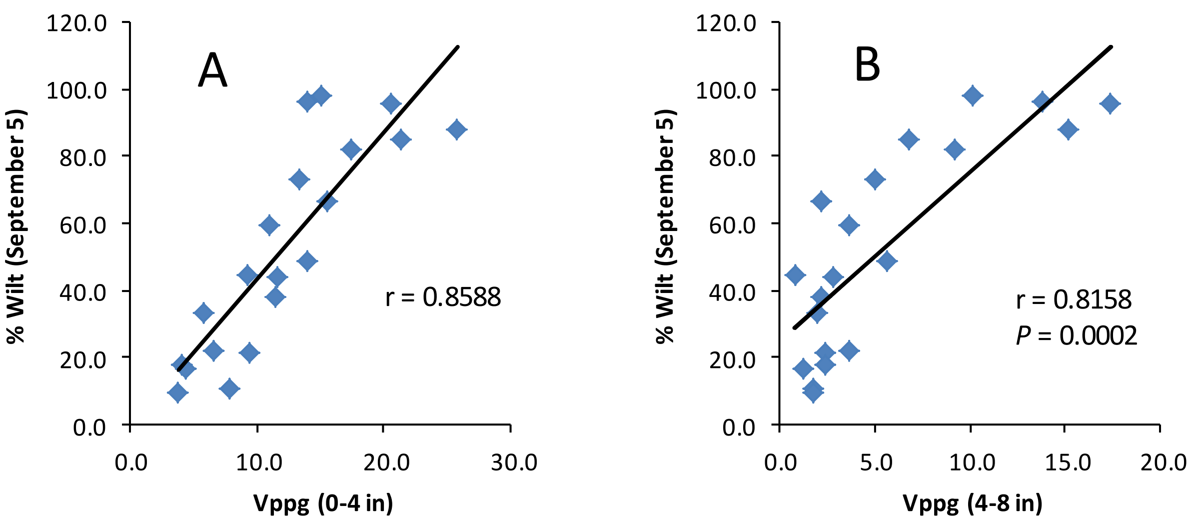


Figure 1. Relationship between percent Verticillium wilt on September 9 and Verticillium propagules per gram (Vppg) of soil post-fumigation at 0-4 inches (A) and 4-8 inches (B).

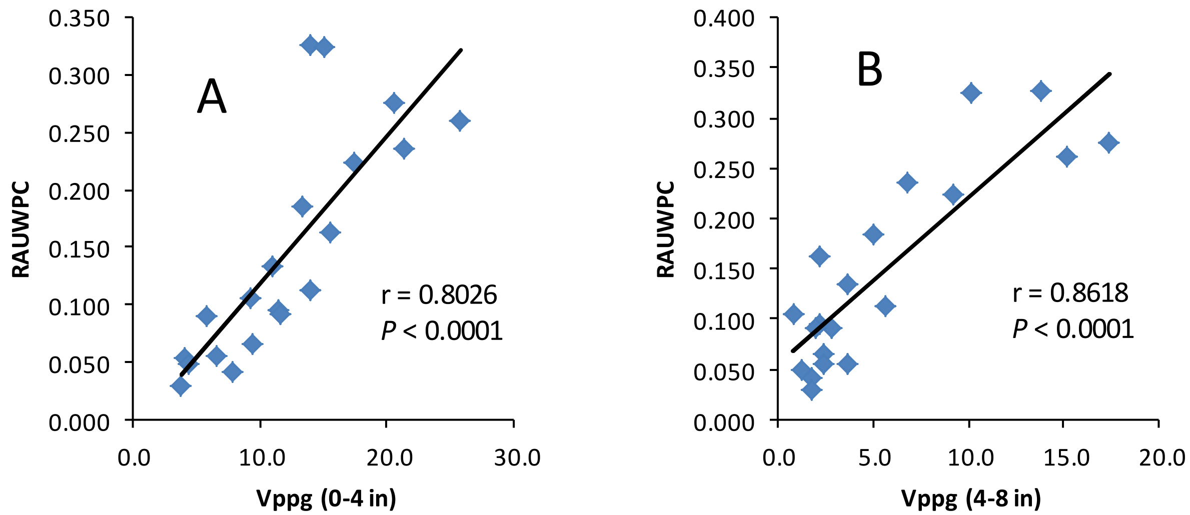


Figure 2. Relationship between relative area under the wilt progress curve (RAUWPC) and Verticillium propagules per gram (Vppg) of soil post-fumigation at 0-4 inches (A) and 4-8 inches (B).

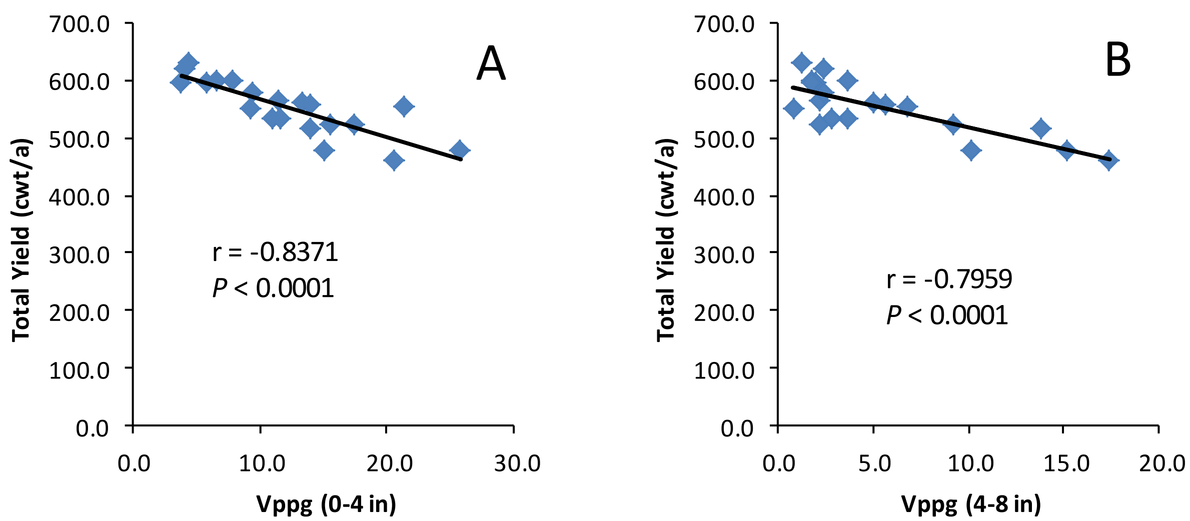


Figure 3. Relationship between total yield (cwt/a) and Verticillium propagules per gram (Vppg) of soil post-fumigation at 0-4 inches (A) and 4-8 inches (B).

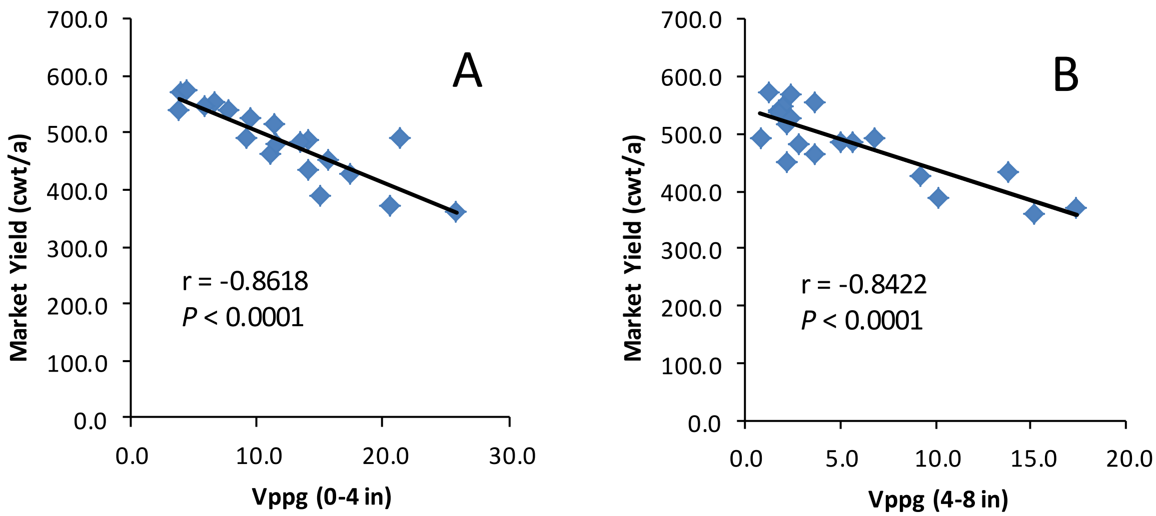


Figure 4. Relationship between market yield (cwt/a) and Verticillium propagules per gram (Vppg) of soil post-fumigation at 0-4 inches (A) and 4-8 inches (B).

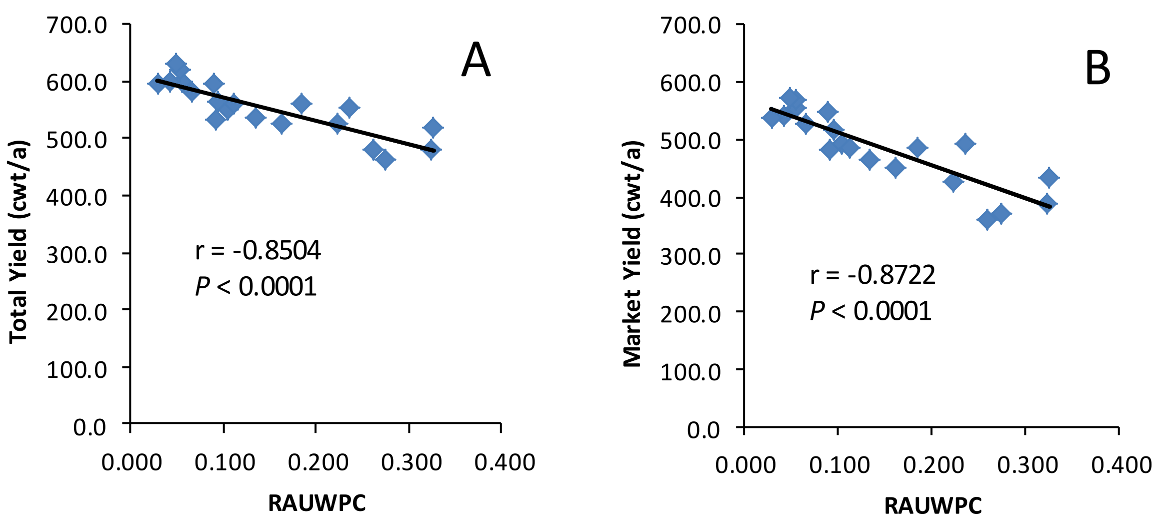


Figure 5. Relationship between total yield (cwt/a) (A) market yield (cwt/a) (B) and relative area under the wilt progress curve (RAUWPC).

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

Principle Investigator: Neil C. Gudmestad, Department of Plant Pathology, North Dakota State University, Fargo, ND. **Neil.Gudmestad@ndsu.edu** 701.231.7547 (O); 701.231.7851 (F)

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:

The studies on powdery scab and on potato mop top will be conducted by two Ph.D. students, Francisco Bittara and Owusu Domfeh, respectively.

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.

One field was used to perform chloropicrin fumigation trials. The goal in this experiment was to assess whether or not chloropicrin would reduce powdery scab incidence and severity on roots and tubers across several cultivars. These fields will be treated with 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 fumigation trial was planted on April 25-27, 2012, and harvested on September 6-7.

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. The powdery scab trial was planted on April 30 to May 1, 2012, and harvested on September 5-6. Cultivar susceptibility to powdery scab was assessed by determining the severity of galls that form on roots and the severity of tuber lesion development. The PMTV susceptibility trial was planted on May 24-45, 2012 and harvested on October 5. 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. However, the use of chloropicrin soil fumigation did not reduce powdery scab incidence or severity on potato tubers, although there were some numerical reductions at the higher use rates (Table 1). However, root gall formation caused by powdery scab significantly increased after chloropicrin soil fumigation (Table 2).

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 compared to white or red-skinned potato cultivars (Table 3). Interestingly, powdery scab lesions were observed on the russet cultivar Dakota Trailblazer. Root gall formation was independent of tuber skin color (Table 4). While russet-skinned potato cultivars appear resistant to the formation of powdery scab on tubers, the roots of cultivars such as Umatilla Russet, Alpine Russet and Russet Burbank are very susceptible to gall formation. In contrast, the roots of russet-skinned cultivars Ranger Russet, Dakota Trailblazer, Russet Norkotah and Bannock Russet were the most resistant to gall formation among the cultivars evaluated.

Tuber necrosis caused by PMTV also varied among cultivars (Tables 5-8). 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 5-8). Russet-skinned and yellow-fleshed cultivars and selections tended to have a lower incidence than white- or red-skinned clones. Tuber necrosis ranged from zero in some cultivars to over 45% in some advanced breeding selections.

PMTV caused tuber necrosis was not observed in the red-skinned cultivar Puyehue and a number of advanced selections (Table 5). Red-skinned cultivars such as Red Pontiac, Red Norland and Red Lasoda also had a low incidence of PMTV tuber necrosis. As previously stated, as a group, russet-skinned cultivars tended to have a lower incidence of tuber necrosis caused by PMTV (Table 6). 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-fleshed cultivars although there was substantial variability in tuber necrosis observed among clones in both market classes (Tables 7 & 8). No PMTV tuber necrosis was observed in Shepody and two advanced breeding selections (Tables 7).

Summary:

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. The results from 2011 and 2012 were consistent which has allowed us to identify cultivars in each market class that appear to resist the development of PMTV caused tuber necrosis. These data will assist growers in making the appropriate cultivar selection if and when they are faced with this devastating disease.

Table 1. Mean powdery scab severity and incidence on potato tubers in 2012 by soil treatment

Fumigant Concentration (lb a.i./acre)	Disease Severity (%)	Disease Incidence (%)
Control	0.53 A	17.1 A
Pic Plus 100	0.59 A	19.64 A
Pic Plus 137.5	0.62 A	18.34 A
Pic Plus 175	0.54 A	18.99 A

Table 2. Mean AUDPC for root gall formation on chloropicrin fumigated soil in 2012 by soil treatment

Fumigant Concentration (lb a.i./acre)	Area Under Disease Progress Curve (S.U.)	
Pic Plus 100	2934.2	A
Pic Plus 175	2278.9	AB
Pic Plus 137.5	2106.3	B
Control	1254	C

Table 3. Mean powdery scab severity and incidence on potato tubers in 2012 by cultivar

Potato Cultivar	Disease Severity (%)	Disease Incidence (%)
Shepody	2.28 A	47.4 A
Kennebeck	2.01 A	47.16 AB
Red LaSoda	1.48 B	46.54 AB
Red Pontiac	1.03 C	42.11 B
Ivory Crisp	0.81 C	34.47 C
Red Norland	0.18 D	18.68 D
Yukon Gold	0.15 D	17.64 D
Ranger Russet	0.007 D	2 E
Russet Burbank	0.006 D	1.61 E
Alpine Russet	0.005 D	0.54 E
Umatilla Russet	0.001 D	0.52 E
Russet Norkotah	0.0009 D	0.34 E
Bannock Russet	0.0005 D	0.18 E
Dakota Trailblazer	0 D	0 E

Table 2. Mean AUDPC for root gall formation on chloropicrin fumigated soil in 2012 by potato cultivar

Potato Cultivar	Area Under Disease Progress Curve (S.U.)	
Red Pontiac	6873.0	A
Red LaSoda	5487.6	B
Kennebec	4340.2	B
Umatilla Russet	2644.1	C
Shepody	2619.5	C
Red Norland	1841.4	CD
Ivory Crisp	1604.4	CDE
Alpine Russet	1111.1	DEF
Russet Burbank	1098.8	DEF
Yukon Gold	803.6	DEF
Ranger Russet	682.0	DEF
Dakota Trailblazer	399.2	EF
Russet Norkotah	287.8	F
Bannock Russet	214.2	F

Table 5. PMTV tuber lesion incidence (%) of red-skinned cultivars and selections.

Cultivar/Selection	Tuber incidence (%)	
SPA 161	29.885	a
ND8314-1R	25.967	a
ND060728-5R	23.48	a
R90134-6	14.423	b
ND050167C-3R	12.518	bc
AND00272-1R	9.655	bcd
R90213-6	8.305	bcde
Dakota Jewel	8.298	bcde
ND8058-11R	8.235	bcde
RA 90213-60	7.498	bcde
T10-12	4.63	cde
ND028842b-1RY	4.335	cde
ND060733b-4RY	4.26	cde
Dark Red Norland	3.135	de
ND8555-8R	2.53	de
Viking	2.14	de
R 91129-11	2.083	de
Red Pontiac	1.96	de
R 90160-5	1.388	de
Red Norland	1.383	de
R 90070-8	1.053	de
ND4659-5R	0.935	de
Red LaSoda	0.095	e
Patagonia	0.058	e
ATND98459-1RY	0.018	e
RC 72-35	0.13	e
Puyehue	0	e
RA 20-6	0	e
RA 89044-45	0	e
$LSD_{P = 0.05}$	8.86	

Table 6. PMTV tuber lesion incidence (%) of russet-skinned cultivars and seclections.

Cultivar/Selection	Tuber incidence (%)	
ND060742C-1Russ	9.622	a
Alpine Russet	8.888	ab
ND6400C-1Russ	7.523	abc
ND049289-1Russ	4.167	abcd
ND8229-3	3.397	bcd
ND050082Cb-2Russ	2.973	cd
ND050105C-1Russ	2.972	cd
ND059769Ab-1Russ	2.412	cd
ND049423b-1Russ	1.112	d
ND8068-5Russ	0.013	d
ND060766b-4Russ	0	d
Bannock Russet	0	d
AND01804-3Russ	0	d
ND060796AB-1Russ	0	d
Dakota Trailblazer	0	d
ND049546b-10Russ	0	d
Russet Burbank	0	d
Russet Norkotah	0	d
Ranger Russet	0	d
Umatilla Russet	0	d
ND8413-7Russ	0	d
$LSD_{P = 0.05}$	**5.89**	

Table 7. PMTV tuber lesion incidence (%) of white-skinned cultivars and selections.

Cultivar/Selection	Tuber incidence (%)	
ND060601CAB-2	23.192	a
ND060715B-15	14.695	ab
ND8304-2	14.075	abc
ND7550C-1	11.937	bcd
ND060847CB-1	11.812	bcde
Nicolet	9.013	bcdef
MSL-292A	8.448	bcdef
RA 151-24	5.358	bcdef
ND060835C-4	5.352	bcdef
ND6956b-13	5.17	cdef
CO 95051-7W	4.178	def
Kennebec	3.333	def
R65A-70	2.875	def
W2717-5	2.705	def
ND7519-1	2.447	ef
ND8307C-3	2.245	f
ND8559-20	2.232	f
Snowden	2.225	f
NY-138	1.667	f
Lamoka	0.99	f
ND8331Cb-2	0.013	f
Ivory Crisp	0.013	f
Shepody	0	f
ND8331Cb-3	0	f
NY-139	0	f
$LSD_{P = 0.05}$	9.40	

Table 8. PMTV tuber lesion incidence (%) of yellow-fleshed cultivars and selections.

Cultivar/Selection	Tuber incidence (%)	
RA 82-4	9.652	a
RA 362-54	5.413	ab
Yagana	5.07	ab
Puren	3.03	b
R 87009-28	3.028	b
Yukon Gold	1.515	b
RA 519-50	1.293	b
RA 517-123	0.98	b
R 91007-5	0.927	b
R 89045-35	0.012	b
RA 16-5	0	b
RA 148-48	0	b
RC 06-109	0	B
$LSD_{P = 0.05}$	6.50	

<u>Simulated Glyphosate Drift on Processing Potatoes.</u> Harlene Hatterman-Valenti and Collin Auwarter.

This study was conducted at the Northern Plains Potato Grower's Irrigation Research site near Inkster, ND to evaluate simulated glyphosate drift at three growth stages on Bannock, Ranger Russet, Russet Burbank, and Umatilla. Corn was the previous crop. 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. Treatments were applied on July 24 (tuber initiation), August 9 (early tuber bulking), and September 4 (late tuber bulking) to the middle 2 rows with a modified ATV sprayer. Potatoes were machine harvested and graded a few weeks later.

Table 1. Glyphosate treatments

Trt No	Treatment Name	Rate	Rate Unit	App Code
1	Untreated			
2	Roundup WeatherMax	2.75	floz/a	A
	AMS	4	lbs/100 gal	A
3	Roundup WeatherMax	1.375	floz/a	A
	AMS	4	lbs/100 gal	A
4	Roundup WeatherMax	0.6875	floz/a	A
	AMS	4	lbs/100 gal	A
5	Roundup WeatherMax	2.75	floz/a	B
	AMS	4	lbs/100 gal	B
6	Roundup WeatherMax	1.375	floz/a	B
	AMS	4	lbs/100 gal	B
7	Roundup WeatherMax	0.6875	floz/a	B
	AMS	4	lbs/100 gal	B
8	Roundup WeatherMax	5.5	floz/a	C
	AMS	4	lbs/100 gal	C
9	Roundup WeatherMax	2.75	floz/a	C
	AMS	4	lbs/100 gal	C
10	Roundup WeatherMax	1.375	floz/a	C
	AMS	4	lbs/100 gal	C

Table 2. Herbicide application information.

Date:		7/24/2012	8/9/2012	9/4/2012
App Code:		A	B	C
Sprayer:	GPA:	20	20	20
	PSI:	40	40	40
	Nozzle:	8002	8002	8002
Air Temperature (F):		78	69	80
Relative Humidity (%):		53	63	46
Wind (MPH):		10	7	9
Cloud Cover (%):		25	10	10
Potato Stage:		Tuber Initiation	Early Tuber Bulking	Late Tuber Bulking

Table 3. Bannock yield.

Trt	Glyphosate	Rate	App	--------------------------------CWT/A--------------------------------					
No	Rate	Unit/a	Code	<4 oz	4-6 oz	6-10 oz	>10 oz	Total	>4 oz
1	untreated			41 b	53 a	129 a	158 ab	381 a	340 ab
2	0.09	lbae	A	86 a	84 a	143 a	78 bc	391 a	305 b
3	0.05	lbae	A	36 b	51 a	140 a	186 a	414 a	378 a
4	0.02	lbae	A	41 b	57 a	146 a	155 ab	399 a	358 ab
5	0.09	lbae	B	105 a	50 a	79 b	65 c	299 b	194 c
6	0.05	lbae	B	48 b	53 a	119 ab	116 abc	336 ab	288 b
7	0.02	lbae	B	40 b	60 a	118 ab	141 ab	360 ab	320 ab
8	0.18	lbae	C	39 b	64 a	125 a	147 ab	375 ab	336 ab
9	0.09	lbae	C	40 b	46 a	121 ab	153 ab	359 ab	319 ab
10	0.05	lbae	C	53 b	62 a	114 ab	118 abc	347 ab	295 b
			LSD (P=.05)	27.1	23.1	30.5	51.6	51.5	45.8

Table 4. Bannock tuber counts.

Trt	Glyphosate	Rate	App	-----------------------Tuber Counts/20’-----------------------					
No	Rate	Unit/a	Code	<4 oz	4-6 oz	6-10 oz	>10 oz	Total	% >4 oz
1	untreated			39 c	24 a	36 ab	27 ab	124 abc	69 a
2	0.09	lbae	A	82 b	37 a	41 a	14 bc	173 a	54 b
3	0.05	lbae	A	32 c	22 a	40 a	30 a	124 abc	75 a
4	0.02	lbae	A	38 c	25 a	41 a	25 ab	129 abc	71 a
5	0.09	lbae	B	112 a	22 a	23 b	11 c	168 ab	34 c
6	0.05	lbae	B	44 c	23 a	34 ab	19 abc	120 bc	63 ab
7	0.02	lbae	B	40 c	27 a	34 ab	23 ab	123 abc	68 a
8	0.18	lbae	C	38 c	28 a	34 ab	25 ab	125 abc	70 a
9	0.09	lbae	C	34 c	20 a	34 ab	24 ab	111 c	69 a
10	0.05	lbae	C	46 c	27 a	33 ab	20 abc	125 abc	63 ab
			LSD (P=.05)	25.4	10.2	8.7	8.2	32.1	8.9

Table 5. Bannock percent tuber Injury (malformation and other deformities).

Trt	Glyphosate	Rate	App	------------% Glyphosate Injury-----------			
No	Rate	Unit/a	Code	4-6 oz	6-10 oz	>10 oz	Total
1	untreated			2.5 bc	0.5 b	1.0 b	1.4 b
2	0.09	lbae	A	16.5 b	17.4 ab	15.3 ab	16.3 b
3	0.05	lbae	A	1.3 c	4.8 b	2.5 b	3.1 b
4	0.02	lbae	A	0.0 c	4.3 b	1.3 b	2.3 b
5	0.09	lbae	B	37.7 a	25.8 a	27.3 a	31.8 a
6	0.05	lbae	B	28.8 a	13.1 ab	10.2 ab	17.0 b
7	0.02	lbae	B	6.0 bc	7.8 b	6.4 ab	6.9 b
8	0.18	lbae	C	4.0 bc	1.0 b	3.7 b	2.9 b
9	0.09	lbae	C	6.1 bc	4.4 b	6.9 ab	5.5 b
10	0.05	lbae	C	0.0 c	2.5 b	4.3 b	2.2 b
			LSD (P=.05)	10.1	13.4	14.7	11.1

Table 6. Ranger yields.

Trt	Glyphosate	Rate	App	---CWT/A---					
No	Rate	Unit/a	Code	<4 oz	4-6 oz	6-10 oz	>10 oz	Total	>4 oz
1	untreated			72 a	87 a	165 a	113 a	437 a	364 a
2	0.09	lbae	A	77 a	94 a	144 a	143 a	458 a	381 a
3	0.05	lbae	A	55 a	101 a	158 a	135 a	450 a	395 a
4	0.02	lbae	A	73 a	75 a	133 a	120 a	401 a	328 a
5	0.09	lbae	B	71 a	95 a	153 a	133 a	452 a	381 a
6	0.05	lbae	B	65 a	86 a	132 a	149 a	432 a	367 a
7	0.02	lbae	B	71 a	90 a	157 a	135 a	451 a	381 a
8	0.18	lbae	C	78 a	97 a	163 a	105 a	443 a	366 a
9	0.09	lbae	C	71 a	94 a	133 a	137 a	454 a	363 a
10	0.05	lbae	C	76 a	87 a	163 a	135 a	461 a	385 a
LSD (P=.05)				29.5	32.2	40.2	49.5	49.3	46.7

Table 7. Ranger tuber counts.

Trt	Glyphosate	Rate	App	---Tuber Counts/20'---					
No	Rate	Unit/a	Code	<4 oz	4-6 oz	6-10 oz	>10 oz	Total	% >4 oz
1	untreated			69 a	38 a	47 a	19 a	173 a	60 a
2	0.09	lbae	A	75 a	42 a	42 a	22 a	180 a	60 a
3	0.05	lbae	A	56 a	45 a	46 a	22 a	168 a	68 a
4	0.02	lbae	A	69 a	33 a	39 a	20 a	160 a	57 a
5	0.09	lbae	B	66 a	42 a	44 a	22 a	173 a	63 a
6	0.05	lbae	B	62 a	38 a	38 a	23 a	160 a	61 a
7	0.02	lbae	B	72 a	40 a	45 a	22 a	178 a	60 a
8	0.18	lbae	C	77 a	43 a	47 a	17 a	183 a	59 a
9	0.09	lbae	C	67 a	42 a	38 a	21 a	167 a	61 a
10	0.05	lbae	C	72 a	38 a	46 a	23 a	179 a	60 a
LSD (P=.05)				27.5	14.3	11.8	7.1	34.1	9.1

Table 8. Ranger percent tuber Injury (malformation and other deformities).

Trt	Glyphosate	Rate	App	---% Glyphosate Injury---			
No	Rate	Unit/a	Code	4-6 oz	6-10 oz	>10 oz	Total
1	untreated			1.5 ab	4.2 b	3.9 a	3.1 b
2	0.09	lbae	A	3.2 ab	6.2 ab	3.1 a	4.4 b
3	0.05	lbae	A	1.7 ab	2.2 b	2.2 a	2.0 b
4	0.02	lbae	A	0.0 b	3.9 b	5.1 a	2.7 b
5	0.09	lbae	B	8.8 a	14.4 a	13.5 a	12.2 a
6	0.05	lbae	B	5.6 ab	9.7 ab	14.5 a	9.0 ab
7	0.02	lbae	B	4.5 ab	6.5 ab	5.9 a	5.4 b
8	0.18	lbae	C	1.6 ab	2.7 b	0.0 a	2.0 b
9	0.09	lbae	C	2.4 ab	5.5 ab	8.6 a	4.9 b
10	0.05	lbae	C	1.7 ab	2.2 b	1.7 a	2.2 b
LSD (P=.05)				4.7	6.8	8.9	4.8

Table 9. Umatilla yields.

Trt	Glyphosate	Rate	App	---CWT/A---					
No	Rate	Unit/a	Code	<4 oz	4-6 oz	6-10 oz	>10 oz	Total	>4 oz
1	untreated			109 a	84 a	110 a	88 a	392 a	283 a
2	0.09	lbae	A	110 a	89 a	97 a	67 a	362 a	253 a
3	0.05	lbae	A	131 a	96 a	113 a	79 a	418 a	288 a
4	0.02	lbae	A	94 a	94 a	158 a	97 a	443 a	349 a
5	0.09	lbae	B	125 a	80 a	100 a	97 a	402 a	277 a
6	0.05	lbae	B	84 a	70 a	103 a	96 a	352 a	269 a
7	0.02	lbae	B	93 a	103 a	117 a	81 a	395 a	301 a
8	0.18	lbae	C	100 a	91 a	123 a	83 a	398 a	298 a
9	0.09	lbae	C	103 a	96 a	130 a	85 a	414 a	311 a
10	0.05	lbae	C	95 a	103 a	125 a	95 a	418 a	323 a
LSD (P=.05)				33.7	25.2	56.0	60.5	98.4	95.8

Table 10. Umatilla tuber counts.

Trt	Glyphosate	Rate	App	---Tuber Counts/20’---					
No	Rate	Unit/a	Code	<4 oz	4-6 oz	6-10 oz	>10 oz	Total	% >4 oz
1	untreated			103 a	38 a	32 a	14 a	186 a	45 a
2	0.09	lbae	A	107 a	39 a	29 a	11 a	185 a	42 a
3	0.05	lbae	A	129 a	43 a	33 a	12 a	217 a	41 a
4	0.02	lbae	A	89 a	42 a	46 a	17 a	193 a	55 a
5	0.09	lbae	B	126 a	36 a	28 a	15 a	204 a	40 a
6	0.05	lbae	B	86 a	31 a	31 a	15 a	162 a	47 a
7	0.02	lbae	B	88 a	46 a	34 a	14 a	182 a	52 a
8	0.18	lbae	C	88 a	41 a	36 a	14 a	178 a	50 a
9	0.09	lbae	C	97 a	43 a	37 a	14 a	191 a	50 a
10	0.05	lbae	C	86 a	45 a	36 a	16 a	183 a	53 a
LSD (P=.05)				34.1	11.0	12.9	9.2	40.6	10.9

Table 11. Umatilla percent tuber Injury (malformation and other deformities).

Trt	Glyphosate	Rate	App	---% Glyphosate Injury---			
No	Rate	Unit/a	Code	4-6 oz	6-10 oz	>10 oz	Total
1	untreated			0.0 b	0.6 b	6.7 b	1.9 b
2	0.09	lbae	A	3.8 b	3.6 b	0.0 b	3.1 b
3	0.05	lbae	A	7.7 b	7.4 b	10.1 b	8.2 b
4	0.02	lbae	A	3.5 b	0.0 b	1.0 b	1.6 b
5	0.09	lbae	B	41.5 a	50.8 a	61.2 a	49.2 a
6	0.05	lbae	B	16.4 b	17.3 b	16.8 b	17.6 b
7	0.02	lbae	B	3.1 b	0.7 b	2.5 b	2.0 b
8	0.18	lbae	C	1.7 b	8.5 b	7.1 b	5.4 b
9	0.09	lbae	C	5.1 b	3.2 b	2.8 b	4.1 b
10	0.05	lbae	C	0.7 b	1.4 b	2.2 b	1.3 b
LSD (P=.05)				10.2	13.5	12.6	10.2

Table 12. Russet Burbank yields.

Trt	Glyphosate	Rate	App	--------------------------------CWT/A--------------------------------					
No	Rate	Unit/a	Code	<4 oz	4-6 oz	6-10 oz	>10 oz	Total	>4 oz
1	untreated			50 a	67 a	111 a	144 ab	372 a	322 a
2	0.09	lbae	A	42 a	53 a	100 a	167 ab	362 a	320 a
3	0.05	lbae	A	38 a	55 a	94 a	112 ab	299 a	261 a
4	0.02	lbae	A	51 a	63 a	117 a	121 ab	351 a	301 a
5	0.09	lbae	B	36 a	45 a	98 a	110 ab	290 a	253 a
6	0.05	lbae	B	51 a	64 a	111 a	154 ab	380 a	329 a
7	0.02	lbae	B	56 a	78 a	114 a	69 b	318 a	261 a
8	0.18	lbae	C	50 a	56 a	86 a	92 ab	285 a	234 a
9	0.09	lbae	C	53 a	54 a	124 a	199 a	431 a	378 a
10	0.05	lbae	C	53 a	64 a	128 a	139 ab	385 a	332 a
LSD (P=.05)				19.1	21.3	37.5	68.9	98.8	93.4

Table 13. Russet Burbank tuber counts.

Trt	Glyphosate	Rate	App	-----------------------Tuber Counts/20’-----------------------					
No	Rate	Unit/a	Code	<4 oz	4-6 oz	6-10 oz	>10 oz	Total	% >4 oz
1	untreated			50 a	30 a	32 a	20 ab	131 a	63 a
2	0.09	lbae	A	44 a	23 a	28 a	27 ab	122 a	64 a
3	0.05	lbae	A	37 a	25 a	27 a	18 ab	106 a	65 a
4	0.02	lbae	A	51 a	28 a	34 a	20 ab	131 a	61 a
5	0.09	lbae	B	40 a	20 a	28 a	18 ab	105 a	62 a
6	0.05	lbae	B	51 a	28 a	31 a	24 ab	134 a	62 a
7	0.02	lbae	B	58 a	35 a	33 a	12 b	137 a	58 a
8	0.18	lbae	C	52 a	25 a	24 a	15 ab	117 a	55 a
9	0.09	lbae	C	54 a	24 a	35 a	31 a	143 a	63 a
10	0.05	lbae	C	52 a	28 a	36 a	23 ab	138 a	63 a
LSD (P=.05)				18.5	9.3	10.5	10.3	31.9	9.1

Table 14. Russet Burbank percent tuber Injury (malformation and other deformities).

Trt	Glyphosate	Rate	App	------------% Glyphosate Injury-----------			
No	Rate	Unit/a	Code	4-6 oz	6-10 oz	>10 oz	Total
1	untreated			4.2 b	2.9 bc	6.9 c	4.1 c
2	0.09	lbae	A	3.1 b	3.6 bc	6.6 c	4.2 c
3	0.05	lbae	A	2.2 b	0.0 c	4.7 c	2.0 c
4	0.02	lbae	A	0.8 b	1.3 bc	4.8 c	2.2 c
5	0.09	lbae	B	32.1 a	33.1 a	64.2 a	40.5 a
6	0.05	lbae	B	12.7 b	19.8 b	38.7 b	23.1 b
7	0.02	lbae	B	5.3 b	6.4 bc	18.3 c	7.5 c
8	0.18	lbae	C	0.0 b	1.9 bc	0.0 c	0.7 c
9	0.09	lbae	C	2.1 b	3.9 bc	4.3 c	3.5 c
10	0.05	lbae	C	1.1 b	3.1 bc	4.2 c	2.9 c
LSD (P=.05)				7.7	11.7	18.2	10.0

Bannock was the most sensitive cultivar tested (Tables 3, 4, and 5). Glyphosate at 0.09 lb/A ETB caused reduced total yield compared to untreated. There were significantly more < 4 oz tubers, fewer 6-10 oz tubers, and fewer > 10 oz tubers. Glyphosate at 0.05 lb/A ETB or higher caused more imperfections in 4-6 oz tubers. Glyphosate at 0.09 lb/A ETB caused more imperfections in 6-10 and >10 oz tubers.

Ranger Russet was the least sensitive cultivar tested (Tables 6, 7, and 8). Glyphosate did not reduce total or graded yields compared to untreated. However, glyphosate at 0.09 lb/A ETB did cause more imperfections in 4-6 and 6-10 oz tubers.

Umatilla was considered a cultivar with intermediate sensitivity to glyphosate (Tables 9, 10, and 11). Glyphosate did not reduce total or graded yields compared to untreated. Glyphosate at 0.09 lb/A ETB caused more imperfections in 4-6, 6-10, and >10 oz tubers.

Russet Burbank was also considered a cultivar with intermediate sensitivity to glyphosate (Tables 12, 13, and 14). Glyphosate at 0.09 lb/A ETB caused approx. 22% market and total yield reduction but not significant compared to untreated. Glyphosate at 0.05 lb/A ETB or higher caused more imperfections in > 10 oz tubers. Glyphosate at 0.09 lb/A ETB caused more imperfections in 4-6 and 6-10 oz tubers.

<u>Solida (rimsulfuron) efficacy on Norland potatoes</u>. Harlene Hatterman-Valenti and Collin Auwarter.

This study was conducted near Glyndon, MN to determine the efficacy of SOLIDA formulation compared to Matrix for weed control in Red Norland potato. Plots were 4 rows by 20 feet arranged in a randomized complete block design with four replicates. Potatoes were planted May 14, 2012. PRE treatments were applied June 1(A), immediately after hilling. POST treatments were applied June 15 (B). Common lambsquarters, redroot pigweed and yellow foxtail were the primary weeds evaluated in this trial.

Table 1. Herbicide application Information.

Date:		6/1/2012	6/15/2012
Time:		A	B
Sprayer:	GPA:	20	20
	PSI:	40	40
	Nozzle:	8002 FF	8002
Air Temperature (F):		65	67
Relative Humidity (%):		40	75
Wind (MPH):		9	5
Cloud Cover (%):		100	0

Table 2. Weed control at 6, 21, and 32 days after application (DAA).

					COLQ	AMARE	GRFT	INJ	COLQ	AMARE	GRFT	INJ	COLQ	AMARE	GRFT	INJ
Trt	Trt		Rate	App	----------------6 DAA----------------				---------------21 DAA---------------				---------------32 DAA---------------			
No	Name	Rate	Unit	Code	---------% Control---------			%	---------% Control---------			%	---------% Control---------			%
1	Unt				0.0d	0.0d	0.0c	0a	0.0d	0.0c	0.0b	0a	0.0a	0.0b	0.0b	0a
2	SOLIDA	0.0117	lbai/a	A	88.8c	87.5c	96.3b	0a	87.5c	90.0b	100a	0a	83.8bc	87.5a	87.5a	0a
3	SOLIDA	0.0234	lbai/a	A	93.8b	96.3ab	100a	0a	92.5b	97.5ab	100a	0a	87.5b	87.5a	87.5a	0a
4	SOLIDA	0.047	lbai/a	A	98.8a	97.5a	100a	0a	98.8a	98.8a	100a	0a	92.5a	90.0a	90.0a	0a
5	MATRIX	0.0234	lbai/a	A	91.3bc	92.5b	98.8a	0a	88.8bc	90.0b	95.0a	0a	86.3b	87.5a	87.5a	0a
6	SOLIDA	0.0117	lbai/a	B	0.0d	0.0d	0.0c	0a	90.0bc	93.8ab	97.5a	0a	80.0c	82.5a	83.8a	0a
	NIS	0.25	% v/v													
7	SOLIDA	0.0234	lbai/a	B	0.0d	0.0d	0.0c	0a	90.0bc	95.0ab	97.5a	0a	83.8bc	82.5a	87.5a	0a
	NIS	0.25	% v/v													
8	SOLIDA	0.047	lbai/a	B	0.0d	0.0d	0.0c	0a	98.8a	97.5ab	100a	0a	87.5b	87.5a	88.8a	0a
	NIS	0.25	% v/v													
9	SOLIDA	0.0234	lbai/a	B	0.0d	0.0d	0.0c	0a	91.3bc	93.8ab	100a	0a	85.0b	83.8a	86.3a	0a
	NIS	0.25	% v/v													
				LSD (P=.05)	3.14	3.94	2.70	0	3.22	5.29	4.03	0	3.60	5.11	5.00	0

The highest rate of SOLIDA (0.047 lbai/a) applied PRE provided the best weed control throughout the study (Table 2). At 6 DAA, 99% of the common lambsquarters (COLQ) were controlled at the 0.047 lbai/a rate compared to 89% control with the 0.0117 lbai/a (lowest rate). Matrix at 0.0234 lbai/a provided 91% control of the COLQ. At 21 DAA “A” (7 DAA “B”) results were similar with the higher rates providing better weed control. Both the PRE and POST treatments at 0.047 lbai/a had significantly better control of COLQ. At 32 DAAA (18 DAAB) the PRE treatments appeared to provide better COLQ control compared to the POST treatments at the same rates. Solida at 0.047 lbai/a PRE had 93% COLQ control while the POST treatment at the same rate only had 88% control. The Matrix treatments at this evaluation showed 80% control with the PRE treatment and 85% control with the POST treatment. Total yield was very minimal due to the dry summer. However, differences were seen among treatments. The highest yield with 13.3 lbs/20 feet of row was from the Solida at 0.047 lbai/a PRE treatment. This was followed by 10.80 lbs/20 feet of row from the Solida at 0.047 lbai/a POST treatment. The untreated treatment yielded the least.

2012 Helena Fertilizer Trial. Harlene Hatterman-Valenti and Collin Auwarter.

This study was conducted at the Oakes Irrigation Research Station to evaluate various rates of in-furrow starter fertilizer on Russet Burbank potato. Plots were 4 rows by 17 feet arranged in a randomized complete block design with four replicates. Starter fertilizers, fert-A and fert-B, was tank-mixed and applied at different rates (shown below). There was also a grower standard application with 10-34-0 at 25 gal/A and an untreated that didn't receive any starter fertilizer. Soil tests taken prior to the trial showed 24 lb N, 17 ppm P, and 145 ppm K. Pre-plant applications of 51 lbs N as 46-0-0 and 200 lbs K (grower standard application, treatment 2) or 140 lbs K (treatments 3-6) as 0-0-60 were applied and incorporated on May 10, 2012. Closing disks were removed from the planter as we planted potatoes to allow in-furrow application of starter fertilizers. In addition to fert-A and fert-B, 28% urea was tank mixed to bring the total N to 100 lbs in each treatment. Fertilizer amounts after planting were 100 lbs N, various lbs P, 200 lbs K in treatment 2, and 140 lbs K in treatments 3-6. Nitrogen, as 28-0-0 was stream barred and immediately irrigated with 0.30" irrigation on June 25 (47 lbs) and July 25 (53 lbs). Potatoes were harvested October 9 with a single-row digger and graded in Fargo.

Trt	Trt	Form	Form		Rate	App	----------------------------CWT/A--------------------------						------------Tuber Count in 34 feet----------				
No	Name	Conc	Type	Rate	Unit	Code	Total	0-4oz	4-6oz	6-10oz	>10oz	>4oz	Total	0-4oz	4-6oz	6-10oz	>10oz
1	N	28%	L	47	lb ai/a	C	380	106	97	120	57	274	369	212	80	59	18
	N	28%	L	53	lb ai/a	E											
2	N	46%	GR	51	lb ai/a	A	470	117	109	149	95	353	354	198	73	63	20
	K	60%	GR	200	lb ai/a	A											
	10-34-0	10,34%	L	25	gal/a	B											
	N	28%	L	47	lb ai/a	B											
	N	28%	L	53	lb ai/a	E											
3	N	46%	GR	51	lb ai/a	A	493	129	101	164	99	364	423	246	79	70	28
	K	60%	GR	140	lb ai/a	A											
	^Fert-A	na	L	15	gal/a	B											
	^Fert-B	na	L	3	gal/a	B											
	N	28%	L	47	lb ai/a	C											
	N	28/%	L	53	lb ai/a	E											
4	N	46%	GR	51	lb ai/a	A	549	122	118	184	125	427	356	187	75	68	26
	N	60%	GR	140	lb ai/a	A											
	^Fert-A	na	L	10	gal/a	B											
	^Fert-B	na	L	2	gal/a	B											
	N	28%	L	47	lb ai/a	C											
	N	28%	L	53	lb ai/a	E											
5	N	46%	GR	51	lb ai/a	A	455	144	97	121	93	311	377	229	72	54	22
	K	60%	GR	140	lb ai/a	A											
	^Fert-A	na	L	15	gal/a	B											
	^Fert-B	na	L	3	gal/a	B											
	N	28%	L	47	lb ai/a	C											
	*Foliar	na	L	na	na	D											
	N	28%	L	53	lb ai/a	E											
	*Foliar	na	L	na	na	F											
6	N	46%	GR	51	lb ai/a	A	435	133	99	133	70	302	383	236	69	59	19
	K	60%	GR	140	lb ai/a	A											
	^Fert-A	na	L	10	gal/a	B											
	^Fert-B	na	L	2	gal/a	B											
	N	28%	L	47	lb ai/a	C											
	*Foliar	na	L	na	na	D											
	N	28%	L	53	lb ai/a	E											
	*Foliar	na	L	na	na	F											
			LSD (P=.05)				125	44	36	65	47	119	99	66	24	25	11

^Fert –A & B – Confidential
*Foliar – Confidential

Fertilizer application code:
A = 5/14/12 – Treatments 2-6 @ Pre-plant
B = 5/14/12 – Treatments 2-6 @ Planting
C = 6/25/12 – Treatments 1-6 @ Tuber initiation
D = na
E = 7/25/12 – Treatments 1-6 @ Early tuber bulking
F = na

Potatoes receiving treatment 4 had the highest total yield at 549 cwt/A, and highest marketable yield at 427 cwt/A. The total and marketable yield was 17 and 21% higher, respectively, than the grower standard (treatment 2). Total tuber counts for treatments 2 and 4 were similar, while the distribution for the various grade categories indicated a shift towards larger tubers with treatment 4.

Loveland Black Label Zn Fertilizer Trial. Harlene Hatterman-Valenti and Collin Auwarter.

This study was conducted at the Oakes Irrigation Research Station near Oakes, ND to evaluate various rates of Black Label Zn applied in-furrow on Russet Burbank potatoes. Plots were 4 rows by 17 feet arranged in a randomized complete block design with four replicates. Black Label Zn was applied at rates; 3, 6, 9, and 12 gal/A at planting. There was a grower standard application with 10-34-0 at 12 gal/A and an untreated that didn't receive any additional phosphorus at planting . Soil tests taken prior to the trial showed 24 lb N, 17 ppm P, and 145 ppm K. Pre-plant applications of 51 lbs N as 46-0-0 and 50 lbs K as 0-0-60 were applied and incorporated on May 10, 2012. Closing disks were removed from the planter as we planted potatoes to expose seed piece in-furrow and applied starter fertilizer. In addition to the Black Label Zn, tank mixing 28-0-0 urea was added to bring the total N to 100 lbs in each treatment. At this point, 100 lbs N, various lbs P, and 50 lbs K. 47 lbs N was applied on June 14 (tuber initiations stage) and 53 lbs N was applied on July 25 (early tuber bulking) to bring total N to 200 lbs.

Treatment 1: 3 gal/A Black Label Zn In-furrow at planting
Treatment 2: 6 gal/A Black Label Zn In-furrow at planting
Treatment 3: 9 gal/A Black Label Zn In-furrow at planting
Treatment 4: 12 gal/A Black Label Zn In-furrow at planting
Treatment 5: 12 gal/A 10-34-0 In-furrow at planting
Treatment 6: No starter

Trt	---------------------------CWT/A-----------------------------						------------Tuber Counts in 34 feet------------				
No	Total	0-4oz	4-6oz	6-10oz	>10oz	>4oz	Total	0-4oz	4-6oz	6-10oz	>10oz
1	411	118	109	123	61	293	355	193	83	61	18
2	453	127	116	139	71	326	366	190	88	68	20
3	459	141	113	138	67	318	400	225	86	70	19
4	459	152	126	132	49	307	417	241	96	65	15
5	410	122	119	125	44	288	358	193	90	62	13
6	408	119	111	117	61	289	353	192	84	58	19
LSD (P=.05)	89.0	28.4	27.5	36.4	46.5	81.0	89.8	43.5	21.4	18.0	12.4

Potatoes receiving at least 6 gal/A Black Label Zn in-furrow at planting yielded over 450 cwt/A, and had over 300 cwt/A of marketable tubers. This was approximately a 10 and 12% increase in marketable and total yield, respectively, compared to the 10-34-0 starter treatment or the no starter treatment. Tuber count data suggested that the yield increase was not necessarily due to larger sets since only treatments 3 and 4 averaged 400 or more tubers in 34 ft of row.

NPPGA/Area II Potato Insect Research Report 2012 - Establishing a Resistance Monitoring Program for Neonicotinoid Insensitive Colorado Potato Beetle in Minnesota and North Dakota

Dr. Ian MacRae
Dept of Entomology, University of Minnesota
Northwest Research & Outreach Center
2900 University Ave
Crookston, MN 56716

Rationale – Colorado Potato Beetle (CPB), *Leptinotarsa decimlineata* Say is one of the most damaging insect pests of potatoes in Minnesota and North Dakota. Typically this defoliating insect has required intensive chemical management with broad spectrum insecticides. This, combined with the detoxification systems which permit the insect to feed on the foliage of potato plants, high in toxic alkyloids, has led to CPB developing resistance to essentially every insecticide ever used against it (Weisz et al. 1994, Alyokhin et al. 2007). This continues to be a significant problem in managing CPB (Jorg et al. (2007). The rapidity with which CPB can develop resistance is remarkable; some insecticides (e.g. oxymyl) have even lost effectiveness within their first season of use (Forgash 1985). In some cases, the development of resistance to insecticides by a local population of CPB results in its 'appearance' as a pest in areas where it has not previously been a problem. This may result from these beetle populations losing their susceptibility to insecticides used in the production system that had previously been suppressing their populations. The introduction of the neonicotinoid insecticides initially provided some alternatives to existing classes of insecticides. The systemic abilities of these insecticides made them especially efficacious for whole field treatment and provided excellent protection. It was, however, recognized that resistance would develop and their effectiveness would eventually fade.

In 2000, the first reports of resistance to the neonicotinoid insecticide Imidacloprid (Admire, Bayer Crop Science) was reported in New York (Olson et al. 2000, Zhang et al. 2000) and later from Maine (Alyokhin & Dwyer 2005). This resistance was later linked to cross-resistance to the neonicotinoid insecticide Thiamethoxam (Platinum, Cruiser, Syngenta Crop Protection) (Alyokhin et al 2007); these insecticides are used on ~70% of all potatoes grown from Maine to North Dakota, belong to the same class of insecticides and have the same mode of action. The development of cross-resistance refers to a population of insects that develop resistance to an insecticide with a specific mode of action are then resistant, or partially resistant, to all other insecticides with the same mode of action (which may include all insecticides in that class).

This situation was reported from a number of field locations in Minnesota in 2007. In certain locations, populations of CPB were not controlled by field rate applications of imidacloprid. It was subsequently learned that an associated cross resistance to thiamethoxam was also present in these populations. Although not a linear relationship (a 15 fold resistance to thiamethoxam was associated with a 100 fold resistance to imidacloprid), the presence of this cross-resistance does suggest that the future use of these and other neonicotinoids to control CPB in Minnesota and North Dakota may be problematic. In addition, research indicates CPB resistant to imidacloprid will be partially resistant to new neonicotinoids, such as acetamiprid introduced in 2005 (Assail, Cerexagri) and dinotefuran (Venom, Valent Corp.) even prior to their use in the field (Grafius & Byrne, 2005).

Recently, populations of CPB that are insensitive to neonicotinoid insecticides have been reported from Central Minnesota and this insensitivity may be spreading geographically. This has resulted in a significant increase in control costs for this insect pest. The initial response to this situation is to identify alternative chemistries and application methods that remain effective or may either alleviate insensitivities in CPB. In 2010, populations were sampled in 3 different locations in Minnesota and sent to University of Michigan to evaluate levels of resistance (Table 1). It was found that populations in Becker and Long Prairie were marginally less susceptible but that populations in Perham were low to moderately resistant to neonicotinoid insecticides. Considering neonicotinoid insecticides were effective in these locations only 10 years ago, it can be assumed we are seeing an increase in resistance to neonicotinoids in CPB in Minnesota. The current and future geographic distribution of resistant CPB in Minnesota and North Dakota would be useful to estimate rates of spread of neonicotinoid resistance to other potato producing areas in the states and facilitate the development of resistance management programs. Unfortunately the number of sites that can be evaluated by outstate labs in any one year is limited. An instate program to test and map developing neonicotinoid resistance in MN and ND would enhance our ability to respond to this developing problem.

Table 1. Neonicitinoid resistance levels found in Colorado Potato Beetle populations from 3 areas in MN in 2010. Resistance level refers to how much more insecticide was necessary to kill 50% of the sampled population than was necessary to kill the susceptible New Jersey population (kept as a colony in the U.Mich. lab).

Location	**Insecticide**	**LD_{50} (mg/ind.)**	**Resistance (X susc.)**
Becker	Imidacloprid Thiomethoxam	0.473 0.102 (.087-.122)	**4 X** **1.3 X**
Perham	Imidacloprid Thiomethoxam	0.904 (.63-1.228) 0.198	**8 X** **2.5 X**
Long Prairie	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**
Becker (U.W.) 74 ind.	Imidacloprid Thiomethoxam	1.19	**10.4 X** **(timing??)**

Methods – Colorado potato beetle adults were be sampled from potato production areas within Minnesota and North Dakota. CPB populations that appear to becoming less susceptible to neonicotinoid insecticides received priority for collection and testing.

Populations of CPB were be collected and tested for neonicotinoid insensitivity. Beetles were collected by R.D. Offut and grower cooperators and UMN staff. Testing consisted of comparing LD_{50} values of collected beetles to those of the susceptible population. Adult beetles were tested using a contact exposure to varying concentration of three neonicotinoid insecticides: Imidacloprid (Admire Pro, Bayer CropScience), Thiamethoxam (Platinum, Syngenta Crop Protection), and Clothianidin (Belay, Valent Agricultural Products). Insecticides were applied in 1µl doses to the first abdominal segment of adult beetles using a micro-syringe applicator (Hamilton Co., Reno NV). Exposed beetles were then placed on potato leaves, the petioles of which were wrapped in damp cotton and placed into petrie plates. Beetles were stored for 7 days at 20C and potato leaves changed and/or re-wetted as necessary. Exposed beetles were examined daily for 7 days with final assessment on day 7, this is because CPB frequently show initial symptoms of intoxication but recover within 3-5 days. Any symptoms remaining after 7 days can be interpreted as susceptibility. Mortality rates between sample populations were compared with those from a known susceptible population using Probit Analyses; results were calculated using LDP (EhabSoft Co, Cairo, Egypt) and POLO Plus (LeOra Software, Petaluma, CA) software. Relative rates of resistance were calculated and compared.

Results & Discussion – Results indicate a number of locations have either well-established or developing resistance to Imidacloprid and/or Clothianidin while resistance to Thiamethoxam does not seem be as well developed in Minnesota (Table 2 a&b). The results from the two software packages used to analyze the results differ somewhat (Polo's algorithms are more conservative than those of LDP) but the patterns are the same. These results are from overwintered beetles in some locations and summer generation in others (e.g. Browerville 1 samples were overwintered adults while Browerville 3 & Danger Field, both in the same area, were summer generation adults). Sites in Becker, Perham, Wadena, and Grand Forks all show minor to low levels of resistance to Imidacloprid. The Forest River population of beetles, while the analyses still indicate susceptibility, are at the high end of this range and this may indicate

Table 2. Comparison of relative resistance rates of sampled sites and those of a known susceptible population. Numbers indicate the comparative resistance factor (i.e. a value of 4.09 indicates the population at that sampled site is 4.09 times as resistance as a susceptible population – i.e. it would take 4.09 times as much insecticide to kill these less susceptible insects). Values of 0x-3x indicate susceptibility to that chemical, values 3x-5x indicate minor resistance, 5x-8x indicate low levels of resistance, values 8x-10x are moderate resistance, values over 10x indicate well-established, high resistance. Rations presented in red or italics are results of concern.

A – Polo Plus Software Analysis					B – LDP Software Analysis			
SITE	**Admire**	**Platinum**	**Belay**		**SITE**	**Admire**	**Platinum**	**Belay**
Becker	*4.095238*	1.867322	0.96291		**Becker**	*4.093506*	1.866093	0.920114
Browerville Field 1	*8.562771*	1.670762	*3.245364*		**Browerville Field 1**	*10.5342*	1.68059	*3.213267*
Browerville Field 3	1.385281	0.31941	0.21398		**Browerville Field 3**	1.372294	0.31941	0.21398
Hubbard	1.021645	0.164619	0.606277		**Hubbard**	1.005195	0.164619	0.542083
Hatton	1.619048	0.012285	0.356633		**Hatton**	1.618182	0.012285	0.278174
Danger Field	1.52381	Product Not tested	*3.2097*		**Danger Field**	1.507359	Product Not tested	*3.2097*
Perham	*5.480519*	1.977887	0.64194		**Perham**	*5.481385*	Not Analyzed	0.848787
Wadena	*4.458874*	1.449631	*7.738944*		**Wadena**	*4.45974*	1.361179	*7.731812*
Grand Forks	*3.818182*	0.687961	1.60485		**Grand Forks**	*3.820779*	0.667076	0.499287
Forest River	Not Analyzed in Polo	Not Analyzed in Polo	Not Analyzed in Polo		**Forest River**	*2.499567*	1.08231	1.049572

this population is losing susceptibility to Imidacloprid. The results from Grand Forks and Forest River are concerning, this is the first confirmation we are seeing the development of Imidacloprid resistance in North Dakota populations. The Browerville 1 site indicates a moderate to high level of resistance to Imidacloprid. Two of the sites in Browerville also indicate minor to low levels of resistance to Clothianidin while the Wadena site results indicate a moderate level of resistance to this chemical. These latter results are worth noting as they are some of the first laboratory confirmations that Clothianidin resistance is also developing in MN.

The lack of data indicating Imidacloprid resistance in the Browerville 3 and Danger Field populations is interesting given the high levels of resistance in the Browerville 1 population. Both the Browerville 3 and Danger Field populations were summer generation adults while the Browerville 1 population was an overwintered 2011 population. This makes the observed pattern even more interesting, Szendrei et al. (2012) reported that neonicotinoid resistance was higher in summer generation adults than in overwintered adults from the same area. Assuming that individuals collected at the Browerville 1, Browerville 3 and Danger Field sites are members of the same population (and given the distances between sample sites, this is likely) then these results are puzzling.

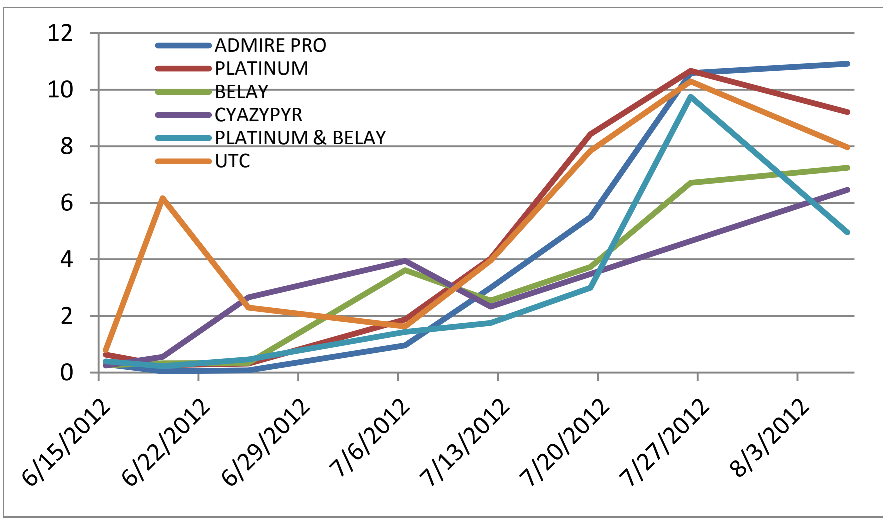
Future Plans – In 2012, laboratory personnel refined their bioassay techniques and over the season decreased the time necessary to complete location replications. Being now able to complete trials in a more timely manner, additional sites will be added (15-30 locations in 2013) providing greater coverage in central MN and additional sites in the RRV and ND. The latter locations are very important as neonicotinoid resistance was recorded for the first time in the Red River Valley. The CPB population tested from the Experimental Farm in Grand Forks had confirmed imidacloprid resistance and there are indications the population from Forest River are losing susceptibility to that insecticide (see Appendix 1 for a summarized report of 2012 findings). Field collection will be conducted with UMN field crews from the same locations both early in the season and later, collecting summer generation adults, requiring increased travel but providing better coverage and hopefully a comparison between overwintering and summer adults in the same populations. Samples will also still be sought from cooperators experiencing product failures or apparent decreased efficacy from neonicotinoid applications.

Colorado Potato Beetle Insecticide Treatment Trials – A series of 3 different insecticide efficacy trials were conducted to support the neonicotinoid resistance research. These trials assessed in-furrow applications, foliar applications, and a worst case rescue application. All trials were conducted at the Becker Sand Plains Research Farm, plots were 4 rows by 35' and planted with Russet Burbank potatoes on May 14 and the first plots emerged the week of June 04. The first observations of CPB in plots occurred the week of June 11 but numbers were insufficient to count until the following week. CPB populations in plots were assessed weekly until Aug 06 in all plots and the numbers of adults and larval beetles counted and percent defoliation estimated. By Aug 06, summer generation beetles had become well-established by this time and beetles were heavily defoliating plants (insecticide residual was depleted to the point where plants were no longer protected). All plots were treated with Spinosad to kill off remaining CPB populations.

In-furrow trial – Treatments (Table 3) were applied at planting, in furrow, on seed pieces with sufficient water to ensure coverage. Average weekly populations in all treatment plots followed similar patterns with the exception of UTC plots early in the season (fig 1). Until June 25, UTC plots held more CPB. By early July, there was little difference between the number of CPB in any plot. This may be because of a protracted emergence of overwintering individuals; as numbers of adults decreased and larval numbers had yet to significantly increase, the number of total CPB in UTC plots decreased. When later emerging adults contributed eggs and eventually larvae to the populations (mid to late July), insecticide titers may well have dropped to the point where CPB were not controlled. The neonicotinoids did hold well early season but did not perform significantly better than the UTC later in the season. It is interesting that Cyzapyr provided somewhat more consistent control throughout the season and the Platinum & Belay plots had a sudden drop in CPB numbers late in the season. This sudden decrease follows a similar pattern most other plots but was most precipitous in the Platinum & Belay plots.

Table 3. Insecticide teatments included in in-furrow application tests.

Insciticide	Rate
1) Untreated Control	N/A
2) Admire Pro	8.7 fl.oz/ac
3) Platinum	8.0 fl.oz/ac
4) Belay	12 fl.oz/ac
5) Cyzypyr	.264 lbs ai/ac
6) Platinum & Belay	8.0 fl.oz/ac & 12.0 fl.oz/ac



Untreated plots suffered more early season defoliation than did treated plots (as would be expected from their increased CPB populations) (fig 2a). New growth in July and a masked the percent defoliation

Yields from in-furrow treated plots showed a significant difference; all

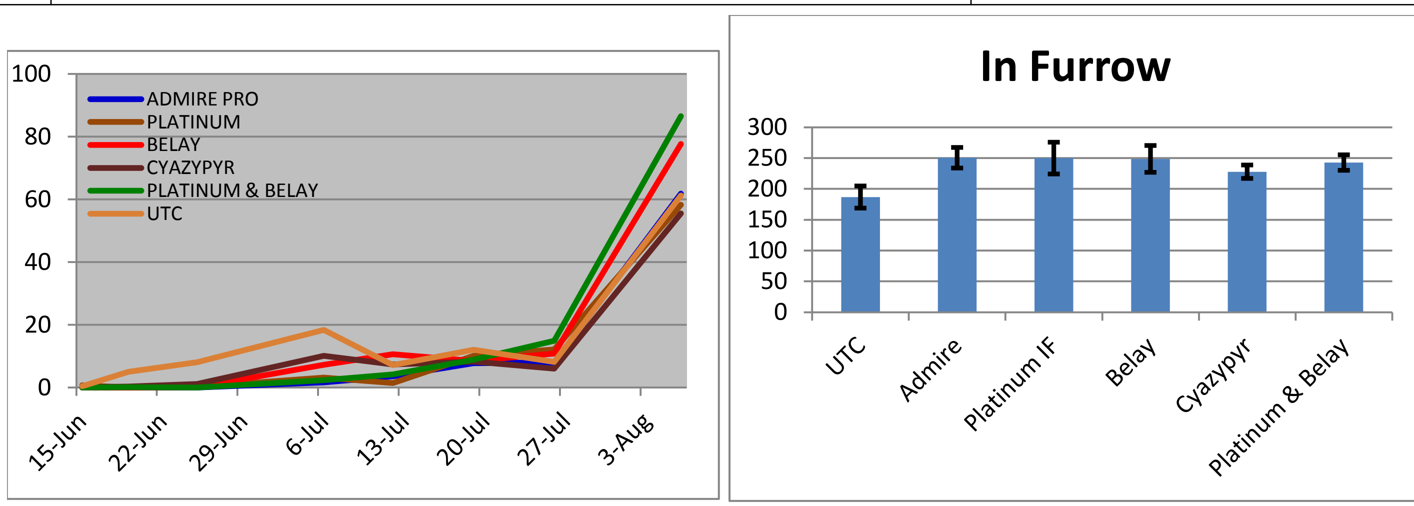


Figure 2. A) The graph on the left is estimated % defoliation in each plot at each date. B) The raph on the right are plot yields; vertical bars represent 95% Confidence Intervals, overlap of bars indicates no significant difference in treatment.

insecticide treated plots yields significantly higher than did the untreated plots. However, there was no significant difference between any insecticide treatment (fig 2b). This is interesting as it infers that although the full rates of both Platinum & Belay were applied in one treatment, this did not significantly increase yield or, apparently, increase the level of protection against CPB damage. None of the in-furrow treatments provided season-long protection against CPB damage, a late season foliar application will obviously be necessary to control summer generation larvae in areas experiencing high CPB pressure.

Foliar trials – A foliar treatment designed to assess the efficacy of one foliar application timed against the first generation larvae was conducted. Treatments included in the foliar treatments included an Untreated Control, a single application of Blackhawk (2.5 oz/ac), 2 applications of Blackhawk (2.5 oz/ac) at 7 day interval, Warrior II (1.92 fl.oz/ac), Provado 1.6 (3.8 fl.oz/ac), Leverage 360 (2.8 fl.oz/ac), and Belay (3 fl.oz/ac). While there were some differences in the patterns and number of CPB population in each plot, the protracted emergence of overwintered adults resulted in a longer presence of 1st summer generation larvae which coincided with larvae of earlier emerging overwintered adults. Together, these caused significant mid to late-season defoliation. As a result there was no difference in final defoliation rates or yields.

Worst Case trials – the worst case rescue foliar application trial was designed to assess the efficacy of attempting to stem late-season, well-established larval CPB populations using foliar applications. Early season CPB populations were not controlled at threshold, allowing larvae to becomes established. When larvae had become well-established and average defoliation across plots had exceeded 20%, a single treatment of Blackhawk (2.5 oz/ac), Belay (3 fl.oz/ac), and Leverage 360 (2.8 fl.oz/ac) and an untreated control were applied. Late-season defoliation was extensive but all insecticide treated plots yielded between 15 and 20 cwt/ac more than did the UTC plots. However, the data was extremely variable and these differences were not significant. This experiment will be repeated in 2013 with a late season application to control later summer generation beetles.

NPPGA/Area II Potato Insect Research Report 2012 - *Aphid Alert II* – Monitoring Aphid Vectors of Virus in Potato

Dr. Ian MacRae
Dept of Entomology, University of Minnesota
Northwest Research & Outreach Center
2900 University Ave
Crookston, MN 56716

Rationale – The Minnesota and North Dakota seed potato industry is at a critical juncture. Seed production acreage has suffered a significant decrease since 1995 in part because of aphid vectored viral diseases of seed potato, notably Potato Leaf Roll Virus (PLRV) and Potato Virus Y (PVY). While PLRV is a non-persistent (circulative) virus which takes a comparatively lengthy time to be transferred to a plant and can be controlled by well-timed insecticide applications against the vector, PVY is a non-persistent and is transferred to the plant within moments of the aphid probing the plant. Consequently, controlling PVY through vector control using insecticides is more problematic. Aphid dynamics in potato fields indicate that aphid populations develop in other host plant systems through the early summer, moving into potatoes usually after mid-July. When first colonizing fields, most aphid species first settle at the edge for 7-10 days before dispersing throughout the rest of the field. This colonization behavior facilitates the targeted application of insecticide at the field edge. When combined with other techniques, such as border plantings of non-PVY hosts (e.g. soybeans), to clean virus from the mouthparts of infected aphids, these techniques can significantly contribute to PVY control.

Certification programs in Minnesota and North Dakota are operationally excellent, but it is difficult to turn the corner on potato virus epidemics because large amounts of virus-inoculum must be flushed from the seed production system. This is an increasingly difficult proposition with Potato Virus Y (PVY). New virus strains with variable levels of expression and a new vector species have resulted in what appears to be a change in the epidemiology of this viral disease.

Figure 3. High soybean populations in Toronto as a result of a dispersal event from SE Minnesota and SW Wisconsin in 2001. These populations disrupted pedestrian traffic and caused a delay in a Toronto Blue Jays professional baseball game. Photo Credit: Toronto Star Newspaper,

The ordinary (common) strain of PVY is PVY^{o}, which is present in all potato growing areas, causes mild to severe mosaic, leaf drop and leaf and stem necrosis. Of greater concern are PVY^{N} (tobacco veinal necrosis) and the relatively new strain PVY^{NTN}. While PVY^{N} produces mild to severe mild to severe mosaic symptoms, PVY^{NTN} potato tuber necrotic ringspot disease (PTNRD). Visible symptoms of infection of either strain vary according to potato cultivar with some cultivars being nearly or completely asymptomatic making within season diagnosis difficult.

In past years, the most important vector of PVY has been green peach aphid, *Myzus persicae* (Sulzer). It is by far the most efficient vector of PLRV and of PVY in the northern Great Plains. Green peach aphid doesn't overwinter in the Red River Valley and populations are reestablished each year by spring immigrants so there is great annual variation in abundance. Distributions of *M. persicae* are concentrated within a few meters of field margins in the days immediately following inflights but this edge distribution is temporally limited with aphid colonies eventually dispersing across fields (Suranyi et al. 2004, Carroll et al. 2004). This alighting preference is likely a response to the contrast provided by the interface of fallow and crop border. This facilitates the use of targeted border applications to control aphid vectors. Treating just the 18 m adjacent to the fallow headlands resulted in spraying only 38.5 of 730 hectares saving an estimated 93% (mean savings of $58.29 per hectare, application costs included) compared to treating the entire field (Carroll et al. 2004, Olson et al. 2004). For this technique to be successful, application timing is critical and treatments must be applied prior to aphid populations dispersing across the field. Consequently, an accurate method of monitoring the arrival of aphids within the fields is essential. From 1992 to 1994 and from 1998 to 2003, this monitoring was delivered by a regional aphid trapping network, *Aphid Alert*, which provided Minnesota and North Dakota seed potato growers with real-time information on virus vector flight activity.

In recent years, however, there have been high rates of certification failure, despite low populations of aphids typically associated as virus vectors. In 2011, for example, MN and ND had extremely high rates of PVY infection in seed potato fields, resulting in one of the lowest annual acreages of certified seed. However, a 9m suction trap, established as part of a multi-state aphid monitoring effort, indicated low populations of *M. persicae* but extremely high numbers of the invasive soybean aphid, *Aphis glycines* Matsumura (Fig. 4).

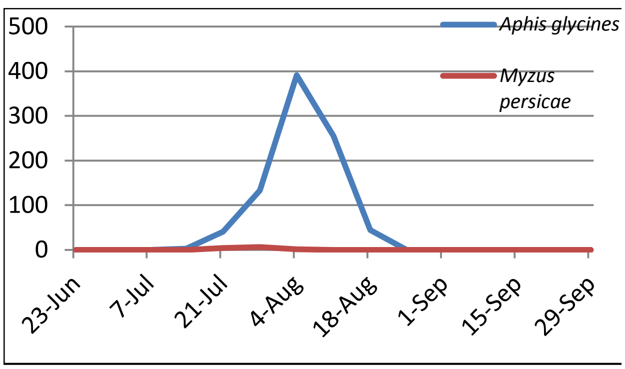


Figure 4. Seasonal dynamics of immigrating soybean aphid, *Aphis glycines* Matsumara, and green peach aphid, *Myzus persicae* Sulzer. Note that while very high numbers of soybean aphid were recovered approximately at the same time as aphids would be colonizing seed potato fields, there were only negligible numbers of green peach recorded.

Soybean aphid was first recorded in the U.S. in 2000 and in Minnesota in 2001 (Rasgdale 2004). Since then, this invasive species has spread to all of the soybean producing states in the North Central region becoming the most important insect pest of soybeans in those states. Of all of the states in the NC plains, Minnesota has the most consistent populations, with some area of the state requiring insecticide treatment every year since 2001. Soybean aphid overwinter as eggs on species of Buckthorn, notably glossy buckthorn, *Rhamnus cathartica*, spend several generations as wingless forms, building numbers. Eventually a winged, dispersive generation is formed and the aphids then move to soybeans, its only acceptable summer host. As a species, soybean aphid is prone to large scale dispersal events. If food quality falls or host plants become too crowded, a winged generation develops and a dispersal event occurs. While these dispersal events occur as a response to host conditions, a late summer dispersal (Ragsdale 2004), probably in response to environmental (i.e. daylength) occurs in late July-early August. Although they do not occur every year, when they do, soybean aphid dispersal events can be almost locust like in scale (Fig. 3 & 4). When colonizing a field, soybean aphid do show some tendency to alight on the edge but not for an extended period of time (Hodgson et al. 2005). In addition, individual soybean aphids will continue into the field, colonizing the interior. Late in August, soybean aphids develop a winged generation that returns to buckthorn to mate, lay eggs and overwinter. Soybean aphid vectors a number of virus diseases to soybean and has been shown to vector PVY to potatoes although not as effectively as green peach aphid (Davis et al. 2005).

The technique of targeted application of insecticide works well with green peach aphid and a number of other aphids that are traditionally important in vectoring PVY into potatoes. This control tactic, however, will not control the colonization of a field by soybean aphid. Soybean aphid will attempt to colonize a number of host plants during summer dispersal events, but will only colonize soybeans. When testing the suitability of a host aphids probe to sample plant fluids, in the process they will transfer any non-persistent virus on their mouthparts. Even if a low number of soybean aphids are viruliferous, and even if only a subset of these can efficiently vector the virus, the sheer numbers of soybean aphids entering fields during a large dispersal event means indicates these insects may be a significant driver in PVY epidemiology.

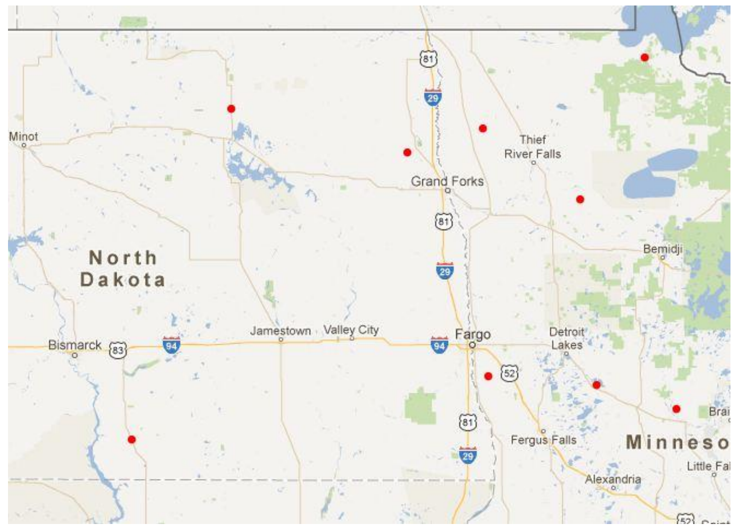


Figure 5. Locations of aphid suction traps in MN and ND.

There are other tactics that may prove much more effective in controlling soybean aphid. The use of crop oils has been demonstrated as an effective method of preventing aphids from feeding on plants and thereby preventing the transmission of virus. While inexpensive, crop oils must be applied 1-2 times per week, beginning prior to the arrival of aphids in the field. Consequently, this method relies heavily on application timing and requires accurate monitoring (DiFonzo et al. 1997).

Regardless of the vector involved in any particular year, monitoring populations and determining where and when aphids are occurring in the region and what species are involved is essential in applying appropriate management tactics. There are a number of methods to trap and monitor aphids but the most effective is using suction traps.

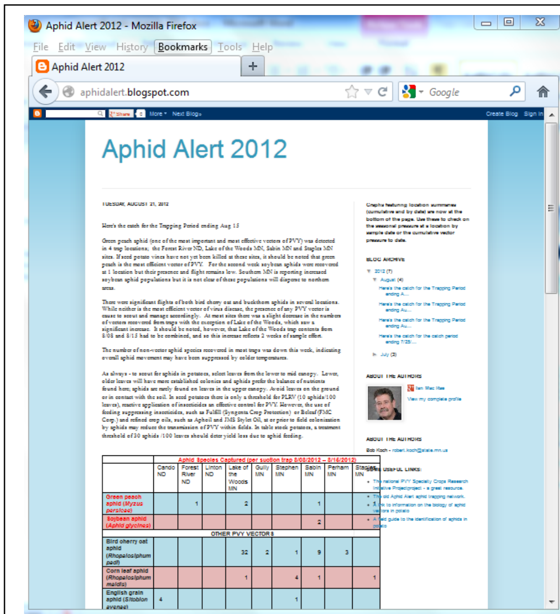


Figure 6. *Aphid Alert II* web site maintained at: aphidalert.blogspot.com

Additional funding for a related project has been obtained from the MN State Block grants for specialty crops. This funding will be used to assist in expanding the network beyond original NPPGA and Area II funding.

Procedures – Buckthorn stands in Fergus Falls, Moorehead and the Red River Valley were scouted in the fall for the presence of successfully overwintered soybean aphid. In addition, inquiries were made to other UMN Extension personnel on local overwintered soybean aphid populations. To monitor aphids colonizing potato fields, 2m tall suction traps was established at 9 seed potato production areas of Minnesota and North Dakota (Figure 5).

These traps consist of a fan drawing air down in through the trap and trapping the incoming aphids in a sample jar which is changed weekly. Traps were monitored and maintained by grower and industry cooperators. Sample jars were returned weekly to the laboratory at Crookston where they were sorted and the aphids identified to species. All species were identified and counted but generally only vector species were reported. These data were used to determine regional aphid population dynamics. Graphs were prepared weekly showing aphids species recovered at each location and made available via the Northern Plains Potato Growers electronic newsletter, *Potato Bytes*, the NPPGA email lists and on a website maintained by the PI (*aphidalert.blogspot.com*) (Fig. 6). A written report accompanied each graph noting the presence of confirmed virus vectors and reviewing management options.

Results & Discussion – Early season scouting of soybean aphid on buckthorn resulted in soybean aphids being found in only one location (Underwood, MN). Aphids were not collected on the first sample day but were planned to be sampled upon the following week's sample. The following week there were no aphids on these plants and remaining eggs had been apparently eaten. These results were echoed by other UMN observers and by entomologists across the North Central region. Apparently the few soybean aphids that successfully overwintered suffered considerable predation mortality early in the season.

Trapping efforts started the week of 7/06/12 and most traps continued until 9/05/12 (one location trapped until 9/12/12 and another until 10/7/12.). Several different locations saw heavy inflights at specific dates leading to increased vector pressure at those dates (Fig. 7) (see Appendix 1 for all weekly trap catches). These generally represented flights of a particular species. The high trap captures at Gully and Sabin in the trapping period ending 8/01 were primarily composed of English grain aphids and Bird Cherry-oat aphids respectively. The high catch in Linton in the trapping period ending 7/20 was comprised principally of Cotton/Melon aphids, that same trapping period both Gully and Sabin sites had trap captures reflecting flights of English grain and sunflower aphids and cotton/melon aphids respectively. The high trap catches in Linton and Lake of the Woods sites over the trapping period ending on 8/29 were comprised mostly of corn leaf aphids and cowpea aphids in Linton and Bird Cherry-oat and Buckthorn aphids in Lake of the Woods. These catches generally reflected the regional movement of those individual species, e.g. a large percentage of the Buckthorn aphid captures occurred later in the season when this species is moving out of alternate host fields and back to its primary, overwintering host, Buckthorn.

Populations of soybean aphid were very low with only 3 individual aphids recovered between two locations in the later season. Green peach aphids were also recovered at only low numbers; 26 total individuals were trapped, but they recovered from all but one location at low numbers from the middle to end of season. lake of the woods had low numbers of green peach aphid until the week ending Aug 29, when 7 were recovered in that trap. The low numbers of green peach aphids and soybean aphids do not, however, mean that the region was vector-free. Numerous other species, while not as efficient a vector as green peach aphid nor as numerous as soybean aphid, are still important vectors and capable of both moving new inoculum into fields and spreading existing inoculum inside fields. Many of these (e.g. bird cherry oat aphid, English grain aphid, corn leaf aphid, sunflower aphid, cotton/melon aphid, cowpea aphid, black bean aphid, buckthorn aphid) were present in moderate and occasionally weekly high numbers in several locations (Table 4). The presence of any vector is cause to scout and initiate appropriate management tactics.

Four locations, Linton, ND, Sabin, Gully and Lake of the Woods MN, had what would be called moderate to high moderate cumulative catches of many vector species through the summer (each of these traps exceeded 150 vector individuals over the season) (fig. 2, Table 4). The remaining 6 sites had what would be called low to moderate populations (under 60 individuals per trap per season). The Lake of the Woods site had generally low to low moderate populations until late summer, when they had heavy late season flights of aphids (Fig. 8). A late season trap catch was received in early Oct but due to the date, these aphids were obviously not important in disease epidemiology as there were no potatoes left in the field by this date. The data is included in the cumulative graphs simply to indicate overall seasonal aphid presence. Complete species information and individual location trap catches by date are presented in Appendix 1.

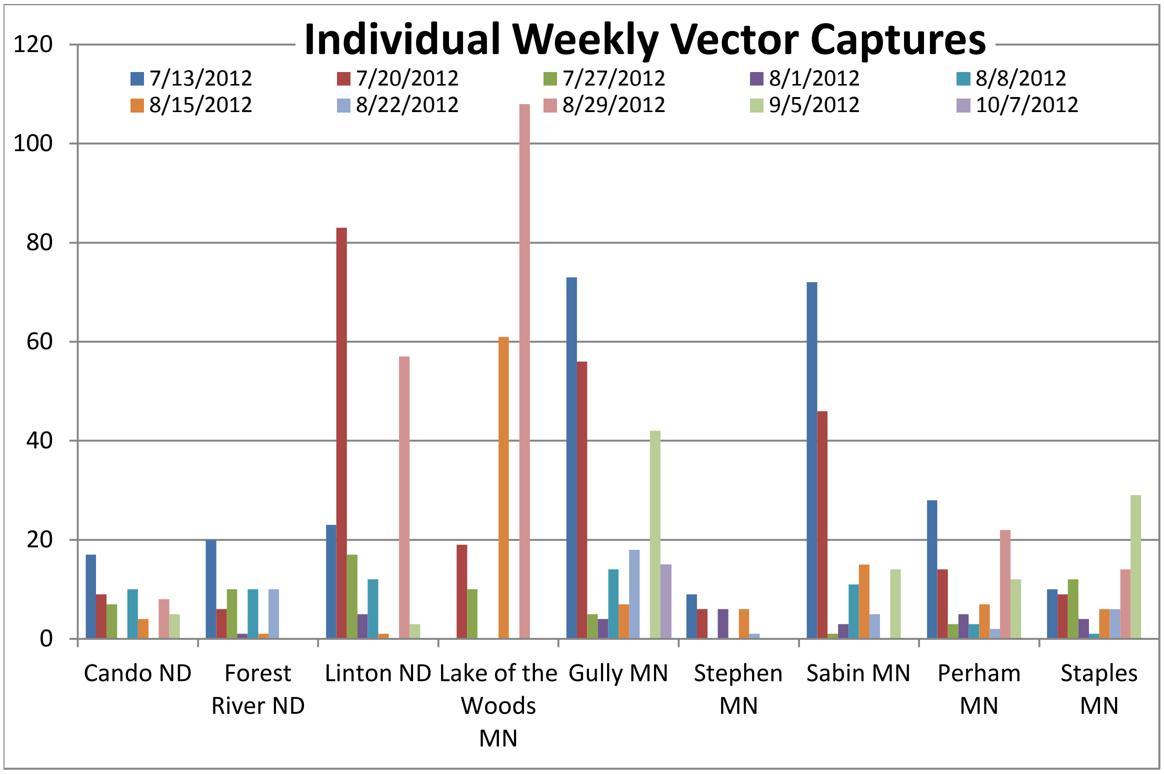


Figure 7. Individual weekly aphid trap catch at each location for summer 2012. Vertical bars represent the capture of combined vector species at each location.

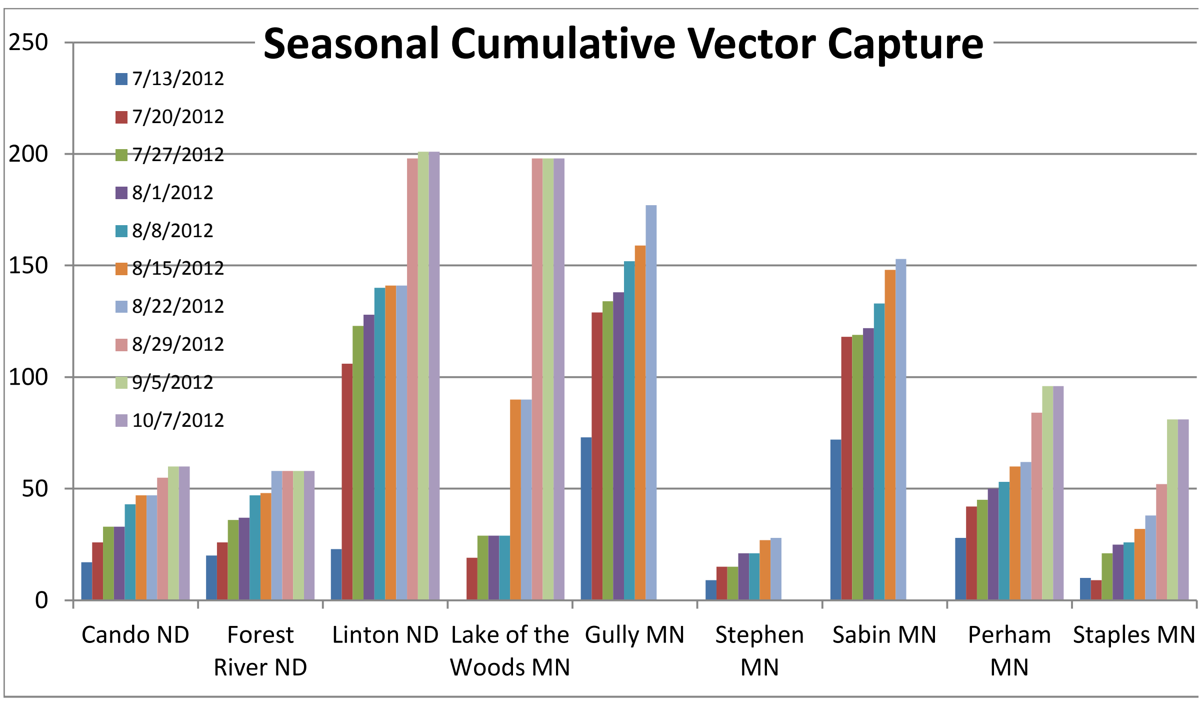


Figure 8. Cumulative weekly aphid trap catch at each location for summer 2012. Vertical bars represent the cumulative capture of all combined vector species at each location.

Table 4. *Aphid Alert II* cumulative vector catches by location 2012.

	Cando ND	Forest River ND	Linton ND	Lake of the Woods MN	Gully MN	Stephen MN	Sabin MN	Perham MN	Staples MN
Green peach aphid (*Myzus persicae*)	**5**	**5**	**1**	**9**	**2**	**0**	**3**	**0**	**1**
Soybean aphid (*Aphid glycines*)	**0**	**0**	**0**	**0**	**0**	**0**	**2**	**1**	**0**
Bird cherry oat aphid (*Rhopalosiphum padi*)	**9**	**10**	**14**	**59**	**13**	**1**	**63**	**9**	**3**
Corn leaf aphid (*Rhopalosiphum maidis*)	**16**	**2**	**51**	**5**	**25**	**7**	**16**	**21**	**4**
English grain aphid (*Sitobion avenae*)	**8**	**6**	**6**	**7**	**90**	**17**	**8**	**27**	**3**
Green bug (*Schizaphis graminum*)	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**0**
Potato aphid (*Macrosiphum euphorbiae*)	**2**	**0**	**5**	**0**	**8**	**0**	**11**	**2**	**1**
Sunflower aphid (*Aphis helianthi*)	**0**	**0**	**0**	**0**	**25**	**0**	**2**	**0**	**0**
Thistle aphid (*Lipaphis erysimi*)	**1**	**0**	**1**	**5**	**1**	**0**	**2**	**0**	**3**
Turnip aphid (*Brevicoryne brassicae*)	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Cotton/melon aphid (*Aphis gossypii*)	**6**	**11**	**85**	**8**	**6**	**0**	**41**	**0**	**11**
Pea aphid (*Acyrthosiphon pisum*)	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**1**	**0**
Cowpea aphid (*Aphis craccivora*)	**2**	**10**	**30**	**8**	**5**	**0**	**2**	**13**	**21**
black bean aphid (*Aphis fabae*)	**0**	**0**	**0**	**71**	**0**	**0**	**0**	**0**	**0**
Buckthorn aphid (*Aphis nasturii*)	**6**	**14**	**2**	**26**	**1**	**3**	**3**	**7**	**4**
Total # captured	**55**	**58**	**198**	**198**	**176**	**28**	**153**	**82**	**52**

Delivery of Information – The weekly dissemination of the weekly reports by email from the NPPGA did apparently reach growers. I received many questions and comments on the postings from clientele. Should the project be funded in 2013, however, additional methods of information dissemination will be necessary. The blogspot.com site (fig. 9) also worked well as a venue for dissemination of the information and offered the benefit of audience reports detailing the number of page views, location of users and the operating systems they used. During the *Aphid Alert II* season, the website received 1829 views from over 200 unique requesting addresses (and has received an additional 150 visits from 20 new unique requesting addresses since October). The audience was predominantly from the U.S. (78%), with views coming from a number of other countries, specifically Russia (3%), Canada (3%), the United Kingdom (3%), followed by a number of others. While most requests originated from Windows operating systems (60%), mobile platforms were also used to access *Aphid Alert II* data; iPhones, iPads and Android platforms each represented approximately 5% of information requests. The most frequent referring site was Google followed by both the extension sites of UMN and NDSU. The most frequent key words resulting in a directed enquiry to the *Aphid Alert II* site was "aphid alert" followed by "green peach aphid".

Figure 9. Aphidalert.blogspot.com

These user statistics are useful in assessing who is using the site and why. It is gratifying to see the most frequent key word is the project name, this probably results from our efforts through the extension season to make growers aware that the network was going to run again this year. Likewise, the overwhelming percentage of US views hopefully indicates we are likely serving our audience (unfortunately, we cannot as yet identify from where within the US these requests come).

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Appendix 1. Weekly trap catches of species at each location from 7/13/2012 through 9/12/2013. Note green peach and soybean aphid species were placed at the top of the table to indicate their importance in the PVY epidemic. Other vector species are not listed in any particular order of vector efficiency. A notation of “NS” indicates no sample was provided from that location for that week.

	Aphid Species Captured (per suction trap)								
Aphid Alert II Suction Trap Catches – week ending 7/13/2012	Cando ND	Forest River ND	Linton ND	Lake of the Woods MN	Gully MN	Stephen MN	Sabin MN	Perham MN	Staples MN
Green peach aphid (*Myzus persicae*)				No Sample					
Soybean aphid (*Aphid glycines*)									
OTHER PVY VECTORS									
Bird cherry oat aphid (*Rhopalosiphum padi*)	9	8	14		11		53	4	
Corn leaf aphid (*Rhopalosiphum maidis*)	7		5		5		6	6	
English grain aphid (*Sitobion avenae*)	1	4	3		52	9	4	13	8
Green bug (*Schizaphis graminum*)									
Potato aphid (*Macrosiphum euphorbiae*)			1		5		9		
Sunflower aphid (*Aphis helianthi*)									
Thistle aphid (*Lipaphis erysimi*)									
Turnip aphid (*Brevicoryne brassicae*)									
Cotton/melon aphid (*Aphis gossypii*)									1
Pea aphid (*Acyrthosiphon pisum*)								1	
Cowpea aphid (*Aphis craccivora*)		8							
black bean aphid (*Aphis fabae*)									1
Buckthorn aphid (*Aphis nasturii*)								4	
Identified non-vectored species								2	
Unidentified									
Total # captured	17	20	23	NS	73	9	72	30	10
Total Vectors	17	20	23	NS	73	9	72	28	10

Aphid Alert II Suction Trap Catches – week ending 7/23/2012

	Aphid Species Captured (per suction trap)								
	Cando ND	Forest River ND	Linton ND	Lake of the Woods MN	Gully MN	Stephen MN	Sabin MN	Perham MN	Staples MN
Green peach aphid (*Myzus persicae*)	2				1				
Soybean aphid (*Aphid glycines*)									
OTHER PVY VECTORS									
Bird cherry oat aphid (*Rhopalosiphum padi*)				2				2	1
Corn leaf aphid (*Rhopalosiphum maidis*)	1	1	3	1			7		1
English grain aphid (*Sitobion avenae*)	2	1	2	7	29	6		10	
Green bug (*Schizaphis graminum*)								1	
Potato aphid (*Macrosiphum euphorbiae*)	1		2				1		
Sunflower aphid (*Aphis helianthi*)			2		25				
Thistle aphid (*Lipaphis erysimi*)	1								
Turnip aphid (*Brevicoryne brassicae*)									
Cotton/melon aphid (*Aphis gossypii*)		4	67				38		1
Pea aphid (*Acyrthosiphon pisum*)									
Cowpea aphid (*Aphis craccivora*)	2		6	1	1			1	1
black bean aphid (*Aphis fabae*)				8					
Buckthorn aphid (*Aphis nasturii*)			1						
Identified non-vectored species	13			9					
Unidentified						17			
Total # captured	22	6	83	28	56	23		14	9
Total Vectors	9	6	83	19	56	6		14	9

Aphid Alert II Suction Trap Catches – week ending 7/30/2012

	Aphid Species Captured (per suction trap)								
	Cando ND	Forest River ND	Linton ND	Lake of the Woods MN	Gully MN	Stephen MN	Sabin MN	Perham MN	Staples MN
Green peach aphid (*Myzus persicae*)									
Soybean aphid (*Aphid glycines*)									
OTHER PVY VECTORS									
Bird cherry oat aphid (*Rhopalosiphum padi*)									
Corn leaf aphid (*Rhopalosiphum maidis*)									1
English grain aphid (*Sitobion avenae*)					1		1		2
Green bug (*Schizaphis graminum*)									
Potato aphid (*Macrosiphum euphorbiae*)	1				1				
Sunflower aphid (*Aphis helianthi*)									
Thistle aphid (*Lipaphis erysimi*)									
Turnip aphid (*Brevicoryne brassicae*)									
Cotton/melon aphid (*Aphis gossypii*)	6	7	16	7	3				5
Pea aphid (*Acyrthosiphon pisum*)									
Cowpea aphid (*Aphis craccivora*)		2	1	3				2	3
black bean aphid (*Aphis fabae*)									
Buckthorn aphid (*Aphis nasturii*)		1						1	1
Identified non-vectored species				4	10	2		2	6
Unidentified									
Total # captured	7	10	17	14	15	2	1	5	18
Total Vectors	7	10	17	13	5	0	1	3	12

Aphid Alert II Suction Trap Catches – week ending 8/01/2012

	Aphid Species Captured (per suction trap 7/25/2012 – 8/01/2012)								
	Cando ND	Forest River ND	Linton ND	Lake of the Woods MN	Gully MN	Stephen MN	Sabine MN	Perham MN	Staples MN
Green peach aphid (*Myzus persicae*)	3		1		1				
Soybean aphid (*Aphid glycines*)									
PVY – vectors									
Bird cherry oat aphid (*Rhopalosiphum padi*)									1
Corn leaf aphid (*Rhopalosiphum maidis*)	1		3			3		2	
English grain aphid (*Sitobion avenae*)	5				1	1	1	3	1
Green bug (*Schizaphis graminum*)									
Potato aphid (*Macrosiphum euphorbiae*)									
Sunflower aphid (*Aphis helianthi*)									
Thistle aphid (*Lipaphis erysimi*)			1						
Turnip aphid (*Brevicoryne brassicae*)									
Cotton/melon aphid (*Aphis gossypii*)					2		2		2
Pea aphid (*Acyrthosiphon pisum*)									
Cowpea aphid (*Aphis craccivora*)	1								
black bean aphid (*Aphis fabae*)									
Buckthorn aphid (*Aphis nasturii*)	2	1				2			
Identified non-vectored species	1	1		1	8	11	5	2	8
Unidentified									
Total # captured	13	2	5	1	12	17	8	7	12
Total Vectors	12	1	5	1	4	6	3	5	4

Aphid Alert II Suction Trap Catches – week ending 8/08/2012

	Aphid Species Captured (per suction trap 8/01/2012 – 8/08/2012)								
	Cando ND	Forest River ND	Linton ND	Lake of the Woods MN	Gully MN	Stephen MN	Sabine MN	Perham MN	Staples MN
Green peach aphid (*Myzus persicae*)	2	2					2		
Soybean aphid (*Aphid glycines*)								1	
OTHER PVY VECTORS									
Bird cherry oat aphid (*Rhopalosiphum padi*)		2					1		1
Corn leaf aphid (*Rhopalosiphum maidis*)	6		9		7		2	1	
English grain aphid (*Sitobion avenae*)	1		1		5		2		
Green bug (*Schizaphis graminum*)									
Potato aphid (*Macrosiphum euphorbiae*)			1					1	
Sunflower aphid (*Aphis helianthi*)							2		
Thistle aphid (*Lipaphis erysimi*)									
Turnip aphid (*Brevicoryne brassicae*)									
Cotton/melon aphid (*Aphis gossypii*)					1		1		
Pea aphid (*Acyrthosiphon pisum*)			1						
Cowpea aphid (*Aphis craccivora*)							1		
black bean aphid (*Aphis fabae*)									
Buckthorn aphid (*Aphis nasturii*)	1	6							
Identified non-vectored species	1	1	3		63		10	1	
Unidentified					1				
Total # captured	11	11	15	0	77	0	21	4	1
Total Vectors	10	10	12	0	14	0	11	3	1

Aphid Alert II Suction Trap Catches – week ending 8/15/2012

	Aphid Species Captured (per suction trap 8/08/2012 – 8/15/2012)								
	Cando ND	Forest River ND	Linton ND	Lake of the Woods MN	Gully MN	Stephen MN	Sabin MN	Perham MN	Staples MN
Green peach aphid (*Myzus persicae*)		1		2			1		1
Soybean aphid (*Aphid glycines*)							2		
OTHER PVY VECTORS									
Bird cherry oat aphid (*Rhopalosiphum padi*)				32	2	1	9	3	
Corn leaf aphid (*Rhopalosiphum maidis*)				1		4	1		1
English grain aphid (*Sitobion avenae*)	4					1			
Green bug (*Schizaphis graminum*)									
Potato aphid (*Macrosiphum euphorbiae*)					2		1	1	
Sunflower aphid (*Aphis helianthi*)									
Thistle aphid (*Lipaphis erysimi*)							1		1
Turnip aphid (*Brevicoryne brassicae*)									
Cotton/melon aphid (*Aphis gossypii*)									
Pea aphid (*Acyrthosiphon pisum*)									
Cowpea aphid (*Aphis craccivora*)			1		2			1	1
black bean aphid (*Aphis fabae*)									
Buckthorn aphid (*Aphis nasturii*)				24	1			2	2
Identified non-vectored species		1	1	1		6	23	1	1
Unidentified				2					
Total # captured	4	2	2	62	7	12	38	8	7
Total Vectors	4	1	1	61	7	6	15	7	6

Aphid Alert II Suction Trap Catches – week ending 8/22/2012

	Aphid Species Captured (per suction trap)								
	Cando ND	Forest River ND	Linton ND	Lake of the Woods MN	Gully MN	Stephen MN	Sabin MN	Perham MN	Staples MN
Green peach aphid (*Myzus persicae*)		2							
Soybean aphid (*Aphid glycines*)									
OTHER PVY VECTORS									
Bird cherry oat aphid (*Rhopalosiphum padi*)									
Corn leaf aphid (*Rhopalosiphum maidis*)									
English grain aphid (*Sitobion avenae*)		1			13				1
Green bug (*Schizaphis graminum*)		1			2				
Potato aphid (*Macrosiphum euphorbiae*)									
Sunflower aphid (*Aphis helianthi*)									1
Thistle aphid (*Lipaphis erysimi*)									
Turnip aphid (*Brevicoryne brassicae*)					1		1		2
Cotton/melon aphid (*Aphis gossypii*)									
Pea aphid (*Acyrthosiphon pisum*)									
Cowpea aphid (*Aphis craccivora*)									
black bean aphid (*Aphis fabae*)					2		1	1	1
Buckthorn aphid (*Aphis nasturii*)									
Identified non-vectored species		6				1	3		1
Unidentified									
Total # captured								1	
Total Verctors	0	10	0	0	18	1	5	2	6
		10			18	1	5	2	6

Aphid Alert II Suction Trap Catches – week ending 8/29/2012

	Aphid Species Captured (per suction trap)								
	Cando ND	Forest River ND	Linton ND	Lake of the Woods MN	Gully MN	Stephen MN	Sabin MN	Perham MN	Staples MN
Green peach aphid (*Myzus persicae*)	1	0		7					
Soybean aphid (*Aphid glycines*)									
OTHER PVY VECTORS									
Bird cherry oat aphid (*Rhopalosiphum padi*)				25					
Corn leaf aphid (*Rhopalosiphum maidis*)	2		31	3				12	
English grain aphid (*Sitobion avenae*)								1	
Green bug (*Schizaphis graminum*)									
Potato aphid (*Macrosiphum euphorbiae*)			1						
Sunflower aphid (*Aphis helianthi*)									
Thistle aphid (*Lipaphis erysimi*)				5					
Turnip aphid (*Brevicoryne brassicae*)									
Cotton/melon aphid (*Aphis gossypii*)			2	1					
Pea aphid (*Acyrthosiphon pisum*)									
Cowpea aphid (*Aphis craccivora*)			22	4				8	14
black bean aphid (*Aphis fabae*)				63					
Buckthorn aphid (*Aphis nasturii*)	5		1						
Identified non-vectored species				2					
Unidentified								1	
Total # captured	8	0	57	110	ns	ns	ns	22	14
Total Vectors	8	0	57	108	ns	ns	ns	22	14

Aphid Alert II Suction Trap Catches – week ending 9/05/2012

	Aphid Species Captured (per suction trap)								
	Cando ND	Forest River ND	Linton ND	Lake of the Woods MN	Gully MN	Stephen MN	Sabin MN	Perham MN	Staples MN
Green peach aphid (*Myzus persicae*)									
Soybean aphid (*Aphid glycines*)									
OTHER PVY VECTORS									
Bird cherry oat aphid (*Rhopalosiphum padi*)									
Corn leaf aphid (*Rhopalosiphum maidis*)	1		2		32		10	8	5
English grain aphid (*Sitobion avenae*)					1			1	
Green bug (*Schizaphis graminum*)									
Potato aphid (*Macrosiphum euphorbiae*)									
Sunflower aphid (*Aphis helianthi*)									
Thistle aphid (*Lipaphis erysimi*)									
Turnip aphid (*Brevicoryne brassicae*)									
Cotton/melon aphid (*Aphis gossypii*)									
Pea aphid (*Acyrthosiphon pisum*)									
Cowpea aphid (*Aphis craccivora*)			1		4			1	13
black bean aphid (*Aphis fabae*)					5		2	1	9
Buckthorn aphid (*Aphis nasturii*)	4						2	1	2
Identified non-vectored species									0
Unidentified									
Total # captured	5	0	3	0	42	0	14	12	29
Total Vectors	5		3		42	0	14	12	29

Aphid Alert II Suction Trap Catches – week ending 9/12/2012

	Aphid Species Captured (per suction trap)								
	Cando ND	Forest River ND	Linton ND	Lake of the Woods MN	Gully MN	Stephen MN	Sabin MN	Perham MN	Staples MN
Green peach aphid (*Myzus persicae*)									
Soybean aphid (*Aphid glycines*)									
OTHER PVY VECTORS									
Bird cherry oat aphid (*Rhopalosiphum padi*)									
Corn leaf aphid (*Rhopalosiphum maidis*)									
English grain aphid (*Sitobion avenae*)					2				
Green bug (*Schizaphis graminum*)									
Potato aphid (*Macrosiphum euphorbiae*)									
Sunflower aphid (*Aphis helianthi*)									
Thistle aphid (*Lipaphis erysimi*)									
Turnip aphid (*Brevicoryne brassicae*)									
Cotton/melon aphid (*Aphis gossypii*)									
Pea aphid (*Acyrthosiphon pisum*)									
Cowpea aphid (*Aphis craccivora*)					4				
black bean aphid (*Aphis fabae*)					6				
Buckthorn aphid (*Aphis nasturii*)					3				
Identified non-vectored species					5				
Unidentified									
Total # captured					20				
Total Vectors					15				

Evaluation of StollerUSA Products (Bio-Forge® 2-0-3, Nitro Plus 9®, and Sugar Mover®) on Potato Yield and Quality

Carl Rosen, Matt McNearney, and James Crants
Department of Soil, Water, and Climate, University of Minnesota
crosen@umn.edu

Summary: A field experiment at the Sand Plain Research Farm in Becker, MN was conducted in 2012 to evaluate the effects Bio-Forge, Nitro Plus 9, and Sugar Mover manufactured by Stoller USA on Russet Burbank potato tuber yield and quality. A comparison was made between a standard practices control and treatments that included the standard control plus the Stoller products in various combinations. The use of the Stoller products (Bio-Forge, Nitro Plus 9 and Sugar Mover) in various combinations did not enhance yield or quality compared with the control under the conditions of this study. Many of the Stoller products are formulated to help the plant withstand stress; however, under irrigated conditions on a sandy soil, there was little water stress during the growing season. There was some heat stress in July resulting in stem end defect, but the products applied did not appear to alleviate the stress.

Background: StollerUSA products are a proprietary blend of compounds intended to increase crops yields. Bio-Forge (2-0-3) contains compounds that are supposed to up-regulate genes that enhance tolerance to drought and other stresses. Nitro Plus 9 (9-0-0, 9% Ca, 0.1% B) is a liquid form of nitrogen containing amine nitrogen, calcium, and boron. Sugar Mover is intended to redirect the flow of sugars in plants from the vegetative parts (leaves) to the fruiting parts of plants to increase yields. In this study, we compared a conventional fertilizer control and various combinations of the three Stoller products on potato yield and quality.

The objective of this study was, under field conditions, to evaluate the effect of Stoller products on yield and quality of Russet Burbank potato.

Materials and Methods

The study was conducted at the Sand Plain Research Farm in Becker, Minnesota on a Hubbard loamy sand using the potato cultivar Russet Burbank. The previous crop was rye. Selected soil chemical properties before planting were as follows (0-6"): water pH, 6.2; organic matter, 2.4%; Bray P1, 62 ppm; ammonium acetate extractable K, Ca, and Mg, 152, 725, and 157 ppm, respectively; Ca-phosphate extractable SO_4-S, 3 ppm; DTPA extractable Zn, 0.9 ppm. Extractable nitrate-N and ammonium-N in the top 2 ft of soil were 1.9 and 12.8 lb/A, respectively.

Whole "B" seed was hand planted in furrows on April 20, 2012. Four, 20 ft rows were planted for each plot with 18 ft of each of the middle two rows used for sampling and harvest. Spacing was 36 inches between rows and 12 inches within each row. Six treatments were replicated four times in a randomized complete block design. Weeds, diseases, and insects were controlled using standard practices. Rainfall was supplemented with sprinkler irrigation using the checkbook method of irrigation scheduling. The six treatments tested are listed below (Table 1).

A starter fertilizer containing 30 lb N/A, 130 lb P_2O_5/A, 181 lb K_2O/A, 20 lb Mg/A, and 46 lb S/A as a blend of ammonium phosp hate (MAP), potassium chloride, potassium magnesium sulfate, and ammonium sulfate were applied to all plots at planting. In addition, the Bio-Forge component was applied at planting at a rate of 8 oz or 16 oz per acre, respectively, to treatments 2, 4, 5, 6 and 3 in the furrow. The 170 lb N/A was sidedressed as polymer-coated urea (ESN, Agrium Inc.) and mechanically incorporated at emergence on May 17 to all treatments. On June 1, 2 weeks after emergence, Bio-Forge was applied at 8 oz/A to treatments 4, 5, and 6 as a foliar application. On June 15, 4 weeks after emergence, Bio-Forge was again applied at 8 oz/A to treatments 4, 5, and 6 as a foliar application. On June 25, Nitro Plus 9 was applied to treatments 5 and 6 at the rate of 20 lb N/A. On July 2 a second application of Nitro Plus 9 was applied to treatment 6 at the rate of 20 lb N/A. An equivalent rate of N was applied to all treatments that did not receive Nitro Plus 9 as urea-ammonium nitrate (UAN). Following the N applications, irrigation was applied to simulate fertigation. On June 29, Sugar mover was applied to treatments 5 and 6 at the rate of 4 oz/A. A second application of Sugar Mover was applied to treatment 6 on July 6 at the rate of 4 oz/A.

Table 1. StollerUSA treatments tested in the Russet Burbank yield and quality study.

Treatment #	Bio-Forge[1] (0, 2, 4)	First Set (Nitro Plus, Sugar Mover)[2]	Second Set (Nitro Plus, Sugar Mover)[2]
1	0, 0, 0	0, 0	0, 0
2	8, 0, 0	0, 0	0, 0
3	16, 0, 0	0, 0	0, 0
4	8, 8, 8	0, 0	0, 0
5	8, 8, 8	20, 4	0, 0
6	8, 8, 8	20, 4	20, 4

[1]BF = oz/ac Bio-Forge; P = planting; 2 = 2 weeks post-planting; 4 = 4weeks post-planting.

[2]NP = gal/ac Nitro Plus 9; SM = oz/ac Sugar Mover.

Plant stands stems per plant were measured on May 30. Petiole samples were collected from the 4th leaf from the terminal on June 11, June 28, and July 10, July 24, and August 9. Petioles were analyzed for nitrate-N on a dry weight basis. On Sept. 21, vines were killed via mechanical beating. Plots were machine-harvested on Sept. 24 and total tuber yield, graded yield, tuber specific gravity, stem and bud end sucrose and glucose and the incidence of scab, hollow heart, and brown center were measured.

All trials of the experiment were statistically analyzed using ANOVA procedures on SAS and means were separated using a Waller-Duncan LSD test at P = 0.10.

Results

Rainfall and irrigation amounts are presented in Figure 1. The 2012 growing season was wet with numerous leaching events through July.

Tuber Yield and Size Distribution: Total yields were greatest for the conventionally fertilized control treatment 1 with 240 lb N/A and significantly lower for three application Bio-Forge (treatment 4), Bio-Forge and one application of Sugar Mover and Nitro Plus 9 (treatment 5), and Bio-Forge and two applications of Sugar Mover and Nitro Plus 9 (treatment 6) (Table 1). Similar trends were observed for marketable yield. Differences observed for total and marketable yield were primarily due to the larger sized tubers.

Petiole Nitrate-N Concentrations: Petiole nitrate concentrations were not affected by treatment on the first sampling date, June 11 (Table 2). However, on the next sampling date, petiole nitrate concentrations were lower in the plots receiving Nitro Plus 9 as the N source (treatments 5 and 6) compared with the treatments receiving UAN as the N source. Similarly, on the third sampling date, petiole nitrate concentrations were lower in the plots receiving Nitro Plus 9 as the N source (treatment 6) compared with the treatments receiving UAN as the N source. At the last two sampling dates, petiole nitrate concentrations were not affected by treatment; however, all N had been applied about 3 weeks prior to the time the samples were collected.

Tuber Quality: Specific gravity was significantly highest in the conventionally fertilized treatment (Table 3). Stoller products tended to result in lower specific gravity readings. Hollow heart and brown center was lowest in treatment 5 (3 applications of Bio Forge and 1 application of Sugar Mover and Nitro Plus 9). This treatment also resulted in smaller tubers, which are less susceptible to hollow heart. Scab incidence, plant stand, number of stems per plant, and tuber dry matter were not affected by treatment.

Tuber Sugar Concentrations and Fry Quality: Stem end sucrose, glucose, chip color and Agtron readings were not affected by treatment (Table 4). Similarly, bud end sucrose, glucose, chip color and Agtron readings were not affected by treatment. The stem end had higher glucose and darker color than the bud end. The poor stem end color and high glucose was likely due to heat stress in July.

Conclusions

The use of the StollerUSA products (Bio-Forge, Nitro Plus 9 and Sugar Mover) in various combinations did not enhance yield or quality compared with the control under the conditions of this study. Nitro Plus 9 resulted in lower petiole nitrate concentrations than UAN. Many of the Stoller products are formulated to help the plant withstand stress; however, under irrigated conditions on a sandy soil, there was little water stress during the growing season. There was some heat stress in July resulting in stem end defect, but the products applied did not appear to alleviate the stress.

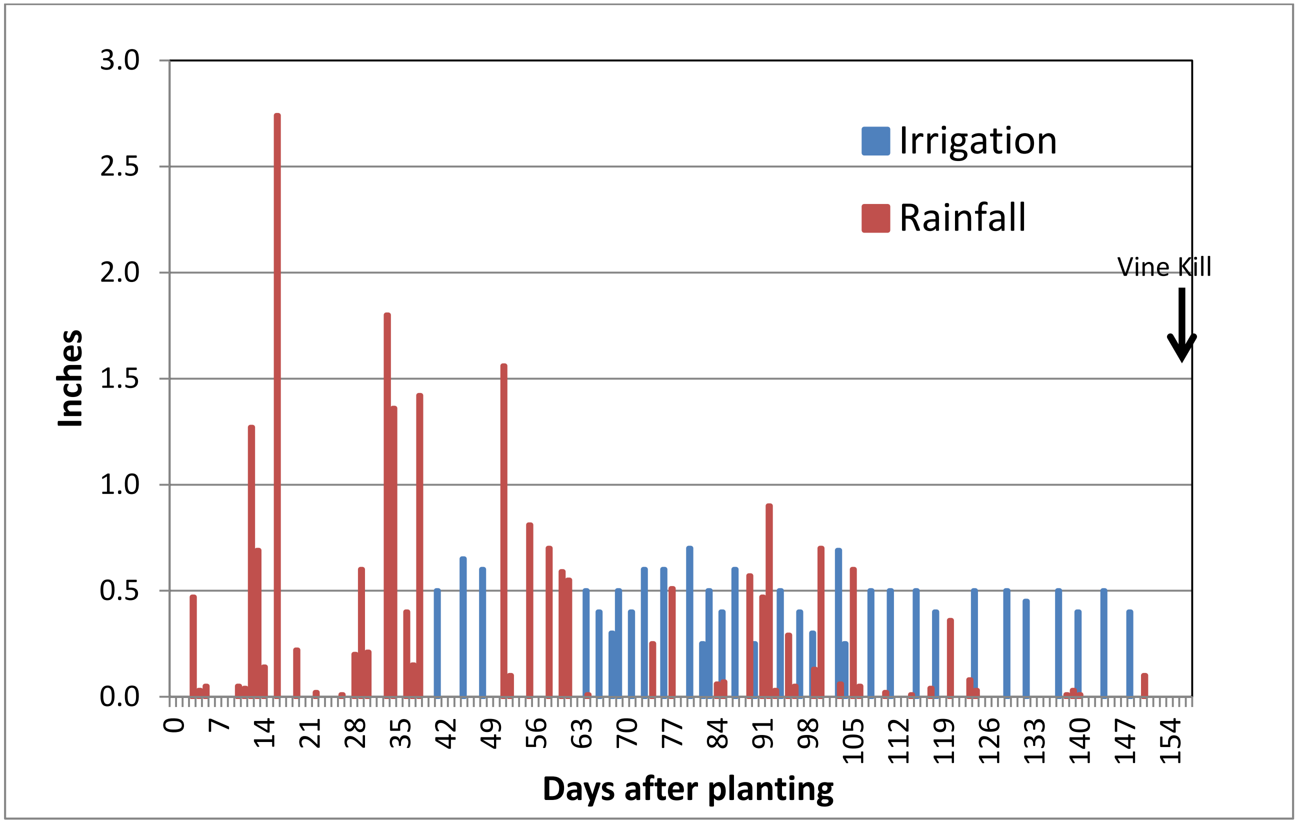

Figure 1. Rainfall and irrigation amounts during the 2012 growing season.

Table 1. Effects of StollerUSA products on Russet Burbank tuber yield and size distribution.

Treatment #	BF[1] (P, 2, 4)	First Set (NP, SM)[2]	Second Set (NP, SM)[2]	Tuber Yield 0-3 oz	3-6 oz	6-10 oz	10-14 oz	>14 oz	Total	#1s > 3 oz.	#2s > 3 oz	Total Marketable	> 6 oz	> 10 oz
				cwt / A									%	%
1	0, 0, 0	0, 0	0, 0	56.7	140.7	191.1	173.6	149.5 a[4]	711.7 a	309.1	345.9	655.0 a	72.2	45.5
2	8, 0, 0	0, 0	0, 0	63.4	150.0	195.2	147.9	133.0 ab	689.4 ab	310.3	315.8	626.1 ab	69.0	40.6
3	16, 0, 0	0, 0	0, 0	61.4	148.0	190.0	155.3	117.4 abc	672.1 abc	310.3	300.4	610.6 abc	68.9	40.6
4	8, 8, 8	0, 0	0, 0	66.7	161.3	169.1	151.6	93.0 bc	641.7 bc	285.5	289.5	575.0 bc	64.5	38.2
5	8, 8, 8	20, 4	0, 0	66.7	139.5	181.6	158.8	83.4 c	630.0 c	272.4	290.9	563.3 c	67.2	38.3
6	8, 8, 8	20, 4	20, 4	63.2	144.1	194.7	152.8	103.1 bc	657.9 bc	288.1	306.5	594.7 bc	68.4	38.7
			Significance[3]	NS	NS	NS	NS	*	++	NS	NS	++	NS	NS
			LSD (0.1)	--	--	--	--	41.2	53.8	--	--	57.5	--	--

[1]BF = oz/ac Bio-Forge; P = planting; 2 = 2 weeks post-planting; 4 = 4weeks post-planting.
[2]NP = gal/ac Nitro Plus 9; SM = oz/ac Sugar Mover.
[3]NS = Non significant; ++, *, ** = Significant at 10%, 5%, and 1%, respectively.
[4]Means followed by the same letter within a column are not significantly different at p=0.10.

Table 2. Effects of StollerUSA products on petiole nitrate concentrations.

Treatment #	BF[1] (P, 2, 4)	First Set (NP, SM)[2]	Second Set (NP, SM)[2]	Petiole Nitrate – N 11-Jun	28-Jun	10-Jul	24-Jul	9-Aug
				----------------- ppm ---------------				
1	0, 0, 0	0, 0	0, 0	16300	14482 abc[4]	9884 ab	6784	813
2	8, 0, 0	0, 0	0, 0	15869	15611 a	10891 a	6517	1093
3	16, 0, 0	0, 0	0, 0	15474	15216 a	9922 ab	7013	1093
4	8, 8, 8	0, 0	0, 0	15312	14867 ab	9400 b	8795	1567
5	8, 8, 8	20, 4	0, 0	15161	12709 bc	9008 b	7171	898
6	8, 8, 8	20, 4	20, 4	15130	12291 c	6813 c	5122	895
			Significance[3]	NS	*	**	NS	NS
			LSD (0.1)	--	2231	1365	--	--

[1]BF = oz/ac Bio-Forge; P = planting; 2 = 2 weeks post-planting; 4 = 4weeks post-planting.
[2]NP = gal/ac Nitro Plus 9; SM = oz/ac Sugar Mover.
[3]NS = Non significant; ++, *, ** = Significant at 10%, 5%, and 1%, respectively.
[4]Means followed by the same letter within a column are not significantly different at p=0.10.

Table 3. Effects of StollerUSA Products on Russet Burbank stems plant per plant, plant stand, and tuber quality.

Treatment #	BF[1] (P, 2, 4)	First Set (NP, SM)[2]	Second Set (NP, SM)[2]	Specific Gravity	Dry Matter	Tuber Quality HH	Tuber Quality Scab	Plant Stand	# of Stems per Plant
					%	%	%	%	
1	0, 0, 0	0, 0	0, 0	1.0767a[4]	20.4	15.0a	10.0	100	2.8
2	8, 0, 0	0, 0	0, 0	1.0759ab	20.3	12.2ab	10.1	100	2.7
3	16, 0, 0	0, 0	0, 0	1.0726c	19.9	12.3a	16.3	99.3	2.7
4	8, 8, 8	0, 0	0, 0	1.0716c	20.3	14.0a	8.0	100	2.8
5	8, 8, 8	20, 4	0, 0	1.0737bc	20.8	6.0b	4.0	99.3	2.6
6	8, 8, 8	20, 4	20, 4	1.0744abc	20.8	17.0a	14.0	100	2.9
			Significance[3]	*	NS	*	NS	NS	NS
			LSD (0.1)	0.0029	--	6.2	--	--	--

[1]BF = oz/ac Bio-Forge; P = planting; 2 = 2 weeks post-planting; 4 = 4weeks post-planting.

[2]NP = gal/ac Nitro Plus 9; SM = oz/ac Sugar Mover.

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

[4]Means followed by the same letter within a column are not significantly different at p=0.10.

Table 4. Effects of StollerUSA producst on Russet Burbank potato sucrose and glucose concentrations and frying quality.

Treatment #	BF[1] (P, 2, 4)	First Set (NP, SM)[2]	Second Set (NP, SM)[2]	Stem End				Bud End			
				CC	AGT	Sucrose, mg/g	Glucose, mg/g	CC	AGT	Sucrose, mg/g	Glucose, mg/g
1	0, 0, 0	0, 0	0, 0	3.0	48.0	1.54	7.69	2.8	53.3	2.06	0.99
2	8, 0, 0	0, 0	0, 0	3.3	45.8	1.69	7.05	2.8	53.3	1.66	1.24
3	16, 0, 0	0, 0	0, 0	3.5	46.8	1.13	6.71	2.5	53.5	1.95	0.78
4	8, 8, 8	0, 0	0, 0	3.5	42.8	1.35	7.48	2.8	53.3	1.97	0.63
5	8, 8, 8	20, 4	0, 0	3.3	44.3	1.66	7.69	3.0	52.3	1.93	0.76
6	8, 8, 8	20, 4	20, 4	3.0	49.5	0.91	7.18	2.8	51.3	1.69	0.69
			Significance[3]	NS	NS	NS	NS	NS	NS	NS	NS
			LSD (0.1)	--	--	--	--	--	--	--	--

[1]BF = oz/ac Bio-Forge; P = planting; 2 = 2 weeks post-planting; 4 = 4weeks post-planting.

[2]NP = gal/ac Nitro Plus 9; SM = oz/ac Sugar Mover.

CC= Chip Color, 1 = light; 5=dark; AGT = Agtron reading (readings above 50 are most desirable).

[3]NS = Non-significant.

On-Farm Evaluation of Polymer Coated Urea Rates and Blends on Potato Yield and Quality

Carl Rosen, Matt McNearney, and James Crants
Department of Soil, Water, and Climate, University of Minnesota
crosen@umn.edu

Summary: An on-farm field experiment in Perham MN was conducted in 2012 to evaluate the effects ESN rate, and an ESN/Duration blend on Russet Burbank potato tuber yield and quality. Seven treatments were evaluated in a randomized complete block design with four replications. All treatments included liquid N applications of 110 lb N/A - 40 lb N/A at planting, 40 lb N/A at emergence and 30 lb N/A through fertigation in June. Treatments included five ESN rates from 90 to 210 lb N/A at emergence. Two additional treatments at the 230 lb N/A rate were conventional urea at 120 lb N/A and a 50/50 blend of ESN and Duration at 120 lb N/A applied at emergence. Yield and size distribution were not significantly affected by treatment. Total yield ranged from a low of 390 cwt/A with the conventional urea treatment to a high of 410 cwt/A with ESN applied at 290 lb N/A (Table 1). There was a trend (but nonsignificant) for increasing tuber size with increasing ESN rate up to 290 lb N/A. At the 230 lb N/A rate, total and marketable yield were numerically highest with the blend followed by ESN and then conventional urea. Specific gravity, internal disorders, and scab were not significantly affected by treatment. Petiole nitrate-N increased with increasing N rate at all three sampling dates. In contrast, SPAD reading increased with increasing N only at the latter two sampling dates. These results indicate that SPAD readings lag behind petiole nitrate readings and therefore may not be as useful for predictive purposes. In general, the lack of significant yield response to N treatments suggests that N was not the limiting factor in this study. The crop died back early, presumably due to verticillium infection and possibly water stress that occurred between the 15th and 24th of July.

Background: Research conducted over the past number of years with coated urea fertilizers such as ESN (Environmentally Smart Nitrogen, Agrium, Inc.) has shown that a onetime application can be as cost effective as multiple applications of conventional N with fertigation. As a result, use of ESN for potato production in Minnesota has increased rapidly. Most of the N is released from ESN within about 60-80 days after application. In addition to ESN, a coated urea called Duration, also manufactured by Agrium, is available. Duration has a slightly thicker coating, and therefore, N release is slower – about 100-120 days. A blend of ESN and Duration may provide an efficient use of N for long season processing potatoes. Because the release characteristics of ESN and Duration can affect tuber set and bulking of potatoes, evaluation of various rates and blends is essential to gain a better understanding of how best to use these products. Most of the calibration research with ESN has been conducted on small plots at the Sand Plain Research Farm in Becker. Additional studies are needed on growers' fields to validate the rates, timing, and blends suggested.

The overall goal of this research was to evaluate ESN and Duration as N sources for irrigated potato production in Minnesota under grower field conditions. The specific objective is to determine the effects of various ESN rates and an ESN/Duration blend on potato yield and quality.

Materials and Methods

The study was conducted on a center pivot near Perham, MN on a Hubbard loamy sand using the potato cultivar Russet Burbank. The previous crop was edible beans and the field was fumigated with Vapam along with an application of 600 lbs of 0-0-60 the fall before planting. Selected soil chemical properties before planting were as follows (0-6"): water pH, 7.2; organic matter, 1.3%; Bray P1, 115 ppm; and ammonium acetate extractable K, 124 ppm.

Whole “B” seed was machine planted in furrows on April 26, 2012. Each plot consisted of 6, 40 ft rows, with the middle four rows used for sampling and harvest. Spacing was 36 inches between rows and 14 inches within each row. Seven treatments were replicated four times in a randomized complete block design. Weeds, diseases, and insects were controlled using standard practices. Rainfall was supplemented with center pivot irrigation using the checkbook method of irrigation scheduling. The seven treatments tested are listed below (Table 1).

A starter fertilizer of 34 gallons/A of 10-34-0; 0.75 gallons/A of Borosol, and 1.6 quarts/A of 20% Zn was applied to all plots at planting, supplying an initial XX lbs N/A. On May 17 (approximately emergence), ESN or ESN + Duration was applied at the rates listed in Table 1 followed by a sidedress of 8.5 gallons/A of ammonium thiosulfate and 8.5 gallons/A of 32% UAN and then hilled in. On June 25, 6 gallons of 32% and 6 gallons of ammonium thiosulfate were applied as fertigation. The liquid applications supplied approximately 110 lb N/A to all plots. The ESN was applied in 30 lb N/A increments, starting at 90 lb N/A up to 210 lb N/A, providing total N rates of 200 to 320 lb N/A in 30 lb N/A increments. At the 230 lb N/A rate, two additional treatments were tested: 120 lb N/A as urea and 120 lb N/A as a 50/50 blend of ESN and Duration.

Table 1. Treatments tested at Perham in 2012.

Treatment Number	Total N rate	Emergence N rate	N Source at Emergence
	---------- lb N/A ----------		
1	200	90	ESN
2	230	120	ESN
3	260	150	ESN
4	290	180	ESN
5	310	210	ESN
6	230	120	Urea
7	230	60+60	ESN / Duration

WaterMark sensors were installed to measure soil moisture at the three inch depth (simulating where the ESN prills were located). Soil temperature at 3 inches and air temperature were also monitored on a daily basis. Nitrogen release from ESN and Duration were measured using the mesh bag technique. Petiole samples were collected from the fourth leaf from the terminal on June 22, July 9, and July 25. Petioles were analyzed for nitrate-N on a dry weight basis. At the same time petioles were collected, chlorophyll readings were measured with a Minolta SPAD chlorophyll meter on the terminal leaflet of the leaf sampled for petioles. On Sept. 19, plots were machine-harvested and total tuber yield, graded yield, tuber specific gravity, and the incidence of scab, hollow heart, and brown center were measured.

All trials of the experiment were statistically analyzed using ANOVA procedures on SAS and means were separated using a Waller-Duncan LSD test at P = 0.10.

Results

Weather: Rainfall and irrigation amounts and soil moisture at 3” are presented in Figure 1. The 2012 growing season was relatively wet early with three significant leaching events: May 26, June 21, and July 26. Soil moisture at the 3” depth was dry in mid June and mid July. Soil temperature at the 3” depth and air temperature are presented in Figure 2. In general, soil and air temperatures were above average over most of the growing season.

Nitrogen Release from ESN and ESN/Duration Blend: Nitrogen release from ESN and the blend is presented in Figure 4. As expected, the release was slower with the blend compared with 100% ESN. For 90% of the N to be released from the prills, it took approximately 47 days for ESN and 70 days for the blend.

Tuber Yield and Size Distribution: Yield and size distribution were not significantly affected by treatment. Total yield ranged from a low of 390 cwt/A with the conventional urea treatment to 410 cwt/A with ESN applied at 290 lb N/A (Table 1). There was a trend (but nonsignificant) for increasing tuber size with increasing ESN rate up to 290 lb N/A. At the 230 lb N/A rate, total and marketable yield were numerically highest with the blend followed by ESN and then conventional urea. However, tuber size tended to be larger with conventional urea than the coated N sources. In general, the lack of significant N response suggests that N was not the limiting factor in this study. The crop died back early, presumably due to verticillium infection and possibly water stress between the 15th and 24th of July (Figure 1).

Tuber Quality: Specific gravity, internal disorders, and scab were not significantly affected by treatment (Table 2). In general, internal disorders and scab incidence were low. Specific gravity was generally in the ideal range for processing.

Petiole Nitrate-N Concentrations: At the 230 lb N/A rate, petiole nitrate concentrations were significantly lower with the blend as the N source compared with ESN or conventional urea on the first sampling date (Table 3). In addition, petiole nitrate tended to increase with increasing ESN rate. In contrast, chlorophyll SPAD readings were not consistently affected by treatment on the first sampling date. At the second and third sampling dates, petiole nitrate-N increased with increasing ESN rates; however at the 230 lb N/A rate petiole nitrate was not significantly affected by N source. At the second and third sampling dates, SPAD readings also increased with increasing ESN rate. Similar to petiole nitrate-N, differences in SPAD reading among N sources at the 230 lb N/A rate were not significant. The lack of significance in SPAD readings at the first sampling date indicates that SPAD readings lag behind petiole nitrate readings and therefore may not be as useful for predictive purposes.

Conclusions: Yield and size distribution were not significantly affected by N treatments. Total yield ranged from a low of 390 cwt/A with the conventional urea treatment to a high of 410 cwt/A with ESN applied at 290 lb N/A. In general, the lack of a significant response to treatments suggests that N was not the limiting factor in this study. The crop died back early, presumably due to verticillium infection and possibly water stress that occurred between the 15th and 24th of July.

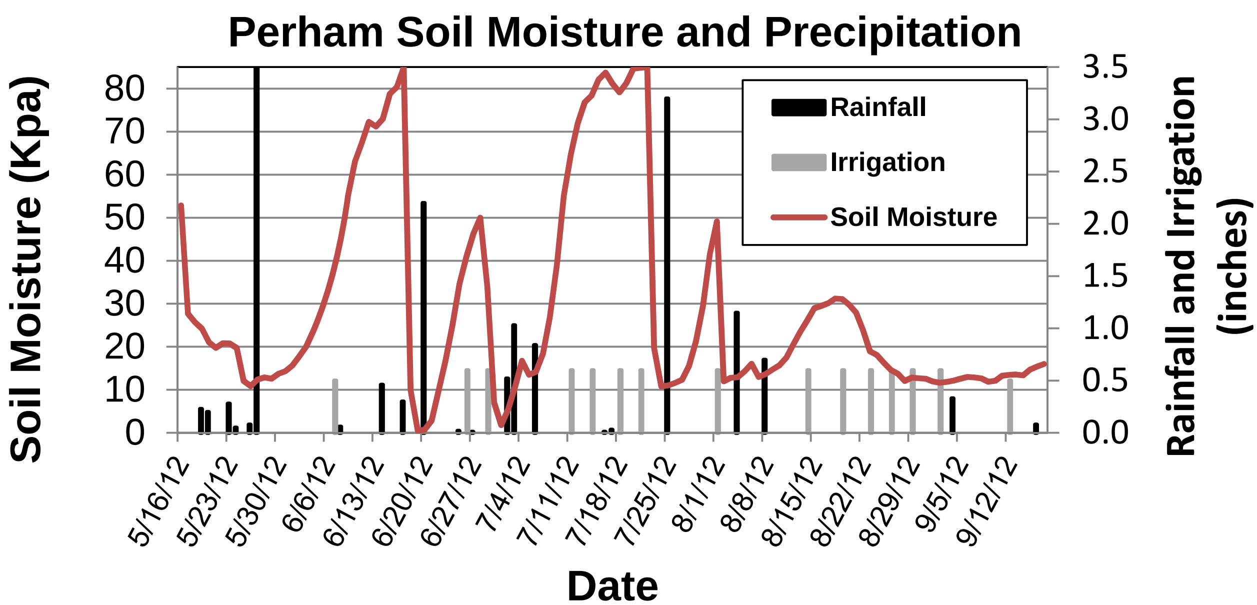

Figure 1. Rainfall and irrigation amounts and soil moisture at Perham during the 2012 growing season.

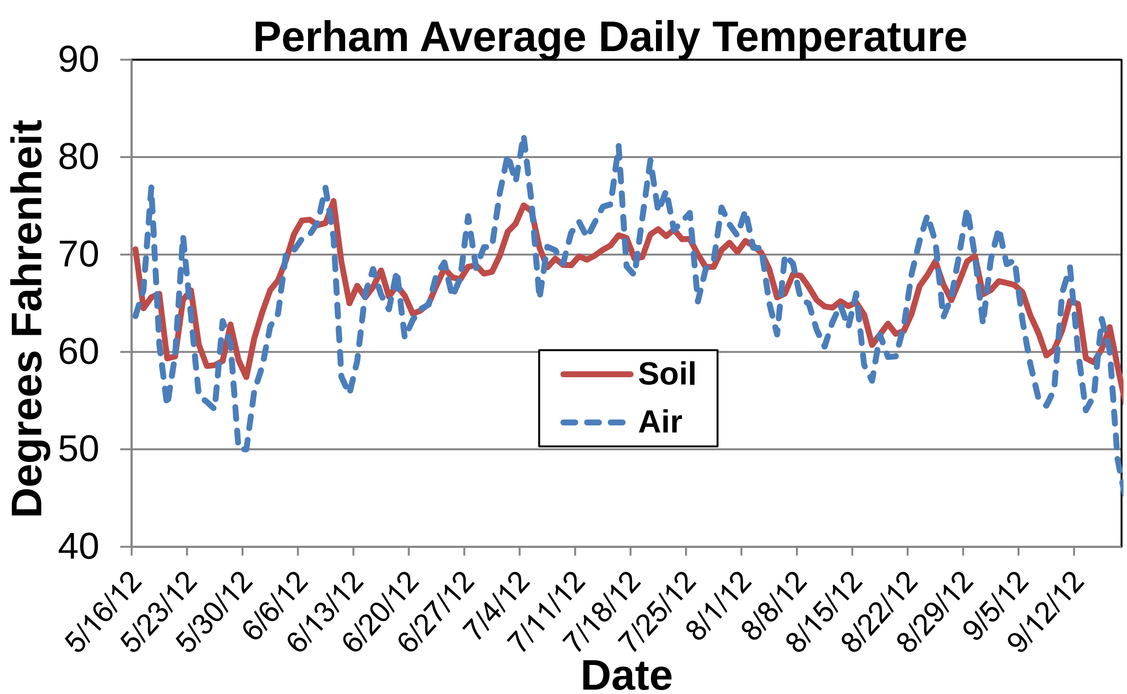

Figure 2. Daily air and 3” soil temperatures at Perham during the 2012 growing season.

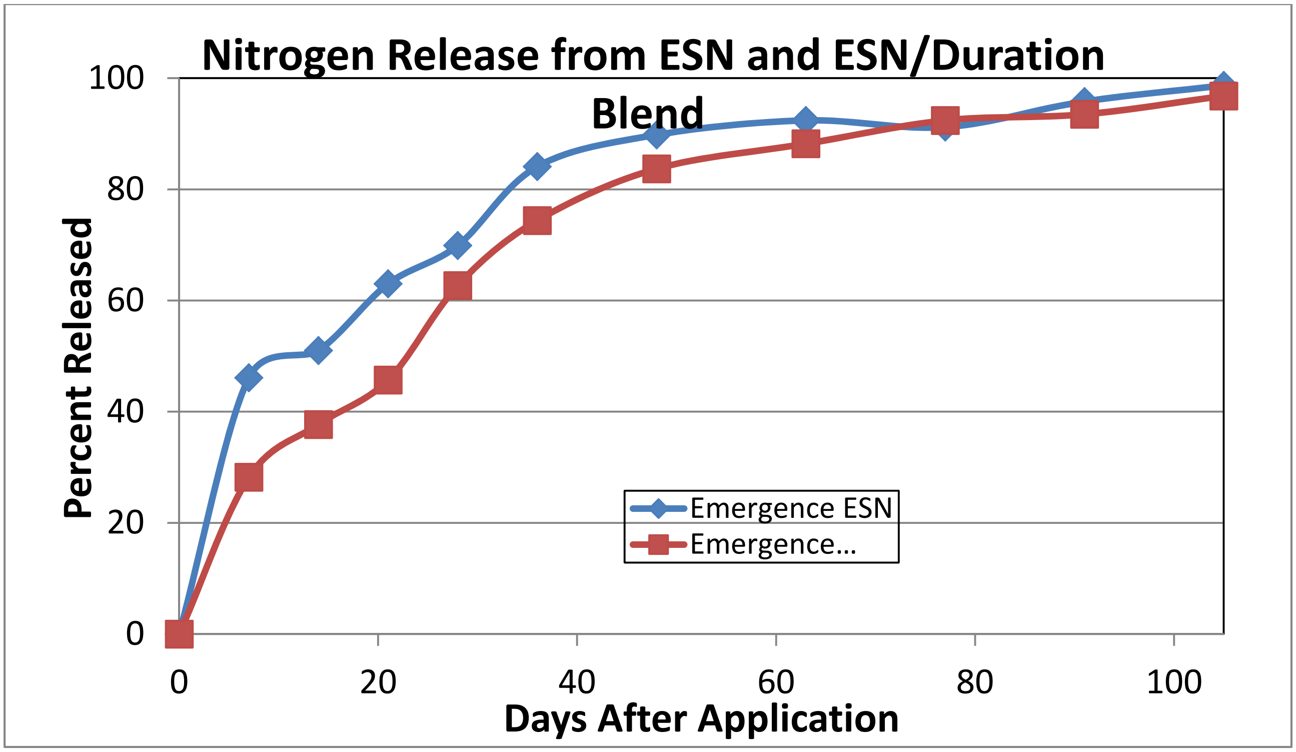

Figure 3. Nitrogen release from ESN and a 50/50 ESN/Duration blend starting on May 16 at Perham.

Table 1. Effects of ESN rate and ESN/Duration Blend on Russet Burbank tuber yield and size distribution.

Treatment #	N Source[1]	N Timing[2] (P, E, C, F)	N Rate (lbs N/A)	Tuber Yield 0-3 oz.	3-6 oz.	6-10 oz.	>10 oz.	Total	#1s > 3 oz.	#2s > 3 oz.	Total Marketable	>6 oz, %	>10 oz, %
				---------------------- cwt/A ----------------------									
1	ESN (90)	40, 90, 40, 30	200	32.4	143.8	168.6	58.2	402.9	315.7	54.9	370.5	56.2	14.4
2	ESN (120)	40, 120, 40, 30	230	29.2	139.2	169.5	59.6	397.4	305.2	63.0	368.2	57.7	15.0
3	ESN (150)	40, 150, 40, 30	260	29.1	137.2	169.5	69.2	404.9	308.5	67.3	375.8	59.1	17.2
4	ESN (180)	40, 180, 40, 30	290	26.1	123.7	168.7	91.4	409.9	298.6	85.3	383.8	63.1	21.9
5	ESN (210)	40, 210, 40, 30	320	27.6	137.7	164.5	67.7	397.5	315.1	54.8	369.9	58.4	17.0
6	Urea (120)	40, 120, 40, 30	230	31.6	131.6	157.1	70.1	390.3	294.9	63.8	358.7	58.2	18.0
7	ESN+Duration (60 + 60)	40, 60+60, 40, 30	230	31.2	145.0	168.1	56.9	401.1	312.6	57.4	370.0	56.3	14.2
Treatment significance[1]				NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Treatment MSD (0.1)				--	--	--	--	--	--	--	--	--	--
Linear Contrast				NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Quadratic Contrast				NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Contrast Trmt 2 vs. 6, 230 N (120 ESN) vs. 230 N (120 Urea)				NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Contrast Trmt 2 vs. 7, 230 N (120 ESN) vs. 230 N (120 Blend)				NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Contrast Trmt 6 vs. 7, 230 N (120 Urea) vs. 230 N (120 Blend)				NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

[1]ESN (Environmentally Smart Nitrogen, Agrium, Inc.) = 44-0-0; Duration (Agrium, Inc.) = 43-0-0; Urea = 46-0-0;

[2]P=Planting, E=Emergence, C=Cultivation, F=Fertigation.

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

Table 2. Effects of ESN rate and ESN/Duration Blend on Russet Burbank tuber quality.

Treatment #	N Source[1]	N Timing[2] (P, E, C, F)	N Rate (lbs N/A)	Tuber Quality: Specific Gravity	Tuber Quality: Internal Disorders (%)	Tuber Quality: Scab (%)
1	ESN (90)	40, 90, 40, 30	200	1.0833	1.07	0.45
2	ESN (120)	40, 120, 40, 30	230	1.0808	0.57	0.19
3	ESN (150)	40, 150, 40, 30	260	1.0790	1.38	0.11
4	ESN (180)	40, 180, 40, 30	290	1.0835	0.93	0.06
5	ESN (210)	40, 210, 40, 30	320	1.0843	0.71	0.08
6	Urea (120)	40, 120, 40, 30	230	1.0813	0.39	0.37
7	ESN+Duration (60 + 60)	40, 60+60, 40, 30	230	1.0815	0.36	0.10
Treatment significance[1]				NS	NS	NS
Treatment MSD (0.1)				--	--	--
Linear Contrast				NS	NS	NS
Quadratic Contrast				++	NS	NS
Contrast Trmt 2 vs. 6, 230 N (120 ESN) vs. 230 N (120 Urea)				NS	NS	NS
Contrast Trmt 2 vs. 7, 230 N (120 ESN) vs. 230 N (120 Blend)				NS	NS	NS
Contrast Trmt 6 vs. 7, 230 N (120 Urea) vs. 230 N (120 Blend)				NS	NS	NS

[1]ESN (Environmentally Smart Nitrogen, Agrium, Inc.) = 44-0-0; Duration (Agrium, Inc.) = 43-0-0; Urea = 46-0-0;

[2]P=Planting, E=Emergence, C=Cultivation, F=Fertigation.

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

Table 3. Effects of ESN rate and ESN/Duration Blend on Petiole Nitrate-N and SPAD readings.

Treatment #	N Source[1]	N Timing[2] (P, E, C, F)	N Rate (lbs N/A)	Petiole Nitrate-N			SPAD Reading		
				22-Jun	9-Jul	25-Jul	22-Jun	9-Jul	25-Jul
				------------------ ppm ----------------					
1	ESN (90)	40, 90, 40, 30	200	15614	9738	7894	41.0	39.8	37.3
2	ESN (120)	40, 120, 40, 30	230	15737	11546	7823	42.0	40.5	37.2
3	ESN (150)	40, 150, 40, 30	260	15810	12816	9694	40.6	40.5	37.7
4	ESN (180)	40, 180, 40, 30	290	16220	13147	11044	42.2	42.2	39.2
5	ESN (210)	40, 210, 40, 30	320	16071	14893	12642	41.7	41.7	38.4
6	Urea (120)	40, 120, 40, 30	230	15740	11789	8590	42.9	40.3	37.6
7	ESN+Duration (60 + 60)	40, 60+60, 40, 30	230	14783	10786	7698	41.8	40.2	36.6
Treatment significance[1]				*	**	**	++	*	*
Treatment MSD (0.1)				747	1192	1924	1.4	1.3	1.4
Linear Contrast				*	**	**	NS	**	**
Quadratic Contrast				NS	NS	NS	NS	NS	NS
Contrast Trmt 2 vs. 6, 230 N (120 ESN) vs. 230 N (120 Urea)				NS	NS	NS	NS	NS	NS
Contrast Trmt 2 vs. 7, 230 N (120 ESN) vs. 230 N (120 Blend)				*	NS	NS	NS	NS	NS
Contrast Trmt 6 vs. 7, 230 N (120 Urea) vs. 230 N (120 Blend)				*	NS	NS	NS	NS	NS

[1]ESN (Environmentally Smart Nitrogen, Agrium, Inc.) = 44-0-0; Duration (Agrium, Inc.) = 43-0-0; Urea = 46-0-0;

[2]P=Planting, E=Emergence, C=Cultivation, F=Fertigation.

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

Optimizing Potassium Management for Irrigated Potato Production

Carl Rosen, Matt McNearney, and Peter Bierman
Department of Soil, Water, and Climate, University of Minnesota
crosen@umn.edu

Summary: A field experiment was conducted at the Sand Plain Research Farm in Becker, MN to evaluate the effect of potassium (K) application rate and timing on Russet Burbank yield and quality, petiole K concentrations, and changes in soil test K at different depths in the soil. Soil test K was also measured in another field on samples collected in June and November, to see if K fertilizer recommendations for the following year were affected by time of sampling. Six K treatments were tested: rates of 0, 90, 180, 270, and 360 lb K_2O/A applied preplant, and a split application of 180 lb K_2O/A preplant + 180 lb K_2O/A at emergence. Potassium rate had no significant effect on either total or marketable yield, but total tuber yield was significantly greater with split application of 360 lb K_2O/A than when the same total amount of K was all applied preplant. Potassium rate did have significant effects on tuber size. As K rate increased, there were linear increases in the percentage of tubers greater than 6 oz and greater than 10 oz. Tuber specific gravity decreased significantly as K application rate increased, but other tuber quality factors were unaffected by either K rate or application timing. There was a significant linear increase in petiole K on three sampling dates as K application rate increased. Petiole K was also significantly greater on all three dates with split application of 360 lb K_2O/A than when the same total amount of K was all applied preplant. For soil tests in the fall postharvest, there was a significant linear increase in residual soil K in the 0-6 in. depth as the rate of K fertilizer application increased. There were no significant differences among treatments in soil K at either the 6-12 or 12-24 in. soil depths. For the treatment with no K fertilizer applied, soil K decreased 44 ppm in the 0-6 in. layer, 42 ppm in the 6-12 in. layer, and 21 ppm in the 12-24 in. soil layer between spring preplant and fall postharvest sampling times. These changes show the drawdown in soil K from a potato crop with a total yield of 614 cwt/A. In the 0-6 in. soil depth, only the two 360 lb K_2O/A treatments were able to maintain soil K near the same level in the fall as was measured in the spring. None of the K fertilizer treatments applied in this study prevented drawdown of soil K in the 6-12 or 12-24 in. depths. For soil samples collected from the 0-6 in. soil depth of a field planted to soybeans in 2012 that will be the site of the second year of this K study in 2013, soil test K was lower for samples collected in late June during the growing season than for samples collected in early Nov after harvest. These differences resulted in average K fertilizer recommendations for an ensuing potato crop that were 37 lb K_2O/A greater when they were based on midseason sampling than when they were based on samples collected in the fall.

Background: Numerous questions about soil test potassium levels and potential leaching losses of K were asked over the 2011 growing season. Agronomists noted lower petiole K levels than normal, which prompted questioning of when the soil should be tested for K. The recommended time is in the fall or early spring prior to planting. However, in some cases samples are taken in June of the previous season while soybeans are being grown. Research is needed to determine when soil test K provides a reasonable measure of K availability, how much K might be leaching, and how much soil K drops after growing a crop of potatoes at various K rates.

The objectives of this study were to: 1) evaluate potato response to K fertilizer rate and timing, 2) determine the effect of timing of sampling on soil test K, 3) determine K drawdown following a crop of potatoes, and 3) determine the extent of K movement through the growing season and over the following winter.

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, 6.5; organic matter, 1.9%; Bray P1, 49 ppm; ammonium acetate extractable K, Ca, and Mg, 101, 904, and 159 ppm, respectively; Ca-phosphate extractable SO_4-

S, 3 ppm; hot water extractable B, 0.2 ppm; and DTPA extractable Zn, 0.7 ppm. Extractable nitrate-N and ammonium-N in the top 2 ft of soil were 12.8 and 3.5 lb/A, respectively.

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 12, 2012. Row spacing was 12 inches within each row and 36 inches between rows. Each treatment was replicated four times in a randomized complete block design. Belay for beetle control and the systemic fungicide Quadris were banded at row closure. Weeds, diseases, and other insects were controlled using standard practices. Rainfall was supplemented with sprinkler irrigation using the checkbook method of irrigation scheduling.

Six K treatments were tested as described in Table 1 below: 0, 90, 180, 270, and 360 lb K_2O/A applied preplant and a split application of 180 lb K_2O/A preplant + 180 lb K_2O/A at emergence. Preplant K was broadcast and incorporated to a depth of four inches with a field cultivator on April 9. Emergence K was sidedressed on May 17 and mechanically incorporated during hilling. Potassium chloride (0-0-60) was the K source for all treatments.

All treatments received a total of 240 lb N/A applied at planting (30-lb N/A), emergence/hilling (170 lb N/A), and post-hilling (two applications of 20 lb N/A). Nitrogen at planting was supplied as monoammonium phosphate (MAP) and was banded 3 inches to each side and 2 inches below the seed piece using a metered, drop fed applicator. Emergence N applications were supplied as ESN and mechanically incorporated during hilling on May 17 (along with the emergence K treatment). 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. Post-hilling N was applied on June 21 and July 2. In addition to N, banded fertilizer at planting (for all treatments) included 136 lb P_2O_5/A, 1.5 lb S/A, 2.0 lb Zn/A, and 0.5 lb B/A applied as a blend of MAP, zinc sulfate and zinc oxide (EZ 20), and boric acid (14% B).

Plant stands and stem number per plant were measured on May 30. Petiole samples were collected from the 4th leaf from the terminal on three dates: June 11, July 10, and Aug 9. Petioles were analyzed for K on a dry weight basis. Vines were killed by mechanical beating on Sept 21 and tubers were machine harvested on Sept 24. Two, 18-ft sections of row were harvested from each plot. Total tuber yield and graded yield were measured. Sub-samples of tubers were collected to determine tuber specific gravity and the incidence of hollow heart, brown center, and scab. Tuber sub-samples were also collected for K analysis, but these results were not available at the time of this report.

Soil samples were collected in the spring and fall from three soil depths (0-6 in., 6-12 in., and 12-24 in.) in each plot and analyzed for ammonium acetate extractable K. Spring samples were collected on Apr 3 before fertilizer application and planting. Fall samples were collected after harvest on Oct 3.

Soil samples were also collected in 2012 from a soybean field that will be rotated to potatoes in 2013 for the second year of this K study. Selected soil chemical properties in this field before soybean planting were as follows (0-6"): pH, 6.2; organic matter, 1.8%; Bray P1, 66 ppm; and ammonium acetate extractable K, 109 ppm. Additional soil samples were collected from this field to see if there were differences in soil test K between samples obtained during the growing season and in the fall after harvest. Composite samples from eight different areas in the field were collected from the 0-6 in. depth on Jun 21 and Nov 2 and analyzed for ammonium acetate extractable K.

In addition to the treatments studied in 2012, the 2013 K study will include fall applied K treatments of 90, 180, 270, and 360 lb K_2O/A. These treatments were applied to replicate plots on Nov 7, 2012 by the same methods used for preplant K applications in the spring of 2012; potassium chloride (0-0-60) was broadcast and incorporated to a depth of four inches with a field cultivator.

Table 1. Potassium treatments[1] tested on irrigated Russet Burbank potatoes.

Trtmt #	--------- K rate and application timing ----------		
	Total K_2O rate	Preplant	Emergence
	------------------------ lb K_2O/A -----------------------		
1	0	0	0
2	90	90	0
3	180	180	0
4	270	270	0
5	360	360	0
6	360	180	180

[1]All K fertilizer was applied as potassium chloride (0-0-60).

Results

Tuber Yield and Size Distribution: Table 2 shows the effects of K rate and timing on tuber yield and size distribution. Potassium rate had no significant effect on either total or marketable yield, but total tuber yield was significantly greater with split application of 360 lb K_2O/A (Treatment #6) than when the same total amount of K was all applied preplant (Treatment #5). Marketable yield was also numerically greater with split application, although this difference was not significant. The split treatment had significantly greater yield of tubers in the 6-10 oz size category, but most of the yield difference between split and preplant applications of 360 lb K_2O/A was accounted for by the significantly greater yield of #2 tubers with split application.

Potassium application rate did have significant effects on tuber size. As K rate increased, tuber yield in the 0-3 oz and 3-6 oz tuber sizes decreased significantly. Because K rate did not affect total tuber yield, this decrease in small tubers was accompanied by comparable significant increases in the >6 oz, >10 oz, and >14 oz tuber size classes as K application rate increased.

Tuber Quality, Stand Count, and Stems per Plant: Tuber specific gravity decreased significantly as K application rate increased (Table 3). The statistical decrease was linear, but differences mainly occurred at the higher 270 and 360 lb K_2O/A rates. Although K rate effects were significant, the difference between the highest (1.0781) and lowest (1.0731) specific gravities may not have been great enough to have a large effect on frying quality or the amount of harvested dry matter. Potassium rate had no significant effect on the incidence of hollow heart, brown center or scab, and K application timing had no effect on any of these disorders or specific gravity. Plant stand and number of stems per plant were not affected by either K rate or application timing.

Petiole K Concentrations: Petiole K concentrations on three dates as affected by K fertilizer rate and application timing are presented in Table 4. There was a significant linear increase in petiole K on all three dates as K application rate increased. Petiole K was also significantly greater on all three dates with split application of 360 lb K_2O/A than when the same total amount of K was all applied preplant. The higher petiole K concentrations with split application of K fertilizer were associated with the greater tuber yields for this treatment described above (see Table 2 and the "Tuber Yield and Size Distribution" section). Increased efficiency in K uptake with split application suggests that there may have been greater K leaching losses when all of the fertilizer was applied preplant, but soil test data indicated little movement of soil K for any treatment (see the next section "Soil Test K"). In the absence of leaching differences, the reason for increased K uptake with split application is unclear.

Although the linear effect of K rate on petiole K was significant, there were two pairs of preplant treatments that were not significantly different from each other when they were compared individually. Petiole K for the 90 and 180 lb K_2O/A treatments was similar on all three sampling dates. The 90 lb K_2O/A treatment was actually numerically higher on two of the three dates. Petiole K for the 270 and (preplant) 360 lb K_2O/A treatments was also similar on all three dates, with the lower K rate again having numerically greater petiole K concentrations on two of the three dates.

The sufficiency range for petiole K concentrations in potatoes is 8.0-10.0%. This range is for petioles from the fourth leaf from the terminal, as sampled in this experiment, and it was established for petioles sampled 40-50 days after emergence. On June 11 (25 days after emergence), the 270 lb K_2O/A rate was required to maintain petiole K in the 8.0-10.0% range. The 90 and 180 lb K_2O/A rates were slightly below this range and petiole K for the zero K control was only 7.0%. There was a distinct decrease in petiole K for all treatments on the 2^nd^ sampling date (July 10, 54 days after emergence) compared with the 1^st^, but the decrease was less as the K rate increased. The 360 lb K_2O/A split application was the only treatment that was maintained near the sufficiency range, which was consistent with the yield differences noted above. On the 3^rd^ sampling date (Aug 9, 84 days after emergence), petiole K increased from the 2^nd^ date for treatments receiving 270 lb K_2O/A or more, but decreased or was unchanged for treatments receiving less than 270 lb K_2O/A. The 360 lb K_2O/A split application had petiole K above 8.0%, which was again consistent with its greater yield compared with the 360 lb K_2O/A preplant treatment (Table 2). All treatments had lower petiole K on the 3^rd^ sampling date than on the 1^st^ sampling date.

As discussed below in the "Soil Test K" section, using preplant soil tests for the entire field would have resulted in a K fertilizer recommendation for potatoes (for a yield goal of 500 cwt/A or more) of 300 lb K_2O/A. This is consistent with the required K rate to maximize petiole K in this experiment, because petiole K concentrations on all three dates increased with preplant K application rate until they plateaued at the 270 and 360 lb K_2O/A rates. Applying more than the recommended 300 lb K_2O/A rate did not increase petiole K when it was all applied preplant, although higher petiole K was achieved with split application of 360 lb K_2O/A. Modifications in application timing could be required to maximize petiole K concentrations.

Soil Test K: Table 5 shows K concentrations in the spring before fertilizer application and in the fall after harvest at the 0-6 in., 6-12 in. and 12-24 in. soil depths. As expected, there were no significant differences among treatments in soil K at any depth before K fertilizer application in the spring. In the fall postharvest, there was a significant linear increase in residual soil K in the 0-6 in. depth as the rate of K fertilizer application increased. There were no significant differences among treatments in soil K at either the 6-12 or 12-24 in. soil depths in the fall. This could indicate that even in this loamy sand soil there was limited movement of K below the zone of K fertilizer incorporation during the growing season.

For Treatment #1, with no K fertilizer applied, soil K decreased 44 ppm in the 0-6 in. layer, 42 ppm in the 6-12 in. layer, and 21 ppm in the 12-24 in. soil layer. These changes show the drawdown in soil K from a potato crop with a total yield of 614 cwt/A (Table 2). For a better-fertilized crop, K drawdown could be greater due to greater K uptake and removal in the same harvested weight of tubers. The increases in petiole K concentration as K application rate increased (Table 4) show that differences in K uptake did occur. Tuber samples were collected for K analysis, so when these results are completed they will show to what extent the amount of K removed in tubers was affected by K application rate.

The change in soil K in the 0-6 in. depth between spring and fall sampling times was significantly less as the rate of K fertilizer application increased. For the two 360 lb K_2O/A treatments, soil K in this depth was relatively unchanged. This indicates that application of 360 lb K_2O/A, or at least something greater than the next highest rate of 270 lb K_2O/A, was necessary to maintain soil K. Based on preplant soil tests for this field, the K fertilizer recommendation for potatoes (for a yield goal of 500 cwt/A or more) would have been 300 lb K_2O/A (using either the 101 ppm K for the field-wide sample reported in the "Materials and Methods" section or the 118 ppm K treatment average for the Spring tests shown in Table 5). Therefore, the current recommendation for ensuring adequate K for crop growth, and limiting substantial drawdown of soil K (at least in the 0-6 in. layer), was consistent with the soil test results from this experiment.

Although 360 lb K_2O/A maintained soil K in the 0-6 in. soil depth (the zone used for standard soil testing and fertilizer recommendations), this K fertilizer rate did not prevent drawdown of soil K in the 6-12 or 12-24 in. depths. Decreases in K in both of these soil layers were not affected by the amount of K fertilizer applied. The average drawdown of K was 44 ppm at 6-12 in. and 22 ppm at 12-24 in. This suggests that similar amounts of K were withdrawn from these depths regardless of differences in K availability in the surface soil. It is unclear if the drawdown is due to actual removal of K from these layers or due to some artifact of the soil K test.

Table 6 shows differences in soil test K, and resulting differences in K fertilizer recommendations for a potato crop, when soil samples are collected at different times. These samples were from the 0-6 in. soil depth of a field planted to soybeans in 2012 that will be the site of the second year of this K study in 2013. The field will be split into two blocks in 2013 and composite soil samples were collected from what will be four replicates of the experimental treatments in each block. Sampling times were once during the growing season on Jun 26 and again on Nov 2 after soybean harvest.

For seven of the eight sampling areas, soil test K was lower for samples collected during the growing season than for samples collected after harvest. The average difference in soil test K was 16 ppm and these differences resulted in different K fertilizer recommendations for an ensuing potato crop. For midseason sampling the average recommendation (for a yield goal of 500 cwt/A or more) was 350 lb K_2O/A, but for fall sampling the average recommendation was 313 lb K_2O/A. Because average soil test K was greater in the fall than at the end of June, these differences were not due to K uptake by soybeans between the two sampling times and subsequent K removal with the harvested crop. The increase may have been due to differences in soil moisture (wetter in June than November) at the time of sampling.

Conclusions

Potassium fertilizer application rate had no significant effect on tuber yield, but it did have significant positive effects on tuber size. As K application rate increased, yield of small tubers decreased as the proportion of harvested tubers in the >6 oz size class increased. Application timing did affect tuber yield. Total tuber yield was significantly greater (and marketable yield numerically greater) with split application of 360 lb K_2O/A than when the same total amount of K was all applied preplant. Although split application significantly increased yield of 6-10 oz tubers, the overall benefit was limited since most of the yield difference was due to significantly greater yield of misshapen #2 tubers. Tuber specific gravity decreased significantly as K application rate increased, mainly at the 270 and 360 lb K_2O/A rates, but these differences may not have been great enough to have a large effect on processing yield and quality. Although K rate significantly increased tuber size, incidence of the disorders hollow heart brown center that are often associated with larger tubers did not increase.

Petiole samples collected in June, July, and August showed a significant linear increase in petiole K on all three dates as K application rate increased. Petiole K was also significantly greater on all three dates with split application of 360 lb K_2O/A than when the same total amount of K was all applied preplant. The K rate effects on petiole K were associated with the increases in tuber size as K rate increased. And the application timing effects on petiole K were associated with the increases in tuber yield with split application. Although petiole K sufficiency levels for potatoes may not be equally applicable to all three sampling dates, it is worth noting that split application of 360 lb K_2O/A was required to maintain petiole K concentrations within or near the sufficiency range. Soil test data indicated little movement of soil K for any treatment, so the reason for increased K uptake with split application is unclear. Preplant K rates of 270 and 360 lb K_2O/A had similar effects on K concentrations and both maintained petiole K at distinctly higher levels than the lower K rates. This was consistent with the K rate of 300 lb K_2O/A that would have been recommended for this field on the basis of preplant soil tests.

The differences between preplant and postharvest soil tests for the zero K fertilizer treatment showed that the drawdown in soil K from a potato crop with a total yield of 614 cwt/A was 44 ppm in the 0-6 in. layer, 42 ppm in the 6-12 in. layer, and 21 ppm in the 12-24 in. soil layer. In the fall postharvest, there was a significant linear increase in residual soil K in the 0-6 in. depth as the rate of K fertilizer application increased, but only the two 360 lb K_2O/A treatments were able to maintain soil K near the same level in the fall as was measured in the spring. As with petiole K, this was consistent the recommendation to apply 300 lb K_2O/A to this field, since it tells us that the amount of K fertilizer required to maintain soil K was somewhere between the 270 and 360 lb K_2O/A rates. There were no significant differences among treatments in soil K at either the 6-12 or 12-24 in. soil depths and none of the K fertilizer treatments applied in this study prevented drawdown of soil K in these soil layers. The lack of differences in soil K below the 0-6 in. depth suggests that even in this loamy sand soil there was limited movement of K below the zone of K fertilizer incorporation. The relatively shallow incorporation of preplant K fertilizer in this study probably resulted in a greater drawdown of K in the 6-12 in. soil depth than would result from deeper incorporation with a moldboard plow. Field cultivation to a four-inch depth was used in the study to prevent soil and fertilizer movement between neighboring experimental plots that received different rates of K fertilizer. Alternatively, the apparent drawdown may have been due to an artifact of the soil K test.

Soil samples from the 0-6 in. depth of a field planted to soybeans showed differences in soil test K, and resulting differences in K fertilizer recommendations for potatoes, when samples were collected at different times. Soil test K was lower for samples collected in late June than for samples collected in early Nov and this resulted in average K fertilizer recommendations that were 12% greater when based on June samples. Because soil test K was greater in Nov than in June, these differences were not due to K uptake by soybeans between the two sampling times. Differences in soil moisture at the time of sampling have been shown to affect soil test K and the wetter conditions in June than Nov were consistent with increases in exchangeable K for samples collected from drier soil. To minimize the effects of environmental factors on soil test K, it is commonly recommended that soil samples be collected at the same time each year to reduce variability. The effects of sampling time on soil test K can be even greater on soils with higher clay content than the loamy sand soil studied here.

Table 2. Effect of potassium application rate and timing on Russet Burbank tuber yield and size distribution.

Treatment #	K_2O Timing[1] (PP, E)	K_2O Rate (lbs/A)	Tuber Yield										
			0-3 oz	3-6 oz	6-10 oz	10-14 oz	>14 oz	Total	#1s > 3 oz.	#2s > 3 oz	Total Marketable	> 6 oz	> 10 oz
			cwt / A									%	%
1	0, 0	0	72.0	156.2	233.8	122.9	29.7	614.7	388.2	154.4	542.6	62.7	24.5
2	90, 0	90	70.1	168.2	214.7	129.6	60.0	642.7	415.7	156.8	572.6	62.9	29.4
3	180, 0	180	63.5	143.6	207.3	131.8	50.8	597.0	435.1	98.4	533.5	65.3	30.5
4	270, 0	270	63.9	152.4	204.9	124.4	80.7	626.3	407.4	155.0	562.4	65.4	32.5
5	360, 0	360	51.2	124.7	196.7	147.0	72.8	592.3	416.7	124.4	541.1	70.3	37.0
6	180, 180	360	61.9	139.5	229.2	143.0	72.5	646.1	415.3	168.9	584.2	68.7	33.3
		Significance[2]	++	NS	NS	NS	++	NS	NS	++	NS	NS	NS
		LSD (0.10)	14.1	--	--	--	36.7	--	--	45.9	--	--	--
		Contrasts											
		Linear K rate (trt 1,2,3,4,5)	**	*	NS	NS	*	NS	NS	NS	NS	*	**
		Quadratic K rate (trt 1,2,3,4,5)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
		Preplant vs. Split (trt 5 vs. 6)	NS	NS	++	NS	NS	++	NS	++	NS	NS	NS

[1]PP = preplant, E = emergence/hilling

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

Table 3. Effect of potassium application rate and timing on Russet Burbank tuber quality, plant stand, and number of stems per plant.

Treatment #	K_2O Timing[1] (PP, E)	K_2O Rate (lbs/A)	Tuber Quality				Plant Stand	# of Stems per Plant
			Specific Gravity	HH	BC	Scab		
				------------------------- %----------------------------				
1	0, 0	0	1.0774	5.0	1.1	1.0	100.0	2.8
2	90, 0	90	1.0772	4.1	1.1	1.0	100.0	2.9
3	180, 0	180	1.0781	6.4	3.2	3.0	99.3	3.4
4	270, 0	270	1.0749	4.1	4.5	4.0	98.6	3.2
5	360, 0	360	1.0738	14.0	0.0	0.0	98.6	2.8
6	180, 180	360	1.0731	4.1	3.2	3.0	100.0	2.8
		Significance[2]	NS	NS	NS	NS	NS	NS
		LSD (0.10)	--	--	--	--	--	--
		Contrasts						
		Linear K rate (trt 1,2,3,4,5)	*	NS	NS	NS	NS	NS
		Quadratic K rate (trt 1,2,3,4,5)	NS	NS	NS	NS	NS	NS
		Preplant vs. Split (trt 5 vs. 6)	NS	NS	NS	NS	NS	NS

[1]PP = preplant, E = emergence/hilling

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

Table 4. Effect of potassium application rate and timing on petiole K concentrations on three dates.

Treatment #	K_2O Timing[1] (PP, E)	K_2O Rate (lbs/A)	Petiole K		
			11-Jun	10-Jul	9-Aug
			----------------------- % -----------------------		
1	0, 0	0	7.03	4.57	4.21
2	90, 0	90	7.68	5.59	5.59
3	180, 0	180	7.62	5.81	5.43
4	270, 0	270	8.46	6.62	7.28
5	360, 0	360	8.14	6.76	7.26
6	180, 180	360	9.02	7.70	8.20
		Significance[2]	**	**	**
		LSD (0.10)	0.79	0.74	0.89
		Contrasts			
		Linear K rate (trt 1,2,3,4,5)	**	**	**
		Quadratic K rate (trt 1,2,3,4,5)	NS	NS	NS
		Preplant vs. Split (trt 5 vs. 6)	++	*	++

[1]PP = preplant, E = emergence/hilling

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

Table 5. Potassium concentrations at three soil depths: 1) in the spring before K fertilizer application and planting, 2) in the fall after harvest, and 3) the change in soil K between spring and fall.

Treatment #	K_2O Timing[1] (PP, E)	K_2O Rate (lbs/A)	Soil K[2] (ppm)								
			Spring			Fall			Change from Spring to Fall		
			Soil depth (in.)								
			0-6	6-12	12-24	0-6	6-12	12-24	0-6	6-12	12-24
1	0, 0	0	113	104	75	69	62	54	44	42	21
2	90, 0	90	119	98	78	76	60	61	43	39	17
3	180, 0	180	112	105	75	88	56	50	24	49	25
4	270, 0	270	115	106	72	98	55	54	17	51	18
5	360, 0	360	118	101	74	113	61	49	5	40	25
6	180, 180	360	130	106	79	128	64	55	2	42	24
		Significance[3]	NS	NS	NS	**	NS	NS	++	NS	NS
		LSD (0.10)	--	--	--	21	--	--	35	--	--
		Contrasts									
		Linear K rate (trt 1,2,3,4,5)	NS	NS	NS	**	NS	NS	**	NS	NS
		Quadratic K rate (trt 1,2,3,4,5)	NS	NS	NS	NS	NS	NS	NS	NS	NS
		Preplant vs. Split (trt 5 vs. 6)	NS	NS	NS	NS	NS	NS	NS	NS	NS

[1]PP = preplant, E = emergence/hilling

[2]Ammonium acetate extractable K.

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

Table 6. Effect of sample timing on soil test K and potash recommendations for potatoes.

Sampling location in soybean field		Soil test K[1] (ppm)		Potash recommendation[2] (lb K_2O/A)	
		Time of sampling			
		26-Jun	2-Nov	26-Jun	2-Nov
Block A	Rep 1	81	101	300	300
	Rep 2	72	102	400	300
	Rep 3	60	93	400	300
	Rep 4	68	84	400	300
Block B	Rep 1	69	90	400	300
	Rep 2	83	94	300	300
	Rep 3	91	96	300	300
	Rep 4	85	75	300	400

[1]Ammonium acetate extractable K in the 0 to 6 inch soil depth.

[2]For a yield goal of 500 cwt or more.

Response of Irrigated Potatoes to Two Controlled Release Fertilizers and a Urea Product Coated with Nitrification Inhibitors

Carl Rosen, James Crants, and Matt McNearney
Department of Soil, Water, and Climate, University of Minnesota
crosen@umn.edu

Summary: A field experiment was conducted at the Sand Plain Research Farm in Becker, MN, to evaluate alternative methods of improving nitrogen use efficiency in irrigated potato production. Treatments compared differences in nitrogen release rates and tuber yield and quality between the two controlled release fertilizers, ESN and Duration. In addition, we evaluated NZone, a urea source coated with compounds intended to maintain nitrogen in the ammonium form and thus reduce nitrate leaching. A total of 18 treatments were examined, all of which included the equivalent of 30 lbs N/ac in a starter blend. There was a starter only control, 12 treatments that received a total nitrogen rate of 240 lbs N/ac, and five treatments that received a total N rate of 170 lbs N/ac. The 240 lbs N/ac treatments included (all rates in lbs N/ac): 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; 105 ESN + 105 Duration at emergence; and 210 NZone at emergence. The 170 lb N/A treatments included: 70 urea at emergence + 70 UAN post-hilling; 140 ESN at emergence; 140 Duration preplant; 70 ESN + 70 Duration preplant; and 140 NZone at emergence. Nitrogen release from ESN was more rapid than nitrogen release from the thicker-coated Duration. ESN installed before planting released 50% of its nitrogen in 32 days, as compared to 80 days for preplant Duration. Similarly, ESN installed at emergence released 50% of its nitrogen in 33 days, versus 64 days for Duration installed at the same time. While virtually all of the urea in ESN had been lost from the prills by the end of the season, between 16 and 22% of the urea in Duration prills still remained at harvest, indicating a risk of nitrate leaching between growing seasons with Duration. ESN produced lower yields than Duration when applied at the same rate and time, but the difference was only significant when they were applied at 210 lbs N/ac before planting. Delayed nitrogen release from Duration may have been more than compensated for by greater nitrogen leaching losses from ESN. ESN produced significantly lower total yield, and non-significantly lower marketable yield, when it was applied before planting than at emergence. Duration produced non-significantly higher total and marketable yields when applied before planting than when applied at emergence. Treatments receiving Duration generally ranked high in total and marketable yields relative to other treatments, but they tended to have tuber sized distributions biased toward smaller sizes (less than six ounces) relative to treatments receiving urea and/or ESN without Duration. They also had lower percentages of their marketable yield represented by U.S. No. 1 tubers. Thus, Duration's beneficial effects on yield were counterbalanced, to some extent, by detrimental effects on tuber size and grade. These effects may be due to low early-season nitrogen availability and high late-season availability in the treatments receiving Duration relative to the other treatments. Data on petiole nitrate-N concentrations throughout the season, as well as field observations of canopy color support this interpretation. Treatments receiving NZone produced similar results to those receiving ESN and/or urea/UAN, but with a non-significant tendency toward larger tubers and more U.S. No. 1 tubers.

Background:

Studies with controlled release nitrogen fertilizer have been conducted for the past nine years at the Sand Plain Research Farm in Becker, Minnesota, using ESN, a polymer coated urea product manufactured by Agrium. ESN has been found to be most effective on potatoes when applied at the time of shoot emergence. While results have been promising and adoption by growers has occurred, a product that could be applied prior to planting would be preferable. A product called "Duration", also manufactured by Agrium, may be one that can substitute for ESN. Because of the thicker coating, release characteristics are slower than ESN. This slower release rate may make a pre-planting application more effective for Duration than an application at shoot emergence.

The overall goal of this research was to evaluate alternative methods of improving nitrogen use efficiency in irrigated potato production. The specific objective was to compare the effects of ESN with Duration on potato yield and quality, relative to an unfertilized control and applications of uncoated urea and ammonium nitrate. In addition, we tested the effectiveness of NZone, a urea source coated with compounds intended to maintain nitrogen in the ammonium form and thus reduce nitrate leaching.

Materials and Methods:

This study was conducted in 2012 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, 6.2-6.3; organic matter, 1.9-2.2%; Bray P1, 38-53 ppm; ammonium acetate extractable K, Ca, and Mg, 111-137, 790-888, and 138-162 ppm, respectively; Ca-phosphate extractable SO_4-S, 5 ppm; hot water extractable B, 0.2-0.3 ppm; and DTPA extractable Zn, 0,9-1.0 ppm. Extractable nitrate-N and ammonium-N in the top two feet of soil were 0.0-0.4 lbs/ac and 3.2 – 3.8 lbs/ac, respectively.

Prior to planting, 250 lb/ac 0-0-60 and 250 lb/ac 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 was hand planted in furrows on April 12, 2012. 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 nitrogen fertilizer treatments as described in Table 1 below. There were 16 treatments with different nitrogen sources (urea/UAN, ESN, and Duration), rates (170 or 240 lbs N/ac), and application timing (a planting application at 30 lbs N/ac alone or with preplant, emergence, and/or post-hilling applications). The other two treatments involved emergence and application of NZone at a rate of 140 or 210 lbs N/ac (plus the 30 lbs N/ac planting fertilizer).

Pre-planting urea, ESN, and Duration fertilizer were hand-broadcast three days before planting, on April 9, and incorporated with a field cultivator. For all treatments, at planting, 30 lbs N/ac as MAP and ammonium sulfate was banded three inches to each side and two inches below the seed piece using a metered, drop-fed applicator incorporated into the planter. This planting fertilizer included 130 lbs P_2O_5/ac, 181 lbs K_2O/ac, 20 lbs Mg/ac, 46 lbs S/ac, 3.3 lbs B/ac, and 5.6 lbs Zn/ac, applied as a blend of monoammonium phosphate, ammonium sulfate, potassium chloride, potassium magnesium sulfate, boric acid, and zinc oxide. Nitrogen applications at emergence were applied using a Gandy metered, drop-fed applicator and mechanically incorporated during hilling, on May 14. Post-hilling UAN was applied over the row with a tractor-mounted sprayer as a 28% UAN solution in 25 gal of water/ac. 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. Post-hilling nitrogen was applied on May 31, June 21, June 28, July 9, and July 19.

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 receiving a pre-planting application of 210 lb N/ac as ESN (treatment 8). 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 receiving 210 lb N/ac from Duration at emergence (treatment 12). 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 pre-planting and emergence applications were made. In addition, bags containing a 1:1 blend of the two fertilizers were buried at emergence. Bags from the pre-planting group were removed on April 20, April 30, May 7, May 15, May 21, June 11, June 27, July 24, and August 15. Bags from the emergence group were removed on May 21, June 6, June 11, June 21, June 27, July 10, July 24, and August 15. Remaining amounts of fertilizer were measured by dry weight for each date to track nitrogen release over time.

Plant stands were measured and stems counted on May 30. Petiole samples were collected from the 4th leaf from the terminal on six dates: June 11, June 25, July 5, July 16, July 26, and August 9. Petioles were analyzed for nitrate nitrogen on a dry weight basis. At the same time petioles were collected on June 25, July 5, and July 26, chlorophyll readings were measured with a SPAD meter on the terminal leaflet of the leaf sampled for petioles.

Vines were harvested on September 20 from two, 10-ft sections of row, and mechanically beaten over the entire plot area. Plots were machine harvested on September 24 and total tuber yield and graded yield were measured. Sub-samples of vines and tubers were collected to determine moisture percentage and nitrogen concentration, which will be used to calculate nitrogen uptake and distribution within the plant (Note: the data for nitrogen uptake were unavailable 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 dry matter content, as well as the prevalences of hollow heart, brown center, and scab. Soil samples were collected from the 0- to 2-foot depth on October 1 to measure residual inorganic nitrogen (nitrate nitrogen and ammonium nitrogen).

ANOVA tests were performed using replicate, nitrogen treatment, cultivar, and the treatment-by-cultivar interaction as independent variables. A Waller-Duncan k-ratio t-test was performed on all significant results for nitrogen treatment to determine the minimum significant difference between treatments.

To determine whether petiole nitrate-N concentration was a valuable predictor of tuber yield and quality traits, linear regressions were performed for each tuber trait as a function of petiole nitrate-N concentration on each petiole sampling date. Results are reported where R^2 (uncorrected) > 0.3.

Results:

Weather:

Rainfall and irrigation for the 2012 growing season are provided in Figure 1, soil moisture is in Figure 2, and air and soil temperatures are in Figure 3. Between April 16 and September 20 (from planting to vine kill), 22.8 inches of rainfall were supplemented with 15.0 inches of irrigation for a total of 37.8 inches of water. There were three leaching events (at least one inch of rainfall) between planting and emergence (May 14; when emergence fertilizer treatments were applied). There were four additional leaching events throughout the rest of the season, all of which occurred on or before June 10. Leaching may also have occurred between July 18 and July 29, as rainfall and irrigation combined delivered 4.6 inches of water in 12 days (Figure 1) and soil water potential dropped to a season low, as measured by the probe installed before planting (Figure 2). High temperatures during this period (Figure 3) and low rainfall over the preceding four weeks (Figure 1) may have contributed to a temporary over-scheduling of irrigation.

Nitrogen release from ESN and Duration:

The release curves for preplant and emergence applications of ESN and Duration, and of an emergence application of a 1:1 blend of the two, are shown in Figure 4. As expected, ESN released its fertilizer faster than Duration, and the blend of the two fertilizers released its nitrogen at a rate intermediate between the two.

ESN installed before planting had released 50% of its urea at the time of shoot emergence, 32 days after planting. In contrast, Duration applied before planting did not release 50% of its urea until nearly 80 days after planting.

ESN installed at emergence had released 50% of its urea by about 65 days after planting, or 33 days after installation. Duration installed at emergence did not release 50% of its urea until about 96 days after planting, or 64 days after installation. The 1:1 blend of ESN and Duration had released 50% of its urea by about 80 days after planting, or 48 days after installation.

Maximum nitrogen uptake rates by Russet Burbank generally occur between 40 and 80 days after planting. Duration installed before planting had released approximately 10% of its urea by 40 days after planting and 50% by 80 days, for a release of about 40% of its urea content during this period. In contrast, ESN installed before planting had released about 55% of its urea by 40 days after planting and 87% by 80 days, and therefore released about 34% of its urea content during this period.

Duration installed at emergence had released 2% of its nitrogen by 40 days after planting and 23% by 80 days after planting, for a total release of just 21% of its urea during the period of maximum uptake. ESN installed at emergence had released 11% of its nitrogen by 40 days after planting and 68% by 80 days after planting, for a release of 57% of its urea during this period. The 1:1 blend of the two fertilizers had released 6% of its nitrogen by 40 days after planting and 50% by 80 days after planting, thus releasing about 44% of its urea content during this period.

By the time of harvest, ESN installed at either time had released 98% of its nitrogen content. In contrast, Duration installed before planting had released 84% of its nitrogen content, while Duration installed at emergence had released just 78% of its nitrogen. The blend of the two fertilizers had released 85% of its nitrogen content.

Plant stand and stems per plant

There were no significant effects of treatment on plant stand (which ranged from 98.1% to 100%) or the number of stems per plant (which ranged from 2.68 to 3.45 stems per plant; Table 2).

Petiole nitrate-N

Results for petiole nitrate-N concentrations are presented in Table 2.

At all sampling periods, treatments receiving 240 lbs total N/ac tended to have higher petiole nitrate-N concentrations than those receiving 170 lbs total N/ac. The control treatment (treatment 1) had the lowest concentration on all dates except July 16, when the treatment receiving 170 lbs N/ac as ESN at emergence had a lower concentration. At all dates, there was at least one treatment that did not have a significantly greater petiole nitrate-N concentration than the control.

For most treatments, petiole nitrate-N concentrations were highest on June 11, 2012, and declined with each subsequent sampling date, except for a smaller peak on July 26. A clear exception was the treatment receiving 210 lbs N/ac as Duration at emergence (treatment 12), which had an increasing petiole nitrate-N concentration from June 25 until July 26 (when it had a significantly higher petiole nitrate-N concentration than any other treatment). Another exception was the treatment receiving 210 lbs N/ac as Duration before planting (treatment 10), which had a slightly higher petiole nitrate-N concentration on June 25 than it did on June 11. This treatment and the one receiving 140 lbs N/ac as Duration before planting (treatment 9) both displayed much slower decreases in petiole nitrate-N between June 25 and July 5 than most of the other treatments did.

The method of application had a strong effect on relative petiole nitrate-N concentrations. On June 11, treatments that received urea, ESN, or NZone at emergence tended to have higher petiole nitrate-N concentrations than similar treatments that did not. The treatments receiving Duration only or the blend of Duration and ESN had the lowest concentrations on this date, with the treatment receiving 210 lbs N/ac as Duration at emergence (treatment 12) having the lowest concentration. These were followed by the treatment receiving 210 lbs N/ac as urea before planting (treatment 4).

As the season progressed, the relative rankings of the nitrogen sources shifted, so that by July 26, six of the eight treatments with the highest petiole nitrate-N had received at least half of their nitrogen from Duration. However, the treatments receiving a blend of ESN and Duration before planting (treatments 13 and 14) had relatively low concentrations throughout the field season.

Leaf chlorophyll content

Results for leaf chlorophyll content (SPAD readings) are presented in Table 2.

SPAD readings were strongly correlated with petiole nitrate-N concentrations collected from the same leaves on the first two sampling dates, but the correlation declined by the third sampling date (June 25, R^2 = 0.714; July 5, R^2 = 0.774; July 26, R^2 = 0.562).

SPAD readings for the control treatment (treatment 1) were consistently significantly lower than the readings for the other treatments, and they declined steadily across the three sampling dates. All treatments showed decreases in SPAD readings between June 25 and July 5, but three showed clear increases between July 5 and July 26. These were the treatment receiving 210 lbs N/ac as Duration before planting (treatment 10), the treatment receiving 210 lbs N/ac as Duration at emergence (treatment 12), and the treatment receiving 210 lbs N/ac as a blend of Duration and urea at emergence (treatment 16).

SPAD readings for fertilized treatments were similar to each other on June 25, but had diverged by July 26. The treatment receiving 240 lbs N/ac as Duration before planting (treatment 10) was distinct from the other treatments. It had significantly higher SPAD readings than any other treatment except the one receiving 210 lbs N/ac as Duration at emergence (treatment 12). The treatment receiving 210 lbs N/ac as urea before planting (treatment 4), the treatment receiving 210 lbs N/ac as ESN before planting (treatment 8), the treatment receiving 140 lbs N/ac as a blend of Duration and ESN before planting, and the treatment receiving 140 lbs N/ac as NZone at emergence (treatment 13) all had SPAD readings significantly lower than any other fertilized treatments.

Vine and tuber nitrogen

Results for vine and tuber nitrogen concentrations are presented in Table 2.

Treatments receiving 240 total lbs N/ac typically had higher vine nitrogen concentrations at harvest than those receiving 170 total lbs N/ac, and almost all fertilized treatments had higher vine nitrogen concentrations than the control. The treatment receiving 210 lbs N/ac as urea before planting (treatment 4) had lower vine nitrogen concentration than any treatment but the control, as expected, given the probable high loss of nitrogen due to nitrate leaching. There were no other striking patterns in how nitrogen sources and times of application related to vine nitrogen concentrations, though there were numerous statistically significant differences.

Tuber nitrogen concentrations correlated positively with vine nitrogen concentrations (linear regression: $R^2 = 0.433$). Tuber nitrogen concentration tended to increase with increasing nitrogen application rate, with the control treatment having the lowest concentration. There were no striking relationships between nitrogen source and application timing, on one hand, and tuber nitrogen concentration, on the other.

Tuber yield

Tuber yield results are presented in Table 3.

The control treatment (30 lbs N/ac applied at planting with no other fertilizer application; treatment 1) had significantly lower total yield and marketable yield than any of the other treatments. Urea applied before planting at 210 lbs N/ac (treatment 4) produced significantly lower total yield and marketable yield than any other treatment except for the control treatment.

In terms of total yield, the three highest-yielding treatments (treatments 11, 14, and 10) all involved the application of Duration prior to planting at 210 lbs N/ac, and the highest-yielding treatment at 140 lbs total N/ac also had Duration applied prior to planting (treatment 9). In terms of marketable yield, the treatment receiving 210 lbs N/ac as urea/UAN (treatment 3) and the treatment receiving 210 lbs N/ac a mixture of urea and Duration at emergence (treatment16) both had higher yields than the treatments receiving either Duration (treatment 10) or an ESN/Duration mix (treatment 14) at a rate of 210 lbs N/ac before planting.

In contrast, the treatment with Duration plus ESN applied prior to planting at 140 lbs N/ac (treatment 13) had the lowest total yield and marketable yield of any treatment at this application rate. The one receiving ESN before planting at 210 lbs N/ac (treatment 8) had the lowest total yield and marketable yield at that application rate, except for the one receiving urea before planting (treatment 4).

Treatments receiving 240 total lbs N/ac usually had higher total and marketable yield than those receiving 170 total lbs N/ac (compare treatment 3 vs. 2, 10 vs. 9, 14 vs. 13, and 18 vs. 17). The only significant differences were for both total and marketable yields, between the two treatments where a blend of ESN and Duration was applied before planting (treatments 13 and 14). The one exception to the general trend of higher yield at 240 lbs total N/ac was where ESN was applied at emergence, in which the treatment receiving 210 lbs N/ac as ESN (treatment 6) had non-significantly lower total and marketable yields than the one receiving 140 lbs N/ac as ESN (treatment 5).

At an application rate of 140 lbs N/ac, total and marketable yields for ESN applied at emergence (treatment 5), Duration applied before planting (treatment 9), and for a combination of the two applied before planting (treatment 13), did not differ significantly from the yield achieved using split applications of urea/UAN at the same rate (treatment 2). The same was true at an application rate of 210 lbs N/ac, comparing treatments with ESN (treatment 6), Duration (treatment 10), and a combination of the two (treatment 14) with an application of urea and a second application of urea and ammonium nitrate (treatment 3). However, the treatment receiving 210 lbs N/ac as ESN at emergence (treatment 6) had a significantly lower total yield, but not marketable yield, than the treatment receiving the same amount of nitrogen as a combination of ESN and Duration at emergence (treatment 14).

Application of 210 lbs N/ac as ESN before planting (treatment 8) resulted in significantly lower total yield, but not marketable yield, than application of Duration at the same rate and time (treatment 10). With application at emergence, ESN (treatment 6) still produced lower total and marketable yield than Duration (treatment 12), but the difference was not significant. When the products were applied in combination with urea at emergence, ESN (treatment 7) again produced non-significantly lower total and marketable yield than Duration (treatment 16).

The treatment receiving 210 lbs N/ac as urea before planting (treatment 4) had significantly lower total and marketable yield than the treatment that received 210 lbs N/ac as urea/UAN (treatment 3). It also had significantly lower total and marketable yield than any of the slow-release fertilizers applied at the same rate and time: ESN (treatment 8), Duration (treatment 10), or an equal mixture of both (treatment 14).

ESN applied before planting at 210 lbs N/ac (treatment 8) produced significantly lower total yield, but not marketable yield, than ESN applied at emergence (treatment 6), and significantly lower total and marketable yield than Duration applied before planting, either alone (treatment 10) or in equal mixture with ESN (treatment 14).

Duration applied at 210 lbs N/ac produced a non-significantly higher total and marketable yields when applied before planting (treatment 10) than when applied at emergence (treatment 12). A similar result was obtained for an equal blend of Duration and ESN (treatment 14 pre-planting; treatment 15 at emergence). When urea was applied at emergence at 105 lbs N/ac, the treatment receiving 105 lbs N/ac as Duration before planting (treatment 11) had significantly higher total yield than the one receiving the Duration at emergence (treatment 16), but the difference was not significant for marketable yield.

There were no significant differences in total or marketable yield among treatments receiving 210 lbs N/ac as ESN, Duration, or a mixture of the two at emergence (ESN: treatment 6; Duration: treatment 12; Mixture: treatment 15). Although the treatment receiving urea/UAN at that application rate (treatment 3) had higher total and marketable yield than any of these, the differences were not significant.

The two NZone treatments (treatments 17 and 18) had similar total and marketable yield to the corresponding urea/UAN treatments (treatments 2 and 3, respectively). Total and marketable yields for the NZone treatments were also not significantly different from those receiving ESN at emergence (5 and 6, respectively), Duration before planting (9 and 10, respectively), or a mixture of ESN and Duration before planting (13 and 14, respectively), at the same application rates.

Tuber size

Tuber size distributions are based on yield in different tuber size categories, as presented in Table 3. Tuber size distributions could be divided into four general patterns.

Pattern 1: The control treatment (treatment 1) had a relatively high yield of 0- to 3-ounce tubers, a distinct peak of yield in the 3- to 6-ounce category, and much lower yields in increasingly large size categories beyond 6 ounces. The control treatment had a significantly higher yield of tubers under 3 ounces than any treatment except the ones receiving a mixture of ESN and Duration before planting (treatments 13 and 14), and significantly smaller percentages of tubers over 6 ounces and 10 ounces than any other treatment.

Pattern 2: The treatment receiving 210 lbs N/acre as urea before planting (treatment 4), the treatments receiving 210 lbs N/ac as Duration either pre-planting or at emergence (treatments 10 and 12), and those receiving a blend of Duration and ESN before planting at either 140 or 210 lbs N/ac (treatments 13 and 14) all had slightly higher yields in the 3- to 6-ounce size category than in the 6- to 10-ounce category, with a rapid, steady decline in yield with increasing category size above 10 ounces. They also tended to have high yields of 0- to 3-ounce tubers, relative to their total yields. Every treatment showing this pattern was in the bottom half of the treatments as ranked by the percentage of yield in tubers over six ounces. Four of the five treatments exhibiting this pattern involved the application of Duration.

Pattern 3: The treatment receiving 140 lbs N/ac as urea/UAN after planting (treatment 2), the treatments receiving ESN alone (treatments 5, 6, and 8), the one receiving 140 lbs N/ac as Duration before planting (treatment 9), the one receiving 210 lbs N/ac as a blend of Duration and ESN at emergence (treatment 15), and the one receiving 210 lbs N/ac as a blend of Duration and urea at emergence (treatment 16) all exhibited the third tuber size distribution pattern. They had slightly higher yields of tubers in the 6- to 10-ounce category than in the 3- to 6-ounce category, with a rapid, steady decline in yield with increasing category size above 10 ounces. They tended to have low yields of 0- to 3-ounce tubers relative to their total yields. The percentages of their yields found in tubers over 6 ounces were broadly distributed around the median for all fertilized treatments. Four of the seven treatments showing this pattern involved ESN, and three involved Duration.

Pattern 4: The fourth group had rapidly, steadily-increasing yields with increasing category size up to a distinct peak of yield in the 6- to 10-ounce category, followed by a rapid, steady decline in yield with increasing category size after that. This group tended to have relatively low yields of 0- to 3-ounce tubers and relatively high yields of 10- to 14-ounce and over-14-ounce tubers. This size-pattern group included the treatment receiving 210 lbs N/ac as urea/UAN after planting (treatment 3), the one receiving 210 lbs N/ac as a blend of ESN and urea at emergence (treatment 7), the one receiving 210 lbs N/ac as a combination of Duration before planting and urea at emergence (treatment 11), and both of the treatments receiving NZone at emergence (treatments 17 and 18). Treatments with this size distribution pattern tended to have relatively few tubers under 3 ounces. Ranking treatments by the percentage of yield in tubers over 6 ounces, the treatments exhibiting this size category distribution occupied five of the top six rankings. None ranked below sixth. Every treatment exhibiting this pattern involved the application of uncoated urea or NZone at emergence. Only two treatments that used urea at emergence showed any other pattern, and they both exhibited the third pattern, which also had peak yield in the 6- to 10-ounce size class.

Tuber grade

Yields for U.S. No. 1 and U.S. No. 2 tubers are presented in Table 3.

When treatments were sorted by the percentage of their marketable yields represented by U.S. No. 1 tubers, treatments receiving Duration occupied six of the seven lowest ranks, all of which had more U.S. No. 2 than U.S. No. 1 tubers (the control treatment had the second-lowest rank). Only one treatment receiving Duration ranked in the top half; the treatment receiving a mixture of ESN and Duration before planting at a rate of 140 lbs N/ac had the eighth highest percentage of yield in U.S. No. 1 tubers. Treatments receiving ESN did not have consistently high or low percentages of yield in U.S. No. 1 tubers compared to similar treatments receiving urea. The treatments receiving NZone had the second- (treatment 18) and fourth- (treatment 17) highest percentages of yield in U.S. No. 1 tubers.

There was a relationship between tuber size distribution and yield of U.S. No. 1 tuber. When treatments were ranked by their yield of U.S. No. 1 tubers, the control treatment (treatment 1), which had tuber size distribution pattern 1, had the lowest rank. Treatments with tuber size distribution pattern 2 were all ranked in the bottom half. Treatments with tuber size distribution pattern 3 occupied the middle ranks, ranging from fourth-highest yield to fourth-lowest yield. Treatments with tuber size distribution pattern 4 occupied five of the top six ranks. No similarly clear relationship was evident when comparing size distribution with total yield, marketable yield, yield of U.S. No. 2 potatoes, or the percentage of yield represented by U.S. No. 1 tubers. However, size distribution patterns 3 and 4 did differentiate from each other when treatments were ranked by the percentage of marketable yield represented by U.S. No. 1 tubers.

Tuber quality

Tuber quality results are presented in Table 4.

There was no significant variation among treatments in the prevalence of hollow heart, brown center, or scab, nor in tuber specific gravity. Tuber dry matter content did vary significantly among treatments, however. The control treatment had the lowest dry matter content, with significantly lower content than ten other treatments. There was a clear tendency for treatments receiving Duration to have high dry matter content relative to those receiving ESN or urea, although the treatment with the highest dry matter content was the one receiving a blend of Duration and ESN before planting at a rate of 210 lbs N/ac (treatment 14). The five treatments with the highest dry matter content (treatments 14, 12, 9, 11, and 10, in order of rank) all involved Duration, as did the seventh- and eighth-ranked treatments (treatments 16 and 13). The treatment receiving 210 lbs N/ac as ESN before planting, which had the sixth-highest dry matter content, was the only non-Duration treatment in the top eight highest-content treatments, and the one receiving 210 lbs N/ac as a mixture of ESN and Duration at emergence was the only treatment with Duration outside of the top eight (it had the 13th highest dry matter content).

Correlations with petiole nitrate-N concentration

Linear regressions were performed to test for relationships between petiole nitrate-N concentration and tuber yield and quality traits. To isolate the effects of nitrogen source and application timing from the effects of absolute nitrogen application rate, only treatments receiving 240 lbs total N/ac were included.

Tuber nitrogen concentration was positively correlated with petiole nitrate-N concentration on June 25 (R^2 = 0.583) and July 5 (R^2 = 0.676), but the two variables were not otherwise strongly related (R^2 < 0.2).

Vine nitrogen concentration at harvest was positively correlated with petiole nitrate-N concentration on July 5 (R^2 = 0.507), but not at any other time (R^2 < 0.3).

Petiole nitrate-N concentration on June 11 was strongly positively correlated with the yield of U.S. No. 1 tubers (R^2 = 0.6941). Petiole nitrate-N on June 25 was still a good predictor (R^2 = 0.521). The two variables were only weakly correlated in the next three sampling dates (R^2 < 0.3), and negatively correlated on the last sampling date, August 9 (R^2 = 0.407).

Petiole nitrate-N concentration was a poor predictor of yield of U.S. No 2 tubers early in the season (R^2 < 0.2), but the two variables were positively correlated by July 16 (R^2 = 0.498) and remained so on July 26 (R^2 = 0.566) and August 9 (R^2 = 0.468).

Consistent with these results, petiole nitrate-N was positively related to the percentage of marketable yield represented by U.S. No. 1 tubers on June 11 (R^2 = 0.423), with the positive correlation weakening and then becoming negative by July 16 (R^2 = 0.467), July 26 (R^2 = 0.592), and August 9 (R^2 = 0.617).

Petiole nitrate-N concentration was not a good predictor of total or marketable yield (R^2 < 0.3 for every sampling date). However, it was positively correlated with the percentage of yield in tubers over 6 ounces on June 11 (R^2 = 0.548), June 25 (R^2 = 0.633), and July 5 (R^2 = 0.454), with no predictive power on later sampling days (R^2 < 0.1). Similar results were obtained for the percentage of yield in tubers over 10 ounces as a function of petiole nitrate-N concentration, with positive correlations on June 11 (R^2 = 0.503), June 25 (R^2 = 0.686), and July 5 (R^2 = 0.533), with negligible correlations thereafter (R^2 < 0.1).

Petiole nitrate-N concentration and tuber dry matter content were negatively correlated on June 11 (R^2 = 0.378). Aside from this relationship, petiole nitrate-N was a poor predictor of tuber quality traits (R^2 <0.3).

The relationship between petiole nitrate-N concentration and the tuber size distribution patterns was determined for all application rates. The four tuber size distribution patterns could be largely distinguished from each other by sorting the treatments by petiole nitrate-N concentrations on June 11. Pattern 1 had lower nitrate-N than pattern 2, which had lower nitrate-N than pattern 3, which had lower nitrate-N than pattern 4. There were just two exceptions to perfect segregation by tuber size distribution pattern. The treatment receiving 140 lbs N/ac as Duration before planting (treatment 9) exhibited pattern 3 but sorted with treatments exhibiting pattern 2. The treatment receiving 210 lbs N/ac as ESN at emergence exhibited pattern 3 but sorted with treatments exhibiting pattern 4. Over the course of the season, petiole nitrate-N concentration became increasingly decoupled from tuber size distribution.

Conclusions:

The treatments receiving Duration or a blend of Duration and ESN had higher yields when the fertilizer was applied before planting, while the treatments receiving ESN or urea produced higher yields when the fertilizer was applied at emergence. This suggests that Duration is an effective option for growers who would prefer to apply fertilizers only once per season, before crops have been planted. However, since nitrogen release experiment found that even Duration applied before planting may retain approximately 15% of its urea by harvest time, there is a risk that using Duration will result in nitrate leaching during the subsequent fall and spring.

The treatments that received Duration tended to have higher total yields than similar treatments receiving urea, which tended to have higher yields than similar treatments receiving ESN. However, treatments using Duration tended to have a tuber size distribution biased toward the smaller size classes compared to treatments receiving ESN, and even more so compared to treatments receiving urea or NZone. This difference in tuber size distribution was somewhat apparent in the relative marketable yields (yield of tubers over 3 ounces) of the various treatments, in which treatments to which Duration was applied ranked lower than they did for total yield. It was also apparent in the percentages of yield in tubers over 6 ounces or 10 ounces, in which treatments receiving Duration were near the middle or bottom of the ranking, while those receiving urea or NZone were near the middle or the top. (Those receiving ESN were spread throughout the rankings).

In addition to having a disproportionate yield of smaller tubers, treatments receiving Duration had a relatively high percentage of their yield in U.S. No. 2 tubers. All but one of the treatments receiving Duration had more than half of their yield in U.S. No. 2 tubers (the exception was the treatment receiving 140 lbs N/ac as a blend of Duration and ESN before planting, treatment 13).

There was a significant relationship between the pattern of the tuber size distribution and the yield of U.S. No. 1 tubers. Tuber size distribution patterns were not expected to sort with relative yields of U.S. No. 1 tubers, especially given that they did not sort well with relative total yields, marketable yields, yields of U.S. No. 2 tubers, or the percentage of marketable yield represented by U.S. No. 1 tubers (although patterns three and four did segregate from each other fairly well based on this last criterion).

Treatments the received Duration only or a blend of Duration and ESN tended to have low petiole nitrate-N concentrations early in the season. By the end of the season, most of the treatments with the highest petiole nitrate-N concentrations involved Duration.

There were similar shifts in the relationships between petiole-nitrate-N concentration and tuber size and grade. Early-season petiole nitrate-N was positively related to the yield of U.S. No. 1 tubers and the percentages of yield in tubers over 6 or 10 ounces. Treatments with high early-season petiole nitrate-N concentrations also tended to have more large-biased tuber size distributions than those with low early-season concentrations. Mid-season petiole nitrate-N concentrations were positively correlated the nitrogen concentrations of tubers and vines at harvest. Late-season petiole nitrate-N concentrations were positively correlated with the yield of U.S. No. 2 tubers and negatively correlated with the yield of U.S. No. 1 tubers and the percentage of yield represented by U.S. No. 1 tubers. Petiole nitrate-N concentration was not strongly correlated with total yield or marketable yield at any sampling date.

These results for petiole nitrate-N concentration suggest a connection between the timing of nitrogen availability and (1) tuber size distribution and (2) tuber grade. Duration treatments may have produced small-biased distributions and smaller percentages of U.S. No. 1 tubers because they had low nitrogen availability early in the season and high nitrogen availability late in the season relative to other treatments.

This interpretation is supported by the release-rate data for buried bags of ESN, Duration, and a blend of the two. In particular, Duration released more nitrogen after the period of maximum expected nitrogen uptake, from 40 to 80 days after planting, than ESN did. (The blend of the two released an intermediate percentage of its stored nitrogen after that period, as expected.) The vines in treatments that received Duration remained green further into the season than those of other treatments, consistent with the results for petiole nitrate-N concentrations. (SPAD readings of chlorophyll content were not taken late enough in the season to quantify this observation.) The difference in the timing of nitrogen release between Duration and ESN was therefore consequential for the vines. Perhaps it was similarly consequential for tuber formation, with beneficial effects on tuber yield but negative consequences for tuber size and grade.

The treatments receiving NZone had average total and marketable yields for the amount of nitrogen applied. However, they had the highest yields of U.S. No. 1 potatoes for their respective nitrogen application rates out of all the treatments, and the percentages of their marketable yields represented by U.S. No. 1 tubers were in the top four of the eighteen treatments. Relatively high percentages of their yields were represented by tubers over 6 or 10 ounces. Overall, the treatments receiving NZone performed similarly to those receiving urea/UAN, ESN, or a mixture of ESN and urea, but with a non-significant tendency toward larger tubers and more U.S. No. 1 tubers.

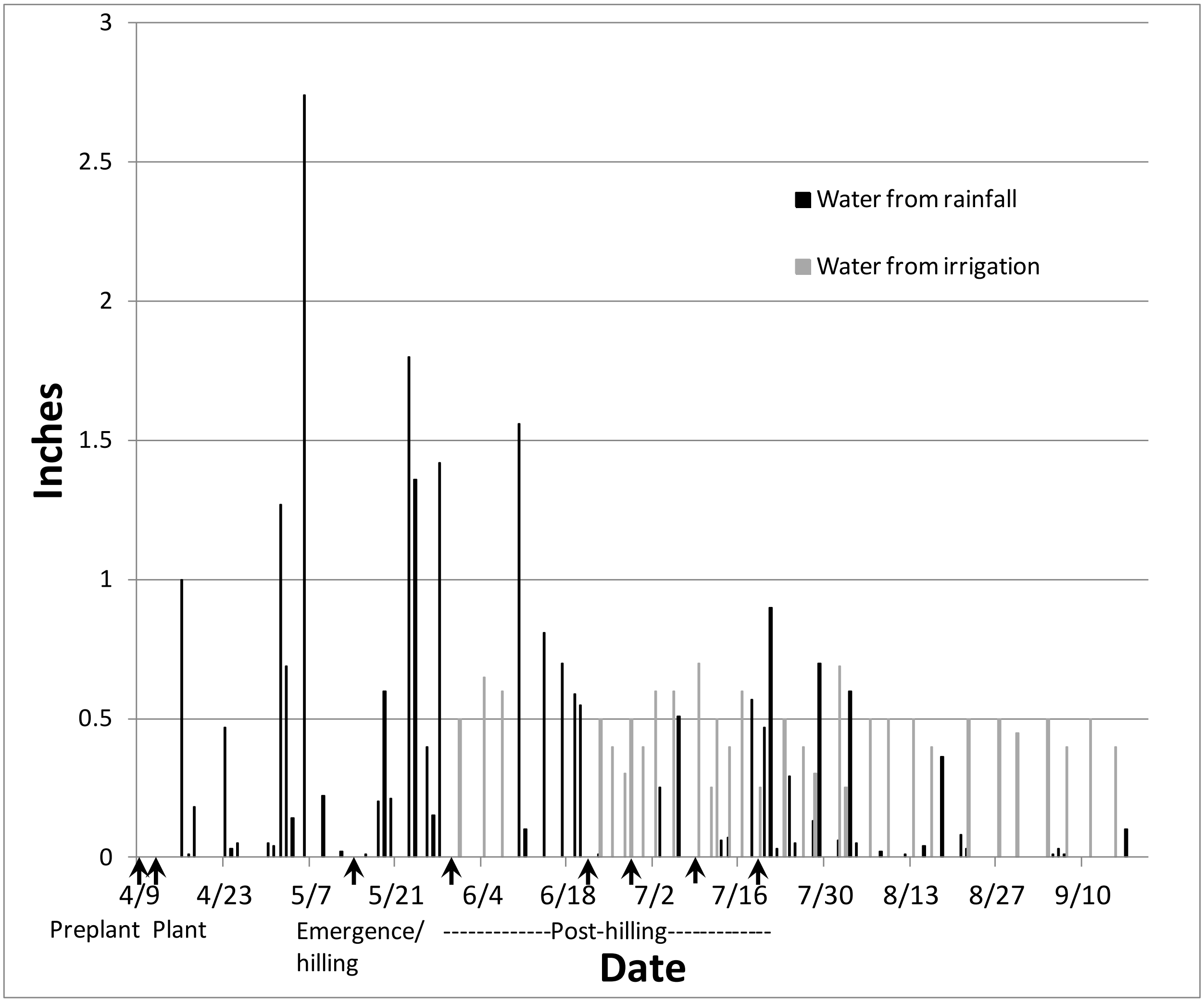

Figure 1. Rainfall and irrigation amounts during the 2012 growing season.

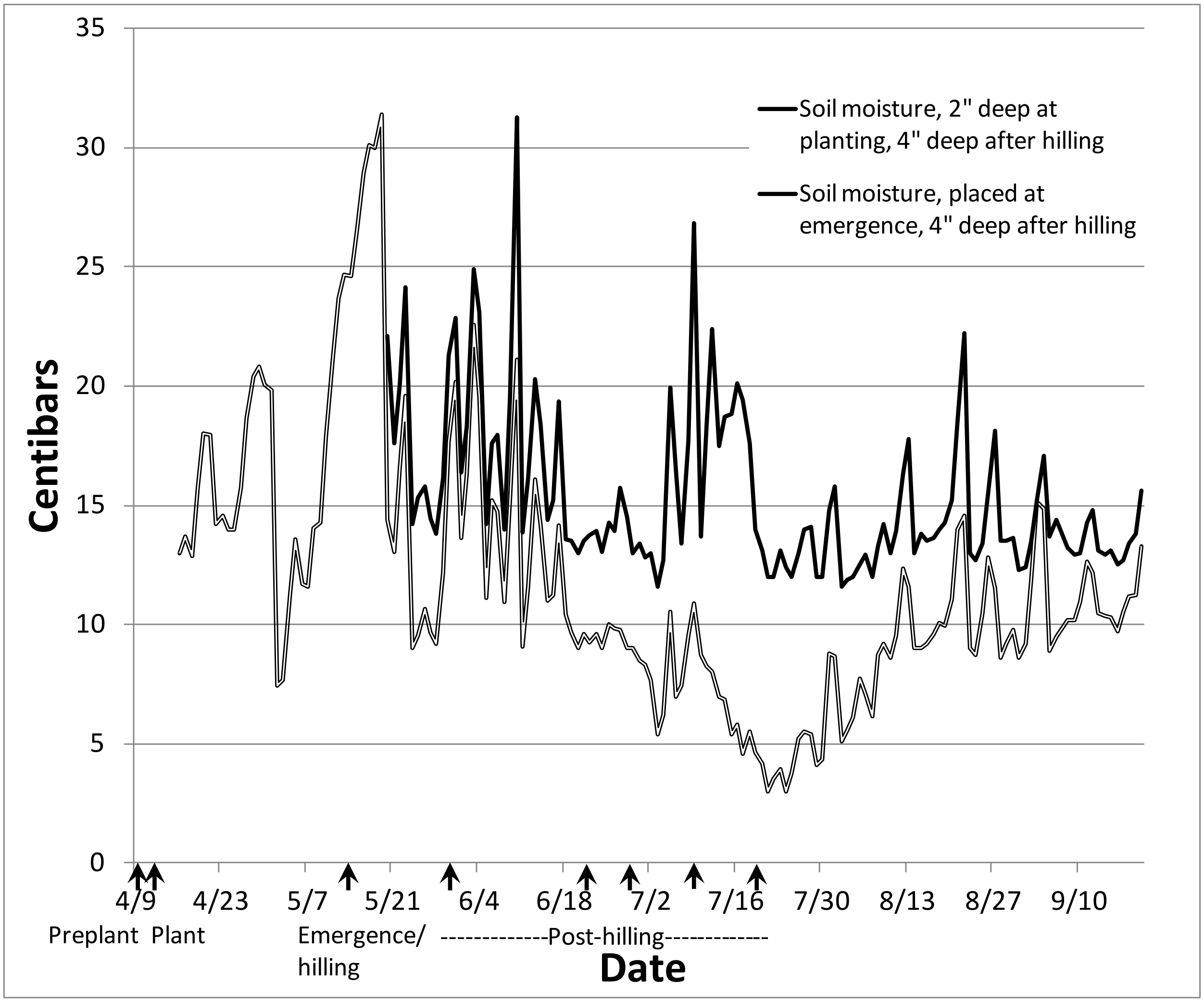

Figure 2. Soil moisture during the 2012 growing season, recorded by probes placed before planting and at potato shoot emergence.

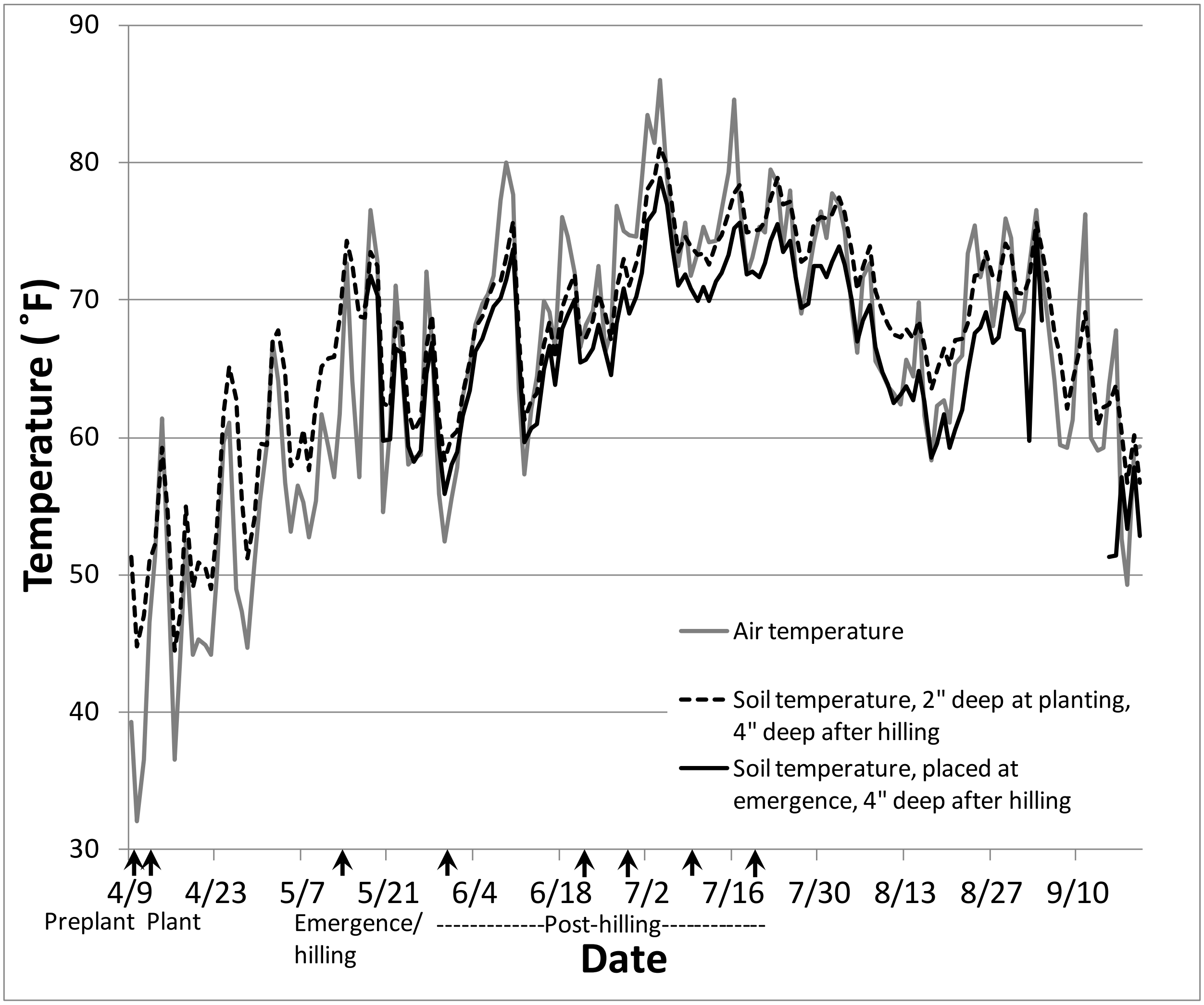

Figure 3. Air temperature and soil temperature during the 2012 field season. Soil temperature recorded by probes placed before planting and at potato shoot emergence.

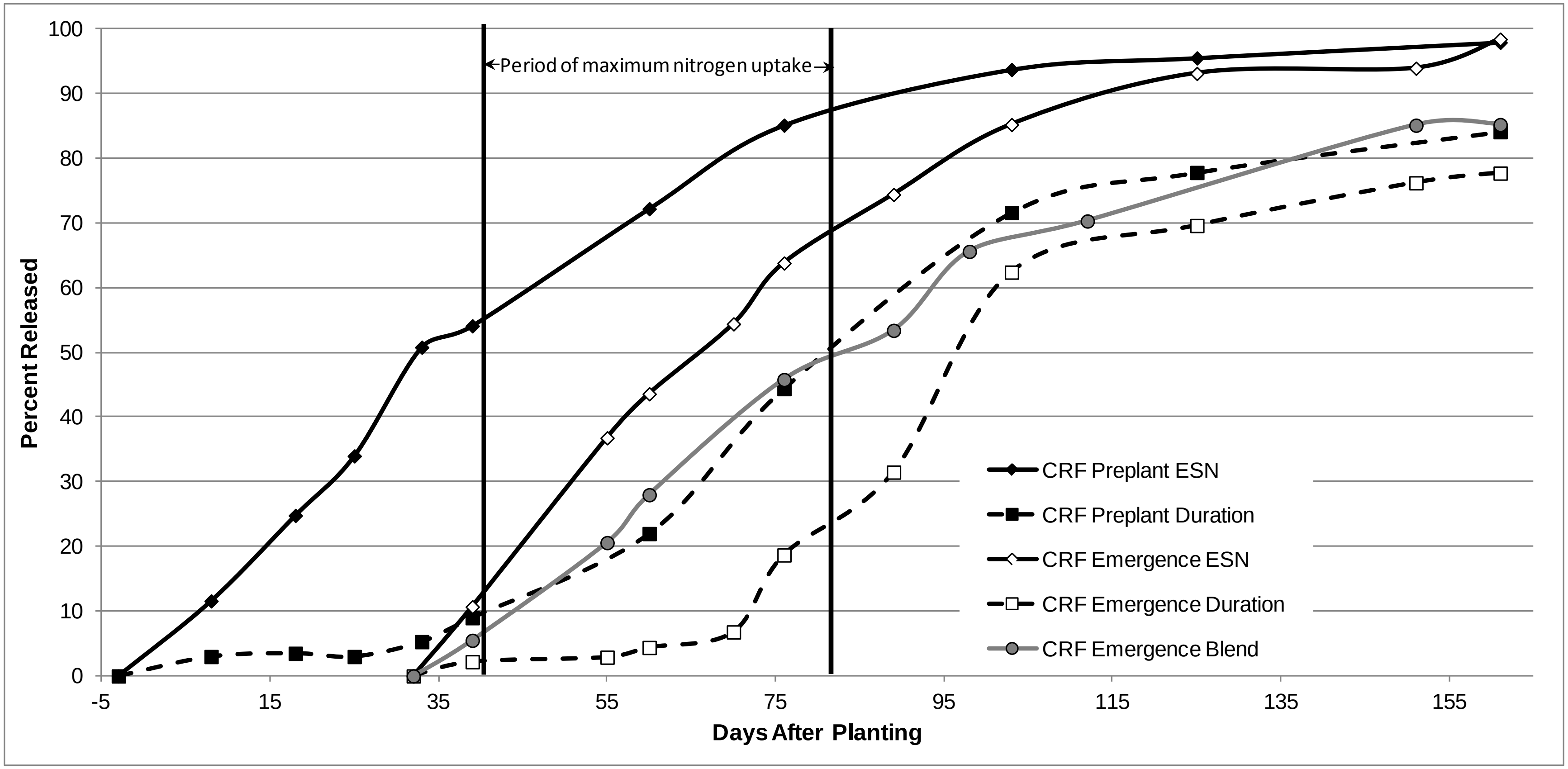

Figure 4. Nitrogen release from ESN, Duration, and a 1:1 blend of the two, applied before planting or at potato shoot emergence.

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

Treatment #	Timing of nitrogen applications				Total Nitrogen (lbs N / ac)
	Preplant	Planting	Emergence	Post-hilling[1]	
	Nitrogen sources[2] and rates (lbs N / ac)				
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	140 NZONE Urea	0	170
18	0	30 MAP + AS	210 NZONE Urea	0	240

[1]Post-hilling nitrogen was applied five times at 7 - 21-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; NZONE (AgXplore International): urea with nitrogen stabilizer coating.

Table 2. Effect of nitrogen source on Russet Burbank plant stand,number of stems per plant, petiole nitrate-N concentration, leaf chlorophyll content, and tissue nitrogen concentration.

Treatment #	Nitrogen Source[1]	Nitrogen Timing[2] (PP, P, E, PH)	Nitrogen Rate (lbs N / ac)	Plant Stand (%)	Stems per Plant	Petiole Nitrate - N						Chlorophyll content			Tissue N	
						11-Jun	25-Jun	5-Jul	16-Jul	26-Jul	9-Aug	25-Jun	5-Jul	26-Jul	Tuber	Vine
						ppm						SPAD readings			%	
1	MAP + AS	0, 30, 0, 0	30	**100.0**	**2.75**	773	193	164	151	151	23	29.7	26.9	23.0	1.00	0.60
2	MAP + AS, Urea, UAN	0, 30, 70, 70	170	**100.0**	**3.05**	11680	3999	2536	2032	1831	120	34.9	33.1	34.2	1.18	0.90
3	MAP + AS, Urea, UAN	0, 30, 105, 105	240	**99.3**	**3.05**	18013	10663	7584	3577	5960	376	36.3	36.3	36.1	1.27	1.02
4	Urea, MAP + AS	210, 30, 0, 0	240	**98.1**	**3.03**	10183	3593	1315	939	561	186	34.7	31.7	28.1	1.15	0.68
5	MAP + AS, ESN	0, 30, 140, 0	170	**100.0**	**3.15**	12857	7551	2650	94	424	214	37.4	33.6	33.7	1.23	0.89
6	MAP + AS, ESN	0, 30, 210, 0	240	**100.0**	**2.93**	16864	13585	9006	2298	4477	491	38.3	36.1	36.0	1.28	1.16
7	MAP + AS, Urea + ESN	0, 30, 105+105, 0	240	**100.0**	**2.98**	15688	14696	8733	2781	2650	297	37.9	36.3	34.2	1.33	0.92
8	ESN, MAP + AS	210, 30, 0, 0	240	**100.0**	**3.03**	13362	6262	2669	577	513	36	36.5	32.0	29.6	1.09	0.92
9	Duration, MAP + AS	140, 30, 0, 0	170	**98.6**	**2.78**	5560	4776	4293	2599	2943	206	36.1	34.8	33.6	1.10	0.77
10	Duration, MAP + AS	210, 30, 0, 0	240	**100.0**	**2.83**	7501	8243	7941	5182	6913	1374	36.6	35.7	38.7	1.32	1.08
11	Duration, MAP + AS, Urea	105, 30, 105, 0	240	**100.0**	**2.90**	17846	10859	4975	2104	2805	222	36.5	34.3	34.0	1.29	0.90
12	MAP + AS, Duration	0, 30, 210, 0	240	**99.3**	**2.98**	2430	1135	3390	4680	8613	1247	33.6	32.9	36.7	1.21	0.87
13	ESN+Duration, MAP + AS	70+70, 30, 0, 0	170	**100.0**	**3.08**	6263	1586	661	526	673	76	33.2	30.9	29.3	1.07	0.84
14	ESN+Duration, MAP + AS	105+105,30,0,0	240	**100.0**	**2.98**	8972	3936	2349	1075	1413	102	34.9	32.8	33.3	1.17	0.93
15	MAP + AS, ESN+Duration	0,30,105+105,0	240	**100.0**	**2.68**	13955	8747	6067	3165	5345	906	36.8	34.0	34.4	1.24	1.15
16	MAP + AS, Urea+Duration	0,30,105+105,0	240	**100.0**	**3.18**	14959	5975	2399	3526	3632	676	35.8	33.2	34.5	1.22	0.87
17	MAP + AS, NZONE Urea	0, 30, 140, 0	170	**98.6**	**3.45**	16342	7957	1011	609	508	83	37.0	32.2	29.3	1.22	0.88
18	MAP + AS, NZONE Urea	0, 30, 210, 0	240	**100.0**	**2.98**	17195	14998	7633	1438	1637	85	37.9	36.9	34.9	1.37	0.95
			Significance[3]	**NS**	**NS**	**	**	**	**	**	**	**	**	**	**	**
			LSD (0.1)	**--**	**--**	2132	2257	2188	2368	1547	512	1.9	1.7	2.5	0.14	0.23

[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 = Environmentally Smart Nitrogen (44-0-0); Duration = 43-0-0; NZone (AgXplore International): urea with nitrogen stabilizer coating.

[2]PP=preplant, 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 on Russet Burbank tuber yield and size distribution.

Nitrogen Treatments				Tuber Yield										
Treatment #	Nitrogen Source[1]	Nitrogen Timing[2]	Nitrgoen Rate	0-3 oz	3-6 oz	6-10 oz	10-14 oz	>14 oz	Total	#1s > 3 oz.	#2s > 3 oz	Total Marketable	> 6 oz	> 10 oz
		PP, P, E, PH	lbs N / ac	cwt / A									%	%
1	MAP + AS	0, 30, 0, 0	30	115.8	212.0	68.8	23.7	0.9	421.1	114.7	190.6	305.3	22.4	6.2
2	MAP + AS, Urea, UAN	0, 30, 70, 70	170	94.6	201.8	224.1	93.9	28.2	642.7	296.9	251.1	548.0	53.9	19.0
3	MAP + AS, Urea, UAN	0, 30, 105, 105	240	76.2	165.3	235.0	149.2	54.0	679.8	336.8	266.7	603.5	64.3	29.7
4	Urea, MAP + AS	210, 30, 0, 0	240	79.2	179.3	172.0	61.9	16.1	508.5	244.6	184.7	429.3	49.0	15.3
5	MAP + AS, ESN	0, 30, 140, 0	170	86.0	186.7	217.1	114.9	44.1	648.8	287.4	275.5	562.9	57.9	24.5
6	MAP + AS, ESN	0, 30, 210, 0	240	81.4	186.6	203.3	116.1	46.7	634.1	277.0	275.7	552.8	57.5	25.4
7	MAP + AS, Urea + ESN	0, 30, 105+105, 0	240	78.9	154.9	221.4	142.1	69.9	667.2	331.4	257.0	588.4	65.0	31.8
8	ESN, MAP + AS	210, 30, 0, 0	240	90.3	201.1	214.6	83.6	18.3	607.9	318.5	199.1	517.6	51.9	16.7
9	Duration, MAP + AS	140, 30, 0, 0	170	91.9	207.3	227.9	105.0	46.2	678.2	253.0	333.3	586.3	55.5	22.0
10	Duration, MAP + AS	210, 30, 0, 0	240	91.1	221.1	214.4	98.9	57.2	682.7	264.7	326.9	591.6	54.5	22.8
11	Duration, MAP + AS, Urea	105, 30, 105, 0	240	84.2	176.0	260.0	129.7	82.2	732.1	310.9	337.0	647.9	64.6	29.1
12	MAP + AS, Duration	0, 30, 210, 0	240	88.4	228.6	226.9	92.4	32.5	668.8	198.2	382.2	580.4	52.4	18.4
13	ESN+Duration, MAP + AS	70+70, 30, 0, 0	170	104.7	222.8	200.3	61.9	25.5	615.2	262.9	247.6	510.5	46.4	13.8
14	ESN+Duration, MAP + AS	105+105,30,0,0	240	98.8	225.6	218.6	100.7	44.5	688.2	285.7	303.7	589.4	52.9	21.1
15	MAP + AS, ESN+Duration	0,30,105+105,0	240	72.8	185.1	219.2	121.1	47.8	646.0	272.3	301.0	573.2	60.1	26.1
16	MAP + AS, Urea+Duration	0,30,105+105,0	240	87.4	201.1	216.3	118.3	56.4	679.5	298.9	293.2	592.0	57.2	25.5
17	MAP + AS, NZONE Urea	0,30,140,0	170	90.7	174.1	212.6	112.3	55.5	645.1	315.1	239.4	554.4	58.7	25.8
18	MAP + AS, NZONE Urea	0,30,210,0	240	88.4	167.0	215.5	129.3	70.0	670.2	345.8	236.0	581.8	61.7	29.4
			Significance[3]	**	*	**	**	**	**	**	**	**	**	**
			LSD (0.1)	20.7	46.7	30.6	37.0	27.9	52.2	44.8	57.7	57.2	6.9	7.5

[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 = Environmentally Smart Nitrogen (44-0-0); Duration = 43-0-0; NZONE (AgXplore International): urea with nitrogen stabilizer coating.

[2]PP=preplant, 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 on Russet Burbank tuber quality.

Nitrogen Treatments				Tuber Quality			Specific Gravity	Dry Matter
Treatment #	Nitrogen Source[1]	Nitrogen Timing[2]	Nitrogen Rate	HH	BC	Scab		
		PP, P, E, PH	lbs N / ac	%				
1	MAP + AS	0, 30, 0, 0	30	0.0	0.0	14.0	1.0712	19.22
2	MAP + AS, Urea, UAN	0, 30, 70, 70	170	1.0	1.0	10.7	1.0734	19.81
3	MAP + AS, Urea, UAN	0, 30, 105, 105	240	2.0	2.0	18.0	1.0724	20.49
4	Urea, MAP + AS	210, 30, 0, 0	240	4.0	4.0	6.9	1.0764	20.46
5	MAP + AS, ESN	0, 30, 140, 0	170	5.0	2.0	15.3	1.0755	20.07
6	MAP + AS, ESN	0, 30, 210, 0	240	5.0	5.0	11.0	1.0727	19.87
7	MAP + AS, Urea + ESN	0, 30, 105+105, 0	240	3.0	3.0	4.0	1.0758	19.76
8	ESN, MAP + AS	210, 30, 0, 0	240	3.0	3.0	12.0	1.0764	20.91
9	Duration, MAP + AS	140, 30, 0, 0	170	5.0	5.0	20.0	1.0762	21.21
10	Duration, MAP + AS	210, 30, 0, 0	240	5.0	5.0	14.0	1.0746	20.91
11	Duration, MAP + AS, Urea	105, 30, 105, 0	240	5.3	5.3	26.7	1.0807	21.19
12	MAP + AS, Duration	0, 30, 210, 0	240	2.0	3.0	11.0	1.0733	21.33
13	ESN+Duration, MAP + AS	70+70, 30, 0, 0	170	2.0	2.0	8.4	1.0757	20.57
14	ESN+Duration, MAP + AS	105+105,30,0,0	240	1.0	1.0	21.0	1.0740	22.02
15	MAP + AS, ESN+Duration	0,30,105+105,0	240	6.0	5.0	7.0	1.0733	20.00
16	MAP + AS, Urea+Duration	0,30,105+105,0	240	7.0	7.0	12.0	1.0780	20.64
17	MAP + AS, NZONE Urea	0, 30, 140, 0	170	6.3	6.3	11.4	1.0766	20.21
18	MAP + AS, NZONE Urea	0, 30, 210, 0	240	6.0	7.0	9.0	1.0742	19.99
			Significance[3]	NS	NS	NS	NS	**
			LSD (0.1)	--	--	--	--	1.03

[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 = Environmentally Smart Nitrogen (44-0-0); Duration = 43-0-0; NZONE (AgXplore International): urea with nitrogen stabilizer coating.

[2]PP=preplant, 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 Cultivar on Tuber Yield and Quality: Effects on Sugars and Acrylamide
- 2012 -

Carl Rosen[1], James Crants[1], Matt McNearney[1], and Marty McGlynn[2]
[1]Department of Soil, Water, and Climate, University of Minnesota and
[2]USDA-ARS Potato Research Worksite, East Grand Forks, MN

Summary: Since the discovery of acrylamide in fried potato products, reducing the amount of acrylamide in fried potato products has become a priority of the potato industry. Acrylamide concentration can potentially be reduced by minimizing the concentrations of acrylamide precursors (reducing sugars and the amino acid asparagine) in mature 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 cultivar and nitrogen fertilization regime on petiole nitrate-N concentration, yield, tuber quality, whole-tuber sucrose, glucose, and nitrogen concentrations, and the acrylamide concentrations of fried potato products. Three frying cultivars (Russet Burbank, Alpine Russet, and Dakota Trailblazer) and two chipping cultivars (Snowden and Ivory Crisp) were grown under five nitrogen fertilization regimes (30 lbs N/ac as MAP and AS for all treatments at planting, plus 0, 90, 150, 210, or 270 lbs N/ac as ESN at emergence). Tuber size distributions shifted toward larger size classes with higher application rates of ESN, with the magnitude of the shift varying among the cultivars. Higher-nitrogen treatments had a significantly higher prevalence of hollow heart, and tended to have higher prevalences of brown center, probably due to their higher percentages of large tubers. Whole-tuber sucrose concentration declined with increasing rate of nitrogen application for Dakota Trailblazer. Whole-tuber glucose concentration declined with increasing rate of nitrogen application, especially in Alpine Russet, with weaker effects in Russet Burbank, Dakota Trailblazer, and Ivory Crisp. The concentrations of both sugars varied significantly among cultivars, but with different rank-orders. The acrylamide concentrations of French fries from freshly harvested tubers tended to increase with increasing application of nitrogen in Dakota Trailblazer and Russet Burbank. French-fry acrylamide concentration was negatively correlated with whole-tuber sucrose concentration in Alpine Russet and positively correlated with whole-tuber glucose concentration in Russet Burbank. Dakota Trailblazer fries had much lower acrylamide concentrations than fries made from Alpine Russet or Russet Burbank. Chips made from the two chipping cultivars did not have significantly different acrylamide concentrations. Potato chip acrylamide concentrations in Ivory Crisp were significantly related to nitrogen treatment, with very low concentrations in the control treatment and very high concentrations in the treatment receiving 180 lbs N/ac. There was no effect of nitrogen treatment on acrylamide concentration in Snowden chips. Potato chip acrylamide concentrations were also positively correlated with whole-tuber glucose concentrations in Ivory Crisp, but they were not related to sucrose concentrations in either cultivar. Darker potato chips were found to have significantly higher concentrations of acrylamide. Additional measurements of sugar concentrations, acrylamide concentration, and fry test scores will be made after three, six, and nine months of storage at 45˚F and reported at a later time. Our results for this year to date suggest that both cultivar selection/breeding and nitrogen management have some potential to limit acrylamide formation in French fries, while neither approach appears very promising in potato chips.

Background:

The discovery of the neurotoxin and possible carcinogen acrylamide in fried potato products has prompted new research into methods for reducing the acrylamide concentration of such products. Acrylamide is formed by the Maillard reaction during frying, from two precursors: reducing sugars (such as fructose and glucose) and the amino acid asparagine. The acrylamide concentration in fried potato projects can potentially be minimized by reducing the concentrations of acrylamide precursors in the raw tuber.

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 influences tuber nitrogen concentration, a strong correlate of tuber asparagine concentration (R = 0.99). Tuber storage time and conditions can influence the concentrations of reducing sugars, as starch breaks down into sucrose, which breaks down into glucose and fructose, over time at low temperature.

The objectives of this study are (1) to determine whether genetics (potato cultivar) and environmental conditions of tuber growth and storage (nitrogen fertilization regime and time in cold storage) influence the concentrations of acrylamide precursors in mature tubers and acrylamide in fried potato products, and (2) to determine whether the concentrations of acrylamide precursors in raw tubers predict the concentration of acrylamide in the fried potato product. The acrylamide precursors we analyzed included the reducing sugar glucose, the disaccharide sucrose (as an indicator of potential glucose and fructose), and tuber nitrogen (as an indicator of asparagine concentration). We also evaluated the effect of nitrogen fertilization regime and potato cultivar on petiole nitrate concentration, tuber yield, vine traits (percent stand and stems per plant), and tuber quality traits (prevalence of hollow heart, brown center, and scab, plus tuber specific gravity and percent dry matter).

Materials and Methods:

This study was conducted in 2012 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, 5.6-5.9 (buffering index, 6.9-7.2); organic matter, 1.3-1.7%; Bray P1, 31-40 ppm; ammonium acetate extractable K, Ca, and Mg, 91-112, 528-566, and 102-109 ppm, respectively; Ca-phosphate extractable SO_4-S, 5 ppm; hot water extractable B, 0.2; and DTPA extractable Zn, 1.5-1.7 ppm. Extractable nitrate-N and ammonium-N in the top 2 ft of soil were 5.8-12.2 lbs/ac and 1.8-2.6 lbs/ac, respectively.

Three frying cultivars (Russet Burbank, Alpine Russet, and Dakota Trailblazer) and two chipping cultivars (Snowden and Ivory Crisp) were studied. Prior to planting, 250 lb/ac 0-0-60 and 250 lb/ac 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 April 12, 2012. Row spacing was 12 inches within each row and 36 inches between rows. 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 five nitrogen fertilizer treatments, described in Table 1, 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 randomized complete block design was used with four replicates and cultivar and amount of nitrogen fertilizer applied as main effects. At planting (April 17), fertilizer was banded 3 inches to each side and 2 inches below the seed piece, including 30 lbs N/ac, 130 lbs P_2O_5/ac, 180.6 lbs K_2O/ac, 25.7 lbs S/ac, 36 lbs Mg/ac, 0.5 lbs B/ac, and 2.3 lbs Zn/ac, applied as a blend of monoammonium phosphate, potassium chloride, potassium magnesium sulfate, ammonium sulfate, boric acid, and zinc sulfate. Emergence applications of nitrogen as ESN were applied on May 17 and mechanically incorporated during hilling. ESN was applied at a rate of 0, 90, 150, 210 or 270 lbs N/ac.

Plant stands were measured on May 30 and stem number per plant on June 6. Petiole samples were collected from the fourth leaf from the terminal on five dates: June 11, June 28, July 10, July 24, and August 9. Petioles will be analyzed for nitrate nitrogen on a dry-weight basis. The vines of the chipping cultivars were mechanically beaten on September 10 and those of the frying cultivars on September 21. The plots were machine harvested on October 2, and total tuber yield and graded yield were measured. Tuber sub-samples were collected and used to determine the incidence of hollow heart, brown center, and scab, and tuber dry matter, specific gravity, and nitrogen concentration. Additional sub-samples were collected to measure whole tuber sugar concentrations and post-frying acrylamide concentrations. Whole-tuber sucrose and glucose concentrations and fry or chip acrylamide concentrations were determined for all five cultivars for freshly-harvested tubers. For the chipping cultivars (Snowden and Ivory Crisp), chip color and Agtron score for chips made from freshly-harvested tubers were also determined. Additional measurements of sugar concentrations, acrylamide concentration, and fry test scores will be made after three, six, and nine months of storage at 45˚ F and reported at a later date.

Results:

Significance results for all ANOVAs performed on multiple cultivars are presented in Table 2. Results for ANOVAs performed on single cultivars are shown in Tables 3-29.

<u>Stand and stems per plant:</u>

Between 88.9% and 100% of tubers planted for each cultivar in each treatment produced standing vines by May 30, 48 days after planting (Tables 3-7). There was a marginally significant cultivar-by-treatment interaction ($P = 0.0694$), but stand did not vary significantly among fertilization treatments or cultivars. There was also no significant or marginally significant effect of fertilizer treatment on plant stand for any individual cultivar.

There was no significant cultivar-by-treatment interaction for the number of stems per plant, nor was there a significant effect of fertilization treatment, either for any given cultivar or for all cultivars taken together. However, there were highly significant differences among cultivars, with the average number of stems per plant varying significantly between any two cultivars. The chipping cultivars had more stems than the frying cultivars, with the order being: Snowden (4.12 stems/plant) > Ivory Crisp (3.05) > Russet Burbank (2.50) > Dakota Trailblazer (2.15) > Alpine Russet (1.94).

Tuber yield:

The cultivar-by-treatment interaction effect on yield was significant or marginally significant for all tuber size categories but three: 10- to 14-ounce tubers, total yield, and total marketable yield.

The control treatment had significantly lower total and marketable yield than the treatment receiving 120 lbs N/ac, which had significantly lower yield than any of the remaining treatments. The treatment receiving 180 lbs N/ac also had significantly lower total and marketable yield than the treatment receiving 240 lbs N/ac. Overall, yield increased asymptotically toward a maximum.

Results for tuber size categories and yields of U.S. No. 1 and 2 tubers are reported for each cultivar separately, due to the significant cultivar-by-treatment interaction effects for most of these categories.

Alpine Russet:

As the amount of nitrogen applied increased, the tuber size distribution shifted toward larger size classes (Table 8). This shift was more pronounced for Alpine Russet than for any other cultivar.

Total yield increased with increasing application of ESN, and the same general trend was evident for U.S. No. 1 tubers, total marketable yield, and the percentage of yield represented by tubers over 10 ounces. Yield of U.S. No. 2 tubers was lower for the control treatment than for any treatment receiving ESN, but there were no significant differences or trends among the ESN-fertilized treatments. The percentage of yield in tubers over 6 ounces increased with fertilizer application rate up to 180 lbs N/ac, but did not increase further at higher rates. Yields increased, overall, with increasing application of nitrogen. The differences in yield among the fertilized treatments were small compared to the difference in yield between those treatments and the control treatment.

Dakota Trailblazer:

The tuber size distribution for Dakota Trailblazer did not shift toward larger sizes with increasing application of fertilizer (Table 9). Rather, both the control treatment and the treatment receiving 240 lbs N/ac had size distributions biased toward smaller size classes, relative to the other three treatments. The treatment receiving 300 lbs N/ac also had a high yield of tubers over 14 ounces. The treatment receiving 240 lbs N/ac had lower percentages of its yield in tubers over 6 ounces or 10 ounces than the other fertilized treatments did. This difference was significant for tubers over 6 ounces, for which this treatment had a lower percentage than even the control treatment.

Total yield, yield of U.S. No. 1 tubers, and marketable yield were all substantially greater for the fertilized treatments than for the control, with relatively little variation among the fertilized treatments. The yield of U.S. No. 2 tubers was low and unrelated to fertilizer treatment. The percentages of yield in tubers over 6 ounces and 10 ounces increased between the control treatment and the treatment receiving 120 lbs N/ac, declined at 240 lbs N/ac, and increased again at 300 lbs N/ac.

Russet Burbank:

The tuber size distribution of Russet Burbank generally shifted toward larger size classes with increasing application of nitrogen, although the treatment receiving 180 lbs N/ac had significantly more tubers over 14 ounces than the treatment receiving 240 lbs N/ac (Table 10).

Total yield, yield of U.S. No. 1 tubers, and marketable yield were all much higher for ESN-fertilized treatments than for the control treatment, while yield of U.S. No. 2 tubers increased gradually with increasing application of nitrogen to a peak at 240 lbs N/ac, declining slightly at 300 lbs N/ac.

The percentages of yield represented by tubers over 6 ounces and 10 ounces increased rapidly with increasing application of fertilizer up to a rate of 180 lbs N/ac. The percentage of yield in tubers over 6 ounces decreased slightly at 240 lbs N/ac, then increased slightly at 300 lbs N/ac, while the percentage of yield in tubers over 10 ounces showed a more dramatic variation of the same pattern.

Ivory Crisp:

The tuber size distribution of Ivory Crisp shifted toward larger tubers with increasing rate of nitrogen application, with the most pronounced shifts occurring between 30 and 180 lbs N/ac (Table 11).

Because the yield of tubers under three ounces was small and the yield of U.S. No. 2 tubers was minimal for this cultivar, the results for total yield, yield of U.S. No. 1 tubers, and marketable yield are very similar. All three were much higher for ESN-fertilized treatments than for the control treatment, and all three increased steadily with increasing application of nitrogen among the ESN-fertilized treatments. Yield of U.S. No. 2 tubers was not significantly related to fertilizer application rate.

The percentages of yield represented by tubers over 6 ounces and tubers over 10 ounces both appeared to increase asymptotically toward a maximum. The percentages in both categories were slightly lower in the treatment receiving 240 lbs N/ac than expected based on the results for the other ESN-fertilized treatments, with the deviation from expectation being greater for tubers over 10 ounces. This treatment had a lower-than-expected yield of 10- to 14-ounce tubers.

Snowden:

The tuber size distribution for Snowden did not shift dramatically with increasing application of nitrogen (Table 12). Each treatment had more yield in 3- to 6-ounce tubers than in any other size class, and yield steadily decreased with increasing size class.

The yield of U.S. No. 2 tubers was at or near zero for all treatments, and yield of U.S. No. 1 tubers and marketable yield were thus nearly identical. Total yield closely paralleled total yield because the yield of tubers less than three ounces was unrelated to treatment. All of these measures of yield showed an increase of yield with increasing application of nitrogen that asymptotically approached a maximum.

The percentages of yield in tubers over 6 and 10 ounces generally increased to a peak at and application rate of 240 lbs N/ac before declining slightly at 300 lbs N/ac.

Tuber quality:

For all cultivars combined, the prevalences of hollow heart and brown center tended to increase with increasing application of nitrogen, although the difference was only significant for hollow heart. Dakota Trailblazer was significantly more prone to both flaws than any other cultivar. Ivory Crisp also had a significantly higher prevalence of hollow heart than Alpine Russet.

The control treatment had a significantly lower prevalence of scab than the treatments receiving 120 or 180 lbs N/ac, and non-significantly lower prevalence than the remaining two treatments. Alpine Russet had the lowest prevalence of scab, with a significantly lower prevalence than Ivory Crisp, Dakota Trailblazer, or Snowden.

Tuber dry matter content was significantly lower for the control treatment than for the ESN-fertilized treatments. Tuber specific gravity was also significantly lower for the control treatment than for the others, and significantly higher for the treatment receiving 240 lbs N/ac than for any other treatment. Dakota Trailblazer tubers had significantly higher dry matter content than Snowden tubers, which had significantly higher dry matter content than Ivory Crisp or Russet Burbank tubers, which had significantly higher dry matter content than Alpine Russet tubers. The results for specific gravity were similar. Dakota Trailblazer tubers had significantly higher specific gravity than Snowden tubers, which had significantly higher specific gravity than Ivory Crisp tubers, which had significantly higher specific gravity than Russet Burbank or Alpine Russet tubers.

Alpine Russet:

Hollow heart and brown center were entirely absent from Alpine Russet tubers (Table 13).

Although the control treatment had a lower incidence of scab than the fertilized treatments, the difference was not significant.

There was also no significant effect of treatment on tuber dry matter content.

Tuber specific gravity generally increased with increasing application of nitrogen, but each treatment did not necessarily produce higher tuber specific gravity than the next-lower-nitrogen treatment.

Dakota Trailblazer:

The prevalence of hollow heart was significantly greater for the treatments receiving 180 through 300 lbs N/ac than for the control treatment or the treatment receiving 120 lbs N/ac (Table 14). The prevalence of brown center closely tracked that of hollow heart, except that the treatment receiving 240 lbs N/ac did not have significantly greater prevalence than the control or the treatment receiving 120 lbs N/ac.

The treatment receiving 180 lbs N/ac had a significantly higher prevalence of scab than any other treatment.

Both tuber specific gravity and dry matter increased with increasing nitrogen application up to a peak, and then decreased beyond that peak. Specific gravity peaked in the treatment receiving 240 lbs N/ac, while dry matter peaked in the treatment receiving

180 lbs N/ac. However, the effect of treatment on specific gravity was not significant, and the effect on dry matter was only marginally significant.

Russet Burbank:

Hollow heart and brown center were both relatively uncommon in this cultivar, and the prevalences of both flaws were unrelated to nitrogen treatment (Table 15).

The treatments receiving 120 to 240 lbs N/ac had higher prevalences of scab than the control treatment or the treatment receiving 300 lbs N/ac, although the difference in prevalence between the control treatment and the treatment receiving 180 lbs N/ac was not significant.

Tuber specific gravity and dry matter both showed a marginally significant effect of treatment. Both traits responded unpredictably to increasing nitrogen application rates, but they had a slight overall tendency toward higher values at higher application rates.

Ivory Crisp:

Hollow heart and brown center were both relatively uncommon in this cultivar and did not show a response to nitrogen treatment (Table 16).

The prevalence of scab also showed no response to nitrogen treatment.

Tuber specific gravity and dry matter both tended to increase with increasing application of nitrogen to a peak, decreasing thereafter. In both cases, the control treatment had significantly lower values than any of the ESN-fertilized treatments. For specific gravity, the value for the treatment receiving 240 lbs N/ac was also significantly greater than those of the treatments receiving 120 or 300 lbs N/ac.

Snowden:

Hollow heart and brown center were rare for this cultivar, and neither showed a significant response to nitrogen treatment (Table 17).

The prevalence of scab was not significantly related to nitrogen treatment.

Tuber specific gravity and dry matter both tended to increase with increasing application of nitrogen. Specific gravity increased at a decreasing rate as the amount of nitrogen applied increased, while dry matter increased linearly, aside from nearly identical dry matter concentrations for the treatments receiving 180 and 240 lbs N/ac.

<u>Tuber sugar concentration:</u>

Nitrogen treatment and the treatment-by-cultivar interaction both had significant effects on glucose concentration, but not on sucrose concentration. The concentrations of both sugars varied significantly among the cultivars.

Tubers of Dakota Trailblazer and Alpine Russet had significantly higher mean sucrose concentrations than those of Snowden, which had a significantly higher concentration than those of Ivory Crisp. Russet Burbank tubers had a mean sucrose concentration intermediate between those of Snowden and Ivory Crisp and not significantly different from either.

Russet Burbank tubers had a significantly higher mean glucose concentration than Alpine Russet tubers, which had a higher concentration than Dakota Trailblazer tubers, which had a higher concentration than Ivory Crisp or Snowden tubers. Dakota Trailblazer and Alpine Russet tubers had a significantly higher mean sucrose concentration than the other three cultivars, and Snowden tubers had a higher concentration than Ivory Crisp tubers.

Glucose concentration tended to decline with increasing application of nitrogen. The tubers from the treatment receiving 240 lbs N/ac had a significantly lower mean concentration than those from the control treatment, and tubers from the treatment receiving 300 lbs N/ac had a significantly lower mean concentration than those from any other treatment.

Because sugars are of interest as acrylamide precursors, and because the acrylamide concentrations chipping and frying cultivars had to be considered separately, we also evaluated sugar concentrations for chipping and frying cultivars separately.

Frying cultivars (Alpine Russet, Dakota Trailblazer, and Russet Burbank), as a group, had significantly greater whole-tuber concentrations of both sucrose and glucose than chipping cultivars (Ivory Crisp and Snowden). The average sucrose concentration of the frying cultivars was only 1.3-fold as high as that of the chipping cultivars, and the two groups overlapped. In contrast, the frying cultivars had an average whole-tuber glucose concentration 3.8-fold as high as that of the chipping cultivars. Each frying cultivar had a significantly higher glucose concentration than either chipping cultivar. The two chipping cultivars had very similar glucose concentrations to each other.

There was a marginally significant effect of nitrogen treatment on sucrose concentration for the frying cultivars. For the frying cultivars, sucrose tended to decline with increasing rate of nitrogen application. There was no effect of nitrogen treatment on whole-tuber sucrose concentration for the chipping cultivars.

The frying cultivars showed a marginally significant treatment-by-cultivar interaction effect on glucose concentration. There was also a highly significant effect of treatment on glucose concentration, with glucose content declining with increasing nitrogen application rate. The chipping cultivars also showed a highly significant treatment-by-cultivar interaction effect on glucose concentration, as well as a marginally significant effect of nitrogen treatment. For the chipping cultivars, glucose concentration for the control treatment was intermediate between those for the treatments receiving 120 and 180 lbs N/ac and those for the treatments receiving 240 and 300 lbs N/ac.

Alpine Russet:

Sucrose concentration was not significantly related to fertilizer treatment for this cultivar (Table 18). In contrast, nitrogen treatment had a highly significant relationship to glucose concentration, with the control treatment and the treatment receiving 120 lbs N/ac having significantly higher glucose concentrations than the other three treatments.

Dakota Trailblazer:

Nitrogen treatment had a highly significant effect on sucrose concentration (Table 19). Tubers from the control treatment had a significantly higher mean sucrose concentration than those from the ESN-fertilized treatments, which all had similar concentrations. Glucose concentration was not significantly related to ESN treatment.

Russet Burbank:

Neither sucrose concentration nor glucose concentration was significantly influenced by nitrogen fertilization rate in this cultivar (Table 20). However, there was a tendency for glucose concentration to decline with increasing fertilization rate.

Ivory Crisp:

Tuber sucrose concentration was not significantly related to nitrogen treatment, but the effect of nitrogen treatment on glucose concentration was highly significant (Table 21). The control treatment had a significantly lower whole-tuber glucose concentration than the treatment receiving 120 lbs N/ac, but significantly higher concentration than the treatment receiving 300 lbs N/ac. Among the ESN-fertilized treatments, the whole-tuber glucose concentrations of the two highest-nitrogen treatments were significantly lower than those of the other two treatments.

Snowden:

Neither sucrose concentration nor glucose concentration was significantly related to nitrogen application rate for this cultivar (Table 22).

<u>Chip frying quality (Chipping cultivars only):</u>

For Ivory Crisp, treatment had a significant effect on subjective chip color scores and a marginally significant effect on the Agtron score (Table 23). Chip color scores for the treatments receiving 120 or 180 lbs N/ac were significantly higher than the scores for the other three treatments, and the Agtron score for the treatment receiving 180 lbs N/ac was significantly lower than that of the control.

Fertilizer treatment had no significant effect on frying quality scores for Snowden tubers (Table 24).

<u>Acrylamide concentrations of fried potato products:</u>

On average, because potato chips have a much lower moisture content than French fries, potato chips had 6.6 times the acrylamide concentration of French fries, on a fresh-weight basis. For that reason, the results for the frying cultivars and the chipping cultivars are considered separately.

1. Frying cultivars

For the frying cultivars as a group, nitrogen treatment had no significant effect on acrylamide concentration, though there was a general tendency for acrylamide concentration to increase with increasing nitrogen application.

French fries from the three cultivars differed significantly in their acrylamide concentrations. Fries made from Dakota Trailblazer tubers (Table 26) had significantly lower acrylamide concentrations than those made from Alpine Russet (Table 25) or Russet Burbank tubers (Table 27).

The effect of nitrogen treatment on acrylamide concentration did not vary significantly among the cultivars. None of the three cultivars showed a significant effect of nitrogen treatment on acrylamide concentration. However, acrylamide concentration showed a tendency to increase with increasing nitrogen application rate in both Dakota Trailblazer and Russet Burbank.

2. Chipping cultivars

Nitrogen treatment had a highly significant effect on potato chip acrylamide concentrations. The control treatment had a significantly lower acrylamide concentration than any treatment except the one receiving 240 lbs N/ac (which had a non-significantly higher acrylamide concentration than the control). This treatment, in turn, had a significantly lower acrylamide concentration than the one receiving 180 lbs N/ac. There was an overall tendency for acrylamide concentration to increase with increasing nitrogen application rate up to a rate of 180 lbs N/ac, after which it declined.

There was no significant difference in potato chip acrylamide concentration between the two chipping cultivars, but there was a marginally significant difference between the cultivars in how acrylamide concentration responded to nitrogen treatment.

For Ivory Crisp (Table 28), acrylamide concentration was significantly related to nitrogen treatment. The treatment receiving 180 lbs N/ac had a significantly higher acrylamide concentration than any other treatment, and the treatment receiving 120 lbs N/ac had a significantly higher concentration than the control treatment.

In contrast, for Snowden (Table 29), nitrogen treatment did not significantly influence acrylamide concentration. However, there was a tendency for acrylamide concentration to increase with increasing application of nitrogen, except for a dip at 240 lbs N/ac.

<u>Acrylamide concentration sugar concentrations and potato chip quality metrics:</u>

Results of regressions of the acrylamide concentrations of fried potato products against whole-tuber sugar concentrations and potato chip quality metrics are shown in Table 30.

For the frying cultivars as a whole, the acrylamide concentration of French fries was significantly negatively related to the sucrose concentrations of whole tubers. It was also significantly positively related to whole-tuber concentration of glucose. However, results for the individual cultivars were not consistent with each other. The acrylamide concentration of Alpine Russet fries decreased marginally significantly with increasing whole-tuber sucrose concentration, but it was not related to sucrose concentration in the other two cultivars. Similarly, the acrylamide concentration of Russet Burbank fries was marginally significantly negatively related to whole-tuber glucose concentration, but the relationship was not significant for the other two cultivars.

For the chipping cultivars as a group, the acrylamide concentration of potato chips was not significantly related to whole-tuber sucrose concentration. However, it did increase significantly with increasing whole-tuber glucose concentration, as was observed for the frying cultivars as a group. The positive relationship between acrylamide concentration and glucose concentration was marginally significant for potato chips made from Ivory Crisp tubers, but not for chips made from Snowden tubers.

For the two chipping cultivars as a group, potato chip acrylamide concentrations were positively correlated with chip color scores and strongly negatively correlated with AGT scores. These correlations were even stronger (based on R^2) for Ivory Crisp analyzed separately. For Snowden, the correlation of acrylamide concentration with chip color was only marginally significant, but the correlation with AGT was significant.

Growers' potatoes:

Alpine Russet and Russet Burbank tubers grown at K&O (Table 31) had somewhat higher sucrose concentrations, but far lower glucose concentrations, than tubers of the same cultivars grown at the Sand Plain Research Farm. The acrylamide concentrations of fries made from these tubers were similar to those found in the higher-nitrogen treatments for these cultivars in our study.

Snowden tubers grown at Goenner had similar sucrose concentrations to those grown at our study site, but much lower glucose concentrations. Chips made from these tubers also had much lower acrylamide concentrations than Snowden chips from any of the nitrogen treatments in our study.

Conclusions:

Percent stand was high for all treatment-cultivar combinations in this year, and was thus not significantly related to either cultivar or treatment. The same result was obtained in 2011. The number of stems per plant was also unrelated to nitrogen treatment, but it did vary significantly among cultivars. The ranking of the cultivars by stems per plant was slightly different than in 2011, and each cultivar produced fewer stems per plant in 2012 than in 2011.

For all cultivars taken together, total and marketable yield both increased with increasing application of ESN, but with diminishing returns. Tuber size distributions shifted toward larger size classes in treatments receiving more nitrogen, with Alpine Russet having a more conspicuous shift than Russet Burbank or Ivory Crisp, which had more conspicuous shifts than Snowden or Dakota Trailblazer. Tuber dry matter content and specific gravity also tended to increase with nitrogen application, up to a rate of 240 lbs N/ac. However, the prevalence of hollow heart also increased at higher application rates, probably due to the higher susceptibility of large tubers to this flaw. Similar results were found in 2011.

Whole-tuber sucrose concentration varied significantly among cultivars. However, for all cultivars as a group, it was not significantly affected by nitrogen treatment. The only individual cultivar for which sucrose concentration varied significantly among treatments was Dakota Trailblazer. In that case, tubers from the control treatment had a significantly higher mean sucrose concentration than those from any ESN-fertilized treatment. The results for whole-tuber sucrose concentration in freshly-harvest tubers in 2011 were similar, except that Snowden was the one cultivar to show a significant effect of nitrogen treatment on sucrose concentration in that year. The rankings of the cultivars by whole-tuber sucrose content were quite similar between the two years.

Whole-tuber glucose concentration was significantly affected by treatment, cultivar, and their interaction. Glucose concentration declined with increasing application of nitrogen for all cultivars taken together. All of the frying cultivars, taken individually, showed the same trend, though it was only significant for Alpine Russet. The trend was also apparent among the ESN-fertilized treatments of Ivory Crisp. The general decline in whole-tuber glucose concentration with increasing rate of nitrogen application was also seen in 2011, though the trend was significant in more individual cultivars in that year. The rankings of the cultivars by whole-tuber glucose concentration were identical between the two seasons.

Frying tests of the two chipping cultivars yielded different results. Snowden chips showed no response to nitrogen treatment, while Ivory Crisp chips were darker for treatments receiving intermediate amounts of nitrogen than for the control treatment or the two highest-nitrogen treatments. The chip color results for Ivory Crisp roughly paralleled the results for whole-tuber sucrose concentration, which may indicate that sucrose availability, or some close correlate, limited the Maillard reaction for this cultivar. It is impossible to know whether this was the case. No similar parallel between sucrose concentration and chip color was observed in 2011.

For the frying cultivars, the acrylamide concentration of French fries was much more strongly influenced by the cultivar used than by the amount of nitrogen applied as ESN during the growing season. There was some tendency toward increasing acrylamide concentration with increasing nitrogen application rate for Dakota Trailblazer and Russet Burbank, but the linear contrast result was not significant for Dakota Trailblazer, and only marginally significant for Russet Burbank. Cultivar selection and selective breeding show much more promise than nitrogen management for limiting acrylamide concentrations in French fries, based on this year's results to date.

For the chipping cultivars, the acrylamide concentration of potato chips was more strongly influenced by nitrogen treatment than by the cultivar used. For the two cultivars as a group, acrylamide concentration increased with nitrogen application rate up to a rate of 180 lbs N/ac, then declined at 240 lbs N/ac, rebounding somewhat at 300 lbs N/ac. However, there was a marginally significant difference between the two cultivars in how acrylamide concentration responded to nitrogen treatment. Ivory Crisp had its highest acrylamide concentration in the treatment receiving 180 lbs N/ac, with acrylamide concentration declining at higher and lower nitrogen application rates. In contrast, in Snowden, acrylamide concentration showed a weak tendency to increase with increasing nitrogen application rate, resulting in a non-significant effect of treatment in the ANOVA, but a significant result for the linear contrast. Overall, neither cultivar selection and selective breeding nor nitrogen management appear promising for regulating acrylamide concentration in the chipping cultivars, based on these results.

Acrylamide concentrations were higher in 2012 than they were in 2011. The acrylamide concentrations of French fries made from freshly-harvested tubers showed a similar tendency to increase with increasing application of nitrogen in that year, with the trend being driven by the results for Russet Burbank. Frying cultivars also showed a significant effect of cultivar on the acrylamide concentrations of French fries in 2011. As in 2012, Dakota Trailblazer tubers produced significantly lower acrylamide concentration than those of the other two cultivars. In addition, Alpine Russet tubers yielded lower acrylamide concentrations than Russet Burbank tubers in that year. For the chipping cultivars, the acrylamide concentrations of potato chips were not significantly related to treatment or cultivar, and the two cultivars did not respond significantly differently to treatment, in 2011. Thus, for both years, cultivar selection and selective breeding show promise for reducing acrylamide concentration in frying cultivars, but not in chipping cultivars, based on our results. Nitrogen management showed some potential to limit acrylamide formation in frying cultivars in both years, but at a cost to yield (because acrylamide concentration had a weak tendency to increase with nitrogen application in both years), and possibly only for Russet Burbank. Nitrogen management showed even less potential to limit acrylamide formation in the chipping cultivars in both years, and cultivar selection and selective breeding seem similarly unpromising.

Both the frying cultivars and the chipping cultivars, as groups, showed significant positive correlations between whole-tuber glucose concentrations and the acrylamide concentrations of fried potato products. There was also a positive relationship between whole-tuber sucrose concentration and the acrylamide concentration of French fries for the frying cultivars. Results for individual cultivars did not generally show the same relationships. These results do not strongly support the hypothesis that acrylamide formation is limited by the availability of reducing sugars for the cultivars and growing conditions used in this study. Acrylamide concentration showed a similarly weak and inconsistent response to the concentrations of acrylamide precursors in 2011. However, significant positive correlations between the acrylamide concentrations of fried products and the glucose concentrations of whole tubers were detected at multiple sampling times in storage for both fries and chips in that year, consistent with the relationship seen for freshly-harvested tubers this year.

Other growers' tubers had similar or slightly higher sucrose concentrations, but much lower glucose concentrations, than tubers of the same cultivars from our study. Fries made from Alpine Russet and Russet Burbank tubers grown at K&O had similar acrylamide concentrations to fries made from high-nitrogen treatments of those cultivars in our study. Potato chips made from Snowden tubers grown at Goenner had much lower acrylamide concentrations than ours. Therefore, while we would provisionally assume that any statistically strong effects of nitrogen treatment or cultivar found in our study site would apply to other sites, the absolute concentrations of sugars in whole tubers and acrylamide in fried products evidently vary from site to site.

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

Treatment #	----------------------- Nitrogen timing -----------------------		
	Planting	Emergence/Hilling	Total N
	--------- Nitrogen rates (lbs N/ac) and sources[1] ---------		
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).

Table 2: Significance results of ANOVAs for each dependent variable as a function of nitrogen treatment, potato variety, their interaction, and replicate[1].

Dependent Variable	All varieties			Chipping varieties only			Frying varieties only		
	Treatment	Variety	Trt * Var	Treatment	Variety	Trt * Var	Treatment	Variety	Trt * Var
Plant % stand	NS	NS	++						
Stems/plant	NS	**	NS						
Yield, 0-3 oz	**	**	*						
Yield, 3-6 oz	**	**	**						
Yield, 6-10 oz	**	**	++						
Yield, 10-14 oz	**	**	NS						
Yield, > 14 oz	**	**	**						
Yield, Total	**	*	NS						
Yield, #1s	**	**	*						
Yield, #2s	**	**	**						
Yield, Marketable	**	NS	NS						
Yield, % > 6 oz	**	**	**						
Yield, % > 10 oz	**	**	**						
Hollow heart	**	**	**						
Brown center	NS	**	*						
Scab	*	*	NS						
Specific gravity	**	**	NS						
Dry matter	**	**	++						
AGT score, harvest				*	++	NS			
Chip color, harvest				**	NS	*			
Glucose, harvest	**	**	*	++	NS	**	**	**	++
Sucrose, harvest	NS	**	NS	NS	**	NS	++	**	NS
Acrylamide, harvest	*	**	**	**	NS	++	NS	**	NS

NS: not significant. ++: $0.05 \le P < 0.10$. *: $0.01 \le P < 0.05$. **: $P < 0.01$. Blank cell: Not anaylyzed. (Agtron score and chip color were only determined for chipping varieties.

Table 3. Effect of nitrogen rate from ESN fertilizer on above-ground traits of Alpine Russet potato plants.

Nitrogen Treatments				Stand (%)	Stems per plant
Treatment #	Nitrogen Source[1]	Nitrogen Rate	Nitrogen Timing[2]		
		lb N/ac	P, E		
1	MAP + AMS	30	30, 0	98.6	2.0
2	MAP + AMS, ESN	120	30, 90	100.0	1.9
3	MAP + AMS, ESN	180	30, 150	100.0	1.8
4	MAP + AMS, ESN	240	30, 210	98.6	1.8
5	MAP + AMS, ESN	300	30, 270	96.5	2.3
			Significance[3]	NS	NS
			LSD (0.10)	--	--
			Linear contrast	NS	NS
			Quadratic contrast	NS	NS

[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 above-ground traits of Dakota Trailblazer potato plants.

Nitrogen Treatments				Stand (%)	Stems per plant
Treatment #	Nitrogen Source[1]	Nitrogen Rate	Nitrogen Timing[2]		
		lb N/ac	P, E		
1	MAP + AMS	30	30, 0	97.9	2.1
2	MAP + AMS, ESN	120	30, 90	100.0	2.3
3	MAP + AMS, ESN	180	30, 150	99.3	2.2
4	MAP + AMS, ESN	240	30, 210	99.3	2.1
5	MAP + AMS, ESN	300	30, 270	98.6	2.1
			Significance[3]	NS	NS
			LSD (0.10)	--	--
			Linear contrast	NS	NS
			Quadratic contrast	NS	NS

[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 above-ground traits of Russet Burbank potato plants.

Nitrogen Treatments				Stand (%)	Stems per plant
Treatment #	Nitrogen Source[1]	Nitrogen Rate	Nitrogen Timing[2]		
		lb N/ac	P, E		
1	MAP + AMS	30	30, 0	100.0	2.5
2	MAP + AMS, ESN	120	30, 90	99.3	2.5
3	MAP + AMS, ESN	180	30, 150	88.9	2.4
4	MAP + AMS, ESN	240	30, 210	100.0	2.6
5	MAP + AMS, ESN	300	30, 270	100.0	2.5
			Significance[3]	NS	NS
			LSD (0.10)	--	--
			Linear contrast	++	NS
			Quadratic contrast	NS	NS

[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 above-ground traits of Ivory Crisp potato plants.

Nitrogen Treatments				Stand (%)	Stems per plant
Treatment #	Nitrogen Source[1]	Nitrogen Rate	Nitrogen Timing[2]		
		lb N/ac	P, E		
1	MAP + AMS	30	30, 0	95.8	3.4
2	MAP + AMS, ESN	120	30, 90	99.3	3.0
3	MAP + AMS, ESN	180	30, 150	97.2	3.1
4	MAP + AMS, ESN	240	30, 210	98.6	2.8
5	MAP + AMS, ESN	300	30, 270	97.9	2.8
			Significance[3]	NS	NS
			LSD (0.10)	--	--
			Linear contrast	NS	NS
			Quadratic contrast	++	*

[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 above-ground traits of Snowden potato plants.

Nitrogen Treatments				Stand (%)	Stems per plant
Treatment #	Nitrogen Source[1]	Nitrogen Rate	Nitrogen Timing[2]		
		lb N/ac	P, E		
1	MAP + AMS	30	30, 0	100.0	3.8
2	MAP + AMS, ESN	120	30, 90	100.0	4.1
3	MAP + AMS, ESN	180	30, 150	100.0	4.1
4	MAP + AMS, ESN	240	30, 210	100.0	4.4
5	MAP + AMS, ESN	300	30, 270	100.0	4.2
			Significance[3]	--	NS
			LSD (0.10)	--	--
			Linear contrast	--	NS
			Quadratic contrast	--	NS

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

Nitrogen Treatments				Tuber Yield										
Treatment #	Nitrogen Source[1]	Nitrogen Rate	Nitrogen 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/ac	P, E	cwt / A						cwt / A			%	
1	MAP + AMS	30	30, 0	43.2 a	126.6 a	103.6 b	53.3 c	11.7 d	338.4 d	92.0 c	203.3 b	295.2 d	49.7 c	19.2 c
2	MAP + AMS, ESN	120	30, 90	25.4 b	112.2 a	158.2 a	153.7 b	112.1 c	561.6 c	215.3 b	320.9 a	536.2 c	75.5 b	47.3 b
3	MAP + AMS, ESN	180	30, 150	20.4 b	66.6 b	159.1 a	182.5 a	156.5 b	585.0 bc	251.6 ab	313.1 a	564.7 bc	85.1 a	57.8 a
4	MAP + AMS, ESN	240	30, 210	15.3 b	73.5 b	153.3 a	179.5 ab	190.5 ab	612.1 ab	295.8 a	301.0 a	596.8 ab	85.5 a	60.4 a
5	MAP + AMS, ESN	300	30, 270	24.8 b	82.6 b	141.5 a	187.6 a	202.7 a	639.2 a	291.9 a	322.6 a	614.4 a	82.9 a	60.6 a
			Significance[3]	**	**	*	**	**	**	**	*	**	**	**
			LSD (0.10)	11.1	25.9	32.9	26.5	41.1	33.9	61.5	58.0	38.7	4.7	7.9
			Linear contrast	**	**	*	**	**	**	**	*	**	**	**
			Quadratic contrast	*	NS	NS	**	**	**	**	*	**	**	**

[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, 2012.

Nitrogen Treatments				Tuber Yield										
Treatment #	Nitrogen Source[1]	Nitrogen Rate	Nitrogen 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						cwt / A			%	
1	MAP + AMS	30	30, 0	17.2	110.2 b	157.6 c	37.2 b	16.1 b	338.3 c	319.2 c	1.9	321.1 b	61.8 b	15.6 b
2	MAP + AMS, ESN	120	30, 90	7.8	119.6 b	218.4 ab	143.8 a	42.9 b	532.5 b	504.5 b	20.2	524.7 a	76.1 a	34.9 a
3	MAP + AMS, ESN	180	30, 150	11.3	107.4 b	245.2 a	145.9 a	42.7 b	552.5 ab	540.3 a	0.9	541.2 a	78.4 a	34.0 a
4	MAP + AMS, ESN	240	30, 210	17.2	200.3 a	184.4 bc	143.2 a	25.5 b	570.6 a	550.0 a	3.5	553.4 a	61.6 b	29.4 a
5	MAP + AMS, ESN	300	30, 270	15.0	112.1 b	208.3 abc	133.7 a	92.1 a	561.1 ab	545.3 a	0.9	546.1 a	77.1 a	40.1 a
			Significance[3]	NS	*	++	**	**	**	**	NS	**	*	*
			LSD (0.10)	--	58.9	55.4	46.3	31.8	29.8	34.0	--	31.6	11.1	13.1
			Linear contrast	NS	NS	*	**	NS	**	**	NS	**	NS	++
			Quadratic contrast	NS	++	NS	*	*	**	**	NS	**	NS	*

[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 Russet Burbank tuber yield and size distribution, 2012.

Nitrogen Treatments				Tuber Yield										
Treatment #	Nitrogen Source[1]	Nitrogen Rate	Nitrogen 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						cwt / A			%	
1	MAP + AMS	30	30, 0	97.8 a	199.8	69.8 c	15.0 c	1.0 c	383.4 c	101.9 c	183.6	285.6 c	21.8 c	3.9 c
2	MAP + AMS, ESN	120	30, 90	68.0 ab	239.2	131.8 b	72.6 b	21.4 bc	533.0 b	221.5 b	243.5	465.0 b	41.9 b	17.1 b
3	MAP + AMS, ESN	180	30, 150	47.5 b	169.1	149.7 b	105.5 ab	81.9 a	553.7 ab	221.3 b	284.9	506.2 ab	61.7 a	35.1 a
4	MAP + AMS, ESN	240	30, 210	62.2 b	191.1	212.6 a	110.0 ab	42.5 b	618.3 ab	260.2 ab	295.9	556.1 ab	59.0 a	24.6 ab
5	MAP + AMS, ESN	300	30, 270	57.8 b	182.1	176.1 ab	131.5 a	86.1 a	633.6 a	298.7 a	277.1	575.8 a	61.6 a	33.8 a
Significance[3]				*	NS	**	**	**	**	**	NS	**	**	**
LSD (0.10)				30.1	--	47.9	46.5	34.4	97.0	40.2	--	91.8	14.1	12.3
Linear contrast				**	NS	**	**	**	**	**	*	**	**	**
Quadratic contrast				NS	NS	**	**	NS	**	**	NS	**	**	++

[1]ESN (Environmentally Smart Nitrogen, Agrium, Inc.) = 44-0-0; MAP (monoammonium phosphate) = 11-50-0; AMS (ammonium sulfate) = 21-0-0-22

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

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

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, 2012.

Nitrogen Treatments				Tuber Yield										
Treatment #	Nitrogen Source[1]	Nitrogen Rate	Nitrogen 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						cwt / A			%	
1	MAP + AMS	30	30, 0	47.9 a	170.6	108.9 b	24.4 c	1.7 c	353.4 d	305.5 d	0.0	305.5 c	38.6 b	7.6 c
2	MAP + AMS, ESN	120	30, 90	31.8 b	175.2	187.9 a	102.5 b	36.0 b	533.4 c	499.4 c	2.3	501.6 b	59.3 a	24.6 b
3	MAP + AMS, ESN	180	30, 150	33.5 b	153.5	191.6 a	142.6 ab	36.0 b	557.2 bc	522.9 bc	0.8	523.7 b	66.5 a	31.6 ab
4	MAP + AMS, ESN	240	30, 210	37.0 b	169.0	237.2 a	124.6 ab	47.1 b	614.9 ab	576.4 ab	1.4	577.8 ab	66.4 a	27.6 ab
5	MAP + AMS, ESN	300	30, 270	39.9 ab	155.3	229.7 a	154.4 a	75.6 a	654.9 a	615.0 a	0.0	615.0 a	70.2 a	35.1 a
Significance[3]				*	NS	*	**	**	**	**	NS	**	**	**
LSD (0.10)				8.5	--	63.7	48.0	22.3	72.3	76.2	--	76.3	11.1	8.9
Linear contrast				*	NS	*	**	*	**	**	NS	**	**	**
Quadratic contrast				NS	NS	**	*	**	**	**	NS	**	**	**

[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 Snowden tuber yield and size distribution, 2012.

Nitrogen Treatments				Tuber Yield										
Treatment #	Nitrogen Source[1]	Nitrogen Rate	Nitrogen 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/ac	P, E	cwt / A						cwt / A			%	
1	MAP + AMS	30	30, 0	73.0	188.0 b	85.3 c	12.0 b	1.0	359.2 d	286.2 d	0.0 b	286.2 d	26.9 c	3.6 b
2	MAP + AMS, ESN	120	30, 90	79.1	290.7 a	152.3 b	15.4 b	0.7	538.1 c	459.0 c	0.0 b	459.0 c	31.0 bc	3.0 b
3	MAP + AMS, ESN	180	30, 150	72.8	278.8 a	179.1 ab	52.1 ab	2.2	585.0 b	511.5 b	0.7 a	512.2 b	39.9 ab	9.3 ab
4	MAP + AMS, ESN	240	30, 210	61.7	298.3 a	213.5 a	87.2 a	8.0	668.7 a	607.0 a	0.0 b	607.0 a	46.2 a	14.2 a
5	MAP + AMS, ESN	300	30, 270	79.4	318.3 a	219.7 a	54.5 ab	6.9	678.8 a	599.4 a	0.0 b	599.4 a	41.4 ab	9.1 ab
Significance[3]				NS	**	**	*	NS	**	**	++	**	*	++
LSD (0.10)				--	39.8	46.2	48.3	--	31.1	50.0	0.5	49.9	10.5	8.1
Linear contrast				NS	**	**	*	NS	**	**	*	**	**	*
Quadratic contrast				NS	**	**	NS	NS	**	**	++	**	*	NS

[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 tuber quality.

Nitrogen Treatments				Hollow Heart (%)	Brown Center (%)	Scab (%)	Specific Gravity	Tuber Dry Matter (%)
Treatment #	Nitrogen Source[1]	Nitrogen Rate	Nitrogen Timing[2]					
		lb N/ac	P, E					
1	MAP + AMS	30	30, 0	0.0	0.0	1.0	1.0681 c	20.3
2	MAP + AMS, ESN	120	30, 90	0.0	0.0	11.0	1.0733 ab	20.8
3	MAP + AMS, ESN	180	30, 150	0.0	0.0	7.0	1.0715 bc	19.7
4	MAP + AMS, ESN	240	30, 210	0.0	0.0	6.9	1.0767 a	20.8
5	MAP + AMS, ESN	300	30, 270	0.0	0.0	7.3	1.0743 ab	20.5
			Significance[3]	--	--	NS	*	NS
			LSD (0.10)	NA	NA	--	0.0039	--
			Linear contrast	--	--	NS	**	NS
			Quadratic contrast	--	--	NS	NS	NS

[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 tuber quality.

Nitrogen Treatments				Hollow Heart (%)	Brown Center (%)	Scab (%)	Specific Gravity	Tuber Dry Matter (%)
Treatment #	Nitrogen Source[1]	Nitrogen Rate	Nitrogen Timing[2]					
		lb N/ac	P, E					
1	MAP + AMS	30	30, 0	4.0 b	6.0 b	13.0 b	1.0974	25.9 b
2	MAP + AMS, ESN	120	30, 90	7.0 b	7.0 b	14.3 b	1.1015	28.0 ab
3	MAP + AMS, ESN	180	30, 150	19.8 a	20.8 a	25.0 a	1.1048	30.0 a
4	MAP + AMS, ESN	240	30, 210	21.0 a	16.0 ab	9.0 b	1.1143	28.7 ab
5	MAP + AMS, ESN	300	30, 270	27.0 a	28.0 a	10.0 b	1.1064	27.2 ab
			Significance[3]	**	*	++	NS	++
			LSD (0.10)	9.8	12.0	10.5	--	2.9
			Linear contrast	**	**	NS	*	NS
			Quadratic contrast	NS	NS	++	NS	*

[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 Russet Burbank tuber quality.

Nitrogen Treatments				Hollow Heart (%)	Brown Center (%)	Scab (%)	Specific Gravity	Tuber Dry Matter (%)
Treatment #	Nitrogen Source[1]	Nitrogen Rate	Nitrogen Timing[2]					
		lb N/ac	P, E					
1	MAP + AMS	30	30, 0	1.0	2.0	4.8 bc	1.0718 b	20.6 b
2	MAP + AMS, ESN	120	30, 90	0.0	0.0	18.7 a	1.0740 ab	22.2 ab
3	MAP + AMS, ESN	180	30, 150	0.9	0.9	12.3 ab	1.0704 b	21.0 ab
4	MAP + AMS, ESN	240	30, 210	3.1	3.1	16.3 a	1.0793 a	23.2 a
5	MAP + AMS, ESN	300	30, 270	0.0	3.0	3.7 c	1.0774 ab	21.5 ab
			Significance[3]	NS	NS	**	++	++
			LSD (0.10)	--	--	7.5	0.0071	2.0
			Linear contrast	NS	NS	N	++	NS
			Quadratic contrast	NS	NS	**	NS	NS

[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 tuber quality.

Nitrogen Treatments				Hollow Heart (%)	Brown Center (%)	Scab (%)	Specific Gravity	Tuber Dry Matter (%)
Treatment #	Nitrogen Source[1]	Nitrogen Rate	Nitrogen Timing[2]					
		lb N/ac	P, E					
1	MAP + AMS	30	30, 0	0.0	0.0	11.0	1.0741 c	20.1 b
2	MAP + AMS, ESN	120	30, 90	4.2	4.2	18.1	1.0852 b	22.4 a
3	MAP + AMS, ESN	180	30, 150	2.0	3.0	11.2	1.0874 ab	22.7 a
4	MAP + AMS, ESN	240	30, 210	4.2	4.2	13.9	1.0891 a	22.3 a
5	MAP + AMS, ESN	300	30, 270	2.9	2.9	20.0	1.0857 b	22.0 a
			Significance[3]	NS	NS	NS	**	**
			LSD (0.10)	--	--	--	0.0034	1.1
			Linear contrast	NS	NS	NS	**	**
			Quadratic contrast	NS	++	NS	**	**

[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 17. Effect of nitrogen rate from ESN fertilizer on Snowden tuber quality.

Nitrogen Treatments				Hollow Heart (%)	Brown Center (%)	Scab (%)	Specific Gravity	Tuber Dry Matter (%)
Treatment #	Nitrogen Source[1]	Nitrogen Rate	Nitrogen Timing[2]					
		lb N/ac	P, E					
1	MAP + AMS	30	30, 0	0.0	8.0	9.0	1.0834 b	22.0 c
2	MAP + AMS, ESN	120	30, 90	0.0	0.0	18.1	1.0875 a	23.0 bc
3	MAP + AMS, ESN	180	30, 150	0.0	0.0	14.4	1.0883 a	23.6 b
4	MAP + AMS, ESN	240	30, 210	1.0	2.0	9.0	1.0897 a	23.6 b
5	MAP + AMS, ESN	300	30, 270	1.0	2.0	16.0	1.0899 a	26.3 a
			Significance[3]	NS	NS	NS	*	**
			LSD (0.10)	--	--	--	0.0033	1.5
			Linear contrast	NS	NS	NS	**	**
			Quadratic contrast	NS	++	NS	NS	NS

[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 18. Effect of nitrogen rate from ESN fertilizer on whole-tuber sugar concentrations of Alpine Russet.

Nitrogen Treatments				Sugar Concentration (mg/g)	
Treatment #	Nitrogen Source[1]	Nitrogen Rate	Nitrogen Timing[2]	0 Months	
		lb N/ac	P, E	Sucrose	Glucose
1	MAP + AMS	30	30, 0	1.78	3.80 a
2	MAP + AMS, ESN	120	30, 90	1.77	3.34 a
3	MAP + AMS, ESN	180	30, 150	1.62	2.35 b
4	MAP + AMS, ESN	240	30, 210	1.37	2.30 b
5	MAP + AMS, ESN	300	30, 270	1.58	1.70 b
			Significance[3]	NS	**
			LSD (0.10)	--	0.86
			Linear contrast	NS	**
			Quadratic contrast	NS	NS

[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 19. Effect of nitrogen rate from ESN fertilizer on whole-tuber sugar concentrations of Dakota Trailblazer.

Nitrogen Treatments				Sugar Concentration (mg/g)	
Treatment #	Nitrogen Source[1]	Nitrogen Rate	Nitrogen Timing[2]	0 Months	
		lb N/ac	P, E	Sucrose	Glucose
1	MAP + AMS	30	30, 0	2.32 a	1.24
2	MAP + AMS, ESN	120	30, 90	1.48 b	1.19
3	MAP + AMS, ESN	180	30, 150	1.59 b	1.18
4	MAP + AMS, ESN	240	30, 210	1.57 b	1.16
5	MAP + AMS, ESN	300	30, 270	1.59 b	0.96
			Significance[3]	**	NS
			LSD (0.10)	0.34	--
			Linear contrast	**	NS
			Quadratic contrast	**	NS

[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 20. Effect of nitrogen rate from ESN fertilizer on whole-tuber sugar concentrations of Russet Burbank.

Nitrogen Treatments				Sugar Concentration (mg/g)	
Treatment #	Nitrogen Source[1]	Nitrogen Rate	Nitrogen Timing[2]	0 Months	
		lb N/ac	P, E	Sucrose	Glucose
1	MAP + AMS	30	30, 0	1.51	3.60
2	MAP + AMS, ESN	120	30, 90	1.02	3.35
3	MAP + AMS, ESN	180	30, 150	0.87	3.82
4	MAP + AMS, ESN	240	30, 210	1.10	3.09
5	MAP + AMS, ESN	300	30, 270	1.06	2.50
			Significance[3]	NS	NS
			LSD (0.10)	--	--
			Linear contrast	NS	++
			Quadratic contrast	NS	NS

[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 21. Effect of nitrogen rate from ESN fertilizer on whole-tuber sugar concentrations of Ivory Crisp.

Nitrogen Treatments				Sugar Concentration (mg/g)	
Treatment #	Nitrogen Source[1]	Nitrogen Rate	Nitrogen Timing[2]	0 Months	
		lb N/ac	P, E	Sucrose	Glucose
1	MAP + AMS	30	30, 0	0.77	0.62 bc
2	MAP + AMS, ESN	120	30, 90	1.05	0.94 a
3	MAP + AMS, ESN	180	30, 150	1.13	0.80 ab
4	MAP + AMS, ESN	240	30, 210	0.99	0.40 cd
5	MAP + AMS, ESN	300	30, 270	1.08	0.36 d
			Significance[3]	NS	**
			LSD (0.10)	--	0.23
			Linear contrast	NS	**
			Quadratic contrast	NS	**

[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 22. Effect of nitrogen rate from ESN fertilizer on whole-tuber sugarconcentrations of Snowden.

Nitrogen Treatments				Sugar Concentration (mg/g)	
Treatment #	Nitrogen Source[1]	Nitrogen Rate	Nitrogen Timing[2]	0 Months	
		lb N/ac	P, E	Sucrose	Glucose
1	MAP + AMS	30	30, 0	1.31	0.60
2	MAP + AMS, ESN	120	30, 90	1.17	0.52
3	MAP + AMS, ESN	180	30, 150	1.25	0.66
4	MAP + AMS, ESN	240	30, 210	1.34	0.60
5	MAP + AMS, ESN	300	30, 270	1.26	0.67
			Significance[3]	NS	NS
			LSD (0.10)	--	--
			Linear contrast	NS	NS
			Quadratic contrast	NS	NS

[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 23. Effect of nitrogen rate from ESN fertilizer on tuber frying quality of Ivory Crisp potato tubers.

Nitrogen Treatments				Frying Quality	
Treatment #	Nitrogen Source[1]	Nitrogen Rate	Nitrogen Timing[2]	0 Months	
		lb N/ac	P, E	Chip Color[4]	AGT Score
1	MAP + AMS	30	30, 0	2.0 b	57.7 a
2	MAP + AMS, ESN	120	30, 90	2.8 a	54.0 b
3	MAP + AMS, ESN	180	30, 150	3.0 a	53.3 b
4	MAP + AMS, ESN	240	30, 210	2.0 b	56.3 ab
5	MAP + AMS, ESN	300	30, 270	2.3 b	55.8 ab
			Significance[3]	**	++
			LSD (0.10)	0.5	3.1
			Linear contrast	NS	NS
			Quadratic contrast	**	*

[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%.

[4]Chip Color Score: 1 = light and 5 = dark.

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

Table 24. Effect of nitrogen rate from ESN fertilizer on tuber frying quality of Snowden potato tubers.

Nitrogen Treatments				Frying Quality	
Treatment #	Nitrogen Source[1]	Nitrogen Rate	Nitrogen Timing[2]	0 Months	
		lb N/ac	P, E	Chip Color[4]	AGT Score
1	MAP + AMS	30	30, 0	2.5	54.5
2	MAP + AMS, ESN	120	30, 90	3.0	52.5
3	MAP + AMS, ESN	180	30, 150	2.3	54.5
4	MAP + AMS, ESN	240	30, 210	2.3	55.3
5	MAP + AMS, ESN	300	30, 270	2.5	54.5
			Significance[3]	NS	NS
			LSD (0.10)	--	--
			Linear contrast	NS	NS
			Quadratic contrast	NS	NS

[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%.

[4]Chip Color Score: 1 = light and 5 = dark.

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

Table 25. Effect of nitrogen rate from ESN fertilizer on acrylamide concentration of Alpine Russet French fries.

Nitrogen Treatments				Acrylamide Concentration (ppb, fresh-weight basis)
Treatment #	Nitrogen Source[1]	Nitrogen Rate	Nitrogen Timing[2]	
		lb N/ac	P, E	
1	MAP + AMS	30	30, 0	943
2	MAP + AMS, ESN	120	30, 90	915
3	MAP + AMS, ESN	180	30, 150	1205
4	MAP + AMS, ESN	240	30, 210	1151
5	MAP + AMS, ESN	300	30, 270	880
			Significance[3]	NS
			LSD (0.10)	--
			Linear contrast	NS
			Quadratic contrast	NS

[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 26. Effect of nitrogen rate from ESN fertilizer on acrylamide concentration of Dakota Trailblazer French fries.

Nitrogen Treatments				Acrylamide Concentration (ppb, fresh-weight basis)
Treatment #	Nitrogen Source[1]	Nitrogen Rate	Nitrogen Timing[2]	
		lb N/ac	P, E	
1	MAP + AMS	30	30, 0	369
2	MAP + AMS, ESN	120	30, 90	469
3	MAP + AMS, ESN	180	30, 150	429
4	MAP + AMS, ESN	240	30, 210	554
5	MAP + AMS, ESN	300	30, 270	571
			Significance[3]	NS
			LSD (0.10)	--
			Linear contrast	NS
			Quadratic contrast	NS

[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 27. Effect of nitrogen rate from ESN fertilizer on acrylamide concentration of Russet Burbank French fries.

Nitrogen Treatments				Acrylamide Concentration (ppb, fresh-weight basis)
Treatment #	Nitrogen Source[1]	Nitrogen Rate	Nitrogen Timing[2]	
		lb N/ac	P, E	
1	MAP + AMS	30	30, 0	916
2	MAP + AMS, ESN	120	30, 90	1158
3	MAP + AMS, ESN	180	30, 150	980
4	MAP + AMS, ESN	240	30, 210	1217
5	MAP + AMS, ESN	300	30, 270	1331
			Significance[3]	NS
			LSD (0.10)	--
			Linear contrast	++
			Quadratic contrast	NS

[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 28. Effect of nitrogen rate from ESN fertilizer on acrylamide concentration of Ivory Crisp potato chips.

Nitrogen Treatments				Acrylamide Concentration (ppb, fresh-weight basis)
Treatment #	Nitrogen Source[1]	Nitrogen Rate	Nitrogen Timing[2]	
		lb N/ac	P, E	
1	MAP + AMS	30	30, 0	4101 c
2	MAP + AMS, ESN	120	30, 90	5810 b
3	MAP + AMS, ESN	180	30, 150	7515 a
4	MAP + AMS, ESN	240	30, 210	4961 bc
5	MAP + AMS, ESN	300	30, 270	4991 bc
			Significance[3]	*
			LSD (0.10)	1532
			Linear contrast	NS
			Quadratic contrast	**

[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 29. Effect of nitrogen rate from ESN fertilizer on acrylamide concentration of Snowden potato chips.

Nitrogen Treatments				Acrylamide Concentration (ppb, fresh-weight basis)
Treatment #	Nitrogen Source[1]	Nitrogen Rate	Nitrogen Timing[2]	
		lb N/ac	P, E	
1	MAP + AMS	30	30, 0	4596
2	MAP + AMS, ESN	120	30, 90	6138
3	MAP + AMS, ESN	180	30, 150	6247
4	MAP + AMS, ESN	240	30, 210	5468
5	MAP + AMS, ESN	300	30, 270	6979
			Significance[3]	NS
			LSD (0.10)	--
			Linear contrast	*
			Quadratic contrast	NS

[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 30. Acrylamide contents of fries and chips vs. raw tuber sugar and nitrogen concentrations[1].

Cultivar	Acrylamide vs:	Rsq (corrected)	P	N	Direction
Frying cultivars[2]	**Sucrose**	**0.1378**	**0.0024**	**58**	**-**
	Glucose	**0.1482**	**0.0017**	**58**	**+**
Chipping cultivars[3]	Sucrose	-0.0182	0.5753	39	+
	Glucose	**0.1018**	**0.0270**	**39**	**+**
	CC	**0.2852**	**0.0003**	**38**	**+**
	AGT	**0.4295**	**<0.0001**	**38**	**-**
Alpine Russet	*Sucrose*	*0.1062*	*0.0878*	*20*	-
	Glucose	-0.0402	0.6124	20	-
Dakota Trailblazer	Sucrose	-0.0534	0.8496	20	+
	Glucose	-0.0524	0.8197	20	+
Russet Burbank	Sucrose	0.0295	0.2359	18	-
	Glucose	*0.1559*	*0.0588*	*18*	-
Ivory Crisp	Sucrose	-0.0379	0.5656	19	+
	Glucose	*0.1509*	*0.0562*	*19*	+
	CC	**0.4447**	**0.0015**	**18**	**+**
	AGT	**0.5014**	**0.0006**	**18**	**-**
Snowden	Sucrose	-0.0461	0.6910	20	-
	Glucose	0.0115	0.2837	20	+
	CC	*0.1164*	*0.0776*	*20*	+
	AGT	**0.2961**	**0.0077**	**20**	**-**

[1]Linear regressions: Acrylamide content of fried potato products as a function of whole-tuber glucose or sucrose content. Boldface: $P < 0.05$. Italics: $0.05 \le P < 0.10$.

[2]Alpine Russet, Dakota Trailblazer, and Russet Burbank, prepared as French fries.

[3]Ivory Crisp and Snowden, prepared as chips.

Table 31. Whole-tuber sugar and acrylamide concentrations of participating growers' potatoes.

Grower	Variety	Preparation	Sucrose[1]	Glucose[1]	Acrylamide[1]
K+O	Alpine Russet	Fry	2.39 ± 0.64	0.43 ± 0.26	1066 ± 223
K+O	Russet Burbank	Fry	1.87 ± 0.22	0.88 ± 0.36	1332 ± 318
Goenner	Snowden	Chip	1.30 ± 0.10	0.11 ± 0.05	2708 ± 444

[1]Mean ± S.D.

Nitrogen Rate and Potato Variety Effects on Tuber Yield and Quality and the Acrylamide Concentrations of French Fries and Chips - 2011-

Carl Rosen[1], James Crants[1], Matt McNearney[1], and Marty McGlynn[2]
[1]Department of Soil, Water, and Climate, University of Minnesota and
[2]USDA-ARS Potato Research Worksite, East Grand Forks, MN

Summary: Since the discovery of acrylamide in fried potato products a decade ago, reducing acrylamide concentrations has become a priority of the potato industry. Acrylamide concentration 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. In 2011, 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 concentration, tuber yield and quality (hollow heart and specific gravity), tuber nitrogen, sucrose, and glucose concentrations, and the acrylamide concentration 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/ac as monoammonium phosphate and ammonium sulfate for all treatments at planting, plus 0, 90, 150, 210, or 270 lbs N/ac as ESN at emergence). The whole-tuber nitrogen concentration was determined at harvest, and the whole-tuber concentrations of the reducing sugars sucrose and glucose and the concentration of acrylamide after frying were determined at harvest and at 3, 6, and 9 months storage at 45˚F. As expected, higher-nitrogen treatments had higher petiole nitrate concentrations. 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/ac 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. Higher-nitrogen treatments yielded higher tuber nitrogen concentrations (an indicator of asparagine concentration). Sucrose concentration did not respond to nitrogen regime, but glucose concentration tended to decline as the amount of nitrogen applied increased. The abundances of both sugars varied significantly among varieties, but not in parallel with each other. The acrylamide concentration in fried products was not generally related to the abundances of any of the precursors, and its response to fertilization treatment varied with both tuber variety and time in storage. Based on one year of data, these results suggest that both nitrogen management and selective breeding have good potential to control the abundance of acrylamide precursors. However, while we found evidence for a strong genetic influence on the acrylamide concentrations of fried potato products, the effects of nitrogen management on acrylamide concentration were highly variety-dependent, and it is therefore difficult to make recommendations regarding nitrogen fertilization based on this single year's data. This study is being repeated in 2012.

Background:

The discovery of the neurotoxin and possible carcinogen acrylamide in fried potato products (Tareke et al. 2002) has prompted new research into methods for reducing the acrylamide concentration of such products (Lineback et al. 2012). Acrylamide is formed by the Maillard reaction during frying, from two precursors: reducing sugars (such as sucrose and glucose) and the amino acid asparagine (Becalski et al. 2003). The acrylamide concentration in fried potato projects can potentially be minimized by reducing the concentrations of acrylamide precursors in the raw tuber (Olsson et al. 2004).

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 (Olsson et al. 2004; see Jackson and Al-Taher 2005). In the field, nitrogen management influences tuber nitrogen concentration, a strong correlate of tuber asparagine concentration (R = 0.99; Eppendorfer and Eggum 1994). Tuber storage time and conditions can influence the concentrations of reducing sugars, as starch breaks down into sucrose, which breaks down into glucose and fructose, over time at low temperature (e.g., Uppal and Verma 1990).

The objectives of this study are (1) to determine whether genetics (potato variety) and environmental conditions of tuber growth and storage (nitrogen fertilization regime and time in cold storage) influence the concentrations of acrylamide precursors in mature tubers and acrylamide in fried potato products, and (2) to determine whether the concentrations of acrylamide precursors in raw tubers predict the concentration of acrylamide in the fried potato product. The acrylamide precursors we analyzed included the reducing sugars sucrose and glucose, and tuber nitrogen (as an indicator of asparagine concentration; see Eppendorfer and Eggum 1994). We also evaluated the effect of nitrogen fertilization regime and potato variety on petiole nitrate concentration, tuber yield, vine traits (percent stand and stems per plant), and tuber quality traits (prevalence of hollow heart, brown center, and scab, plus tuber specific gravity and percent dry matter).

Materials and Methods:

This study was conducted in 2011 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 (BI, 6.6-6.7 for samples with pH < 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 two feet of soil were 4.9 – 6.6 and 11.8 – 19.9 lbs/ac, respectively.

Three frying varieties (Alpine Russet, Dakota Trailblazer, and Russet Burbank) and two chipping varieties (Ivory Crisp and Snowden) were studied. Prior to planting, 250 lb/ac 0-0-60 and 250 lb/ac 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 Alpine Russet, Dakota Trailblazer, Ivory Crisp, and Snowden were hand planted in furrows on May 3. Row spacing was 12 inches within each row and 36 inches between rows. 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 five 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 randomized complete block design was used with four replicates and variety and amount of nitrogen fertilizer applied as main effects. At planting (May 3), fertilizer was banded 3 inches to each side and 2 inches below the seed piece, including 30 lbs N/ac, 130 lbs P_2O_5/ac, 180.6 lbs K_2O/ac, 25.7 lbs S/ac, 36 lbs Mg/ac, 0.5 lbs B/ac, and 2.3 lbs Zn/ac, applied as a blend of monoammonium phosphate, potassium chloride, potassium magnesium sulfate, ammonium sulfate, boric acid, and zinc sulfate. Emergence nitrogen applications as ESN were applied on May 25 and mechanically incorporated during hilling.

Plant stand was 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 whole-tuber analyses and frying tests. Whole-tuber nitrogen concentration was measured on tubers collected at harvest and assumed not to change substantially throughout subsequent storage.

Approximately 50 lbs of tubers in the 6- to 10-ounce size category from each plot were shipped to the USDA-ARS Potato Research Worksite in East Grand Forks for sugar analysis and frying. Whole-tuber sucrose and glucose concentrations were determined at harvest and after three, six, and nine months of storage at 45˚F. At the same times, a subset of the tubers was processed into fries (Alpine Russet, Dakota Trailblazer, and Russet Burbank) or chips (Ivory Crisp and Snowden), and the fresh-weight acrylamide concentrations of the fried products were determined.

In addition to tubers from the study conducted at the Sand Plain Research Farm, tubers were also collected from growers' fields to determine if acrylamide levels in fried potatoes from the commercial fields were similar to those in the study. Three, 50 pound bags of tubers were collected from each field and shipped along with tubers from the Becker study samples to East Grand Forks. Cooperating grower fields included Russet Burbank and Alpine Russet from K&O near Becker, Russet Burbank from two fields in Park Rapids, Dakota Trailblazer and Ivory Crisp from Perham, and Snowden from Goenners near Clear Lake,

To process the frying varieties into fries, tubers were steam-pealed for 30 seconds, washed at high pressure, cut on an Urschel cutter, and blanched at 170˚F for 7 to 10 minutes. They were dried at 140˚F for 3 to 6 minutes, until they lost 9 to 11% of their weight. They were then par-fried at 365˚F for 90 seconds, and then at 375˚F for 35 to 50 seconds more, after which they were sharp-frozen at -15˚F. After one week, the frozen fries were fried at 350˚F for 2:45 to 3:00 minutes.

Chips were made by steam-pealing tubers for 30 seconds, pressure-washing and slicing them, rinsing the slices in a cold water bath, and frying them at 365˚F for 90 seconds. The chips were then run across a de-oiling table, crushed, and scanned with an Agtron Analyzer to quantify chip darkness. Chips were also analyzed visually by trained observers to obtain subjective chip-color scores.

Fried samples were shipped frozen to the University of Minnesota's St. Paul Campus for acrylamide analysis. For each study plot, three fries or 1.0 – 2.0 g of chips were ground for 30 seconds in a coffee grinder, and 0.8 – 1.0 g (for fries) or 0.20 – 0.25 g (for chips) of ground sample were placed in a sample tube with ten parts distilled, deionized water and vortexed for 30 seconds. After resting for one hour, the resulting suspension was centrifuged and the aqueous fraction pipetted away from the fatty and solid fractions. This aqueous fraction was centrifuged again, and the resulting aqueous fraction was pipetted away from the fatty and solid fractions. This centrifugation-isolation step was repeated once more, after which 1 ml of purified aqueous solution was pipetted into a 1.5-mL centrifuge tube for each sample. To 1 ml of extract, 100pg of heavy acrylamide (Cambridge Isotope Laboratories, INC Andover MA (Acrylamide (2,3,3-D3, 98%))) were added. Standard curves for quantification were constructed using 100pg heavy acrylamide/ml with light acrylamide ranging from 5pg-1500pg/ml. Samples were subjected to solid phase extraction with a Phenomenex Strata™-X-C 33 µm Polymeric Strong Cation column. Then, 20 µl were subjected to HPLC using an Agilent autosampler with an analytical Thermo Hypercarb* (100L x 1.0mm I.D. Columns, 5µm Particle Size) column connected to the Applied Biosystem 4000 iontrap fitted with a turbo V electrospray source. The samples were subjected to a linear gradient of 0 to 100 percent acetonitrile for 15 minutes at a column flow rate of 150 µl/minute. Transitions monitored were the m/z 72 > m/z 44 and m/z 72> m/z 55 for the light acrylamide and the m/z 75 >44 m/z and m/z 75> m/z 58 for the heavy acrylamide. The data were analyzed using MultiQuant (ABI) providing the peak area ratio for the m/z 58 // m/z 55 transitions. A standard curve was constructed using ratio H/L concentrations of acyrlamide from 0-1000 nanograms light acrylamide in 20 µl. The amount of acrylamide was determined and expressed as ng acryamide/g solid material (ppm). All analyses were conducted at the University of Minnesota Center for Mass Spectrometry and Proteomics.

ANOVAs of above-ground plant traits, petiole nitrate, tuber yield, tuber characteristics, chip color, Agtron (AGT) score, whole-tuber nitrogen and sugar concentrations, and fried-potato acrylamide concentration as functions of treatment, variety, their interaction, and replicate, were conducted using the GLM procedure in SAS 9.2. Because significant treatment-by-variety interaction effects were found for tuber nitrogen and glucose concentrations (both of which represent acrylamide precursors) and for acrylamide concentration itself, and because fresh-weight acrylamide concentration differed greatly between the two preparation methods, ANOVAs were also performed for chipping and frying varieties separately for these variables (Table 2). Because of grower interest in varietal performance, results for each variety are presented separately. Regressions of fried-potato acrylamide concentration against whole-tuber nitrogen and sugar concentrations, split by variety, were performed for each variety at each sampling time using the REG procedure in SAS 9.2.

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/ac) -------------		
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:

<u>Vine traits, petiole nitrate:</u>

Vine traits:

Plant stand at two weeks post-emergence differed significantly among the five potato varieties used in this study (Table 2). 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 three weeks post-emergence (Table 2). Snowden (5.0 stems per plant) had significantly more than any other variety; Russet Burbank (4.5 stems) had significantly more than any variety but Snowden; and 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 was there a significant treatment-by-variety interaction (Table 2). Within any given variety, plant stand and the number of stems per plant did not generally differ among fertilizer treatments, with three exceptions. In Dakota Trailblazer plants (Table 4), the treatment receiving 120 lbs N/ac had significantly lower percent stand than all other treatments, including the control. In Russet Burbank plants (Table 5), the control treatment had significantly more stems per plant than the ESN-fertilized treatments. In Ivory Crisp plants (Table 6), the treatment receiving 300 lbs N/ac had significantly fewer stems per plant than the control treatment or the treatment receiving 180 lbs N/ac; the treatment that received 180 lbs N/ac also had significantly more stems per plant than the treatments receiving 120 or 240 lbs N/ac.

Petiole nitrate concentration:

Petiole nitrate increased significantly with increasing application of ESN for all combinations of variety and testing date (Table 2, Tables 3 – 7).

Petiole nitrate also varied significantly among varieties in all four sampling periods (Table 2), 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.

Different lines had generally parallel responses to increasing nitrogen fertilization. However, for the July samples, there was a marginally significant treatment-by-variety interaction (Table 2). The lowest-nitrate varieties in these two sampling dates (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/ac), but stronger responses at higher rates of nitrogen (between 180 and 300 lbs N/ac). In general, nitrate concentrations in all varieties were in the deficient range at rates less than 180 lbs N/ac.

Tuber yield:

Tuber yield was significantly influenced by variety for all size and quality categories, and by nitrogen treatment for all categories except for tubers under 3 ounces and number 2 tubers (Table 2). There were significant or marginally significant treatment-by-variety interactions for all size categories except 3-to-6-ounce tubers, and for number 2 tubers, but not for total yield, number 1 tubers, total marketable yield, or the percentage of yield in tubers over 6 or 10 ounces (Table 2).

Total yield was significantly greater for plants receiving 180 or 240 lbs N/ac, and significantly lower for plants in the control treatment, than for plants receiving 120 or 300 lbs N/ac. The yield of number 1s followed a similar pattern, except that the yield for the treatment receiving 240 lbs N/ac was not significantly different from those of the treatments receiving 120 or 300 lbs N/ac. Total marketable yield showed a similar pattern to total yield, except that the treatment receiving 240 lbs N/ac did not have significantly greater yield than the treatment receiving 120 lbs N/ac.

In contrast to total yield, yield of number 1 tubers, and total marketable yield, the percentage of yield represented by tubers over 6 or 10 ounces were sorted in order of the amount of ESN applied. The treatment receiving 300 lbs N/ac had a significantly greater percentage of its yield in tubers over 6 ounces than any other treatment, while the control treatment's percentage of yield in this size range was significantly lower than that of any other treatment. The treatment receiving 240 lbs N/ac also had a significantly greater percentage of yield in tubers over 6 ounces than the one receiving 120 lbs N/ac. Each treatment group had a significantly lower percentage of yield in tubers over 10 ounces than the one receiving the next higher amount of ESN.

Total yields were significantly greater for Snowden and significantly lower for Alpine Russet than for any other variety, and Dakota Trailblazer had significantly higher total yields than Ivory Crisp. Dakota Trailblazer had significantly higher yields of number 1 tubers and higher total marketable yields than Snowden or Ivory Crisp, which had significantly higher yields than Russet Burbank, which had significantly higher yields than Alpine Russet. The lower yield of Alpine Russet tubers was likely due to dry rot of the seed tubers, which significantly reduced stand. Dakota Trailblazer and Ivory Crisp had significantly greater percentages of yield in tubers over 6 ounces than Alpine Russet, which had a greater percentage than Snowden, which had a greater percentage than Russet Burbank. For the percentage of tubers over 10 ounces, Ivory Crisp and Alpine Russet had greater percentages than Dakota Trailblazer, which had a greater percentage than Russet Burbank or Snowden.

Because treatment-by-variety interactions were generally significant for the remaining yield categories (Table 2), results for those categories are only reported on a variety-by-variety basis. 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).

Alpine Russet: The control treatment had significantly higher yields of 3- to 6-ounce tubers than the treatment receiving 300 lbs N/ac (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/ac. 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, but it had a higher yield of #2 tubers than any fertilized treatment except the one receiving 120 lbs N/ac. 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/ac had a significantly 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/ac. However, the treatment receiving 180 lbs N/ac produced a significantly greater yield of 6- to 10-ounce tubers, #1 tubers, and total marketable tubers than the treatment receiving 300 lbs N/ac.

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/ac) to 47% (at 30 lbs N/ac) 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 or 300 lbs N/ac, more 3- to 6-ounce tubers than the treatment receiving 300 lbs N/ac, and fewer 6- to 10-ounce tubers than the treatment receiving 180 lbs N/ac (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/ac. 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/ac had a significantly higher yield of 0- to 3-ounce tubers than the treatment receiving 120 lbs N/ac, but a lower yield of 3- to 6-ounce tubers than the treatments receiving 180 and 240 lbs N/ac. It had a significantly lower yield of 6- to 10-ounce tubers than the treatment receiving 180 lbs N/ac, but a higher yield of tubers over 14 ounces than any treatment except the one receiving 240 lbs N/ac. A larger percentage of yield for this treatment included tubers over 10 ounces than for the treatments receiving 120 and 180 lbs N/ac. However, it had a significantly lower yield of

6- to 10-ounce tubers, total yield, yield of firsts, and total marketable yield, than the treatment receiving 180 lbs N/ac.

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

Russet Burbank: The control treatment had significantly more 0- to 3-ounce tubers than any of the ESN-fertilized treatments, but significantly fewer 10- to 14-ounce tubers than any treatment but the one receiving 120 lbs N/ac and fewer tubers over 14 ounces than the treatments receiving 240 or 300 lbs N/ac (Table 10). This treatment had lower total yield than the treatments receiving 180 and 240 lbs N/ac, 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.

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

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

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

The treatment receiving 300 lbs N/ac 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/ac, and a lower yield of 6- to 10-ounce tubers than any other ESN-fertilized treatment except the one receiving 180 lbs N/ac. It had a greater yield of tubers over 14 ounces (3.75 inches) than the treatment receiving 120 lbs N/ac. 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/ac 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/ac, and for #1 tubers and marketable yield, the yield was only statistically significantly greater than the yield for the treatment receiving 120 lbs N/ac and the control treatment.

Less than 1% of marketable Ivory Crisp tubers were #2 tubers 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/ac, 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 12). 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/ac, and a lower yield of tubers over 14 ounces (3.75 inches) than the treatments receiving 240 and 300 lbs N/ac. 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/ac.

The treatment receiving 300 lbs N/ac 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/ac. This treatment had a larger percentage of its yield in tubers over 10 ounces (3.25 inches) than did 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/ac. 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.

<u>Tuber quality traits:</u>

Nitrogen treatment had a significant effect on all tuber quality traits except percent scab (Table 2). 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 (Table 2). 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 matter and specific gravity, the varieties ranked as follows: Dakota Trailblazer > Snowden > Ivory Crisp > Russet Burbank > Alpine Russet. All of these differences were statistically significant for dry matter. For specific gravity, the difference between Snowden and Ivory Crisp was not significant, but all other differences were.

There were significant nitrogen treatment by variety interactions for the incidences of hollow heart and brown center and for tuber dry matter (Table 2).

Alpine Russet: There were no significant effects of nitrogen treatment on tuber quality traits measured 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: The treatment receiving 240 lbs N/ac had significantly more hollow heart and brown center than any other treatment, and the treatment receiving 300 lbs N/ac had a higher prevalence of these flaws than the control treatment (Table 14).

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

Russet Burbank: The treatments receiving 240 and 300 lbs N/ac had significantly higher incidences of hollow heart and brown center than the control treatment or the treatment receiving 120 lbs N/ac (Table 15). The treatment receiving 240 lbs N/ac also had significantly higher incidences of both flaws than the one receiving 180 lbs N/ac.

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

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

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

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/ac had significantly lower percent dry matter than the treatment receiving 300 lbs N/ac, and the treatment receiving 120 lbs N/ac also had significantly lower percent dry matter than the one receiving 240 lbs N/ac.

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%.

Snowden: Tubers in the control treatment had a significantly lower percentage of dry matter than tubers in the treatments receiving 180 and 300 lbs N/ac (Table 17). There were no other significant effects of fertilizer treatment on tuber quality traits; though, hollow heart and brown center tended to be more common in treatments receiving more ESN at emergence. The prevalence of scab ranged from 0% to 12%.

<u>Acrylamide precursors in mature tubers:</u>

Tuber nitrogen concentration:

Whole-tuber nitrogen concentration was significantly influenced by both treatment and variety, as well as their interaction (Table 2). For all varieties combined, tuber nitrogen concentration increased with increasing application of ESN. The control treatment had significantly lower tuber nitrogen than any other treatment, while the treatment receiving 300 lbs N/ac had significantly higher tuber nitrogen than any other.

The treatment receiving 240 lbs N/ac had significantly higher tuber nitrogen than the treatments receiving 120 or 180 lbs N/ac.

There were also significant differences among varieties in tuber nitrogen concentration for all treatments combined. Alpine Russet tubers had significantly higher nitrogen concentration than Ivory Crisp tubers, which had significantly higher nitrogen concentration than Snowden or Russet Burbank tubers, which, in turn, had significantly higher nitrogen concentration than Dakota Trailblazer tubers.

The treatment-by-variety interaction effect was not eliminated by analyzing chipping varieties and frying varieties separately; the frying varieties still showed a marginally significant interaction effect (Table 2).

Some of the treatment-by-variety interaction effect can be attributed to differences in the strength of the response to variation in ESN application rate. There was no relationship between treatment and tuber nitrogen for Snowden (Table 22), and Russet Burbank showed only a weak response to additional ESN above the rate of 120 lbs total N/ac (Table 20), while the other varieties generally showed increased tuber N with increasing application of ESN (Tables 18, 19, and 21).

Tuber sugar concentration:

For all treatments combined, both sucrose and glucose concentration varied significantly among varieties at all four storage time periods (Table 2). At harvest, Alpine Russet and Dakota Trailblazer had significantly higher whole-tuber sucrose concentrations than the other three varieties, and Ivory Crisp had a significantly lower tuber sucrose concentration than any other variety. Three months later, Snowden and Ivory Crisp had significantly lower tuber sucrose concentrations than the other three varieties, and Alpine Russet had a significantly higher tuber sucrose concentration than Russet Burbank. After six months in storage, Snowden tubers had significantly *higher* sucrose concentrations than those of any other variety, while Russet Burbank tubers had significantly lower sucrose concentrations than those of any other variety. A similar pattern was seen at nine months, except that Alpine Russet joined Russet Burbank in having a significantly lower sucrose concentration than the other varieties. Overall, sucrose concentration tended to decline with storage time for the frying varieties and increase for the chipping varieties.

At harvest, Russet Burbank tubers had significantly higher glucose concentrations than Alpine Russet tubers, which had higher glucose concentrations than Dakota Trailblazer tubers, which had higher glucose concentrations than Snowden or Ivory Crisp tubers. After three months in storage, the glucose concentrations of Alpine Russet and Russet Burbank tubers were significantly higher than those of Dakota Trailblazer tubers, which were higher than those of Ivory Crisp and Snowden tubers. At six months, Alpine Russet tubers had significantly higher glucose concentrations than Russet Burbank tubers, which had higher glucose concentrations than any of the other three varieties. After nine months in storage, Alpine Russet and Snowden tubers had significantly higher glucose concentrations than Russet Burbank tubers, which had higher glucose concentrations than Ivory Crisp or Dakota Trailblazer. Glucose concentration tended to increase with storage time for all varieties.

For all varieties combined, there were no significant effects of nitrogen treatment on sucrose concentration, nor was there a significant treatment-by-variety interaction

(Table 2). In contrast, at all four sampling periods, glucose concentration was significantly affected by the nitrogen treatment applied, and the treatment-by-variety interaction effect was significant (Table 2). This interaction effect was still significant for the frying varieties when the chipping and frying varieties were analyzed separately (Table 2).

For all varieties combined, glucose concentration declined with increasing application of nitrogen. At harvest, the control treatment had a significantly higher glucose concentration than any ESN-fertilized treatment, and the treatment receiving 120 lbs N/ac had a significantly lower glucose concentration than the treatment receiving 300 lbs N/ac. Three months later, the treatment receiving 180 lbs N/ac also had a significantly lower tuber glucose concentration than the treatment receiving 300 lbs N/ac, and the treatment receiving 90 lbs N/ac had a lower glucose concentration than the one receiving 270 lbs N/ac. At six months, the control treatment had a significantly higher glucose concentration than any of the ESN-fertilized treatments, and the treatment receiving 300 lbs N/ac had a significantly lower glucose concentration than those receiving 120 and 180 lbs N/ac. After nine months in storage, the control treatment continued to have a higher glucose concentration than the ESN-fertilized treatments, and the treatments receiving 240 and 300 lbs N/ac had significantly lower glucose concentrations than those receiving 120 and 180 lbs N/ac.

Among individual varieties, nitrogen treatment only influenced whole-tuber sucrose concentration at harvest in Snowden (Table 22), for which the control treatment had a higher sucrose concentration than the treatments receiving 180 and 300 lbs N/ac, and the treatment receiving 300 lbs N/ac had a significantly lower sucrose concentration than the one receiving 120 lbs N/ac. Three months after harvest, nitrogen treatment was significantly related to sucrose concentration only in Alpine Russet tubers (Table 18). The treatment receiving 180 lbs N/ac had a significantly lower sucrose concentration than any but the one receiving 240 lbs N/ac, which in turn had a significantly lower sucrose concentration than the treatment receiving 120 lbs N/ac. At six months or nine months storage, sucrose concentration was not related to fertilizer treatment for any variety.

Tuber glucose concentration at harvest was at least marginally related to nitrogen treatment in all varieties except for Russet Burbank (Tables 18-22). For Alpine Russet tubers, glucose concentration declined with increasing application of ESN (Table 18). The control treatment had a significantly higher glucose concentration than the treatments receiving 180, 240 and 300 lbs N/ac. The treatment receiving 120 lbs N/ac had a higher glucose concentration than the treatments receiving 240 and 300 lbs N/ac; and the treatment receiving 180 lbs N/ac had higher glucose concentration than the treatment receiving 300 lbs N/ac. For Dakota Trailblazer tubers, the treatment receiving 120 lbs N/ac had a significantly higher glucose concentration than one receiving 240 lbs N/ac or the control treatment (Table 19). For Snowden tubers, the control treatment and the treatment receiving 120 lbs N/ac had significantly higher glucose concentrations than the treatments receiving 180 and 300 lbs N/ac (Table 22). For Ivory Crisp tubers, the control treatment had a significantly higher glucose concentration than any of the ESN-fertilized treatments (Table 21).

Three months after harvest, nitrogen treatment was significantly related to tuber glucose concentration for Alpine Russet, Russet Burbank, and Ivory Crisp. For Alpine Russet, tuber glucose concentration was greater for the control treatment than for any other treatment except the one receiving 180 lbs total N/ac (Table 18). For Russet Burbank, glucose concentration was significantly greater in the control treatment than in the treatments receiving 180, 240, or 300 lbs N/ac, and it was significantly greater for the group receiving 120 lbs N/ac than for the group receiving 300 lbs N/ac (Table 20). For Ivory Crisp, the control treatment had a significantly greater tuber glucose concentration than any of the treatments receiving ESN (Table 21).

After six months' storage, for Alpine Russet tubers, glucose concentration was significantly lower for the treatment receiving 300 lbs N/ac than for any other treatment (Table 18). For Russet Burbank, tuber glucose concentration was significantly higher in the control treatment than in any ESN-fertilized treatment (Table 20). The other three varieties exhibited no significant response of tuber glucose concentration to fertilization treatment at this sampling time.

Glucose concentrations of Alpine Russet tubers after nine months in storage was significantly lower for the treatments receiving 240 or 300 lbs N/ac than for the other three treatments (Table 18). For Ivory Crisp, tuber glucose concentration was significantly higher for the control treatment than for any ESN-fertilized treatment, and significantly higher for the treatment receiving 120 lbs N/ac than for the one receiving 300 lbs N/ac (Table 21). No other varieties showed a response of tuber glucose to fertilization treatment at nine months.

Frying quality (Chipping varieties only):

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

There was no significant treatment by variety interaction effects at any sampling time (Table 2). For all treatments combined, there were significant effects of variety on both chip color and AGT at six and nine months' storage (Table 2). At both of these sampling times, chips made from Snowden tubers had significantly higher chip color scores and lower AGT scores than those made from Ivory Crisp tubers (i.e., Snowden chips were darker). For both varieties combined, nitrogen treatment only significantly affected chip quality at nine months' storage (Table 2). At this time, the control treatment yielded significantly higher chip color scores and lower AGT scores (i.e., darker chips) than the fertilized treatments. Chips from the treatment receiving 120 lbs N/ac also had significantly higher chip color scores than those from the treatment receiving 240 lbs N/ac.

There were no significant differences in whole-tuber frying quality (chip color or AGT score) from treatment to treatment for Snowden at any time point (Table 23).

AGT scores varied among treatments for Ivory Crisp after three months in storage, and again after nine months (Table 22). At three months, chips made from tubers grown in the treatment receiving 180 lbs total N/ac had significantly lower AGT scores (darker chips) than those receiving 240 or 300 lbs N/ac. At nine months, the control treatment yielded significantly lower AGT scores than any of the other treatments. This effect at nine months was mirrored in the results of the more subjective chip color tests, which found darker chips from control-treatment tubers than from tubers from any other treatment group.

Acrylamide concentrations of fried potato products:

Potato chips had 3.5 to 8.3 times as much acrylamide (in ppb of fresh weight) as French fries. For that reason, the results for the frying varieties and the chipping varieties are considered separately, although ANOVA significance results for the combined analyses are presented in Table 2.

For the frying varieties as a group, nitrogen treatment had a marginally significant effect on the acrylamide concentrations of fries made soon after harvest (Table 2); fries made from the treatments receiving 180 or 300 lbs N/ac had significantly higher acrylamide concentrations than those made from the other treatments. After three months in storage, nitrogen treatment was not significantly related to the acrylamide concentrations of fries. However, after six months in storage, there was again a significant effect of nitrogen treatment. Specifically, the control treatment had a significantly lower acrylamide concentration than the treatments receiving 120 to 240 lbs N/ac, and the treatment receiving 300 lbs N/ac had a lower acrylamide concentration than the treatments receiving 180 or 240 lbs N/ac.

There was a significant effect of tuber variety among the frying varieties at each sampling period (Table 2). Fries made from Dakota Trailblazer had significantly lower acrylamide concentrations than those made from the other two varieties at all four sampling periods. Alpine Russet fries had significantly lower acrylamide concentrations than Russet Burbank fries at harvest and after six months in storage. After nine months in storage, Alpine Russet fries were significantly higher in acrylamide concentration than Russet Burbank fries. There was no difference in acrylamide concentrations between these two varieties after three months of storage.

The frying varieties showed significant treatment-by-variety interactions at harvest and at three months storage and a marginally significant interaction at six month's storage (Table 2). At harvest, the acrylamide contents of Russet Burbank fries varied significantly but unpredictably with nitrogen treatment (Table 27), while the responses of the other two varieties were more muted but in opposite directions to each other (Tables 25 and 26). At three months storage, none of the varieties showed significant responses of acrylamide concentration to nitrogen treatment. However, the responses they did show were quite different from each other, with acrylamide concentration peaking in the treatment receiving 180 lbs N/ac in Russet Burbank (Table 27), and with the other two varieties again showing responses in opposite directions to each other (Tables 25 and 26). At nine months storage, only Alpine Russet showed a significant response of acrylamide concentration to nitrogen treatment, with acrylamide concentration increasing with increasing application of nitrogen before dropping precipitously between the 240 lbs N/ac and 300 lbs N/ac (Table 25). Russet Burbank showed a similar pattern, but with peak acrylamide concentration in the treatment receiving 180 lbs N/ac (Table 27), while Dakota Trailblazer showed a general trend toward increasing acrylamide concentration with increasing application of nitrogen, except that acrylamide concentration was higher at 120 lbs N/ac than this trend would predict (Table 26).

For the two chipping varieties, acrylamide concentration was marginally related to nitrogen treatment at all times except harvest (Table 2). There was a general tendency for acrylamide concentration to decline with increasing nitrogen fertilization after six and nine months in storage, with the chips from the control treatment having significantly higher acrylamide concentration than those from the treatments receiving 240 or 300 lbs N/ac at both time periods. There were also significant effects of variety at all times except harvest (Table 2). Ivory Crisp chips had significantly higher acrylamide concentrations than Snowden chips after three months in storage, but significantly lower concentrations after that. The two varieties yielded similar acrylamide concentrations at harvest. There was no treatment-by-variety interaction for the chipping varieties at any sampling time (Table 2).

For individual varieties, the acrylamide concentrations of fries or chips were not significantly related to nitrogen treatment for most combinations of variety and sampling date. Significant or marginally significant effects of treatment on acrylamide concentration were observed for Alpine Russet at six months (Table 25), Dakota Trailblazer and Russet Burbank at harvest (Tables 26 and 27), Ivory Crisp at six and nine months (Table 28), and Snowden at three and six months (Table 29). The significant effects in Ivory Crisp reflected a decrease in acrylamide concentration with increasing application of ESN, particularly at nine months (Table 28). In all other cases, the relationship between the amount of nitrogen applied in the field and the acrylamide concentrations of finished chips was neither linear nor quadratic in form.

<u>Acrylamide concentration versus precursor concentrations:</u>

To determine whether the acrylamide concentrations of fried potato products were related to the concentrations of acrylamide precursors in the raw tubers, we performed linear regressions of acrylamide concentration as a function of precursor concentrations. Because there were significant treatment-by-variety interactions for the concentrations of acrylamide and its precursors, even when we considered the frying varieties and chipping varieties separately, we tested for relationships between acrylamide concentration and the concentrations of its precursors for each variety separately (Table 30).

Acrylamide concentrations in Alpine Russet fries made from freshly harvested tubers had a marginally significant positive relationship to whole-tuber sucrose concentrations, and acrylamide was positively related to tuber glucose concentration at six months' storage. Acrylamide concentrations for Dakota Trailblazer fries from freshly harvested tubers had a marginally significant negative relationship to tuber nitrogen concentration at harvest. The acrylamide concentration of Russet Burbank fries was significantly positively related to sucrose concentration at six months' storage. Acrylamide concentration in Ivory Crisp chips was significantly positively related to sucrose concentration at three months and glucose concentration at nine months in storage. Acrylamide concentration for this variety at nine months was also negatively related to tuber nitrogen concentration at harvest. Acrylamide concentration in Snowden chips showed a marginally significant positive relationship to tuber sucrose concentration at six months' storage and significant positive relationships to glucose concentration at three months and six months' storage. Snowden acrylamide concentration at three months' storage was also positively related to tuber nitrogen concentration at harvest.

<u>Growers' potatoes:</u>

Tubers from participating growers' farms often had somewhat different concentrations of reducing sugars (Table 31) than tubers of the same variety from our study site. Alpine Russet tubers from K+O tended to have high sucrose and low glucose concentrations relative to tubers of this variety from our study plots. Dakota Trailblazer tubers from Perham-Karsina had sugar levels similar to those found for this variety in our study plots. Russet Burbank tubers from K+O, Park Rapids Bliss, and Park Rapids HCBE initially had similar sucrose levels to those from our study sites, but did not exhibit the decline in sucrose in months six and nine that tubers from our site did. These growers' tubers also had lower glucose than Russet Burbank tubers from our study site throughout the storage period. Ivory Crisp tubers from Perham-RDO generally had high sucrose concentrations and low glucose concentrations relative to tubers of this variety from our study site. Snowden tubers from Goenners had glucose concentrations slightly lower than tubers of this variety from our study plots at all sampling times. They initially had similar sucrose concentrations to our study tubers, but their late-storage sucrose increase lagged behind that of the tubers from our study site. As sucrose concentrations began to rise in tubers from our study site at six months, the Goenner tubers retained steady, low sucrose concentrations. However, by nine months, even as sucrose concentrations continued to rise in Snowden tubers from our study site, the tubers from Goenners had converged again on similar concentrations.

Chips made from Ivory Crisp potatoes from Perham-RDO (Table 32) had similar chip color scores and AGT readings to chips of the same variety from fertilized treatments in our study site at all three sampling times for which we have data for the Perham-RDO chips. Chips from Snowden tubers grown by Goenners (Table 32) tended to have higher AGT scores (i.e., lighter color) than chips from Snowden tubers grown at our site, especially at harvest and after nine months in storage.

Acrylamide concentrations were also determined at each sampling period for fried products made from growers' tubers (Table 33). Acrylamide concentrations for fries made from K+O Alpine Russet tubers were similar to those found for this variety grown in our study site. Fries made from Dakota Trailblazer tubers grown at Perham-Karsina had higher acrylamide concentrations than those made from tubers grown at our site, except at three months' storage, when they had similar acrylamide concentrations. Fries made from Russet Burbank tubers from growers' farms had similar acrylamide levels to those found for our study site, except that K+O tubers had particularly high acrylamide levels after nine months in storage. Chips made from Ivory Crisp tubers grown at Perham-RDO had similar acrylamide levels to those found with tubers from our study site, except that the Perham-RDO tubers yielded slightly lower acrylamide levels at nine months' storage. Snowden tubers from Goenners yielded chips with lower acrylamide levels than found in Snowden chips from our study site tubers, except at nine months' storage, when the Goenner chips and our study site chips had similar acrylamide levels.

Conclusions:

The conclusions from this study are based on only one year of data. This study was repeated in 2012, and results from that year will be merged with the 2011 data set once analysis is completed.

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, Alpine Russet plants had poor mean stand (61.4%), probably as a result of dry rot. While 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; its poor performance in this year may be due to unusually hot weather conditions in July.

Petiole nitrate concentration increased with increasing fertilization rate, as expected. The rank-order of varieties by petiole nitrate was not constant over time, suggesting that varieties either take up nitrate or transfer nitrate from aboveground 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 of petiole nitrate to nitrogen fertilization rate than the other varieties at low rates (< 180 lbs N/ac), but a stronger response at high rates (> 180 lbs N/ac). This effect occurred because petiole nitrate for these varieties was quite low at 180 lbs N/ac, leaving little room for further response below that rate, but it is not clear why petiole nitrate was so low for these varieties at 180 lbs N/ac.

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/ac). In addition, since large tubers are more prone to hollow heart and brown center, there was a tendency for higher-nitrogen treatments to have higher incidences of these flaws. More heavily fertilized plants also produced tubers with higher dry matter concentrations for three of the five varieties (Alpine Russet, Snowden, and Ivory Crisp). For Dakota Trailblazer, however, peak dry matter concentration was found with intermediate fertilizer application (180 lbs N/ac).

Tuber nitrogen concentration increased significantly with increasing application of ESN for all varieties except Snowden, and it varied significantly among varieties, suggesting that this variable can be manipulated through both selective breeding and nitrogen management. The concentration of the acrylamide precursor asparagine is positively related to tuber nitrogen concentration ($R = 0.99$; Eppendorfer and Eggum 1994). Thus, our results suggest that the concentration of the acrylamide precursor asparagine may be minimized by restricting nitrogen fertilization, planting low-tuber-nitrogen varieties such as Dakota Trailblazer in preference to higher-nitrogen varieties like Alpine Russet, and selecting for low tuber nitrogen in breeding programs.

Sucrose concentration varied significantly among varieties at all sampling points, but it was never significantly influenced by the amount of nitrogen fertilization. This suggests that lower tuber sucrose concentration can be achieved through potato breeding efforts and selection of existing low-sucrose varieties, but not through nitrogen management in the field.

In contrast, while glucose concentration also varied significantly among varieties, it was also significantly influenced by nitrogen fertilization regime, and the effect of nitrogen fertilization on glucose concentration was variety-dependent. Generally, tubers had lower glucose concentration if they were more heavily fertilized. The exceptional cases showed no response to nitrogen: Dakota Trailblazer at three to nine months in storage, Russet Burbank at nine months in storage, Ivory Crisp at six months in storage, and Snowden at three and six months in storage. In some cases, the differences between the control and fertilized treatments were minor (Russet Burbank at harvest and Snowden at nine months). In other cases, the responses were difficult to explain biologically (Dakota Trailblazer at harvest and Russet Burbank at six months). Based on these results, both plant breeding and nitrogen management show good potential for minimizing glucose concentration in potatoes. Adequate nitrogen fertilization is important for keeping glucose concentration low (in contrast to the results for tuber nitrogen), and Alpine Russet and Russet Burbank tubers were substantially higher in glucose than the other varieties until nine months storage, when Snowden tubers converged on similar glucose concentrations.

Nitrogen fertilization treatment had contradictory responses for the three acrylamide precursors measured. Sucrose showed little response; glucose tended to decrease; and tuber nitrogen, representing asparagine, tended to increase with increasing nitrogen application. These responses could potentially produce a wide variety of final acrylamide concentrations, assuming that acrylamide formation is limited by the availability of precursors at standard potato frying temperatures. However, if the concentration of one of these precursors limited acrylamide formation more than those of the other two, (1) the concentration of acrylamide in fried products should be correlated with the concentration of this precursor in the raw tuber, and (2) acrylamide concentration and the concentration of the key precursor should respond to nitrogen fertilization rate similarly.

Unfortunately, none of the three precursor concentrations in raw tubers performed particularly well as predictors of final acrylamide concentration. The strongest predictor, glucose concentration, was significantly positively related to acrylamide concentration in two of four sampling periods for Snowden, for one sampling period in Ivory Crisp, and marginally significantly for one sampling period in Alpine Russet. However, four regressions with $P < 0.10$ out of 20 regressions performed for glucose concentration do not constitute strong evidence for whole-tuber glucose concentration as a predictor of the acrylamide concentration of fried potato products. Furthermore, whole-tuber glucose concentration and fried-product acrylamide concentration did not respond similarly to nitrogen fertilization, with glucose concentration generally decreasing with increasing application of ESN, while the response of acrylamide concentration was unique for each variety and sampling period. Nevertheless, the fact that every significant or marginally significant relationship between the whole-tuber concentration of a sugar and the concentration of acrylamide in fries or chips was a positive relationship indicates that there is some potential to minimize acrylamide formation by minimizing the concentrations of reducing sugars in tubers.

The only clear predictors of acrylamide concentration in fried products that could be identified in this study were preparation method (French fries versus chips) and potato variety. Chips consistently had much higher fresh-matter acrylamide concentrations than fries. This was expected, since chips have much lower moisture concentrations, and a larger proportion of their mass is exposed to temperatures high enough for the Maillard reaction during frying. Within each preparation method, the different varieties usually yielded significantly different acrylamide concentrations, the one exception being the chipping varieties at harvest. However, the rank-order of the varieties by acrylamide concentration within a preparation method varied with storage time for both chips and fries. The only inter-varietal relationship that held constant through all sampling periods was that Dakota Trailblazer fries always had lower acrylamide concentrations than fries made from the other two frying varieties.

It is possible that acrylamide formation is limited by a precursor molecule other than one of the three represented in this study. Fructose, for example, is known to be highly significant as an acrylamide precursor (see Lineback et al. 2012 for review). Lacking any clear, explicable relationship between acrylamide concentration and fertilization regime or the concentrations of acrylamide precursors in raw tubers, we cannot make recommendations for controlling acrylamide concentration through nitrogen fertilization management, based on this year's data. However, our results suggest that there is some potential to minimize acrylamide formation though selection of low-acrylamide varieties, such as Dakota Trailblazer, through selective breeding, and through minimizing the duration of cold storage prior to processing.

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Table 2: Significance results of ANOVAs for each dependent variable as a function of nitrogen treatment, potato variety, their interaction, and replicate[1].

Dependent Variable	All varieties			Chipping varieties only			Frying varieties only		
	Treatment	Variety	Trt * Var	Treatment	Variety	Trt * Var	Treatment	Variety	Trt * Var
Plant % stand	NS	**	NS						
Stems/plant	NS	**	NS						
Petiole nitrate, June 20	**	**	NS						
Petiole nitrate, June 28	**	*	NS						
Petiole nitrate, July 11	**	**	++						
Petiole nitrate, July 26	**	**	++						
Yield, 0-3 oz	NS	**	**						
Yield, 3-6 oz	**	**	NS						
Yield, 6-10 oz	**	**	*						
Yield, 10-14 oz	**	**	++						
Yield, > 14 oz	**	**	++						
Yield, Total	**	**	NS						
Yield, #1s	**	**	NS						
Yield, #2s	NS	**	**						
Yield, Marketable	**	**	NS						
Yield, % > 6 oz	**	**	NS						
Yield, % > 10 oz	**	**	NS						
Hollow heart	**	**	**						
Brown center	**	**	**						
Scab	NS	**	NS						
Specific gravity	++	**	NS						
Dry matter	**	**	*						
AGT score, harvest				NS	NS	NS			
AGT score, 3 months				NS	NS	NS			
AGT score, 6 months				++	NS	NS			
AGT score, 9 months				++	**	NS			
Chip color, harvest				NS	NS	NS			
Chip color, 3 months				NS	NS	NS			
Chip color, 6 months				*	NS	NS			
Chip color, 9 months				**	**	NS			
Tuber nitrogen	**	**	**	**	++	**	**	**	++
Glucose, harvest	**	**	**	**	NS	++	**	**	**
Glucose, 3 months	**	**	*	**	NS	NS	**	**	++
Glucose, 6 months	**	**	*	*	NS	NS	**	**	*
Glucose, 9 months	**	**	*	*	**	NS	**	**	**
Sucrose, harvest	NS	**	NS	NS	**	++	NS	**	NS
Sucrose, 3 months	NS	**	NS	NS	++	NS	NS	NS	++
Sucrose, 6 months	NS	**	NS	NS	*	NS	NS	**	NS
Sucrose, 9 months	NS	**	NS	NS	**	NS	NS	**	NS
Acrylamide, harvest	NS	**	NS	NS	NS	NS	*	**	**
Acrylamide, 3 months	*	**	*	*	**	NS	NS	**	*
Acrylamide, 6 months	*	**	**	*	*	NS	**	**	++
Acrylamide, 9 months	*	**	++	++	**	NS	NS	**	NS

NS: not significant. ++: $0.05 \le P < 0.10$. *: $0.01 \le P < 0.05$. **: $P < 0.01$. Blank cell: Not anaylyzed. (Agtron score and chip color were only determined for chipping varieties.

Table 3. Effect of nitrogen rate from ESN fertilizer on plant stand, stems per plant, and petiole nitrate concentration of Alpine Russet potato plants.

Nitrogen Treatments				Stand (%)	Stems per plant	Petiole NO_3-N Concentration (ppm)			
Treatment #	Nitrogen Source[1]	Nitrogen Rate	Nitrogen Timing[2]						
		lb N/ac	P, E			June 20	June 28	July 11	July 26
1	MAP + AMS	30	30, 0	61.8	3.4	10197 b	1423 c	181 d	206 c
2	MAP + AMS, ESN	120	30, 90	61.8	3.5	20449 a	10819 b	2417 c	781 c
3	MAP + AMS, ESN	180	30, 150	67.4	3.5	21559 a	12151 b	3032 c	1329 c
4	MAP + AMS, ESN	240	30, 210	63.9	3.7	21206 a	19265 a	9571 b	3834 b
5	MAP + AMS, ESN	300	30, 270	52.1	3.6	22655 a	19594 a	14510 a	9299 a
Significance[3]				NS	NS	*	**	**	**
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 plant stand, stems per plant, and petiole nitrate concentration of Dakota Trailblazer potato plants.

Nitrogen Treatments				Stand (%)	Stems per plant	Petiole NO_3-N Concentration (ppm)			
Treatment #	Nitrogen Source[1]	Nitrogen Rate	Nitrogen Timing[2]						
		lb N/ac	P, E			June 20	June 28	July 11	July 26
1	MAP + AMS	30	30, 0	99.3 a	2.6	8011 c	981 d	379 e	194 d
2	MAP + AMS, ESN	120	30, 90	95.8 b	2.5	17102 b	7813 c	3301 d	1092 cd
3	MAP + AMS, ESN	180	30, 150	100.0 a	2.9	18381 ab	10133 c	7121 c	2682 c
4	MAP + AMS, ESN	240	30, 210	99.3 a	2.8	20606 a	16080 b	9954 b	5071 b
5	MAP + AMS, ESN	300	30, 270	99.3 a	2.8	21556 a	20186 a	12828 a	7515 a
Significance[3]				++	NS	**	**	**	**
LSD (0.10)				2.8	--	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 plant stand, stems per plant, and petiole nitrate concentration of Russet Burbank potato plants.

Nitrogen Treatments				Stand (%)	Stems per plant	Petiole NO_3-N Concentration (ppm)			
Treatment #	Nitrogen Source[1]	Nitrogen Rate	Nitrogen Timing[2]						
		lb N/ac	P, E			June 20	June 28	July 11	July 26
1	MAP + AMS	30	30, 0	100.0	5.2 a	4415 c	689 e	333 e	112 e
2	MAP + AMS, ESN	120	30, 90	100.0	4.5 ab	14864 b	5353 d	2919 d	1600 d
3	MAP + AMS, ESN	180	30, 150	99.3	4.4 b	17714 a	10181 c	7442 c	4367 c
4	MAP + AMS, ESN	240	30, 210	100.0	4.1 b	19549 a	14070 b	12438 b	6683 b
5	MAP + AMS, ESN	300	30, 270	99.3	4.3 b	19893 a	17249 a	15501 a	9377 a
Significance[3]				NS	++	**	**	**	**
LSD (0.10)				--	0.8	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 6. Effect of nitrogen rate from ESN fertilizer on plant stand, stems per plant, and petiole nitrate concentration of Ivory Crisp potato plants.

Nitrogen Treatments				Stand (%)	Stems per plant	Petiole NO_3-N Concentration (ppm)			
Treatment #	Nitrogen Source[1]	Nitrogen Rate	Nitrogen Timing[2]						
		lb N/ac	P, E			June 20	June 28	July 11	July 26
1	MAP + AMS	30	30, 0	88.2	3.7 ab	4032 c	346 d	160 d	100 c
2	MAP + AMS, ESN	120	30, 90	90.3	3.5 bc	16220 b	5157 c	937 d	275 c
3	MAP + AMS, ESN	180	30, 150	86.7	4.0 a	19321 ab	9918 b	4265 c	1721 bc
4	MAP + AMS, ESN	240	30, 210	88.2	3.5 bc	21115 a	16604 a	8705 b	3536 b
5	MAP + AMS, ESN	300	30, 270	88.9	3.4 c	22467 a	16943 a	14872 a	7478 a
			Significance[3]	NS	**	**	**	**	**
			LSD (0.10)	--	0.3	3467	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 plant stand, stems per plant, and petiole nitrate concentration of Snowden potato plants.

Nitrogen Treatments				Stand (%)	Stems per plant	Petiole NO_3-N Concentration (ppm)			
Treatment #	Nitrogen Source[1]	Nitrogen Rate	Nitrogen Timing[2]						
		lb N/ac	P, E			June 20	June 28	July 11	July 26
1	MAP + AMS	30	30, 0	100.0	5.3	3556 c	573 d	260 e	306 d
2	MAP + AMS, ESN	120	30, 90	100.0	5.0	15618 b	6535 c	2766 d	1490 c
3	MAP + AMS, ESN	180	30, 150	99.3	5.2	20797 a	11989 b	6237 c	2561 b
4	MAP + AMS, ESN	240	30, 210	100.0	4.8	22039 a	16424 a	10604 b	6679 a
5	MAP + AMS, ESN	300	30, 270	99.3	5.0	20957 a	18960 a	14041 a	7535 a
			Significance[3]	NS	NS	**	**	**	**
			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 8. Effect of nitrogen rate from ESN fertilizer on Alpine Russet tuber yield and size distribution.

Nitrogen Treatments				Tuber Yield										
Treatment #	Nitrogen Source[1]	Nitrogen Rate	Nitrogen 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/ac	P, E	---------- cwt / A ----------						---------- 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	++	*	*	**	*	**	++	**	**	**
			MSD (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										
Treatment #	Nitrogen Source[1]	Nitrogen Rate	Nitrogen 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/ac	P, E	---------- cwt / A ----------						---------- 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	**	**	**
			MSD (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 Russet Burbank tuber yield and size distribution.

Nitrogen Treatments				Tuber Yield										
Treatment #	Nitrogen Source[1]	Nitrogen Rate	Nitrogen 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/ac	P, E	cwt / A						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	*	**	**
MSD (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 11. Effect of nitrogen rate from ESN fertilizer on Ivory Crisp tuber yield and size distribution.

Nitrogen Treatments				Tuber Yield										
Treatment #	Nitrogen Source[1]	Nitrogen Rate	Nitrogen 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/ac	P, E	cwt / A						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	**	**	**
MSD (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 Snowden tuber yield and size distribution.

Nitrogen Treatments				Tuber Yield										
Treatment #	Nitrogen Source[1]	Nitrogen Rate	Nitrogen 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/ac	P, E	---------- cwt / A ----------						---------- 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	**	**	**
			MSD (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 13. Effect of nitrogen rate from ESN fertilizer on Alpine Russet tuber quality.

Nitrogen Treatments				Hollow Heart (%)	Brown Center (%)	Scab (%)	Specific Gravity	Tuber Dry Matter (%)
Treatment #	Nitrogen Source[1]	Nitrogen Rate	Nitrogen Timing[2]					
		lb N/ac	P, E					
1	MAP + AMS	30	30, 0	0.0	0.0	0.0	1.0802	17.6
2	MAP + AMS, ESN	120	30, 90	0.0	0.0	0.0	1.0725	19.5
3	MAP + AMS, ESN	180	30, 150	2.0	2.0	0.0	1.0758	20.0
4	MAP + AMS, ESN	240	30, 210	2.0	2.0	0.0	1.0765	19.8
5	MAP + AMS, ESN	300	30, 270	3.3	4.3	0.0	1.0798	20.7
			Significance[3]	NS	NS	--	NS	NS
			LSD (0.10)	--	--	--	--	--

[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 tuber quality.

Nitrogen Treatments				Hollow Heart (%)	Brown Center (%)	Scab (%)	Specific Gravity	Tuber Dry Matter (%)
Treatment #	Nitrogen Source[1]	Nitrogen Rate	Nitrogen Timing[2]					
		lb N/ac	P, E					
1	MAP + AMS	30	30, 0	4.3 c	4.3 c	0.0	1.0985	26.6 ab
2	MAP + AMS, ESN	120	30, 90	11.0 bc	11.0 bc	4.3	1.1074	26.3 b
3	MAP + AMS, ESN	180	30, 150	15.0 bc	15.0 bc	0.0	1.1045	27.3 a
4	MAP + AMS, ESN	240	30, 210	37.8 a	37.8 a	0.0	1.1057	26.7 ab
5	MAP + AMS, ESN	300	30, 270	22.3 b	22.3 b	0.0	1.1020	24.9 c
			Significance[3]	**	**	NS	NS	**
			LSD (0.10)	14.2	14.2	--	--	1.0

[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 Russet Burbank tuber quality.

Nitrogen Treatments				Hollow Heart (%)	Brown Center (%)	Scab (%)	Specific Gravity	Tuber Dry Matter (%)
Treatment #	Nitrogen Source[1]	Nitrogen Rate	Nitrogen Timing[2]					
		lb N/ac	P, E					
1	MAP + AMS	30	30, 0	0.0 c	0.0 c	0.0	1.0758 c	20.0
2	MAP + AMS, ESN	120	30, 90	3.0 c	2.0 c	0.0	1.0839 a	19.7
3	MAP + AMS, ESN	180	30, 150	6.3 bc	6.3 bc	0.0	1.0823 ab	21.0
4	MAP + AMS, ESN	240	30, 210	19.0 a	19.0 a	3.0	1.0799 b	21.1
5	MAP + AMS, ESN	300	30, 270	18.3 ab	18.3 ab	0.0	1.0831 ab	20.8
			Significance[3]	*	++	NS	**	NS
			LSD (0.10)	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 16. Effect of nitrogen rate from ESN fertilizer on Ivory Crisp tuber quality.

Nitrogen Treatments				Hollow Heart (%)	Brown Center (%)	Scab (%)	Specific Gravity	Tuber Dry Matter (%)
Treatment #	Nitrogen Source[1]	Nitrogen Rate	Nitrogen Timing[2]					
		lb N/ac	P, E					
1	MAP + AMS	30	30, 0	0.0	0.0	18.8	1.0758 c	18.9 d
2	MAP + AMS, ESN	120	30, 90	1.0	1.0	9.0	1.0851 b	20.9 c
3	MAP + AMS, ESN	180	30, 150	1.0	1.0	20.0	1.0864 ab	21.1 bc
4	MAP + AMS, ESN	240	30, 210	1.0	2.0	17.0	1.0880 ab	22.1 ab
5	MAP + AMS, ESN	300	30, 270	1.0	1.0	18.0	1.0894 a	22.5 a
			Significance[3]	NS	NS	NS	**	**
			LSD (0.10)	--	--	--	0.0038	1.1

[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 17. Effect of nitrogen rate from ESN fertilizer on Snowden tuber quality.

Nitrogen Treatments				Hollow Heart (%)	Brown Center (%)	Scab (%)	Specific Gravity	Tuber Dry Matter (%)
Treatment #	Nitrogen Source[1]	Nitrogen Rate	Nitrogen Timing[2]					
		lb N/ac	P, E					
1	MAP + AMS	30	30, 0	0.0	0.0	1.0	1.0835	20.8 b
2	MAP + AMS, ESN	120	30, 90	0.0	0.0	12.0	1.0875	22.2 ab
3	MAP + AMS, ESN	180	30, 150	3.0	4.0	1.0	1.0893	22.8 a
4	MAP + AMS, ESN	240	30, 210	3.0	3.0	0.0	1.0871	22.4 ab
5	MAP + AMS, ESN	300	30, 270	6.0	6.0	4.3	1.0922	23.5 a
			Significance[3]	NS	NS	NS	NS	++
			LSD (0.10)	--	--	--	--	1.6

[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 18. Effect of nitrogen rate from ESN fertilizer on whole-tuber nitrogen, sucrose, and glucose concentrations of Alpine Russet potato plants.

Nitrogen Treatments				Tuber Nitrogen (%)	Sugar Concentration (mg/g)							
Treatment #	Nitrogen Source[1]	Nitrogen Rate	Nitrogen Timing[2]		0 Months		3 Months		6 Months		9 Months	
		lb N/ac	P, E		Sucrose	Glucose	Sucrose	Glucose	Sucrose	Glucose	Sucrose	Glucose
1	MAP + AMS	30	30, 0	1.16 c	1.52	2.37 a	1.30 ab	3.11 a	1.29	2.65 a	0.75	3.76 a
2	MAP + AMS, ESN	120	30, 90	1.29 bc	1.50	1.86 b	1.57 a	2.17 b	0.93	3.48 a	0.73	3.80 a
3	MAP + AMS, ESN	180	30, 150	1.18 c	1.46	1.50 bc	0.92 c	2.64 ab	0.98	2.99 a	0.72	3.50 a
4	MAP + AMS, ESN	240	30, 210	1.43 b	1.34	1.24 c	1.17 bc	1.81 b	0.89	2.75 a	0.38	1.96 b
5	MAP + AMS, ESN	300	30, 270	1.62 a	1.49	0.73 d	1.48 ab	1.74 b	0.86	1.40 b	0.51	1.38 b
			Significance[3]	**	NS	**	*	++	NS	*	NS	**
			LSD (0.10)	0.16	--	0.44	0.34	0.91	--	1.09	--	1.26

[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 19. Effect of nitrogen rate from ESN fertilizer on whole-tuber nitrogen, sucrose, and glucose concentrations of Dakota Trailblazer potato plants.

Nitrogen Treatments				Tuber Nitrogen (%)	Sugar Concentration (mg/g)							
Treatment #	Nitrogen Source[1]	Nitrogen Rate	Nitrogen Timing[2]		0 Months		3 Months		6 Months		9 Months	
		lb N/ac	P, E		Sucrose	Glucose	Sucrose	Glucose	Sucrose	Glucose	Sucrose	Glucose
1	MAP + AMS	30	30, 0	0.82 c	1.45	0.31 b	1.32	0.72	0.81	1.63	1.14	0.62
2	MAP + AMS, ESN	120	30, 90	0.86 c	1.35	0.61 a	1.07	0.54	0.88	0.68	0.94	0.95
3	MAP + AMS, ESN	180	30, 150	0.98 b	1.39	0.41 ab	1.79	0.51	1.13	0.60	1.18	0.85
4	MAP + AMS, ESN	240	30, 210	1.07 b	1.50	0.25 b	0.81	0.41	0.61	0.37	0.96	1.11
5	MAP + AMS, ESN	300	30, 270	1.19 a	1.38	0.48 ab	0.88	0.48	0.50	0.65	0.75	0.89
			Significance[3]	**	NS	++	NS	NS	NS	NS	NS	NS
			LSD (0.10)	0.12	--	0.26	--	--	--	--	--	--

[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 20. Effect of nitrogen rate from ESN fertilizer on whole-tuber nitrogen, sucrose, and glucose concentrations of Russet Burbank potato plants.

Nitrogen Treatments				Tuber Nitrogen (%)	Sugar Concentration (mg/g)							
Treatment #	Nitrogen Source[1]	Nitrogen Rate	Nitrogen Timing[2]		0 Months		3 Months		6 Months		9 Months	
		lb N/ac	P, E		Sucrose	Glucose	Sucrose	Glucose	Sucrose	Glucose	Sucrose	Glucose
1	MAP + AMS	30	30, 0	0.79 c	0.94	2.40	0.86	3.07 a	0.48	3.45 a	0.23	2.61
2	MAP + AMS, ESN	120	30, 90	1.06 b	0.78	1.49	1.22	2.42 ab	0.56	1.36 b	0.32	2.24
3	MAP + AMS, ESN	180	30, 150	1.12 ab	0.83	1.37	1.02	1.81 bc	0.49	1.98 b	0.23	1.81
4	MAP + AMS, ESN	240	30, 210	1.14 ab	0.95	1.76	0.85	1.88 bc	0.42	1.68 b	0.29	1.50
5	MAP + AMS, ESN	300	30, 270	1.23 a	1.24	1.56	1.27	1.58 c	0.60	1.52 b	0.33	1.67
			Significance[3]	**	NS	NS	NS	*	NS	*	NS	NS
			LSD (0.10)	0.18	--	--	--	0.72	--	1.09	--	--

[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 21. Effect of nitrogen rate from ESN fertilizer on whole-tuber nitrogen, sucrose, and glucose concentrations of Ivory Crisp potato plants.

Nitrogen Treatments				Tuber Nitrogen (%)	Sugar Concentration (mg/g)							
Treatment #	Nitrogen Source[1]	Nitrogen Rate	Nitrogen Timing[2]		0 Months		3 Months		6 Months		9 Months	
		lb N/ac	P, E		Sucrose	Glucose	Sucrose	Glucose	Sucrose	Glucose	Sucrose	Glucose
1	MAP + AMS	30	30, 0	0.98 d	0.37	0.61 a	0.48	0.44 a	0.55	1.67	0.33	2.16 a
2	MAP + AMS, ESN	120	30, 90	1.09 c	0.52	0.28 b	0.61	0.21 b	0.41	0.60	1.05	1.10 b
3	MAP + AMS, ESN	180	30, 150	1.19 b	0.66	0.29 b	0.76	0.15 b	0.95	0.66	1.30	0.73 bc
4	MAP + AMS, ESN	240	30, 210	1.20 b	0.63	0.24 b	0.81	0.14 b	0.86	0.53	0.92	0.56 bc
5	MAP + AMS, ESN	300	30, 270	1.48 a	0.92	0.11 b	0.72	0.18 b	1.24	0.22	1.39	0.48 c
			Significance[3]	**	NS	*	NS	**	NS	NS	NS	**
			LSD (0.10)	0.07	--	0.21	--	0.08	--	--	--	0.59

[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 22. Effect of nitrogen rate from ESN fertilizer on whole-tuber nitrogen, sucrose, and glucose concentrations of Snowden potato plants.

Nitrogen Treatments				Tuber Nitrogen (%)	Sugar Concentration (mg/g)							
Treatment #	Nitrogen Source[1]	Nitrogen Rate	Nitrogen Timing[2]		0 Months		3 Months		6 Months		9 Months	
		lb N/ac	P, E		Sucrose	Glucose	Sucrose	Glucose	Sucrose	Glucose	Sucrose	Glucose
1	MAP + AMS	30	30, 0	1.11	1.18 a	0.29 a	0.91	0.42	1.43	0.99	2.36	3.41
2	MAP + AMS, ESN	120	30, 90	1.21	1.13 ab	0.30 a	0.87	0.44	1.17	0.53	1.22	2.48
3	MAP + AMS, ESN	180	30, 150	1.03	0.95 bc	0.16 b	0.96	0.23	1.87	0.77	1.98	2.93
4	MAP + AMS, ESN	240	30, 210	1.14	1.05 abc	0.22 ab	0.67	0.20	1.32	0.42	2.67	2.57
5	MAP + AMS, ESN	300	30, 270	1.16	0.91 c	0.12 b	0.73	0.10	0.97	0.33	2.23	2.82
			Significance[3]	NS	++	++	NS	NS	NS	NS	NS	NS
			LSD (0.10)	--	0.20	0.12	--	--	--	--	--	--

[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 23. Effect of nitrogen rate from ESN fertilizer on tuber frying quality of Ivory Crisp potato tubers.

Nitrogen Treatments				Frying Quality							
Treatment #	Nitrogen Source[1]	Nitrogen Rate	Nitrogen Timing[2]	0 Months		3 Months		6 Months		9 Months	
		lb N/ac	P, E	Chip Color[4]	AGT Score	Chip Color[4]	AGT Score	Chip Color[4]	AGT Score	Chip Color[4]	AGT Score
1	MAP + AMS	30	30, 0	2.3	56.0	2.0	57.3 ab	2.0	56.0	3.0 a	50.3 b
2	MAP + AMS, ESN	120	30, 90	2.0	58.5	2.0	57.8 ab	2.0	57.5	2.3 b	57.0 a
3	MAP + AMS, ESN	180	30, 150	2.0	58.0	2.3	56.0 b	2.0	59.0	2.0 b	58.8 a
4	MAP + AMS, ESN	240	30, 210	2.3	58.0	2.0	59.0 a	2.0	58.0	2.0 b	59.5 a
5	MAP + AMS, ESN	300	30, 270	2.0	58.3	2.0	59.3 a	2.0	58.3	2.3 b	58.0 a
			Significance[3]	NS	NS	NS	++	--	NS	*	*
			LSD (0.10)	--	--	--	2.4	--	--	0.5	5.5

[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%.

[4]Chip Color Score: 1 = light and 5 = dark.

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

Table 24. Effect of nitrogen rate from ESN fertilizer on frying quality of Snowden potato tubers.

Nitrogen Treatments				Frying Quality							
Treatment #	Nitrogen Source[1]	Nitrogen Rate	Nitrogen Timing[2]	0 Months		3 Months		6 Months		9 Months	
		lb N/ac	P, E	Chip Color[4]	AGT Score	Chip Color[4]	AGT Score	Chip Color[4]	AGT Score	Chip Color[4]	AGT Score
1	MAP + AMS	30	30, 0	2.0	58.8	2.0	58.3	2.3	53.7	3.8	42.0
2	MAP + AMS, ESN	120	30, 90	2.0	57.8	2.0	58.8	2.5	54.8	3.8	43.0
3	MAP + AMS, ESN	180	30, 150	2.0	58.3	2.0	59.0	2.5	55.3	3.5	43.0
4	MAP + AMS, ESN	240	30, 210	2.0	58.8	2.0	57.8	2.0	57.8	3.0	46.8
5	MAP + AMS, ESN	300	30, 270	2.3	59.0	2.0	58.8	2.0	58.0	3.3	44.0
			Significance[3]	NS	NS	NA	NS	NS	NS	NS	NS
			LSD (0.10)	--	--	--	--	--	--	--	--

[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%.

[4]Chip Color Score: 1 = light and 5 = dark.

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

Table 25. Effect of nitrogen rate from ESN fertilizer on acrylamide concentration of Alpine Russet French fries.

Nitrogen Treatments				Acrylamide Concentration (ppb, fresh-weight basis)			
Treatment #	Nitrogen Source[1]	Nitrogen Rate	Nitrogen Timing[2]				
		lb N/ac	P, E	0 Months	3 Months	6 Months	9 Months
1	MAP + AMS	30	30, 0	420	629	543 cd	912
2	MAP + AMS, ESN	120	30, 90	359	824	705 bc	1071
3	MAP + AMS, ESN	180	30, 150	532	525	816 ab	1520
4	MAP + AMS, ESN	240	30, 210	476	529	1010 a	1128
5	MAP + AMS, ESN	300	30, 270	403	789	478 d	756
			Significance[3]	NS	NS	**	NS
			LSD (0.10)	--	--	225	--

[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 26. Effect of nitrogen rate from ESN fertilizer on acrylamide concentration of Dakota Trailblazer French fries.

Nitrogen Treatments				Acrylamide Concentration (ppb, fresh-weight basis)			
Treatment #	Nitrogen Source[1]	Nitrogen Rate	Nitrogen Timing[2]				
		lb N/ac	P, E	0 Months	3 Months	6 Months	9 Months
1	MAP + AMS	30	30, 0	137 ab	691	114	257
2	MAP + AMS, ESN	120	30, 90	181 a	254	312	192
3	MAP + AMS, ESN	180	30, 150	85 b	445	192	449
4	MAP + AMS, ESN	240	30, 210	93 b	413	219	459
5	MAP + AMS, ESN	300	30, 270	100 b	382	226	306
			Significance[3]	++	NS	NS	NS
			LSD (0.10)	67	--	--	--

[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.

Rb =

Table 27. Effect of nitrogen rate from ESN fertilizer on acrylamide concentration of Russet Burbank French fries.

Nitrogen Treatments				Acrylamide Concentration (ppb, fresh-weight basis)			
Treatment #	Nitrogen Source[1]	Nitrogen Rate	Nitrogen Timing[2]				
		lb N/ac	P, E	0 Months	3 Months	6 Months	9 Months
1	MAP + AMS	30	30, 0	407 b	491	408	564
2	MAP + AMS, ESN	120	30, 90	474 b	669	845	996
3	MAP + AMS, ESN	180	30, 150	760 a	1085	1118	840
4	MAP + AMS, ESN	240	30, 210	443 b	755	788	955
5	MAP + AMS, ESN	300	30, 270	826 a	745	713	1016
			Significance[3]	**	NS	NS	NS
			LSD (0.10)	186	--	--	--

[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 28. Effect of nitrogen rate from ESN fertilizer on acrylamide concentration of Ivory Crisp potato chips.

Nitrogen Treatments				Acrylamide Concentration (ppb, fresh-weight basis)			
Treatment #	Nitrogen Source[1]	Nitrogen Rate	Nitrogen Timing[2]				
		lb N/ac	P, E	0 Months	3 Months	6 Months	9 Months
1	MAP + AMS	30	30, 0	3533	2929	3039 a	4037 a
2	MAP + AMS, ESN	120	30, 90	3031	2737	1334 b	2832 b
3	MAP + AMS, ESN	180	30, 150	3615	3484	1024 b	2194 bc
4	MAP + AMS, ESN	240	30, 210	3187	1840	1802 b	1555 c
5	MAP + AMS, ESN	300	30, 270	3114	2861	1376 b	1727 c
			Significance[3]	NS	NS	++	**
			LSD (0.10)	--	--	1044	1094

[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 29. Effect of nitrogen rate from ESN fertilizer on acrylamide concentration of Snowden potato chips.

Nitrogen Treatments				Acrylamide Concentration (ppb, fresh-weight basis)			
Treatment #	Nitrogen Source[1]	Nitrogen Rate	Nitrogen Timing[2]				
		lb N/ac	P, E	0 Months	3 Months	6 Months	9 Months
1	MAP + AMS	30	30, 0	2950	1697 b	2993 a	10044
2	MAP + AMS, ESN	120	30, 90	3363	3152 a	2564 ab	10881
3	MAP + AMS, ESN	180	30, 150	3182	1725 b	3035 a	11632
4	MAP + AMS, ESN	240	30, 210	2568	1291 b	1553 b	7431
5	MAP + AMS, ESN	300	30, 270	3330	1587 b	1620 b	7760
			Significance[3]	NS	**	*	NS
			LSD (0.10)	--	816	1042	--

[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 30. Acrylamide contents of fries and chips vs. raw tuber sugar and nitrogen concentrations[1].

Cultivar	Acrylamide vs:	R^2 (corrected)	P	N	Direction
Alpine Russet	Sucrose, harvest	0.1593 (0.1099)	0.0905	19	+
	Sucrose, 3 months	0.0987 (0.0386)	0.2194	17	+
	Sucrose, 6 months	0.0430 (-0.0169)	0.4093	18	-
	Sucrose, 9 months	0.0025 (-0.0529)	0.8334	20	+
	Glucose, harvest	0.0096 (-0.0487)	0.6903	19	-
	Glucose, 3 months	0.0592 (-0.0035)	0.3468	17	+
	Glucose, 6 months	0.1663 (0.1142)	0.0930	18	+
	Glucose, 9 months	0.0783 (0.0271)	0.2321	20	+
	Nitrogen, harvest	0.0009 (-0.0579)	0.9035	19	+
	Nitrogen, 3 months	0.1302 (0.0723)	0.1547	17	+
	Nitrogen, 6 months	0.0440 (-0.0157)	0.4033	18	-
	Nitrogen, 9 months	0.1211 (0.0722)	0.1328	20	-
Dakota Trailblazer	Sucrose, harvest	0.0109 (-0.0440)	0.6608	20	-
	Sucrose, 3 months	0.1177 (0.0625)	0.1634	18	-
	Sucrose, 6 months	0.0178 (-0.0578)	0.6356	15	+
	Sucrose, 9 months	0.0422 (-0.0110)	0.3850	20	+
	Glucose, harvest	0.1416 (0.0940)	0.1019	20	+
	Glucose, 3 months	0.1091 (0.0534)	0.1808	18	+
	Glucose, 6 months	0.0502 (-0.0229)	0.4222	15	-
	Glucose, 9 months	0.1107 (0.0613)	0.1517	20	+
	Nitrogen, harvest	0.1625 (0.1160)	0.0780	20	-
	Nitrogen, 3 months	0.0125 (-0.0492)	0.6583	18	-
	Nitrogen, 6 months	0.0024 (-0.0743)	0.8616	15	-
	Nitrogen, 9 months	0.0000 (-0.0555)	0.9801	20	-
Russet Burbank	Sucrose, harvest	0.0748 (0.0204)	0.2572	19	+
	Sucrose, 3 months	0.1239 (0.0723)	0.1395	19	-
	Sucrose, 6 months	**0.2564 (0.2099)**	**0.0320**	**18**	**+**
	Sucrose, 9 months	0.0406 (-0.0158)	0.4082	19	+
	Glucose, harvest	0.0316 (-0.0254)	0.4667	19	-
	Glucose, 3 months	0.0141 (-0.0439)	0.6278	19	+
	Glucose, 6 months	0.0289 (-0.0318)	0.5002	18	-
	Glucose, 9 months	0.0282 (-0.0290)	0.4972	19	-
	Nitrogen, harvest	0.1474 (0.0973)	0.1046	19	+
	Nitrogen, 3 months	0.0007 (-0.0581)	0.9140	19	+
	Nitrogen, 6 months	0.0629 (0.0043)	0.3156	18	+
	Nitrogen, 9 months	0.0784 (0.0242)	0.2456	19	+
Ivory Crisp	Sucrose, harvest	0.0459 (-0.0138)	0.3935	18	-
	Sucrose, 3 months	**0.2274 (0.1791)**	**0.0454**	**18**	**+**
	Sucrose, 6 months	0.0396 (-0.0204)	0.4286	18	-
	Sucrose, 9 months	0.0114 (-0.0467)	0.6633	19	+
	Glucose, harvest	0.0247 (-0.0362)	0.5330	18	+
	Glucose, 3 months	0.0813 (0.0239)	0.2515	18	+
	Glucose, 6 months	0.0034 (-0.0589)	0.8177	18	+
	Glucose, 9 months	**0.3272 (0.2876)**	**0.0105**	**19**	**+**
	Nitrogen, harvest	0.0009 (-0.0615)	0.9045	18	+
	Nitrogen, 3 months	0.0088 (-0.0531)	0.7108	18	+
	Nitrogen, 6 months	0.1174 (0.0623)	0.1639	18	-
	Nitrogen, 9 months	**0.2660 (0.2229)**	**0.0238**	**19**	**-**
Snowden	Sucrose, harvest	0.0417 (-0.0116)	0.3879	20	+
	Sucrose, 3 months	0.0591 (0.0068)	0.3017	20	+
	Sucrose, 6 months	0.1458 (0.0984)	0.0966	20	+
	Sucrose, 9 months	0.0105 (-0.0445)	0.6672	20	-
	Glucose, harvest	0.0783 (0.0271)	0.2322	20	+
	Glucose, 3 months	**0.2305 (0.1877)**	**0.0322**	**20**	**+**
	Glucose, 6 months	**0.2131 (0.1694)**	**0.0405**	**20**	**+**
	Glucose, 9 months	0.0638 (0.0118)	0.2828	20	+
	Nitrogen, harvest	0.0645 (0.0126)	0.2797	20	-
	Nitrogen, 3 months	0.1492 (0.1019)	0.0925	20	+
	Nitrogen, 6 months	0.1415 (0.0938)	0.1022	20	-
	Nitrogen, 9 months	0.0213 (-0.0331)	0.5329	20	-

[1]Linear regressions: Acrylamide content of fried potato product at each sampling period as a function of whole-tuber glucose or sucrose content in the same period or whole-tuber nitrogen content at harvest.

Table 31. Whole-tuber sugar concentrations of participating growers' potato plants.

Grower	Variety	Preparation	Sugar Concentration (mg/g)							
			0 Months		3 Months		6 Months		9 Months	
			Sucrose[1]	Glucose[1]	Sucrose[1]	Glucose[1]	Sucrose[1]	Glucose[1]	Sucrose[1]	Glucose[1]
K+O	Alpine Russet	Fry	2.11 ± 0.74	0.82 ± 0.34	1.74 ± 0.44	0.97 ± 0.54	0.94 ± 0.10	0.73 ± 0.17	2.75 ± 2.74	1.90 ± 1.97
K+O	Russet Burbank	Fry	1.82 ± 0.84	0.95 ± 0.42	1.58 ± 0.57	1.05 ± 0.23	0.77 ± 0.33	0.71 ± 0.16	1.49 ± 0.85	1.22 ± 0.41
Park Rapids Bliss	Russet Burbank	Fry	0.89 ± 0.33	0.74 ± 0.30	1.03 ± 0.19	1.13 ± 0.36	0.73 ± 0.06	1.17 ± 0.21	0.90 ± 0.13	1.19 ± 0.50
Park Rapids HCBE	Russet Burbank	Fry	1.22 ± 0.12	1.02 ± 0.27	0.98 ± 0.22	1.16 ± 0.42	0.55 ± 0.08	0.91 ± 0.33	0.89 ± 0.14	0.74 ± 0.36
Perham-Karsina	Dakota Trailblazer	Fry	1.12 ± 0.15	0.58 ± 0.13	1.44 ± 0.05	0.90 ± 0.23	1.00 ± 0.28	0.57 ± 0.11	1.08 ± 0.09	0.45 ± 0.34
Perham-RDO	Ivory Crisp	Chip	1.75 ± 0.63	0.12 ± 0.04	1.28 ± 0.26	0.27 ± 0.15	0.72 ± 0.05	0.05 ± 0.03	1.66 ± 0.10	0.39 ± 0.20
Goenner	Snowden	Chip	0.81 ± 0.14	0.08 ± 0.04	0.61 ± 0.01	0.11 ± 0.03	0.83 ± 0.15	0.27 ± 0.19	2.69 ± 0.38	2.39 ± 0.78
		Significance[2]	*	**	**	**	NS	**	NS	NS
		LSD (0.10)	0.85	0.39	0.48	0.49	--	0.27	--	--

[1]Mean ± S.D.

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

Table 32. Tuber frying quality of participating growers' potato tubers.

Grower	Variety	Preparation	Frying Quality							
			0 Months		3 Months		6 Months		9 Months	
			Chip Color[1,2]	AGT Score[1]	Chip Color[1,2]	AGT Score[1]	Chip Color[1,2]	AGT Score[1]	Chip Color[1,2]	AGT Score[1]
Perham-RDO	Ivory Crisp	Chip	2.0 ± 0.0	57.7 ± 3.1	2.0 ± 0.0	59.3 ± 2.1	-	-	2.0 ± 0.0	58.0 ± 1.7
Goenner	Snowden	Chip	2.0 ± 0.0	62.7 ± 1.2	2.0 ± 0.0	59.0 ± 1.0	2.0 ± 0.0	57.3 ± 1.2	3.0 ± 0.0	50.3 ± 3.2

[1]Mean ± S.D.

[2]Chip Color Score: 1 = light and 5 = dark.

Table 33. Acrylamide concentrations of French fries and chips from participating growers' potato plants.

Grower	Variety	Preparation	Acrylamide Concentration[1] (ppb, fresh-weight basis)			
			0 Months	3 Months	6 Months	9 Months
K+O	Alpine Russet	Fry	409 ± 205	619 ± 34	633 ± 395	1291 ± 643
K+O	Russet Burbank	Fry	582 ± 281	802 ± 362	519 ± 219	1306 ± 249
Park Rapids Bliss	Russet Burbank	Fry	678 ± 220	717 ± 427	781 ± 91	788 ± 142
Park Rapids HCBE	Russet Burbank	Fry	493 ± 67	838 ± 321	681 ± 171	834 ± 116
Perham-Karsina	Dakota Trailblazer	Fry	554 ± 49	371 ± 243	584 ± 121	908 ± 363
Perham-RDO	Ivory Crisp	Chip	3510 ± 859	2020 ± 658	1056 ± 119	1469 ± 320
Goenner	Snowden	Chip	2197 ± 608	1311 ± 156	1908 ± 994	5930 ± 563

[1]Mean ± S.D.

Glyphosate residues affect granddaughter seed potato growth in commercial potato fields
Submitted to MN Area II and NPPGA

Andrew P. Robinson
Department of Plant Sciences
North Dakota State University and University of Minnesota

Executive Summary
Seed potato plants exposed to glyphosate can translocate the herbicide to the daughter tubers causing emergence problems the following year. Symptoms of glyphosate carryover in clones include erratic and slow emergence, malformed leaves, multiple shoots from a single eye, and/or enlarged shoots. The purpose of this study was to determine the effect of glyphosate residues in seed pieces on yield. Ten plant-to-plant comparisons were made to compare a normally growing plant to a glyphosate-affected plant. Seed pieces with glyphosate residues there were delayed in emergence by 3 weeks had a 67% reduction in yield, a 50% reduction in tuber number, and a 38% reduction in tuber weight.

Introduction
Seed potato (*Solanum tuberosum*) plants exposed to low levels of glyphosate during the growing season can store the glyphosate in the daughter tubers resulting in delayed emergence when they are planted the next growing season (Worthington, 1985). Glyphosate is the one of the most widely used herbicide in the United States because of the rapid adoption of genetically modified crops, low cost, and effective control of weeds. In North Dakota 31% of crop acreage was treated with glyphosate in 2008 (Zollinger, McMullen, et al., 2009).

Seed potato fields can unintentionally come into contact with glyphosate by contamination of spraying equipment, inversions, physical drift, or misapplication. The level of glyphosate that comes into contact with potatoes will vary, but often the low levels of glyphosate during bulking do not cause visible foliar symptoms. This can make early detection of glyphosate toxicity in daughter tubers difficult to determine. Because glyphosate is phloem mobile, it will translocate throughout the plant reaching highest levels within four days in the meristematic tissues (Smid and Hiller, 1981). The amount translocated will vary by the amount of glyphosate coming in contact with the potato plant and the temperature, with greater absorption of glyphosate at higher temperatures (Masiunas and Weller, 1988).

Symptoms of glyphosate carryover in seed pieces include an erratic and slow emergence; bending, twisting, and yellowing of new leaves; multiple shoots coming from a single eye; “candelabra” formation of shoots; “cauliflower” formation of shoots around an eye; enlarged shoots; and reduced rooting (Figure 1 and 2) (Worthington, 1985). Less in known about the effect glyphosate residues in potato seed have on the yield of potatoes planted the following year.

Research Objectives
1. The purpose of this study was to compare normally growing plants with plants affected by glyphosate residues in the seed.

Materials and Methods

Three commercial fields planted with confirmed glyphosate contamination were identified in North Dakota and Minnesota. Glyphosate contamination was suspected based on symptomology in the field and confirmed in samples from two fields sent to a commercial laboratory for analysis using a liquid chromatography with tandem mass spectrometry detection. Levels ranged from 0.015 to 0.036 ppm glyphosate. The potato clones from each field were grown in North Dakota in 2011. The potato cultivars were Dark Red Norland, Yukon Gold, and Red LaSoda. In each field 10 adjacent plants were flagged to compare a normally growing plant to a glyphosate-affected plant that was delayed in emergence by approximately three weeks (Figure 3). After vine kill potato hills were hand harvested and yield and tuber number were recorded. Data was analyzed using the SAS MIXED procedure with field as the replication. Means were separated using Tukey's pair-wise comparison ($P \leq 0.05$).

Results

Yield in plants from seed pieces affected by glyphosate had a 67% (from 2.25 to 0.75 lb/hill) reduction in yield, a 50% reduction in tuber number (10 to 5 tubers/hill), and a mean tuber weight reduction of 38% (3.92 to 2.40 oz/tuber) (Figure 4).

Summary and Conclusions

The amount of glyphosate in the tubers can determine the degree that the potato tubers are affected, with higher levels preventing or reducing emergence for a greater period of time. However, a low incidence of seed with glyphosate residues may not reduce field production significantly, because the affected plants may have little delay in emergence. Additionally, potato plants affected by glyphosate can be weak and may be easily attacked by pests and diseases, and allow weeds to germinate. It is unknown if glyphosate residues in seed pieces will effect tuber initiation, or if the reduction in tuber number and mass is a result of plant-to-plant competition.

Literature Cited

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Figure 1. Effects of glyphosate residues in seed potato on potato foliage, (a) delayed and erratic emergence, (b) yellowing of leaves, (c) bending and twisting of leaves, and (d) swollen stems.

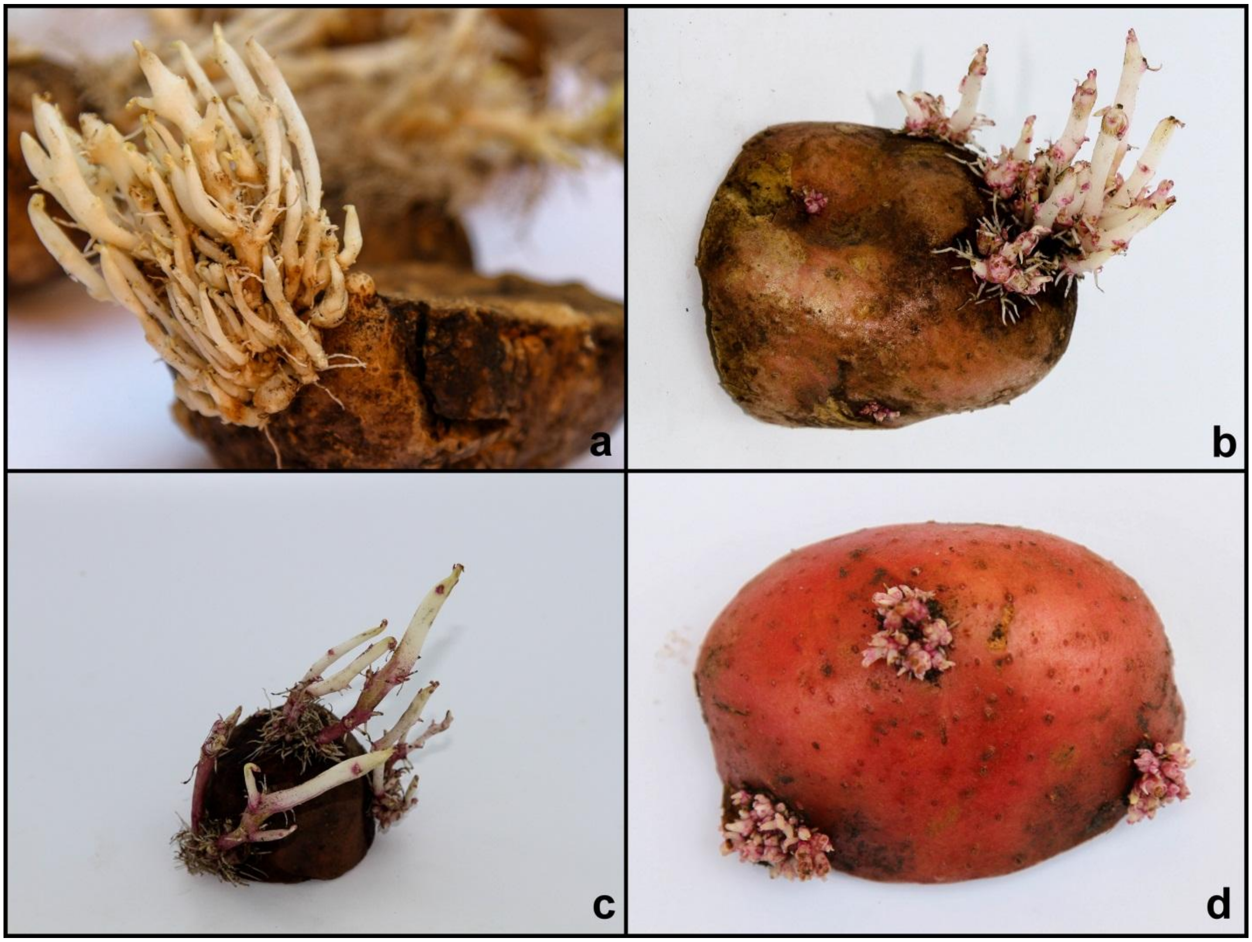

Figure 2. Effects of glyphosate residues in seed potatoes when planted the following year (1) multiple sprouting from a single eye, (b) delay in sprouting, (c) ‘candelabra’ sprouts starting to develop, (d) ‘cauliflower’ formation of sprouts.

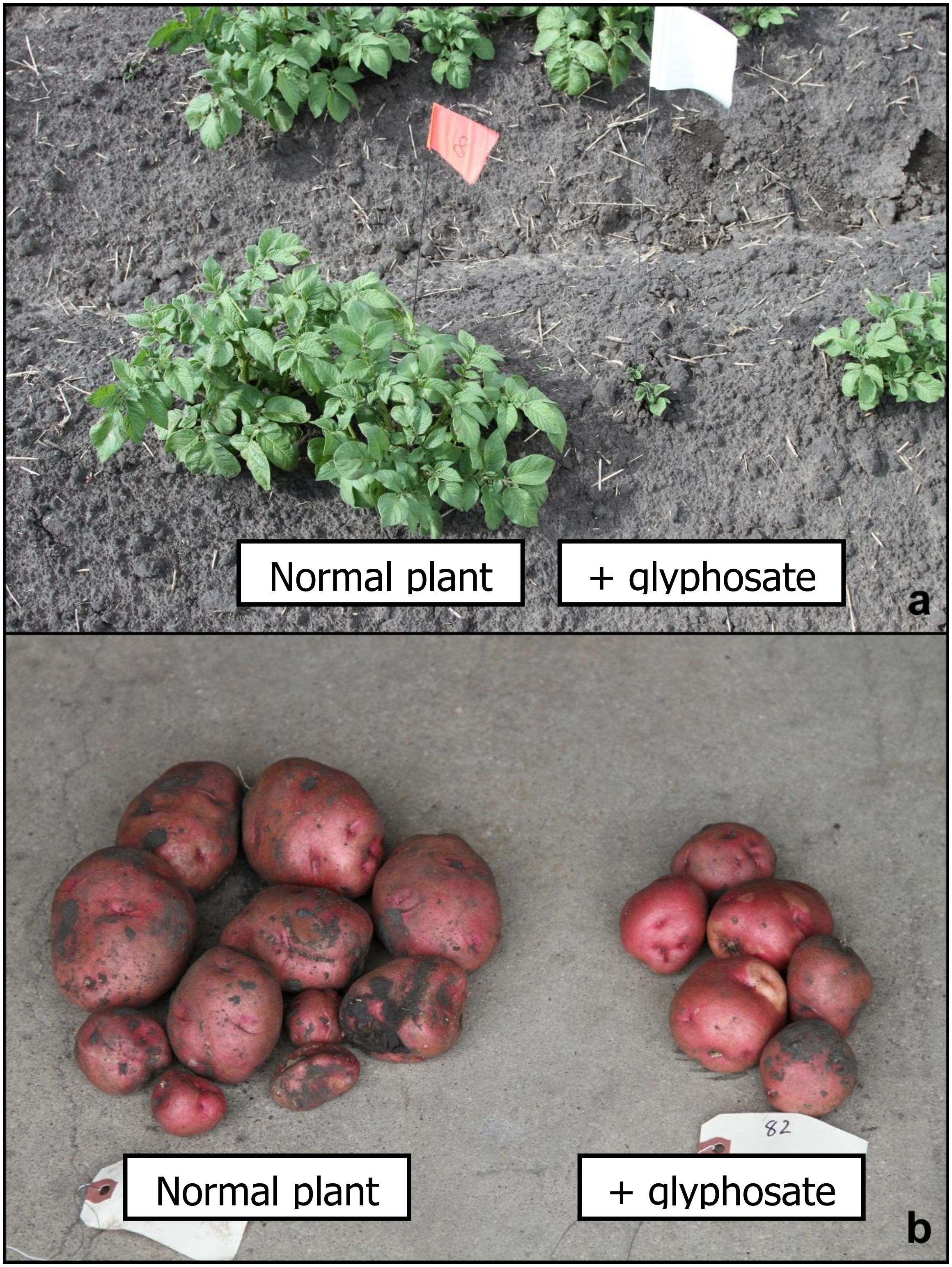
Normal plant
+ glyphosate
a
82
Normal plant
+ glyphosate
b

Figure 3. Effect of glyphosate residues in potato seed compared to a normally growing plant at (a) emergence and (b) harvested yield.

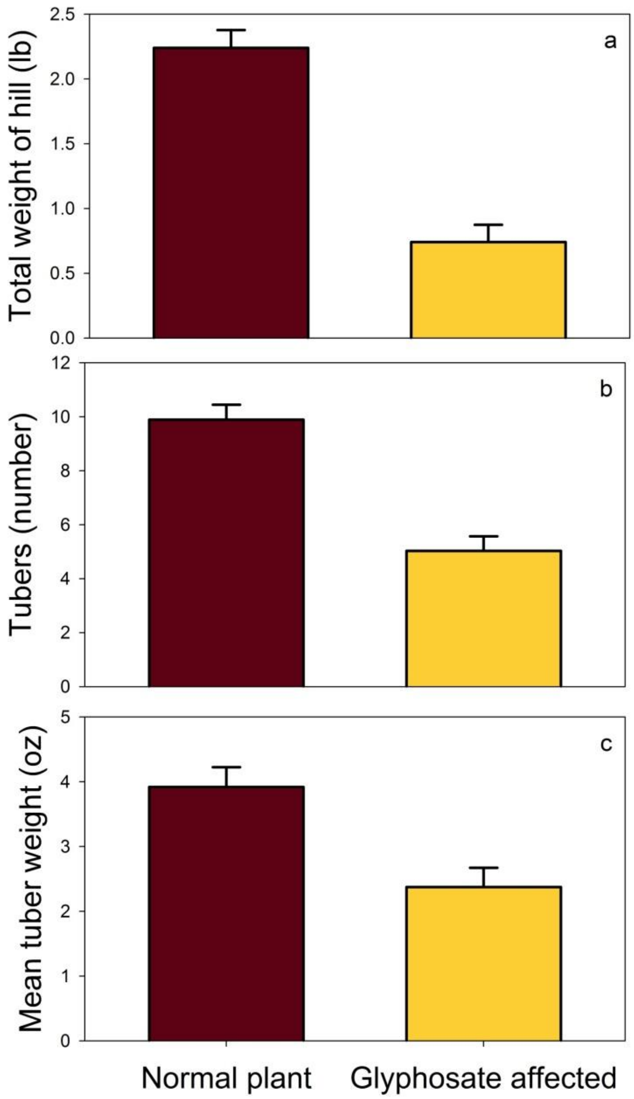

Figure 4. Effect of glyphosate residues in potato seed on a single potato hill's (a) yield, (b) tuber number, and (c) mean tuber weight. Error bars represent one standard deviation.

Effect of Nitrogen and In-row Spacing on Red Norland Yield
Submitted to MN Area II and NPPGA

Andrew P. Robinson
Department of Plant Sciences
North Dakota State University and University of Minnesota

Executive Summary

Potato production in the Red River Valley on non-irrigated soils has seen little increase (0.7 cwt/acre/year) in yields in the past 20 years. Adjusting seeding rate and nitrogen fertilization are two easy practices that may improve yield and profits. Fertilization and seed costs account for 38% of operating inputs. This study was designed to quantify the effect of nitrogen rates and in-row seed spacing on yield and size. Seed spacing made the great difference in potato yield and size distribution. The 9 and 12 inch spaces produced the higher total yield and A-sized potatoes.

Introduction

The Red River Valley is known for its red potato production and is the top producer of red potatoes in the United States. Over the past twenty years, yields of non-irrigated potatoes have averaged 0.7 cwt/acre/year increase in yield, while irrigated potatoes averaged 4.9 cwt/acre/year increase in yield (USDA-NASS, 2012). Increased yields may be attributed to better cultivars, improved management practices, and technology to name a few reasons.

Cultural practices are perhaps the most important and least expensive considerations that affect yield. These may include planting date, crop rotations, and seeding rate. Potato seed spacing can be adjusted to change the size profile of potatoes, but this can vary by cultivar. Moisture may also affect the response of potatoes to seeding rates. Seed costs account for 13% of operating inputs or $370/acre in Russet Burbank potatoes (Patterson, 2012).

Potatoes require a high amount of fertilization for production. It was estimated that $720/acre, or 25% of operating input costs were spent on fertilization in Idaho in 2012 on Russet Burbank potatoes (Patterson, 2012). By reducing nitrogen, not only are costs reduced, but this reduces the risk of nitrogen pollution in the environment, weed growth and competition in potato fields, and the work load of growers. Nitrogen requirements for non-irrigated potatoes in North Dakota ranges from 80 to 160 lb/N/acre for 200 to 400 cwt/acre potato yield (Dahnke and Nelson, 1993). Alterations in cultural practices and nutrient management are two simple ways that can dramatically effect plant growth and yield and potentially reduce operating inputs. Little research has been done to quantify the effect of in-row seed spacing and nitrogen rates.

Research Objectives

1. To quantify the effect of different nitrogen rates and in-row seed spacing on red potato yield and quality.

Materials and Methods

A replicated field trial using a randomized complete block design with a factorial arrangement was established at the NPPGA research farm in Grand Forks, ND on 4 June 2012. Red Norland potatoes were planted at 6, 9, and 12 inch spacing in-row in 36-inch rows. Plots measured 25 feet long by 12 feet wide. Starter fertilizer of 30 lb N/acre was applied at planting. Two weeks after planting controlled release nitrogen, ESN was broadcast over plots to bring total nitrogen levels to 80, 120, 160, and 200 lb N/acre. All other fertility and pest management practices were conducted according to NDSU recommended practices. Vines were killed on 23 September by frost. The middle two rows of each plot were mechanically harvested on 10 October. Potatoes were thereafter sorted into C size (<1.5 in), B size (1.5 to 2.25 in), A size (2.25 to 3.5 in), and Jumbo size (>3.5 in) using a Kerian Speed Sizer. Analysis of variance was performed to determine the differences between nitrogen and seed spacing.

Results and Conclusions

Nitrogen rate only affected total yield. Total yield was similar at 80, 120, and 160 lb N/a, but at 200 lb N/acre yield was deceased (Table 1). This was likely a result of too much nitrogen encouraging vine growth and not enough nitrogen being partitioned to tuber growth. Seed spacing affected total yield and each size of potato (Table 2). The 9 and 12 inch spacing had higher total yield and A size than 6 inch spacing. Jumbo size was increased at 6 and 9 inches, while B and C size were maximized at 12 inch spacing. Increase in total yield, A, B, and C sizes at the greater seed spacing could be attributed to the low amount of precipitation. At lower seeding rates, less water is needed; whereas at higher plant populations more water is needed to sustain plant growth. Also, the greater the spacing the more tubers set, which encourages more tubers in the B and C sizes. A lower tuber set from higher plant population resulted in more Jumbo sized potatoes. Year-to-year variability in precipitation will greatly affect the response of dryland potato production. Future research will continue this study to determine if any trends can be found across years.

Literature Cited

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USDA-NASS. 2012. United States Department of Agriculture National Agricultural Statistics Service Quick Stats. Online. http://quickstats.nass.usda.gov.

Patterson, P. E. 2012. 2012 cost of potato production in Idaho: 5 – year trend. Agricultural Economics Series No. 12-04. University of Idaho. Online: http://web.cals.uidaho.edu/idahoagbiz/files/2013/01/2012-Cost-of-Potato-Production-5-Year-Trends.pdf

Table 1. Effect of nitrogen rate on tuber yield. Means followed by the same letter are not different within column (P<0.05).

Nitrogen rate (lb/acre)	Yield (lb)	
80	81.36	AB
120	84.72	A
160	82.72	AB
200	75.37	B

Table 2. Effect of seeding rate on tuber yield. Means followed by the same letter are not significantly different within column (P<0.05).

Seeding rate (in)	Total yield		Jumbo size		A size		B size		C size	
	lbs.									
6	70.86	B	8.17	AB	46.24	B	15.52	B	0.93	B
9	83.25	A	8.87	A	54.01	A	19.23	B	1.15	B
12	89.02	A	5.38	B	52.18	AB	29.88	A	1.58	A

Breeding & Development for the Northern Plains Region – 2012

University of Minnesota Potato Breeding & Genetics

Dr. Christian A. Thill, Associate Professor, Potato Breeder
Department of Horticultural Sciences
St. Paul, MN

Mr. Jeffrey Miller, Research Scientist
Department of Horticultural Sciences
USDA Potato Research Laboratory
East Grand Forks, MN

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.

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, MN02467Rus/Y, MN10001PLWR-03LW for fry processing; MN02467Rus/Y & MN10013PLWR-02LW/Y for fresh russet; MN10001PLWR-01R, MN10003PLWR-02R, MN10003PLWR-06R, MN10008PLWR-07R, MN10020PLWR-04R, & MN10025PLWR-07R & MN02616R/Y for fresh red; MN03339-4, MN02588, MN99380-1Y & MN10013PLWR-04 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 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. The red skin yellow flesh line MN02616R/Y is being expanded for commercialization was released 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 (10) and ND (4). 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 2012: 165

Single Hill Population: 4,000 @ UMORE Park, 26,620 @ Nesson Valley (Russet only population); 30,000@PLWR

Single Hill (G0) Selections:

	Nesson	*PLWR*	*Total*
Russet	62	60	122
Red	11	49	60
Chip	9	123	132
Yellow		9	9
Other			
Total	82	241	323

First Year (G1) Selections: 10 @ Becker; 21 @ Nesson Valley; 17 @ Grand Rapids

Second Year (G2) Selections: 53 @ Becker, 53 @ 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. Of the 49 red selections grown in 2012, 17 of the selections will be advanced into 2013. These clones were evaluated on-farm at Petersons (Big Lake), Moquist (Northern Valley), and PLWR (as seed). The 17 selections will be evaluated on-farm in 2013.

Third year (G3) Selections: 7 @ Becker, and Nesson Valley, All 3 Disease Trials

Fourth Year (G4) selections: 7 @ Becker and Nesson Valley, All 3 Disease Trials

Fifth Year and greater Selections: 16 @ Becker, 16 @ Nesson Valley, All 3 Disease Trials

Strip-trial at Nesson Valley;

Five breeding lines were grown in 200-hill, 2-row strip plots to determine commercial handling and adaptation. Red lines are stored at USDA and are being evaluated monthly for storage quality.

Processing MonDak Gold

Russet Fresh MN02467Y

Yellow MN02586Y & MN04844-07Y

Speciality MN07112WB-1W/P

2012 Locations & Entries: (& planting dates)

A) MN Locations:

1) **UM Sand Plains Research and Outreach Station:** Becker, MN: Minnesota yield trials, North Central Regional Potato Trials (NCRPVT); Planted: 25.April.2012. Common scab nursery: screening of MN clones, NCRPVT clones, NCPT, NFPT, National Scab, & other's as requested. The primary focus of common scab 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). Planted: 26.April.2012. Christian Thill, Jeffrey Miller, Susie Thompson, David Douches, Jiwan Palta, Kathy Haynes, USPB National Chip Performance Trial, and USPB National Fry Performance Trial.

2) **UM North Central and Outreach Center**: Grand Rapids, MN: Seed Potato Certification Trial involving the increase of UM potato breeding lines for seed potato certification. Planted: 17.May.2012. 17 of the 549 entries were selected to move forward in 2013. This is a new seed growing location. We are trying to have a location to build early generation seed for grower-based field trials.Christian Thill, Jeffrey Miller, Terrance Nennich

Grand Rapids:
(**549 Entries**)

3) **UMore Park:** Rosemount, MN: PVY & Late Blight (LB) disease screening trials. PVY nursery: screening of MN clones, NCRPVT clones, NCPT, NFPT, & other's as requested. The primary focus of PVY 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. PVY planted: 31.May.2012; LB nursery: screening of MN clones, NCRPVT clones, NCPT, NFPT, NLB, & other's as requested. The primary focus of LB 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 linesLB planted: 22.June.2012 Christian Thill, Jeffrey Miller, Kathy Haynes , USPB National Chip Performance Trial, and USPB National Fry Performance Trial

Rosemount: PVY Trial
(**581 Entries**)

Rosemount; SH & G1
Selection field

4) **Edling Potato Farm**: Clear Lake, MN: Agronomic performance trials of advancing FM potato breeding lines developed at the University of Minnesota. Clones tested: MN04844-07Y & MN02586Y. Christian Thill, Jeffrey Miller, Jerome Edling

5) **Peterson Potato Farm**: Big Lake, MN: Agronomic performance trials of advancing FM potato breeding lines developed at the University of Minnesota. Planted: 3.April.2012. Christian Thill, Jeffrey Miller, Art Peterson

Peterson Farms, Big Lake
(**54 Red Entries**)

6) **Wingard Potato Farms**: Elk River, MN: Agronomic performance trials of advancing FM potato breeding lines developed at the University of Minnesota. Planted: 30.March.2012.

Clones tested: MN04844-07Y, MN02467Rus/Y, & MN02419Rus. Christian Thill, Jeffrey Miller, Tom Wingard

7) **Pine Lake Wild Rice Farms**: Gonvik, MN; Nuclear seed production/selection; G2 seed increase lots. Certified by Minnesota Department of Agriculture. Planted; 17-18.May.2012. Christian Thill, Jeffrey Miller, Paul & Peter Imle

Pine Lake Wild Rice Farm
(**36 Red Entries**)

8) **5-Star Potato**: Clear Lake, MN: Agronomic performance trials of advancing FM potato breeding lines developed at the University of Minnesota. Planted: 2.April.2012. Christian Thill, Jeffrey Miller

9) **Kent Mason Farm**: Williams, MN; G1 production of MN02616R/Y & MN04844-07Y.

10) **Hugh's Garden - Organic Potatoes**: Sebeka, MN: Testing of advanced MN clones under organic conditions: MN02467Rus/Y, MN02574Y, MN02586Y, MN04844-07Y & 12 early generation FM red skinned clones. Planted: 8.May.2012. 7 of the 16 clones entered looked favorably under organic conditions & will be moved forward in 2013. Christian Thill, Jeffrey Miller, Hugh Duffner, Larry Heitkamp

Sabeka, MN Organic Trial
(**16 Entries**)

B) ND Locations:

1) **Northern Plains Potato Growers Association Research Farm**: Grand Forks, ND: Non-irrigated site; Minnesota fresh market reds/whites & white chipping clones. Planted: 6.June.2012. Christian Thill, Jeffrey Miller, NPPGA

Grand Forks: Dryland
(**67 Entries**)

2) **Williston Research Extension Center**: Nesson Valley Irrigation Site, Williston, ND: Minnesota yield trials, MN strip trials of advanced clones, MN G1 Selection field, MN single hill field (approx. 5 ac.). Planted: 1.May.2012. Christian Thill, Jeffrey Miller, Jerry Bergman

Williston: Yield Trial
(**158 Entries**)

3) **Moquist Potato Farm**: Crystal, ND: Agronomic performance trials of advancing FM potato breeding lines developed at the University of Minnesota. Christian Thill, Jeffrey Miller, Dave & Andy Moquist

Crystal: Red Trial
(**41 Entries**)

Crystal: Red Trial; 92 DAP

4) **Tri-Campbell Farms**: Grafton, ND; Testing of advanced MN clones: MN19298R/Y, MN02616R/Y, & MonDak Gold.

C) MN Clonal entries:

1) **North Central Regional Potato Variety Trial (NCRPVT)**: MN02419, MN02467Rus/Y, MN18747, MN02586Y, & MN04844-07Y
2) **National Fry Processors Trial (NFPT)**: MonDak Gold (tested as MN15620) & MN18747
   Both low in Acrylamide production.
3) **Snack Food Association Trial (SFA)**: MN99380-1Y
4) **USDA Potato Research Laboratory Trial (USDAPRL)**: MN02419, MN02467Rus/Y, MN18747, MN02586Y, MN99380-1Y, & MN04844-07Y
5) **Black Gold Variety Trial**: MN04844-07Y

SELECTIONS RELEASED IN 2012

In February of 2012 the Minnesota Agricultural Experiment Station (MAES) & the University of Minnesota release committee gave approval for the release of 3 new varieties: **MN02616R/Y, MN99380-1Y, & MN18747**.

1) **"RuneStone Gold" (MN02616R/Y)** (Minnesota Family #149 x OP)
A fresh market red skin yellow fleshed potato with excellent culinary qualities.

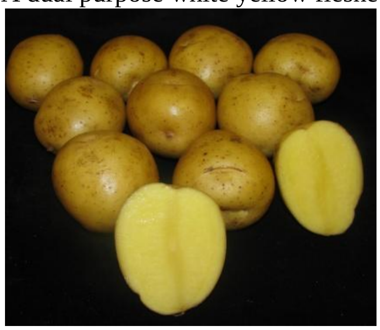
2) **MN99380-1Y** (Atlantic x MSA091-1)
A dual purpose white skin yellow fleshed potato for the fresh market & chip industry.

3) **MN18747** (ND2264-7 x MN47.82-6 [MN14489])
An 80 day dual purpose long white for the fresh market & french fry industry due to its low acrylamide production. (< 150ppb USPB national testing)

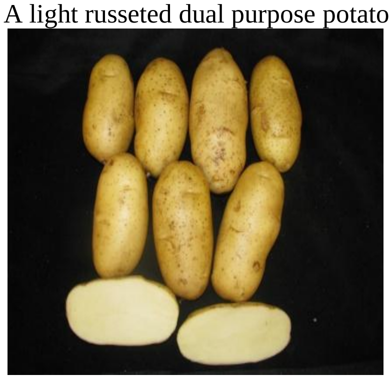
Cards are available for all 3. PVP's will be applied for.

Promising Clones

1) **MN04844-07Y** (W2257-2 x Dakota Pearl)
A dual purpose white yellow fleshed potato for the fresh market & chip industry.



MN10001PLWR-03Rus (Blazer Russet x AOND95249-1Russ (Dakota Trailblazer)
A light russeted dual purpose potato in early stage of development. Flesh color is white.



Specialty/Niche Market

MN07112WB-1W/P

(CO97227-2P/PW x CO972163P/PW)

1) A round oval white/purple skinned novelty potato with purple/cream flesh that makes a beautiful purple/cream colored potato chip.

Thank You:

1) Minnesota Area II Research & Promotion Council
2) Northern Plains Potato Growers Association
   MN & ND area farmers whose support in field trials is crucial to the development of new releases.

Potato Breeding and Cultivar Development for the Northern Plains
North Dakota State University
2012 Summary

Asunta (Susie) L. Thompson, Ph.D.
Department of Plant Sciences
North Dakota State University
Fargo, North Dakota 58108
asunta.thompson@ndsu.edu
701.231.8160 (office)

Potato is the most important vegetable and horticultural crop grown in North Dakota. In 2012, potatoes were planted on about 35,612 ha; total ha harvested were approximately 33,994. The average yield was 33.6 t per ha. In 2012, 43% of ha eligible for certification by the North Dakota State Seed Department were planted to cultivars developed by the NDSU potato breeding program, or to strains thereof.

Potato research has been conducted at NDSU since the late 1800s. Early work was mainly in regard to production practices such as plant population and planting depth. The potato breeding program was initiated in 1930 by the North Dakota Agricultural Experiment Station (NDAES). Since 1930, 25 cultivars have been named and released by the NDAES, in cooperation with the USDA-ARS, and others. Many additional collaborative releases with state Agricultural Experiment Stations, the USDA-ARS, and Agriculture Canada have also occurred. Traditionally, NDSU potato cultivar releases have been widely adapted and adopted, significantly impacting production in North Dakota and Minnesota, the Northern Plains, and throughout North America. As a leader in potato breeding, selection, and cultivar development, our goal is to identify and release superior, multi-purpose cultivars that are high yielding, possess multiple resistances to diseases, insect pests, and environmental stresses, have excellent processing and/or culinary quality, and that are adapted to production in North Dakota, Minnesota, and the Northern Plains. Our interdisciplinary 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. Dedicated crossing blocks are used in hybridizing efforts to develop resistance to pests and stresses, and in improving quality attributes. 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 meet the needs of producers and industry, we have established the following research objectives:

1) Develop potato (*Solanum tuberosum* Group Tuberosum L.) cultivars for North Dakota, 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 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.

In 2012, 248 families were created using 139 parental genotypes. Of these families, 59% included late blight resistance breeding, 38% Colorado potato beetle (CPB) resistance breeding, 28% chip processing and 47% frozen processing with cold sweetening resistance breeding. Two hundred families from botanical seed (TPS) were grown in the summer and fall greenhouse crops. The North Dakota Agricultural Experiment Station Greenhouse Complex is allowing a crop in two months, with larger seedling tuber size and more tubers per individual seedling.

In 2012, at Langdon, 94,580 seedlings, representing 458 families, were evaluated; 581 selections were retained. Unselected seedling tubers from cooperating programs in Colorado, Idaho, Texas and Maine were grown at Larimore, ND; 167 were retained. Unselected seedlings were shared with the breeding programs in Idaho, Maine, Colorado and Texas as in past years. In 2012, 938 second, 123 third year, and 345 fourth year and older selections, were produced in maintenance and increase lots at Absaraka, ND, and Baker, MN. All were submitted for certification through the North Dakota State Seed Department and the Minnesota Dept. of Agriculture.

Yield and evaluation trials were grown at eight locations in North Dakota and Minnesota, five irrigated (Inkster, Larimore, Oakes, Park Rapids and Williston) and three non-irrigated locations (Crystal, Grand Forks and Hoople). At Crystal, 28 entries were grown in the fresh market trial, including 20 advancing selections and nine named cultivars. In the preliminary fresh market trial 57 entries were evaluated, including 50 advanced selections and seven industry standards. Four trials were grown at the NPPGA Research Farm south of Grand Forks. They included seedling family evaluation for Colorado Potato Beetle (CPB) resistance (information used during selection at Langdon in September), along with three others where individual clones were assessed for defoliation twice weekly throughout the summer. Two were projects by graduate students, assessing germplasm with two different mechanisms for CPB control, glandular trichomes and glycoalkaloid mediated resistance. Twenty-four entries were grown in the chip trial at Hoople, including 15 advancing selections from the NDSU program, and nine standard chipping cultivars. In the preliminary chip trial 120 entries were grown; these are chipped in order to more efficiently determine what to maintain and what to perhaps fast track, and what to drop from further consideration. 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, had 107 entries in the unreplicated and 56 in the replicated trials.

Trials at Inkster ranged from the chip processing yield trial with 30 entries, the regional trials (irrigated), and evaluation of genotypes for resistance to Verticillium wilt in collaboration with Dr. Neil Gudmestad and Julie Pasche (21 clones across all market types). Twenty-four selections and commercially acceptable cultivars were grown in the Larimore processing trial, 24 in the Oakes processing trial, and 24 in the Williston processing trial; 16 advanced NDSU selections in each, compared to 8 commercially acceptable check cultivars. The preliminary processing trial at Larimore had 79 entries. As with the preliminary chip trial, this trial gives a rapid assessment providing the breeding program with information on processing quality so that lines may be continued, fast tracked if exceptional, or discarded from further evaluation. The NFPT is an industry driven trial with evaluations in WA, ID, ND, WI and ME. There were 87 clones evaluated (12 lines from NDSU); clones are evaluated for sugar, asparagine and acrylamide levels. Seventy-nine clones selected from out-of-state seedlings in 2011 and prior were grown in maintenance plots. A processing trial with 28 entries, including 12 NDSU advancing selections) was grown at Park Rapids, in collaboration with RDO/Lamb-Weston. The acrylamide trial was also grown at this site. It includes five cultivars and five nitrogen rates and is in collaboration with Carl Rosen. Funding for our programs is via the Specialty Crop Block Grant Programs in MN and ND. Four entries from NDSU were evaluated in the North Central Regional Potato Variety Trial (NCRPVT), including ND7519-1 and ND8305-1, two cold chipping selections, and ND8068-5Russ and AND00618-2RussY, both dual-purpose russets. NCRPVT locations are Crystal (fresh market), Hoople (chip processing), Larimore (processing), and Inkster (fresh market, chip and processing). Our efforts continue to identify chip and frozen processing genotypes 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 2012, Dr. Gary Secor's program evaluated seedling families using a detached leaf assay in the greenhouse; resistant selections are retained for field evaluations in 2013. Collaborative field trials for late blight foliar and tuber evaluations with Dr. Secor were lost due to the inability to get late blight established at Prosper. Twenty-eight advancing selections and released cultivars (including resistant and susceptible controls) were evaluated by Dr. Neil Gudmestad's program for resistance to pink rot, Pythium leak, and *P. nicotianae*. Many selections were rated as resistant to the latter two. This information is used to select parents in breeding for resistance, and is integral for cultivar releases. Four trials were grown at the NPPGA Research Farm south of Grand Forks. They included seedling family evaluation for Colorado Potato Beetle resistance (information used during selection at Langdon in September), along with three others where individual clones were assessed for defoliation twice weekly throughout the summer. 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. Many entries were submitted for cooperative trials with various producers, industry, and research groups across North America.

The NDSU potato breeding program is supported by Dick (Richard) Nilles, research technician, and Dr. Rob Sabba, post doctoral research fellow. Rob's work involves marker assisted selection work primarily, in addition to other laboratory projects. There are currently four graduated students working with the potato breeding program. Juan Calle-Belido, Ph.D. candidate from Peru, is working on developing a molecular marker for Fusarium dry rot resistance. Adriana Rodriguez, MSc. candidate from Puerto Rico, is working on Colorado potato beetle resistance, specifically glandular trichome mediated resistance. Irene Roman Martinez, MSc. candidate also from Puerto Rico, is working on glycoalkaloid mediated resistance to Colorado potato beetle. Whitney Harchenko, MSc. candidate and NDSU graduate, is working on marker assisted selection for PVY resistance and is assisting in establishing a ‘fast track’ program similar to the one we have with Potato Pathology for late blight for these genotypes.

The most promising advancing red fresh market selections continue to include ND4659-5R, ND8555-8R, AND00272-1R, ND6002-1R and ND7132-1R. Dual-purpose russet selections, including ND8068-5Russ, WND8625-2Russ, and several hybrids between Dakota Russet and Dakota Trailblazer possess excellent appearance, yield, and processing qualities. An exceptional clone, ND8229-3, was released as Dakota Russet, in 2012. ND7519-1 and ND8304-2, advancing chip processing selections, possess excellent appearance and cold sweetening resistance. Additionally, several specialty type selections with unique colored flesh and skin are of interest for specific market niches.

Goals for 2013 continue to include developing improved potato cultivars for ND, MN, the Northern Plains and beyond, using traditional hybridization, and utilizing early generation selection techniques including emphasis the use of marker assisted selection and greenhouse screening procedures for rapid identification of genetically superior germplasm. Our focus will be on resistance to major insect, disease and nematode pests, and to environmental stresses, with an emphasis on improved quality characteristics, addressing shortcomings of currently commercially accepted cultivars, and with greater emphasis on economic and environmental sustainability. Finally, working with the NDSSD and MN Department of Agriculture we will continue 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, the North Central and other research programs across the globe, and potato producers and industry in ND, MN, and beyond. A sincere thanks to our many grower, industry, and research cooperators in North Dakota, Minnesota, and beyond. Your support of our research program is wonderful, making our work fun and a stimulating challenge.

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
- Russet Norkotah fertility regime

ND070927-2Russ

- AH66-4x ND860-2
- Medium vine size
- Medium-late vine maturity
- Medium to high yield potential
- Dual-purpose
- High specific gravity
- Good storability with low sugar accumulation and good French fry processing quality
- Early in evaluation process for cultivar specific management information, including fertility rates, with-in row spacing and disease resistance evaluations

ND071079-2Russ

- ND6242-10Russ x Dakota Russet
- Medium-large vine size
- Medium-late vine maturity
- High yield potential
- Dual-purpose
- High specific gravity
- Good storability with low sugar accumulation and excellent processing quality
- Early in evaluation process for cultivar specific management information, including fertility rates, with-in row spacing and disease resistance evaluations

WND8625-2Russ

- W2699-1Russ x Silverton Russet
- Medium-large vine size
- Medium vine maturity
- Medium to high yield potential
- Dual-purpose
- High specific gravity (+1.087 across ND and MN irrigated locations)
- Good storability with low sugar accumulation and good frozen processing quality after 7 months storage
- Early in evaluation process for cultivar specific management information, including fertility rates, with-in row spacing and disease resistance evaluations

AND97279-5Russ

- A92001-2 x Ranger Russet
- Medium-large vine size
- Medium-late vine maturity
- Medium to high yield potential
- Dual-purpose
- High specific gravity (about 1.087 across ND and MN irrigated locations)
- Good storability with low sugar accumulation and good frozen processing quality
- Early in evaluation process for cultivar specific management information, including fertility rates, with-in row spacing and disease resistance evaluations.

Dakota Russet x Dakota Trailblazer Hybrids

- Hybrids include ND049546B-10Russ, ND049546B-15Russ, ND049546b-27Russ, ND050032-4Russ, and ND060735-3Russ
- Yield potential for all is medium to high
- Maturity is medium for all
- Specific gravity is midpoint between parents
- All are dual-purpose
- All have excellent French fry quality and low sugar accumulation in storage
- Early in evaluation process for cultivar specific management information

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

ND6002-1R

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

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

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

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