Response of Irrigated Russet Burbank Potatoes to Nitrogen Rate, Polymer-Coated Urea Sources, and a Microbial Additive

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Summary

A field experimented was conducted at the Sand Plain Research Farm in Becker, MN, to evaluate the effects of the form, rate, and timing of nitrogen (N) application on a crop of Russet Burbank potatoes, and the effectiveness of MicroAZ-ST Liquid, a formulation of *Azospirillum* intended to stimulate root growth. Two polymer-coated ureas (PCUs), Environmentally Smart Nitrogen (ESN; Agrium, Inc.; 44-0-0) and Agrocote (Everris; 25% 44-0-0, 75% 43-0-0), were compared to urea/UAN, at total N application rates of 120, 180, and 240 lbs·ac^{-1} N. Urea/UAN was also evaluated at 150, 210, and 270 lbs·ac^{-1} N total, and there was a control treatment receiving no N after planting (at which time all treatments received 30 lbs·ac^{-1} N). In addition to single applications at emergence, both ESN and Agrocote were applied at 150 lbs·ac^{-1} N at emergence with 60 lbs·ac^{-1} N added in five applications of UAN later in the season (240 lbs·ac^{-1} N total, including the planting application), similar to the application schedule of the urea/UAN treatment at the same total N rate. MicroAZ-ST Liquid was applied at emergence in a urea/UAN treatment receiving 180 lbs·ac^{-1} N total and at planting in two urea/UAN treatments receiving 180 and 240 lbs·ac^{-1} N total. N application rate was found to be positively related to petiole NO_3-N concentration, terminal leaflet SPAD readings, tuber yield, and tuber size. In contrast, N source was only related to early-season SPAD readings, early- to mid-season petiole NO_3-N concentration, and tuber size. Urea/UAN produced higher early-season SPAD readings and petiole NO_3-N concentration than Agrocote and larger tubers than either PCU, while ESN produced higher mid-season petiole NO_3-N concentrations than Agrocote or urea/UAN. For both ESN and Agrocote, the use of a modest application of PCU at emergence with post-hilling UAN applications slowed the decline in petiole NO_3-N and leaflet SPAD throughout the season relative to a single large N application of PCU at emergence, but had no effect on tuber yield, size, or quality. The use of MicroAZ-ST Liquid had almost no significant effects on potato plants, and no effects on potato tuber variables. Marketable yield was maximized at an application rate of 210 to 240 lbs·ac^{-1} N total.

Background

The nitrogen (N) fertilizer urea has a high N density (46% by weight), which minimizes transportation and application costs. Its other benefits include its versatility (it can be applied in granular or liquid forms), its handling safety (relative to ammonium nitrate and anhydrous ammonia), and its fairly low cost of production. Because of these factors, urea is among the more popular N sources for agricultural crops worldwide.

Urea is rapidly converted to plant-available forms of N (ammonium and nitrate) through the enzymatic activities of soil microorganisms. These compounds are rapidly lost (through volatilization and leaching, respectively) if not taken up by plants, and ammonium is phytotoxic in high concentration, especially to seedlings. For these reasons, a single application of urea at planting to meet the crop's annual N requirements is not advisable. Instead, it is common practice to use a modest application of granular urea at planting with multiple applications of aqueous urea and ammonium nitrate (UAN) after hilling.

The use of multiple applications increases urea's application costs, diminishing one of its advantages. An alternative is to extend the release period of urea using polymer-coated urea products (PCUs). The use of PCUs both reduces the concentration of urea (and nitrate and ammonium) in the soil immediately after application and extends the period over which N is supplied to the crop.

Studies on PCUs as N sources for potato plants have been conducted over twelve years at the Sand Plain Research Farm (SPRF) in Becker, MN. Environmentally Smart Nitrogen (ESN; 44-0-0, Agrium, Inc.) has received particular attention and has been found to be a viable alternative to urea/UAN. There are other PCU products on the market that may also be effective alternatives to urea/UAN, and one goal of the PCU studies at SPRF has been to evaluate some of these other products.

In 2015, in addition to ESN, we evaluated a blend of Agrocote products (25% 44-0-0, 75% 43-0-0; Everris) as an N source for Russet Burbank potato plants. We applied these N sources, as well as urea/UAN, at rates of 120, 180, and 240 $lbs \cdot ac^{-1}$ N, with urea/UAN also being applied at 150, 210, and 270 lbs $lbs \cdot ac^{-1}$ N. For ESN and Agrocote, the full application was given at emergence, while the applications of urea/UAN were divided between 60 to 150 $lbs \cdot ac^{-1}$ N as urea at emergence and 30 – 130 $lbs \cdot ac^{-1}$ N applied as urea/UAN in 3 – 5 applications later in the season. In addition to the single-application treatments for both ESN and Agrocote, N was also applied at 150 $lbs \cdot ac^{-1}$ N as PCU at emergence and 90 $lbs \cdot ac^{-1}$ N in 5 applications of UAN later in the season (similar to the urea/UAN treatment receiving 240 total $lbs \cdot ac^{-1}$ N). A check treatment receiving 0 $lbs \cdot ac^{-1}$ N at emergence was also included. All treatments received 30 $lbs \cdot ac^{-1}$ N at planting as DAP.

The overall objective of PCU studies at SPRF is to evaluate methods of improving N use efficiency (tuber yield and N uptake per pound of N applied) and the economic efficiency of N fertilizer application (tuber yield per dollar invested in fertilization) in irrigated potato production. In 2015, this involved an evaluation of different sources of N (urea/UAN, ESN, and Agrocote) at different rates, with a comparison of a single large PCU application at emergence to a smaller emergence PCU application with subsequent applications of UAN at the expected optimum rate (240 $lbs \cdot ac^{-1}$ N total). In addition, we tested the effectiveness of TerraMax MicroAZ-ST Liquid, a formulation of *Azospirillum* intended to stimulate root growth and improve stand development in wheat. Its effectiveness in potato agriculture has not been previously assessed.

Materials and Methods

The study was conducted in 2015 at the Sand Plain Research Farm in Becker, MN, on a Hubbard loamy sand soil. The previous crop was rye. Selected characteristics of the top six inches of soil in the study field, collected on March 30, 2015, are shown in Table 1.

The study was replicated four times in a randomized complete block design. The four blocks were planted, two to a field, in two adjacent fields. Russet Burbank potatoes were planted by hand with three feet between rows and one-foot spacing within rows. Each of the two fields was surrounded by a buffer strip of Russet Burbank potatoes one row wide along either side and five feet long at either end. Each plot had four, 20-foot rows, the middle two being used for sampling and harvest. One red seed potato (cv. Chieftain) was planted at the end of each harvest row, so that each harvest row held 18 Russet Burbank seed potatoes at planting. In the buffer strips at each end of each field, red potatoes were also planted in place of Russet Burbanks for each harvest row. Whole B seed was used for Russet Burbank, and cut "A" seed was used for the red potatoes.

Eighteen different N fertilizer treatments were applied (Table 2). A check treatment received no N fertilizer after planting. Fourteen treatments were designed to evaluate the effects of N source (urea/UAN, ESN, or Agrocote) and rate, as well as the effect of using a single large application of ESN or Agrocote compared to a smaller application supplemented with subsequent UAN applications. The remaining three treatments evaluated the effects of MicroAZ-ST Liquid (TerraMax) applied at planting or emergence, with urea/UAN as the N source, applied at two N rates.

Belay was applied in-furrow for beetle control, along with the systemic fungicide Quadris. Weeds, diseases, and insect pests were controlled using standard practices. Rainfall was supplemented with sprinkler irrigation using the checkbook method of irrigation scheduling. The nitrate and ammonium concentrations of irrigation water were monitored throughout the year.

Two hundred lbs·ac^{-1} 0-0-60 and 200 lbs·ac^{-1} 0-0-22 (164 lbs·ac^{-1} K_2O total) were broadcast on April 13 and 14, respectively, and incorporated with a chisel plow on April 15. Potatoes were planted on April 22. Planting fertilizer was applied to all plots at row closure, banded three inches to each side and two inches below the seed piece using a metered, drop-fed applicator incorporated into the planter. The planting fertilizer included 30 lbs·ac^{-1} N, 77 lbs·ac^{-1} P_2O_5, 181 lbs·ac^{-1} K_2O, 20 lbs·ac^{-1} Mg, 41.5 lbs·ac^{-1} S, 1 lbs·ac^{-1} B, and 1 lb·ac^{-1} Zn, as a blend of diammonium phosphate (DAP), potassium chloride, potassium magnesium sulfate, Granubor 2, and Blu-Min granular zinc sulfate.

N applications at emergence (May 21) were hand-broadcast and mechanically incorporated during hilling. Post-hilling UAN was applied with a tractor-mounted sprayer as 28% UAN at 25 gal·ac^{-1}. The tractor traveled in the irrigation alleys to prevent damage to the crop. Irrigation was applied immediately following fertilizer application to simulate fertigation with an overhead irrigation system. Post-hilling N applications were administered on June 25, July 6, July 16, July 23, and August 3. Treatments receiving 30 lbs·ac^{-1} N post-hilling did not receive UAN on July 6 or July 23.

WatchDog weather stations (Spectrum Technologies) were used to monitor soil moisture and temperature. Two pairs of soil moisture and temperature sensors were in two plots, one receiving 150 lbs·ac^{-1} N as ESN (treatment 10, in rep 4) and the second receiving 150 lbs·ac^{-1} N as Agrocote at emergence (treatment 14, in rep 1). The probes were installed after hilling, four inches below the surface of the hill. Air temperature and precipitation were also recorded by the station in the plot receiving ESN. Soil moisture and soil and air temperature data are presented in Figure 1, and precipitation is presented in Figure 2.

Plant stands were measured in each plot on June 4, and stems per plant were determined for the harvest rows on June 10.

The petiole of the 4th leaf from the shoot tip was collected from 25 harvest-row plants per plot on five dates: June 15, June 24, July 9, July 22, and August 3. Petioles will be analyzed for NO_3-N concentration with a Wescan N analyzer. The chlorophyll concentration of the terminal leaflet of the 4th leaf from the shoot tip was measured for 40 harvest-row plants per plot using a SPAD meter on the same dates, except that the fourth reading was taken on July 23.

Vines were harvested on September 2 from one 10-ft section of each harvest row in each plot. Vines were chopped on September 4. Plots were machine harvested on September 8, and tubers were sorted and graded on September 10-11. Subsamples of vines and tubers were collected to determine moisture percentage and N concentration, which will be used to calculate N uptake and distribution within the plant. Tuber sub-samples were also used to determine tuber specific gravity and dry matter content and the prevalences of hollow heart, brown center, and scab.

Samples from the top two feet of soil were collected on October 26. Their concentrations of NH_4-N and NO_3-N will be determined with a Wescan N analyzer.

Measured amounts of ESN or Agrocote Max fertilizer were placed in plastic mesh bags and buried at the depth of fertilizer placement on May 21. Bags were collected on 9 dates: May 26, June 3, June 12, June 18, June 29, July 9, July 23, August 12, and

September 2. The dry weight of the remaining fertilizer (minus the mean prill coat weight) will be determined for each collection date to track urea release over time.

Plant response data were analyzed using the GLM procedure in SAS 9.4. Dependent variables were modeled as functions of treatment and block. Results for a subset of the treatments (treatments 2, 4, 6, 8-10, and 12-14) were modeled as functions of N source, application rate, and their interaction, in a second set of GLMs. Significant differences between treatments at alpha = 0.10 were determined with Waller-Duncan k-ratio t tests.

Results

Plant stand and stems per plant

Results for plant stand and the number of stems per plant are presented in Table 3. Plant stand was very high for all plots, and no treatment had less than 98.6% average stand. The number of stems per plant also varied little among treatments, ranging from 2.5 to 3.1 stems/plant. Consequently, there was no significant effect of treatment on either variable. However, the number of stems per plant was significantly related to the source*rate interaction. The number of stems per plant tended to increase with application rate for treatments receiving urea/UAN, to decrease with rate for treatments receiving Agrocote, and to decrease and then increase for those receiving ESN.

Petiole NO_3-N concentration and terminal leaflet SPAD readings

Results for petiole NO_3-N concentration and terminal leaflet SPAD readings are presented in Table 3.

N treatment had highly significant effects on petiole NO_3-N concentrations and SPAD readings on all five sampling dates. The control treatment (treatment 1) consistently had significantly lower SPAD readings than any other treatment. The same was true for petiole NO_3-N only on the first two sampling dates (June 15 and June 24), though the control treatment continued to have among the lowest mean petiole NO_3-N concentrations through the remaining three sampling dates.

In general, treatments receiving more total N had higher SPAD readings and petiole NO_3-N concentrations. N source had weaker effects than application rate overall, but the treatments receiving urea/UAN (treatment 2, 4, and 6) had relatively high values for both variables on the first sampling date (June 15), while those receiving ESN had high values on the second date (June 24) and high petiole NO_3-N on the third sampling date (July 9).

There was a tendency for the treatments receiving a PCU with post-hilling UAN (treatments 11 and 15) to have higher late-season petiole NO_3-N concentrations and

SPAD readings than those receiving the same amount of N from the PCU applied at emergence alone (treatments 10 and 14, respectively). The effect was more pronounced for petiole NO_3-N concentration. The two treatments with the highest petiole NO_3-N on the final sampling date (August 3) were the two receiving a PCU with post-hilling UAN (treatments 11 and 15).

Petiole NO_3-N concentrations and leaflet SPAD readings for the treatments receiving MicroAZ-ST Liquid (treatments 16 – 18) did not generally differ from those of the treatments receiving urea/UAN at the same rates without MicroAZ-ST Liquid (treatments 4 and 6). The exception was on July 9, when the treatment receiving 150 lbs·ac^{-1} N as urea/UAN with MicroAZ-ST Liquid at planting (treatment 17) had lower petiole NO_3-N than the corresponding treatment without MicroAZ-ST Liquid (treatment 4).

Tuber yield

Tuber yield results are presented in Table 4. The zero-N check treatment (treatment 1) had significantly lower total and marketable yield, and a smaller portion of its yield in large size classes, than all other treatments.

Total and marketable yield and the proportion of yield in large size classes all tended to increase with application rate, with stronger responses between 120 and 180 lbs·ac^{-1} N total than between 180 and 240 lbs·ac^{-1} N total. Yield in the smallest two size classes (0 to 3 oz and 3 to 6 oz) decreased with increasing application rate, while yield in the largest two classes (10 to 14 oz and greater than 14 oz) increased.

N source did not have a significant effect on total or marketable yield, but Agrocote and ESN had significantly higher yields of 3- to 6-oz tubers and significantly lower yields of tubers over 14 oz than urea-UAN. As a result, Agrocote had a significantly lower percentage of tubers over 6 oz, and both PCUs had significantly lower percentages of tubers over 10 oz, than urea/UAN, averaged across the three rates at which all three N sources were applied (120, 180, and 240 lbs·ac^{-1} N).

The treatment receiving 210 lbs·ac^{-1} N at emergence as ESN (treatment 10) had the highest total and marketable yield of all treatments, and its marketable yield and yield of U.S. No. 1 tubers were significantly greater than those of the treatment receiving 150 lbs·ac^{-1} N at emergence as ESN and 60 lbs·ac^{-1} N post-hilling as UAN (treatment 11). In no other respect did applying 210 lbs·ac^{-1} N as a PCU at emergence produce a significantly different yield result than applying 150 lbs·ac^{-1} N at emergence as that PCU with subsequent applications of UAN.

There was a significant source*rate interaction in the yield of U.S. No. 1 tubers. While the yield for the treatments receiving a single emergence application of ESN (treatments 8-10) or Agrocote (treatments 12-14) increased with application rate, especially between 120 and 180 $lbs \cdot ac^{-1}$ N, the yield for treatments receiving urea/UAN at the same rates (treatments 2, 4, and 6) did not respond to application rate. The same lack of response to application rate was observed for yield of U.S. No. 1 tubers across the full range of application rates of urea/UAN (treatments 2 – 7). The positive response of marketable yield to application rate observed among the urea/UAN treatments, especially between 150 and 270 $lbs \cdot ac^{-1}$ N total (treatments 3 – 7), was largely due to a response in the yield of U.S. No. 2 tubers.

By no measure of yield did the application of MicroAZ-ST impart a significant advantage or disadvantage relative to no application (comparing treatments 16 and 17 to treatment 4 and treatment 18 to treatment 6).

Tuber quality

Tuber quality results are presented in Table 5. No tuber quality variable was significantly related to the treatment applied.

N uptake

N uptake results are presented in Table 6. Tuber dry-matter yield, N concentration, and N uptake all tended to be higher in treatments receiving more N, this tendency being more pronounced for N concentration and uptake than for dry-matter yield. The relationship between application rate and dry-matter yield, N concentration, and N uptake was less apparent for vines, though still present. In particular, the check treatment (treatment 1) did not have the lowest vine N concentration.

Among the treatments receiving urea/UAN, ESN, or Agrocote at 120, 180, or 240 $lbs \cdot ac^{-1}$ N (treatments 2, 4, 6, 8-10, and 12-14), the dry-matter yield of tubers was not significantly related to N application rate. The concentration of N in tubers and the amount of N taken up into tubers increased approximately linearly with the amount of N applied, regardless of which N source was applied. There was no effect of N source or the source*rate interaction on tuber dry yield, N concentration, or N uptake.

The treatment receiving MicroAZ-ST at planting with 150 $lbs \cdot ac^{-1}$ N as urea at emergence and 60 $lbs \cdot ac^{-1}$ N as UAN post-hilling (treatment 18) had significantly lower mean vine N concentration and uptake than the corresponding treatment without MicroAZ-ST (treatment 6). In contrast, the treatment receiving MicroAZ-ST at planting with 120 $lbs \cdot ac^{-1}$ N as urea at emergence and 30 $lbs \cdot ac^{-1}$ N as UAN post-hilling (treatment 17) had higher vine dry-matter yield and N uptake than the corresponding treatment without MicroAZ-ST (treatment 4). MicroAZ-ST did not significantly affect tuber dry-matter yield, N concentration, or N uptake, nor did it affect total N uptake.

Conclusions

Overall, the application rate of N in this study had a much greater effect on potato plants than the form or timing of its application. Leaflet SPAD, tuber yield, and tuber size all increased with application rate. The only clear effect of N source on leaflet SPAD was higher SPAD values on the first sampling date (June 15) for treatments receiving urea/UAN (treatments 2, 4, and 6) than those receiving Agrocote without UAN at the same total application rates (treatments 12-14). There were also source effects on tuber size, with treatments receiving urea/UAN having larger tubers than those receiving either PCU without UAN, averaged across the three shared application rates (120, 180, and 240 lbs·ac^{-1} N total).

Applying 150 lbs·ac^{-1} N as a PCU at emergence and 60 lbs·ac^{-1} N as multiple applications of UAN later in the season produced higher late-season leaflet SPAD readings than applying the same total amount of N as a single emergence application of PCU. However, this effect of late-season UAN on late-season leaflet SPAD did not translate into an effect on tuber yield, size distribution, grade, or quality.

Based on the response of marketable yield to N application rate, whether considering all 18 treatments together or the control and urea/UAN treatments alone (treatments 1 – 7), marketable yield peaked at an application rate of between 210 and 240 lbs·ac^{-1} N total. ESN and Agrocote applied at emergence both performed approximately the same as multiple applications of urea/UAN applied at the same rate, in terms of tuber yield and quality.

MicroAZ-ST Liquid may have affected vine N concentration (which was lower in treatment 18 than treatment 6) and vine dry-matter yield (which was higher in treatment 17 than treatment 4), and therefore vine N uptake. It may also have had some effect on petiole NO_3-N (which was lower in treatment 17 than treatment 4 on July 9). Aside from these effects, MicroAZ-ST Liquid did not have any impact on any of the yield response variables measured.

Table 1. Soil characteristics of the study site at the beginning of the season (March 30, 2015).

Primary macronutrients			Secondary macronutrients			Micronutrients					Other characteristics	
NO_3-N (ppm)	Bray P (ppm)	NH_4OAc-K (ppm)	NH_4OAc-Ca (ppm)	NH_4OAc-Mg (ppm)	SO_4-S (ppm)	Hot Water B (ppm)	DTPA-Cu (ppm)	DTPA-Fe (ppm)	DTPA-Mn (ppm)	DTPA-Zn (ppm)	Water pH	O.M. LOI (%)
4.22	37	118	940	160	2.5	0.294	0.685	37.8	10.16	2.15	6.2	2.3

Table 2. N treatments applied to irrigated Russet Burbank potatoes at the Sand Plain Research Farm in Becker, MN, in 2015.

Nitrogen sources[2] and rates ($lbs \cdot ac^{-1}$)				
Treatment	Planting	Emergence	Post-hilling[1]	Total N ($lbs \cdot ac^{-1}$)
1	30 DAP	0	0	30
2	30 DAP	60 Urea	10, 0, 10, 0, 10	120
3	30 DAP	90 Urea	10, 0, 10, 0, 10	150
4	30 DAP	120 Urea	10, 0, 10, 0, 10	180
5	30 DAP	150 Urea	10, 0, 10, 0, 10	210
6	30 DAP	150 Urea	12, 12, 12, 12, 12	240
7	30 DAP	150 Urea	24, 24, 20, 12, 10	270
8	30 DAP	90 ESN	0	120
9	30 DAP	150 ESN	0	180
10	30 DAP	210 ESN	0	240
11	30 DAP	150 ESN	12, 12, 12, 12, 12	240
12	30 DAP	90 Agrocote	0	120
13	30 DAP	150 Agrocote	0	180
14	30 DAP	210 Agrocote	0	240
15	30 DAP	150 Agrocote	12, 12, 12, 12, 12	240
16	30 DAP	120 Urea + MicroAZ-ST[3]	10, 0, 10, 0, 10	180
17	30 DAP + MicroAZ-ST[3]	120 Urea	10, 0, 10, 0, 10	180
18	30 DAP + MicroAZ-ST[3]	150 Urea	12, 12, 12, 12, 12	240

[1]Post-hilling N applied as 28% UAN on each of five application dates: 6/25, 7/6, 7/16, 7/23, 8/3

[2]DAP (diammonium phosphate): 18-46-0. ESN (Environmentally Smart Nitrogen, Agrium, Inc.): 44-0-0. Agrocote (Everris): 25% 44-0-0, 75% 43-0-0. UAN (urea + ammonium nitrate): 28-0-0. Urea: 46-0-0.

[3]TerraMax MicroAZ-ST Liquid, 12.8 $oz \cdot ac^{-1}$

Figure 1. Air temperature and soil moisture and temperature between emergence (May 21) and five days before harvest (September 3) at the Sand Plain Research Farm in Becker, MN, in 2015.

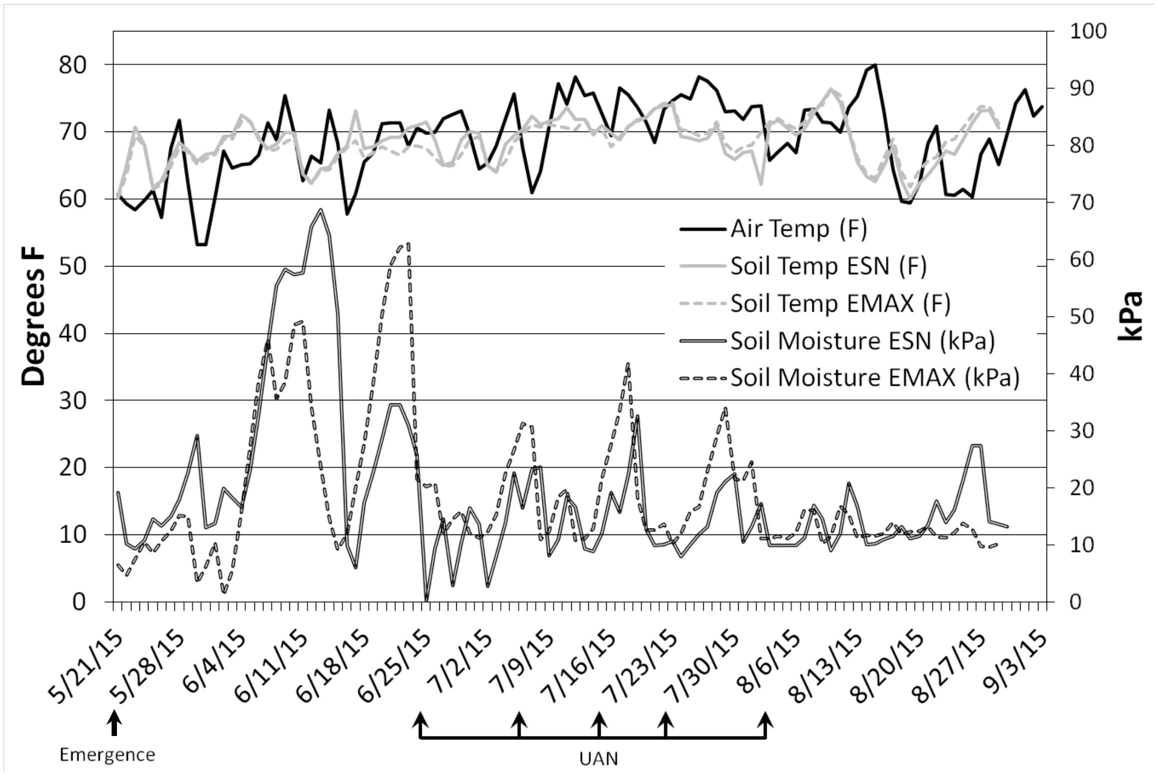
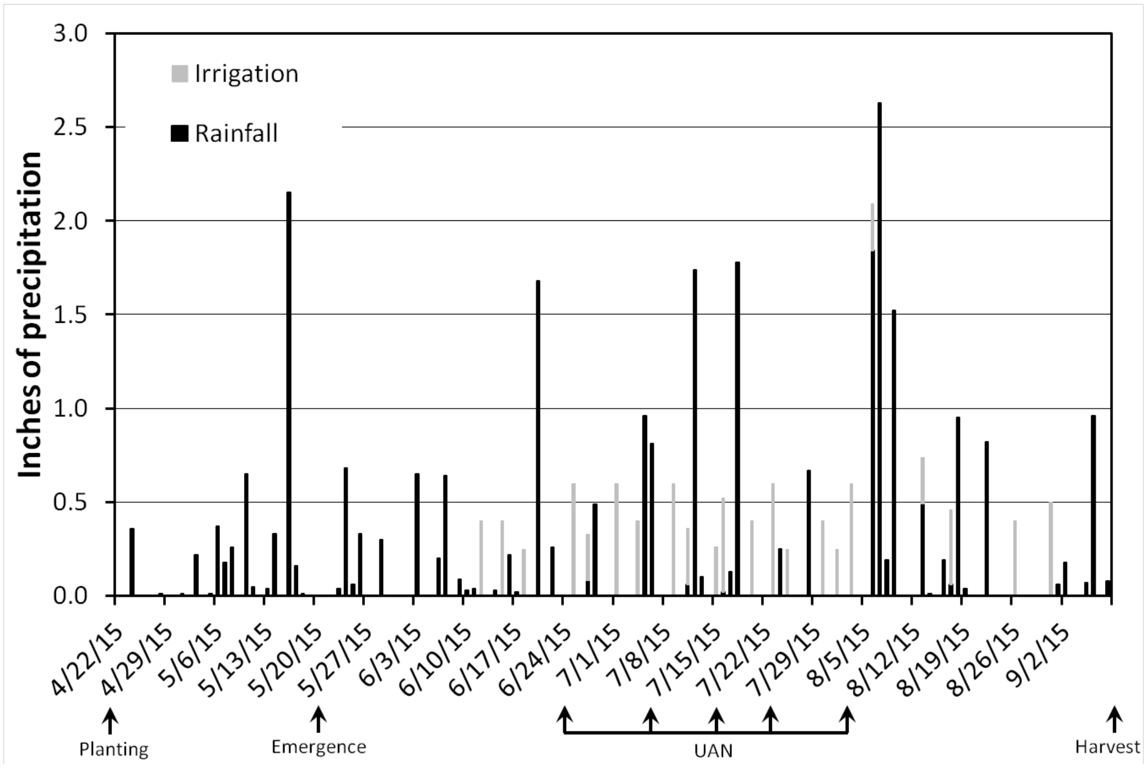


Figure 2. Precipitation as rainfall or irrigation between planting (April 22) and harvest (September 8) at the Sand Plain Research Farm in Becker, MN, in 2015.



Inches of precipitation
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Irrigation
Rainfall
4/22/15
4/29/15
5/6/15
5/13/15
5/20/15
5/27/15
6/3/15
6/10/15
6/17/15
6/24/15
7/1/15
7/8/15
7/15/15
7/22/15
7/29/15
8/5/15
8/12/15
8/19/15
8/26/15
9/2/15
Planting
Emergence
UAN
Harvest

Table 3. Effect of N treatment on plant stand, stems per plant, leaflet SPAD readings (chlorophyll concentration), and petiole NO_3-N concentrations of Russet Burbank potato plants grown at the Sand Plain Research Farm in Becker, MN, in 2015.

Nitrogen sources[2] and rates ($lbs \cdot ac^{-1}$)					Stand and stems		Leaflet SPAD					Petiole NO_3-N ($\mu g \cdot g^{-1}$)				
Treatment	Planting	Emergence	Post-hilling[1]	Total N ($lbs \cdot ac^{-1}$)	June 4 plant stand (%)	June 10 stems per plant	15-Jun	24-Jun	9-Jul	23-Jul	3-Aug	15-Jun	24-Jun	9-Jul	22-Jul	3-Aug
1	30 DAP	0	0	30	100	2.7	38.5	35.5	29.2	24.4	19.8	3119	430	142	200	170
2	30 DAP	60 Urea	3 x 10 UAN	120	100	2.5	41.9	38.3	33.4	29.7	25.7	15016	4994	206	321	306
3	30 DAP	90 Urea	3 x 10 UAN	150	100	2.7	44.1	40.4	34.5	31.5	28.0	17616	8527	398	632	407
4	30 DAP	120 Urea	3 x 10 UAN	180	100	2.6	43.9	42.3	35.4	32.9	28.7	18773	12154	2364	1042	258
5	30 DAP	150 Urea	3 x 10 UAN	210	99	2.7	43.9	41.9	36.1	34.8	31.6	18521	14672	5403	3171	603
6	30 DAP	150 Urea	5 X 12 UAN	240	99	3.1	44.7	42.5	37.2	37.1	34.1	18609	14832	3643	4281	2798
7	30 DAP	150 Urea	24, 24, 20, 12, 10	270	100	3.0	43.4	42.6	37.0	37.4	36.6	18586	15265	6281	7008	2292
8	30 DAP	90 ESN	0	120	99	2.8	42.2	40.0	34.1	29.2	26.3	14325	6246	485	109	231
9	30 DAP	150 ESN	0	180	100	2.8	43.0	42.5	35.7	33.2	29.6	16009	12993	2520	1375	548
10	30 DAP	210 ESN	0	240	100	2.9	42.6	42.8	38.4	36.1	33.7	16891	17341	6666	3127	2930
11	30 DAP	150 ESN	5 X 12 UAN	240	100	2.8	42.7	43.3	37.9	38.0	37.7	17024	13228	4071	6052	5266
12	30 DAP	90 Agrocote	0	120	100	2.9	40.5	38.5	33.4	29.1	25.7	11729	3709	202	152	416
13	30 DAP	150 Agrocote	0	180	100	2.7	41.7	40.3	36.0	32.1	29.4	13945	9231	1332	1874	1015
14	30 DAP	210 Agrocote	0	240	100	2.6	43.8	42.3	36.7	36.0	33.8	16343	14439	3975	4710	4047
15	30 DAP	150 Agrocote	5 X 12 UAN	240	100	2.9	41.3	39.4	37.0	35.7	35.5	13810	7543	1502	6093	4833
16	30 DAP	120 Urea + MicroAZ-ST[3]	3 x 10 UAN	180	99	2.7	44.3	41.7	35.3	32.9	29.6	18644	12331	2310	1072	1631
17	30 DAP + MicroAZ-ST[3]	120 Urea	3 x 10 UAN	180	100	2.9	43.4	42.1	35.1	32.4	29.7	18782	12842	991	1930	1542
18	30 DAP + MicroAZ-ST[3]	150 Urea	5 X 12 UAN	240	100	2.9	44.7	42.6	37.5	35.9	34.8	18677	14052	3379	4272	2517
Treatment significance[4]					NS	NS	**	**	**	**	**	**	**	**	**	**
Minimum significant difference (0.1)					--	--	1.0	1.1	1.3	1.2	2.0	1335	1865	1330	1271	1693

[1]Post-hilling N applied as 28% UAN on each of five application dates: 6/25, 7/6, 7/16, 7/23, 8/3

[2]DAP (diammonium phosphate): 18-46-0. ESN (Environmentally Smart Nitrogen, Agrium, Inc.): 44-0-0. Agrocote (Everris): 25% 44-0-0, 75% 43-0-0. UAN (urea + ammonium nitrate): 28-0-0. Urea: 46-0-0.

[3]TerraMax MicroAZ-ST Liquid, 12.8 $oz \cdot ac^{-1}$

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

Table 4. Effect of N treatment on tuber yield, size, and grade for Russet Burbank potato plants grown at the Sand Plain Research Farm in Becker, MN, in 2015.

Nitrogen sources[2] and rates ($lbs \cdot ac^{-1}$)					Tuber Yield										
Treatment	Planting	Emergence	Post-hilling[1]	Total N ($lbs \cdot ac^{-1}$)	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
					$cwt \cdot ac^{-1}$									%	
1	30 DAP	0	0	30	166	199	39	1	0	406	214	25	239	10	0
2	30 DAP	60 Urea	3 x 10 UAN	120	65	198	216	69	21	569	439	65	504	53	16
3	30 DAP	90 Urea	3 x 10 UAN	150	75	162	199	82	28	546	418	54	471	56	20
4	30 DAP	120 Urea	3 x 10 UAN	180	72	141	210	90	54	566	432	62	494	62	25
5	30 DAP	150 Urea	3 x 10 UAN	210	66	157	182	124	70	598	447	85	532	63	33
6	30 DAP	150 Urea	5 X 12 UAN	240	58	127	214	114	68	580	430	92	522	68	31
7	30 DAP	150 Urea	24, 24, 20, 12, 10	270	67	146	197	115	74	598	452	79	532	64	31
8	30 DAP	90 ESN	0	120	84	196	215	51	7	554	417	52	469	49	10
9	30 DAP	150 ESN	0	180	60	185	230	95	29	599	478	61	539	59	20
10	30 DAP	210 ESN	0	240	68	164	236	108	40	616	462	85	548	62	24
11	30 DAP	150 ESN	5 X 12 UAN	240	73	147	221	89	46	575	417	85	502	62	23
12	30 DAP	90 Agrocote	0	120	85	236	159	48	5	533	374	74	448	39	10
13	30 DAP	150 Agrocote	0	180	69	178	231	70	29	577	444	64	508	57	17
14	30 DAP	210 Agrocote	0	240	62	162	219	103	32	577	444	71	515	61	23
15	30 DAP	150 Agrocote	5 X 12 UAN	240	67	176	242	75	40	600	439	94	533	59	19
16	30 DAP	120 Urea + MicroAZ-ST[3]	3 x 10 UAN	180	58	135	220	120	50	583	450	75	525	66	29
17	30 DAP + MicroAZ-ST[3]	120 Urea	3 x 10 UAN	180	72	154	190	94	58	568	431	65	496	60	26
18	30 DAP + MicroAZ-ST[3]	150 Urea	5 X 12 UAN	240	55	119	215	147	89	625	473	97	570	72	38
Treatment significance[4]					**	**	**	**	**	**	**	*	**	**	**
Minimum significant difference (0.1)					12	34	35	27	23	41	33	35	43	7	6

[1]Post-hilling N applied as 28% UAN on each of five application dates: 6/25, 7/6, 7/16, 7/23, 8/3

[2]DAP (diammonium phosphate): 18-46-0. ESN (Environmentally Smart Nitrogen, Agrium, Inc.): 44-0-0. Agrocote (Everris): 25% 44-0-0, 75% 43-0-0. UAN (urea + ammonium nitrate): 28-0-0. Urea: 46-0-0.

[3]TerraMax MicroAZ-ST Liquid, 12.8 $oz \cdot ac^{-1}$

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

Table 5. Effect of N treatment on Russet Burbank tuber quality (prevalences of hollow heart, brown center, and scab; percent dry matter; and specific gravity) at the Sand Plain Research Farm in Becker, MN, in 2015.

Nitrogen sources[2] and rates (lbs·ac^{-1})					Tuber Quality				
Treatment	Planting	Emergence	Post-hilling[1]	Total N (lbs·ac^{-1})	Hollow Heart	Brown Center	Scab	Dry matter	Specific Gravity
					%				
1	30 DAP	0	0	30	0	0	11	20.8	1.0745
2	30 DAP	60 Urea	3 x 10 UAN	120	7	7	0	20.8	1.0729
3	30 DAP	90 Urea	3 x 10 UAN	150	8	8	5	21.1	1.0808
4	30 DAP	120 Urea	3 x 10 UAN	180	3	3	4	20.2	1.0753
5	30 DAP	150 Urea	3 x 10 UAN	210	4	4	3	20.7	1.0804
6	30 DAP	150 Urea	5 X 12 UAN	240	1	1	4	20.4	1.0787
7	30 DAP	150 Urea	24, 24, 20, 12, 10	270	2	2	1	21.0	1.0757
8	30 DAP	90 ESN	0	120	4	4	0	20.7	1.0805
9	30 DAP	150 ESN	0	180	0	0	6	21.3	1.0837
10	30 DAP	210 ESN	0	240	3	3	5	21.0	1.0768
11	30 DAP	150 ESN	5 X 12 UAN	240	1	1	1	20.1	1.0768
12	30 DAP	90 Agrocote	0	120	1	1	0	21.5	1.0815
13	30 DAP	150 Agrocote	0	180	11	11	3	21.3	1.0904
14	30 DAP	210 Agrocote	0	240	1	1	5	20.3	1.0770
15	30 DAP	150 Agrocote	5 X 12 UAN	240	2	2	7	21.0	1.0774
16	30 DAP	120 Urea + MicroAZ-ST[3]	3 x 10 UAN	180	4	4	2	20.9	1.0769
17	30 DAP + MicroAZ-ST[3]	120 Urea	3 x 10 UAN	180	1	1	6	20.6	1.0776
18	30 DAP + MicroAZ-ST[3]	150 Urea	5 X 12 UAN	240	4	4	4	20.6	1.0783
Treatment significance[4]					NS	NS	NS	NS	NS
Minimum significant difference (0.1)					--	--	--	--	--

[1]Post-hilling N applied as 28% UAN on each of five application dates: 6/25, 7/6, 7/16, 7/23, 8/3

[2]DAP (diammonium phosphate): 18-46-0. ESN (Environmentally Smart Nitrogen, Agrium, Inc.): 44-0-0. Agrocote (Everris): 25% 44-0-0, 75% 43-0-0. UAN (urea + ammonium nitrate): 28-0-0. Urea: 46-0-0.

[3]TerraMax MicroAZ-ST Liquid, 12.8 oz·ac^{-1}

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

Table 5. Effect of N treatment on Russet Burbank tuber and vine dry-matter yield, N concentration, and N uptake, as well as total N uptake, at the Sand Plain Research Farm in Becker, MN, in 2015.

Nitrogen sources[2] and rates (lbs·ac^{-1})					Dry yield, N concentration, and N uptake						
Treatment	Planting	Emergence	Post-hilling[1]	Total N (lbs·ac^{-1})	Tuber DM (lbs·ac^{-1})	Tuber % N	Tuber N uptake (lbs·ac^{-1})	Vine DM (lbs·ac^{-1})	Vine % N	Vine N uptake (lbs·ac^{-1})	Total N uptake (lbs·ac^{-1})
1	30 DAP	0	0	30	8438	0.91	77	508	0.99	5	82
2	30 DAP	60 Urea	3 x 10 UAN	120	11820	1.25	147	1173	1.13	13	161
3	30 DAP	90 Urea	3 x 10 UAN	150	11521	1.24	143	1288	1.22	16	159
4	30 DAP	120 Urea	3 x 10 UAN	180	11462	1.39	157	1401	1.37	19	177
5	30 DAP	150 Urea	3 x 10 UAN	210	12434	1.46	180	2026	1.58	32	212
6	30 DAP	150 Urea	5 X 12 UAN	240	11831	1.54	181	2111	1.69	35	216
7	30 DAP	150 Urea	24, 24, 20, 12, 10	270	12617	1.50	188	1890	1.56	29	217
8	30 DAP	90 ESN	0	120	11483	1.18	136	1113	0.90	10	146
9	30 DAP	150 ESN	0	180	12757	1.34	170	1816	1.50	27	197
10	30 DAP	210 ESN	0	240	12936	1.39	179	1694	1.38	24	203
11	30 DAP	150 ESN	5 X 12 UAN	240	11558	1.53	176	1605	1.69	28	204
12	30 DAP	90 Agrocote	0	120	11449	1.17	133	1055	1.22	13	146
13	30 DAP	150 Agrocote	0	180	12284	1.25	153	1322	1.20	16	169
14	30 DAP	210 Agrocote	0	240	11756	1.50	174	1367	1.52	20	194
15	30 DAP	150 Agrocote	5 X 12 UAN	240	12581	1.42	179	1929	1.39	26	205
16	30 DAP	120 Urea + MicroAZ-ST[3]	3 x 10 UAN	180	12194	1.30	158	1732	1.21	21	179
17	30 DAP + MicroAZ-ST[3]	120 Urea	3 x 10 UAN	180	11733	1.38	162	1932	1.41	27	189
18	30 DAP + MicroAZ-ST[3]	150 Urea	5 X 12 UAN	240	12868	1.50	193	1485	1.23	18	211
Treatment significance[4]					**	**	**	**	**	**	**
Minimum significant difference (0.1)					1275	0.14	15	420	0.30	6	17

[1]Post-hilling N applied as 28% UAN on each of five application dates: 6/25, 7/6, 7/16, 7/23, 8/3

[2]DAP (diammonium phosphate): 18-46-0. ESN (Environmentally Smart Nitrogen, Agrium, Inc.): 44-0-0. Agrocote (Everris): 25% 44-0-0, 75% 43-0-0. UAN (urea + ammonium nitrate): 28-0-0. Urea: 46-0-0.

[3]TerraMax MicroAZ-ST Liquid, 12.8 oz·ac^{-1}

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