Evaluation of Polymer Coated Urea and Stabilized Nitrogen Products on Irrigated Potato Production

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Summary: Field experiments were conducted at the Sand Plain Research Farm in Becker, MN to evaluate controlled release fertilizers and stabilized N products. Treatments compared differences in N release rates and tuber yield and quality between dealer grade ESN and potentially damaged ESN collected from airboom deflector plates. Stabilized N products SuperU and Agrotain Plus were also evaluated. Fifteen treatments in total were examined, all of which included the equivalent of 30 lb N/A in a starter blend. Except for a starter only control, all treatments received a total of 240 lb N/A. Three of the treatments were solely urea with the following rates (lb N/A), 210 as preplant, 210 at emergence, and a combination of 100 as preplant and 110 at emergence. Three other treatments included 110 lb N/A at emergence as either urea, UAN, or UAN + Agrotain Plus, and also included 4 post-hilling applications of UAN at 20, 20, 30, and 30 lb N/A. Four treatments included dealer grade ESN(C) at the following rates (lb N/A): 210 as preplant, 100 as preplant and 110 at emergence, 210 at emergence, and a combination of 110 of urea and 100 ESN(C), both applied at emergence. In addition, one treatment included 210 lb N/A as airboom ESN(A) applied at emergence. The remaining three treatments include SuperU at the following rates (lb N/A): 210 as preplant, 210 at emergence, and 100 as preplant combined with 110 of UAN and Agrotain Plus applied at emergence. Nitrogen release from the airboom ESN(A) was found to be much more rapid than release from a comparable application of dealer grade product – ESN(C) - which released N at a rate consistent with what was seen in previous years: 60% of the N had been released 8 days after application for the air boom ESN sample (ESN-A), while only 12% had been released from the undamaged control ESN sample (ESN-C). Tuber yields with ESN(C) were numerically higher than with ESN(A), but these differences were not statistically significant. In a leaching year, risk of losses would be minimized by using undamaged ESN. Marketable yield was significantly higher from plants fertilized at emergence solely with ESN(C) or SuperU treatments when compared with urea + ESN(C) and urea + split applied UAN treatments. Petiole nitrate concentration data suggest that when applied at equivalent rates and timing, the undamaged ESN has the potential to release N through the season longer than SuperU and damaged ESN. Overall results indicate that the use of emergence applied ESN, SuperU, or adding Agrotain Plus to a UAN treatment can produce marketable yield and tuber quality comparable to or higher than conventional fertilizer treatments. However, yields in all treatments in this study were somewhat compromised as a result of early vine death in August due to unknown causes.

Background: This study is a continuation of research conducted over a six year period on enhanced efficiency N fertilizers – primarily polymer coated urea. The study was expanded this year to include stabilized N products, SuperU and Agrotain Plus. While plot research results have been quite positive with ESN, a polymer coated controlled release N fertilizer manufactured by Agrium, responses from on-farm grower trials are sometimes less favorable. One possible reason for these differences is increased abrasion of the ESN polymer coating in grower trials, particularly when product is applied with air boom spreaders. Abrasion damage to prills results in faster N release (up to 56% release after 24 h in laboratory water tests), negating some of the enhanced efficiency benefits. In this current potato response study, we compared ESN collected from the deflector plates of an airboom spreader to the dealer grade ESN that we have used in earlier trials. Additionally we examined stabilized N products SuperU (granular urea) and Agrotain Plus (a UAN solution additive), both manufactured by Agrotain. These products are designed to slow nitrate-N loss by including urease and nitrification inhibitors, in contrast to the physical barrier of a polymer coating.

The objectives of this study were, under field conditions, to 1) compare the effects of dealer grade ESN with ESN collected from an air boom spreader on potato yield and quality, and 2) evaluate the effectiveness of stabilized N products on potato yield and quality.

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, 6.7; organic matter, 1.7%; Bray P1, 37 ppm; ammonium acetate extractable K, Ca, and Mg, 107, 890, and 178 ppm, respectively; Ca-phosphate extractable SO_4-S, 1 ppm; and DTPA extractable Zn, Cu, Fe, and Mn, 0.8, 1.0, 16.6, and 4.7 ppm, respectively. Extractable nitrate-N in the top 2 ft prior to planting was equivalent to 14.3 lb/A.

Whole "B" seed was hand planted in furrows on April 15, 2010. 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. Each treatment was 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.

Agrium, Inc. produces Environmentally Smart Nitrogen (ESN, 44-0-0), which is a polymer coated urea. Two grades of ESN were tested in this study (dealer grade and ESN collected from the deflector plates of an air boom spreader), along with uncoated urea (46-0-0). In addition two stabilized N products were examined: SuperU (46-0-0) and Agrotain Plus (an additive used for UAN solutions) – both produced by Agrotain International L.L.C. Fifteen treatments were tested and are listed below (Table 1).

Table 1. Nitrogen treatments tested in the controlled release/stabilized N fertilizer study.

Trmt	N Timing[1]				Total
	Preplant	Planting	Emergence/Hilling	Post-Hilling[2] (4 apps)	
	lb N / A				
1	0	30	0	0	30
2	0	30	110 Urea	100 UAN	240
3	0	30	110 UAN	100 UAN	240
4	0	30	110 UAN + Agrotain Plus	100 UAN	240
5	0	30	110 Urea + 100 ESN(C)	0	240
6	0	30	210 Urea	0	240
7	0	30	210 ESN(C)	0	240
8	0	30	210 ESN(A)	0	240
9	0	30	210 SuperU	0	240
10	100 Urea	30	110 Urea	0	240
11	100 ESN(C)	30	110 ESN(C)	0	240
12	100 SuperU	30	110 UAN + Agrotain Plus	0	240
13	210 Urea	30	0	0	240
14	210 ESN(C)	30	0	0	240
15	210 SuperU	30	0	0	240

[1]ESN = Environmentally Smart Nitrogen 44-0-0, Agrium Inc; (C) = control: dealer grade; (A) = airboom; UAN = a combination of granular urea and ammonium nitrate.

[2]Post-hilling N was applied 4 times (2 times at 20 lb N/A and 2 times at 30 lb N/A) at approximately 2-wk intervals.

Preplant fertilizers were broadcast applied 6 days before planting on April 9 and incorporated with a field cultivator. At the same time, 150 lb K_2O/A as potassium chloride was applied and incorporated on all plots. 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 phosphate (MAP), potassium chloride, potassium magnesium sulfate, and ammonium sulfate were applied to all plots at planting.

Plant emergence N applications were sidedressed as urea, ESN, SuperU, or Agrotain Plus on May 10 and mechanically incorporated into the hill. Post-hilling N was applied by hand over the plots as 50% granular urea and 50% granular ammonium nitrate and watered-in with overhead irrigation to simulate fertigation with 28% N. The four post-hilling applications took place on June 3, June 16, June 30, and July 19.

Plant stands were measured on June 2 and the number of stems per plant was counted on June 9. Petiole samples were collected from the 4^{th} leaf from the terminal on June 7, June 22, July 8, July 27, and Aug 12. Petioles were analyzed for nitrate-N on a dry weight basis. Vines were harvested from two, 10-ft sections of row on September 10, followed by mechanically beating the vines over the entire plot area. On September 22, 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.

Measured amounts of ESN fertilizer were placed in plastic mesh bags and buried at the depth of fertilizer placement when both the preplant and emergence applications were made. Bags were removed on April 21, May 4, May 18, June 2, June 14, June 28, July 19, Aug 17, Sept 10, and Oct 5 for preplant applied, and May 18, June 2, June 14, June 28, July 12, July 27, Aug 12, Aug 25, Sept 10, and Oct 5 for emergence applied fertilizer to track N release over time. Soil samples from the 0-2 ft depth were collected on Oct 13 & 14 to measure residual inorganic N levels. Each sample consisted of four soil cores that were composited, oven dried at 90° F, extracted with 2M KCl, and analyzed for nitrate-N and ammonium-N. A WatchDog weather station from Spectrum Technologies was used to monitor air temperature, soil temperature, and soil moisture (utilizing Watermark soil moisture sensors). Soil temperature and soil moisture were measured at about 4 inches below the top of the hill and 2 inches in from the side of the hill.

The experiment was statistically analyzed using ANOVA procedures on SAS and means were separated using a Waller-Duncan LSD test at P=0.10

Results

Weather and Environmental: Rainfall and irrigation amounts are shown in Fig. 1 and air temperature, soil temperature, and soil moisture in Fig. 2. From April 15 to September 12 (planting to vine kill), approximately 33.2 inches of rainfall was supplemented with 11.8 inches of irrigation for a total of 45.0 inches of water. Significant leaching occurred in May and June. Vine die-off began early in this study, with noticeable decline occurring by the 2^{nd} week in August. The causes of the decline are likely to have been disease (potentially black dot), exacerbated by high N leaching in June.

Nitrogen release from ESN: Release curves for the various grades and application timings of ESN controlled release fertilizer are presented in Fig. 1. Despite application dates a month apart, preplant and emergence applications of the control (dealer grade) ESN(C) had similar release rates early on as shown by nearly parallel release curves. In both cases, 40% of the N was released after about 20 days. Release from the airboom emergence ESN(A) was much faster with over 60% released after only 8 days, while only 12% was released from ESN(C). At about 20 days post application, release from the preplant ESN(C) and the emergence ESN(A) began to slow until percent N released for all three treatments converged at 74 DAP and 92%. From then on, ESN release rates for all treatments were approximately equal. At the last measurement at 173 DAP, totals were between 98 and 100% N released, suggesting low to no risk of significant post-season N release.

ESN release rates in all three treatments matched the N uptake pattern of Russet Burbank potatoes fairly consistently. Russet Burbank takes up the majority of its N between 40 and 80 days after planting. ESN had released 78, 87, and 91% of its N by 60 days after planting for the emergence ESN(C), preplant ESN(C), and emergence ESN(A) treatments, respectively. When compared to past years, the ESN(C) preplant application released N at a rate comparable to similar treatments in 2008 and 2009 with a release of approximately 45% by 25 DAP. The quicker release of ESN(A), however, may result in early season N losses if leaching rainfall occurs.

Tuber Yield: Total yields were greatest for the emergence applied dealer grade control - ESN(C) - and SuperU (trmts 7 and 9, respectively), although they were only significantly greater than the control and the emergence applied urea/ESN(C) blended treatment (trmt 5; Table 2). Significantly lower yields were also realized from the 110 lb N/A UAN + Agrotain Plus applied at emergence with 100 lb N/A UAN applied in 4 split post-hilling applications (trmt 4) when compared with the emergence SuperU treatment (trmt 9). As expected, all treatments receiving N fertilizer had significantly greater total yields than the control. There were no significant differences in yields among preplant treatments. The mean yield from ESN(A) was numerically lower than that of ESN(C) by nearly 45 cwt/A (8.5%). However, this was not found to be a significant difference, so the effect of the potential damage to the polymer coating from airboom application on total yield is not conclusive.

Three of the 5 treatments with top marketable yields were those with 210 lb/A fertilizer applied at emergence (ESN(C), SuperU, and urea; trmts 7, 9, and 6, respectively). The other two were ESN(C) applied at preplant (trmt 14) and treatment 12, which combined SuperU applied at preplant with emergence applied UAN + Agrotain Plus. The conventional treatment of emergence applied urea with UAN split applied post emergence did, however, produce significantly lower yields than both the emergence applied ESN(C) and SuperU treatments (trmts 7 & 9, respectively). There were no significant differences in marketable yields between the comparable preplant vs. postplant applications of urea and none between the ESN(C) preplant/postplant treatments. The emergence applied SuperU yield, however, was significantly higher than the preplant. Significantly lower marketable yields were harvested from the preplant urea (trmt 13) when compared with emergence applied ESN(C) (trmt 7). Emergence applied ESN(C) also produced significantly higher marketable yields than the emergence ESN(C)/urea blend (trmt 5). The addition of Agrotain Plus to UAN (trmt 4) did not significantly affect yields when compared to straight UAN (trmt 3). The yield from the control was again significantly lower than any of the fertilized treatments.

Emergence applied ESN(C) (trmt 7) had a significantly higher percentage of large tubers (>10 oz) than half of the fertilized treatments, but was not different from the ESN(A). Two urea treatments, 210 lb/A applied at preplant (trmt 13) and split between preplant and emergence (trmt 10), did not produce significantly more tubers >10 oz than the control. Treatment 10 was also not significantly different to the control with respect to the number of tubers >6 oz.

Stand Count, Stems per Plant, and Tuber Quality: Plant stands ranged from about 98 to 100% and there were no significant differences among treatments with respect to plant stand (Table 3). There were also no significant differences among treatments with respect to the number of stems per plant with a study average of 3.6. The emergence applied ESN(C)/Urea blend (trmt 5) resulted in the highest tuber specific gravity. There were no significant differences in incidence of scab among treatments (all treatments under 25%). Both hollow heart and brown center were numerically lowest in the control, but other significant differences were not consistently associated with differences in N treatment.

Vine Dry Matter: ESN(C) applied at a rate of 210 lb N/A at emergence (trmt 7) produced the most vines, measured as dry matter (Table 3). Its production was significantly higher than that of any of the other treatments. The next two highest vine dry matter producing treatments were those that included Agrotain Plus (trmts 4 and 12). However, these were not significantly higher than the production of any of the other remaining fertilized treatments. Vine dry matter from the control was the lowest by a significant amount.

Petiole Nitrate-N Concentrations: June 7 mean nitrate concentrations were highest in petioles collected from the preplant SuperU treatment (trmt 15; Table 4). However, these concentrations were only significantly higher than those of the 50/50 preplant/emergence urea and ESN(C) treatments (trmts 10 & 11, respectively), the emergence only ESN(C) (trmt 7), and the control. On that date, petioles from the emergence only ESN(C) were also lower in NO_3^- than the preplant ESN(C) and urea treatments (trmts 14 & 13, respectively), the emergence applied ESN(A) treatment (trmt 8), and the emergence urea with post hilling split applied UAN treatment (trmt 2). On June 22, petioles from the emergence applied control grade ESN(C) treatment (trmt 7) contained mean concentrations of NO_3^- significantly higher than those of any of the other treatments. On July 8, petiole N concentrations in the emergence and post hilling UAN with Agrotain Plus treatment (trmt 4) were the highest among treatments, although not significantly different than the N concentrations from emergence only ESN(C) petioles. The remainder of the treatments produced petioles on July 8 that were significantly lower in N, and were in fact deficient in N for the tuber bulking growth stage. On July 27, petiole samples from the emergence applied urea + post hilling UAN (trmt 2) and UAN with Agrotain Plus (trmt 4) were significantly higher in NO_3^- than all other treatments but not different from each other, while samples collected on Aug 12 from the urea + post hilling UAN (trmt 2) were numerically higher in nitrate than all other samples collected on that date, but not significantly different from petioles collected from treatments the emergence only ESN(C) (trmt 7), the emergence and post hilling UAN with and without Agrotain Plus treatment (trmts 4 & 3, respectively), or the 50/50 preplant/emergence ESN(C) (trmt 7). The emergence only ESN(C) treatment did, however, produce petioles with significantly higher nitrate content than the emergence applied SuperU treatment (trmt 9).

When tracking emergence applied ESN(C), ASN(A) and SuperU though the season, the ESN(A) treatment resulted in highest readings on the first date followed by Super(U), and then ESN(C). After that date, ESN(C) resulted in the highest readings followed by ESN(A) and then Super U. These results point to a slower release nature of ESN when it is not damaged. The results also suggest when applied at equivalent rates and timing, the undamaged ESN has the potential to release N through the season longer than SuperU and damaged ESN.

Mean concentrations of NO_3^- in the petiole samples were numerically lowest for the control (trmt 1) on all dates except Aug 12 and significantly lower than those of all treatments on June 7 and June 22. On July 8 the control produced significantly lower petiole nitrate levels than all other treatments except the preplant + emergence urea (trmt 10) and the preplant urea (trmt 13). On Aug 12, the preplant urea treatment (trmt 13) produced the lowest petiole N levels, but not significantly different than preplant + emergence urea, urea or SuperU applied only at emergence, or SuperU applied at preplant with emergence applied UAN + Agrotain Plus (trmts 10, 6, 9, & 12, respectively).

Residual soil N: There were no significant differences among individual treatments with respect to post-harvest residual soil N (Table 5). Mean soil N levels were the equivalent of between 0.8 and 4.8 lb/A N for ammonium and 22.2 and 27.9 lb/A N for nitrate. Contrast analysis suggests no significant difference between the control (trmt 1) and the fertilized treatments with respect to residual nitrate or ammonium. These results suggest significant leaching during the season

Conclusions

Nitrogen release from the air boom ESN(A) was found to be much more rapid than release from a comparable application of dealer grade product – ESN(C) - which released N at a rate consistent with what was seen in previous years. Tuber yields with ESN(C) were numerically higher than with ESN(A), but these differences were not statistically significant. In a leaching year early in the growing season, risk of losses would be minimized by using undamaged ESN. Marketable yield was significantly higher from plants fertilized at emergence solely with ESN(C) or SuperU treatments when compared with urea + ESN(C) and urea + split applied UAN treatments. Results indicate that the use of emergence applied ESN, SuperU, or adding Agrotain Plus to a UAN treatment can produce marketable yield and tuber quality comparable to or higher than conventional fertilizer treatments. However, yields in all treatments in this study were somewhat compromised as a result of early vine death in August due to unknown causes.

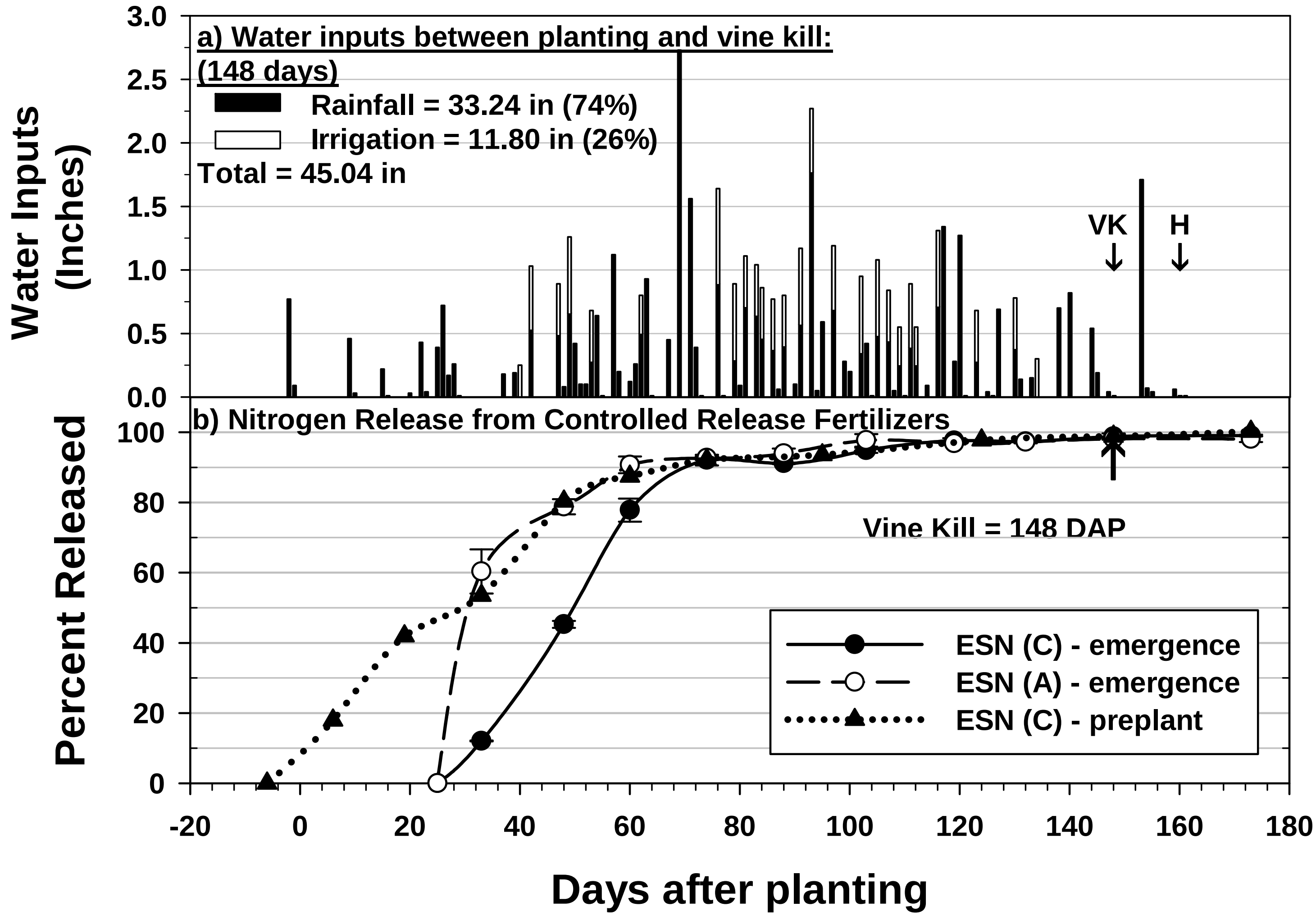

Figure 1. a) Rainfall and irrigation amounts and; b) nitrogen release from controlled release fertilizers during the 2010 growing season. ESN(C) = Control: Dealer grade ESN; ESN(A) = Airboom ESN. Planting (April 15); VK = Vine Kill (Sept 10); H = Harvest (Sept 22)

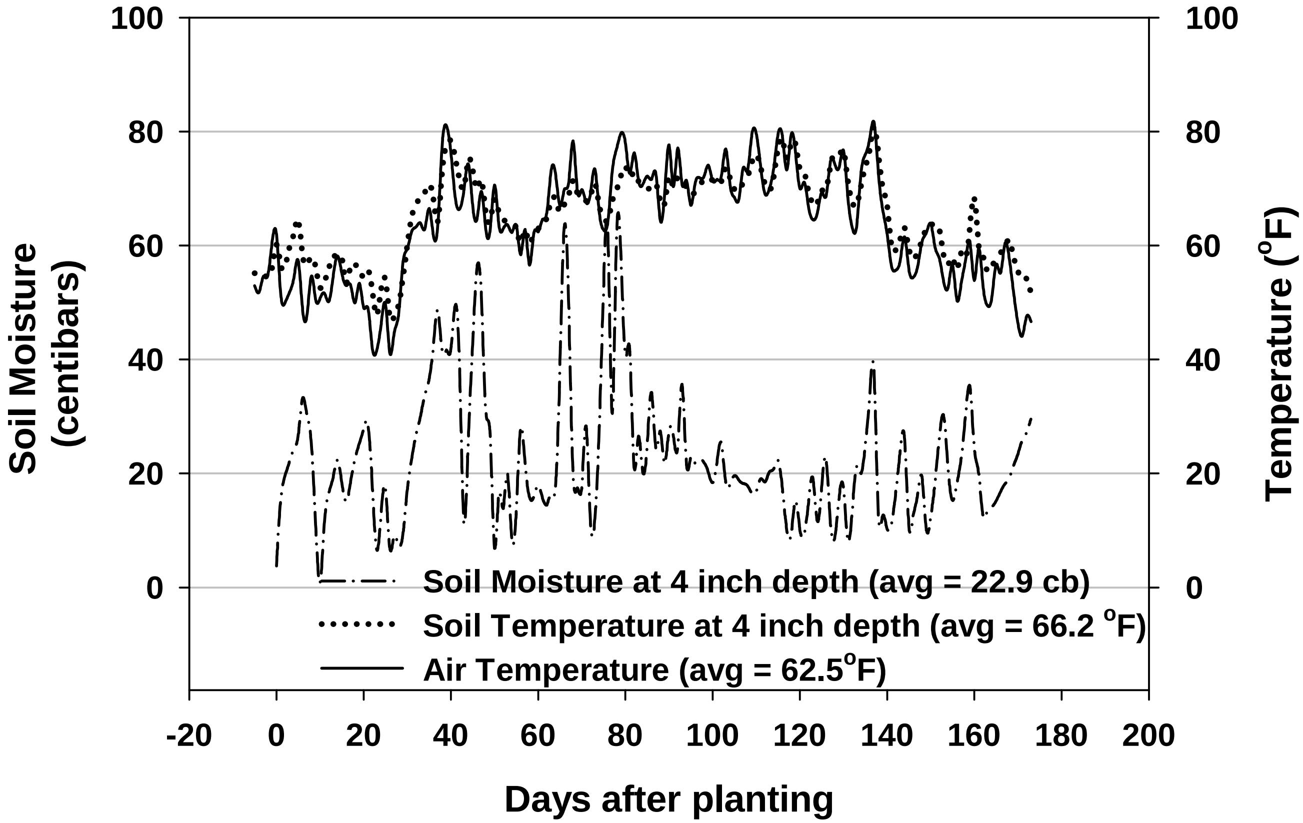

Figure 2. Soil moisture and soil & air temperatures during the 2010 growing season.

Table 2. Effects of N source, quality, and timing on Russet Burbank tuber yield and size distribution.

Nitrogen Treatments				Tuber Yield											Vines
Trtmt #	N Source[1]	N Rate	N Timing[2]	0-3 oz	3-6 oz	6-10 oz	10-14 oz	>14 oz	Total	#1 > 3 oz	#2 > 3 oz	Total Marketable	> 6 oz	> 10 oz	DM
		lb N / A	PP, P, E, PH	cwt / A									%		ton / A
1	Control	30	0, 30, 0, 0	120.3	210.2	51.1	1.9	0.0	383.5	208.1	55.1	263.2	13.38	0.44	0.27
2	Urea / UAN	240	0, 30, 110, 100	110.2	206.4	127.8	32.9	5.6	482.8	326.7	45.9	372.6	34.30	7.91	0.59
3	UAN	240	0, 30, 110, 100	105.8	198.3	136.5	38.1	18.6	497.4	328.3	63.2	391.5	38.75	11.29	0.79
4	UAN / Agrotain Plus	240	0, 30, 110, 100	79.0	182.7	151.4	36.8	18.1	467.8	323.1	65.7	388.9	43.90	11.90	0.87
5	Urea / ESN(C)	240	0, 30, 210, 0	89.6	198.4	132.9	34.3	6.1	461.4	349.2	22.5	371.8	37.49	8.79	0.72
6	Urea	240	0, 30, 210, 0	90.9	214.3	144.0	41.4	5.1	495.7	374.7	30.0	404.8	38.17	9.27	0.65
7	ESN(C)	240	0, 30, 210, 0	72.8	208.0	164.4	44.2	27.8	517.2	370.1	74.4	444.4	45.31	13.81	1.32
8	ESN(A)	240	0, 30, 210, 0	78.2	190.9	144.2	51.3	8.7	473.3	371.4	23.7	395.1	43.17	12.71	0.71
9	SU	240	0, 30, 210, 0	78.6	217.1	172.8	36.9	13.7	519.0	390.1	50.4	440.4	43.12	9.79	0.64
10	Urea	240	100, 30, 110, 0	134.4	254.4	88.4	10.1	0.9	488.2	328.9	25.0	353.8	20.36	2.27	0.63
11	ESN(C)	240	100, 30, 110, 0	85.4	202.2	137.9	44.6	9.8	479.9	352.6	41.8	394.5	39.97	11.33	0.74
12	SU / UAN / Agrotain Plus	240	100, 30, 110, 0	95.0	226.4	144.6	28.8	3.5	498.3	356.5	46.8	403.3	35.50	6.56	0.81
13	Urea	240	210, 30, 0, 0	116.0	251.5	116.3	21.2	1.6	506.6	355.7	34.9	390.6	27.48	4.52	0.66
14	ESN(C)	240	210, 30, 0, 0	85.2	225.8	144.7	32.4	5.2	493.4	383.5	24.8	408.2	36.58	7.54	0.67
15	SU	240	210, 30, 0, 0	96.6	224.2	123.9	26.2	8.1	479.1	327.9	54.5	382.4	32.89	7.08	0.58
			Significance[3]	**	**	**	**	**	**	**	NS	**	**	**	**
			LSD (0.10)	14.8	47.4	30.5	20.6	9.7	50.1	43.8	--	53.0	6.95	4.62	0.31

[1]ESN(C) = Control: Dealer grade ESN; ESN(A) = Airboom ESN; SU = Super U.

[2]PP, P, E, PH = Preplant, Planting, Emergence, and Post-Hilling, respectively; 4 post-hilling applications were as follows: 20%, 20%, 30%, 30%.

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

Table 3. Effects of N source, quality, and timing on Russet Burbank tuber quality, plant stand, number of stems per plant, and vine dry matter.

Trtmt #	N Source[1]	N Rate	N Timing[2]	Specific Gravity	Tuber Quality[3] HH	BC	Scab	Plant Stand	# Stems per Plant	Vine DM[4]
		lb N / A	PP, P, E, PH		%					ton / A
1	Control	30	0, 30, 0, 0	1.0742	0.0	1.0	20.3	100.0	3.5	0.27
2	Urea / UAN	240	0, 30, 110, 100	1.0697	11.0	12.3	21.3	99.3	3.8	0.59
3	UAN	240	0, 30, 110, 100	1.0712	9.8	9.8	23.8	100.0	3.6	0.79
4	UAN / Agrotain Plus	240	0, 30, 110, 100	1.0712	14.8	14.8	18.3	100.0	3.7	0.87
5	Urea / ESN(C)	240	0, 30, 210, 0	1.0756	7.0	7.0	16.0	100.0	3.5	0.72
6	Urea	240	0, 30, 210, 0	1.0720	14.0	14.0	20.0	97.9	3.4	0.65
7	ESN(C)	240	0, 30, 210, 0	1.0720	11.0	11.0	23.0	100.0	3.5	1.32
8	ESN(A)	240	0, 30, 210, 0	1.0701	12.3	12.3	15.3	99.3	3.3	0.71
9	SU	240	0, 30, 210, 0	1.0741	16.0	16.0	22.3	100.0	3.3	0.64
10	Urea	240	100, 30, 110, 0	1.0749	4.0	4.0	23.3	100.0	3.9	0.63
11	ESN(C)	240	100, 30, 110, 0	1.0712	16.5	16.5	20.3	99.3	3.6	0.74
12	SU / UAN / Agrotain Plus	240	100, 30, 110, 0	1.0723	6.0	6.0	25.0	97.9	3.6	0.81
13	Urea	240	210, 30, 0, 0	1.0744	7.0	7.0	16.0	99.3	3.7	0.66
14	ESN(C)	240	210, 30, 0, 0	1.0727	7.3	7.3	12.3	98.6	3.6	0.67
15	SU	240	210, 30, 0, 0	1.0725	11.3	11.3	22.3	98.6	3.5	0.58
			Significance[5]	++	**	**	NS	NS	NS	**
			LSD (0.1)	0.0045	7.4	7.7	--	--	--	0.31

[1]ESN(C) = Control: Dealer grade ESN; ESN(A) = Airboom ESN; SU = Super U.

[2]PP, P, E, PH = Preplant, Planting, Emergence, and Post-Hilling, respectively; 4 post-hilling app. as: 20%, 20%, 30%, 30%.

[3]HH = Hollow Heart; BC = Brown Center

[4]DM = Dry Matter

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

Table 4. Effects of N source, rate, and timing on nitrate-N concentrations in petioles from Russet Burbank potato on five sampling dates.

Trtmt #	N Source[1]	N Timing[2] PP, P, E, PH	N Rate lb N / A	NO_3^- concentration (mg/kg) by sampling date June 7	June 22	July 8	July 27	August 12
1	Control	0, 30, 0, 0	30	6097	215	342	692	1568
2	Urea / UAN	0, 30, 110, 100	240	21447	5755	8480	10266	6349
3	UAN	0, 30, 110, 100	240	20732	7586	10191	5518	6206
4	UAN / Agrotain Plus	0, 30, 110, 100	240	19276	8787	13317	8476	6238
5	Urea / ESN(C)	0, 30, 210, 0	240	19845	9081	6060	2745	4933
6	Urea	0, 30, 210, 0	240	19222	8186	2917	741	1703
7	ESN(C)	0, 30, 210, 0	240	17277	12007	11691	4036	6333
8	ESN(A)	0, 30, 210, 0	240	21013	9275	7537	3475	4723
9	SU	0, 30, 210, 0	240	19611	9204	3479	1152	2856
10	Urea	100, 30, 110, 0	240	19011	3520	939	709	2111
11	ESN(C)	100, 30, 110, 0	240	18888	9505	8350	3101	5332
12	SU/UAN/Agrotain Plus	100, 30, 110, 0	240	20712	7514	4033	1380	1877
13	Urea	210, 30, 0, 0	240	21397	5757	1478	860	1675
14	ESN(C)	210, 30, 0, 0	240	22147	7091	3414	1733	3812
15	SU	210, 30, 0, 0	240	22590	6841	2488	2768	3339
			Significance[3]	**	**	**	**	**
			LSD (0.1)	3514	2103	1829	1948	1381

[1]ESN(C) = Control: Dealer grade ESN; ESN(A) = Airboom ESN; SU = Super U.
[2]PP, P, E, PH = Preplant, Planting, Emergence, and Post-Hilling, respectively;
4 post-hilling applications as: 20%, 20%, 30%, 30%.
[3]NS = Not significant, * Significant at 1%, ** Significant at 5%, ++ Significant at 10%

Table 5. Effects of N source, rate, and timing on residual inorganic soil N after harvest of Russet Burbank potato.

Trtmt #	N Source[1]	N Rate	N Timing[2]	Residual Soil N		
				NO_3	NH_4	Total
		lb N / A	PP, P, E, PH	lb N/A		
1	Control	30	0, 30, 0, 0	22.2	1.2	23.5
2	Urea / UAN	240	0, 30, 110, 100	26.0	2.7	28.7
3	UAN	240	0, 30, 110, 100	26.5	3.1	29.6
4	UAN / Agrotain Plus	240	0, 30, 110, 100	27.4	3.5	30.9
5	Urea / ESN(C)	240	0, 30, 210, 0	27.9	4.8	32.7
6	Urea	240	0, 30, 210, 0	24.7	1.4	26.1
7	ESN(C)	240	0, 30, 210, 0	26.3	2.3	28.6
8	ESN(A)	240	0, 30, 210, 0	25.9	1.4	27.2
9	SU	240	0, 30, 210, 0	23.2	0.8	24.1
10	Urea	240	100, 30, 110, 0	26.0	3.8	29.8
11	ESN(C)	240	100, 30, 110, 0	26.5	1.6	28.0
12	SU/UAN/Agrotain Plus	240	100, 30, 110, 0	22.8	4.8	27.6
13	Urea	240	210, 30, 0, 0	23.3	1.7	24.9
14	ESN(C)	240	210, 30, 0, 0	26.8	1.7	28.6
15	SU	240	210, 30, 0, 0	23.5	1.8	25.3
			Significance[3]	NS	NS	NS
			LSD (0.1)	--	--	--
Contrasts						
			Control vs. Rest (1 vs. 2-15)	NS	NS	NS

[1]ESN(C) = Control: Dealer grade ESN; ESN(A) = Airboom ESN; SU = Super U.
[2]PP, P, E, PH = Preplant, Planting, Emergence, and Post-Hilling, respectively;
4 post-hilling applications as: 20%, 20%, 30%, 30%.
[3]NS = Not significant, * Significant at 1%, ** Significant at 5%, ++ Significant at 10%