Response of Processing Potato Varieties to Nitrogen Source, Rate, and Timing

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Summary: A field experiment was conducted at the Sand Plain Research Farm in Becker, Minn. to evaluate the effects of nitrogen rate, source and timing on yield and quality of four processing russet potato varieties/selections: Russet Burbank, Umatilla Russet, Premier Russet, and Bannock Russet. Ten N treatments were evaluated. Six of the ten treatments were conventional N sources with the following N rates (lb/A): 30, 120, 180, 240 (early), 240 (late) and 300. Four of the ten treatments were ESN: 180 and 240 lb N/A preplant and 180 and 240 lb N/A at emergence. A starter N rate of 30 lb N/A as monoammonium phosphate was included in the total N rate applied. Release of N from ESN was similar to that recorded in 2008 and tended to be 20-30 days faster than that recorded prior to 2008, suggesting that the coating may have been more abraded than in previous years. In general, marketable and total yields of all varieties increased with increasing N rate with optimum yield between 240 lb N/A and 300 lb N/A depending on timing and source. For conventional N at the 240 lb N/A rate, more up front N was optimum for all varieties. Unlike 2008 when Umatilla responded favorably to late season applied, Umatilla vines died back early in 2009 due to disease, which apparently prevented efficient use of late season applied N. Russet Burbank tended to be the highest yielding variety followed by Bannock and Premier, and then Umatilla. Premier, Bannock, and Umatilla all had fewer misshaped potatoes than Russet Burbank with Premier having the fewest #2 potatoes. Tubers greater than 6 and 10 oz were highest for Premier followed by Bannock, Russet Burbank and then Umatilla. Hollow heart incidence was highest in Bannock, followed by Premier, Russet Burbank, and then Umatilla. Surface scab incidence was highest with Umatilla, followed by Russet Burbank and then Bannock and Premier. Specific gravity was highest in Russet Burbank and Umatilla, followed by Premier, and then Bannock. Stem and bud end chip color was darkest for Russet Burbank and lowest for Premier. AGT scores were highest for Premier and lowest for Russet Burbank. Stem end glucose concentrations were highest for Russet Burbank followed by Bannock, and then Premier and Umatilla.

Background: Studies with ESN, a controlled release N fertilizer, have been conducted for a number of years using ‘Russet Burbank’ as the test cultivar. The main findings have shown that the fertilizer can be used as a substitute for many split applications of UAN with fertigation. In 2008, a study was initiated to evaluate this product as well as characterize N response of some of the newer cultivars available for processing. The cultivars evaluated in 2008 included: ‘Umatilla Russet’, ‘Premier Russet’ from the northwest breeding program and a new selection, AOND95249-1Rus, from the NDSU breeding program. In addition, ‘Russet Burbank’ was included as the conventional cultivar. In 2009, ‘Russet Burbank’, ‘Umatilla Russet’, ‘Premier Russet’ and Bannock Russet (also from the Northwest breeding program) were evaluated. Specific advantages of the new cultivars/selections include better tuber uniformity and less susceptibility to sugar ends. The best results with ESN indicate an early sidedress application provides the best yield and quality. However, there is interest in using ESN as a preplant fertilizer. In previous studies, use of ESN shows the greatest advantage of reducing nitrate leaching when excessive rainfall occurs in May and June. Because the release characteristics of ESN can affect tuber set and bulking of potatoes, evaluation of this new technology is

essential for adoption. The use of newer cultivars in combination with newer cost effective urea coated fertilizer technology has the potential to greatly improve N use efficiency in potato and reduce nitrate losses. Research over different growing seasons is needed to evaluate the N response and use efficiency characteristics of new cultivars in comparison with Russet Burbank, as well as to estimate an N budget (inputs vs. outputs). These data will be useful for growers to more efficiently manage N for these cultivars.
The overall goal of this research is to optimize N fertilizer management for new processing potato cultivars under Minnesota growing conditions. Specific objectives include: a) Determine the effect of N rate and source on tuber yield and quality of new cultivars/selections potato cultivars, and b) Evaluate the effectiveness of a cost-effective coated urea product on tuber yield and quality of the potato cultivars/selections. This is the second year of the study.

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, 4.9; organic matter, 2.2%; Bray P1, 19 ppm; ammonium acetate extractable K, Ca, and Mg, 62, 319, and 37 ppm, respectively; Ca-phosphate extractable SO_4-S, 3.3 ppm; and DTPA extractable Zn, Cu, Fe, and Mn, 1.2, 0.5, 99.1, and 31.6 ppm, respectively. Extractable nitrate-N and ammonium-N in the top 2 ft of soil were 10.9 and 14.1 lb/A, respectively.

Prior to planting, 250 lb/A 0-0-60 and 250 lb/A 0-0-22 were broadcast and incorporated with a moldboard plow. Four, 20-ft rows were planted for each plot with the middle two rows used for sampling and harvest. Whole "B" seed of Russet Burbank, and cut "A" seed of Umatilla, Premier, and Bannock were hand planted in furrows on April 24, 2009. Row spacing was 12 inches within each row and 36 inches between rows. Each treatment was replicated four times for each variety in a randomized complete block design. Admire Pro was applied in-furrow for beetle control, along with the systemic fungicides Quadris and Ultra Flourish. 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 ten N treatments with different N sources, rates, and application timing as described in Table 1 below. A complete factorial arrangement was used with cultivar and N treatment as main effects.

Preplant ESN fertilizer was applied 8 days before planting on April 16 and disked in. The 30-lb N/A application at planting as MAP was banded 3 inches to each side and 2 inches below the seed piece using a belt type applicator. For all treatments, banded fertilizer at planting included 130 lb P_2O_5/A as monommonium phosphate, 180 lb K_2O/A as potassium chloride and potassium magnesium sulfate, and 20 lb Mg/A and 45 lb S/A as potassium magnesium sulfate. Emergence N applications were supplied as urea and mechanically incorporated during hilling. Also at emergence, 950 lb/A gypsum was applied and incorporated into the hill. Post-hilling N was applied by hand as 50%

granular urea-N and 50% ammonium nitrate-N, which was watered-in with overhead irrigation to simulate fertigation with a 28% UAN solution. Emergence fertilizer was applied on May 15 and post-hilling N was applied on June 15, June 25, July 6, and July 16.

A WatchDog weather station from Spectrum Technologies was used to monitor rainfall, air temperature, soil moisture and soil temperature at the fertilizer band depth. 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 28, May 11, May 22, June 3, June 16, July 1, July 22, Aug 12, Sept 23, and Oct 20 to track N release over time. Plant stands and stem number per plant were measured on June 9. Petiole samples were collected from the 4th leaf from the terminal on three dates: June 24, July 7, and July 21. Petioles were analyzed for nitrate-N on a dry weight basis.

Table 1. Nitrogen treatments tested on processing potato varieties.

Treatment	Preplant	Planting	Emergence	Post-hilling**	Total
	------------------------ N sources* and rates (lb N/A) ------------------------				
1	0	30 MAP	0	0	30
2	0	30 MAP	50 Urea	10 UAN x 4	120
3	0	30 MAP	70 Urea	20 UAN x 4	180
4	0	30 MAP	90 Urea	30 UAN x 4	240
5	0	30 MAP	50 Urea	40 UAN x 4	240
6	0	30 MAP	90 Urea	45 UAN x 4	300
7	150 ESN	30 MAP	0	0	180
8	210 ESN	30 MAP	0	0	240
9	0	30 MAP	150 ESN	0	180
10	0	30 MAP	210 ESN	0	240

*ESN = Environmentally Smart Nitrogen (44-0-0), MAP = monoammonium phosphate, urea = 46-0-0, UAN = a combination of granular urea and ammonium nitrate.
**Post-hilling N was applied 4 times at 10-11 day intervals.

Vines were harvested on Sept 22 from two, 10-ft sections of row, followed by mechanically beating the vines over the entire plot area. Plots were machine harvested on Sept 30 and total tuber yield and graded yield were measured. Sub-samples of vines and tubers were collected to determine moisture percentage and N concentrations, which were then used to calculate N uptake and distribution within the plant (Note: all the data for N uptake were not available at the time of this report and therefore will be presented at a later time). Tuber sub-samples were also used to determine tuber specific gravity and the incidence of hollow heart and brown center. Stem and bud end sugar contents after frying were determined after harvest. Additional fry tests will be made after six months of storage at about 45 F.

RESULTS

Weather

Rainfall and irrigation for the 2009 growing season are provided in Figure 1. From April 21 to September 22, approximately 13.4 inches of rainfall was supplemented with 16.2 inches of irrigation. There were no leaching events early in the season. Leaching events (greater than 1 inch of water) occurred at 53, 106, and 117 days after planting. Air temperature measurements and soil temperature and moisture measurements in the hill (4-5 inches below the top of the hill) are provided in Figure 2.

Nitrogen Release from ESN

Figure 3 shows release of N from ESN applied preplant and at emergence. Release of N from ESN tended to be faster than that recorded in previous years. In 2007, approximately 90% of N was released by 70 days after planting for preplanted fertilizer and by 80 days after planting for ESN applied at emergence. In 2008, 80% had been released by 40 days after planting for the preplant application and by about 50 days for the emergence application. In 2009, 80% had been released by 40 days after planting for the preplant application and by about 55 days for the emergence application. Differences in release rate are likely due to difference in abrasion of the coating as well as temperature difference. Temperatures in 2009 were cooler than those in 2008.

Tuber Yield, Stand Count, Stem Number, and Vine Dry Matter

Nitrogen rate, source, and timing comparisons on yield

Tables 2-5 show the effects of N application rate, source, and timing on tuber yield and size distribution as well as stand count, stem number and vine dry matter at harvest for the four processing varieties. For Russet Burbank (Table 2), marketable and total yields increased with increasing N rate with optimum yield between 240 and 300 lb N/A depending on timing and source. As in 2008, numerically highest total, marketable and #1 yields were with ESN applied preplant at the 240 lb N/A rate. Yields with preplant ESN tended to be higher than those with emergence applied ESN, although these differences were not significant. Within conventional N sources at the 240 lb N/A rate, N applied earlier (treatment 4) resulted in yields that were statistically the same as N applied later in the season (treatment 5). At equivalent N rates, N source did not significantly affect yield. For Umatilla (Table 3), marketable and total yields increased with increasing N rate with optimum yield between 240 to 300 lb N/A depending on timing and source. Numerically highest yields were with conventional N 300 lb N/A rate, while numerically highest total yields were with ESN applied preplant at the 240 lb N/A rate. Yields with preplant ESN tended to be higher than those with emergence applied ESN. At the 240 lb N/A rate, yields with emergence applied ESN tended to be lower than prelant applied ESN and conventional N applied at 300 lb N/A. Within conventional N sources at the 240 lb N/A rate, N applied earlier (treatment 4) resulted in yields that were statistically the same as N applied later in the season (treatment 5). At equivalent N rates, N source did not significantly affect yield. For Premier, (Table 4), marketable and total yields increased with increasing N rate with optimum yield between 180 and 240 lb N/A depending on timing and source. Numerically highest total, marketable and #1 yields were with ESN applied preplant at the 240 lb N/A rate. Yields with preplant ESN were significantly higher than those with emergence applied ESN at the 180 lb N/A rate, but no significant differences due to timing were observed at the 240 lb N/A rate with ESN. Within conventional N sources at the 240 lb N/A rate, N applied earlier (treatment 4) resulted in yields that were statistically the same as N applied later in the season (treatment 5). At equivalent N rates, N source did not significantly affect marketable yield. For Bannock, (Table 5), marketable and total yields increased with increasing N rate with optimum yield between 180 to 240 lb N/A depending on timing and source. Numerically highest total, marketable and #1 yields were with ESN applied preplant at the 240 lb N/A rate. Yields with preplant ESN tended to be higher than those with emergence applied ESN, although statistically there were not differences among the ESN rates or timing tested. Within conventional N sources at the 240 lb N/A rate, N applied later (treatment 4) tended to result in numerically higher yields than N applied earlier in the season (treatment 5), although differences were not statistically significant. At the equivalent N rates, N source/timing did not significantly affect yield; although ESN treatments resulted in smaller tuber size than conventional N treatments. Tubers greater than 10 ounces increased with increasing N rate regardless of source/timing for all varieties.

General varietal comparisons for yield

Russet Burbank tended to be the highest yielding variety followed by Bannock and Premier, and then Umatilla. Premier, Bannock, and Umatilla all had fewer misshaped potatoes than Russet Burbank with Premier having the fewest #2 potatoes. Tubers greater than 6 and 10 oz were highest for Premier followed by Bannock, Russet Burbank and then Umatilla.

Nitrogen rate, source, and timing comparisons for stand count, stem number and vine dry matter at harvest

Stand count was generally not affected by N treatment, although for Premier, there was a slight reduction of 3% in stand in the control and 300 lb N/A rate compared with the other N treatments. Reasons for this reduction are not clear and probably not significant from a practical standpoint. In general, averaged over N treatments, stand was significantly lower for Bannock (~90%) compared with the other three varieties (> 98%). Stems per plant were not significantly affected by N treatments. The highest stem number per plant was with Bannock (4.8) followed by Umatilla (3.5) and then Premier (3.0) and Russet Burbank (2.9). This result is surprising since “B” seed, which usually results in higher stem number, was used for Russet Burbank, while cut “A” seed was used for the other varieties. Vine dry matter at harvest increased with increasing N rate for all varieties regardless of source. For Umatilla, late season N at the 240 lb N/A rate resulted in lower vine yield than early season applied at the same rate. Overall, vines died back earlier for Umatilla than the other varieties resulting in lowest vine yields. It is not know why Umatilla vines died back early, but it was probably due to disease. Early vine dieback in Umatilla resulted in poor utilization of late season applied N.

Tuber Quality

Nitrogen rate, source, and timing comparisons for tuber quality

Tables 6 to 9 show the effects of N application rate, source, and timing on tuber hollow heart, specific gravity and frying quality for the four processing varieties. Surface scab incidence was not affected by N treatment for any of the varieties. For Russet Burbank (Table 6), incidence of hollow heart ranged from 1 to 12% with inconsistent effects due to N treatment. The 180 lb N/A rate with conventional N resulted in the highest incidence while ESN applied at emergence at 240 lb N/A and the conventional N applied at 300 lb N/A had the lowest incidence. Timing of conventional N at the 240 lb N/A rate did not affect hollow hear in this year. Specific gravity was not affected by treatment and generally in the optimum for all treatments. Stem end chip color was not consistently affected by N treatments, but tended to be lighter with early applied N. It was darker for the control, ESN preplant 180 lb/A and late N 240 lb N/A rate treatments, while lightest for the conventional N at 180, early N at 240 lb N/A and ESN preplant at 240 lb N/A. Stem end AGT score was lowest in the control and highest with conventional N applied at 180 and 300 lb N/A. Stem end sucrose was not affected by treatment. Stem end glucose was highest in the control and lowest with preplant applied ESN at the 240 lb N/A rate. In general, stem end glucose decreased with increasing N rate and late season N tended increase stem end glucose. Bud end chip color, AGT score, sucrose and glucose were not affected by N treatment. For Umatilla (Table 7), incidence of hollow heart was quite low ranging from 0 to 4% with no effect due to N treatment. Specific gravity decreased with increasing conventional N rate and was lowest with late season N and N applied at the 300 lb N/A rate. ESN at the 240 lb N/A rate applied at emergence resulted in the highest specific gravity reading. Stem end chip color, AGT score, and glucose levels were not affected by N treatment. Stem end sucrose decreased with increasing N rate and was lower with preplant applied ESN than planting applied ESN. Bud end chip color, AGT score sucrose and glucose were not affected by treatment. For Premier (Table 8), incidence of hollow heart ranged from 3 to 16% and was not significantly affected by treatment. Specific gravity tended to decrease with increasing conventional N rate and was lowest with late season N and N applied at the 300 lb N/A rate. At equivalent N rates, ESN resulted in higher specific gravity than conventional N. Frying quality was also not affected by treatment. For Bannock (Table 9), incidence of hollow heart ranged from 6 to 15% and was not affected by treatment. Specific gravity ranged from 1.075 to 1.082 and was not affected by N treatment. Frying quality was also not affected by N treatment.

General varietal comparisons for tuber quality

Averaged over N treatments, hollow heart incidence was highest in Bannock, followed by Premier, Russet Burbank, and then Umatilla. Surface scab incidence was highest with Umatilla, followed by Russet Burbank and then Bannock and Premier. Specific gravity was highest in Russet Burbank and Umatilla and followed by Premier and then Bannock.

Stem and bud chip color was darkest for Russet Burbank and lowest for Premier. AGT scores were highest for Premier and lowest for Russet Burbank. Stem end glucose concentrations were highest for Russet Burbank followed by Bannock, and then Premier, and Umatilla. Stem end sucrose was highest with Umatilla and Premier followed by Bannock and then Russet Burbank. Bud end glucose concentrations were highest for Bannock and Russet Burbank, followed by Umatilla and then Premier. Bud end sucrose was highest with Premier and Russet Burbank followed by Umatilla and Bannock.

Petiole Nitrate-N Concentrations

Nitrogen rate, source, and timing comparisons

Petiole NO_3-N concentrations on three dates as affected by N rate, N source, and N timing are presented in Tables 10-13. As expected, petiole NO_3-N generally increased with increasing N rate for all varieties and decreased as the season progressed. Petiole NO_3-N levels with the 300 lb N/A rate applied through the season were generally the highest of any treatment, especially later in the season. Late season applied conventional N at the 240 lb N/A rate had inconsistent effects on petiole NO_3-N. For Russet Burbank and Premier, petiole NO_3-N was lower at all sampling dates with late applied N compared with early applied N. For Umatilla and Bannock, this trend was the same for the first two sampling dates, but by the third sampling date petiole NO_3-N with late season N was higher than with early season N, which is what would be expected. Reasons for the lower petiole NO_3-N concentrations for Russet Burbank and Premier with late season N are not known.

At equivalent N rates, differences between urea and ESN treatments depended on the time of the season. For the first sampling date (June 24), petiole NO_3-N concentrations were similar between the two N sources for preplant applied ESN and early applied conventional N. Concentrations were higher with early applied N than when ESN was applied at planting and when late season N was applied. The similarity between ESN and split applied conventional N is consistent with the release of N from the polymer, which appears to be faster than in earlier studies. By the second sampling date (July 7), planting ESN treatments tended to result in petiole NO_3-N levels higher than conventional N especially at the 240 lb N/A rate. Preplant applied ESN resulted in petiole NO_3-N levels that were either the same or slightly lower than conventional. By the last sampling date (July 21), petiole NO_3-N levels were lower with ESN compared with conventional N when applied at equivalent N rates. These lower petiole NO_3-N levels with ESN later in the season are again consistent with the faster release from the polymer than in previous years.

General varietal comparisons for petiole NO_3-N

At the June 24 sampling date, petiole nitrate levels were higher for Umatilla and Premier and Bannock than for Russet Burbank. Difference became less distinct towards the July 7 sampling date. However, Umatilla petiole NO_3-N levels were higher than those for the other cultivars. Based on yield responses to N, petiole nitrate levels should be higher for Umatilla during the growing season than other varieties tested.

CONCLUSIONS

As in 2008, release of N from ESN was 20-30 days faster in 2009 than that recorded in previous years, suggesting that the there was more abrasion of the coated with the ESN source used the past two years. In general, marketable and total yields of all varieties increased with increasing N rate, with optimum yield between 240 lb N/A and 300 lb N/A depending on timing and source. For conventional N at the 240 lb N/A rate more up front N resulted in higher yields than late applied N for all varieties. This is in contrast to 2008 when Umatilla responded better to late season-applied N. The difference in 2009 was that Umatilla vines died back early due to disease and were not able to fully utilize the late applied N. At equivalent N rates, yields with ESN applied preplant were generally higher than those when ESN was applied at emergence and when conventional N was split applied.

Russet Burbank tended to be the highest yielding variety followed by Bannock and Premier, and then Umatilla. Premier, Bannock, and Umatilla all had fewer misshaped potatoes than Russet Burbank with Premier having the fewest #2 potatoes. Tubers greater than 6 and 10 oz were highest for Premier followed by Bannock, Russet Burbank and then Umatilla. Surprisingly, hollow heart incidence was highest in Bannock, followed by Premier, Russet Burbank, and then Umatilla. Surface scab incidence was highest with Umatilla, followed by Russet Burbank and then Bannock and Premier. Specific gravity was highest in Russet Burbank and Umatilla and followed by Premier and then Bannock. Stem and bud end chip color were darkest for Russet Burbank and lowest for Premier.

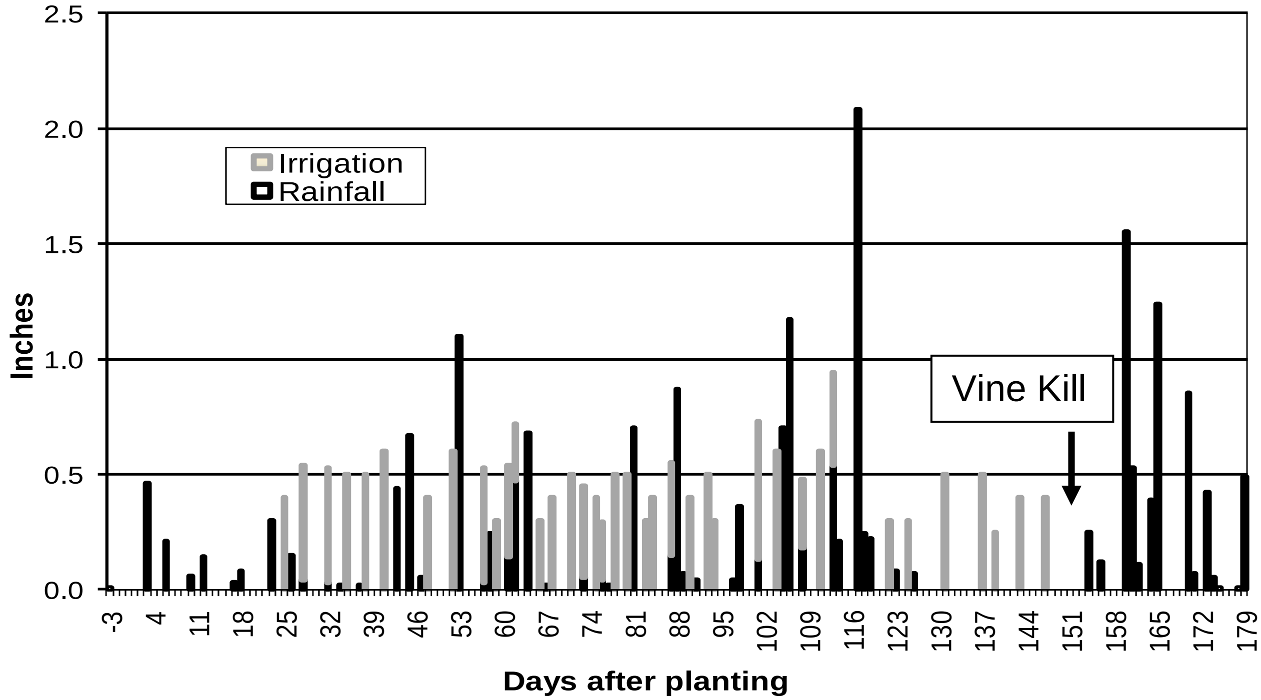

Figure 1. Rainfall and irrigation over the 2009 growing season.

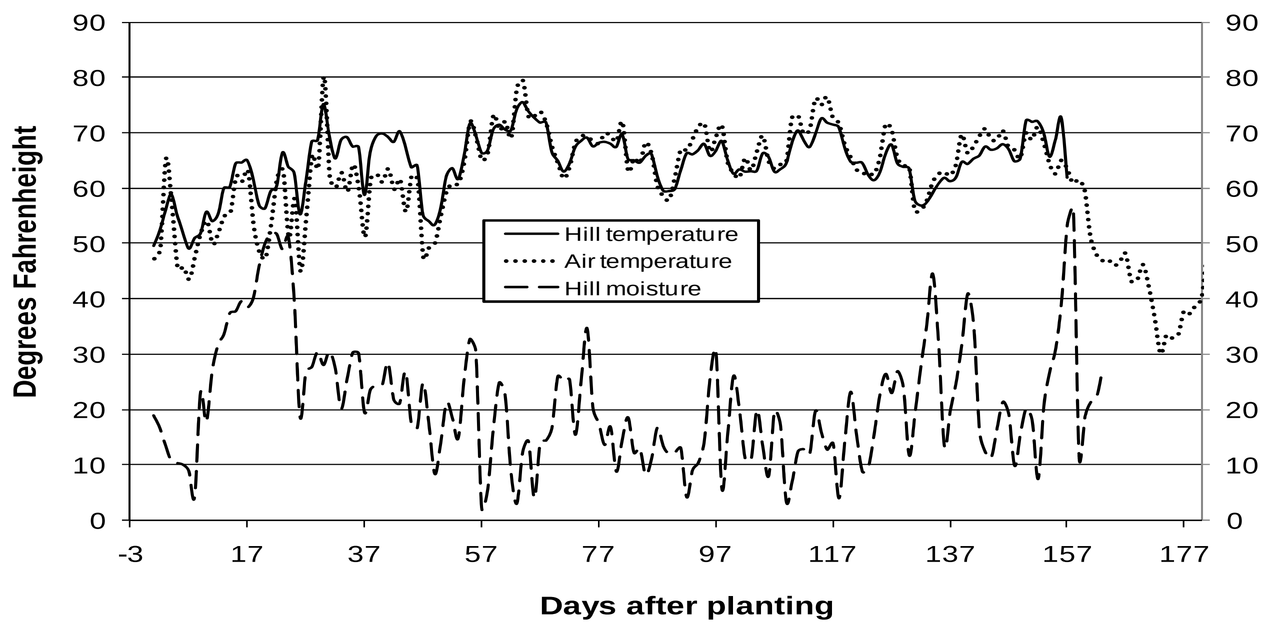

Figure 2. Average daily air temperature and soil moisture and temperature at the 4-5 inch inch depth below the top of the hill over the growing season.

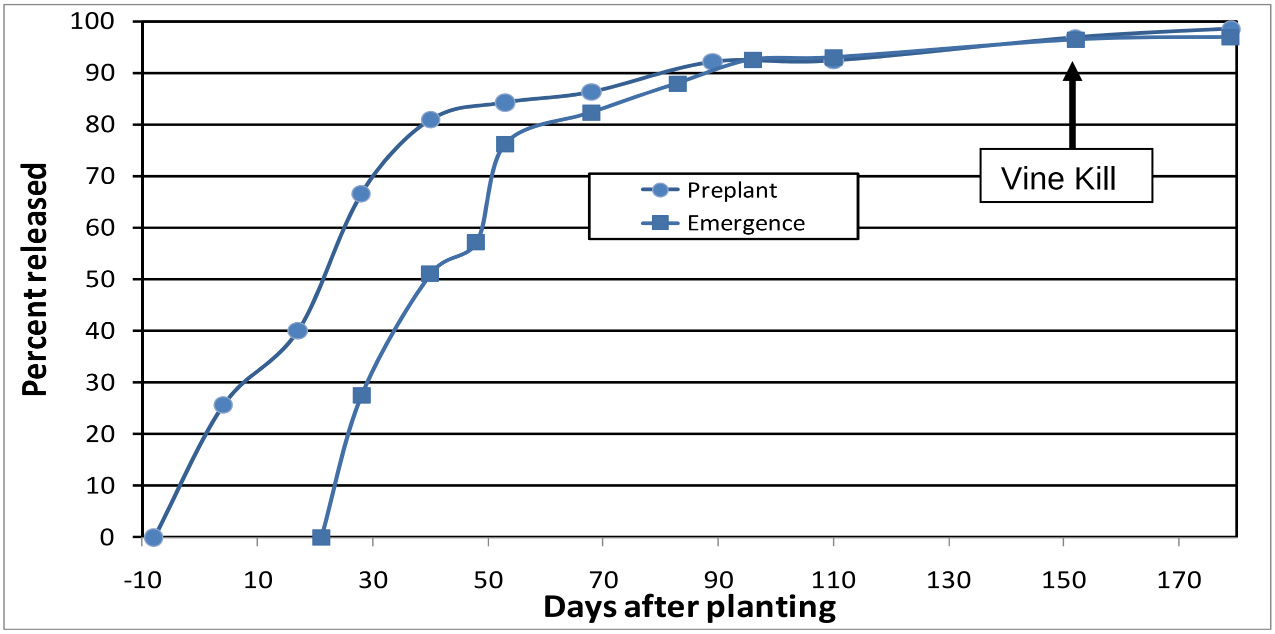

Figure 3. N released from ESN applied preplant and at emergence in 2009.

Table 2. Effect of N rate, source, and timing on Russet Burbank tuber yield and size distribution, stand count, stem number and vine dry matter at harvest.

Nitrogen Treatments				Tuber Yield													
Trtmt	N Source	N Rate	N Timing[1]	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	Stand	Stems	Vine DM
#		lb N / A	PP, P, E, PH	---------- cwt / A ----------									---------- % ----------		%	per Plant	Tons/Acre
1	control	30	0, 30, 0, 0	69.6	264.2	165.1	35.0	15.7	549.6	270.4	209.6	480.0	39.2	9.0	99.3	3.2	0.47
2	urea	120	0, 30, 50, 40	69.4	234.3	173.9	68.5	46.7	592.8	321.4	202.0	523.4	48.8	19.5	99.3	2.7	0.62
3	urea	180	0, 30, 70, 80	72.9	210.4	188.7	71.6	84.0	627.7	364.9	189.9	554.8	54.9	24.9	100.0	2.8	0.97
4	urea	240	0, 30, 90, 120	59.4	167.6	202.8	105.5	144.9	680.2	413.6	207.2	620.8	66.3	36.4	99.3	3.1	1.01
5	urea	240	0, 30, 50, 160	64.9	188.2	195.3	105.6	125.9	679.9	413.8	201.2	615.0	62.5	33.6	99.3	3.0	1.01
6	urea	300	0, 30, 90, 180	47.8	159.3	196.5	116.1	167.8	687.5	439.9	199.8	639.7	69.9	41.4	98.5	2.6	1.12
7	ESN	180	150, 30, 0, 0	63.7	194.7	209.0	110.8	82.4	660.7	439.7	157.3	597.0	61.0	29.4	100.0	3.0	0.88
8	ESN	240	210, 30, 0, 0	54.2	170.1	206.7	120.3	149.6	700.9	461.5	185.2	646.7	68.0	38.5	99.3	2.8	1.24
9	ESN	180	0, 30, 150, 0	59.4	209.9	231.2	87.8	80.3	668.6	400.9	208.3	609.2	59.6	25.1	100.0	3.0	0.63
10	ESN	240	0, 30, 210, 0	61.7	210.2	231.1	104.1	86.3	693.4	414.7	217.0	631.7	60.7	27.3	100.0	2.9	0.94
Significance[2]				*	**	**	**	**	**	**	NS	**	**	**	NS	NS	**
LSD (0.10)				14.3	44.6	33.0	22.5	50.0	39.9	41.9	--	39.8	6.3	8.4	--	--	0.29

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

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

Table 3. . Effect of N rate, source, and timing on Umatilla Russet tuber yield and size distribution, stand count, stem number and vine dry matter at harvest.

Nitrogen Treatments				Tuber Yield													
Trtmt	N Source	N Rate	N Timing[1]	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	Stand	Stems	Vine DM
#		lb N / A	PP, P, E, PH	---------- cwt / A ----------									---------- % ----------		%	per Plant	Tons/Acre
1	control	30	0, 30, 0, 0	72.9	212.3	114.0	8.3	0.0	407.4	329.6	5.0	334.6	30.0	2.0	99.3	3.6	0.25
2	Urea	120	0, 30, 50, 40	72.7	218.2	201.1	17.2	6.5	515.7	434.5	8.5	443.0	42.9	4.4	98.5	3.5	0.30
3	Urea	180	0, 30, 70, 80	70.7	238.3	226.0	48.5	14.5	598.0	497.7	29.5	527.3	48.3	10.6	98.0	3.6	0.45
4	Urea	240	0, 30, 90, 120	62.0	197.8	244.6	68.5	31.4	604.3	498.6	43.7	542.3	56.9	16.5	97.0	3.6	0.62
5	Urea	240	0, 30, 50, 160	66.2	211.3	223.3	57.3	25.9	584.1	470.4	47.5	517.9	52.3	14.1	96.5	3.3	0.44
6	Urea	300	0, 30, 90, 180	58.5	211.2	225.3	68.8	58.0	621.8	494.9	68.4	563.3	56.5	20.4	97.3	3.3	0.49
7	ESN	180	150, 30, 0, 0	65.7	202.5	240.8	72.6	37.4	619.0	510.1	43.2	553.3	56.4	17.7	98.5	3.9	0.49
8	ESN	240	210, 30, 0, 0	56.9	217.7	230.7	72.3	47.5	625.0	520.3	47.8	568.1	56.0	19.1	100.0	3.5	0.52
9	ESN	180	0, 30, 150, 0	65.8	217.1	227.8	40.3	19.4	570.5	486.0	18.7	504.7	50.4	10.4	97.8	3.8	0.41
10	ESN	240	0, 30, 210, 0	55.2	195.4	238.9	67.7	26.9	584.0	470.9	57.9	528.9	57.1	16.2	98.5	3.5	0.49
Significance[2]				NS	NS	**	**	**	**	**	**	**	**	**	NS	NS	**
LSD (0.10)				--	--	33.5	15.3	16.1	41.5	39.8	18.0	42.4	5.8	3.7	--	--	0.16

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

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

Table 4. Effect of N rate, source, and timing on Premier Russet tuber yield and size distribution, stand count, stem number and vine dry matter at harvest.

Nitrogen Treatments				Tuber Yield													
Trtmt	N Source	N Rate	N Timing[1]	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	Stand	Stems	Vine DM
#		lb N / A	PP, P, E, PH	---- cwt / A ----									---- % ----		%	per Plant	Tons/Acre
1	control	30	0, 30, 0, 0	22.0	94.6	197.6	103.7	49.9	467.8	442.4	3.5	445.8	74.9	32.7	97.0	2.9	0.47
2	Urea	120	0, 30, 50, 40	17.9	77.6	175.2	133.5	126.8	530.9	501.8	11.3	513.1	81.9	48.7	100.0	2.7	0.54
3	Urea	180	0, 30, 70, 80	18.6	66.7	159.9	113.3	196.5	554.9	529.0	7.4	536.4	84.6	55.8	100.0	3.1	0.87
4	Urea	240	0, 30, 90, 120	18.7	66.4	140.0	114.4	219.1	558.6	528.8	11.1	539.9	84.8	59.7	100.0	3.1	0.95
5	Urea	240	0, 30, 50, 160	15.1	73.4	158.6	124.7	189.9	561.5	514.4	32.1	546.5	84.2	56.1	99.3	2.8	0.90
6	Urea	300	0, 30, 90, 180	18.4	52.6	136.3	116.6	241.2	565.2	525.7	21.1	546.8	87.4	63.3	97.8	2.6	1.02
7	ESN	180	150, 30, 0, 0	22.7	79.8	164.1	127.5	174.3	568.3	528.7	17.0	545.7	81.9	53.0	100.0	3.2	0.77
8	ESN	240	210, 30, 0, 0	19.0	63.8	165.5	123.3	216.7	588.3	537.5	31.8	569.3	85.9	57.4	99.3	3.1	1.20
9	ESN	180	0, 30, 150, 0	19.5	70.9	175.6	122.6	139.7	528.3	497.9	10.9	508.8	82.9	49.7	100.0	3.3	0.86
10	ESN	240	0, 30, 210, 0	17.4	57.9	153.8	142.2	198.0	569.3	524.3	27.6	551.9	86.8	59.9	100.0	3.1	0.98
			Significance[2]	NS	**	NS	NS	**	**	**	**	**	**	**	*	NS	**
			LSD (0.10)	--	14.1	--	--	51.5	27.3	27.5	8.6	28.1	3.3	8.3	2.0	--	0.23

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

Table 5. Effect of N rate, source, and timing on Bannock Russet tuber yield and size distribution, stand count, stem number and vine dry matter at harvest.

Nitrogen Treatments				Tuber Yield													
Trtmt	N Source	N Rate	N Timing[1]	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	Stand	Stems	Vine DM
#		lb N / A	PP, P, E, PH	---- cwt / A ----									---- % ----		%	per Plant	Tons/Acre
1	control	30	0, 30, 0, 0	42.8	154.6	188.4	62.9	18.7	467.3	413.2	11.3	424.5	57.6	17.4	87.0	4.8	0.46
2	urea	120	0, 30, 50, 40	30.9	131.7	206.8	118.7	59.7	547.9	498.2	18.8	517.0	70.4	32.7	90.3	4.8	0.68
3	urea	180	0, 30, 70, 80	33.5	115.0	202.5	139.2	95.9	585.9	524.4	28.1	552.5	74.9	40.3	89.0	5.1	1.19
4	urea	240	0, 30, 90, 120	29.4	94.5	200.8	136.9	119.8	581.4	517.1	34.9	552.0	79.1	45.2	90.3	4.9	1.40
5	urea	240	0, 30, 50, 160	27.0	99.6	198.2	143.6	130.0	598.4	517.5	53.9	571.4	78.8	45.9	91.5	4.7	1.57
6	urea	300	0, 30, 90, 180	28.3	95.0	189.0	130.1	156.7	599.1	530.6	40.2	570.8	79.6	47.9	89.0	4.6	1.65
7	ESN	180	150, 30, 0, 0	38.7	147.4	224.6	113.0	77.1	600.7	540.1	21.9	562.0	69.3	31.9	90.3	5.0	1.06
8	ESN	240	210, 30, 0, 0	27.7	124.9	191.1	128.9	135.4	608.0	548.3	32.1	580.3	75.0	43.3	93.8	4.3	1.42
9	ESN	180	0, 30, 150, 0	33.4	127.5	239.3	120.0	83.2	603.5	540.3	29.8	570.1	73.3	33.6	93.5	4.8	1.14
10	ESN	240	0, 30, 210, 0	31.8	128.5	189.3	116.2	135.3	601.1	542.0	27.3	569.3	73.3	41.8	88.3	4.6	1.41
			Significance[2]	NS	*	NS	**	**	*	*	**	**	**	**	NS	NS	**
			LSD (0.10)	--	34.0	--	21.8	28.9	74.7	64.4	18.2	64.5	5.3	6.1	--	--	0.38

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

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

Table 6. Effect of N rate, source, and timing on Russet Burbank tuber quality, frying quality, and sucrose and glucose levels.

Nitrogen Treatments				Tuber Quality			Frying Quality							
	N	N	N	Hollow		Specific	STEM				BUD			
Trtmt	Source	Rate	Timing[1]	Heart	Scab	Gravity								
#		lb N / A	PP, P, E, PH	%	%		Chip Color	AGT Score	Sucrose	Glucose	Chip Color	AGT Score	Sucrose	Glucose
1	control	30	0, 30, 0, 0	4.0	14.0	1.0827	3.0	48.8	1.122	4.499	2.5	55.0	1.704	0.465
2	urea	120	0, 30, 50, 40	9.0	12.0	1.0854	2.5	53.8	0.405	3.590	2.5	56.0	1.825	0.536
3	urea	180	0, 30, 70, 80	12.0	14.3	1.0849	2.0	56.0	0.395	3.142	2.8	53.8	1.650	0.294
4	urea	240	0, 30, 90, 120	2.0	14.0	1.0851	2.3	55.3	0.602	2.131	2.8	53.5	1.301	0.285
5	urea	240	0, 30, 50, 160	4.0	16.0	1.0852	3.0	53.8	0.437	3.043	2.8	53.5	1.604	0.352
6	urea	300	0, 30, 90, 180	1.0	18.5	1.0848	2.3	56.5	0.795	2.385	2.5	55.0	1.587	0.540
7	ESN	180	150, 30, 0, 0	8.0	16.0	1.0860	3.0	52.5	0.441	2.930	3	52.0	1.687	0.407
8	ESN	240	210, 30, 0, 0	8.0	18.3	1.0879	2.3	54.8	0.692	1.520	2.5	55.3	1.772	0.477
9	ESN	180	0, 30, 150, 0	3.0	7.0	1.0874	2.8	52.5	0.570	3.255	2.8	52.3	1.716	0.724
10	ESN	240	0, 30, 210, 0	1.0	14.0	1.0844	2.8	54.3	0.829	2.501	2.5	55.5	1.971	0.442
			Significance[2]	*	NS	NS	**	**	NS	++	NS	NS	NS	NS
			LSD (0.10)	6.6	- -	- -	0.5	3.4	--	1.857	--	--	--	--

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

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

Table 7. Effect of N rate, source, and timing on Umatilla Russet tuber quality, frying quality, and sucrose and glucose levels.

Nitrogen Treatments				Tuber Quality			Frying Quality							
	N	N	N	Hollow		Specific	STEM				BUD			
Trtmt	Source	Rate	Timing[1]	Heart	Scab	Gravity								
#		lb N / A	PP, P, E, PH	%	%		Chip Color	AGT Score	Sucrose	Glucose	Chip Color	AGT Score	Sucrose	Glucose
1	control	30	0, 30, 0, 0	0.0	11.0	1.0867	2.0	56.5	1.145	0.933	2.5	54.0	1.489	0.442
2	urea	120	0, 30, 50, 40	3.0	15.0	1.0868	2.3	54.5	1.251	0.691	2.5	54.3	1.516	0.393
3	urea	180	0, 30, 70, 80	3.0	17.0	1.0841	2.0	58.0	1.066	0.890	2.3	56.5	1.731	0.288
4	urea	240	0, 30, 90, 120	3.0	30.0	1.0836	2.0	56.0	1.080	0.811	2.0	57.0	1.922	0.575
5	urea	240	0, 30, 50, 160	3.0	13.0	1.0814	2.3	55.3	1.055	1.026	2.5	53.8	1.340	0.376
6	urea	300	0, 30, 90, 180	4.0	22.0	1.0768	2.0	57.5	1.111	0.955	2.0	57.5	1.681	0.281
7	ESN	180	150, 30, 0, 0	1.0	22.3	1.0835	2.3	56.0	0.993	0.845	2.5	53.8	1.460	0.363
8	ESN	240	210, 30, 0, 0	0.0	24.0	1.0838	2.3	56.5	0.985	0.899	2.5	54.8	1.703	0.380
9	ESN	180	0, 30, 150, 0	2.0	16.3	1.0885	2.0	58.3	1.717	1.276	2.3	55.3	1.736	0.405
10	ESN	240	0, 30, 210, 0	3.0	22.0	1.0911	2.0	57.5	1.471	1.026	2.3	56.3	1.642	0.433
			Significance[2]	NS	NS	*	NS	NS	*	NS	NS	NS	NS	NS
			LSD (0.10)	--	--	0.0078	--	--	0.3987	--	--	--	--	--

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

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

Table 8. Effect of N rate, source, and timing on Premier Russet tuber quality, frying quality, and sucrose and glucose levels.

Nitrogen Treatments				Tuber Quality											
	N	N	N	Hollow		Specific	Frying Quality								
Trtmt	Source	Rate	Timing[1]	Heart	Scab	Gravity	STEM				BUD				
#		lb N / A	PP, P, E, PH	%	%		Chip Color	AGT Score	Sucrose	Glucose	Chip Color	AGT Score	Sucrose	Glucose	
1	control	30	0, 30, 0, 0	10.0	11.0	1.0829	1.8	60.8	1.239	1.085	2.0	59.8	1.861	0.271	
2	urea	120	0, 30, 50, 40	13.0	11.3	1.0852	2.3	59.3	0.886	1.259	2.0	61.3	1.705	0.327	
3	urea	180	0, 30, 70, 80	10.3	10.3	1.0838	2.0	60.3	1.045	0.788	2.0	60.3	1.683	0.302	
4	urea	240	0, 30, 90, 120	3.0	13.0	1.0817	2.0	58.3	1.140	0.770	2.0	61.8	1.520	0.326	
5	urea	240	0, 30, 50, 160	7.0	13.0	1.0793	2.0	59.3	1.029	0.835	2.0	59.3	1.935	0.138	
6	urea	300	0, 30, 90, 180	8.0	11.0	1.0800	2.0	60.5	1.160	0.842	2.0	60.8	1.785	0.150	
7	ESN	180	150, 30, 0, 0	16.0	10.0	1.0859	2.0	58.0	1.235	1.011	2.3	58.5	1.816	0.409	
8	ESN	240	210, 30, 0, 0	4.3	7.8	1.0863	2.0	61.3	1.125	0.538	2.0	60.0	1.965	0.195	
9	ESN	180	0, 30, 150, 0	4.0	10.0	1.0896	2.0	61.0	1.334	0.914	2.0	59.5	1.864	0.099	
10	ESN	240	0, 30, 210, 0	8.0	8.0	1.0848	1.8	60.3	1.014	0.577	2.0	58.5	1.957	0.186	
			Significance[2]	NS	NS	*	NS	NS	NS	NS	NS	NS	NS	NS	
			LSD (0.10)	--	--	0.0052	--	--	--	--	--	--	--	--	

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

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

Table 9. Effect of N rate, source, and timing on Bannock Russet tuber quality, frying quality, and sucrose and glucose levels.

Nitrogen Treatments				Tuber Quality										
	N	N	N	Hollow		Specific	Frying Quality							
Trtmt	Source	Rate	Timing[1]	Heart	Scab	Gravity	STEM				BUD			
#		lb N / A	PP, P, E, PH	%	%		Chip Color	AGT Score	Sucrose	Glucose	Chip Color	AGT Score	Sucrose	Glucose
1	control	30	0, 30, 0, 0	15.0	12.0	1.0778	2.8	54.0	0.806	2.171	2.0	56.0	1.226	0.851
2	urea	120	0, 30, 50, 40	9.0	7.0	1.0816	2.8	53.0	0.597	1.911	2.5	55.8	1.437	0.449
3	urea	180	0, 30, 70, 80	8.0	13.0	1.0808	2.8	53.3	0.676	2.503	2.0	57.3	1.388	0.475
4	urea	240	0, 30, 90, 120	9.0	12.0	1.0802	2.3	55.0	1.017	2.174	2.3	55.5	1.700	0.613
5	urea	240	0, 30, 50, 160	11.0	11.0	1.0801	2.3	55.3	0.840	1.690	2.5	55.0	1.538	0.285
6	urea	300	0, 30, 90, 180	6.0	3.0	1.0788	2.3	55.0	0.756	1.928	2.5	57.0	1.713	0.504
7	ESN	180	150, 30, 0, 0	15.0	18.0	1.0819	2.5	53.8	0.959	2.024	2.5	55.3	1.477	0.807
8	ESN	240	210, 30, 0, 0	14.3	9.3	1.0752	2.3	56.0	0.826	1.906	2.3	55.3	1.553	0.483
9	ESN	180	0, 30, 150, 0	6.0	10.0	1.0822	2.8	53.8	0.870	1.430	2.0	57.5	1.248	0.502
10	ESN	240	0, 30, 210, 0	10.0	14.0	1.0775	2.8	53.5	0.790	1.502	2.3	56.0	1.504	0.306
			Significance[2]	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
			LSD (0.10)	--	--	--	--	--	--	--	--	--	--	--

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

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

Table 10. Effect of N rate, source, and timing on Russet Burbank petiole nitrate-N levels.

Nitrogen Treatments				NO_3-N, ppm		
	N	N	N			
Trtmt	Source	Rate	Timing[1]			
#		lb N / A	PP, P, E, PH	June 24	July 7	July 21
1	control	30	0, 30, 0, 0	6939	512	192
2	urea	120	0, 30, 50, 40	13433	5710	2224
3	urea	180	0, 30, 70, 80	16598	9488	8740
4	urea	240	0, 30, 90, 120	18429	13467	13690
5	urea	240	0, 30, 50, 160	16130	10511	11498
6	urea	300	0, 30, 90, 180	17618	14558	14035
7	ESN	180	150, 30, 0, 0	16147	10866	4865
8	ESN	240	210, 30, 0, 0	17319	13425	8819
9	ESN	180	0, 30, 150, 0	16028	11623	6003
10	ESN	240	0, 30, 210, 0	15755	13488	9844
			Significance[2]	**	**	**
			LSD (0.10)	1468	1676	1863

[1]PP, P, E, PH = Preplant, Planting, Emergence, and Post-Hilling, respectively;
4 post-hilling applications were as follows: 20%, 20%, 30%, 30%.
[2]NS = Non-significant; ++, *, ** = Significant at 10%, 5%, and 1%, respectively.

Table 11. Effect of N rate, source, and timing on Umatilla Russet petiole nitrate-N levels.

Nitrogen Treatments				NO_3-N, ppm		
	N	N	N			
Trtmt	Source	Rate	Timing[1]			
#		lb N / A	PP, P, E, PH	June 24	July 7	July 21
1	control	30	0, 30, 0, 0	8159	1478	510
2	urea	120	0, 30, 50, 40	14060	7638	3041
3	urea	180	0, 30, 70, 80	18391	11933	8276
4	urea	240	0, 30, 90, 120	19571	16143	11657
5	urea	240	0, 30, 50, 160	18280	13742	12021
6	urea	300	0, 30, 90, 180	20757	17278	13350
7	ESN	180	150, 30, 0, 0	19686	10393	5949
8	ESN	240	210, 30, 0, 0	21088	16371	11241
9	ESN	180	0, 30, 150, 0	17963	13680	6568
10	ESN	240	0, 30, 210, 0	19555	17101	11687
			Significance[2]	**	**	**
			LSD (0.10)	1821	2119	2229

[1]PP, P, E, PH = Preplant, Planting, Emergence, and Post-Hilling, respectively;
4 post-hilling applications were as follows: 20%, 20%, 30%, 30%.
[2]NS = Non-significant; ++, *, ** = Significant at 10%, 5%, and 1%, respectively.

Table 12. Effect of N rate, source, and timing on Premier Russet petiole nitrate-N levels.

Nitrogen Treatments				NO_3-N, ppm		
	N	N	N			
Trtmt	Source	Rate	Timing[1]			
#		lb N / A	PP, P, E, PH	June 24	July 7	July 21
1	control	30	0, 30, 0, 0	8373	678	320
2	urea	120	0, 30, 50, 40	16267	6640	3052
3	urea	180	0, 30, 70, 80	18834	10370	8233
4	urea	240	0, 30, 90, 120	20492	13747	11409
5	urea	240	0, 30, 50, 160	17723	12400	9589
6	urea	300	0, 30, 90, 180	22119	16050	13994
7	ESN	180	150, 30, 0, 0	16844	6878	3202
8	ESN	240	210, 30, 0, 0	20657	14091	8513
9	ESN	180	0, 30, 150, 0	17628	12305	5363
10	ESN	240	0, 30, 210, 0	19098	15100	10236
			Significance[2]	**	**	**
			LSD (0.10)	2371	2102	1771

[1]PP, P, E, PH = Preplant, Planting, Emergence, and Post-Hilling, respectively;
4 post-hilling applications were as follows: 20%, 20%, 30%, 30%.
[2]NS = Non-significant; ++, *, ** = Significant at 10%, 5%, and 1%, respectively.

Table 13. Effect of N rate, source, and timing on Bannock Russet petiole nitrate-N levels.

Nitrogen Treatments				NO_3-N, ppm		
	N	N	N			
Trtmt	Source	Rate	Timing[1]			
#		lb N / A	PP, P, E, PH	June 24	July 7	July 21
1	control	30	0, 30, 0, 0	7773	3189	377
2	urea	120	0, 30, 50, 40	14305	6546	4212
3	urea	180	0, 30, 70, 80	18794	9227	8985
4	urea	240	0, 30, 90, 120	20850	14480	11714
5	urea	240	0, 30, 50, 160	18004	11397	12935
6	urea	300	0, 30, 90, 180	21177	15971	13994
7	ESN	180	150, 30, 0, 0	16803	7823	4283
8	ESN	240	210, 30, 0, 0	21220	14419	9673
9	ESN	180	0, 30, 150, 0	19017	12001	7474
10	ESN	240	0, 30, 210, 0	19289	15074	10491
			Significance[2]	**	**	**
			LSD (0.10)	1397	2463	1577

[1]PP, P, E, PH = Preplant, Planting, Emergence, and Post-Hilling, respectively;
4 post-hilling applications were as follows: 20%, 20%, 30%, 30%.
[2]NS = Non-significant; ++, *, ** = Significant at 10%, 5%, and 1%, respectively.