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Response of Four Potato Cultivars to Rate and Timing of Nitrogen Fertilizer

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ABSTRACT

The release of three new potato (*Solanum tuberosum* L.) cultivars, Bannock Russet, Gem Russet, and Summit Russet, with unique plant growth characteristics, necessitates the development of appropriate N fertilizer recommendations. These three new cultivars, along with the standard cultivar, Russet Burbank, were treated with four N rates (0, 100, 200, and 300 kg N ha^{-1}) using two different application timing procedures ("early," with two-thirds N applied preplant, and "late," with one-third applied preplant). Measurements included total and U.S. No. 1 yields, petiole NO_3-N concentrations, and net returns derived from economic analysis using a processing-based contract. Each of the four cultivars showed a unique response to N application treatments. Bannock Russet achieved maximum yield and net returns with relatively small amounts of N fertilizer. It also showed no response to N application timing and had moderate NO_3-N sufficiency concentrations early in the season, that decreased markedly late in the season. Gem Russet N requirement for maximum yield was similar to that of Russet Burbank, but required a higher amount of N for maximum net returns. Gem Russet also showed no response to application timing and had NO_3-N sufficiency concentrations similar to or slightly higher than those of Russet Burbank. Summit Russet showed a strong trend for improved N use-efficiency when most of the N was applied early. On the other hand, analysis of net returns revealed a trend for greater profitability for Summit Russet when the majority of N was applied during tuber bulking. Petiole NO_3-N sufficiency concentrations for Summit Russet were generally higher than those for the other three cultivars. In comparison with some earlier studies with Russet Burbank, this research suggested lower optimal N rates and petiole NO_3-N sufficiency concentrations.

RESUMEN

La liberación de tres nuevos cultivares de papa (*Solanum tuberosum* L.), Bannock Russet, Gem Russet, y Summit Russet que tienen características únicas de crecimiento, requieren del desarrollo de recomendaciones apropiadas de fertilización nitrogenada. Estos tres nuevos cultivares junto con el cultivar estándar Russet Burbank, fueron tratados con tres dosis (0,100,200 y 300 Kg de N/ha^{-1}) utilizando dos procedimientos de aplicación ("temprano," con las dos terceras partes de nitrógeno aplicadas antes de la siembra y "tardío," con la tercera parte de N aplicada antes de la siembra). Se tomó en cuenta el rendimiento total y el rendimiento de U.S. No. 1, concentración de NO_3-N en los pecíolos y utilidades netas derivadas del análisis económico neto por contrato de procesamiento. Cada uno de los cuatro cultivares mostró una respuesta especial a los tratamientos de aplicación de N. Bannock Russet alcanzó un rendimiento máximo y utilidad neta con cantidades relativamente pequeñas de fertilizante nitrogenado. No mostró respuesta a la época de aplicación de N y tuvo una moderada concentración de NO_3-N en los inicios, la misma que fue decreciendo marcadamente hacia finales

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ABBREVIATIONS: N, nitrogen; NO_3-N, nitrate nitrogen

del período de cultivo. Los requerimientos de N de Gem Russet para un rendimiento máximo fueron similares a los de Russet Burbank pero necesitó una mayor cantidad de N para obtener una utilidad neta máxima. Gem Russet tampoco mostró respuesta a la época de aplicación y presentó suficiente concentración de NO_3-N similar o ligeramente superior a la de Russet Burbank. Summit Russet mostró una fuerte tendencia al uso de N cuando se aplicó con la modalidad de "temprano." Por otra parte, el análisis de utilidades netas reveló la tendencia de Summit Russet a una mayor utilidad, cuando la mayor cantidad de N se aplicó en la etapa de desarrollo del cultivo. Las concentraciones adecuadas de NO_3-N en el pecíolo fueron generalmente mayores para Summit Russet que para los otros tres cultivares. Comparativamente con algunos estudios anteriores de Russet Burbank, esta investigación sugiere el empleo de dosis más bajas de N y de concentraciones adecuadas de NO_3-N en el pecíolo.

INTRODUCTION

Nitrogen (N) fertilizer recommendations for potatoes (*Solanum tuberosum* L.) in Idaho and the Pacific Northwest historically have been based on the requirements of the Russet Burbank cultivar (Kleinkopf and Westermann 1986; Lauer 1986b; Roberts and Dow 1982; Roberts et al. 1982, 1991; Rykbost et al. 1993; Westermann and Kleinkopf 1985; Westermann et al. 1988). Previous research has demonstrated that uptake, use efficiency, petiole nitrate-nitrogen (NO_3-N) concentration, and optimal response to N differ by cultivar (Johnson et al. 1995; Kleinkopf et al. 1981; Lauer 1986a; Porter and Sisson 1991a, 1991b). The release of new potato cultivars necessitates additional N research to provide a better understanding of N response and to allow development of appropriate fertilizer recommendations.

Between 1999 and 2003, the Northwest potato cultivar development program released three new cultivars, Bannock Russet (Novy et al. 2002), Gem Russet (Love et al. 2002), and Summit Russet (University of Idaho unpublished). Each cultivar has morphological and developmental characteristics that differ from Russet Burbank and may consequently have unique N fertilizer requirements. Bannock Russet is very late maturing, indeterminate, exhibits delayed tuber initiation, and is resistant to most field diseases. Summit Russet also is very late maturing, indeterminate, is even more prone to delayed tuber initiation than Bannock Russet, and is resistant to most foliar and soil fungal diseases. Gem Russet is medium maturing, moderately determinate, not prone to tuber initiation delays, and only moderately resistant to most field diseases. The specific characteristics of each cultivar, along with likely differences in ability to extract and utilize soil N, suggests each cultivar will have unique N requirements.

Proper N fertilization is critical for optimizing potato yield and quality (Lauer 1986b; Millard and Marshall 1986; Porter and Sisson 1991b; Roberts et al. 1982; Rykbost et al. 1993; Westermann and Kleinkopf 1985). Insufficient available N leads to reduced growth (Millard and Marshall 1986; Roberts et al. 1982), reduced light interception (Millard and Marshal 1986), limited yields (Lauer 1986b; Porter and Sisson 1991b; Roberts et al. 1982), and early crop senescence (Kleinkopf et al. 1981). Excessive available N can result in reduced yields (Lauer 1986a), especially in late-maturing varieties (Porter and Sisson 1991b), delayed tuber set (Kleinkopf et al. 1981), and reduced tuber dry matter content (Millard and Marshall 1986; Porter and Sisson 1991b). Excessive N also reduces uptake efficiency and increases the potential for environmental problems associated with leaching or runoff (Millard and Robinson 1990; Westermann et al. 1988).

In recent years, split or periodic N application procedures have become common in many potato-producing regions. Split applications have been effective in increasing yield in areas with long growing seasons or with coarse-textured soils (Lauer 1986b; Roberts et al. 1982; Westermann and Kleinkopf 1985). In areas with short seasons and/or heavy-textured soils, split applications have not been as effective (MacLean 1984; MacMurdo et al. 1988). However, N-use efficiency has consistently increased with split application procedures. Vos (1999) found that under growing conditions in The Netherlands, the majority of N was taken up within 60 days of emergence. Methods that matched crop N needs with applications during this 60-day period, improved N-use efficiency. Westermann et al. (1988) documented N efficiency values as high as 80% with split applications, compared with 60% for preplant applications. Nitrogen efficiency has been shown to decrease as total application rates increase (Vos 1999).

Tissue testing has become the primary method for determining the need for in-season N applications for potatoes. The most commonly used method of tissue testing involves frequent measurement of petiole nitrate-N. Gardner and Jones (1975) completed early studies on petiole analysis for N management for Russet Burbank potatoes. They found that petiole nitrate-N concentrations were affected by both plant age and amount of N fertilizer applied, findings confirmed by Westcott et al. (1991). As a result of these studies, a relationship was confirmed between yield and published petiole NO_3-N critical concentrations. Williams and Maier (1990) found that the sensitivity of petiole testing depended on the site and the time of sampling. Early season analysis was less reliable for establishing crop need. Other factors have been found to affect the results of petiole testing, including location of the sampled petiole on the plant, time of day during sample collection, and potato cultivar (Vitosh and Silva 1996).

Critical levels of petiole NO_3-N concentration have been shown to differ among cultivars. Waterer (1997) showed that the critical range is markedly lower for cv Norland than for cvs Shepody or Russet Burbank. Porter and Sisson (1991a) established different critical levels for two cultivars, Russet Burbank and Shepody. This strongly suggests that critical petiole NO_3-N concentrations for each cultivar should be individually determined. Additionally, Rykbost et al. (1993) evaluated potato N management based on petiole analysis in a short-season environment and found it to be effective, but determined that petiole NO_3-N sufficiency concentrations require adjustment from those established for long-season environments.

This study was designed to establish optimum N recommendations for three new potato cultivars. Individual objectives included determination of optimal N fertilizer rate and application timing to maximize tuber yield, establishment of critical petiole NO_3-N concentrations, and determination of application procedures that maximize crop profitability.

MATERIALS AND METHODS

Experiments were conducted in 1999, 2000, and 2001 on a Declo silt loam (coarse-loamy, mixed, mesic, Xerollic Calciorthid) soil at the University of Idaho Aberdeen Research and Extension Center at Aberdeen, Idaho. Soil samples were taken prior to planting and soil residual N amounts calculated. Fifty-six to 70-g seedpieces of four cultivars, Russet Burbank, Gem Russet, Bannock Russet, and Summit Russet, were planted at a 26-cm spacing on rows 91 cm apart. The experimental field design was a randomized complete block (RCB) split plot with N rate as the main plot, cultivar as subplot, and four replications. Subplots consisted of four rows, 12.1 m long. The center two rows were used for measurements and evaluations. Other experimental parameters are given in Table 1. Experimental plots were sprinkler irrigated using a solid set system and available soil moisture was maintained above 65% throughout the growing season. Plots were managed using University of Idaho recommendations for fertility other than N. Crop management procedures common to the region were used.

Prior to fertilization, residual N was measured in the top 30 cm of the soil profile. Ammonium and nitrate concentrations were determined using automated flow injection colorimetric analysis. Nitrate was quantified using cadmium reduction and the sulfanilamide/N-(I-naphthyl)-ethylenediamine method and ammonia determined using indophenol blue method (Keeney and Nelson 1982).

Seven N treatments were included in the study, with a zero applied N rate serving as control. The other six treatments incorporated all combinations of three applications rates and two application timings. Total N applied was 100, 200, or 300 kg ha^{-1}. Timing involved differences in the ratio between preplant and seasonal N applications, including an early treatment wherein two-thirds of the total N was applied preplant, and a late treatment wherein one-third of the N was applied preplant. The remaining N was applied beginning the first week of July and included three equal bi-weekly applications for the early treatments (one-third postplant) and six equal weekly applications for the late treatments (two-thirds postplant). All N applied was in the urea (46-0-0) form. Preplant applications were incorporated mechanically. Postemergence applications were topdressed and incorporated immediately during the normally scheduled irrigation using 3 to 4 cm of water.

TABLE 1—*Experimental parameters for three years of nitrogen fertilizer experiments.*

Year	Preplant Soil N $NO_3 + NH_4$ $\mu g\ g^{-1}$	Planting Date	Petiole Sampling Dates	Vine Kill Date	Harvest Date
1999	7.2	13 May	8, 15, 22, 29 Jul; 5, 12, 19, 26 Aug; 2 Sep	14 Sep	6 Oct
2000	7.1	7 May	6, 13, 20, 27 Jul; 3, 10, 17, 24, 31 Aug	7 Sep	24 Sep
2001	11.7	7 May	6, 13, 20, 27 Jul; 3, 10, 17, 24, 31 Aug	6 Sep	24 Sep

Vines were killed chemically (Diquat®) 22, 16, and 17 days prior to mechanical harvest in 1999, 2000, and 2001, respectively. Tubers were graded according to USDA standards, weighed, and total and U.S. No. 1 yields determined. Specific gravity of a 3 kg sample (168 to 336 g tubers) was determined using the weight-in-air/weight-in-water method. Analysis of variance was computed for the entire accumulated data set for total and U.S. No. 1 yield. Quadratic regression analysis was used to further evaluate varietal response to N. Relative yield for each cultivar was calculated by dividing the U.S. No. 1 yield for each plot by the highest average treatment value within each year. Two quadratic regression equations were calculated for each cultivar. The first was inclusive of the control (0 applied rate) and all early-applied treatments. The second included the control and the late-applied treatments. A test of coincidence between the early and late quadratic curves was completed, a sums of squares procedure wherein the variability for a model consisting of separate lines is compared against the combined line model.

Predicted maximum yields and corresponding N rates for each N application timing treatment were determined for each cultivar by calculating the first derivative of the regression equations and setting the slope equal to zero. Residual soil N amounts of 32 kg ha^{-1} in 1999, 31 kg ha^{-1} in 2000, and 54 kg ha^{-1} in 2001, were added to the applied N rates to put computation on the basis of total N requirement.

Petiole samples were taken weekly, beginning at the approximate date the largest Russet Burbank tubers reached 1 cm in size and continuing until vine kill. See Table 1 for actual petiole sampling dates. The fourth youngest petiole (first fully expanded leaf) was collected randomly from each of 20 plants in the center two rows of each plot. The petioles were air dried at 60 C, ground through a 40-mesh screen, and analyzed for NO_3-N using the salicylic titration method of Cataldo et al. (1975). Sufficiency curves for petiole NO_3-N for each cultivar were developed using the method described by Roberts and Dow (1982). Curve modeling involved calculation of petiole NO_3-N values at 95% and 100% of maximum yield to define sufficiency values at each sampling date and fitting of quadratic equations.

Using a method similar to that described by Hutchinson et al. (2003), an economic analysis of N application was made for each of the four varieties. The analysis was designed as a processing contract model that incorporated a base price adjusted using incentive clauses for tuber size (percentage of tubers over 336 g), tuber grade (percentage of U.S. No. 1 tubers), and tuber specific gravity. Production costs were calculated using a partial budget approach, with N fertilizer costs, associated changes in financing costs, and harvest (hauling) costs being the only variables altered during computation. Net returns were calculated as the gross returns minus production costs. Analysis of variance was computed for individual varieties.

RESULTS

Analysis of Variance

ANOVA revealed significant main affects for N and cultivar for both total and U.S. No. 1 yields (Table 2). Cultivar accounted for more variability than any other variable, especially with respect to U.S. No. 1 yields. Nitrogen fertilizer by year and year by cultivar interactions for total and U.S. No. 1 yields were also significant. Year by N treatment interaction was not significant for either total or U.S. No. 1 yields.

Relative Yield/N Rate Regression

Graphs of the quadratic equations defining the relationship between yield and N rate for each cultivar were used to demonstrate the cultivar by N fertilizer treatment interactions (Figures 1-4). The equations allowed determination of four important values: maximum yield for early application treatments, maximum yield for late application treatments, and the

TABLE 2—*Analysis of variance for total and U.S. No. 1 yield.*

Source	df	MS	F-value[1]
Total Yield			
Year	2	331.0	39.20***
Rep (Year)	9	47.5	5.63***
Nitrogen Treatment	6	303.1	35.89***
Year x Nitrogen	12	13.4	1.59ns
Rep x Nitrogen (Year)	54	16.4	1.94***
Cultivar	3	498.4	59.02***
Nitrogen x Cultivar	18	15.9	1.88*
Year x Cultivar	6	458.5	54.29***
Year x Nitrogen x Cultivar	36	11.9	1.40ns
U.S. No. 1 Yield			
Year	2	20.9	2.36ns
Rep (Year)	9	43.4	4.90***
Nitrogen Treatment	6	214.0	24.17***
Year x Nitrogen	12	9.3	1.05ns
Rep x Nitrogen (Year)	54	18.2	2.06***
Cultivar	3	1482.7	167.52***
Nitrogen x Cultivar	18	19.9	2.25**
Year x Cultivar	6	467.0	52.76***
Year x Nitrogen x Cultivar	36	11.3	1.28ns

[1] Not significant (ns), or significant at $P = 0.05$ (**) or $P = 0.01$ (***)

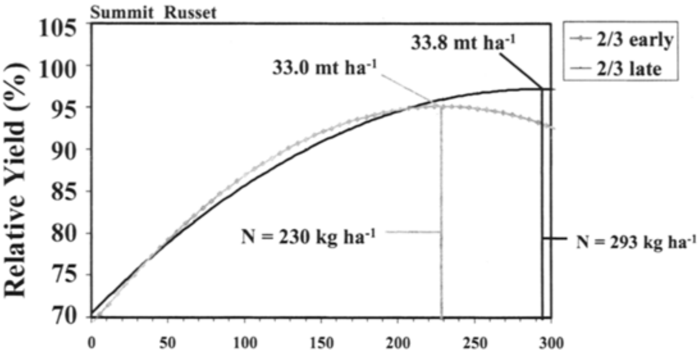

FIGURE 1.

Quadratic curves modeled to fit the response of Bannock Russet to N fertilizer application timing and rates. N was applied either two-thirds preplant and one-third incrementally during tuber bulking (2/3 early) or one-third preplant and two-thirds during bulking (2/3 late). Computation of regression curves was based on both soil residual and fertilizer N. Relative U.S. No. 1 yield was determined for each plot as a percentage of the highest average treatment within each year. Values in the graph show the predicted maximum yield and the amount of soil and fertilizer N needed to achieve maximum yield.

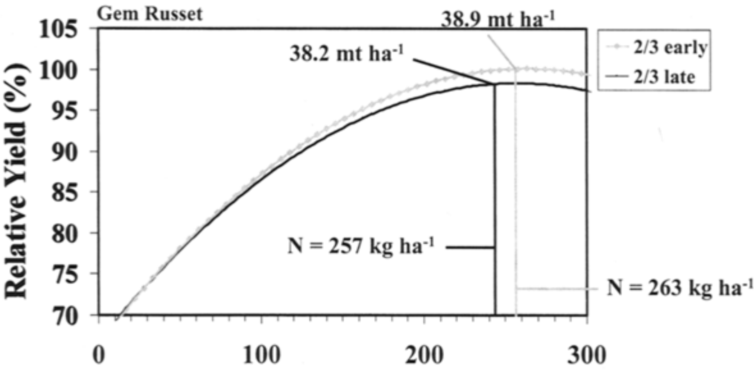

FIGURE 2.

Quadratic curves modeled to fit the response of Gem Russet to N fertilizer application timing and rates. N was applied either two-thirds preplant and one-third incrementally during tuber bulking (2/3 early) or one-third preplant and two-thirds during bulking (2/3 late). Computation of regression curves was based on both soil residual and fertilizer N. Relative U.S. No. 1 yield was determined for each plot as a percentage of the highest average treatment within each year. Values in the graph show the predicted maximum yield and the amount of soil and fertilizer N needed to achieve maximum yield.

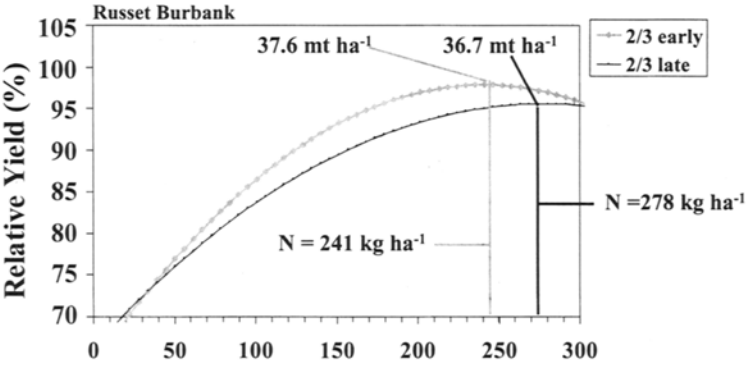

FIGURE 3.

Quadratic curves modeled to fit the response of Russet Burbank to N fertilizer application timing and rates. N was applied either two-thirds preplant and one-third incrementally during tuber bulking (2/3 early) or one-third preplant and two-thirds during bulking (2/3 late). Computation of regression curves was based on both soil residual and fertilizer N. Relative U.S. No. 1 yield was determined for each plot as a percentage of the highest average treatment within each year. Values in the graph show the predicted maximum yield and the amount of soil and fertilizer N needed to achieve maximum yield.

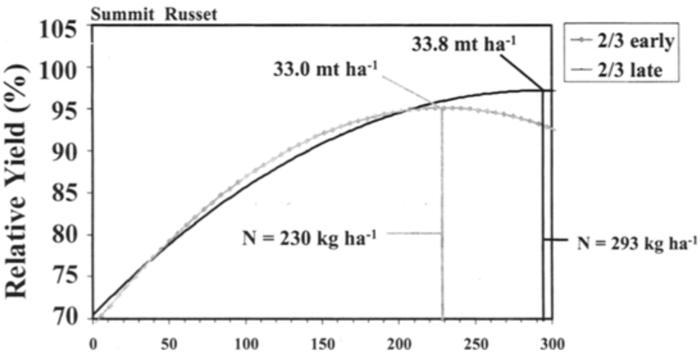

FIGURE 4.

Quadratic curves modeled to fit the response of Summit Russet to N fertilizer application timing and rates. N was applied either two-thirds preplant and one-third incrementally during tuber bulking (2/3 early) or one-third preplant and two-thirds during bulking (2/3 late). Computation of regression curves was based on both soil residual and fertilizer N. Relative U.S. No. 1 yield was determined for each plot as a percentage of the highest average treatment within each year. Values in the graph show the predicted maximum yield and the amount of soil and fertilizer N needed to achieve maximum yield.

amount of N fertilizer required to reach maximum yield for each application regime.

The relative yield response curves for early and late N treatment for Bannock Russet were nearly identical (Figure 1). Maximum yield when two-thirds of the N was applied early was 39.5 mt ha^{-1} (353 cwt/A). The N rate (applied plus soil residual) at the point of maximum yield was 211 kg ha^{-1} (188 lbs/A). Maximum yield with late application was 39.1 mt ha^{-1} (349 cwt/A), occurring at an N rate of 213 kg ha^{-1} (190 lbs/A). The early and late application curves for Bannock Russet were coincident meaning there was no statistically significant difference between the curves.

Gem Russet also showed very little difference in response of relative yield to timing of N application (Figure 2). The two-thirds early application produced a maximum yield of 38.9 mt ha^{-1} (347 cwt/A) and an N rate (applied plus soil residual) at the point of maximum yield of 263 kg ha^{-1} (235 lbs/A). Maximum yield with late application was 38.2 mt ha^{-1} (341 cwt/A), at an N rate (applied plus soil residual) of 257 kg ha^{-1} (229 lbs/A). As with Bannock Russet, there was no significant difference between early and late application regression lines.

Russet Burbank demonstrated a positive trend toward higher yields with two-thirds of the N fertilizer applied early, although the regression lines were not significantly different (Figure 3). The early application produced a maximum yield of 37.6 mt ha^{-1} (336 cwt/A), while the late application resulted in a maximum yield of 36.7 mt ha^{-1} (328 cwt/A). The advantage resulted from more efficient use of N. With early applications of N, maximum yield corresponded with a rate of 241kg N ha^{-1} (215 lbs/A) applied plus residual, while the late application required 278 kg N ha^{-1} (248 lbs/A) to produce maximum yield. Because this trend between early and late application response was not significant, these results require careful interpretation in association with the other results from the study.

The response of Summit Russet to N application was similar to that of Russet Burbank (Figure 3), but more pronounced (Figure 4). The differences in maximum yield between the two-thirds early and two-thirds late applications were small. The early application produced a maximum yield of 33.0 mt ha^{-1} (295 cwt/A), while the late application showed a maximum yield of 33.8 mt ha^{-1} (302 cwt/A). However, the difference in efficiency with Summit Russet was greater than for Russet Burbank. With early applications of N, maximum yield was produced with an N rate (applied plus soil residual) of 230 kg ha^{-1} (205 lbs/A), while the late application required 293 kg N ha^{-1} (261 lbs/A) to produce maximum yield. As with Russet Burbank, there was no significant difference between early and late application regression lines, even though the two lines for Summit Russet provided widely disparate statistics.

Each cultivar responded differently with respect to the amount of N needed to reach maximum yield (Figures 1-4). Bannock Russet required the least, reaching maximum yields at 211-213 kg N ha^{-1} while at the same time producing the highest overall yields of any of the four cultivars. Gem Russet and Russet Burbank required similar amounts of N, both requiring more than Bannock Russet. Summit Russet required less N than the other cultivars to reach maximum yields if applications were made early, but required the highest amounts in the trial if applications were made late.

Petiole NO_3-N Sufficiency Curves

Petiole NO_3-N sufficiency curves were constructed for each of the four cultivars. Using a quadratic model, petiole NO_3-N was regressed over relative yield. The first derivative was computed for each equation to determine the nitrate-N level associated with maximum yield. These values were plotted for all petiole-sampling dates. A second line was calculated at 95% of maximum yield and plotted on the same graph. Petiole NO_3-N values that fall between the two curves during the season are considered sufficient.

During the process of constructing the petiole NO_3-N sufficiency curves, the petiole and yield data were generally adequate to define a quadratic equation describing maximum yield at each petiole sampling date. However, data from three Gem Russet samples collected early in the season failed to demonstrate a relationship between petiole NO_3-N concentration and yield. The same was true for two samples for Russet Burbank and five for Summit Russet. In each case, the lack of a meaningful relationship resulted in a non-useable data point on the sufficiency curve, and these points were excluded from this portion of the analysis. Sufficiency curves for all four cultivars did not show a significant deviation from linearity. Therefore, all were depicted as straight-line relationships (Figures 5-8).

Petiole sampling dates ranged from 57 to 115 days after planting (DAP). At 100% of maximum yield for Bannock Russet, the upper limit (determined at maximum relative yield) for predicted optimal petiole NO_3-N concentration declined from a starting value of approximately 24,000 µg g^{-1} at 57 DAP to 3,000 µg g^{-1} at 115 DAP (Figure 5). At the lower limit (95% of

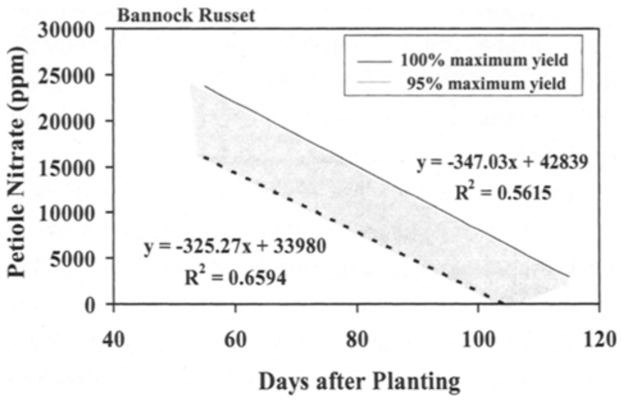

FIGURE 5.
Petiole NO_3-N sufficiency curves based on 100% (upper limit) and 95% (lower limit) of maximum yield for Bannock Russet. Petioles from the fourth youngest leaf were sampled for analysis.

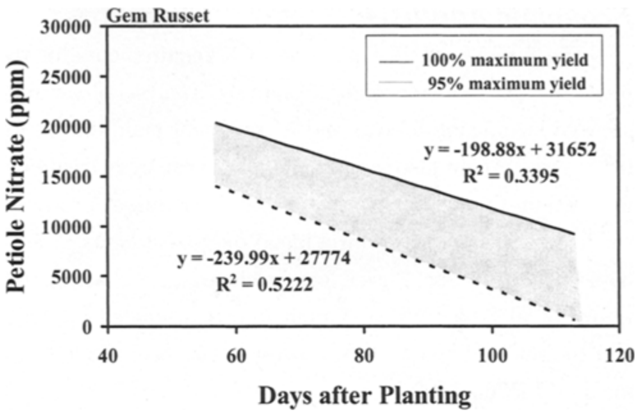

FIGURE 6.
Petiole NO_3-N sufficiency curves based on 100% and 95% of maximum yield for Gem Russet. Petioles from the fourth youngest leaf were sampled for analysis.

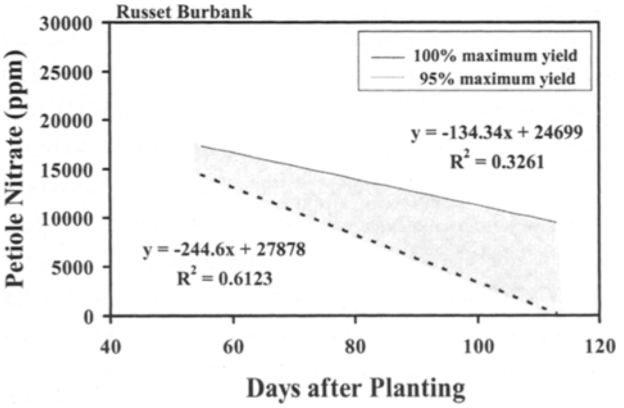

FIGURE 7.
Petiole NO_3-N sufficiency curves based on 100% and 95% of maximum yield for Russet Burbank. Petioles from the fourth youngest leaf were sampled for analysis.

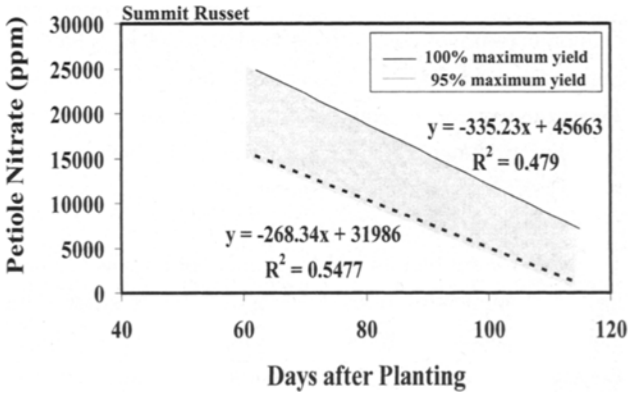

FIGURE 8.
Petiole NO_3-N sufficiency curves based on 100% and 95% of maximum yield for Summit Russet. Petioles from the fourth youngest leaf were sampled for analysis.

maximum yield), the earliest value was about 16,000 µg g^{-1} and declined to zero by 115 DAP. The sufficiency concentration range, by definition, lies between these two curves. Bannock Russet had a narrow sufficiency range and the 95% and 100% lines were nearly parallel.

Early in the season, the Gem Russet sufficiency range (approximately 14,000 to 21,000 µg g^{-1}) was similar to, or slightly lower than, that of Bannock Russet (Figure 6). As the season progressed, the Gem Russet sufficiency range became wider and remained somewhat higher than that of Bannock Russet.

Sufficiency concentrations for Russet Burbank were somewhat lower than expected, based on information available in previous literature, but otherwise typical for the cultivar (Westermann and Kleinkopf 1985). The early season Russet Burbank range (14,000 to 17,000 µg g^{-1}) was narrower than that of Gem Russet and the upper limit was lower (Figure 7). However, late in the season, the range was similar to that of Gem Russet. The range for Russet Burbank, like that for Gem Russet, tended to widen as the season progressed.

The sufficiency curves for Summit Russet were unique among the four cultivars in that they tended to be wider apart early in the season and tended to converge as the season progressed (Figure 8). The early season range was approximately 15,000 to 25,000 µg g^{-1}, while the late season range was 2,000 to 7,000 µg g^{-1}.

Economic Analysis

The final phase of evaluation of N requirements for the four cultivars was an economic analysis. Analysis of variance showed significant cultivar and N treatment main effects for net returns. There also was a significant year by N treatment interaction. Of the four cultivars, Bannock Russet produced the highest net returns with a mean over treatments of \$655 ha^{-1} (Table 3). Gem Russet was a close second with a net return of \$618 ha^{-1}, while Summit Russet produced \$529 ha^{-1} and Russet Burbank had the lowest net return, producing a mean of \$457 ha^{-1}.

Bannock Russet produced its highest returns with applications of 100 kg N ha^{-1} (Table 3). The timing of N applications made very little difference in the final value of the crop. With Bannock Russet, the 300 kg N ha^{-1} treatments, regardless of whether applied early or late, resulted in a significantly lower economic return as compared to the 100 or 200 kg N ha^{-1} treatments. The 300 kg N ha^{-1} treatments produced numerically lower, but statistically equal, returns in comparison with the 0 kg N ha^{-1} treatment. The lower returns at the high N application rates resulted from a combination of lower yield and increased costs associated with the high N inputs.

Gem Russet had its highest numerical returns at the 200 kg N ha^{-1} application rates. However, there were few significant differences between the treatments receiving N applications. As with Bannock Russet, there appeared to be a trend for the highest application rate, in comparison with the other two N rates, to result in a negative impact on net returns. A lack of N application to Gem Russet resulted in a substantial decline in returns. There was little influence of application timing on returns for Gem Russet.

Russet Burbank, like Gem Russet, showed little difference between N application timing treatments within each rate. It produced numerically highest returns at the 100 kg N ha^{-1} application rate, although all applied N treatments were statistically the same. Russet Burbank, as with Bannock Russet, showed a trend for a substantial loss in revenue with the high N application treatments when compared with the lower applied treatments. The 0 kg N ha^{-1} resulted in significantly lower returns than all treatments with N applied, except the highest rate (300 kg N ha^{-1}).

Summit Russet had the most unusual economic return response of the four varieties. Generally, there was little statistical difference between treatments with applied N, although all were higher than the 0 kg N ha^{-1} control. Numerically, the highest returns occurred with an application rate of 100 N kg ha^{-1} with two-thirds applied late. There were other interesting trends, with the lowest returns resulting with early application at the highest N rate. Although the application timing was not significantly different for Summit Russet within each rate, trends were for the late applications to consistently produce higher net dollar returns than the early applications.

TABLE 3—*Economic analysis showing net returns resulting from N fertilizer rate and timing treatments for four potato cultivars.*[1]

Nitrogen Treatment[2]	Cultivar Bannock Russet	 Gem Russet	 Russet Burbank	 Summit Russet
	Net Returns \$ ha^{-1}			
Control (0 Kg ha^{-1})	618	504	382	441
100 Kg ha^{-1} (2/3 early, 1/3 late)	704	639	492	557
100 Kg ha^{-1} (2/3 late, 1/3 early)	719	645	497	565
200 Kg ha^{-1} (2/3 early, 1/3 late)	697	646	477	532
200 Kg ha^{-1} (2/3 late, 1/3 early)	674	659	479	557
300 Kg ha^{-1} (2/3 early, 1/3 late)	585	630	433	503
300 Kg ha^{-1} (2/3 late, 1/3 early)	591	603	438	549
Cultivar Means	655	618	457	529
LSD (.05)	60	51	69	59

[1] Analysis based on a processing contract model, which includes a base price and incentive clauses for tuber size, tuber grade, and tuber specific gravity.

[2] Nitrogen rates listed in the table reflect only the amount applied as fertilizer and do not include residual soil N.

DISCUSSION

Considerable N fertilizer research has been done using the Russet Burbank cultivar as a model. Comparing the results of this study with earlier findings should help define and validate the conclusions for the three new cultivars. An article by Westermann and Kleinkopf (1985) has become the basis for managing Russet Burbank potatoes in the arid regions of southern Idaho. The research for their paper was completed near Twin Falls, an area of Idaho with warmer summer temperatures and a growing season 2 to 3 wk longer than in Aberdeen. In the Twin Falls study, residual soil N was not factored into the total N requirement. The recommendations from their paper were to split-apply N with preplant applications of 78 to 100 kg ha^{-1}, a total N application of 224 to 235 kg ha^{-1}, and to maintain a minimum critical petiole NO_3-N level of 15,000 µg g^{-1} through most of the tuber-bulking period.

Studies completed in the Columbia Basin of Washington, another area with longer growing seasons and higher average yields, showed optimal N rates for Russet Burbank ranging from 336 to 448 kg ha^{-1} (Lauer 1986b; Roberts et al. 1982). In these studies, no petioles sufficiency levels were established. However, Roberts et al. (1982) made reference to studies completed by Jones and Painter (1975) in the warm regions of western Idaho, wherein petiole sufficiency levels were assumed to be 18,000 to 22,000 µg g^{-1} at tuber set. In these studies, as with the Westermann and Kleinkopf (1985) study, only the applied N was accounted for in relation to the yield measurements.

Based on the current study, amounts of soil and fertilizer N needed to produce maximum yield for Russet Burbank would be established at 241 to 278 kg N ha^{-1}, similar to those predicted by Westermann and Kleinkopf (1985) for Twin Falls. However, because soil residual N was included in determination of required amounts, recommendations resulting from this current study are below, or at least on the low side of, those based on the Westermann and Kleinkopf (1985) study. Recommendations resulting from this study are likely to reflect N rates that are markedly lower than those indicated in the Columbia Basin studies referenced above. The critical petiole NO_3-N sufficiency concentrations resulting from the current study also will likely reflect lower values that dictated by these earlier studies.

Optimal N rates and petiole NO_3-N sufficiency levels were similar to earlier studies completed at Aberdeen and Twin Falls (Gardner and Jones 1975), and in studies completed in Klamath Falls, Oregon (Rykbost et al. 1993), a location with an environment almost identical to that of Aberdeen. Evidence for the idea that lower N requirements and lower petiole NO_3-N sufficiency concentrations are adequate in areas with cool, short seasons is also found in the work of Porter and Sisson (1991b) in Maine.

Two other factors, soil type and irrigation practices, may also have contributed to the comparatively low optimal N application rates found in this study. The current experiments were conducted on a silt loam soil and near-optimal irrigation water amounts were applied using a solid set irrigation system. Both of the factors tended to limit N leaching and reduce overall N requirements for producing optimum yields. Improved control over N leaching also tends to minimize the differences in N-use efficiency between preplant and split N applications (Stark et al. 1995)

This study demonstrated the importance of developing N recommendations for new cultivars. Each of the four cultivars evaluated showed a unique response to N fertilizer for each of the characteristics evaluated. The initial evidence for this conclusion was a significant cultivar by N fertilizer treatment interaction for U.S. No. 1 tuber yield (Table 2). Additional evidence is found in the unique response for one or more measured variables of each cultivar to the conditions imposed by N treatments. Bannock Russet was unique in every aspect in that it reached higher yields than Russet Burbank and the other two cultivars, did so with less total N, and showed no trend toward a response to application timing. Optimal N application rates for Gem Russet were similar to those established for Russet Burbank, but the petiole critical levels were higher and showed a trend toward a timing response. Summit Russet showed the widest discrepancy in response between early and late application treatments for yield and economic returns.

The most critical factor for potato growers in determining optimal fertilizer rates for new cultivars is economic return. Each cultivar responded uniquely in comparison with the other three cultivars, with respect to returns across treatments. However, one trend for N rate was evident across cultivars. Net returns were relatively low when no N was applied, rose to a maximum at some intermediate rate, then fell again at the highest rate(s). Also, net returns for the new cultivars were higher than for Russet Burbank regardless of N treatment.

This new information should provide valuable guidance in managing N for Bannock Russet, Gem Russet, and Summit Russet. In some environments higher rates of N fertilizer and higher petiole NO_3-N sufficiency levels may be required for these cultivars. However, the response of each cultivar, when considered relative to Russet Burbank, should provide useful comparisons for establishing appropriate N recommendations.

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LITERATURE CITED

Cataldo DA, M Haroon, LE Schrader, and VL Youngs. 1975. Rapid colorimetric determination of nitrate in plant tissue by titration of salicylic acid. Comm Soil Plant Sci 6:71-80.

Gardner BR, and JP Jones. 1975. Petiole analysis and the nitrogen fertilization of 'Russet Burbank' potatoes. Am Potato J 52:195-200.

Hutchinson PJS, DJ Tonks, and BR Beutler. 2003. Efficacy and economics of weed control programs in glyphosate-resistant potato (*Solanum tuberosum*). Weed Tech (in press).

Johnson CL, TA Tindall, M Thornton, and RA Brooks. 1995. Petiole NO_3-N sufficiency curves in newly developed potato cultivars. Proc Univ Idaho Winter Commodity Schools 27:209-216.

Jones JP, and CG Painter. 1975. Tissue analysis, a guide to nitrogen fertilization of Idaho 'Russet Burbank' potatoes. Univ of Idaho Current Info Series No 240.

Keeney DR, and DW Nelson. 1982. Nitrogen–Inorganic forms. *In:* AL Page, RH Miller, and DR Keeney (eds), Methods of Soil Analysis, Part 2 Chemical and Microbiological Properties, 2nd Ed. ASA, SSSA, Inc., Madison, WI.

Kleinkopf GE, and DT Westermann. 1986. Scheduling nitrogen applications for Russet Burbank potatoes. Univ of Idaho Curr Info Series No 637.

Kleinkopf GE, DT Westermann, and RB Dwelle. 1981. Dry matter production and nitrogen utilization by six potato cultivars. Agron J 73:799-802.

Lauer DA 1986a. Response of Nooksack potatoes to nitrogen fertilizer. Am Potato J 63:251-262.

Lauer DA. 1986b. 'Russet Burbank' yield response to sprinkler-applied nitrogen fertilizer. Am Potato J 63:61-69.

Love SL, R Novy, DL Corsini, JJ Pavek, AR Mosley, RE Thornton, SR James, and DC Hane. 2002. 'Gem Russet': a long russet potato cultivar with excellent fresh market and french fry processing quality. Amer J Potato Res 79:25-31.

MacLean AA. 1984. Time of application of fertilizer nitrogen for potatoes in Atlantic Canada. Am Potato J 61:23-29.

MacMurdo W, RK Prange, and R Veinot. 1988. Nitrogen fertilization and petiole tissue testing in production of whole seed tubers of the potato cultivars Sebago and Atlantic. Can J Plant Sci 68:901-905.

Millard P, and B Marshall. 1986. Growth, nitrogen uptake and partitioning within the potato (*Solanum tuberosum* L.) crop, in relation to nitrogen application. J Agric Sci Camb 107:421-429.

Millard P, and D. Robinson. 1990. Effect of the timing and rate of nitrogen fertilization on the growth and recovery of fertilizer nitrogen within the potato (*Solanum tuberosum* L.) crop. Fert Res 21:133-140.

Novy RG, DL Corsini, SL Love, JJ Pavek, AR Mosley, SR James, DC Hane, CC Shock, KA Rykbost, CR Brown, and RE Thornton. 2002. 'Bannock Russet': a dual-purpose russet potato cultivar with high U.S. No. 1 yield and multiple disease resistances. Amer J Potato Res 79:147-153.

Porter GA, and JA Sisson. 1991a. Petiole nitrate content of Maine-grown 'Russet Burbank' and 'Shepody' potatoes in response to varying nitrogen rates. Am Potato J 68:493-505.

Porter GA, and JA Sisson. 1991b. Response of 'Russet Burbank' and 'Shepody' potatoes to nitrogen fertilizer in two cropping systems. Am Potato J 68:425-443.

Roberts S, and AI Dow. 1982. Critical nutrient ranges for petiole phosphorus levels of sprinkler-irrigated 'Russet Burbank' potatoes. Agron J 74:583-585.

Roberts S, HH Cheng, and FO Farrow. 1991. Potato uptake and recovery of nitrogen-15-enriched ammonium nitrate from periodic applications. Agron J 83:378-381.

Roberts S, WH Weaver, and JP Phelps. 1982. Effect of rate and time of fertilization in nitrogen and yield of 'Russet Burbank' potatoes under center pivot irrigation. Am Potato J 59:77-86.

Rykbost KA, NW Christensen, and J Maxwell. 1993. Fertilization of 'Russet Burbank' in short-season environment. Am Potato J 70:699-710.

Stark JC, DT Westermann, and JF Guenthner. 1995. Economic and environmental concerns related to potato irrigation and nitrogen management. Western Nutrient Mgt. Conf Proc 1:87-92. Potash and Phosphate Inst.

Vitosh ML, and GH Silva. 1996. Factors affecting potato petiole sap nitrate tests. Comm Soil Sci Plant Anal 27:1137-1152.

Vos J. 1999. Split application in potato: affects on accumulation of nitrogen and dry matter in the crop and on the nitrogen budget. J Agric Sci Camb 133:263-274.

Waterer D. 1997. Petiole sap NO_3-N testing as a method for monitoring nitrogen nutrition of potato crops. Can J Plant Sci 77:273-278.

Westcott MP, VR Stewart, and RE Lund. 1991. Critical petiole nitrate levels in potato. Agron J 83:844-850.

Westermann DT, and GE Kleinkopf. 1985. Nitrogen requirements of potatoes. Agron J 77:616-621.

Westermann DT, GE Kleinkopf, and LK Porter. 1988. Nitrogen fertilizer efficiencies on potatoes. Am Potato J 65:377-386.

Williams CMJ, and NA Maier. 1990. Determination of the nitrogen status of irrigated potato crops: I. Critical nutrient ranges for nitrate-nitrogen in petioles. J Plant Nutr 13:971-984.