Defining In-Season Nitrogen Management Needs for Alturas and Premier Russet

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Managing nutrient inputs properly, especially nitrogen (N) is essential for maximizing tuber quality and yield (Rowe 1993). Improper N management can significantly compromise yield and quality (Rowe 1993). Insufficient N can lead to reduced growth (Harris 1992), reduced light interception, limited yield (Chase et al. 1990; Laurer 1986; Munro et al. 1977; Santerre et al. 1986; White et al. 1974) delayed tuber set (Harris 1992), reduced dry matter content (Love et al. 2005; MacKerron and Davies 1986; McDole 1972; Painter and Augustin 1976; Westermann et al. 1994; Yungen et al.1958) and an increase in diseases such as early die, late blight, and Verticillium wilt (Davis et al. 1990; Rowe 1993). In contrast, excess N may reduce tuber N uptake efficiency, delay tuber initiation (Westermann and Kleinkopf 1985), and promote overgrowth of vines which can reduce the effectiveness of vine desiccants (Pavlista and Blumenthal 2000) and create a humid environment that promotes diseases associated with moisture such as aerial stem rot, Sclerotinia stem rot, pink rot, and other foliar and tuber diseases (Rowe 1993). Excess N may also affect storability (Long et al. 2004) and have adverse environmental effects such as groundwater run-off and leaching (Rowe 1993), which increases the risk of environmental pollution.

In light of the importance of N management, there is considerable need in the potato industry for cultivar specific N recommendations that reduce excess N applications while returning maximum economic value to the grower. Standard industry fertilization practices for potato are generally driven by published regional fertilization guidelines. However, these guidelines are often based on the nutrient requirements of the well-studied Russet Burbank cultivar (Kleinkopf and Westermann 1986; Lauer 1986; Roberts and Dow 1982; Roberts et al. 1982; Rykbost et al. 1993; Westermann and Kleinkopf 1985; Westermann et al. 1988), which has demonstrated maximum yields with applied N rates from as little as 45 kg ha^{-1} following red clover (*Trifolium pratense* L.) to as much as 400 kg ha^{-1} (Lauer 1986; Porter and Sisson 1991*b*). Different potato cultivars have unique morphological, physiological and developmental characteristics that may differ from Russet Burbank in response to N fertilization (Arsenault et al. 2001) and as such may differ in their N requirements. Therefore, fertilizing cultivars other than Russet Burbank with typical Russet Burbank rates may not be the most effective strategy. In addition to being of limited value when a cultivar other than Russet Burbank is being produced, regional guidelines are rarely accompanied by a thorough economic analysis. Economics take into account the price/cost ratio of N fertilizer and potato value in a particular year and help quantify the true efficiency of a grower's fertilizer regime. Nitrogen affects a number of key processing characteristics in potato that directly relate to economic return. Processing contracts include economic penalties and incentives for processing parameters such as tuber size, internal and external quality, and specific gravity, all of which can be affected by N (Knowles et al. 2009). Without examining the economics related with a particular N rate, a grower is not getting the whole picture. To further complicate the issue, N recommendations in potato are generally performed with the main goal of maximizing total yield. However maximum biological yield does not always equate to maximum economic yield (Pavek and Holden 2008) and there may be a large disparity between the two. Thus, a grower fertilizing a new cultivar in accordance with standard Russet Burbank fertilization practices may be compromising yield, quality, and net income.

The recent release of two new cultivars from the Tri-State Breeding Program and the USDA/ARS, Alturas and Premier Russet (Premier), has necessitated the development of appropriate in-season N fertilizer recommendations tailored to each cultivar. The reported research examines in-season N rates that are associated with maximum economic return and tuber quality for these two cultivars with the following specific objectives: 1) assess a new research method for N application that closely mimics commercial fertigation and allows for a large number of treatments, 2) develop a cultivar-specific understanding of N response as it relates to yield, quality, and economics of these cultivars, 3) define specific petiole and soil critical concentrations for each cultivar for maximum economic returns and 4) increase grower bottom line.

MATERIALS AND METHODS

This experiment was conducted at the WSU Othello Research Station in Othello, WA, on a Shano silt loam during the 2007 through 2009 growing seasons. Each cultivar was planted in a randomized complete block design with five-row plots, 25 ft long, with 5 ft borders and 10 inch spacing between plants. Plots were treated with five in-season N rates: 0%, 25%, 50%, 100%, and 150%. Treatments are expressed as a percentage of the current in-season N recommendations for Russet Burbank. All treatments received the same pre-plant fertilizer during a particular year. Pre-plant, in-season and total season N rates and associated in-season N expense are shown in Tables 1-4.

In-season N (UAN-32) was applied weekly between 50 days after planting (DAP) and 100 DAP via a custom designed fertigation simulator that delivered 0.15 in. of water (Figure 1; Table 3). Petioles were collected weekly from center data rows between 60 DAP and 120 DAP and soil samples were collected bi-weekly at one and two foot levels. Hand digs were initiated at 70 DAP and performed every eighteen days. Data on stem number, tuber number, vine weight, tuber weight and tuber number were collected. At the end of the season, tubers were harvested via a two row digger and graded and sized using a custom two lane electronic sizer. An economic evaluation was performed on both cultivars via a mock processing contract modeled after contracts currently in use in the Columbia Basin.

RESULTS

Petiole and Soil Nitrogen Trends

Treatment differences were evident and distinct in the petiole NO_3-N analyses for both cultivars, especially as each season progressed (Fig. 2). As expected, increasing N rates typically led to increased N concentration in the plant tissue and the soil (Fig. 2) throughout the growing season. Petiole differences were evident within ten days of the first in-season application across all years for both cultivars. As N applications began for both cultivars, petiole values typically climbed and eventually peaked between 70 and 80 DAP. Following the peak, petioles declined steadily as the season progressed. For both cultivars, treatment differences in soil N were not as defined or obvious as with the petioles (Fig. 3). Often, the soil N levels appeared to reflect the rates being applied. Occasionally, however, the soil values from the treatments intertwined and trends were not clear. During mid to late season, the highest N rate could typically be resolved from the other treatments, with soil values far in excess of the other treatments.

Vine Weights, Senescence and Harvest Index

The effects of N became somewhat apparent within 10 days after the first in-season N application. The two highest N treatments of both cultivars typically started to develop the heaviest overall canopy weights, which continued throughout most of the season (Fig. 4). Vine weight differences between the lowest three N rates, and occasionally all N rates, were not always apparent. For the most part, however, the 0% treatments of both cultivars produced the lowest vine weights. As the season progressed, fresh vine weights of Premier typically peaked close to 100 DAP while Alturas vine weights appeared to have peaked 20 to 40 days later. Although the vine weights did not always appear to correlate with the in-season N treatments, the differences between the lowest and highest treatments were typically quite pronounced and indicated that much of the additional N available to the plants in the high N treatments was directed toward vine production in both cultivars. Beyond 100- to 120-DAP, vine weights across most treatments of both cultivars began to decline due to the onset of natural vine senescence, suggesting a changing source/sink relationship between the vines and tubers.

In-season N rate substantially affected the harvest index for both cultivars across years (Fig. 5). By the time foliar weight had peaked during the season, those plants receiving lower N rates had partitioned more fresh weight to tubers than plants receiving higher amounts of N. In essence, plants receiving less N favored tuber production and plants receiving virtually unlimited N favored vine production as a percentage of whole-plant fresh weight at this point in the growing season.

When vine senescence was regressed against N rate, highly significant non-linear trends were revealed (Fig. 6). Lush growth was seen across all Alturas treatments for most of the year during 2009. As a result, the trend that existed in the previous years was not seen, and treatments were not different at 140 DAP (data not shown).

Tuber Quality and Specific Gravity

In-season N rate did not significantly affect blackspot bruise, stem end discoloration, shatter bruise, hollow heart, internal brown spot, length-to-width ratio or brown center (data not shown). Overall, incidences of these tuber defects were very low with the exception of shatter bruise in Premier. Though treatments were not statistically different, Premier appeared to be genetically susceptible to shatter bruise averaging 70%, 77%, and 88% in 2007, 2008, and 2009, respectively, across all treatments.

Tuber specific gravity was highly correlated with N rate for both cultivars across all years (Fig. 6), with the exception of Premier in 2009 (data not shown). Specific gravity increased as in-season N rate decreased. Because there were highly significant trends during the previous years for both cultivars, it is plausible that climate and/or field variability during 2009 complicated the otherwise typical specific gravity x N rate trend seen in Premier (data not shown). Relative to the mock processing contract parameters, the specific gravity values for all treatments of both cultivars were well within the range where the maximum incentives could be achieved.

Stem Number, Tuber Number, and Average Tuber Weight

Stem and tuber number per plant were not significantly different across treatments and years for either cultivar (data not shown). Stem number averages across three years were 2.5 stems per plant for Premier and 3.04 stems per plant for Alturas.

Total Tuber Yield and Size Distribution

In-season N levels had a significant and substantial affect on total tuber yields in both cultivars in all years of the study. As in-season N rates increased, total yield of both cultivars increased in a highly significant non-linear trend (Fig. 6). Alturas maximum yield occurred when the highest rate of N was applied (approximately 355 lbs in-season N/A). Premier total yield peaked at 123% (approximately 295 lbs in-season N, Fig. 6). The difference in total yield between the 0% and 100% treatment of Premier was approximately 100 CWT/A. Based on the decline in total yield beyond 123%, it appears as though excess N did not contribute to a corresponding yield response in Premier. Total yields in both cultivars were substantially lower in 2008 than in 2007 or 2009 (data not shown).

In-season N level influenced tuber size distribution for both cultivars across all years. Significant correlations were obtained when market yields of >4 oz (data not shown) and >6 oz (Fig. 7) tubers were regressed against in-season N. The trends and responses to applied in-season N were similar for both cultivars, differing only in the amount of in-season N required to reach maximum yields in the size categories examined.

For Alturas, maximum yields of marketable tubers >6 oz peaked, at 160% of the typical in-season N rates (384 lbs in-season N/A, Fig. 7). >12 oz tubers peaked at 120% of the typical Russet Burbank in-season rate (approximately 288 lbs N/A; Fig. 7). In Premier, yield of tubers >6 oz reached a maximum at 108% (259 lbs in-season N/A, Fig. 7). Maximum yield of >12 oz tubers occurred at 117% of typical Russet Burbank in-season rates (Fig. 7).

Economics

With the exception of Premier in 2007, adjusted gross processing income reached a maximum at in-season N rates at, or slightly above, the 100% rate (Fig. 7). Too much N (150%) was typically detrimental to the grower’s bottom line (Fig. 7). In Alturas, revenue was optimized at 108% of the typical in-season N rate (259 lbs in-season N/A) and Premier revenue was optimized at in-season N rates of 100% (240 lbs in-season N/A). During 2007-09 in Alturas and 2008-09 in Premier, the marginal revenue gains from in-season N declined as the total amount of N increased beyond the maximum. Beyond the optimal rates of 108% for Alturas and 100% for Premier, additional in-season N only served to reduce revenue, despite any marginal gains in yield. Adjusted gross income was maximized at the various rates for both cultivars due to a mix of optimizing incentives within the processing contract, producing relatively high market yields, and minimizing N expense per unit of production. Importantly, the economic analyses for both cultivars demonstrated that maximum biological yield was typically not synonymous with maximum economic yield.

Nitrogen response patterns were established for both cultivars by dividing the total yield (tons/A) associated with the N rate that provided maximum economic returns (423 lbs total season N for Alturas and 392 lbs total season N for Premier) by the pounds of N required to reach that yield. Both cultivars required 11 pounds of total season N/A to produce one ton of fresh tuber weight.

DISCUSSION

Current Columbia Basin nutrient guidelines recommend optimum petiole NO_3-N values for Russet Burbank of 1.5 to 2.6%, 1.2 to 2.0% and 0.6 to 1.0% during tuber initiation (45-60 DAP), tuber bulking (60 DAP), and tuber maturation (120 DAP), respectively (Lang et al. 1999). The petiole values from the 100% treatment of both cultivars were typically within these recommended Russet Burbank ranges, while the 150% treatment values were significantly higher for much of the season. Similar to the 100 and 150% treatment, the reduced N treatments (0%, 25%, and 50%) produced petiole NO_3-N levels that appeared to be largely dose-dependent. Petiole values from these treatments fell in line with the lowest in-season N producing the lowest overall petiole levels. According to Pavek and Holden (2008), petiole NO_3-N concentrations for Alturas and Premier typically exceed those of Russet Burbank early to mid season but track closer to Russet Burbank mid to late season. They also found that Alturas petiole levels tend to be similar or slightly above Russet Burbank's near the end of the season while Premier's petiole NO_3-N values are typically lower.

Tested and proven previously by Pavek and Holden (2008), the fertigation simulator appeared to be an extremely effective method for testing the five water-applied fertilizer treatments, as evidenced by the distinct petiole and soil trends among treatments (Figs 2 and 3). The unique design allowed precise and accurate applications of in-season N and, similar to commercial potato production, utilized water as the fertilizer carrier. There is the potential to utilize the fertigation simulator for further research into water-applied pesticides, fungicides, and miticides in a variety of field crops outside of potatoes.

Both Alturas and Premier responded somewhat uniquely yet appeared to share a common trend relative to adjusted gross returns. Except for Premier in 2007, the adjusted gross returns for both cultivars followed the classic "law of diminishing returns" across all years; adjusted gross returns increased steadily as in-season N rates increased, eventually reaching a maximum (Fig. 7). Beyond this maximum, the marginal increase in yield was offset by a disproportional increase in N expense, resulting in a decline of adjusted gross returns. For Alturas, maximum economic yield was found at 108% of the typical in-season N rate for Russet Burbank (approximately 258-280 lbs/A in-season N, 405-410 lbs/A total season N, including residual and pre-plant). For Premier in 2008-09, maximum economic yield was achieved with 100% of the typical in-season Russet Burbank rate (approximately 240 lbs/A in-season N, 390 lbs/A total season N).

Alturas total yield from the 100% treatment was 756 CWT/A across years and total yield from the 150% treatment was 781 CWT/A, a difference of 25 cwt. Although the 150% treatment had higher total yields, the fertilizer-cost-adjusted base price/CWT after contract incentives/decentives was higher at the 100% treatment ($7.50/cwt at 150% vs $7.56/CWT at the 100% treatment), an increase of $0.06/CWT; N cost per acre was $54/A higher for 150% treatment than for the 100% treatment. To produce potatoes at the 150% rate, it cost more but returned less than at the 100% treatment. A closer look at the economics reveals that the proportion of 6 oz and greater tubers was higher at the 100% treatment than the 150% treatment (32% vs 29%) and the proportion of culls and tubers <4 oz was less at the 100% treatment than the 150% (12% vs 14%). Though these differences appear minute, the extra $0.06/CWT multiplied by a yield of 750 CWT/A translates into an extra $5,625 in processing contract incentives per 125 acre pivot.

Economics for Premier were quite similar to those of Alturas, with the exception that the 100% treatment in Premier had higher total yields than the 150% treatment (719 CWT/A vs 714

CWT/A, respectively). Similar to Alturas, the percentage of undersize tubers was less at the 100% treatment (7.56%) than the 150% treatment (7.92%) and the percentage of > 6oz tubers was higher at the 100% treatment (79%) than the 150% treatment (77%). This combination led to a contract-adjusted base price of $7.59/CWT at the 100% and $7.58 for the 150% treatment. For a standard sized pivot, the extra $0.01 incentive resulted in an $875 gain (per 125 acre pivot), illustrating again that a fractional shift in tuber size distribution can affect the growers bottom line. These data suggests that the appropriate amount of in-season N management is essential for producing tuber size profiles of maximum economic value.

Increasing N resulted in depressed specific gravities in both cultivars in a highly significant non-linear trend (with the exception of Premier in 2009; Fig 6). Although specific gravity decreased as N increased, the gravity values for both Alturas and Premier remained within the acceptable range for processing at all in-season N levels. This demonstrates that even at multiple levels of in-season N (0% and 150%), these cultivars will likely be eligible for specific gravity incentives.

Prior to the initiation of this study, it was common knowledge within the industry that many Alturas and Premier growers were applying 50% of the N typically (full season) used to produce Russet Burbank. It is now apparent that these growers may have been losing more than $250/A of potential profits in Alturas due to insufficient N. This equates to a loss of over $31,000 per average size center pivot (125 acres). Following the Columbia Basin guidelines for Premier (Novy et al. 2008), growers could have lost as much as $390/A in 2007 and $57/A in 2008-09 compared with the economically optimum rates determined in this study. The resulting loss in grower adjusted gross income could have been as high as $48,750 per pivot during 2007 and $7,125 in 2008-09.

Data from these experiments confirm the well known but often forgotten concept that maximum biological yield is not always the same as maximum economic yield. For potato growers growing a new cultivar for the first time, maximum economic return, as opposed to maximum yield, should be the most important consideration in determining optimum fertilizer rates (Love et al. 2005). An understanding of a cultivar's nitrogen response pattern (lbs of N required to produce each unit of yield) and how it relates to economics is an important contributor to maximum economic return and should also be evaluated when considering growing a new cultivar. Cultivars can vary significantly in the amount of N required per unit of final yield and N costs related to production will vary as well. For example, a study by Pavek and Holden (2008, unpublished) showed that Alturas was 26% more efficient in nitrogen use (yield per pound of N required) than Russet Burbank while Premier was 13% more efficient. Indeed, maximum total yields for Alturas and Premier were obtained with 150% and 125% of the typical Russet Burbank in-season N rate, respectively. For both cultivars, however, *revenue* was generally optimized at a rate closer to 100% of typical for Russet Burbank. In addition to revenue loss from the costs associated with higher N rates, some reduction in economic return came from a shift in tuber size profile. Contract incentives were reduced on yields from the higher N rates because there were fewer tubers within the desirable size range (6-12 oz). This is of special concern to producers who enter into processing contracts with deductions for oversize tubers.

. In order for Columbia Basin growers to minimize risk and maximize returns when producing Alturas and Premier, we recommend that petiole and soil N concentrations be maintained within the ranges found in Tables 5 and 6. These values were established following a detailed review of data from all years for both cultivars with the goal of finding ranges that were relatively low-risk, yet profitable. Due to all the different elements involved in crop production, it is difficult to recommend a specific N fertilizer regime that will work for all growers across all situations and seasons. Soil type, organic matter content, previous crop residues, weather and other factors all affect N availability; producers may find they can apply less N than levels found in this study and still produce profitable yields. However, coarse textured soils, prevalent in many parts of the Columbia Basin, may require slightly higher rates of N if leaching is prevalent. In addition, as input costs and potato prices changes the amount of in-season N required to maximize profits may change.

By utilizing the recommended petiole NO_3-N and soil N ranges, growers can adjust their inputs as needed for each situation, thereby maintaining plant growth and health that is necessary to produce a profitable crop. It is essential for growers to keep all other nutrients at appropriate levels, according to Columbia Basin Russet Burbank recommendations (Lang et al. 1999). Although it may be possible to make a profit with in-season N rates and petiole and soil values lower or higher than those found in this study, our intent was to identify N management that would lead to the maximum economic yields for these cultivars. As with any research and crops, these recommendations may be modified in the future as the management of these two cultivars becomes better understood.

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Figure 1. Chemigation simulation unit applying in-season fertilizer treatments on the Othello Research station.

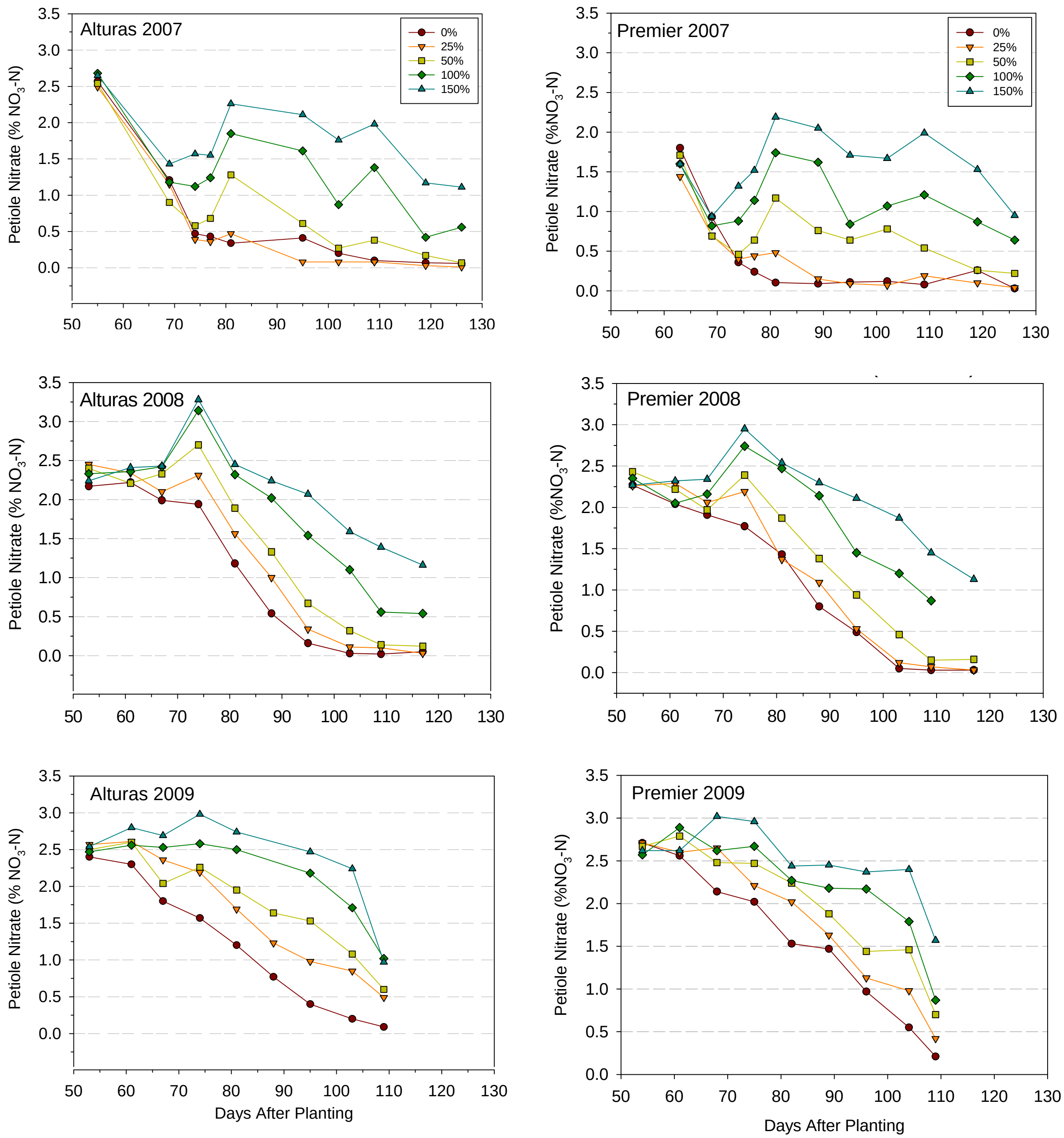

Figure 2. Alturas and Premier petiole NO_3-N trends across 5 different in-season N rates for 2007-09.

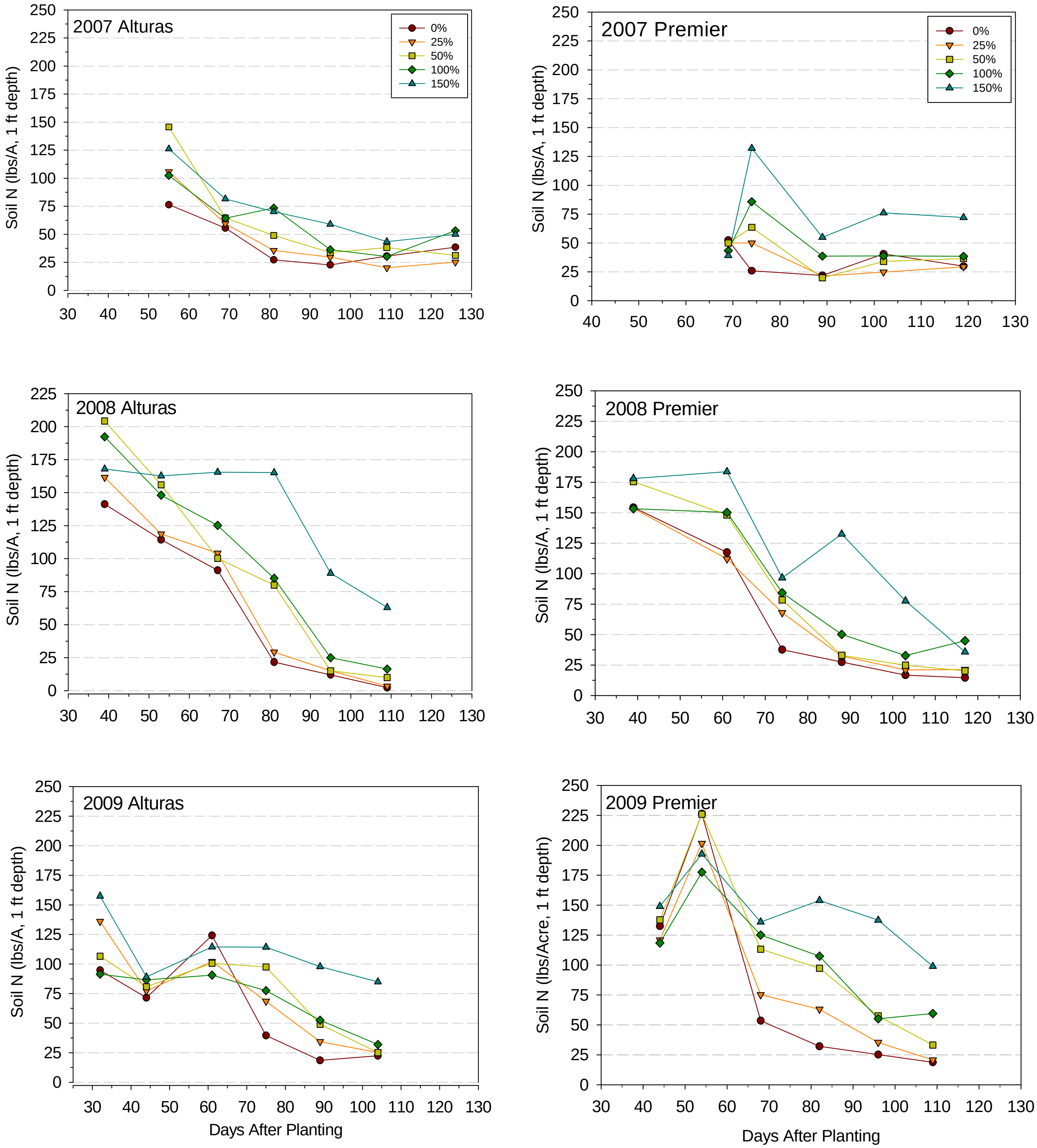

Figure 3. Alturas and Premier soil total N (NO_3 + NH_4) levels across five different in-season N treatments during 2007-09.

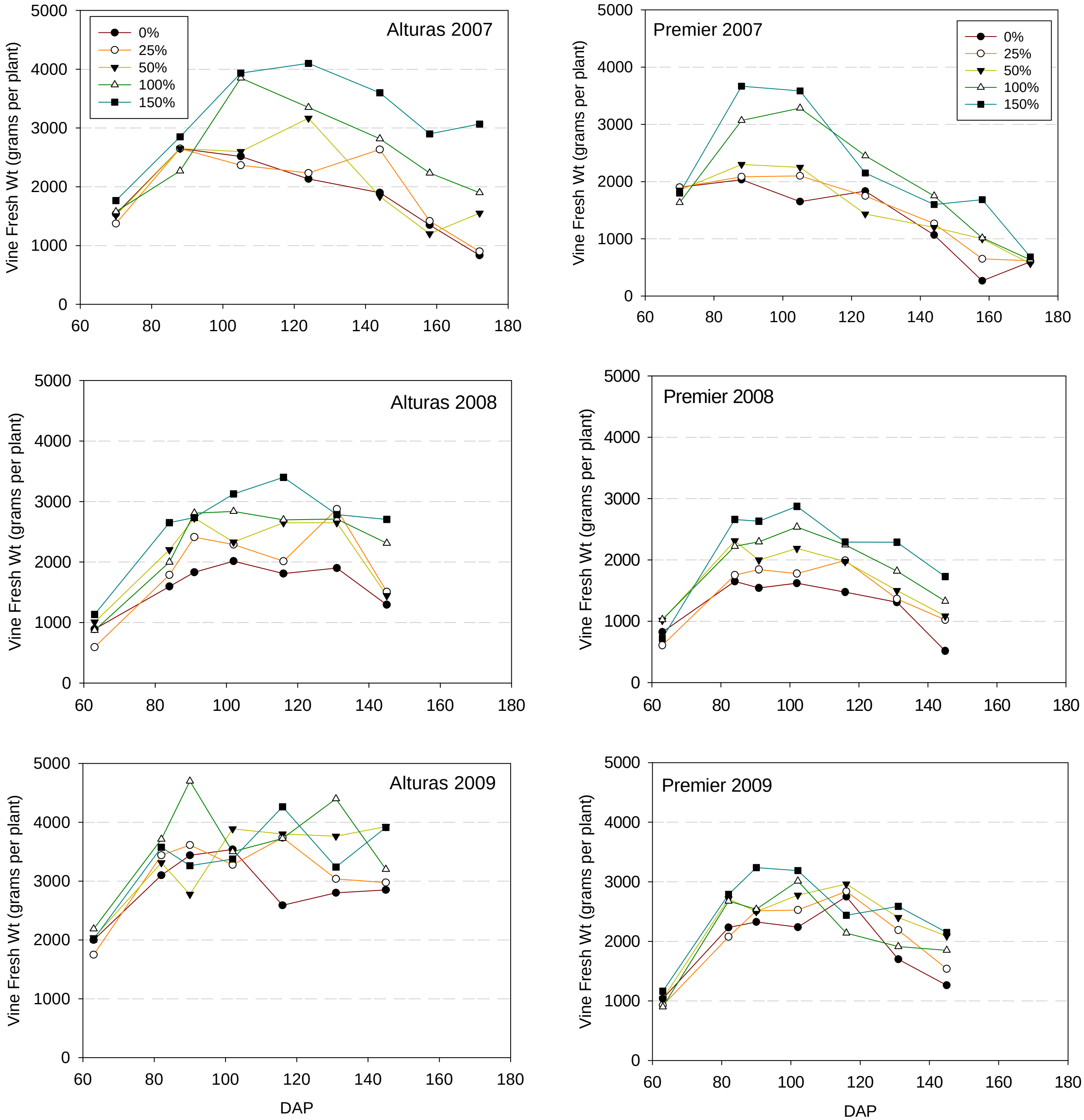

Figure 4. Alturas and Premier fresh vine weights across the growing season for five different in-season N rates during 2007-09.

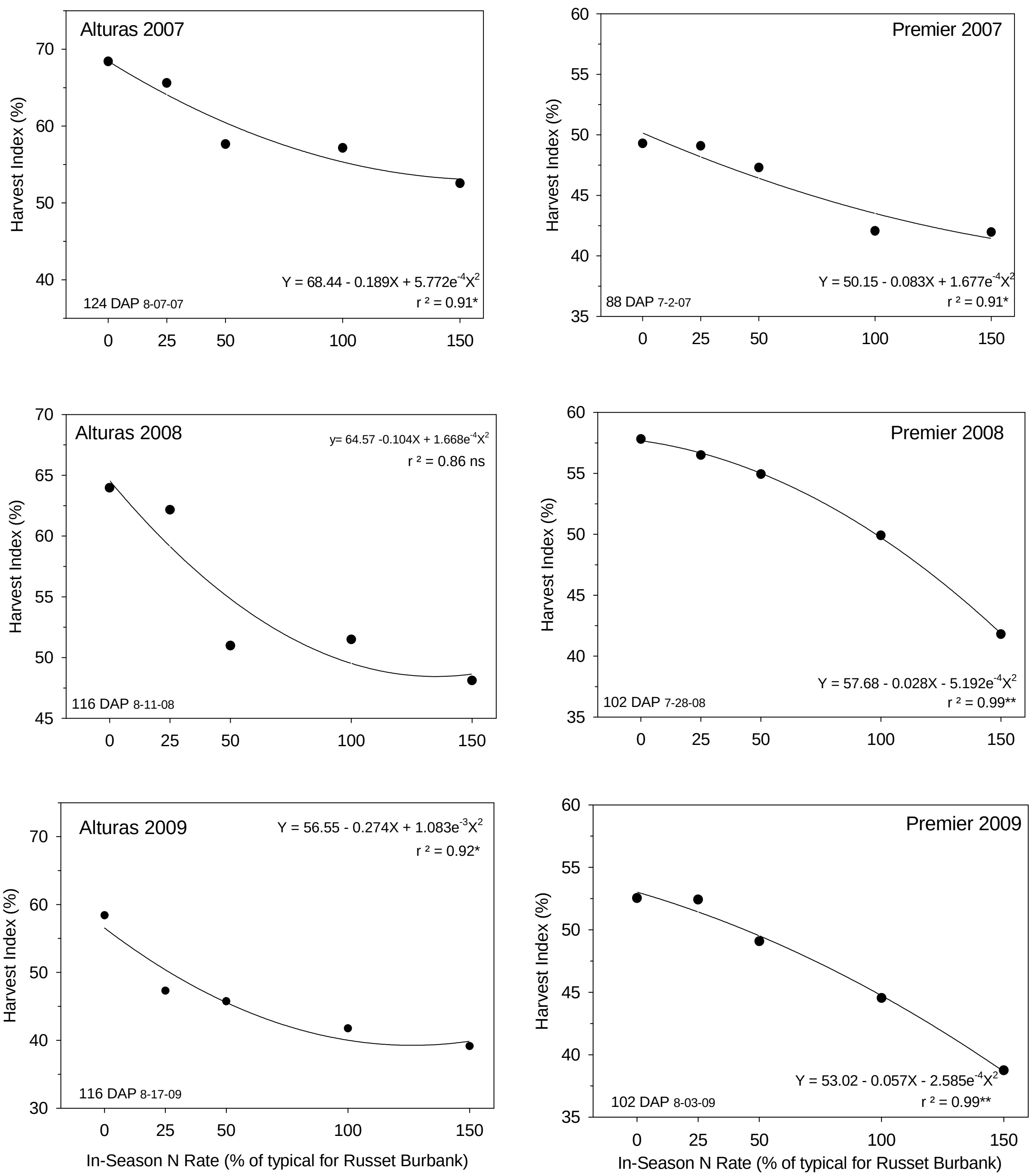

Figure 5. Alturas and Premier harvest index (calculated as tuber weight/tuber weight + above ground-fresh plant weight x 100) at 124 DAP (2007) and 116 DAP (2008-09).
*, **, ***, ns: significant at $P \geq 0.05$, 0.01, or 0.001 respectively, or non-significant.

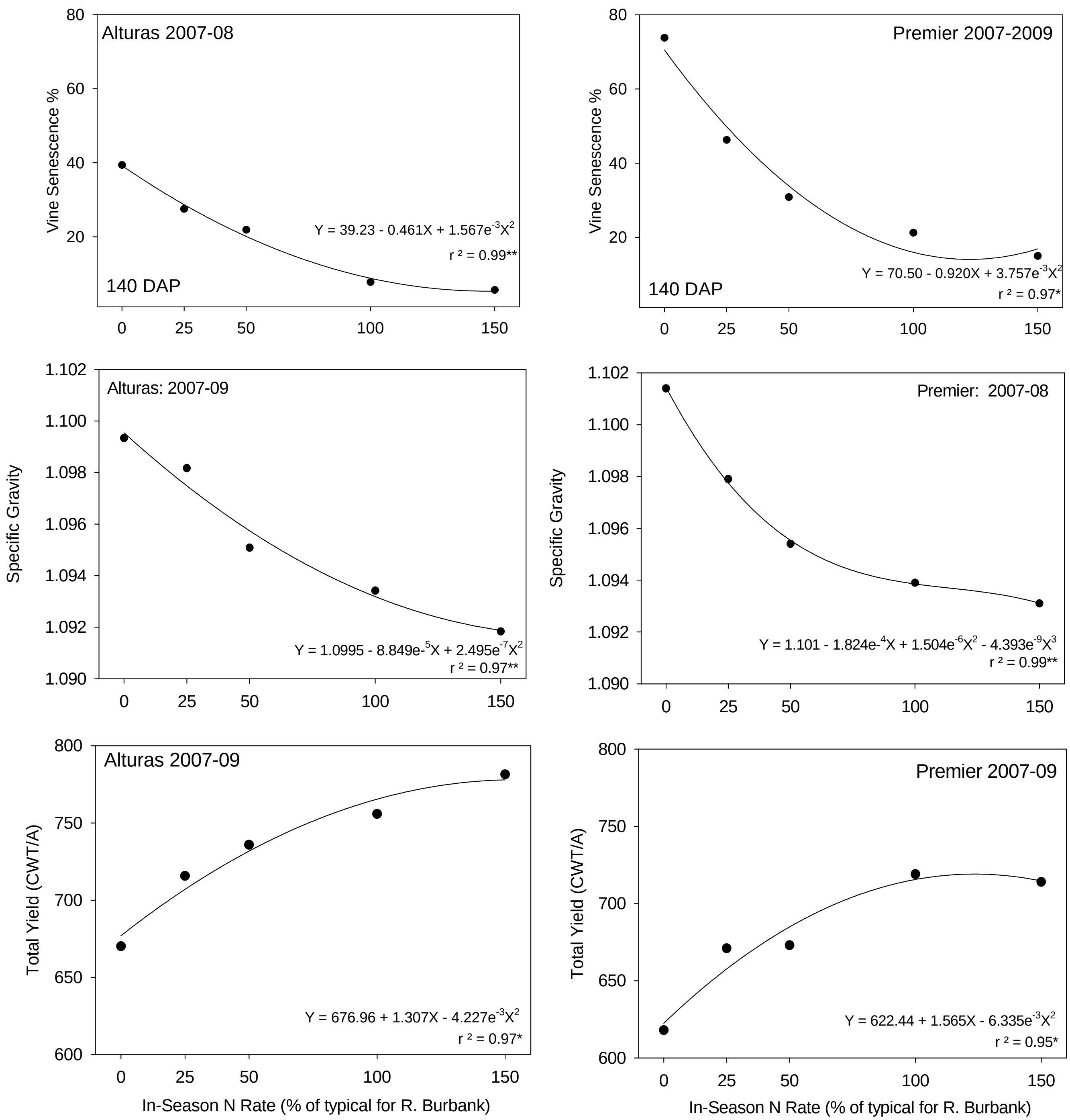

Figure 6. Vine senescence, specific gravity and total yield for Alturas and Premier across five in-season N rates in 2007-09. Data on vine senescence for Alturas in 2009 and specific gravity for Premier in 2009 were non-significant.

*, **, ***, ns: significant at $P \geq 0.05$, 0.01, or 0.001 respectively, or non-significant.

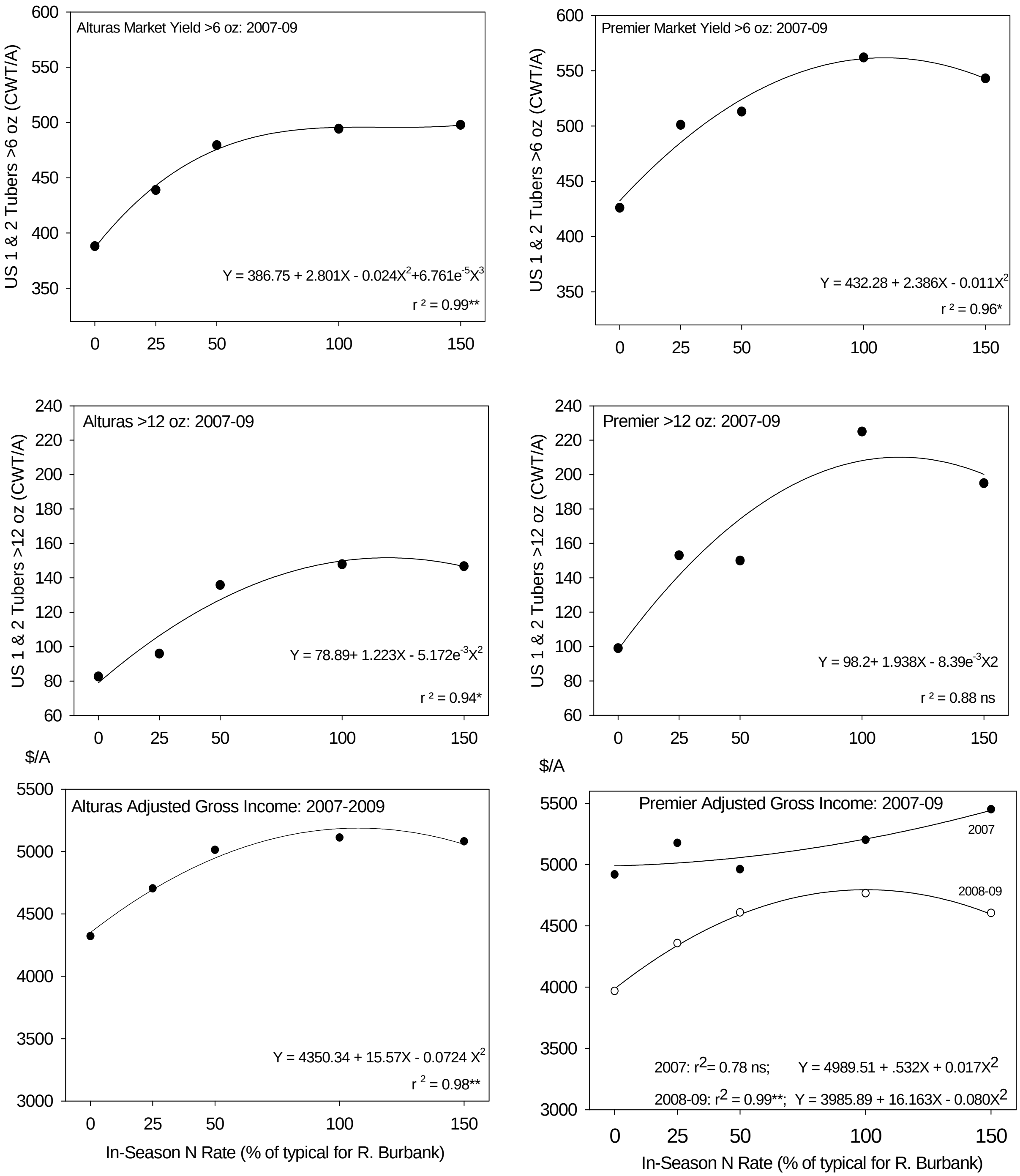

Figure 7. US 1 and 2 tubers greater than 6 and 12 oz and nitrogen-cost adjusted gross income for Alturas and Premier during 2007-09. The economic evaluation was based on a mock processing contract modeled after contracts currently in use in the Columbia Basin of Washington and Oregon with the cost of N set at $0.44/lb.
*, **, ***, ns: significant at $P \geq 0.05$, 0.01, or 0.001 respectively, or non-significant.

Table 1. Preplant, in-season, and total season nitrogen for 2007 and associated in-season N expense for five rates of in-season N applied to Premier and Alturas

Treatment As a % of Standard RB Rate	Applied Pre-plant N + Soil Residual[a]	Measured At-Emergence Soil N[b]	Applied In-Season N	Applied In-Season N Via Phos Applications	Total Applied In-season N	Total N Applied in 2007	In-season N Fert Expense ($0.44/lb)
%	--			lbs/A		--	$/A
0	125	127	0	30	30	155	0
25	125	127	58	30	88	213	23
50	125	127	115	30	145	270	46
100	125	127	230	30	260	385	92
150	125	127	345	30	375	500	138

[a]Soil residual values derived from a composite of twenty, 1 ft soil samples across trial location prior to planting; urea application (75 lbs/A) plus soil N (NO_3-N 8 lbs/A, NH_4 42 lbs/A) = 125 lbs/A.

[b]At-emergence soil N values derived from 120, 1 ft soil samples across trial location upon >90% plant emergence (NO_3 100 lbs/A, NH_4 27 lbs/A).

Table 2. Preplant, in-season, and total season nitrogen for 2008 and associated in-season N expense for five rates of in-season N applied to Premier and Alturas

Treatment As a % of Standard RB Rate	Applied Pre-plant N + Soil Residual[a]	Measured At-Emergence Soil N[b]	Applied In-Season N	Applied In-Season N Via Phos Applications	Total Applied In-season N	Total N Applied in 2008	In-season N Fert Expense ($0.44/lb)
%	--			lbs/A		--	$/A
0	152	168	0	9	9	161	0
25	152	168	58	9	67	219	23
50	152	168	115	9	124	276	46
100	152	168	230	9	239	391	92
150	152	168	345	9	354	506	138

[a]Soil residual values derived from a composite of twenty, 1 ft soil samples across trial location prior to planting; urea application (80 lbs/A) plus soil N (NO_3-N 24 lbs/A, NH_4 48 lbs/A) = 152 lbs/A.

[b]At-emergence soil N values derived from 120, 1 ft soil samples across trial location upon >90% plant emergence (NO_3 159 lbs/A, NH_4 9 lbs/A).

Table 3. Preplant, in-season, and total season nitrogen for 2009 and associated in-season N expense for five rates of in-season N applied to Premier and Alturas

Treatment As a % of Standard RB Rate	Applied Pre-plant N + Soil Residual[a]	Measured At-Emergence Soil N[b]	Applied In-Season N	Applied In-Season N Via Phos Applications	Total Applied In-season N	Total N Applied in 2009	In-season N Fert Expense ($0.44/lb)
%	--			lbs/A		--	$/A
0	152	171	0	10	10	162	0
25	152	171	58	10	68	220	23
50	152	171	115	10	125	277	46
100	152	171	230	10	240	392	92
150	152	171	345	10	355	507	138

[a]Soil residual values derived from a composite of twenty, 1 ft soil samples across trial location prior to planting; urea application (90 lbs/A) plus soil N (NO_3^- 30 lbs/A, NH_4^+ 32 lbs/A) = 152 lbs/A.

[b]At-emergence soil N values derived from 120, 1 ft soil samples across trial location upon >90% plant emergence (NO_3 163 lbs/A, NH_4 8 lbs/A).

Table 4. Rate scheme for five in-season N rates for 2007-2009

Treatment as a % of RB standard	Number of Applications*			
	Two	Four	Two	Two
%	----------------------------N lbs/A----------------------------			
0	0	0	0	0
25	5	7.5	6	3
50	10	15	13	5
100	20	30	25	10
150	30	45	38	15

***Applications started approximately 10 days after >90% emergence**

Table 5. Recommended petiole values at 60-, 90-, and 120-days after planting (DAP) for Alturas and Premier Russet.

Variety	End Tuber Initiation Mid June 60 DAP	Mid Bulking Early July 90 DAP	Late Bulking Late July 120 DAP
	(ppm NO3)	ppm (NO3)	(ppm NO3)
Alturas	23-26,000	17-20,000	<8,000
Premier	23-26,000	17-20,000	<10,000

Table 6. Recommended total soil N values (N03-N + NH4) at 60-, 90-, and 120-days after planting (DAP) for Alturas and Premier Russet in the top 12".

Variety	End Tuber Initiation Mid June 60 DAP	Mid Bulking Early July 90 DAP	Late Bulking Late July 120 DAP
	(lbs/A)	ppm (NO3)	(ppm NO3)
Alturas	90-150	50	<50
Premier	90-150	50	<50