Developmental Profiles, Nitrogen Use & Postharvest Quality of Alpine & Sage Russet Potatoes in the Columbia Basin

Rick Knowles, Mark Pavek, & Lisa Knowles
Potato Agronomy & Postharvest Physiology Program, Dept. of Horticulture
Washington State University, Pullman

Introduction

Alpine Russet and Sage Russet are relatively new cultivars from the Northwest Potato Variety Development Program. Alpine was released in 2008 (Whitworth et al., 2011) and Sage in 2010. Both cultivars have excellent potential for the frozen process industry.

Advanced agronomic and postharvest trials funded by the Washington State Potato Commission (WSPC) were completed in 2014 to model foliar growth, tuber growth and postharvest retention of process quality for each cultivar as affected by nitrogen (N) fertility. Results from this 3-year study can be used as a guide for growers to refine best management practices for maximum yield and postharvest quality in the Columbia Basin.

Past research funded by the WSPC demonstrated that healthy tubers harvested at physiological maturity (PM) retain process quality the longest in storage (Knowles et al., 2011). Physiological maturity coincides with maximum yield and tuber dry matter (specific gravity) and minimum concentrations of sucrose and reducing sugars in tubers. **Delaying harvest well beyond PM potentially exposes tubers to high temperatures during maturation under dead vines, which can compromise retention of process quality during storage, but the effects are cultivar-dependent.**

Nitrogen (N) rate significantly affects key indices of foliar and tuber development, source/sink (foliar/tuber growth) relationships and tuber PM. As N rate increases, foliar growth increases, crop development is prolonged and the attainment of tuber PM is delayed. **Nitrogen management can indirectly affect process quality during storage by influencing the timing of PM in relation to harvest.** Extending the maturation period of tubers under dead vines at season end often compromises postharvest quality and storability. In the Columbia Basin, most late-season cultivars reach PM before the vines have totally senesced.

The goals of this project were to define how nitrogen rate affects:

(1) crop development and productivity of Alpine and Sage Russet in the Columbia Basin

(2) relative N use efficiencies (cwt tubers produced per lb N per acre)

(3) tuber physiological maturity (PM) in relation to retention of postharvest quality

(4) precursors of acrylamide formation (reducing sugars and asparagine).

Both cultivars were grown with 190, 278, 365 and 453 lb N/A (average rates over the 3-yr period from 2011-13). These rates included approximately 182 lb N/A pre-plant incorporated plus residual. Planting dates for both cultivars averaged April 15. Plants and tubers were harvested at approximately 12-day intervals from about 59 to 178 days after planting (DAP) and detailed growth profiles were constructed for each cultivar. **This approach revealed how N rate affected overall growth and development, yield, N use efficiency and the attainment of tuber physiological maturity for each cultivar**.

Developmentally linked changes in tuber specific gravity, sucrose and reducing sugars (glucose and fructose) were modelled as components of physiological maturity. Various indices

of crop development were calculated for each cultivar at each level of N based on polynomial models describing foliar growth, tuber growth, and changes in sucrose, reducing sugars, and specific gravity of tubers over time (Figs. 2, 4 & 5). These indices included: DAP and yield at 50% harvest index (HI); HI at maximum foliar growth; DAP to maximum foliar growth, maximum specific gravity, minimum concentrations of sucrose and reducing sugars in tubers, and maximum tuber yield; percentage foliar senescence, and days and cumulative degree days (DD) to reach tuber physiological maturity (PM). Tuber samples were stored full season to assess retention of process quality in relation to N-induced differences in tuber maturity at harvest. Growth and storage characteristics of the two cultivars are summarized and compared in Figure 1 with reference to the relevant data in this report.

Growth & Storage Characteristics of Alpine & Sage Russet
(three-year summary 2011-13)

Characteristics	Sage	Alpine	Figure
Petiole NO_3 (6/15-7/30)	2.9-3.2 to 2.2-2.5 %	2.7-3.0 to 1.5-1.8 %	7
Harvest index (at max vine growth)	~58-62%	~49-53%	4, 5 & 8
Max foliar growth	Lower (16-18 T/A)	Higher (18-20 T/A)	2, 3A
Total biomass (vines + tubers)	Lower (55-57 T/A)	Higher (57-58 T/A)	2
Source/sink efficiency (38-T/A yld)	2.3 T tubers/T vines	2.0 T tubers/T vines	3C
N use efficiency (38-T/A yld)	2.38 cwt per lb N/A	1.92 cwt per lb N/A	3B
H_2O use efficiency	TBD	>RB (ID), TBD in WA	-
Vine senescence	Delayed with >N; earlier than Alpine	Delayed with >N; later than Sage	2
Physiological maturity (delayed with increasing N)	142-146 DAP; 2600-2700 DD (45°F base); 60% vines dead	150-154 DAP; 2750-2850 DD (45°F base); 65% vines dead	4, 5 & 8
Postharvest retention fry color	Better	Good	10
Low Temp Sweetening	More resistant	More susceptible	10
Delayed harvest (after PM)	Less sensitive –retains process quality longer in storage	More sensitive for earlier loss process quality in storage	10
Higher N	Increases tuber N, protein, amino acids & asparagine		11
Acrylamide forming potential	Lower	Higher	10 & 11
Approximate Dormancy	115 days @ 45°F (Ranger=85 days)	165 days @ 45°F (RB=155 days)	-

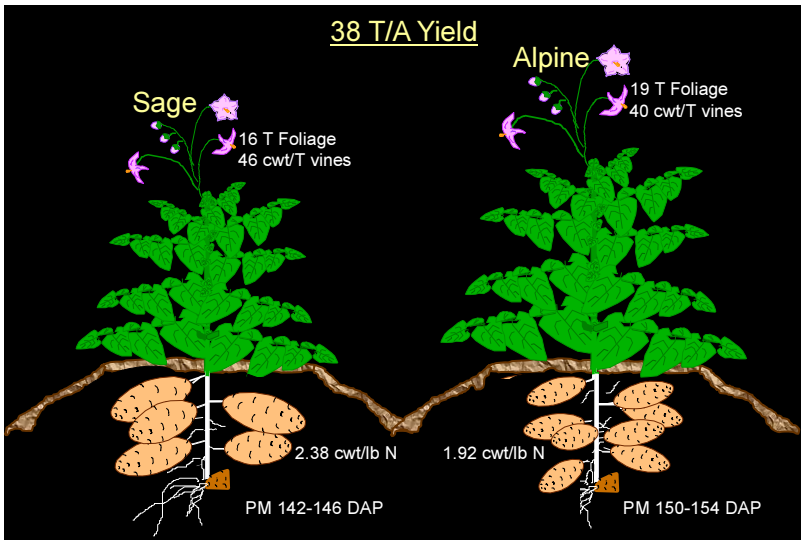

Fig. 1. Summary of growth, storage and processing characteristics of cultivars Alpine and Sage Russet grown in the central Columbia Basin. Harvest Index is defined as tuber fresh weight as percent of total plant (tubers + foliage) fresh weight at maximum foliar growth. The schematic diagram (bottom) compares the relative foliar and tuber growth, tuber number, tuber size and N use efficiency for a 38 T/A yield produced by each cultivar. PM, physiological maturity.

Detailed Results

Foliar & Tuber Growth

- **The partitioning of total plant biomass to foliar and tuber growth in response to increasing N rate depended on cultivar over the 3-year study period (Fig. 2).** At the lowest N rate (190 lb/A), Alpine produced 7% more vine growth than Sage (16.7 vs 15.6 T/A; Figs. 2 & 3) and this difference increased to 10% as N increased to 453 lb/A (Fig. 3). V**ine growth (maximum T/A) of Alpine was thus slightly more sensitive to increasing N than that of Sage over the three growing seasons.**
- Average tuber weights at 70 DAP were 14 g/tuber (0.5 oz/tuber) for Alpine and 28 g/tuber (1 oz/tuber) for Sage, suggesting earlier tuber set for Sage (Figs. 4 & 5). At 70 DAP, Alpine averaged 1.4 T/A more foliar growth to support early bulking than Sage (12.5 vs 11.1 T/A).
- The DAP to maximum foliar growth (T/A) increased from 94 to 106 for both cultivars with increasing N rate (Fig. 2). Harvest index (HI) is the percentage of total plant fresh weight accounted for by tubers. The HI at maximum foliar growth averaged 52% for Alpine, indicating relatively equal partitioning of fresh weight to vines and tubers at this point in the season (Fig. 2). **In contrast, tuber growth exceeded foliar growth at maximum foliar development for Sage. The HI for Sage averaged 60% at maximum foliar development (tubers accounted for 60% of total plant biomass).**
- The HI for both cultivars increased marginally with N, a consequence of the delay in attaining maximum foliar development with increasing N (Fig. 2). For most late season russet cultivars we have studied, the ideal HI at maximum vine growth should be 40-50%, either slightly favoring foliar growth or equal foliar and tuber growth, which is indicative of an optimum balance between source and sink (vine and tuber) for maximum yield at season end. Harvest indices greater than 50% have been correlated with lower yields of Ranger, Burbank, Alturas, GemStar, Premier, Defender, and several other cultivars in the Columbia Basin. **Sage is therefore somewhat unique in its ability to produce high total yields with less foliar growth (Fig. 3); a consequence of its more determinate growth habit.**
- **Nitrogen rate affected key indices of crop maturity in both cultivars.** For Alpine, increasing N from 190 to 453 lb/A delayed the attainment of 50% HI (where foliar and tuber growth curves intersect) and maximum foliar growth, increased foliar biomass, slightly increased the HI at maximum foliar growth, and increased final tuber yields (Figs. 2 & 3AB). For Sage, increasing N from 190 to 453 lb/A had no effect on DAP to 50% HI or yields at 50% HI, delayed the attainment of maximum foliar growth, increased foliar biomass, slightly increased the HI at maximum foliar growth, and increased final tuber yield. Averaged over the three growing seasons, tuber yields increased by 4.9 T/A in Alpine (from 33.7 to 38.6 T/A) and 6 T/A in Sage (from 33.4 to 39.4 T/A) with increasing N rate (Figs. 2 & 3B).
- **Vine persistence (foliar duration) increased with rate of in-season N**, as evident by higher foliar biomass 131 to 161 DAP (Fig. 2). The N-induced increases in yields (Figs. 2 & 3B) were therefore attributable to the increased foliar growth and delayed senescence of vines with increasing N.

- The source/sink efficiency of Sage was superior to Alpine. Sage produced comparable yields with less foliar growth than Alpine. To produce a 38 T/A yield, Sage required only 16.4 T maximum foliage versus 18.9 T for Alpine (Fig. 3C). This equates to 46 cwt of tubers produced per ton of vines for Sage (2.3 T tubers/T vines) versus 40 cwt of tubers per ton of vines for Alpine (2 T tubers/T vines) as summarized in Fig. 1.
- The N use efficiency of Sage was also superior to Alpine. For a 38 T/A yield, Sage produced 2.38 cwt per lb of N/A versus 1.92 cwt per lb of N/A for Alpine (Fig. 3B). The 24% higher N use efficiency of Sage was partly due to more efficient partitioning of fresh weight to tubers rather than vines (Fig. 3C).
- **N use efficiency (cwt tubers per lb N) was highest at 190 lb/A N (3.5 cwt/lb N) and decreased to 1.7 cwt/lb N when grown with 453 lb/A N for both cultivars (Fig. 6).** Moreover, both cultivars were most efficient in removing N from the field when grown with 190 and 278 lb/A N. At these low levels of N, virtually 100% of the N applied was accounted for in the tubers and removed from the field (Fig. 6). The efficiency of N removal decreased to 76% and 68% at 453 lb/A in Alpine and Sage tubers, respectively. These data underscore the efficiency with which N is translocated to tubers during vine senescence under late season management in a long growing season area.
- **The recommended petiole nitrate-N levels for maximum economic returns are higher for Sage than Alpine (Fig. 7);** likely a consequence of the more determinate foliar growth habit of Sage.

Tuber Physiological Maturity & Raw Product Quality

- Changes in sucrose, specific gravity and reducing sugar (glc & fru) concentrations were profiled during tuber development to define the attainment of physiological maturity (PM) for each cultivar as affected by N rate (Figs. 4 & 5).
- Specific gravities increased to a maximum and then decreased marginally from PM to harvest (Figs. 4 & 5). Specific gravities decreased with increasing N.
- Reducing sugars in the stem ends of tubers typically increase toward season end, particularly during maturation under dead vines. **On average, the concentrations of reducing sugars in the stem ends of Alpine and Sage were higher at 178 DAP when grown with lower levels of N, indicating physiologically older tubers at harvest (Figs. 4 & 5).**
- Physiological maturity (PM) was calculated as the average DAP to reach maximum yield, maximum specific gravity, minimum sucrose, and minimum reducing sugars in the stem ends of tubers (Figs. 4 & 5). Sage tubers reached PM earlier than Alpine and PM was delayed in both cultivars with increasing level of N (Fig. 8). **Therefore, tubers grown with higher N rates were physiologically younger at harvest (178 DAP) than tubers from the 190 lb/A N regime where the vines had senesced earlier and PM was achieved earlier in the season (Figs 4 & 5).**

Retention of Process Quality

Tubers appear to be particularly sensitive to heat-induced accelerated aging during the maturation period under dead vines at season end. The maturation period extends from physiological maturity (PM) to harvest. For best quality and longest storage life, tubers should

be harvested within 7-10 days of PM. For most late season russet cultivars in the Columbia Basin, PM will be reached approximately 145 to 155 DAP when grown with optimum fertility and water. Delaying harvest beyond PM exposes tubers to prolonged periods of daily fluctuation in soil temperature (e.g. Fig. 9). We believe this exposure accelerates physiological aging even more so than if tubers were to remain at a constant average temperature in storage over the same period. The longer the maturation period at fluctuating temperatures the more advanced the physiological age of tubers at harvest. The notable upswing in reducing sugar concentrations, particularly in the stem end of tubers, following PM is indicative of this accelerated aging response (Figs. 4 & 5).

The maturation period (from PM to harvest at 178 DAP) was longer for tubers grown with low N than high N and therefore the low-N tubers were exposed to a longer period of fluctuating temperatures and were physiologically older than tubers from the high N crop. The higher concentrations of reducing sugars in the stem and bud ends of low-N tubers were insufficient to affect fry color at harvest which was excellent for both cultivars (Fig. 10). However, fry color deteriorated noticeably by ~230 days after harvest for both cultivars when stored at 48 and 44^{o}F. **Tubers grown with higher N rates retained lighter fry color, especially when stored at 44^{o}F.** For Alpine tubers grown with the lowest rates of N, the average interval between PM and harvest was 34 days. At the highest level of N, this interval decreased to 23 days. For Sage Russet grown with the lowest levels of N, the average interval between tuber PM and harvest was 41 days. At the highest level of N, this interval shortened to 29 days. **Better retention of process quality for tubers grown at higher N rates was likely a consequence of delayed PM, which resulted in physiologically younger tubers at the 178 DAP harvest.**

The effects of N on retention of process quality for Sage and Alpine are consistent with results of similar studies with other cultivars (e.g. Alturas, Premier and Ranger) and indicate that the time between PM and harvest should be minimized for longest retention of process quality during storage. **Planting and harvest dates should be coordinated to limit over-maturation of tubers under dead vines. Tubers should be harvested within 7 to 10 days of achieving PM. PM can be estimated by a combination of DAP, the degree of vine senescence, and the accumulated degree days from planting (45^{o}F base) for these cultivars (see Fig. 1).** Over maturation of tubers in warm soil under dead vines at season end can contribute to premature loss of process quality during storage. The potential for sugar ends and bruise also increase when harvest is significantly delayed beyond PM.

Funding from the NIFA-SCRI acrylamide project was used to determine the effects of N rate on tuber N, protein and amino acid concentrations. **Tuber total N and soluble protein N concentrations (not shown) increased with N rate, thus enhancing the nutritional value of tubers.** Alpine was the most responsive; total N increased 49% (versus 33% in Sage) as N rate increased from 190 to 453 lb/A. Similar results were documented for Alturas and Premier Russet (Knowles, et al., 2011).

Total amino acid concentration and the concentration of asparagine increased in tubers of both cultivars during development and with N rate (Fig. 11). Asparagine accounted for ~37-40% of total amino acids in both cultivars at 159 DAP and this percentage remained relatively constant with increasing N. **Asparagine (asn) reacts with reducing sugars during processing to form acrylamide (Fig. 11).** At 159 DAP, Alpine and Sage tubers grown with the highest level of N had 29 and 19% higher concentrations of asn than at the lowest level of N (Fig. 11).

Previous work with Alturas and Premier Russet demonstrated that tubers grown with the highest level of N had 62% more asn than tubers grown with the lowest level. **Nitrogen nutrition therefore affects the acrylamide forming potential of processed tubers by affecting the concentrations of acrylamide precursors (asn, glc, fru). and ability to retain process quality of raw product following harvest (see below).** These effects should be considered in managing N fertility in relation to PM and harvest at season end.

Literature Cited and other Relevant Publications

Blauer, J.M., Knowles, L.O. and N.R. Knowles. 2013. Evidence that tuber respiration is the pacemaker of physiological aging in seed potatoes (*Solanum tuberosum* L.). J Plant Growth Regul 32:708-720. (DOI 10.1007/s00344-013-9338-4).

Driskill, E.P. Jr., L.O. Knowles, and N.R. Knowles. 2007. Temperature-induced changes in potato processing quality during storage are modulated by tuber maturity. **Am. J. Pot. Res.** 84:367-383.

Hiles, C., M.J. Pavek, and Z. Holden. 2010. Defining In-Season Nitrogen management needs for Alturas and Premier Russet. Proceedings of the Washington and Oregon Potato Conference 2010. pp. 27-44.

Hiles, C.D., M.J.Pavek, N.R. Knowles and Z. Holden. 2010. Defining in-season nitrogen needs to maximize profits from Alturas and Premier Russet. Proceedings of the 94th Annual Meeting of the Potato Association of America. Am. J. Pot. Res. 88:43-44.

Knowles, N.R., L.O. Knowles, G.N.M. Kumar, M.J. Pavek. 2013. Developmental profiles and physiological processes affecting quality of seed and processing potatoes. Washington State Potato Commission Progress Reports for the year 2012 pp. 141-164.

Knowles, N.R., L.O. Knowles, G.N.M. Kumar and M.J. Pavek. 2012. Developmental profiles and physiological processes affecting quality of seed and processing potatoes. In: Washington State Potato Commission Progress Reports for the year 2011 pp. 138-164.

Knowles, N.R., L.O. Knowles, G.N.M. Kumar, M.J. Pavek. 2011. Factors affecting seed productivity and post harvest quality of new cultivars. Washington State Potato Commission Progress Reports for the year 2010 pp. 183-210.

Knowles, N.R., E.P. Driskill. Jr., and L.O. Knowles. 2009. Sweetening responses of potato tubers of different maturity to conventional and non-conventional storage temperature regimes. **Postharvest Biol Tech.** 52:49-61.

Knowles, N.R., M.J. Pavek, L.O. Knowles, and Z. Holden. 2008. Developmental profiles and postharvest behavior of long-season processing cultivars. Proceedings of the 47th Annual Washington State Potato Conference, Feb. 5-7, Moses Lake, WA, pp. 45-65.

Knowles, N.R., E.P. Driskill Jr., L.O. Knowles, M.J. Pavek, and M.E. Martin. 2006. Physiological maturity of Ranger Russet tubers affects storability and processing quality. **Potato Progress** 6(3):1-4.

Knowles LO, NR Knowles and ME Martin. 2001. Postharvest behavior of vine-desiccated versus green-harvested Ranger Russet tubers. Potato Progress 7(1):1-3.

Novy, R.G., J.L. Whitworth, J.C. Stark, S.L. Love, D.L. Corsini, J.J. Pavek, M.I. Vales, S.R. James, D.C. Hane, C.C. Shock, B.A. Charlton, C.R. Brown, N.R. Knowles, M.J. Pavek, T.L. Brandt, and N. Olsen. 2008. Premier Russet: A dual-purpose potato cultivar with significant resistance to low temperature sweetening during long-term storage. Am. J. Pot. Res. 85(3): 198-209.

Zommick D.H., Kumar, G.N.M., Knowles, L.O. and N.R. Knowles. 2013. Translucent tissue defect in potato (*Solanum tuberosum* L.) tubers is associated with oxidative stress accompanying an accelerated aging phenotype. Planta 238:1125-1145.

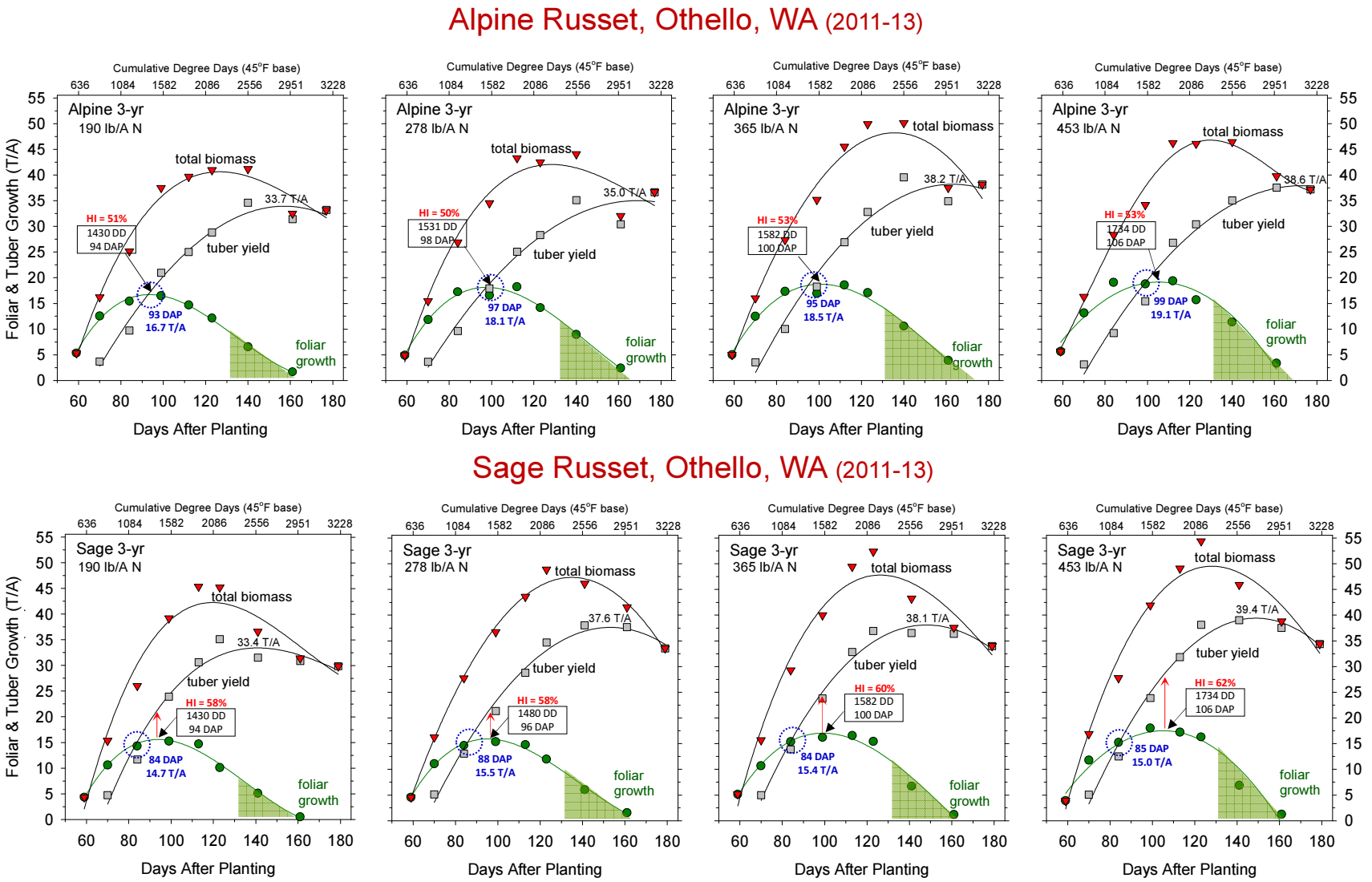

Fig. 2. Foliar and tuber growth of **Alpine Russet** (top row) and **Sage Russet** (bottom row) in response to four levels of nitrogen (N) at Othello, WA (3-yr average, 2011-13). Planting date averaged April 15 for both cultivars. Cumulative degree days (DD) are shown on the top axis of each graph. DAP, DD, and harvest indices (HI) at maximum foliar growth are indicated for each cultivar and N level. Harvest index equals tuber fresh weight as percent total plant (tubers + vines) fresh weight at maximum foliar growth. The DAP to 50% HI are indicated in blue (where foliar and tuber growth curves cross). The green shaded area shows the relative effects of N on the amount of foliar growth remaining from 131 days to season end. The N-induced increases in tuber yield were partly due to more foliar growth late in the season.

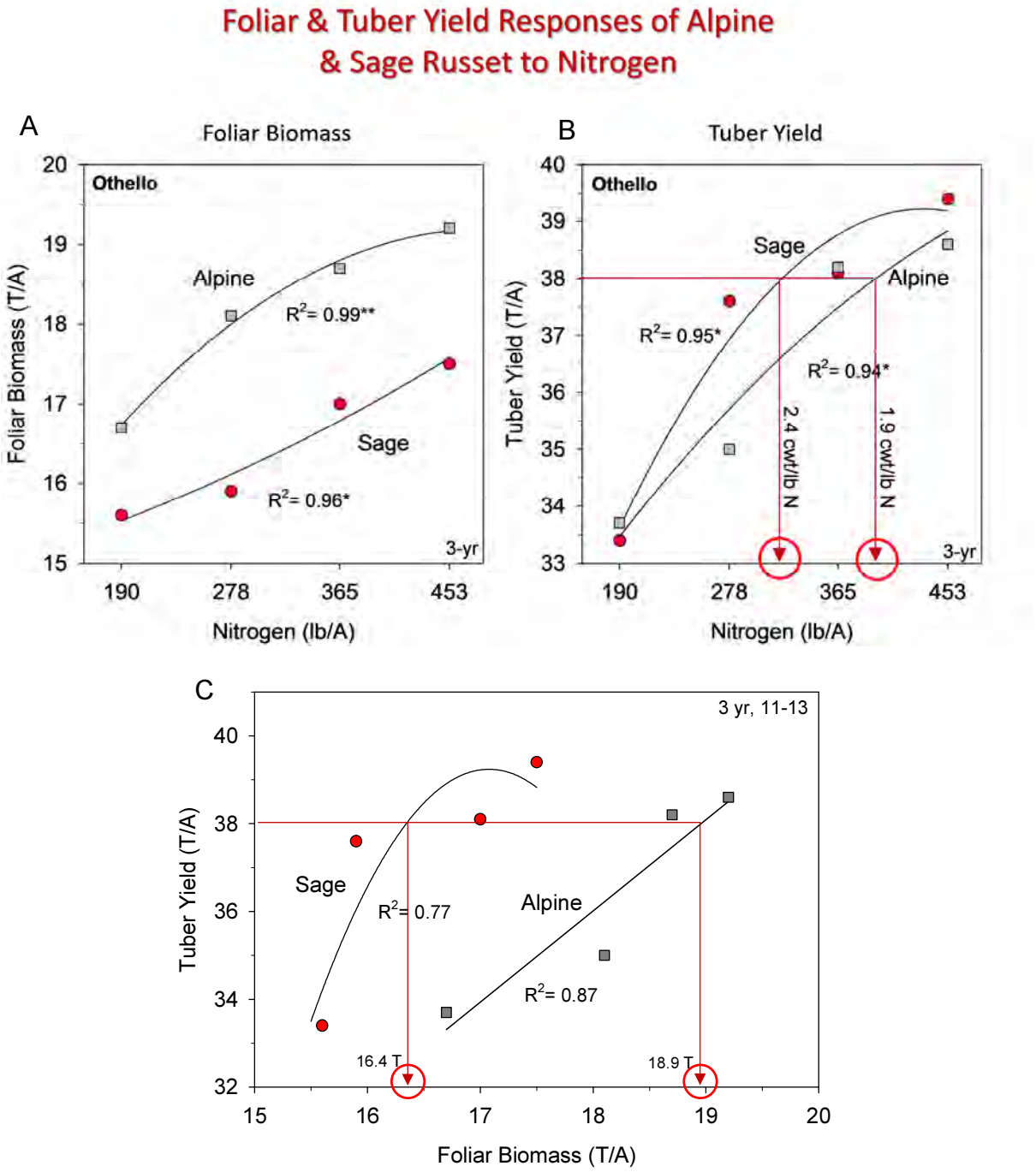

Fig. 3. Average maximum foliar biomass production **(A)** and tuber yields **(B)** of Alpine and Sage Russet as affected by N rate at Othello, WA. Nitrogen levels included 182 lb/A residual plus pre-plant incorporated N averaged over the 3-yr period; the balance was applied in-season. Planting date averaged April 15 and vines were mowed 160 DAP. Maximum foliar biomass and tuber yields at each N level were derived from regressions of yield and vine weight over time (see Fig. 2). Alpine produced more foliar biomass and equal or marginally lower yield than Sage at all N levels. **(C)** Changes in tuber yield with increasing foliar biomass. Alpine and Sage needed 18.9 and 16.4 T of foliage, respectively, to produce a 38 T/A yield. Sage was thus more 'source-efficient', producing the same yield with less foliage than Alpine. The N use efficiencies (B) for a 38 T/A yield were 2.4 and 1.9 cwt per lb of N for Sage and Alpine, respectively.

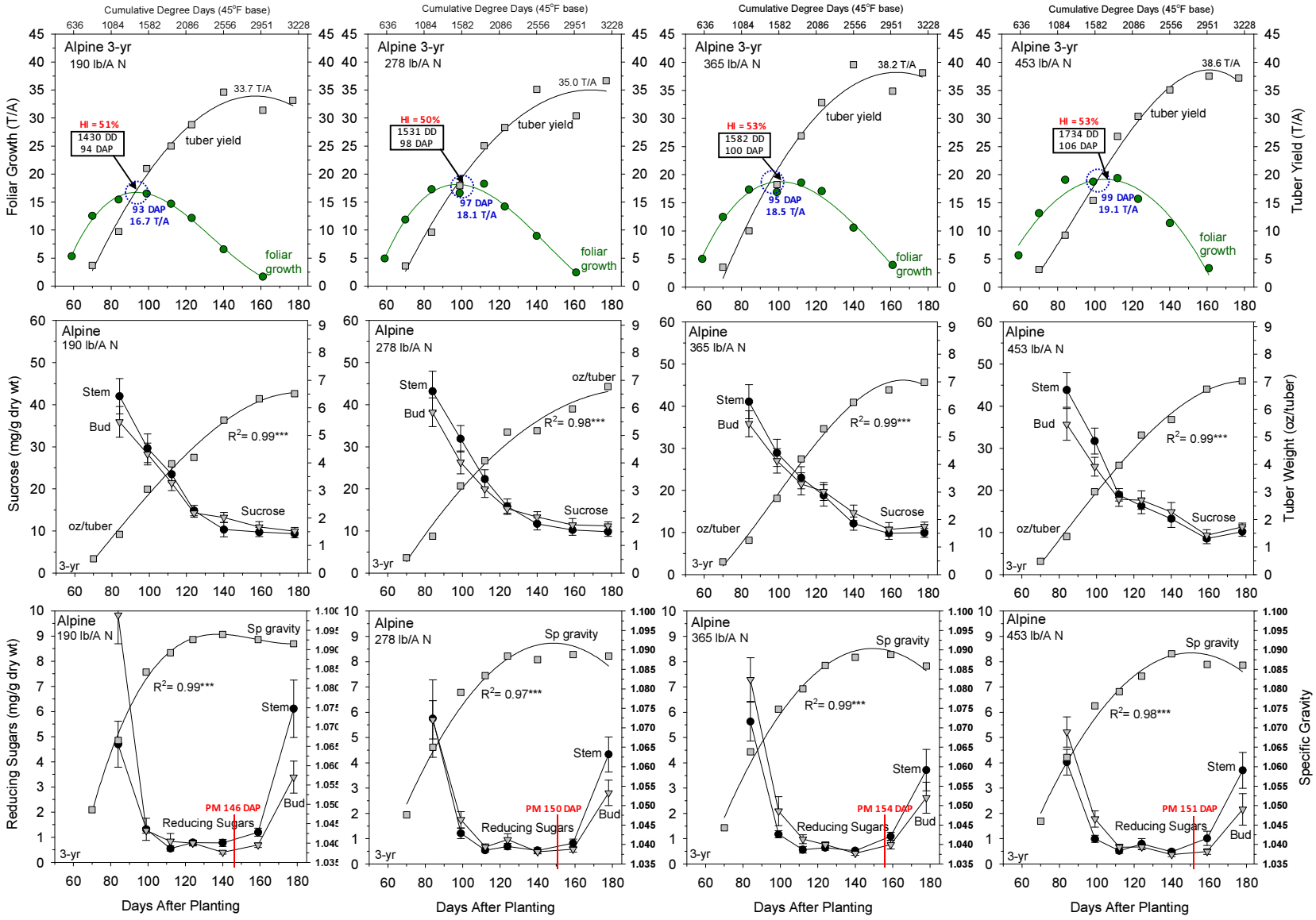

Fig. 4. (top row) Foliar and tuber growth responses of **Alpine Russet** to four levels of in-season nitrogen (N) at Othello, WA (2011-13). Cumulative degree days (DD) at the corresponding days after planting (DAP) are shown (top row). DAP, DD, and harvest indices (HI) at maximum foliar growth are indicated (top row). Harvest index equals tuber fresh weight as percent of total plant (tubers + foliage) fresh weight at maximum foliar growth. The DAP to 50% HI (where foliar and tuber growth curves cross) are also indicated. Note that foliar and tuber yields are equal (circled in blue) at 50% HI. Changes in tuber sucrose concentrations, average tuber weights (middle row), reducing sugars (glucose and fructose) and specific gravity (bottom row) were profiled as components of physiological maturity (PM). PM was estimated at 146, 150, 154, and 151 DAP as N rate increased from 190 to 453 lb/A (bottom row). Trends in PM with N are compared for Alpine and Sage in Fig. 8.

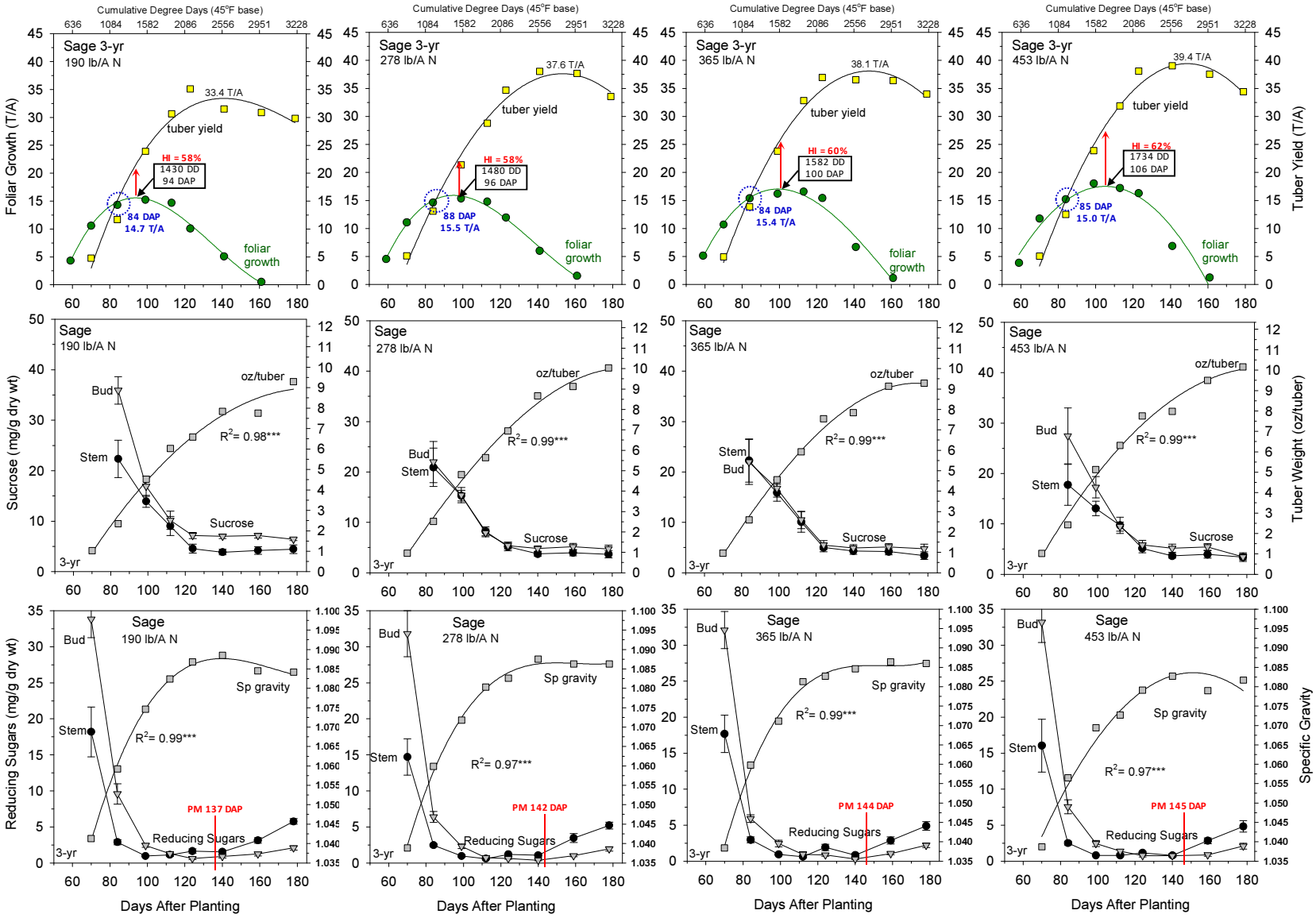

Fig. 5. (top row) Foliar and tuber growth responses of **Sage Russet** to four levels of in-season nitrogen (N) at Othello, WA (2011-13). Cumulative degree days (DD) at the corresponding days after planting (DAP) along with DAP, DD, and harvest indices (HI) at maximum foliar growth are indicated (top row). Harvest index equals tuber fresh weight as percent of total plant (tubers + foliage) fresh weight at maximum foliar growth. The DAP to 50% HI (where foliar and tuber growth curves cross) are also indicated. Foliar and tuber yields are equal at 50% HI (circled in blue). Changes in tuber sucrose concentrations, average tuber weights (middle row), reducing sugars (glucose and fructose) and specific gravity (bottom row) were profiled as components of physiological maturity (PM). PM was estimated at 137, 142, 144, and 145 DAP as N rate increased from 190 to 453 lb/A (bottom row). Trends in PM with N are compared for Alpine and Sage in Fig. 8.

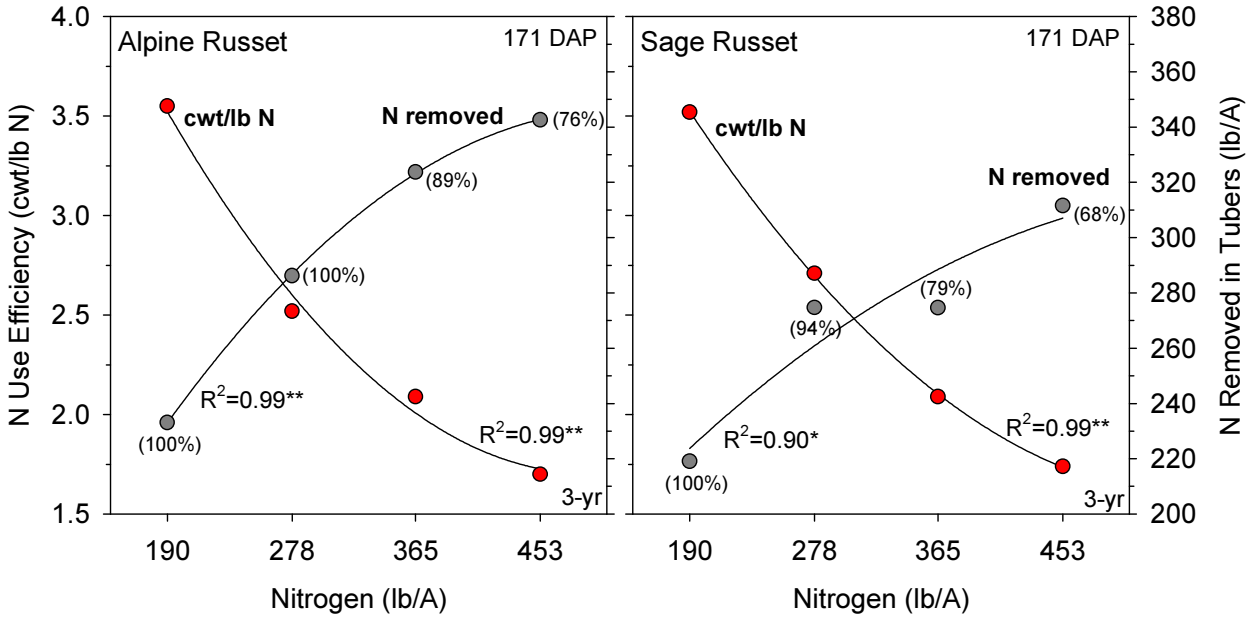

Fig. 6. Effects of nitrogen (N) rate on N use efficiencies of Alpine Russet (left) and Sage Russet (right) at Othello WA (3-yr average 2011-13). Nitrogen use efficiency is expressed as tuber yield (cwt) per lb N. Estimates of the total amount of N removed in tubers are also provided in lb/A and as percent seasonal N applied.

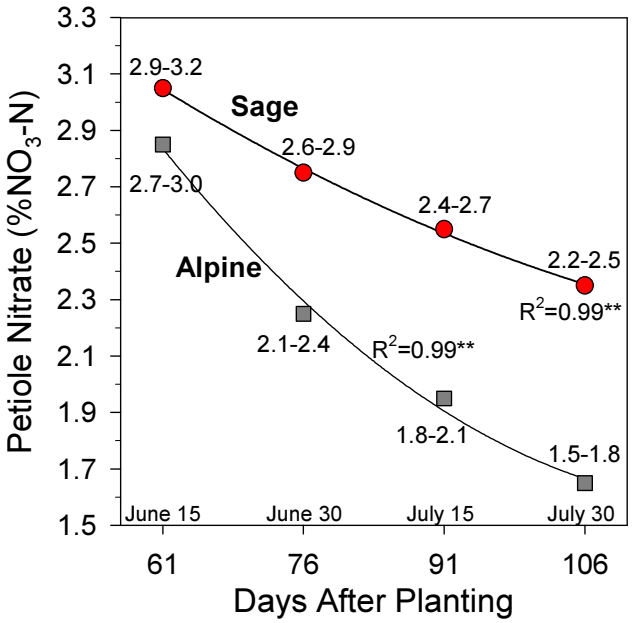

Fig. 7. Petiole nitrate ranges that optimized economic returns for Alpine Russet and Sage Russet grown in the Columbia Basin of Washington. The optimum ranges are indicated on each point. Planting date averaged April 15 over the 3-yr study period.

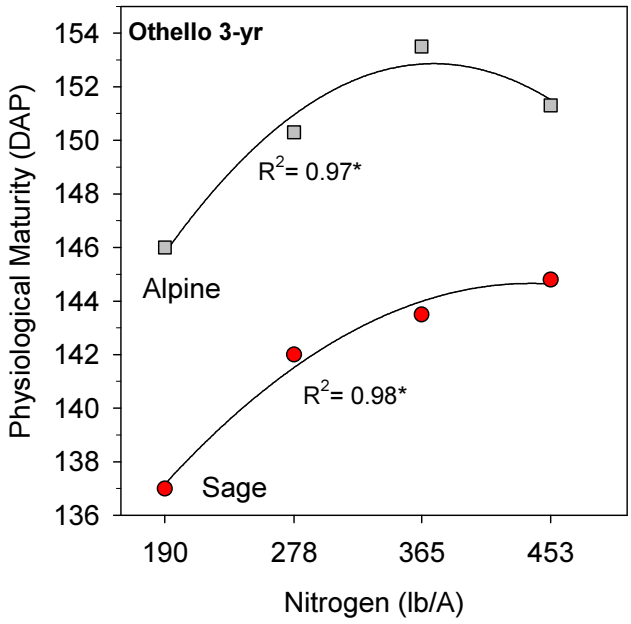

Fig. 8. Three year average (2011-13) effects of N rate on days after planting to physiological maturity (PM) for Alpine and Sage Russet tubers. Planting date averaged April 15. PM is the average of DAP to reach max yield, max specific gravity, minimum sucrose, and minimum reducing sugars in tubers (see Figs. 4 & 5). Sage reached PM earlier than Alpine. Tubers should be harvested soon after PM for best quality retention during storage.

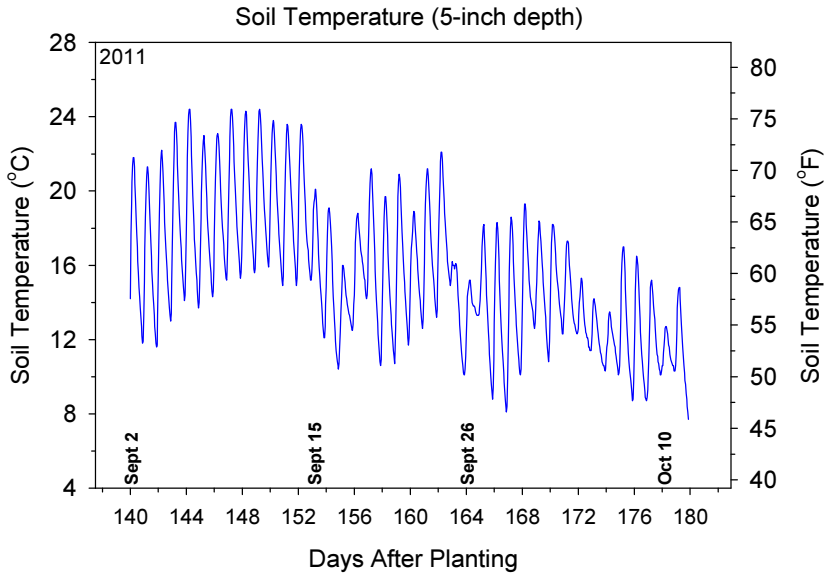

Fig. 9. Diurnal fluctuation in soil temperature (5-inch depth) during the period of maturation of tubers under dead vines at season end. Prolonged exposure to fluctuating temperatures accelerates physiological aging of tubers which can compromise retention of process quality during full season storage. For maximum retention of process quality tubers should be harvested within 7 to 10 days of PM. N management can affect the timing of PM in relation to harvest and thus retention of process quality (see Fig. 10).

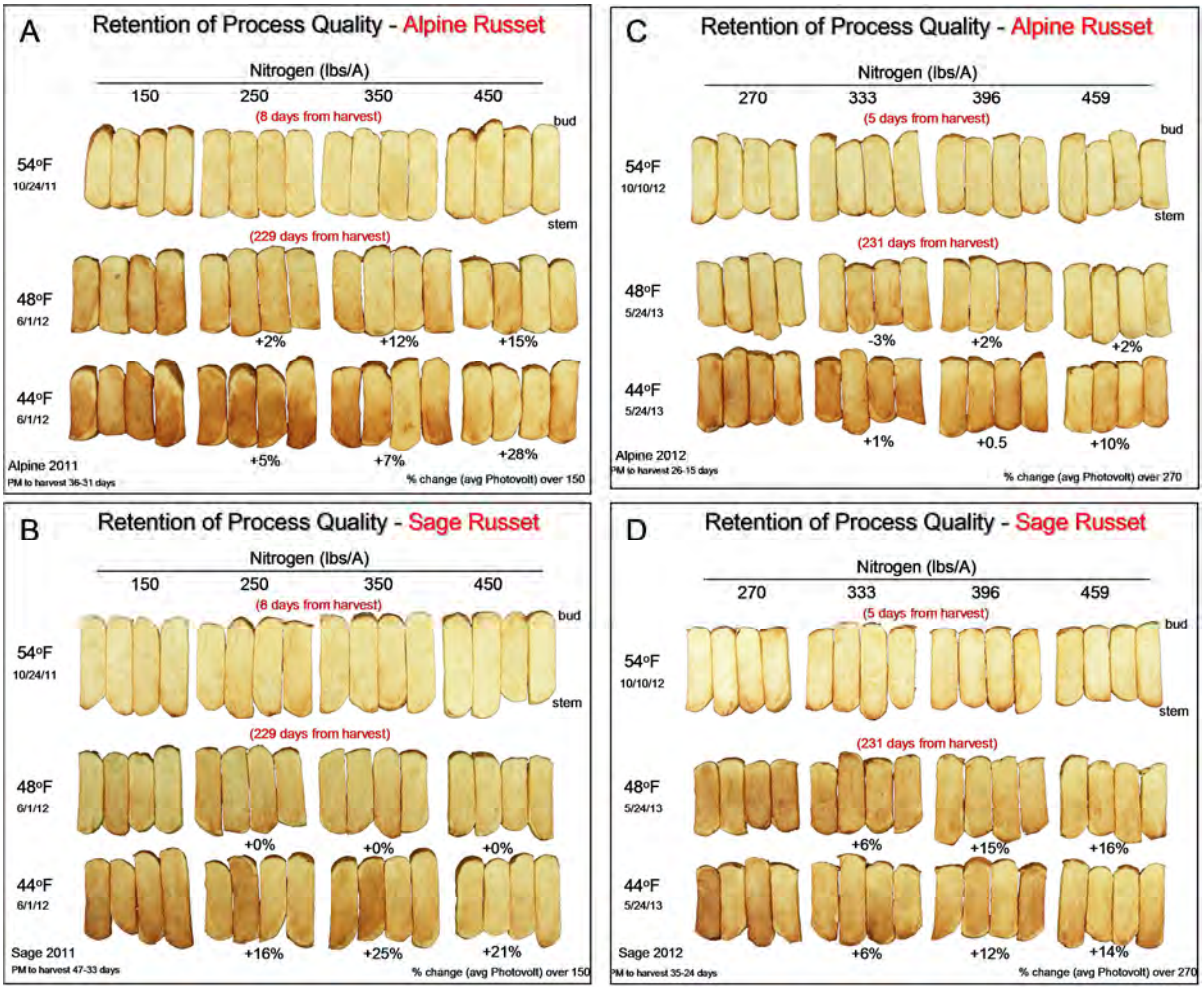

Fig. 10. Effects of nitrogen and storage temperature on retention of process quality of **Alpine** (A, C) **and Sage Russet** (B, D) tubers following wound healing at 54°F and storage at 48 and 44°F in 2011 (A, B) and 2012 (C, D) (avg 230 days storage). Photovolt readings of fry color averaged 50 after wound healing, indicating very light and uniform USDA 0 fry color regardless of N rate. Process quality deteriorated noticeably by ~230 days after harvest for both cultivars at both storage temperatures. Tubers grown with higher N rates retained lighter fry color, especially when stored at 44°F. The percent values indicate the degree to which tubers fried lighter than those grown with the lowest levels of N in both years. For Alpine Russet grown with the lowest level of N, the average (2011 & 12) interval between tuber PM and harvest was 34 days. At the highest level of N, this interval shortened to 23 days. For Sage Russet grown with the lowest levels of N, the average interval between tuber PM and harvest was 41 days. At the highest level of N, this interval shortened to 29 days. Each fry plank is from a different tuber selected to represent the average fry color in a 12-tuber sample.

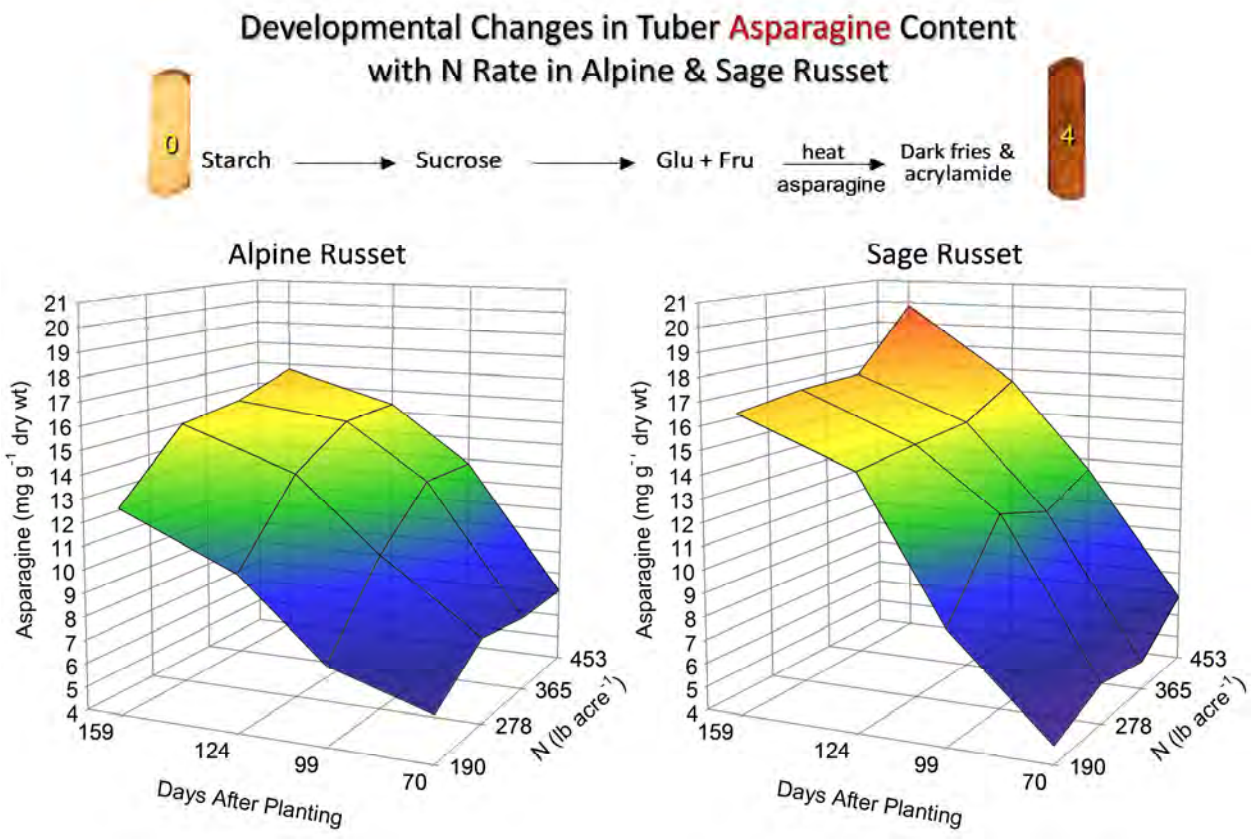

Fig. 11. Changes in asparagine concentrations of Alpine and Sage Russet tubers during development under varying levels of nitrogen fertility. Asparagine concentration increased with tuber development at each level of N and with increasing N at each developmental stage (DAP). Data are the average of 3 years of field research at Othello, WA.