Tuber Maturity & Postharvest Behavior

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Background and Objectives

The Pacific Northwest Potato Variety Development Program has recently released new cultivars with excellent potential for the processing industry. Within the tri-state region, differences in climate, soils and management practices can have a tremendous impact on the attainment of physiological maturity (PM) and storability of processing potatoes. Physiological maturity coincides with maximum dry matter (specific gravity) and minimum sucrose and reducing sugars in tubers. Tubers have the longest storage life for processing if harvested at PM. Developing best management practices that culminate in tubers of ideal maturity depends on knowing when critical stages of crop growth and development occur for a particular cultivar and how management affects the attainment of PM in a particular production area.

A main focus of our research is to understand and demonstrate how in-season management affects the attainment of PM and retention of processing quality during storage for newly released cultivars. We firmly believe that production of a high quality crop with maximum ability to retain postharvest quality requires a holistic approach that combines in-depth knowledge of how the crop grew (stresses and responses to in-season management), matured, and was handled at season end, with determining how best to manage it in storage. Our studies indicate that optimizing source/sink (foliar/tuber growth) relationships during the bulking phase of tuber development is important to achieving maximum yield. Moreover, extending the maturation period under dead vines at season end compromises postharvest quality and storability. In the Columbia Basin, most cultivars reach PM before vines have totally senesced.

The objectives of this work were three-fold:

(1) Define and understand how Alturas and Premier Russet tubers attain PM under Columbia Basin growing conditions.

(2) Determine how in-season N management affects the attainment of tuber maturity and influences subsequent retention of postharvest quality.

(3) Using Ranger Russet, demonstrate the effects of crop maturity on the ability to retain processing quality.

These objectives required that we model crop growth in detail to define key indices of crop development and to relate their importance to final yield and quality. Nitrogen (N) management was used to effectively produce tubers that differed in PM for subsequent studies on retention of postharvest quality. Source/sink relationships were expressed as harvest index (HI), which was compared at maximum foliar growth (see below). Note that HI measures tuber yield as a percentage of total plant biomass.

$$HI = \left(\frac{\text{Tuber Fresh Wt}}{\text{Foliar + Tuber Fresh Wt}} \right) x\ 100$$

Key indices of crop development included:

- Harvest index (HI) at maximum foliar growth
- Days after planting (DAP) to 50% HI & yield at 50% HI (foliar biomass = tuber biomass at 50% HI)
- DAP to:
  - max. foliar fresh wt
  - max. tuber yield
  - max. sp gravity
  - min sucrose
  - min reducing sugars
- Max. foliar biomass (T/A)
- Max. tuber yield (T/A)
- Specific gravity at harvest

Tuber physiological maturity was estimated as the average of DAP to achieve these indices.

Results – Alturas & Premier Russet

- Alturas and Premier Russet were grown with four levels of in-season N (0, 50, 100, and 150% of recommended rate). Replicated plots were planted at the Othello Research Station on April 5, 17, and 23 in 2007, 2008 and 2009, respectively. Plants and tubers were harvested at approximately 10-day intervals from about 63- to 180-days-after-planting (DAP) and detailed growth profiles were constructed for each cultivar (Figs. 1 & 2). **This approach revealed how in-season N management affected growth and development and the attainment of physiological maturity during each season**.
- Various indices of foliar and tuber growth (see above) were calculated for each cultivar based on polynomial models describing foliar and tuber growth and changes in sucrose, reducing sugars, and specific gravity of tubers over time for each year (Figs. 1 & 2). 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, maximum tuber yield; and days to reach physiological maturity of tubers. **The 3-year average effects of N rate on these indices of foliar and tuber development are summarized in Tables 1 and 2 for Alturas and 3 and 4 for Premier.**

Foliar & Tuber Growth

- During all three seasons and at all N levels, Alturas produced significantly more foliar growth (24%, 4.2 tons on average) than Premier (Tables 2 & 4). The 2009 season was significantly warmer than 2007 and 2008. The greatest difference in foliar growth occurred in 2009 (Alturas produced 35% more foliar growth than Premier), reflecting the increased sensitivity of Alturas vine growth to higher degree day accumulation (450 more degree days accumulated in 2009 than in 2007 and 2008).
- **The rate of in-season N significantly and substantially affected key indices of crop maturity.** On average, increasing N from 0 to 150% of the recommended in-season rate, delayed the attainment, in terms of DAP, of 50% HI (where foliar and tuber growth curves cross), increased foliar and tuber biomass (T/A) at 50% HI, shifted the attainment of maximum foliar growth later, increased the maximum amount (T/A) of foliar biomass,

reduced the HI at maximum foliar growth, and increased final tuber yield (Figs. 1 & 2; Tables 1-4).

- Vine persistence (foliar duration) increased with rate of in-season N, as evident by higher foliar biomass 140 to 160 DAP (Figs. 1 & 2). This effect of N was greater for Alturas than for Premier.
- **In general, vine growth (maximum T/A) was much more sensitive to increasing rate of in-season N than tuber yield (Tables 2 & 4).** For both cultivars, tuber yield increased linearly by approximately 0.7 T/A per ton increase in foliar biomass at maximum vine growth ($P<0.001$) (Fig. 3). Hence, the old adage that increasing N stimulates vine growth only without affecting yield is not true for these cultivars. More N resulted in more source (foliage) that in turn resulted in more sink (tubers) and thus enhanced yield. These results suggest that managing N to maximize foliar growth is best because of the enhanced yield. However, we believe this approach is short-sighted because it doesn't consider the economics of production (see report by Hiles and Pavek in this proceedings) and issues related to tuber maturity, postharvest use, and ability to retain processing quality.
- At maximum foliar development (~95-120 DAP), the balance between tuber and foliar growth also affected final yield potential. This balance is indicated by the HI, which expresses tuber weight as a percentage of total plant weight (foliar plus tuber weight). For Alturas, maximum tuber yields were obtained when tubers accounted for 38 to 42% of total plant fresh weight at maximum foliar growth (Fig. 3). **A source/sink imbalance occurred when tuber growth dominated plant growth (e.g. HI = 62%) at maximum foliar development, resulting in significantly lower final yield.** Similar results were evident for Premier where maximum yields were obtained when tubers accounted for 43 to 49% of total plant fresh weight at maximum foliar growth (Fig. 3). As HI increased beyond 49%, final yields of Premier Russet declined. Therefore, management should favor foliar development during the first half of the season to assure adequate source/sink balance to support maximum yield potential.

<u>Tuber Physiological Maturity & Raw Product Quality</u>

- Changes in sucrose, glucose, and fructose (reducing sugars) concentrations, along with specific gravity were profiled during tuber development to define the attainment of physiological maturity for each cultivar as affected by in-season N rate. Reducing sugars in the stem ends of tubers typically increase toward season end, particularly during maturation under dead vines. **On average, the concentration of reducing sugars in the stem ends of Alturas and Premier tubers at harvest was higher when grown with lower levels of in-season N, indicating physiologically older tubers (Figs. 1 & 2).**
- Physiological maturity (PM) was calculated as the average DAP to reach maximum yield, maximum specific gravity, minimum sucrose, and beginning of end-of-season increase in reducing sugars in the stem ends of tubers (Figs. 1 & 2, Tables 1 & 3). PM ranged from 141 to 158 DAP and occurred later in the season with increasing level of N. This effect is clearly reflected in the DAP to PM data averaged over the 3-year study period (Tables 1 & 3). **Therefore, tubers from 100 and 150% in-season N regimes were less mature (physiologically younger) at harvest than tubers from 0 and 50% N regimes where the vines had senesced earlier in the season.**

- On average, days after planting to maximum specific gravity increased with N level and maximum specific gravity decreased with increasing N level, reflecting delayed maturity (Tables 1-4). Specific gravity at harvest was less than the maximum achieved during the growing seasons (Tables 2 & 4). **It is clear that N management can be tailored to influence gravity for the processing industry; lower N will produce higher gravity potatoes for dehy, higher N will prevent gravities from becoming too high for frozen processing.** These effects on dry matter need to be considered in the overall economic analysis of N management.
- **Total N and protein concentrations of tubers increased with in-season N rate, thus enhancing the nutritional value of tubers (data not shown).** Premier was the most responsive; total N increased 76% and protein N increased 48% as in-season N rate increased from 0 to 150% of recommended rate in 2007. In contrast, total- and protein-N of Alturas tubers increased 48% and 30%, respectively, over the two extremes of in-season N. In 2009, the increase in N content of Premier tubers averaged 23% from the lowest to the highest rate of in-season N.
- **The concentrations of twenty two free amino acids also increased in tubers with in-season N rate (data not shown).** On average, tubers grown with high N (150% in-season) contained 50 and 55% higher concentrations of free amino acids in the bud and stem ends of tubers, respectively, than tubers grown with low N (0% in-season). **The amino acid profiles were dominated by asparagine (Asn), which reacts with reducing sugars during processing to form acrylamide. Asparagine was 62% higher in tubers grown with high N compared with those grown with low N.** Nitrogen nutrition may, therefore, affect the acrylamide forming potential of tubers**.** This possibility warrants further investigation and should also be considered in determining optimum levels of in-season N for processing potatoes.

<u>Retention of Processing Quality</u>

- Alturas and Premier tubers (8- to 12-oz) from 0, 50%, and 150% in-season N plots were harvested 186-, 172- and 167- DAP in 2007, 2008 and 2009, respectively, cured at 54^{o}F, and stored at 40, 44, and 48^{o}F (95% RH) for 228 days. Changes in fry color during storage were cultivar-dependent, reflecting the different sensitivities of each genotype to low temperature sweetening (LTS) and the associated loss of processing quality. **On average, Alturas produced darker fries than Premier, regardless of storage temperature.**
- The effects of in-season N on out-of-storage fry color were subtle and depended on storage temperature, cultivar, and season. In 2007/08, Alturas sweetened rapidly during the initial 32 days at 40^{o}F and N-induced differences in PM had no effect on this response (data not shown). By April 16 (191 days) however, tubers grown with 150% in-season N produced fries that were 15% and 25% lighter (=USDA 2) than tubers produced with 0% in-season N (=USDA 3). When stored at 44^{o}F to mid April, tubers grown with all levels of in-season N produced acceptable fry color (USDA 1 or better); however, the physiologically younger tubers grown with 150% in-season N produced lighter fries (USDA 0) than the physiologically older tubers grown with 0% in-season N (USDA 1). At 48^{o}F, tubers grown with high N processed lighter than those grown with lower in-season N through mid February. **These results were a consequence of higher levels of in-season N delaying the attainment of PM, which resulted in physiologically**

younger tubers at harvest, and underscore the importance of PM to storability for processing.

- N-induced differences in PM also affected the uniformity of fry color from bud to stem end. For Alturas, the delay in attainment of PM by high N (150%) produced physiologically younger tubers at harvest, as evident by a lower concentration of reducing sugars in the stem ends of tubers and a smaller difference between bud and stem end reducing sugar concentrations as compared with tubers grown under low N (Fig. 4). This translated into a longer storage life for processing in 2007/08. The physiologically younger tubers harvested from the high N plots retained uniform fry color (<9 reflectance units difference between stem and bud ends) through 228 days of storage at 44°F (Fig. 4). In contrast, tubers from low N plots were physiologically older at harvest, had a higher concentration of reducing sugars in the stem end, and developed unacceptable non-uniform fry color (stem to bud fry color difference ≥9 reflectance units) sooner in storage (by 131 days after harvest). **Hence, N management affected the timing of attainment of tuber physiological maturity (Tables 1 & 3), which in turn affected the retention of processing quality of Alturas tubers during storage in 2007/08 (Fig. 4).**
- In 2008/09, the processing quality of Alturas tubers was acceptable throughout the 227-day storage period at 48 and 44°F regardless of N level; however, fry color was affected by in-season N nutrition late in the storage season (Fig. 5). Tubers grown with 150% in-season N fried 16% lighter than those grown with 0% and 50% N following 227 days of storage (mid May). The difference in color from bud to stem end was also significantly less (46%) for tubers grown with 50 to 150% in-season N compared with those grown with 0% in-season N after 227 days of storage. The time between attainment of PM and harvest for tubers grown with 0, 50 and 150% in-season N was 27, 23, and 19 days, respectively. **Hence, the physiologically younger tubers grown with high N were harvested closer to PM and processed significantly lighter and more uniform color than the physiologically older tubers grown with low N.**
- Effects of in-season N on the out-of-storage processing quality of Premier Russet in 2007/08 were similar to Alturas (data not shown). The greatest effects of N were evident when tubers were stored at 40°F. Tubers grown with 150% in-season N fried 26% lighter than the 0% N tubers through mid April. These N effects on processing quality were not apparent at higher storage temperatures (44 and 48°F), reflecting the high degree of inherent resistance of Premier to sweetening over time at these temperatures.
- In 2009, Premier Russet tubers from the 0% in-season N regime processed significantly darker at harvest (prior to storage) than those grown with higher levels of in-season N (Fig. 6). Tubers grown with 50 and 150% in-season N regimes produced fries that were 20% and 28% lighter ($P<0.01$) than those grown with 0% in-season N. These differences are likely a consequence of over maturation of the low N tubers in warm soil under dead vines at season end. The time between attainment of PM and harvest for tubers grown with 0, 50 and 150% in-season N was 21, 17, and 9 days, respectively, in 2009.

Results – Ranger Russet

- Like Alturas and Premier Russet, Ranger Russet tubers should be harvested slightly immature or at physiological maturity (approximately 155 DAP) for optimum processing quality and longest storage life. A prolonged maturation period between PM and harvest will result in over-maturation of tubers, which will compromise retention of processing quality. Over-mature tubers generally enter storage with higher levels of reducing sugars than physiologically mature tubers (Driskill et al., 2007), and continued increase in reducing sugars during storage will result in premature loss of processing quality in the former (Fig. 7). This was shown in studies where end-of-season tuber maturity was altered by planting in mid April and mid May and then harvesting on the same date (Sept. 25) to produce crops grown for 133- and 163-days, respectively. Eight-ounce tubers from the early- and late-planted crops were then stored under various temperature regimes (combinations of conditioning and holding temperatures) to study the effects of tuber maturity on changes in fry color over a 251-day storage period (Fig. 7). Regardless of storage temperature regime, over-mature tubers (from dead vines) produced darker fries than those harvested closer to PM (from partly green vines).

- The decreased storability of Ranger tubers from the over-mature crop was readily apparent by the limited choice of storage temperature regimes resulting in acceptable quality of processed French fries. Tubers harvested from partly green vines produced lighter colored fries under a broader range of temperature regimes (5 out of 9 total) than chronologically older tubers from senesced vines (only 3 regimes out of 9 total) (Table 5). Like Alturas and Premier, Ranger tubers showed a tendency to become over mature if produced over a relatively long season (>160 days), particularly if the tubers were left under dead vines for more than 10 days prior to harvest. Over maturation thus decreased the ability to maintain processing quality, as evidenced by darker fries under many of the temperature regimes, resulting in fewer conditioning/holding temperature options for storing tubers with acceptable quality (Table 5).
- While tuber maturity was manipulated indirectly by varying the planting dates in this study, the results agree with previous studies in WA and ID where tubers harvested without vine kill (i.e. from partially green vines) maintained lower sugar levels and better processing quality than those left to mature for 2 to 4 weeks under dead vines (Knowles et al., 2001; Woodell et al., 2004). **Therefore, for Ranger Russet produced in the Columbia Basin and destined for storage, planting dates, vine kill dates, and harvest dates should be coordinated to limit over-maturation. Tubers should be harvested within a week of achieving PM, which normally occurs approximately 145 to 155 DAP.** The potential for sugar ends and bruise also increase when harvest is significantly delayed (Fig. 8).

Summary

- Rate of in-season N significantly affected key indices of foliar & tuber maturity.
- Vine growth was more sensitive to in-season N than tuber yield – tuber yield increased with N-induced increases in foliar growth & decreased as HI at max foliar growth increased.
- Tuberization too early in development restricts foliar growth & limits final yield. Therefore, N should be managed to promote early foliar growth to optimize source/sink relationships & maximize yield and quality. The HI at maximum foliar development (95 to 120 DAP) should favor foliage rather than tubers.

- As N rate increased, the duration of crop development was extended and the attainment of PM was delayed. High in-season N plots were thus harvested closer to PM than low N plots where the vines had senesced earlier in the season.
- Reducing sugars in the stem ends of tubers were higher at harvest when grown with lower levels of in-season N, indicating physiologically older tubers – this resulted in earlier loss of processing quality during storage, particularly for Alturas.
- It is clear that N management can be tailored to influence gravity for the processing industry - lower N will produce higher gravity potatoes for dehy, higher N will prevent gravities from becoming too high for frozen processing.
- In-season N rate also affected total-N, protein-N, and asparagine content and thus the nutritional value of tubers. While asparagine increased with high N, reducing sugars were lower at harvest and in storage in tubers from high N plots, which probably negates the potential for increased acrylamide formation.
- For maximum retention of processing quality during storage, planting dates, vine kill dates, and harvest dates should be coordinated to limit over-maturation of tubers under dead vines at season end. Tubers should be harvested within a week of achieving PM, which normally occurs approximately 145 to 155 DAP (approximately 2700-2950 cumulative degree days (45^{o}F base) from planting) for most of the late season russet cultivars we have worked with (Alturas, Premier, Ranger, Burbank, Umatilla).

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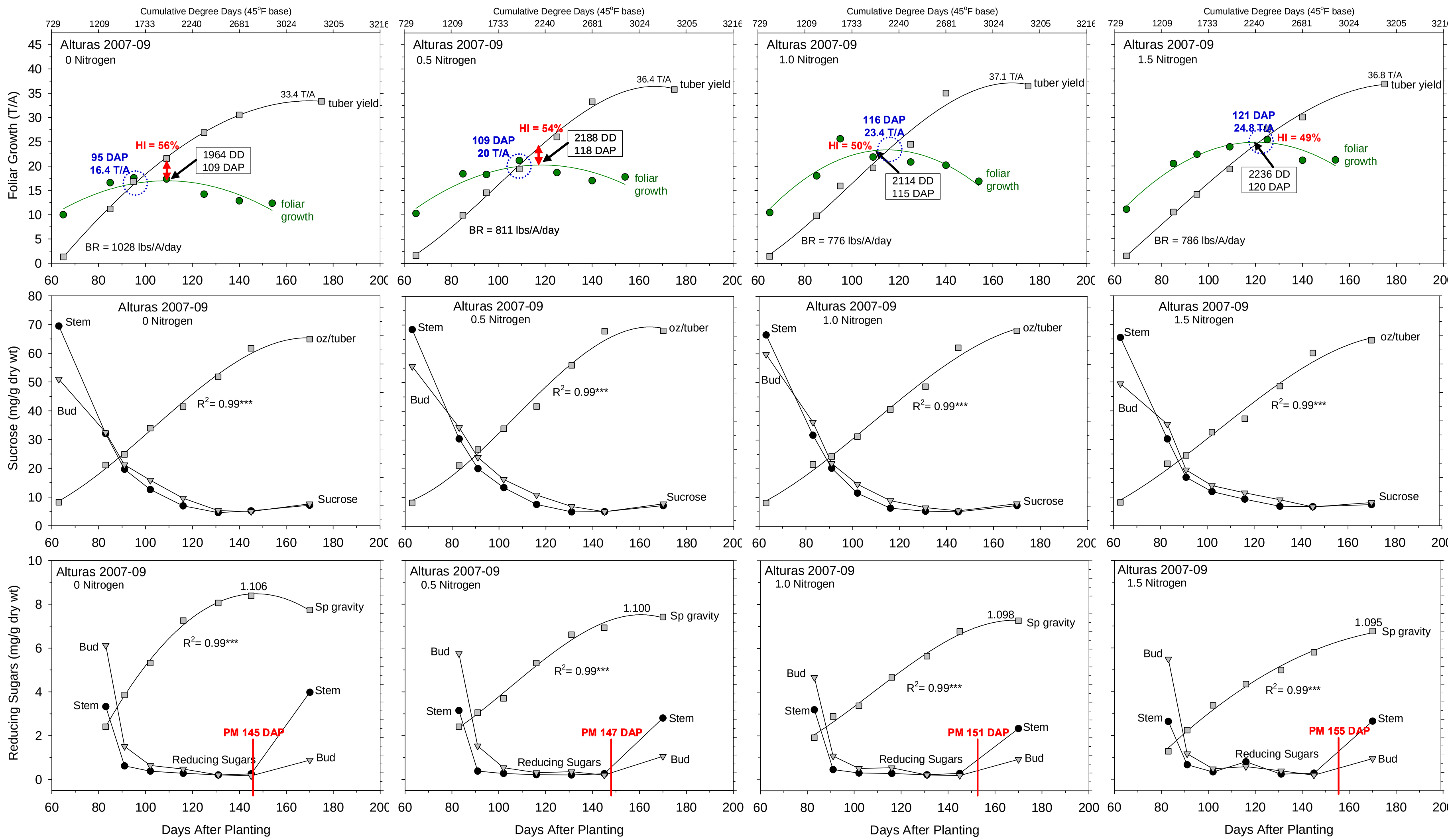


Fig. 1. Foliar and tuber growth (top row) responses of **Alturas** to four levels of in-season nitrogen (N) at Othello, WA averaged over 3 seasons (2007-09). The N levels (0, 0.5, 1.0, and 1.5) equal 0, 50%, 100%, and 150% of recommended in-season rates. See table 1 for planting and harvest dates. Changes in tuber sucrose concentrations and average tuber weights (middle row), and reducing sugars (glucose and fructose) and specific gravity (bottom row) are also shown. X- and Y-axis scales are equal to facilitate comparisons across N levels. Cumulative degree days (DD) at the corresponding days after planting (DAP) are shown (top row). BR = initial tuber bulking (growth) rate from 65 DAP to foliar maximum (top row). The days after planting (DAP), DD, and harvest indices (HI) at maximum foliar growth are shown (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 are also indicated (where foliar and tuber growth curves cross). Note that foliar and tuber yields are equal (shown in blue) at 50% HI. Physiological maturity (PM) was estimated at 145-, 147-, 151-, and 155-DAP as N increased from 0 to 150% of the recommended in-season rate (bottom row). Maturity indices are summarized in Tables 1 and 2.

Table 1. Effects of in-season N level on crop maturity indices of **Alturas** averaged over 3 growing seasons (2007-09) at Othello, WA. Nitrogen levels are expressed as percent of recommended in-season rates. Planting dates were April 5, 2007, April 17, 2008, and April 23, 2009. Vines were beat 172 DAP (9/24), 159 DAP (9/23) and 166 DAP (10/6) in 2007, 08 and 09, respectively. Final harvests were 186 DAP, 172 DAP, and 167 DAP in 2007, 08 and 09, respectively. The maturity indices were derived from regressions of foliar growth, tuber growth, and tuber carbohydrates versus DAP for each N regime averaged over years (see Fig. 1).

Alturas 2007-09			DAP to		Days After Planting (DAP) to				
	50% HI		Maximum	HI^2	Max	Max	Min	Min Red.	Physiological
Nitrogen[1]	*DAP*	*T/A*	Foliar F.Wt.	%	Yield	Gravity	Sucrose	Sugars[3]	Maturity[4]
0	95	16.4	109	56.2	171	147	137	124	145
50	108	20.0	118	54.4	166	159	141	122	147
100	116	23.4	115	49.8	168	168	144	122	151
150	121	24.8	120	49.3	175	170	150	123	155
R^2	0.99**	0.99**	0.71ns	0.92*	0.99**	0.99**	0.99**	0.98*	0.99**
Trend	Q	Q	Q	L	Q	Q	L	Q	Q

[1]In-season nitrogen as a percentage of recommended rate. [2]HI= tuber wt/tuber wt + foliar wt at maximum foliar development. [3]DAP to reach a minimum in reducing sugar concentration in the stem end of tubers. [4]Physiological maturity is the average DAP to reach maximum yield, specific gravity, minimum sucrose, and minimum reducing sugars in the stem ends of tubers. *,**P<0.05 and 0.01, respectively, for linear (L) or quadratic (Q) correlation coefficients (vs. N rate).

Table 2. Effects of in-season N level on foliar growth, tuber yield, and specific gravity of **Alturas** averaged over the 2007-09 growing seasons at Othello, WA. Nitrogen levels are expressed as percent of recommended in-season rates. See Table 1 and Fig. 1.

Alturas 2007-09				
	Max. Foliar	Final Tuber	Specific Gravity	
Nitrogen[1]	Biomass	Yield	Maximum	At harvest
	T/A	*T/A*	*SG*	*SG*
0	16.9	33.4	1.106	1.101
50	20.3	36.4	1.100	1.099
100	23.4	37.1	1.098	1.098
150	25.0	36.8	1.095	1.095
R^2	0.99**	0.99**	0.98*	0.98**
Trend	Q	Q	Q	L

[1]In-season nitrogen as a percentage of recommended rate. [2]Derived from regressions of gravity vs DAP. *,**P<0.05 and 0.01, respectively, for linear(L) and quadratic (Q) correlation coefficients (vs. N rate).

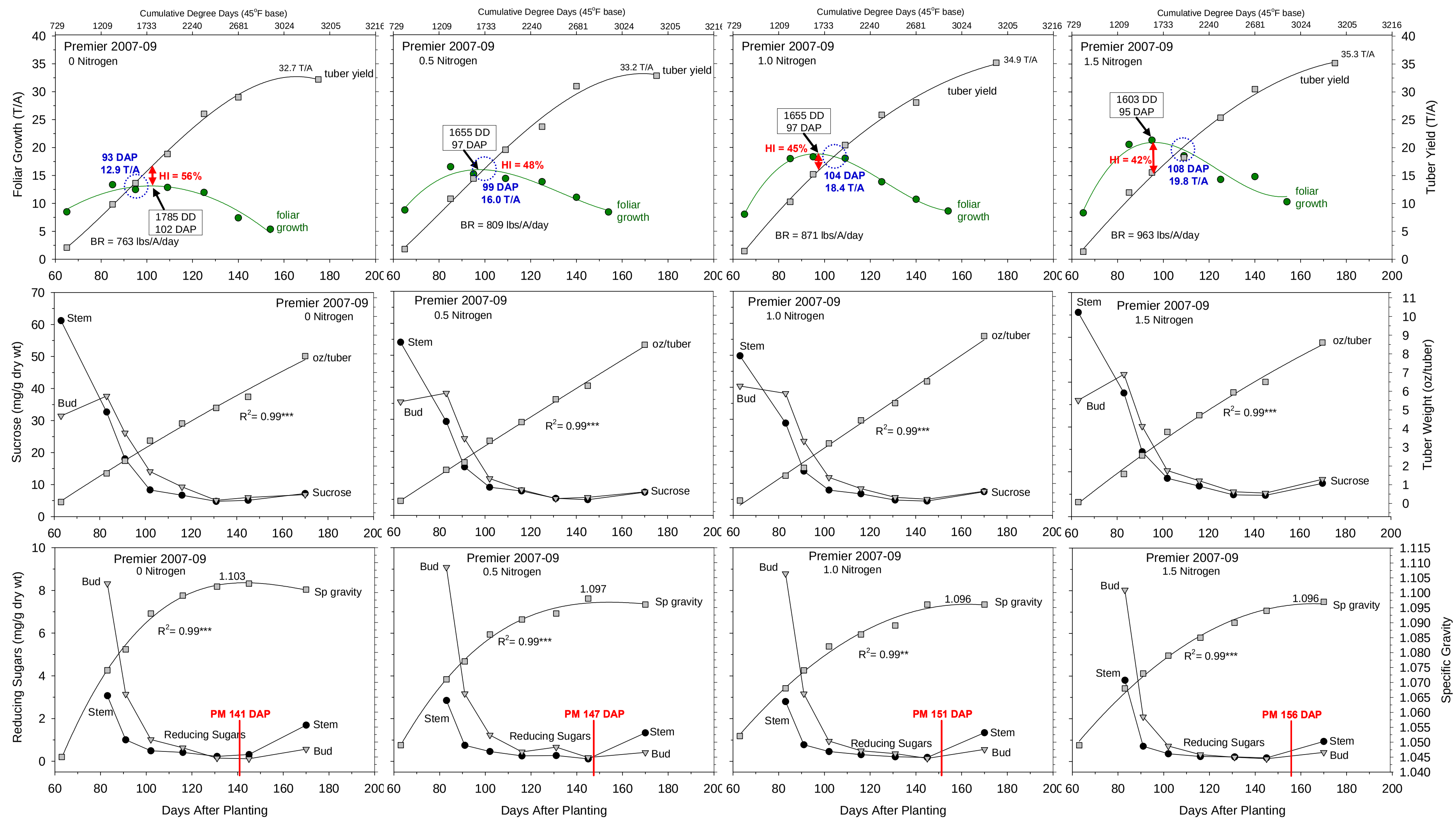


Fig. 3. Foliar and tuber growth (top row) responses of **Premier Russet** to four levels of in-season nitrogen (N) at Othello, WA averaged over 3 seasons (2007-09). The N levels (0, 0.5, 1.0, and 1.5) are equivalent to 0, 50%, 100%, and 150% of recommended in-season rates. See table 3 for planting and harvest dates. Changes in tuber sucrose concentrations and average tuber weights (middle row), and reducing sugars (glucose and fructose) and specific gravity (bottom row) are also shown. X- and Y-axis scales are equal to facilitate comparisons across N levels. Cumulative degree days (DD) at the corresponding days after planting (DAP) are shown (top row). BR = initial tuber bulking (growth) rate from 65 DAP to foliar maximum (top row). The days after planting (DAP), DD, and harvest indices (HI) at maximum foliar growth are shown (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 are also indicated (where foliar and tuber growth curves cross). Note that foliar and tuber yields are equal (shown in blue) at 50% HI. Physiological maturity (PM) was estimated at 141-, 147-, 151-, and 156-DAP as N increased from 0 to 150% of the recommended in-season rate (bottom row). Maturity indices are summarized in Tables 3 and 4.

Table 3. Effects of in-season N level on crop maturity indices of **Premier Russet** averaged over 3 growing seasons (2007-09) at Othello, WA. Nitrogen levels are expressed as percent of recommended in-season rates. Planting dates were April 5, 2007, April 17, 2008, and April 23, 2009. Vines were beat 172 DAP (9/24), 159 DAP (9/23) and 166 DAP (10/6) in 2007, 08 and 09, respectively. Final harvests were 186 DAP, 172 DAP, and 167 DAP in 2007, 08 and 09, respectively. The maturity indices were derived from regressions of foliar growth, tuber growth, and tuber carbohydrates versus DAP for each N regime averaged over years (see Fig. 3)

Premier 2007-09	50% HI		DAP to Maximum Foliar F.Wt.	HI^2 %	Days After Planting (DAP) to				
Nitrogen[1]	*DAP*	*T/A*			Max Yield	Max Gravity	Min Sucrose	Min Red. Sugars[3]	Physiological Maturity[4]
0	93	12.9	102	55.8	166	143	131	125	141
50	99	16.0	97	48.4	167	155	137	127	147
100	104	18.4	97	45.4	175	163	127	137	151
150	108	19.8	95	41.8	175	166	140	142	156
R^2	0.99**	0.99**	0.84*	0.99**	0.85*	0.99**	0.14ns	0.95*	0.99**
Trend	Q	Q	L	Q	L	Q	L	Q	L

[1]In-season nitrogen as a percentage of recommended rate. [2]HI= tuber wt/tuber wt + foliar wt at maximum foliar development. [3]DAP to reach a minimum in reducing sugar concentration in the stem end of tubers. [4]Physiological maturity is the average DAP to reach maximum yield, specific gravity, minimum sucrose, and minimum reducing sugars in the stem ends of tubers. *,**P<0.05, and 0.01, respectively, for linear (L) or quadratic (Q) correlation coefficients (vs. N rate).

Table 4. Effects of in-season N level on foliar growth, tuber yield, and specific gravity of **Premier Russet** averaged over 3 growing seasons (2007-09) at Othello, WA. Nitrogen levels are expressed as percent of recommended in-season rates. See Table 3 and Fig. 3.

Premier 2007-09			Specific Gravity	
Nitrogen[1]	Max. Foliar Biomass	Final Tuber Yield	Maximum	At harvest
	T/A	*T/A*	*SG*	*SG*
0	13.1	32.7	1.103	1.101
50	16.0	33.2	1.097	1.096
100	18.8	34.9	1.096	1.096
150	20.9	35.3	1.096	1.096
R^2	0.99**	0.93**	0.97*	0.97*
Trend	Q	L	Q	Q

[1]In-season nitrogen as a percentage of recommended rate. [2]Derived from regressions of gravity vs DAP. *,**P<0.05 and 0.01, respectively, for linear(L) and quadratic (Q) correlation coefficients (vs. N rate).

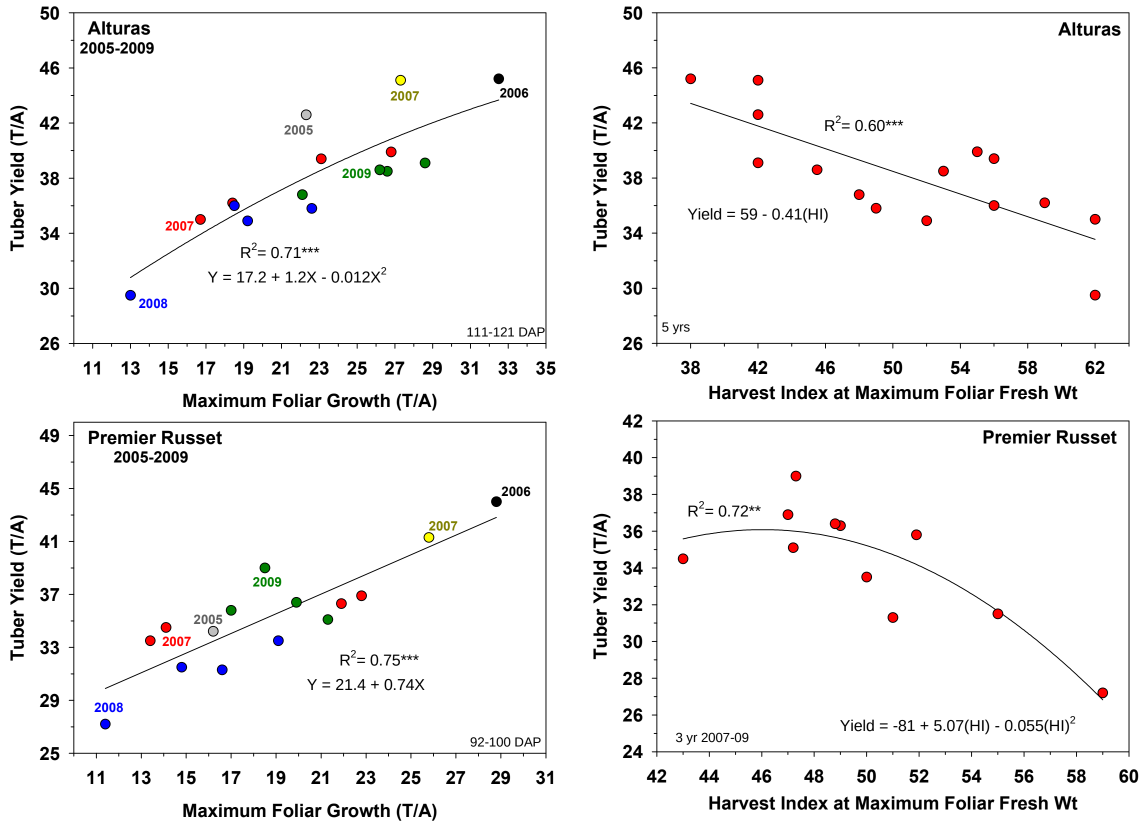


Fig. 3. Left: Dependency of tuber yield on foliar growth in Alturas (top left) and Premier Russet (bottom left). The yield (T/A) of above ground foliage at maximum foliar development was estimated from regressions of foliar fresh weight vs. days after planting (see foliar growth curves in Figs. 1 & 2). Data from 5 years of trials (color coded) are shown. **Right:** Tuber yields declined with increasing harvest index (HI) of Alturas (top right) and Premier Russet (bottom right). HI was calculated at maximum foliar development (95-120 DAP, see Figs. 1 & 2). HI is tuber fresh weight as % total plant (tubers + tops) fresh weight. Maximum yields were obtained when tubers accounted for 38 to 42% of total plant fresh weight at maximum foliar growth (109-120 DAP) for Alturas and 43 to 49% of total plant fresh weight (95-102 DAP) for Premier Russet. **Source/sink imbalances occurred when tuber growth dominated plant growth (e.g. HI = 62%) at maximum foliar development, resulting in lower yields.**

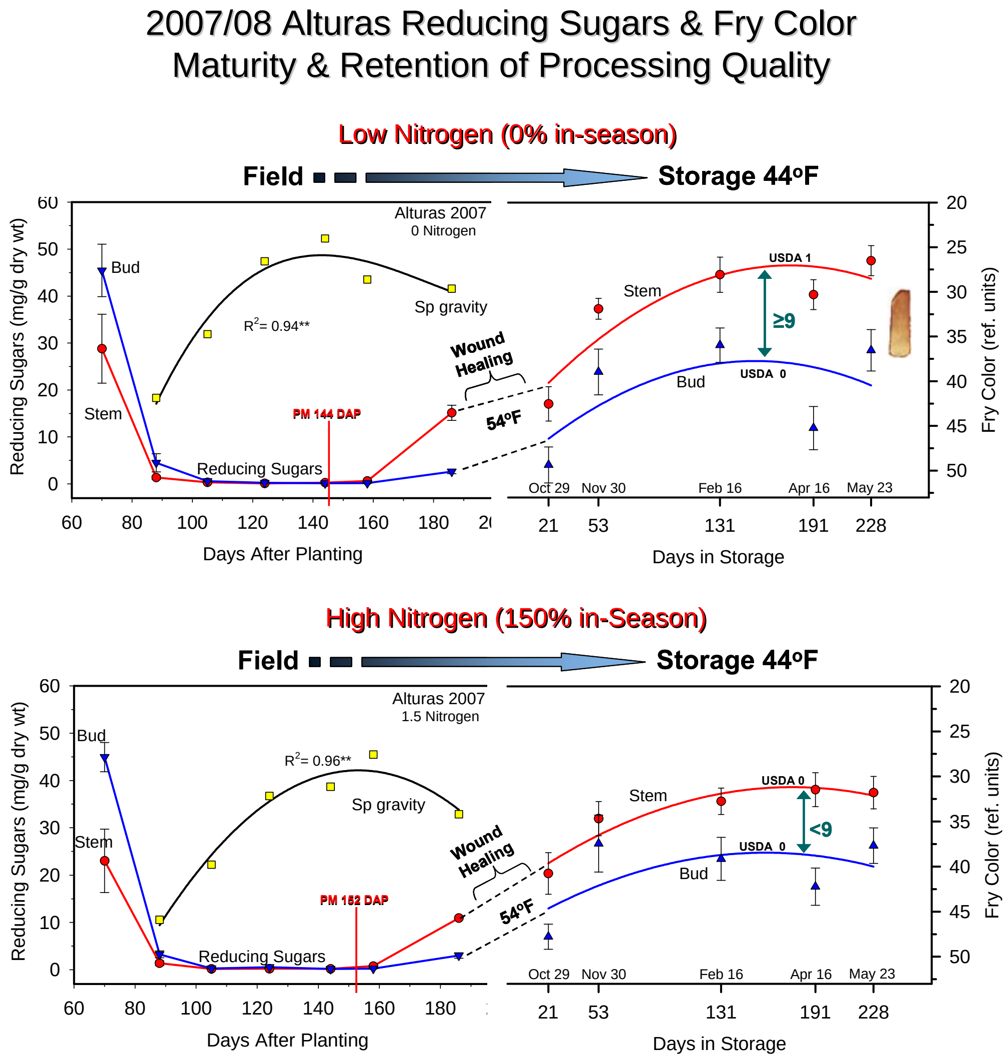


Fig. 4. Changes in reducing sugars (glucose + fructose), specific gravity and fry color of Alturas tubers during development and in storage (2007 growing season and 2007/08 storage season). The crop was planted April 5, 2007 at Othello, WA and grown with 0% (top) and 150% (bottom) of the recommended in-season rate of N. Vines were beat 172 DAP and tubers were harvested 186 DAP. Physiological maturity (PM) of tubers was estimated at 144 and 152 DAP for the low- and high-N crops, respectively. Tubers were harvested, wound-healed at 54°F for 21 days and then stored at 44°F until May 23. Changes in processing quality (fry color) of the bud and stem ends of fries were compared over the 228-day storage period. Fry color was measured as Photovolt reflectance. Note the inverted scale on the fry color axis (right). Low reflectance values indicate darker fries. **Tubers grown with low N matured earlier, resulting in physiologically older tubers at harvest (186 DAP).** The reducing sugar content of the stem ends of these tubers was very high at harvest and fry color became non-uniform by mid March (bud to stem difference in Photovolt ref units ≥9). In contrast, reducing sugar levels in the stem ends of high-N tubers were less than in low N tubers at harvest. **High N tubers were physiologically younger than low N tubers at harvest and maintained uniform fry color throughout the storage period (bud to stem difference in Photovolt ref <9). Nitrogen management can thus affect tuber physiological maturity, which in turn affects retention of processing quality during storage.** Photovolt readings >31= USDA 0; 25-30= USDA 1; 20-24= USDA 2; 15-19= USDA 3; <14= USDA 4. Each point is the average of 12 tubers ±SE.

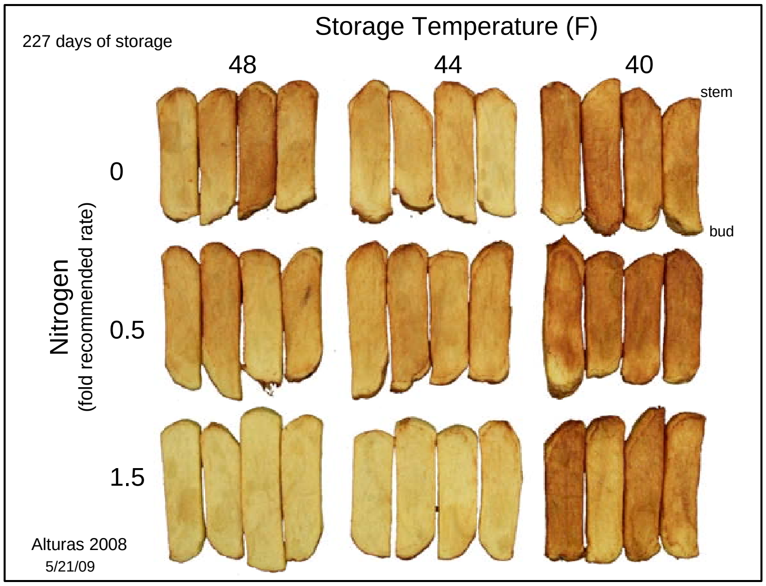


Fig. 5. Effects of in-season N and storage temperature on processing quality of Alturas following 227 days of storage (**2008/09** storage season). Planting date was April 17. The N levels (0, 0.5, and 1.5) are equivalent to 0, 50%, and 150% of recommended in-season rates. Physiological maturity (PM) was estimated at 145-, 148-, and 153-DAP for tubers grown with 0, 0.5 and 1.5 levels of in-season N, respectively. The intervals between PM and harvest (172 DAP) were 27, 23 and 19 days for 0, 50 and 150% N regimes, respectively. Each fry plank is from a different tuber selected to represent the average fry color in a 12-tuber sample.

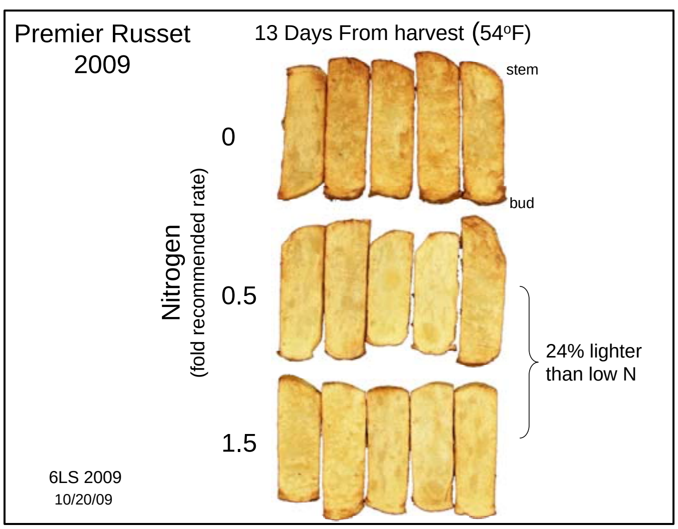


Fig. 6. Effects of in-season N on processing quality of Premier Russet 13 days after wound-healing at 54^{o}F following harvest in **2009** (Oct. 20). Planting date was April 23. The N levels (0, 0.5, and 1.5) are equivalent to 0, 50%, and 150% of recommended in-season rates. Physiological maturity (PM) was estimated at 146-, 150-, and 158-DAP for tubers grown with 0, 0.5 and 1.5 levels of in-season N, respectively. Tubers grown with 50 and 150% in-season N regimes produced fries that were 20% and 28% lighter ($P<0.01$) than those grown with 0% in-season N. These differences are likely a consequence of over maturation of the low N tubers in warm soil under dead vines at season end. Each fry plank is from a different tuber selected to represent the average fry color in a 12-tuber sample.

Ranger Russet - Tuber Maturity Affects Fry Color During Storage

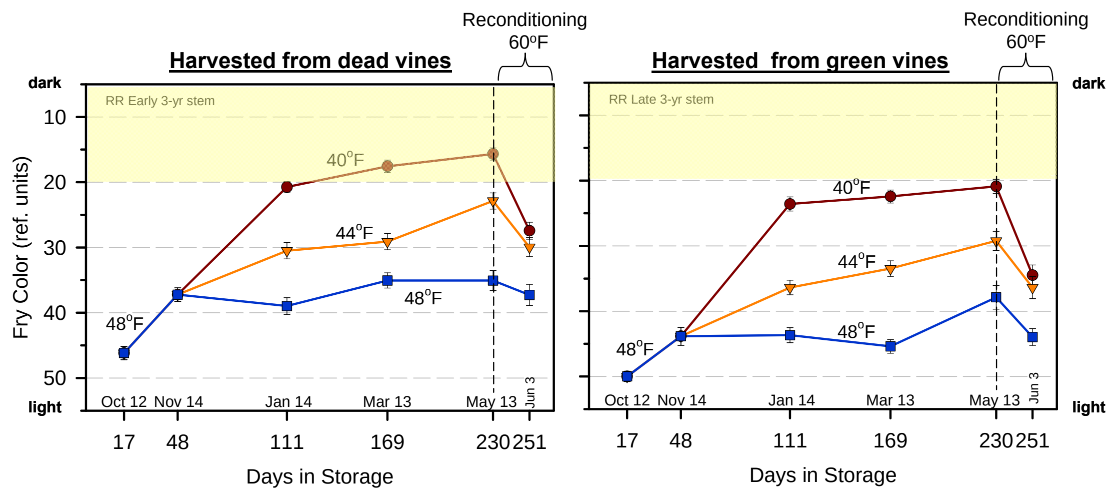
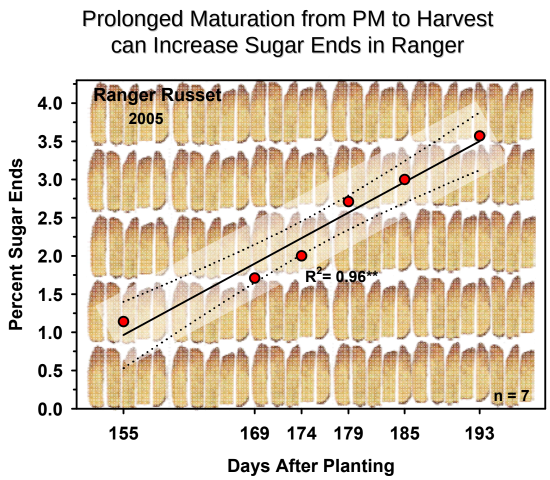


Fig. 7. Changes in the processing quality of French fries (photovolt reflectance units of the stem ends of fries) prepared from Ranger Russet tubers harvested overmature from dead vines (left) and from partially green vines (right) in response to different combinations of conditioning (initial), holding, and reconditioning temperatures over a 251-day storage interval. Differences in tuber maturity were produced by planting April 15 (left) and May 15 (right) and harvesting September 25. Tubers were wound-healed at 54ºF for 17 days following harvest, conditioned at 48ºF for a month (12 Oct.-14 Nov.), and then stored at 40, 44 and 48ºF (holding) for an additional 182 days (until 13 May). The tubers were then reconditioned for 21 days at 60ºF (13 May-3 June). Note the inverted scale on the French fry color axis. Low photovolt reflectance values indicate darker fries. A photovolt reflectance ≤19 is unacceptable by industry standards (≥USDA 3). The temperature regimes giving acceptable fry color (based on USDA values and color uniformity) are summarized in Table 5. Data are averaged over the 2002-04 storage seasons. Each point is the average of 36 tubers ±SE (bars). Similar results were obtained for Umatilla Russet and Russet Burbank tubers.

Ranger Russet CT/HT Storage Regime Options

Storage Days	Crop Maturity: Dead Vine	Crop Maturity: Green Vine
111	44/48 48/44 48/48	40/48 44/44 44/48 48/44 48/48
169	Same as above	Same as above
230	48/48	Same as above
Reconditioning (21 d @ 60ºF)	44/40 44/44 48/44 48/48	40/40 40/44 40/48 44/40 44/44 44/48 48/40 48/44 48/48

Table 5. Combinations of storage conditioning (CT) and holding (HT) temperatures resulting in acceptable processing quality of French fries from Ranger Russet tubers of different maturity after 111 169, and 230 days of storage. Tuber maturity was manipulated by planting date. The dead vine and green vine crops were planted April 15 and May 15, respectively, and harvested on 25 Sept. Tubers were then wound-healed at 54ºF for 17 days following harvest, conditioned (CT) at 40, 44 or 48ºF for a month, and then stored at 40, 44 and 48ºF (HT) for the remainder of the storage period. Fries were processed after the indicated storage days and fry color and uniformity were evaluated for acceptability. For a storage CT/HT regime to be acceptable, less than 20% of the tubers produced French fries exceeding a USDA 2 rating and the difference in color (lightness) from stem to bud end was less than 9 photovolt reflectance units. Note that reconditioning after 230 days of storage resulted in additional CT/HT regimes (indicated in red) that resulted in acceptable fry color. These data represent the storability of tubers over three storage seasons (2002-04).



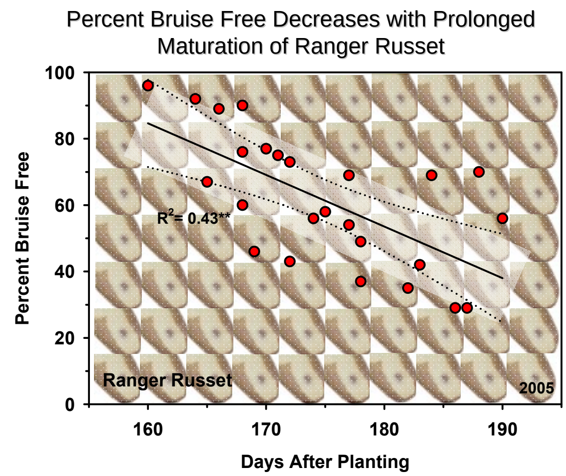


Fig. 8. Trends in the percentage of tubers with sugar ends and percentage bruise free with increasing days after planting for Ranger Russet in the Columbia Basin during the 2005 growing season. Ranger Russet tubers reach maturity approximately 145 to 155 days after planting. Sugar end and bruise free data are the average of 42 and 25 commercial farms, respectively. **,***Correlation coefficients significant at P<0.01 and 0.001, respectively (compiled from data provided by Mel Martin, J.R. Simplot Co.).