Balancing Foliar & Tuber Growth to Optimize Yield, Quality & Storability

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Background

Premier Russet (A93157-6LS), GemStar Russet (A9014-2), Defender (A90586-11) and Alturas (A82360-7) are newly released cultivars (since 2002) from the Pacific Northwest Potato Variety Development Program. These cultivars have excellent traits for the frozen processing and long-russet fresh pack industries, produce high total and U.S. no. 1 yields, and have the potential of supplanting Russet Burbank in fresh and/or French fry processing markets. With previous funding from the WSPC (2004-07), we defined key stages of growth and development and the attainment of tuber physiological maturity for these cultivars under Columbia Basin growing conditions and determined how their processing qualities change in storage in response to conventional and non-conventional temperature regimes (Knowles *et al*., 2007; 2008). This research suggested that optimizing source/sink (foliar/tuber growth) relationships during the bulking phase of tuber development was important to maximizing yield, quality and storability. **Further research to determine how in-season N management (rate and timing) alters source/sink relationships to affect yield and quality began in 2007/08.** Herein we summarize two to four years of research to define the importance of source/sink relationships to yield, final crop maturity, and storability of Alturas and Premier Russet. Source/sink relationships were expressed as harvest index (HI), which was calculated at maximum foliar growth (see below). Collectively, these studies will contribute to recommendations for fine-tuning management to maximize yield and tuber quality (at-harvest and out-of-storage) and thus profitability for WA growers. The studies are continuing through the 2009/10 season.

$$HI = \frac{\text{Tuber Yld}}{\text{Foliar + Tuber Yld}}$$

Objectives

(1) Identify key indices of crop maturity & define their importance to yield & tuber quality.

(2) Determine how in-season N management impacts tuber maturity & postharvest quality.

Approach

Use N management to alter key milestones of crop development and evaluate effects on yield, tuber quality, and storability. Important milestones of crop development include:

- Days after planting (DAP) to emergence
- Harvest index (HI) at maximum foliar growth
- DAP to 50% HI & T/A 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
- tuber physiological maturity

➢ Max. foliar biomass (T/A)

➢ Max. tuber yield (T/A)

➢ Specific gravity at harvest

Results

- 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, 2007 and April 17, 2008. Plants and tubers were harvested at approximately 10-day intervals from about 75 to 180 days after planting (DAP) and detailed seasonal growth profiles were constructed for each cultivar.
- The early part of 2008 was much cooler than 2007 and the 5- and 10-year temperature averages (Holden and Pavek, 2008), resulting in lower cumulative degree days during the period of plant emergence from 0 to 44 DAP (Fig. 1). Consequently, plants emerged later in 2008 than in 2007.
- Various indices of foliar and tuber development were calculated for each cultivar based on polynomial models describing growth and changes in sucrose, reducing sugars, and specific gravity of tubers over time (Figs. 2 & 3, 5 & 6). These indices included: DAP and yield at 50% harvest index (HI); HI at maximum foliar development; DAP to maximum foliar development, maximum specific gravity, minimum concentrations of sucrose and reducing sugars in tubers, maximum tuber yield; and DAP to physiological maturity of tubers (Tables 1-4).
- The warmer establishment period combined with higher soil temperature in 2007 hastened plant establishment, resulting in higher rates of bulking (BR) from tuber initiation to maximum foliar development (71 to 128 DAP) for both cultivars and at all levels of in-season N when compared with 2008 (Figs. 2 & 3, 5 & 6). For Alturas, 50% harvest index (tuber biomass equals foliar biomass) was reached earlier and foliar and tuber biomass at 50% HI were higher in 2007 than in 2008 (Figs. 2 & 3). For Premier, the DAP to 50% HI was comparable across years; however, more foliar and tuber biomass were produced at 50% HI in 2007 than in 2008 (Figs. 5 & 6). Maximum foliar biomass was also greater in 2007 versus 2008.
- **The level 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 (DAP) of 50% HI, 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 (except for Premier in 2007), and increased final tuber yields (Tables 1 & 2, 3 & 4).
- Vine persistence (foliar duration) increased with rate of in-season N, as evident by higher foliar biomass 140 to 160 DAP (Figs. 2 & 3, 5 & 6). 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 was tuber yield (Tables 2 & 4).** For both cultivars, tuber yield increased by approximately 0.8 T/A for every ton increase in foliar biomass at maximum foliar development ($P<0.001$) (Figs. 4 & 7). Final tuber yields declined as HI at maximum foliar biomasss (71-128 DAP) increased. For Alturas, final yields were highest when tubers accounted for 38 to 42% of total plant fresh weight at maximum foliar development (109-128 DAP) (Fig. 4 bottom). When tuber growth dominated whole plant growth at maximum foliar development (e.g. HI = 62%), final yield was reduced by about 11 T/A. Similar results were obtained for Premier (Fig. 7). **Clearly, management should be tailored to produce (favor) sufficient foliar growth during the first half of the growing season to maximize yield potential.** However, maximum yield should not be the only consideration; the economics of production and issues related to tuber maturity, postharvest use, and ability to retain processing quality should also be considered in deciding how best to manage N.
- Tuber sucrose and reducing sugar (glucose and fructose) concentrations, along with specific gravity, were profiled during development to define the attainment of physiological maturity for each cultivar, as affected by in-season N rate. Tuber 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. 2 & 3, 5 & 6; Tables 1 & 3). PM ranged from 143 to 154 DAP (Figs. 2 & 3; 5 & 6) and occurred later with increasing level of N (Tables 1 & 3). **Hence, tubers from 100 and 150% in-season N plots were less mature (physiologically younger) at harvest than tubers from 0 and 50% N plots where the vines had senesced earlier in the season.**
- Reducing sugars in the stem ends of tubers typically increase toward the end of the season, particularly during the maturation phase under dead vines. **On average, the concentration of reducing sugars in Alturas and Premier tubers at harvest was higher when grown with lower levels of in-season N, indicating physiologically older tubers (Figs. 2 & 3, 5 & 6).**
- Days after planting to maximum specific gravity increased with N level (Tables 1 & 3), while maximum specific gravity decreased with increasing N level (Tables 2 & 4), reflecting delayed maturity. On average, specific gravity at harvest was less than the maximum achieved during the growing seasons (Figs. 2 & 3, 5 & 6). **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.
- In-season N rate also affected the total- and protein-N content and thus the nutritional value of tubers (Table 5). 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 contrast, total- and protein-N of Alturas tubers increased 48% and 30%, respectively, in response to the two levels of in-season N. **The concentration of asparagine (Table 5) and other free amino acids in tubers also increased in response to the higher level of in-season N, which may affect acrylamide forming potential**

during processing. This possibility warrants further investigation and should also be considered in determining optimum levels of in-season N.

- Alturas and Premier tubers (8- to 12-oz) from 0, 50%, and 150% in-season N plots were harvested 172 DAP (2007), cured at 54^{o}F, and stored at 40, 44, and 48^{o}F for 228 days. Changes in fry color during storage were cultivar-dependent, reflecting differential sensitivities to low temperature sweetening (LTS) and associated loss of processing quality (Figs. 8 & 9). 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 and cultivar. Alturas sweetened rapidly during the initial 32 days at 40^{o}F and N-induced differences in PM had no effect on this response (Fig. 8). 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 produced 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.**
- 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. 10). This translated into a longer storage life for processing. 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^{o}F (Fig. 10). 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, tuber physiological maturity was affected by N management, which in turn affected retention of processing quality in storage.** While the attainment of PM in Premier tubers was also delayed with increasing N, processing quality was maintained throughout the 228-day storage period, likely due to the inherent resistance of this cultivar to LTS.
- Effects of in-season N on the out-of-storage processing quality of Premier Russet were similar to Alturas. The greatest effects of N were evident when tubers were stored at 40^{o}F (Fig. 9). Tubers produced with 150% in-season N fried 26% lighter than the 0% N tubers through mid April. The N effects on processing quality were not apparent at higher storage temperatures (44 and 48^{o}F), reflecting the high degree of inherent resistance of Premier to sweetening over time at these temperatures.

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 maximum 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. (HI favoring foliage at max foliar dev.)
- Tubers from 100 and 150% in-season N plots were less mature (physiologically younger) at harvest than tubers from 0 and 50% N plots where the vines had senesced earlier in the season.
- Stem-end reducing sugars in 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.

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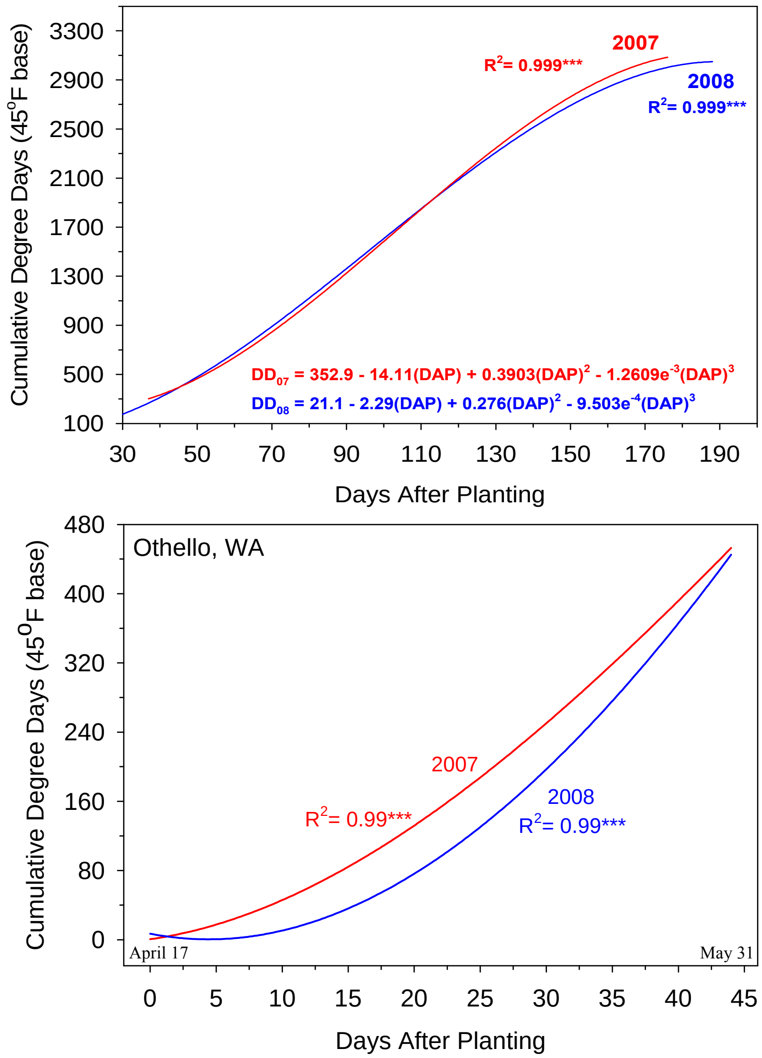


Fig. 1. Cumulative air degree days at Othello, WA during 2007 and 2008. Degree days are plotted through the entire season (top) and during plant establishment (bottom) from planting (April 17) through full emergence (44 DAP).

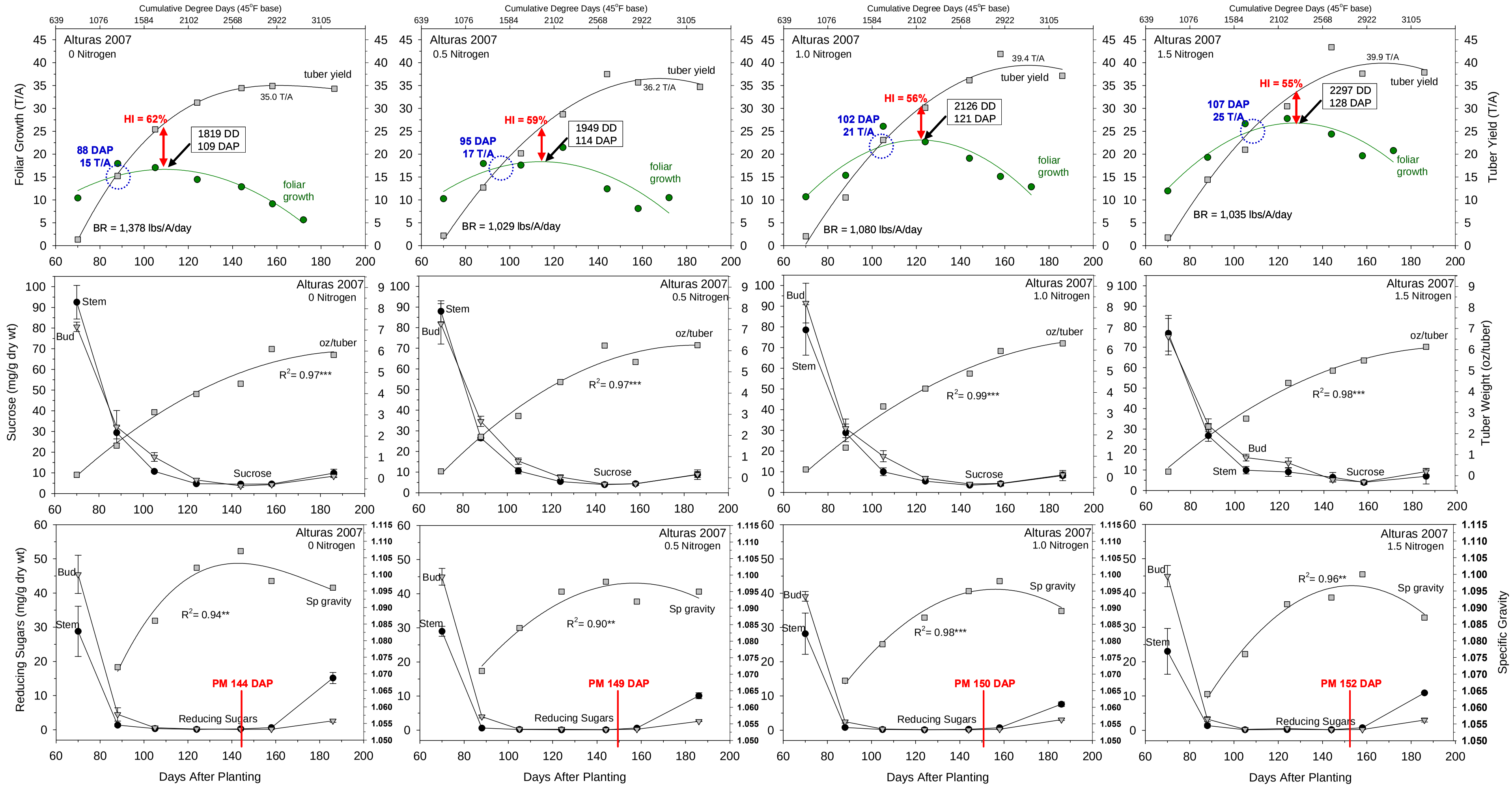


Fig. 2. Foliar and tuber growth (top row) responses of **Alturas** to four levels of in-season nitrogen (N) at Othello, WA during **2007**. Planting date was April 5. The N levels (0, 0.5, 1.0, and 1.5) are equivalent to 0, 50%, 100%, and 150% of recommended in-season rates. Plants and tubers were harvested at approximately 10-day intervals over the 186-d growing season. 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 among N levels. Cumulative degree days (DD) at the corresponding days after planting (DAP) are shown (top row). BR = initial tuber bulking (growth) rate from 70 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 intersect). Note that foliar and tuber yields are equal (shown in blue) at 50% HI. Physiological maturity (PM) was estimated at 144-, 149-, 150-, and 152-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.

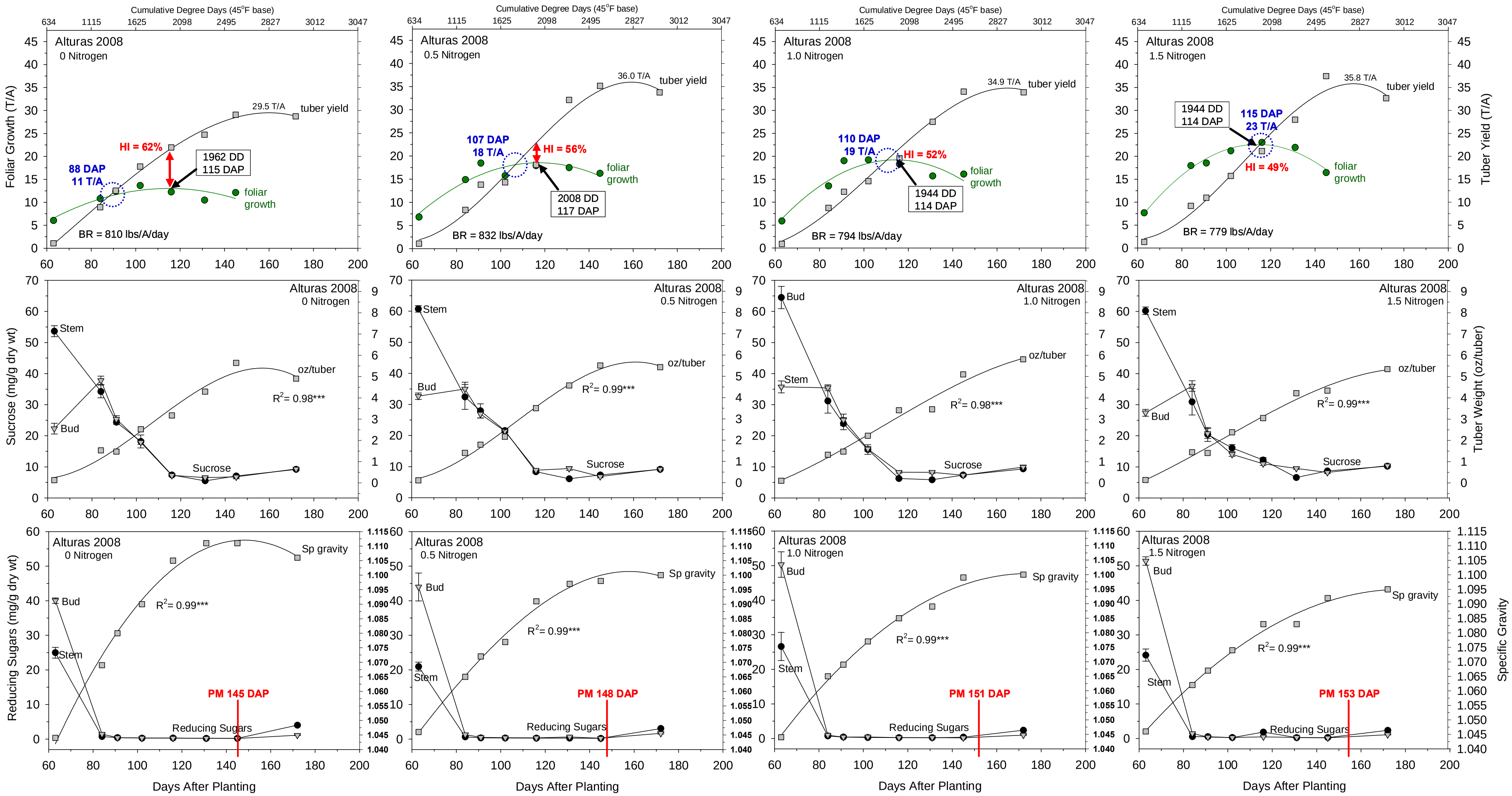


Fig. 3. Foliar and tuber growth (top row) responses of **Alturas** to four levels of in-season nitrogen (N) at Othello, WA during **2008**. Planting date was April 17. The N levels (0, 0.5, 1.0, and 1.5) are equivalent to 0, 50%, 100%, and 150% of recommended in-season rates. Plants and tubers were harvested at approximately 10-day intervals over the 172-d growing season. 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 among N levels. Cumulative degree days (DD) at the corresponding days after planting (DAP) are shown (top row). BR = initial tuber bulking (growth) rate from 63 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 intersect). Note that foliar and tuber yields are equal (shown in blue) at 50% HI. Physiological maturity (PM) was estimated at 144-, 149-, 150-, and 152-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 the 2007 and 2008 growing seasons at Othello, WA. Nitrogen levels are expressed as percent of recommended in-season rates. Planting dates were April 5, 2007 and April 17, 2008. Vines were beat 172 DAP (9/24) and final harvest was 186 DAP in 2007. Vines were beat 159 DAP (9/23) and final harvest was 172 DAP in 2008. The maturity indices were derived from regressions of foliar growth, tuber growth, and tuber carbohydrates versus DAP for each N regime (see Figs. 2 & 3).

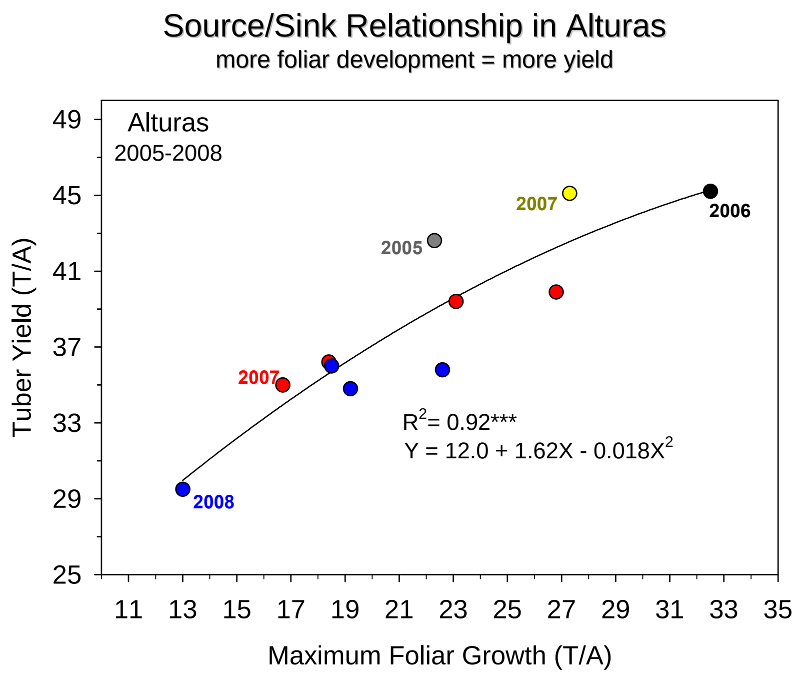
Alt 2-yr	50% HI		DAP to Maximum	HI[2]	Days After Planting (DAP) to				
Nitrogen[1]	*DAP*	*T/A*	Foliar F.Wt.	%	Max Yield	Max Gravity	Min Sucrose	Min Red. Sugars[3]	Physiological Maturity[4]
0	88	13	112	62	160	145	145	129	145
50	101	18	116	57	164	158	148	126	148
100	106	20	118	54	168	165	147	124	151
150	111	24	121	52	162	166	151	128	153
R^2	0.99*	0.99**	0.99**	0.99*	0.81ns	0.99**	0.79ns	0.88ns	0.99**
Trend	Q	L	L	Q	Q	L	Q	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 2. Effects of in-season N level on foliar growth, tuber yield, and specific gravity of **Alturas** averaged over the 2007 and 2008 growing seasons at Othello, WA. Nitrogen levels are expressed as percent of recommended in-season rates. See Table 1 and Figs. 2 & 3.

Alt 2007			Specific Gravity	
Nitrogen[1]	Max. Foliar Biomass	Final Tuber Yield	Maximum	At harvest
	T/A	*T/A*	*SG*	*SG*
0	14.9	32.3	1.108	1.101
50	18.3	36.1	1.100	1.096
100	21.2	37.2	1.098	1.095
150	24.7	37.9	1.096	1.091
R^2	0.99**	0.99**	0.98**	0.95*
Trend	L	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).



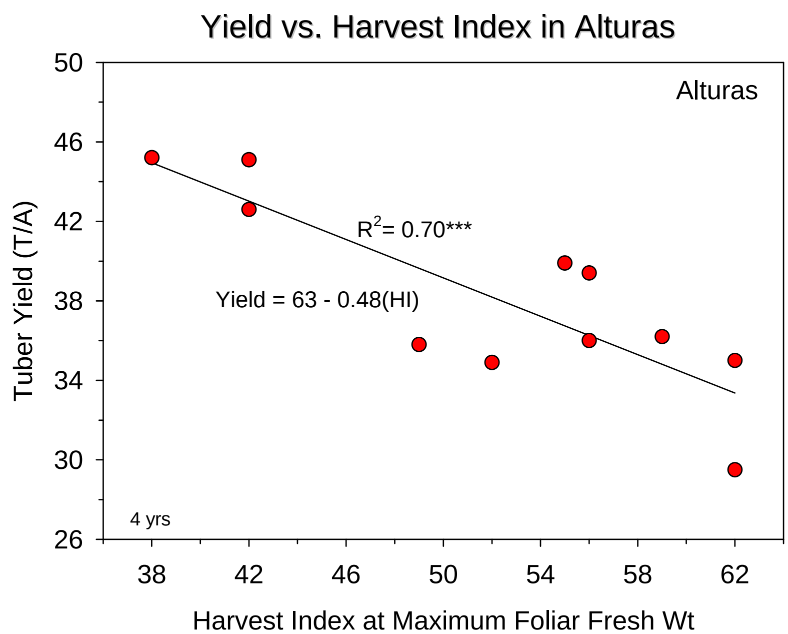


Fig. 4. Top: Dependency of tuber yield on foliar growth in Alturas. The yield (T/A) of above ground foliage at maximum foliar development was estimated from regressions of foliar fresh weight vs. Days after planting (see foliar growth curves in Figs. 2 & 3). Data from 4 years of trials (color coded) are shown. **Bottom:** Tuber yield declines with increasing harvest index (HI). HI was calculated at the point of maximum foliar development. 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 (109-128 DAP). A source/sink imbalance occurs if tuber growth dominates plant growth (e.g. HI = 62%) at maximum foliar development, resulting in lower yield.

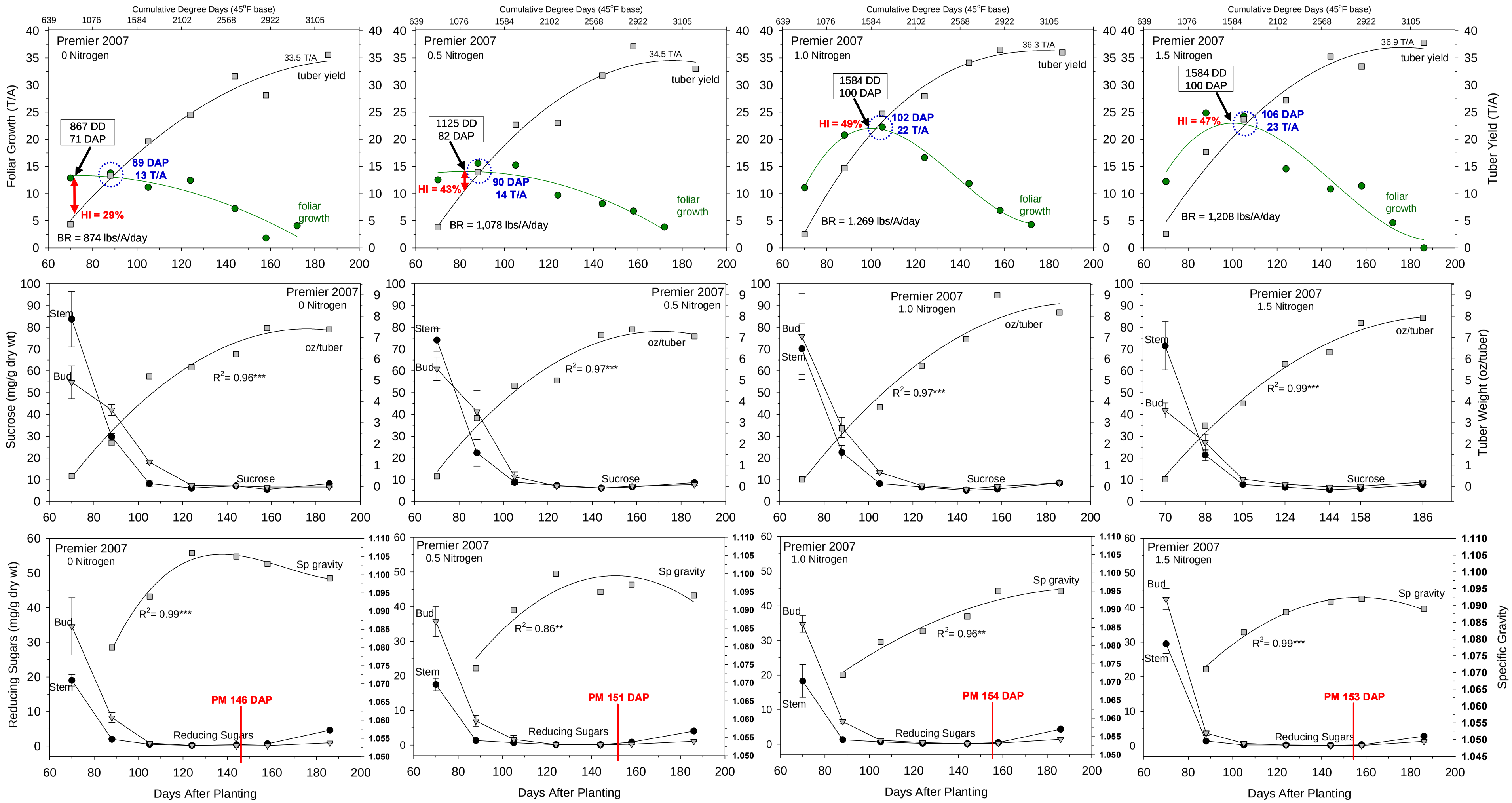


Fig. 5. Foliar and tuber growth (top row) responses of **Premier Russet** to four levels of in-season nitrogen (N) at Othello, WA during **2007**. Planting date was April 5. The N levels (0, 0.5, 1.0, and 1.5) are equivalent to 0, 50%, 100%, and 150% of recommended in-season rates. Plants and tubers were harvested at approximately 10-day intervals over the 186-d growing season. 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 among N levels. Cumulative degree days (DD) at the corresponding days after planting (DAP) are shown (top row). BR = initial tuber bulking (growth) rate from 70 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 144-, 149-, 150-, and 152-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.

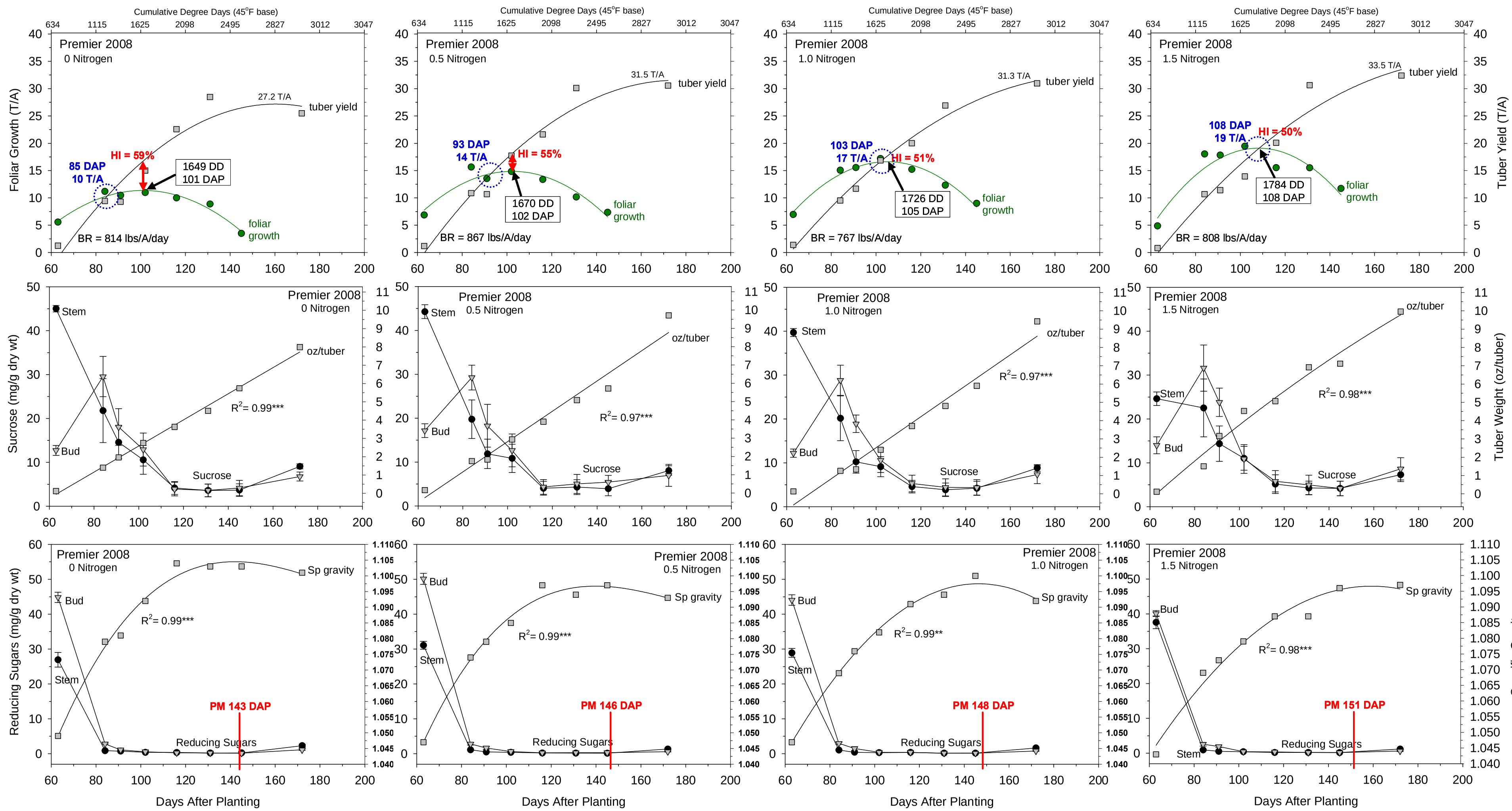


Fig. 6. Foliar and tuber growth (top row) responses of **Premier Russet** to four levels of in-season nitrogen (N) at Othello, WA during **2008**. Planting date was April 17. The N levels (0, 0.5, 1.0, and 1.5) are equivalent to 0, 50%, 100%, and 150% of recommended in-season rates. Plants and tubers were harvested at approximately 10-day intervals over the 172-d growing season. 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 among N levels. Cumulative degree days (DD) at the corresponding days after planting (DAP) are shown (top row). BR = initial tuber bulking (growth) rate from 63 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 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 143-, 146-, 148-, and 151-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 the 2007 and 2008 growing seasons at Othello, WA. Nitrogen levels are expressed as percent of recommended in-season rates. Planting dates were April 5, 2007 and April 17, 2008. Vines were beat 172 DAP (9/24) and final harvest was 186 DAP in 2007. Vines were beat 159 DAP (9/23) and final harvest was 172 DAP in 2008. The maturity indices were derived from regressions of foliar growth, tuber growth, and tuber carbohydrates versus DAP for each N regime (see Figs. 5 & 6).

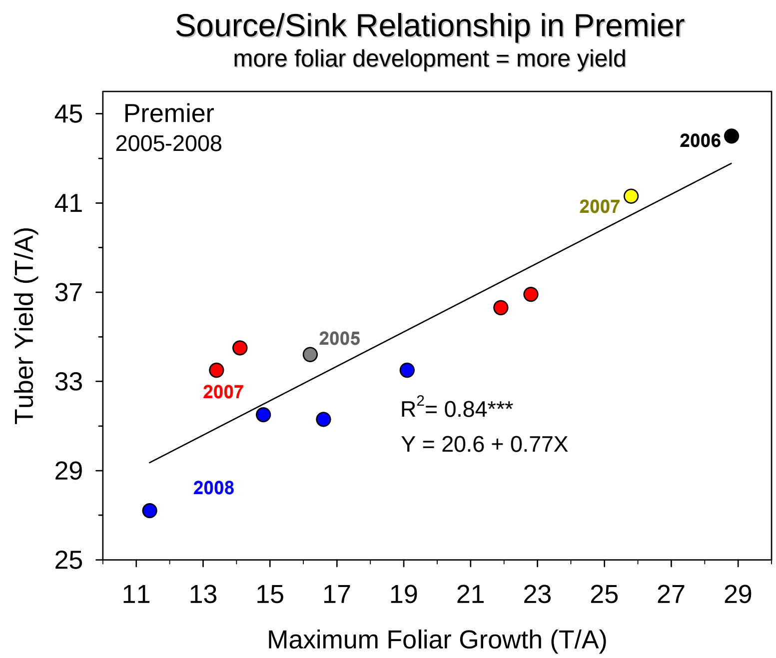
6LS 2-yr	50% HI		DAP to Maximum	HI^2	Days After Planting (DAP) to				
Nitrogen[1]	*DAP*	*T/A*	Foliar F.Wt.	%	Max Yield	Max Gravity	Min Sucrose	Min Red. Sugars[3]	Physiological Maturity[4]
0	87	12	86	44	166	139	143	130	145
50	92	14	92	49	174	145	144	132	148
100	103	20	103	50	175	152	143	135	151
150	107	21	104	49	174	158	144	134	153
R^2	0.97**	0.96**	0.94**	0.99**	0.97*	0.99***	0.00ns	0.88ns	0.99***
Trend	L	L	L	Q	Q	L	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<0.10, 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 the 2007 and 2008 growing seasons at Othello, WA. Nitrogen levels are expressed as percent of recommended in-season rates. See Table 3 and Figs 5 & 6.

6LS 2-yr			Specific Gravity	
Nitrogen[1]	Max. Foliar Biomass	Final Tuber Yield	Maximum	At harvest
	T/A	*T/A*	*SG*	*SG*
0	12.4	30.4	1.105	1.100
50	14.5	33.0	1.098	1.093
100	19.3	33.8	1.096	1.094
150	21.0	35.2	1.094	1.093
R^2	0.97**	0.98*	0.98*	0.59ns
Trend	L	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).



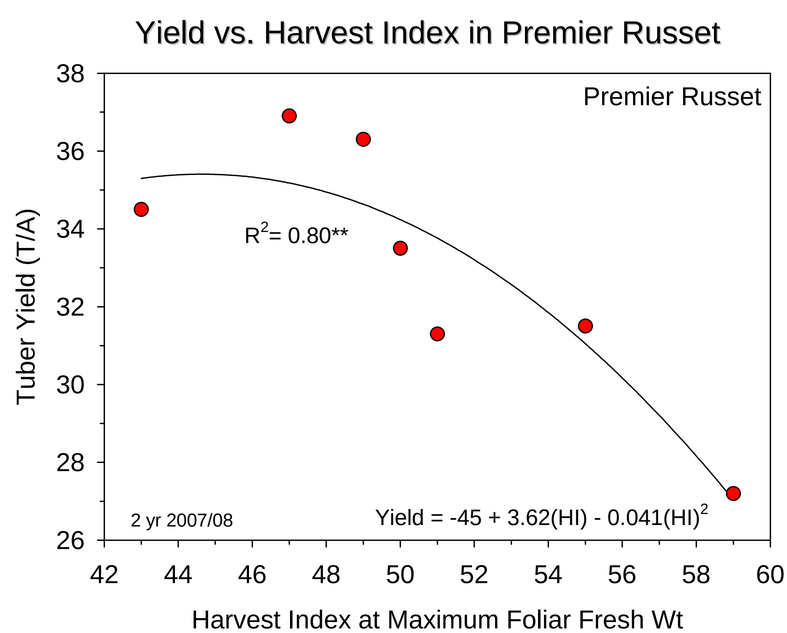


Fig. 7. Top: Dependency of tuber yield on foliar growth in Premier Russet. The yield (T/A) of above ground foliage at maximum foliar development was estimated from regressions of foliar fresh weight vs. days after planting (see foliar growth curves in Figs. 5 & 6). Data from 4 years of trials (color coded) are shown. **Bottom:** Tuber yield declines with increasing harvest index (HI). HI was calculated at the point of maximum foliar development. HI is tuber fresh weight as % total plant (tubers + tops) fresh weight. Maximum yields were obtained when tubers accounted for 43 to 46% of total plant fresh weight at maximum foliar growth (71-108 DAP). A source/sink imbalance occurs if tuber growth dominates total plant growth (e.g. = 59%) at maximum foliar development, resulting in lower yield.

Table 5. Effects of in-season N level on total-N and soluble protein-N concentrations in tubers at final harvest (186 DAP) during 2007 (Othello, WA). Nitrogen levels are expressed as percent recommended in-season rates. Tuber asparagine concentrations are also shown (avg 2007 & 08 seasons). Asparagine reacts with reducing sugars to yield acrylamide during processing.

Cultivar	In-season Nitrogen[1]	Tuber Nitrogen[2]		Asparagine
		Total-N	Protein-N	
	%	*mg/g dry wt*		*nmol/g dry wt*
Alturas	0	11.5	2.69	51.1
	150	17.0	3.49	87.2
Premier	0	11.1	2.19	57.5
	150	19.6	3.25	86.2
Cultivar (C)		ns	**	ns
In-season N		**	**	**
C x N		**	ns	*

[1]In-season nitrogen as a percentage of recommended rate. [2]Protein assessed by Bradford with BSA (16% N) as a standard. *,**P<0.05 & 0.01 (ns, not significant).

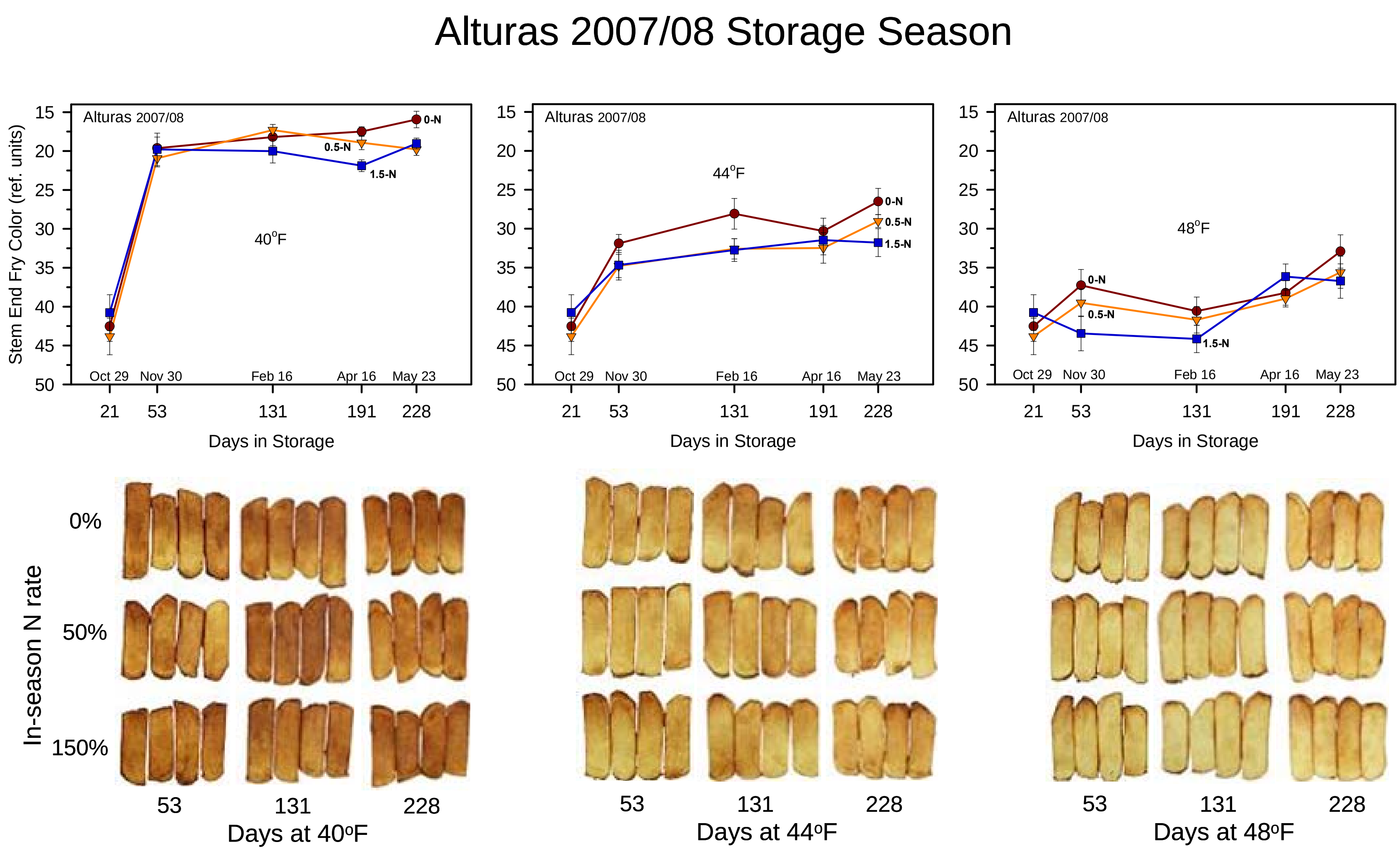


Fig. 8. Changes in fry color (Photovolt reflectance) during storage of Alturas tubers at 40, 44, and 48°F as affected by in-season nitrogen regimes. The crop was planted April 5, 2007 at Othello, WA and grown with 0, 50% and 150% of the recommended in-season rate of N. Vines were beat 172 DAP and tubers harvested 186 DAP. Tubers were wound-healed at 54°F for 21 days and then stored at the indicated temperatures. Note the inverted scale on the fry color axis. Low reflectance values indicate darker fries. 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. Each fry plank is from a different tuber selected to represent the average fry color in a 12-tuber sample. See Fig. 2 for growth profiles.

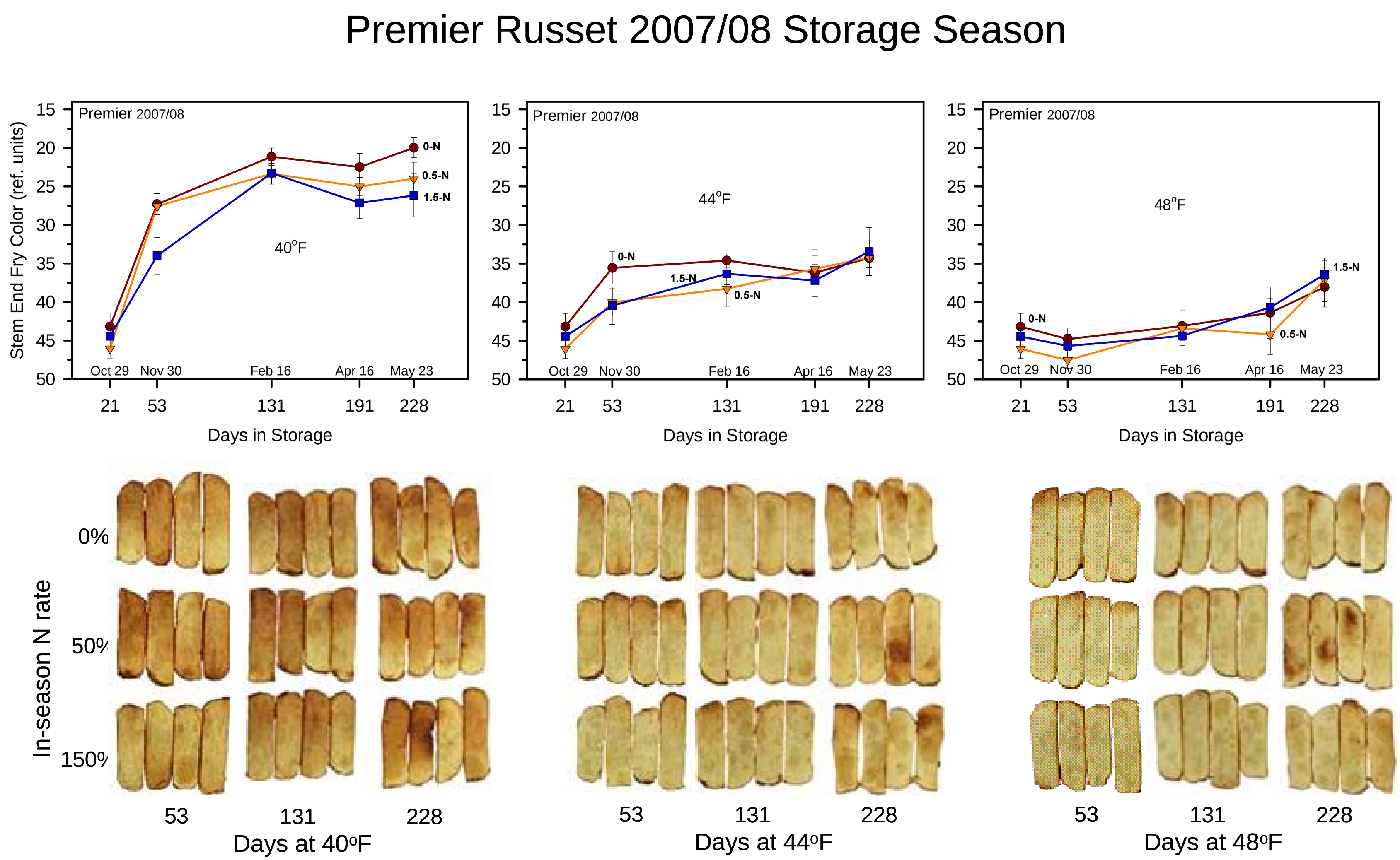


Fig. 9. Changes in fry color (Photovolt reflectance) during storage of Premier Russet tubers at 40, 44, and 48°F as affected by in-season nitrogen regimes. The crop was planted April 5, 2007 at Othello, WA and grown with 0, 50% and 150% of the recommended in-season rate of N. Vines were beat 172 DAP and tubers harvested 186 DAP. Tubers were wound-healed at 54°F for 21 days and then stored at the indicated temperatures. Note the inverted scale on the fry color axis. Low reflectance values indicate darker fries. 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. Each fry plank is from a different tuber selected to represent the average fry color in a 12-tuber sample. Note the mottling of fries at 228 DAP. See Fig. 5 for growth profiles.

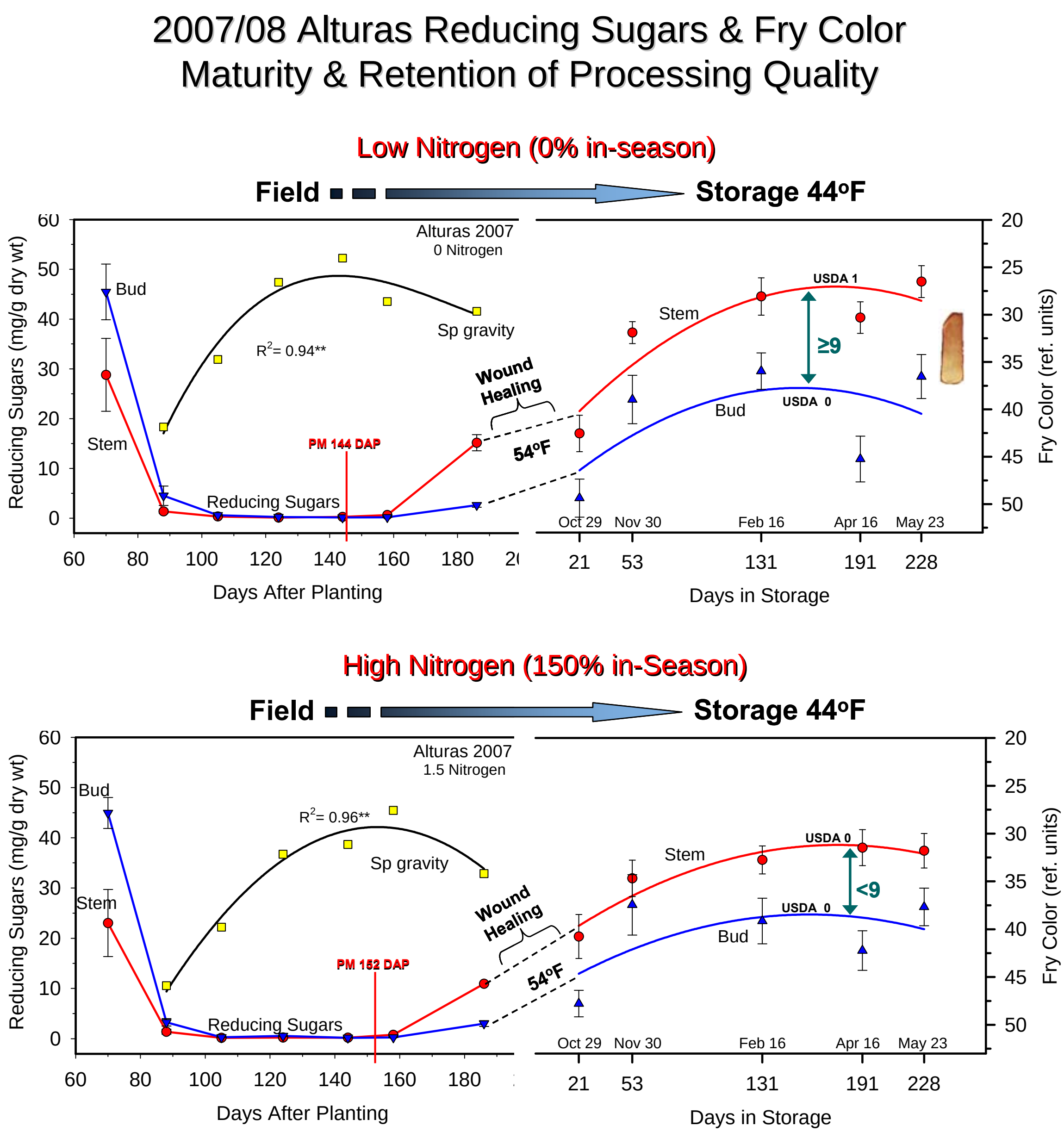


Fig. 10. Changes in reducing sugars (glucose + fructose), specific gravity and fry color of tubers during development and in storage (2007 growing season and 2007/08 storage season). The crop was planted April 5, 2007 at Othello, WA and grown with 0% (top) and 150% (bottom) of the recommended in-season rate of N. Vines were beat 172 DAP and tubers harvested 186 DAP. Physiological maturity (PM) of tubers was estimated at 144 and 152 DAP for 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. 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. Each fry plank is from a different tuber selected to represent the average fry color in a 12-tuber sample. See Fig. 2 for growth profiles.