Developmental Profiles & Postharvest Behavior of Long-Season Processing Cultivars

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Background

GemStar, Defender, Alturas, and A93157-6LS (Premier Russet) are among the newest frozen-processing cultivars to be released from the Northwest Potato Variety Development Program since Ranger Russet (1991) and Umatilla Russet (1997). Ranger and Umatilla have had significant impacts on the processing industry, accounting for 22.8% and 11.9% of WA processing potatoes in 2006, respectively. It is anticipated that GemStar, Defender, Alturas, and 6LS will also find niches in the WA potato industry, with the potential to capture a significant portion of the frozen French fry market in particular. However, as was the case with Ranger and Umatilla, developing best management practices for these cultivars under Columbia Basin growing conditions will involve a 'learning curve'.

Best management practices often vary among operations and are best developed in relation to the specific edaphic, climatic and agronomic variables unique to each farm. The goal of this project was to provide comprehensive data that describes and compares the growth and development of each cultivar over several seasons, including storage performance. The project thus provides the prerequisite fundamental data on crop growth and postharvest behavior, which will enhance the ability of growers to optimize production of each cultivar in the Columbia Basin. Detailed comparisons of foliar and tuber growth are provided for each cultivar in relation to days after planting, cumulative degree days, and soil and petiole nitrogen. The timing of the five critical stages of crop growth (emergence and plant establishment, vegetative growth, tuber initiation, tuber bulking, and maturation) is characterized for each cultivar.

Seasonal changes in sucrose, glucose and fructose (reducing sugars), and specific gravity in tubers were modeled for each cultivar to estimate the attainment of tuber physiological maturity at season end. Physiological maturity is defined as the window at the end of the growing season where tubers have reached maximum dry matter content (specific gravity), with minimum concentrations of sucrose and reducing sugars (Iritani and Weller, 1980; Pritchard and Adam, 1992). Coleman et al. (1996) used the term chemical maturity to refer to the point in tuber development when sucrose and glucose concentrations are minimal and processing quality is optimal. For many cultivars, tubers will maintain processing quality the longest during storage if harvested at physiological maturity.

Information on the relative sensitivities of these cultivars to variation in end-of-season tuber maturity for subsequent storability and processing quality (e.g. onset of sweetening in storage, development of sugar ends, reconditioning ability) is provided. The resulting growth and storability profiles provide a basis for ongoing work on nitrogen nutrition (timing, rate responses) and can ultimately be used by growers as an aid to scheduling irrigation, fertilizer, and pesticide applications more effectively, according to specific stages of crop development.

Objectives of the 3-year project

(1) Develop detailed crop growth stage profiles for A93157-6LS, GemStar Russet, Defender, Alturas, Umatilla Russet, Ranger Russet, and Russet Burbank.

(2) For each cultivar, estimate the attainment of tuber physiological maturity at season end and determine how storability and processing quality of 6LS, GemStar and Defender are affected by conventional and non-conventional storage temperatures over an 8-month storage period.

Experimental Approaches

- Profile foliar & tuber development for each cultivar through the season – define the growth curves and compare harvest indices.
- Identify the 'windows' corresponding to the five growth stages and characterize the attainment of tuber physiological maturity by modelling sugar content with time through the season for each cultivar.
- For each cultivar, evaluate the extent to which differences in crop maturity affect yield, tuber size distribution, crop value, and retention of processing quality during storage.

Results

- The morphology trials, involving seven cultivars (Defender, 6-LS, GemStar, Alturas, Ranger, Russet Burbank, Umatilla), were planted in replicated plots at the Othello Research Station on April 13, 2005 and April 11, 2006 and 2007. The early part of 2005 was warmer than in 2006 and 2007, resulting in higher soil and air cumulative degree days from 0 to 80 DAP (Fig. 1). Consequently, plants emerged earlier in 2005 than in 2006 and 2007 (Fig. 1, inset)
- Plants and tubers were harvested at approximately 10-day intervals from about 50- to 176-days-after-planting (DAP) and detailed seasonal growth profiles were constructed for each cultivar (Figs. 3-9). The 'windows' of tuberization were calculated for each cultivar (shaded in Figs. 3-9, summarized in Table 1) based on polynomial models describing the percentage of stolons tuberized versus time.
- **Tuberization** of GemStar, 6-LS, and Alturas occurred consistently 4 to 10 days later than Burbank, Defender, Umatilla, and Ranger (Table 1).
- On average, the **initial bulking (tuber growth) rate** of Alturas was less than all other cultivars (Table 2); however, it produced more foliar growth (kg/plant) that persisted longer than any of the other cultivars over the 3-yr study period (Fig. 8). Alturas thus continues to bulk late in the season, which no doubt contributes to its high yield potential.
- On average, row closure occurred approximately 60 to 65 DAP, well after tuberization but prior to the attainment of maximum foliar fresh weight per plant (Figs. 3-9).
- Relative to DAP and foliar development, the warmer establishment period combined with higher soil temperature in 2005 shifted tuberization and the early stages of bulking earlier for all cultivars when compared with 2006 and 2007 (Figs. 3-9, Table 1). This resulted in an apparent source/sink (foliar vs. tuber growth) imbalance in 2005. The earlier tuberization limited the amount of top (foliar) growth (Table 3) and shifted the attainment of maximum foliar growth (fresh wt/plant) earlier in 2005 than in 2006 and 2007 for most cultivars (Figs. 3-9). The harvest indices (HI = percent of plant fresh weight accounted for by tubers) at maximum foliar growth were thus highest in 2005 (Fig. 10), a consequence

and thus indicator of the source/sink imbalance created by tuberization and bulking too early in plant development. **For maximum yield potential, tuber fresh weight should ideally equal approximately 40% of total plant (foliage + tubers) fresh weight (HI=40%) at maximum foliar growth under Columbia Basin growing conditions.** Early season management (e.g. nitrogen nutrition) should thus be tailored to promote sufficient foliar growth to support the subsequent bulking needed for maximum yield.

- Vine persistence (foliar duration) was also substantially less in 2005 (Figs. 3-9) for all cultivars, likely also a consequence of tuberization too early in foliar development coupled with insufficient nitrogen later in the season. The latter was indicated by a relatively rapid drop in the petiole NO_3 concentrations of Russet Burbank after June 20 in 2005 (Fig. 2).
- These seasonal differences in foliar and tuber growth allowed us to relate the importance of foliar growth and the timing of critical stages of tuber development to final yield and quality for each cultivar. A key question was… **how sensitive are these cultivars to variation in foliar growth (maximum amount, timing in relation to tuberization, foliar duration) for effects on overall yield?** Seasonal differences in final marketable yields (Table 4) were positively correlated with maximum foliar growth (fresh wt/plant) for Ranger, 6LS, Defender, Russet Burbank (RB) and Umatilla (Table 5). In contrast, Alturas and GemStar averaged 44 and 38 T/A, regardless of the seasonal differences in maximum foliar growth and foliar duration. **The lack of correlation between maximum foliar fresh weight and yield in Alturas and GemStar suggests that high yields are achievable in these cultivars with less foliar development.** Indeed, Alturas and GemStar produced the same yields in 2005 as in 2006 and 2007 (Table 4) but did so with 26 to 48% less foliar biomass in 2005 (Table 3, Figs. 6 and 8). Considering the dependency of foliar growth on nitrogen, these cultivars thus appear more efficient in their nitrogen (N) use. Evidence for this is provided by Dr. Pavek's N fertility studies over the same years (2005-07) (see Pavek et al., reported herein). From 50 to 130 DAP, the petiole nitrate concentrations of Alturas and GemStar were higher than RB 65% and 70% of the time, respectively. On average, GemStar petiole nitrate was 32% higher than RB and Alturas petiole nitrate was 17% higher than RB throughout the seasons (3-yr average). Further studies by Dr. Pavek demonstrated that GemStar and Alturas produced the same yield when grown with half the recommended (RB) in-season rate of nitrogen. **These results underscore a need for further work to define the N requirements (timing and rates) for these cultivars for maximum economic return.**
- 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 during each season. 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. 3-9, Table 6). PM was achieved earlier in 2005 than in 2006 for all cultivars and in most cases was achieved prior to or coincident with vine kill (156 DAP) during all three seasons.
- In addition to yield, changes in tuber size distributions (Fig. 11) and gross economic values (Table 7) were compared among the cultivars at 130, 148, and 176 DAP in 2006 and 2007. **These data characterized the extent of end-of-season yield increases for each cultivar and revealed tendencies to oversize; important considerations for tailoring end-of-season management to achieve maximum returns from each cultivar.** In general, yields and thus crop value increased significantly for all cultivars over the last three harvest

dates (vine kill = 156 DAP), emphasizing a need for continued diligence in managing the crop toward season end.

- **Defender, GemStar, 6LS, and Ranger had much greater tendencies than the other cultivars to produce oversize (>14 oz) tubers from 130 DAP to season end (Fig. 11).** Interestingly, the yields of <4- to 12-oz tubers remained relatively constant from 130 to 176 DAP while the yields of >14-oz tubers increased the most. At 176 DAP the average oz/tuber were: Defender=8.0, GemStar=9.5, 6LS=8.8, Ranger=8.7. Despite the increase in oversize and associated contract penalties, process values for these cultivars increased from 148 to 176 DAP, due primarily to the increases in overall yields (Fig. 11, Table 7). These data indicate an opportunity to add value to these cultivars by shifting tuber size distribution to favor more moderate size tubers at the expense of >14-oz tubers. One way to accomplish this is through closer (<10-inch) in-row spacing. **Hence, further work is needed to define the optimal spacing for maximum returns from these cultivars in the Columbia Basin.** In contrast, Alturas, Umatilla, and Russet Burbank averaged 7.1, 7.0, and 7.5 oz/tuber by season end, reflecting more desirable size distributions.
- GemStar, Defender, and 6-LS tubers (8- to 12-oz) from the final harvests in 2005 and 2006 (170 and 176 DAP) were cured at 54^{o}F and stored at 40, 44, and 48^{o}F for 227 days. Changes in sucrose, reducing sugars (glu + fru) and fry color during storage were cultivar-dependent, reflecting differential sensitivities to low temperature sweetening (LTS) and associated loss of processing quality (Figs. 12 and 13). **Unlike Defender, GemStar and 6LS are highly resistant to low temperature sweetening.** Decreasing the storage temperature from 48 to 40^{o}F resulted in relatively modest increases in sucrose content of Defender and 6LS tubers from Oct. 22 to Nov. 25, but a 3-fold increase in the sucrose concentration of GemStar tubers. In contrast to 6-LS and GemStar, reducing sugars increased substantially in Defender tubers at all storage temperatures over the 227-day storage period and the response was inversely proportional to temperature. These results reveal major differences in sweetening metabolism among these cultivars. The mechanism of resistance to LTS for GemStar is different than 6LS, as indicated by the cold-induced buildup of sucrose in GemStar and apparent inability to invert it to reducing sugars. **Further research is needed to characterize differences in the mechanisms of resistance to LTS in GemStar and 6LS.**
- Defender is highly susceptible to LTS, resulting in rapid deterioration of processing quality, particularly at 44 and 40^{o}F (Figs. 12 and 13). Defender also had the highest rate of respiration initially in storage (data not shown). **Defender should be stored at no less than 48^{o}F and storage duration should not exceed 180 days for a WA-grown crop.** While 6LS tubers had considerable resistance to low temperature sweetening, the extent of fry mottling increased during storage of the 2005, 2006, and 2007 crops (2005 crop shown in Fig. 14). Mottling appeared less when stored at 40^{o}F than at higher temperatures, suggesting a tendency of 6LS tubers to age faster and undergo irreversible senescent sweetening earlier than the other cultivars. 6LS had the second highest respiration rate initially in storage, which is consistent with a faster rate of aging and may contribute to the purported greater potential for shrink. 6LS also appears to absorb more oil than the other cultivars during frying. GemStar sweetens uniformly from bud to stem end as storage temperature declines; however, tubers stored for 227 days at 44 and 40^{o}F still produced acceptable USDA 1 and 2 colored fries, respectively (Fig. 14).

- ➢ Processing quality of the 2005 crop of Defender, 6LS and GemStar deteriorated more rapidly during storage at 48°F (and sometimes 44°F) than the 2006 crop (Figs. 12 and 13). This is consistent with the earlier maturation and attainment of physiological maturity in the 2005 crops. **Reducing sugars in the stem ends of Ranger, Defender and Russet Burbank tubers can increase substantially toward season end and delaying harvest well beyond physiological maturity can result in accelerated loss of processing quality in storage.**
- ➢ The reducing sugar content of 6LS and GemStar Russet tubers decreases to very low levels during maturation. These cultivars are therefore more "forgiving" than Ranger and Defender for deleterious effects of delayed harvest (beyond physiological maturity) on sugar end development and storability.

References Cited

Coleman WK, J LeBlanc and T Morishita. 1996. A rapid test for chemical maturity monitoring of tubers. Am Pot J 73:201-507.

Driskill EP Jr., LO Knowles and NR Knowles. 2007. Temperature-induced changes in potato processing quality during storage are modulated by tuber maturity. Am J Pot Res 84:367-383.

Iritani WM and LD Weller. 1980. Sugar development in potatoes. Coop Ext Bull #0717, Washington State University, Pullman.

Pritchard MK and LR Adam. 1992. Preconditioning and storage of chemically immature Russet Burbank and Shepody potatoes. Am Pot J 69:805-815.

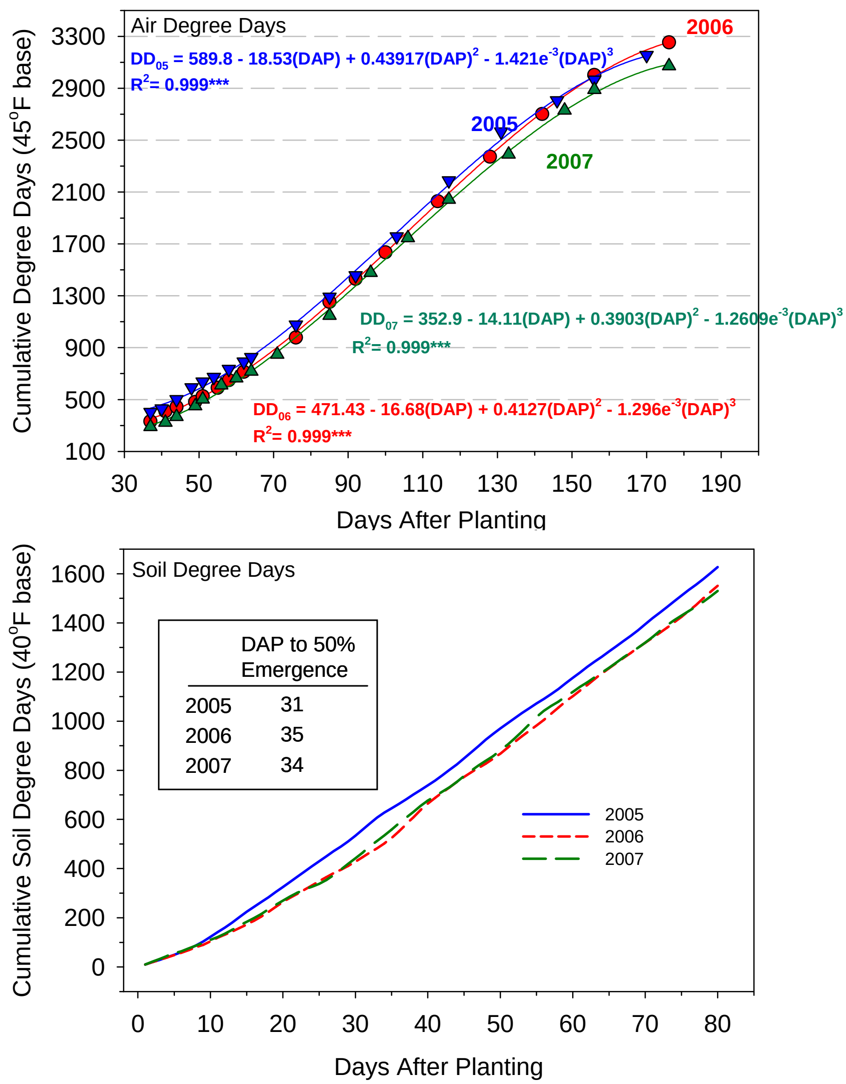


Fig. 1. Cumulative air (top) and soil (bottom) degree days at Othello, WA during the 2005, 2006, and 2007 growing seasons. Degree days were assessed from planting (April 13 in 2005 and April 11 in 2006 and 2007). Soil degree days were monitored at 6-inch depth. Days after planting (DAP) to 50% plant emergence is shown in the inset table (bottom).

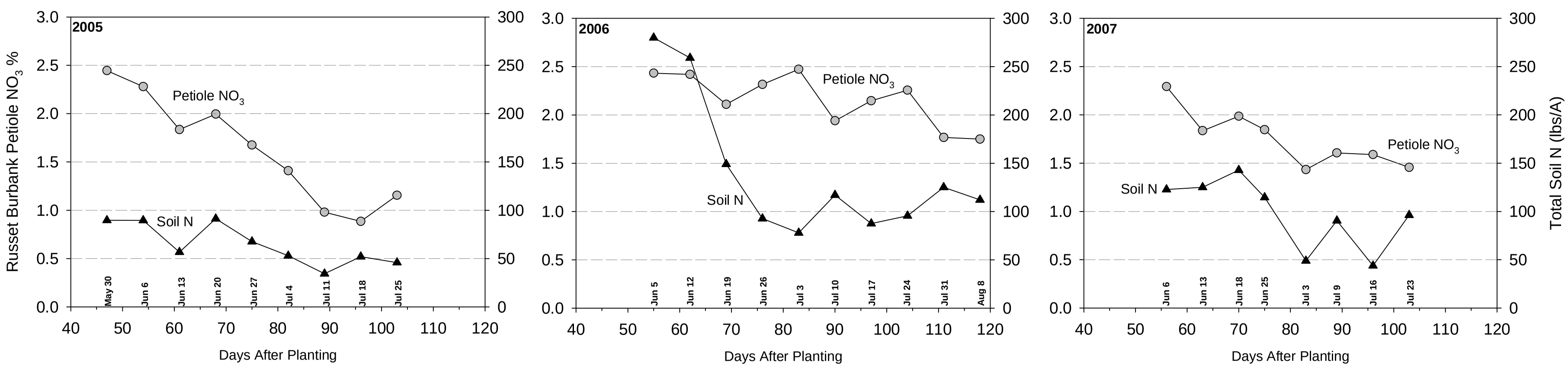


Fig. 2. Changes in **Russet Burbank** petiole nitrate and soil nitrogen levels in 2005 (left), 2006 (middle), and 2007 (right). Note that soil N levels were less than 100 lb/A in 2005 and the rate of decline in petiole nitrate concentration was 2.9- and 1.8-fold greater in 2005, reaching 1% by 90 DAP, than in 2006 and 2007, respectively. Petiole nitrate levels decreased linearly ($P<0.05$) by 0.28, 0.01 and 0.15% every 10 days during the 2005, 2006, and 2007 seasons, respectively.

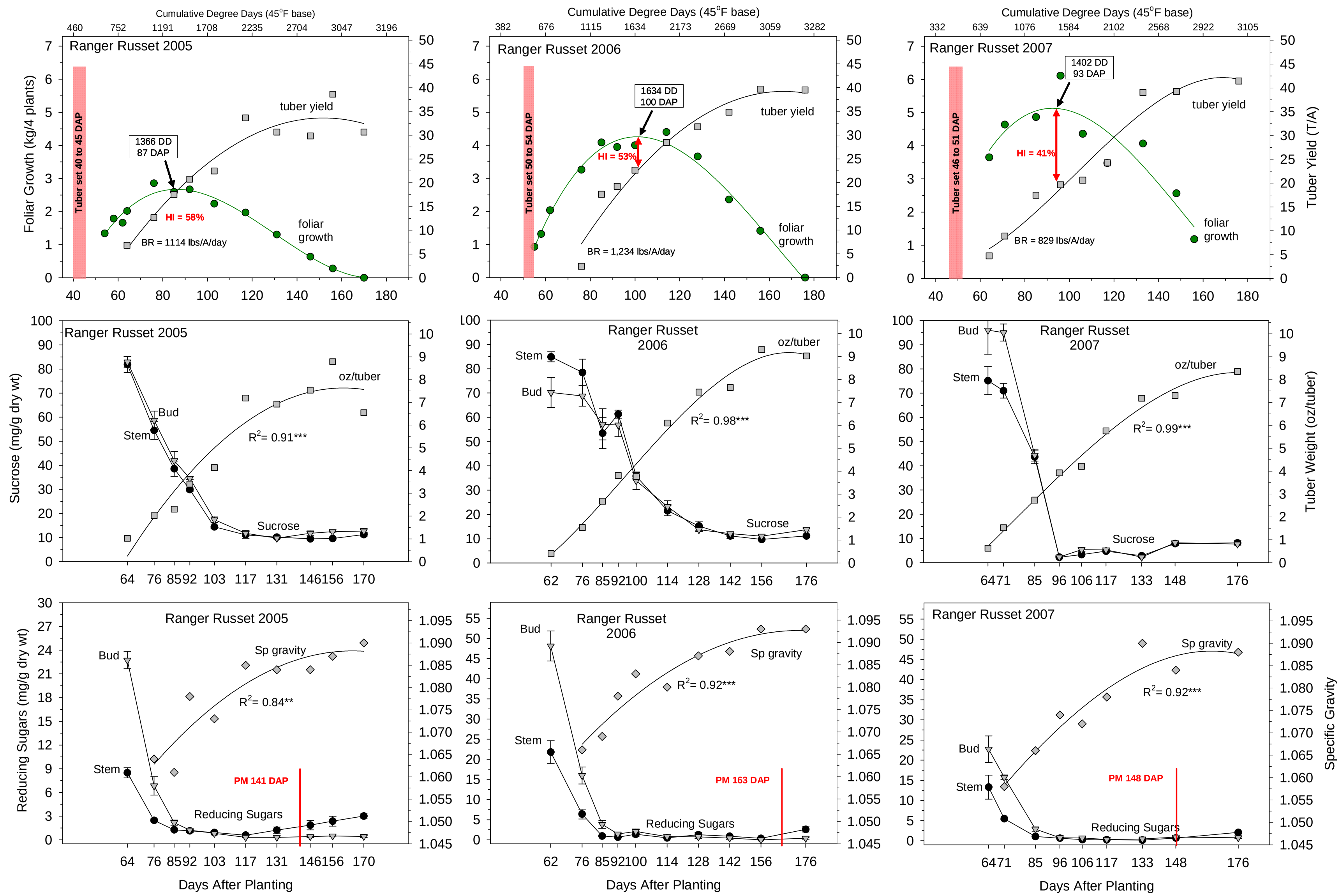


Fig. 3. Foliar and tuber growth (top row) of **Ranger Russet** under late-season management at Othello, WA during 2005 (left), 2006 (middle), and 2007 (right). Planting dates were April 11 (2006 & 07) and April 13 (2005). Plants were harvested at approximately 10-day intervals over the 170-176-d growing seasons. Changes in sucrose concentration and average tuber weight (middle row), and reducing sugars (glucose and fructose) and specific gravity (bottom row) are also shown. Except for 2005 reducing sugars, Y- and X-axis scales are equal to facilitate comparisons over years. The onsets and durations of tuberization are indicated (shaded windows, top row). Physiological maturity (PM) was estimated at 141-, 163-, and 148-DAP in 2005, 2006 and 2007, respectively (bottom row). HI = Harvest Index (percentage of plant fresh weight accounted for by tubers at maximum foliar growth). Cumulative degree days (DD) at the corresponding days after planting (DAP) are shown (top row). BR = initial tuber bulking (growth) rate from about 64 DAP to foliar maximum (top row).

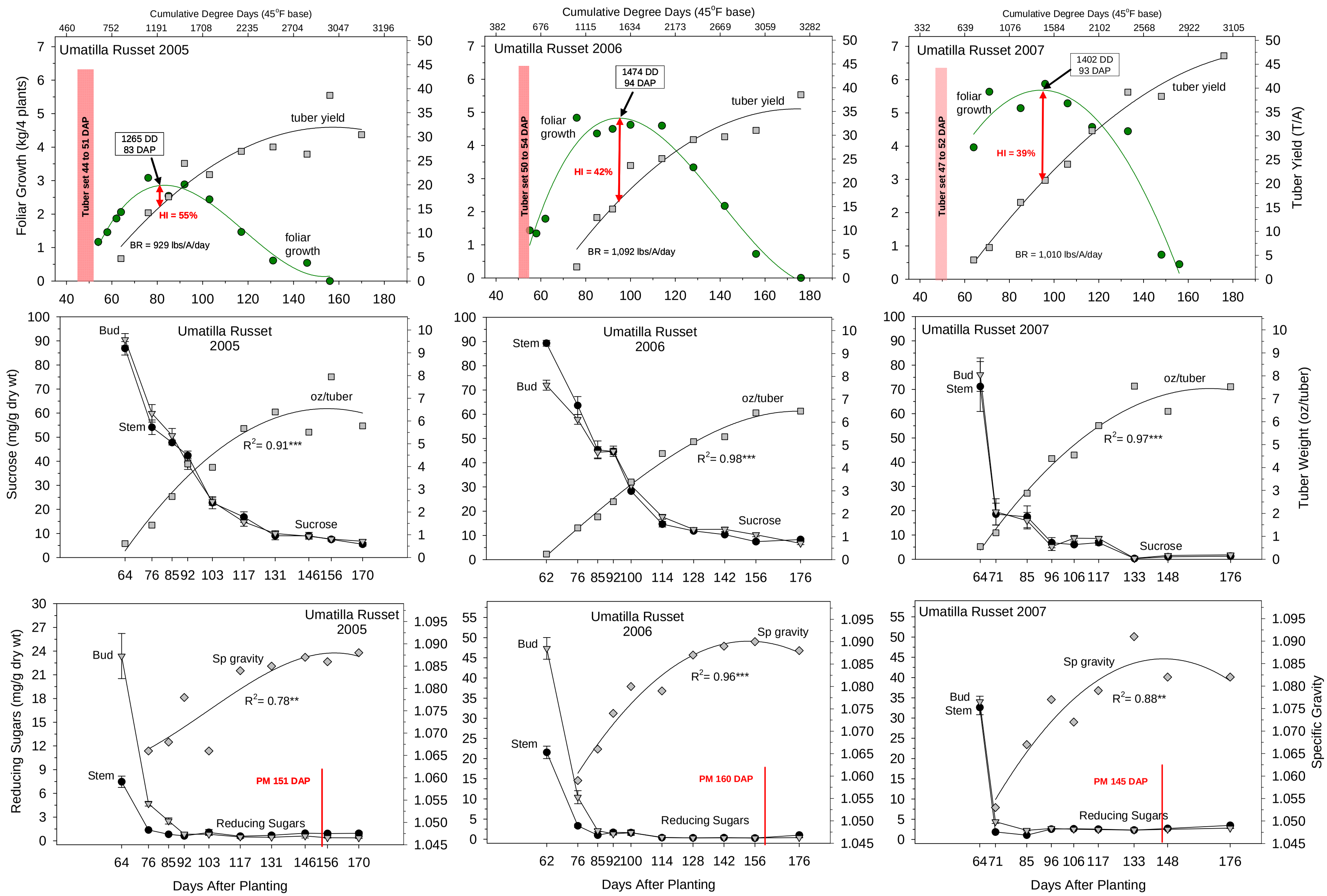


Fig. 4. Foliar and tuber growth (top row) of **Umatilla Russet** under late-season management at Othello, WA during 2005 (left), 2006 (middle), and 2007 (right). Planting dates were April 11 (2006 & 07) and April 13 (2005). Plants were harvested at approximately 10-day intervals over the 170-176-d growing seasons. Changes in sucrose concentration and average tuber weight (middle row), and reducing sugars (glucose and fructose) and specific gravity (bottom row) are also shown. Except for 2005 reducing sugars, Y- and X-axis scales are equal to facilitate comparisons over years. The onsets and durations of tuberization are indicated (shaded windows, top row). Physiological maturity (PM) was estimated at 151-, 160-, and 145-DAP in 2005, 2006 and 2007, respectively (bottom row). HI = Harvest Index (percentage of plant fresh weight accounted for by tubers at maximum foliar growth). Cumulative degree days (DD) at the corresponding days after planting (DAP) are shown (top row). BR = initial tuber bulking (growth) rate from about 64 DAP to foliar maximum (top row).

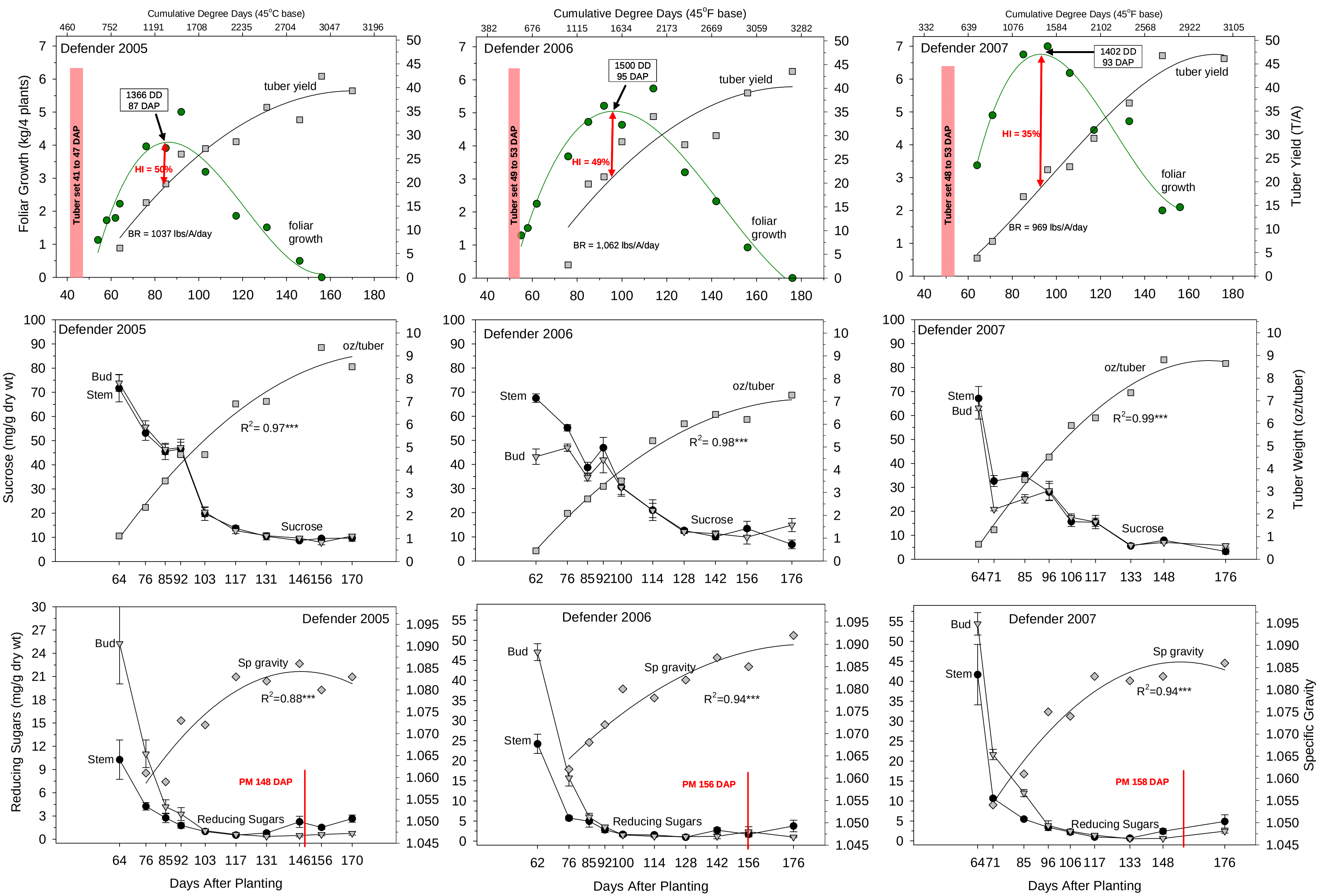


Fig. 5. Foliar and tuber growth (top row) of **Defender** under late-season management at Othello, WA during 2005 (left), 2006 (middle), and 2007 (right). Planting dates were April 11 (2006 & 07) and April 13 (2005). Plants were harvested at approximately 10-day intervals over the 170-176-d growing seasons. Changes in sucrose concentration and average tuber weight (middle row), and reducing sugars (glucose and fructose) and specific gravity (bottom row) are also shown. Except for 2005 reducing sugars, Y- and X-axis scales are equal to facilitate comparisons over years. The onsets and durations of tuberization are indicated (shaded windows, top row). Physiological maturity (PM) was estimated at 148-, 156-, and 158-DAP in 2005, 2006 and 2007, respectively (bottom row). HI = Harvest Index (percentage of plant fresh weight accounted for by tubers at maximum foliar growth). Cumulative degree days (DD) at the corresponding days after planting (DAP) are shown (top row). BR = initial tuber bulking (growth) rate from about 64 DAP to foliar maximum (top row).

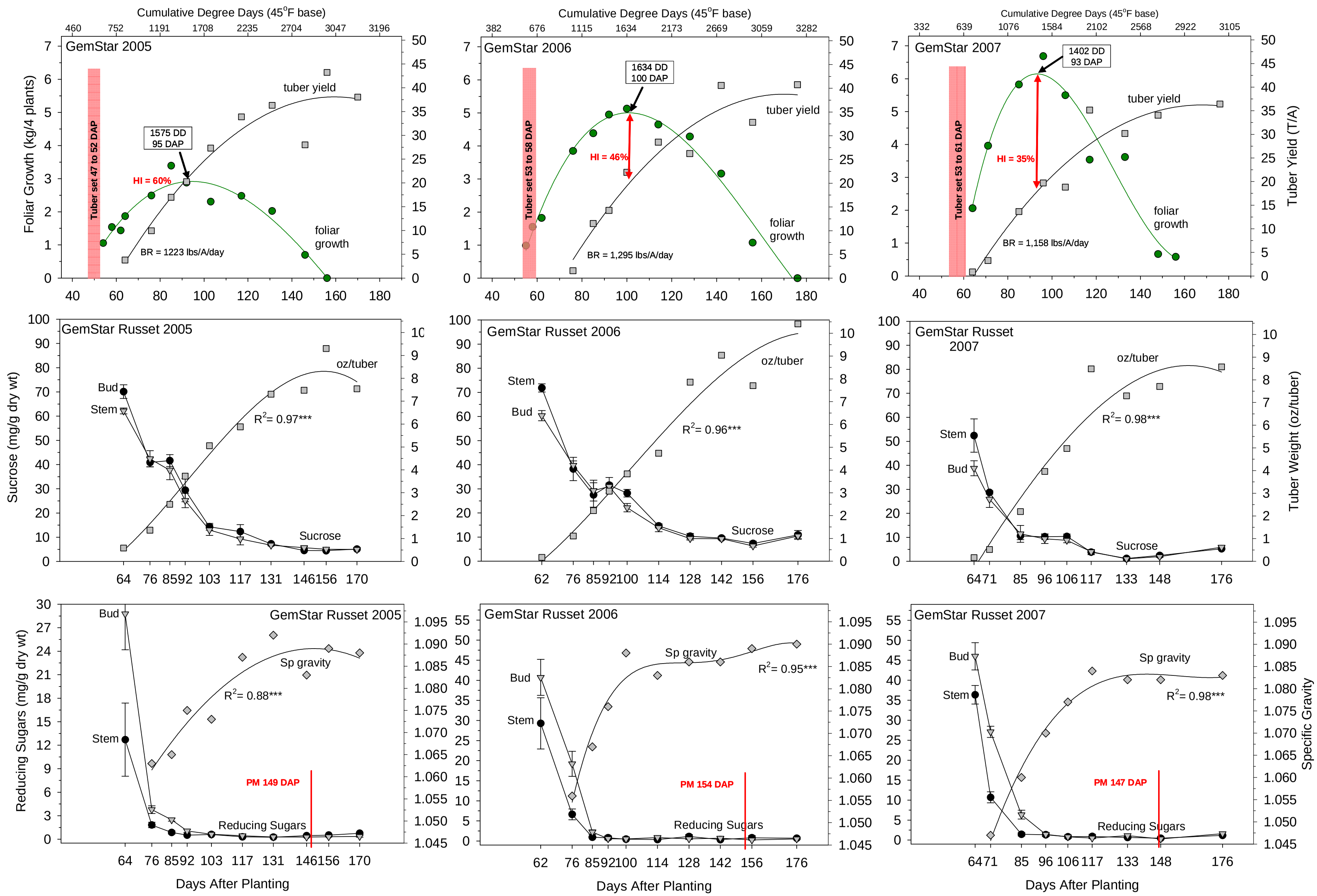


Fig. 6. Foliar and tuber growth (top row) of **GemStar Russet** under late-season management at Othello, WA during 2005 (left), 2006 (middle), and 2007 (right). Planting dates were April 11 (2006 & 07) and April 13 (2005). Plants were harvested at approximately 10-day intervals over the 170-176-d growing seasons. Changes in sucrose concentration and average tuber weight (middle row), and reducing sugars (glucose and fructose) and specific gravity (bottom row) are also shown. Except for 2005 reducing sugars, Y- and X-axis scales are equal to facilitate comparisons over years. The onsets and durations of tuberization are indicated (shaded windows, top row). Physiological maturity (PM) was estimated at 149-, 154-, and 147-DAP in 2005, 2006 and 2007, respectively (bottom row). HI = Harvest Index (percentage of plant fresh weight accounted for by tubers at maximum foliar growth). Cumulative degree days (DD) at the corresponding days after planting (DAP) are shown (top row). BR = initial tuber bulking (growth) rate from about 64 DAP to foliar maximum (top row).

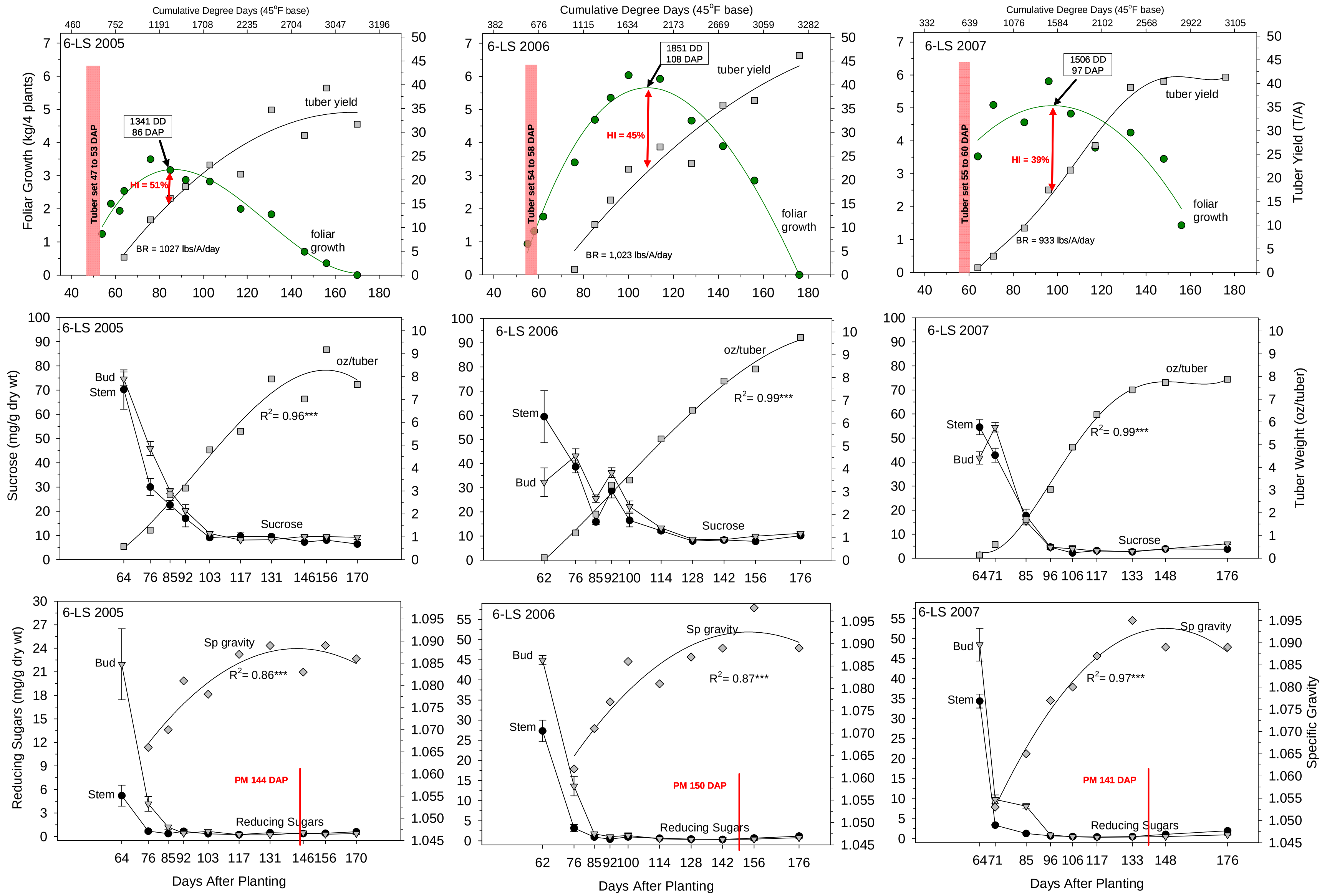


Fig. 7. Foliar and tuber growth (top row) of **6LS** under late-season management at Othello, WA during 2005 (left), 2006 (middle), and 2007 (right). Planting dates were April 11 (2006 & 07) and April 13 (2005). Plants were harvested at approximately 10-day intervals over the 170-176-d growing seasons. Changes in sucrose concentration and average tuber weight (middle row), and reducing sugars (glucose and fructose) and specific gravity (bottom row) are also shown. Except for 2005 reducing sugars, Y- and X-axis scales are equal to facilitate comparisons over years. The onsets and durations of tuberization are indicated (shaded windows, top row). Physiological maturity (PM) was estimated at 144-, 150-, and 151-DAP in 2005, 2006 and 2007, respectively (bottom row). HI = Harvest Index (percentage of plant fresh weight accounted for by tubers at maximum foliar growth). Cumulative degree days (DD) at the corresponding days after planting (DAP) are shown (top row). BR = initial tuber bulking (growth) rate from about 64 DAP to foliar maximum (top row).

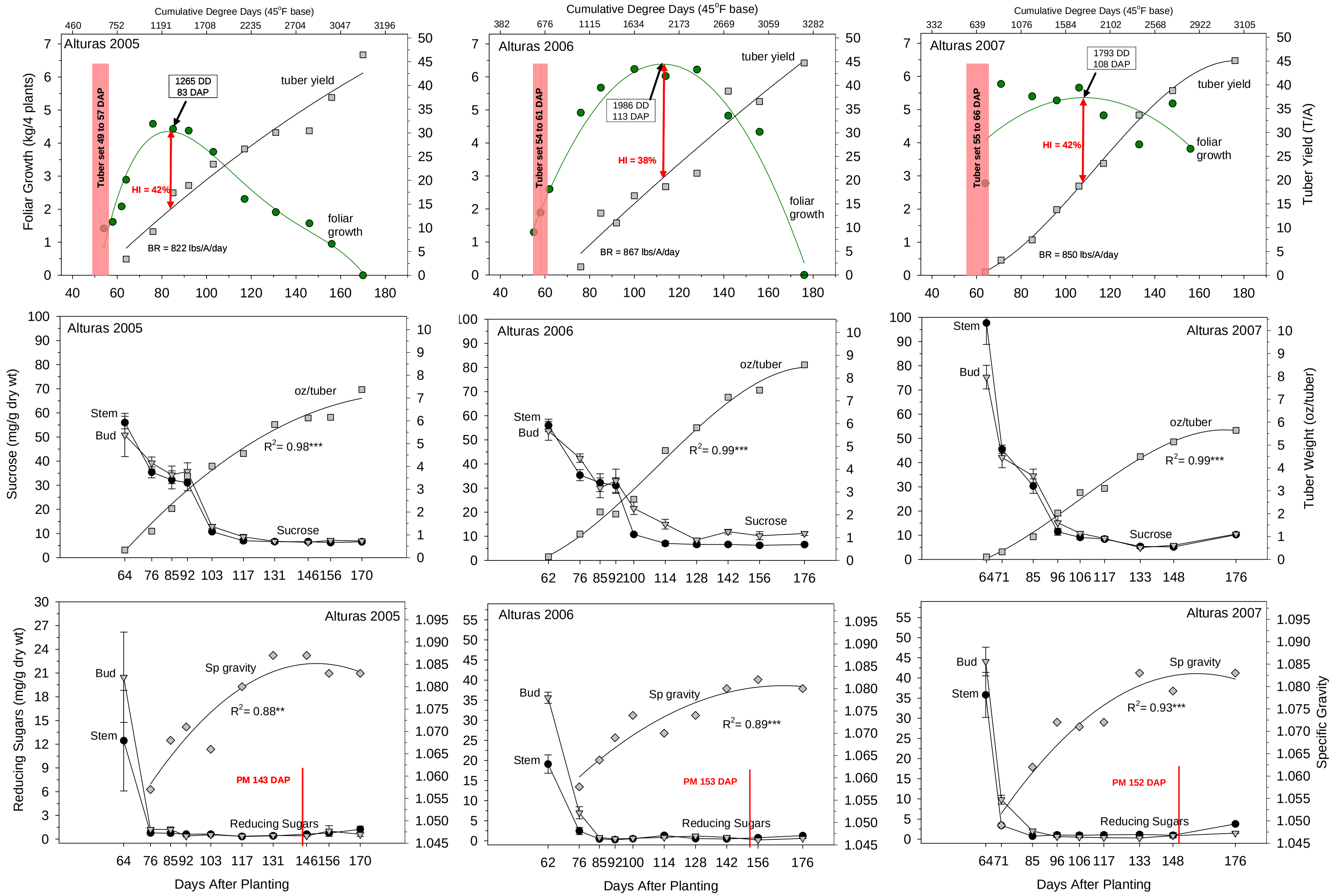


Fig. 8. Foliar and tuber growth (top row) of **Alturas** under late-season management at Othello, WA during 2005 (left), 2006 (middle), and 2007 (right). Planting dates were April 11 (2006 & 07) and April 13 (2005). Plants were harvested at approximately 10-day intervals over the 170-176-d growing seasons. Changes in sucrose concentration and average tuber weight (middle row), and reducing sugars (glucose and fructose) and specific gravity (bottom row) are also shown. Except for 2005 reducing sugars, Y- and X-axis scales are equal to facilitate comparisons over years. The onsets and durations of tuberization are indicated (shaded windows, top row). Physiological maturity (PM) was estimated at 143-, 153-, and 152-DAP in 2005, 2006 and 2007, respectively (bottom row). HI = Harvest Index (percentage of plant fresh weight accounted for by tubers at maximum foliar growth). Cumulative degree days (DD) at the corresponding days after planting (DAP) are shown (top row). BR = initial tuber bulking (growth) rate from about 64 DAP to foliar maximum (top row).

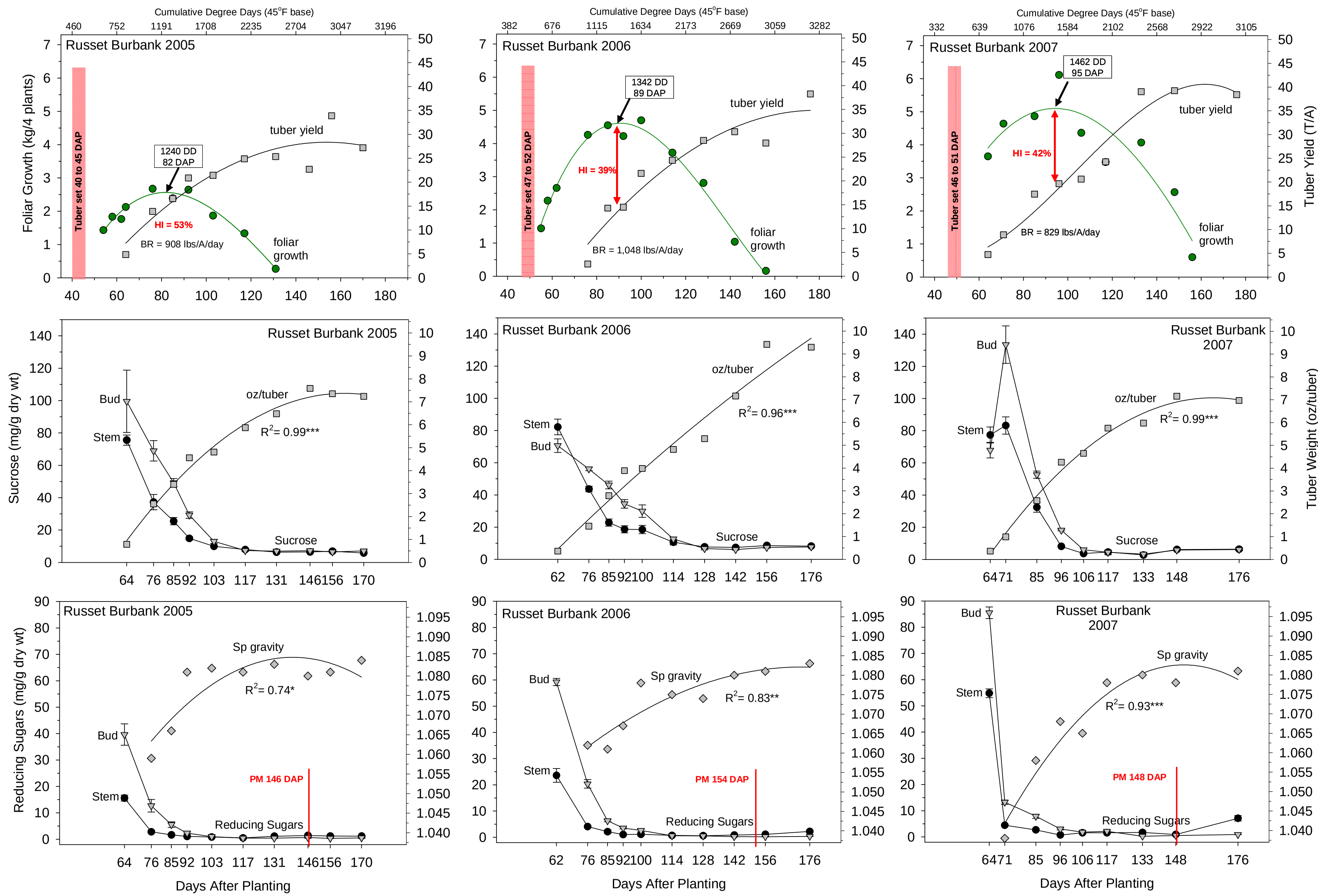


Fig. 9. Foliar and tuber growth (top row) of **Russet Burbank** under late-season management at Othello, WA during 2005 (left), 2006 (middle), and 2007 (right). Planting dates were April 11 (2006 & 07) and April 13 (2005). Plants were harvested at approximately 10-day intervals over the 170-176-d growing seasons. Changes in sucrose concentration and average tuber weight (middle row), and reducing sugars (glucose and fructose) and specific gravity (bottom row) are also shown. Y- and X-axis scales are equal to facilitate comparisons over years. The onsets and durations of tuberization are indicated (shaded windows, top row). Physiological maturity (PM) was estimated at 146-, 154-, and 148-DAP in 2005, 2006 and 2007, respectively (bottom row). HI = Harvest Index (percentage of plant fresh weight accounted for by tubers at maximum foliar growth). Cumulative degree days (DD) at the corresponding days after planting (DAP) are shown (top row). BR = initial tuber bulking (growth) rate from about 64 DAP to foliar maximum (top row).

Fig. 10. Harvest indices (HI) of seven cultivars grown under late-season management at Othello, WA in 2005, 06, and 07. HI is the ratio of tuber fresh wt to tuber plus foliar fresh wt (expressed as a percentage) and is a measure of the efficiency with which a cultivar partitions fresh wt into tubers. HI was calculated at maximum foliar fresh weight for each cultivar in each year. Numbers in bars are days after planting (DAP) to maximum foliar fresh weight (see growth curves in Figs. 3-9).

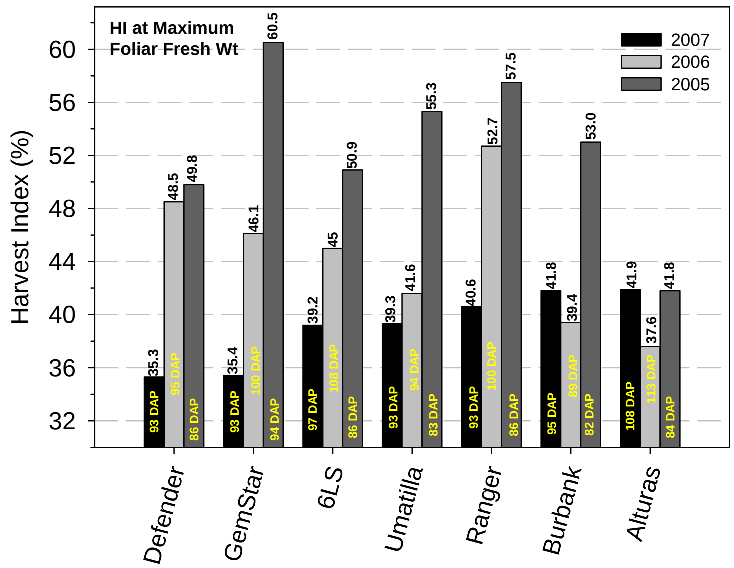


Table 1. Timing of tuberization for various cultivars grown at the Irrigated Agriculture Extension and Research Center (IAERC), Othello, WA. Planting dates were April 13 in 2005 and April 11 in 2006 and 2007. The days after planting (DAP) to 35% tuberization and 20-50% tuberization 'windows' were calculated from polynomial regressions of percentage stolons tuberized versus DAP. Tuberization windows are shaded in Figs. 3-9.

	2005 % stolons tuberized		2006 % stolons tuberized		2007 % stolons tuberized	
Cultivar	35%	20–50%	35%	20–50%	35%	20–50%
	Days After Planting to Tuberization					
R. Burbank	42	40–45	50	47–52	49	46–51
Defender	43	41–47	51	49–53	50	48–53
Umatilla	47	44–51	52	50–54	49	47–52
Ranger	42	40–45	52	50–54	48	46–51
GemStar	50	47–52	56	53–58	58	53–61
6-LS	50	47–53	57	54–58	58	55–60
Alturas	53	49–57	57	54–61	61	55–66

Cultivar	Initial Bulking Rate* 2005	2006	2007	Avg
	Lbs/acre/day			
Burbank	908	1048	829	928
Defender	1037	1062	969	1023
Umatilla	929	1092	1010	1010
Ranger	1114	1234	829	1059
GemStar	1223	1295	1158	1225
6LS	1027	1023	933	994
Alturas	822	867	850	846

*Bulking rate calculated from 1st tuber harvest (64-76 DAP) to maximum foliar fresh wt.

Table 2. Initial tuber bulking (growth) rates for seven cultivars grown under late season management at Othello, WA (2005-07). Planting dates were April 13 in 2005 and April 11 in 2006 and 2007. Bulking rates were calculated from polynomial regressions of tuber yield versus days after planting (DAP) over the period from 64 DAP to foliar maxima (see Figs. 3-9).

Cultivar	Maximum Foliar Biomass 2005	2006	2007	Avg
	T/Acre			
Burbank	13.0	23.4	25.9	20.8
Defender	20.8	25.7	34.4	26.9
Umatilla	14.5	24.5	28.9	22.6
Ranger	13.6	21.7	26.1	20.4
GemStar	14.9	25.4	31.3	23.8
6LS	16.2	28.8	25.8	23.6
Alturas	22.3	32.5	27.3	27.3

Vine weights are estimated from growth curves.

Table 3. Foliar biomass (above ground vines) produced by seven cultivars grown under late season management at Othello, WA (2005-07). Vine fresh weights were measured at maximum foliar growth which occurred 82 to 113 days after planting, depending on cultivar and season (see Figs. 3-9). Planting dates were April 13 in 2005 and April 11 in 2006 and 2007.

Cultivar	Final* Marketable Yields			
	2005	2006	2007	Avg
	T/Acre			
Burbank	28.4	34.8	40.5	34.6
Defender	39.3	40.3	47.0	42.2
Umatilla	32.0	35.5	46.3	37.9
Ranger	33.6	39.2	42.2	38.3
GemStar	38.1	38.7	36.2	37.7
6LS	34.2	44.0	41.3	39.8
Alturas	42.6	45.2	45.1	44.3

*U.S. No.1 + <4-oz tubers; 170 DAP in 2005 and 176 DAP in 2006 and 2007. Vine kill was 156 DAP in all years. Final yields are estimated from tuber yield curves in Figs. 1-7.

Table 4. Final marketable yields for seven cultivars grown under late season management at Othello, WA (2005-07). Planting dates were April 13 in 2005 and April 11 in 2006 and 2007. Foliar growth, tuber growth, and changes in tuber carbohydrates are detailed in Figs. 3-9.

Cultivar	Tuber Yield vs. Foliar F Wt	
	slope	R^2
Burbank	0.8	0.91
Defender	0.6	0.94
Umatilla	0.9	0.76
Ranger	0.7	0.99
GemStar	-0.1	0.36
6LS	0.8	0.99
Alturas	0.2	0.77

T/A final yield vs. T/A max vine wt.

Table 5. Linear regression coefficients (slope) and coefficients of determination (R^2) for tuber yield versus maximum foliar fresh weight (biomass). On a per acre basis, slopes indicate the tonnage increase in final yield of marketable tubers expected per ton extra of vine growth at maximum foliar development (82-113 days after planting).

Table 6. Days after planting to reach tuber physiological maturity for seven cultivars grown under late season management at Othello, WA (2005-07). Planting dates were April 13 in 2005 and April 11 in 2006 and 2007. Foliar growth, tuber growth, and changes in tuber carbohydrates are detailed in Figs. 3-9.

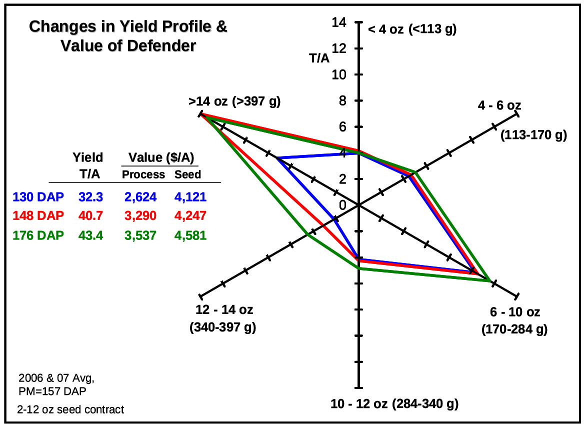
	Days After Planting to Physiological Maturity*			
Cultivar	**2005**	**2006**	**2007**	**Avg**
	Days After Planting			
Burbank	146	154	148	151
Defender	148	156	158	154
Umatilla	151	160	145	152
Ranger	141	163	148	151
GemStar	149	154	147	150
6LS	144	150	141	145
Alturas	143	153	152	149

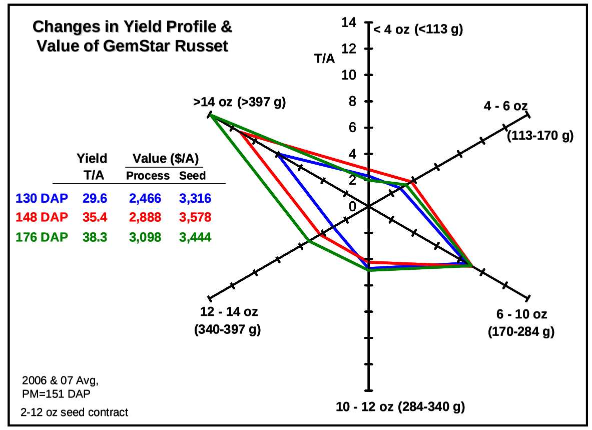
*PM is defined as the average of DAP to reach maximum sp gravity, maximum tuber yield, minimum tuber sucrose, and the beginning of increase in reducing sugars in the stem ends of tubers.

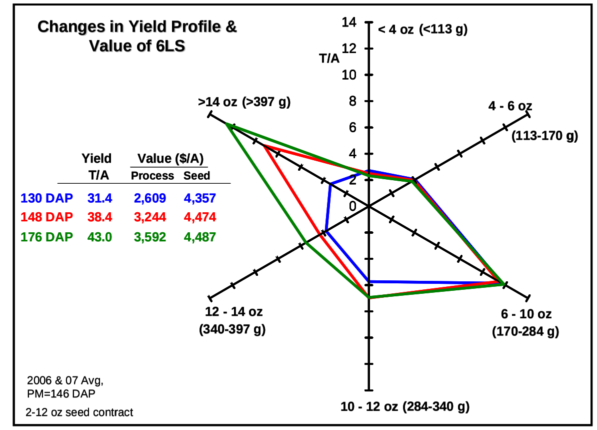
Table 7. Changes in gross value per acre for seven cultivars grown under late season management at Othello, WA (2006-07). Values were assessed based on yield and tuber size distribution in accordance with standard Columbia Basin late processing contracts. Changes in tuber size distribution are shown in Fig. 11. The days after planting to physiological maturity (PM) were assessed as described in Table 6 (footnote). Planting date was April 11 in both years.

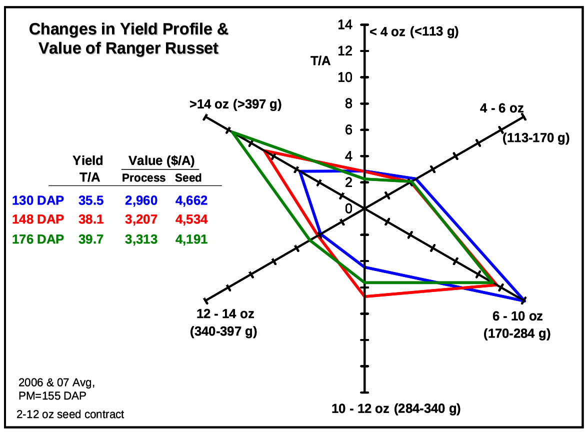
		Avg 2006/2007 Days After Planting		
Cultivar	**PM***	**130**	**148**	**176**
	DAP	*$/Acre (T/A)*		
Burbank	151	2,231 (29.1)	2,919 (35.7)	3,175 (38.0)
Defender	157	2,624 (32.3)	3,290 (40.2)	3,537 (43.4)
Umatilla	153	2,603 (32.2)	2,717 (34.5)	3,429 (41.9)
Ranger	155	2,960 (35.5)	3,207 (38.1)	3,313 (39.7)
GemStar	151	2,466 (29.6)	2,888 (35.4)	3,098 (38.3)
6LS	146	2,609 (31.4)	3,244 (38.4)	3,592 (43.0)
Alturas	153	1,895 (27.6)	2,997 (38.3)	3,536 (43.6)

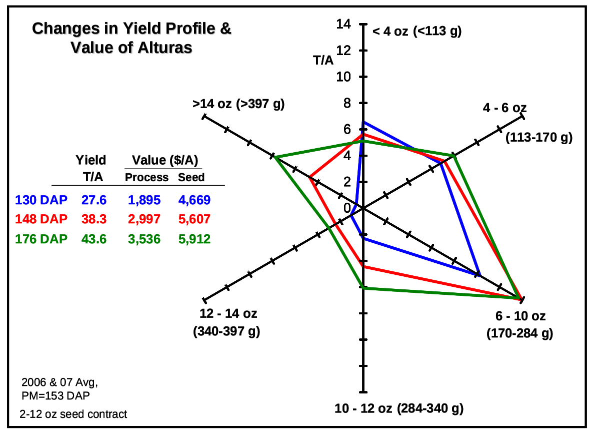
*PM, physiological maturity. Vine kill = 156 DAP.

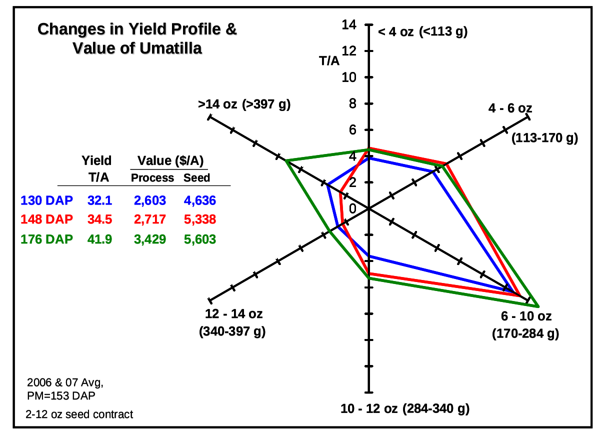












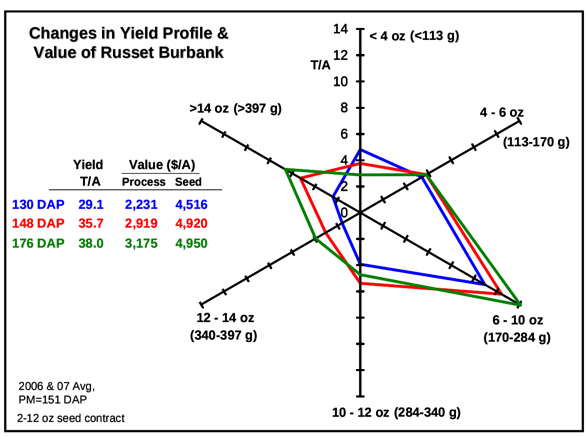


Fig. 11. Polygonal plots illustrating tuber size distributions at 130-, 148- and 176-days after planting (DAP) for seven cultivars grown under late season management at Othello, WA (average of 2006 and 2007). The yields (T/A) of <4-oz, 4-6 oz, 6-10 oz, 10-12 oz, 12-14 oz, and >14-oz U.S. No. 1 tubers are plotted on the six axes for each cultivar. All axes range from 0 to 14 T/A. Changes in shape and size (area) of the resulting polygons with DAP illustrate shifts in tuber size distribution and yield, respectively, over the latter part of the growing season. The yields, process values, and seed values (i.e. as a seed crop) at 130, 148, and 176 DAP (corresponding to each polygon for a particular cultivar) are shown in the inset tables and in Table 7. Vine kill was 156 DAP.

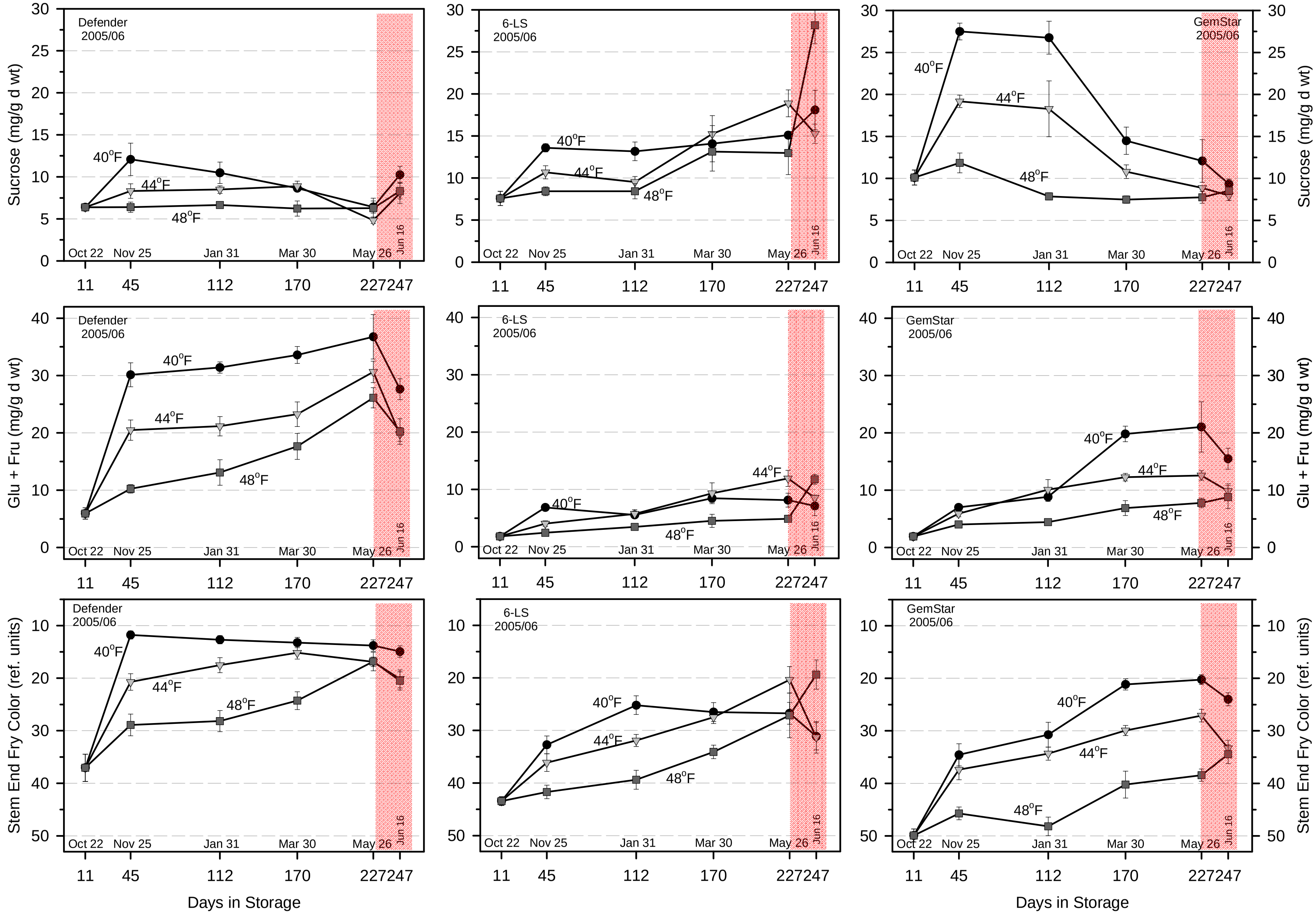


Fig. 12. Temperature-induced changes in sucrose (top row), reducing sugars (middle row), and fry processing quality (bottom row) during storage of Defender (left column), 6LS (middle column), and GemStar (right column) tubers grown in **2005** at Othello, WA. The tubers were wound-healed at 54°F for 11 days prior to storage at the indicated temperatures and reconditioned at 60°F from May 26 to June 16 (shaded). Note the inverted scale on the fry color axis (bottom row). Low photovolt reflectance (ref) values indicate darker fries. A photovolt reflectance ≤19 is a USDA 3 or greater French fry, which is unacceptable by industry standards. USDA 2 = 20-24 ref. units, USDA 1 = 25-30 ref. units, USDA 0 ≥31 ref. units. Each point is the average of 12 tubers ±SE.

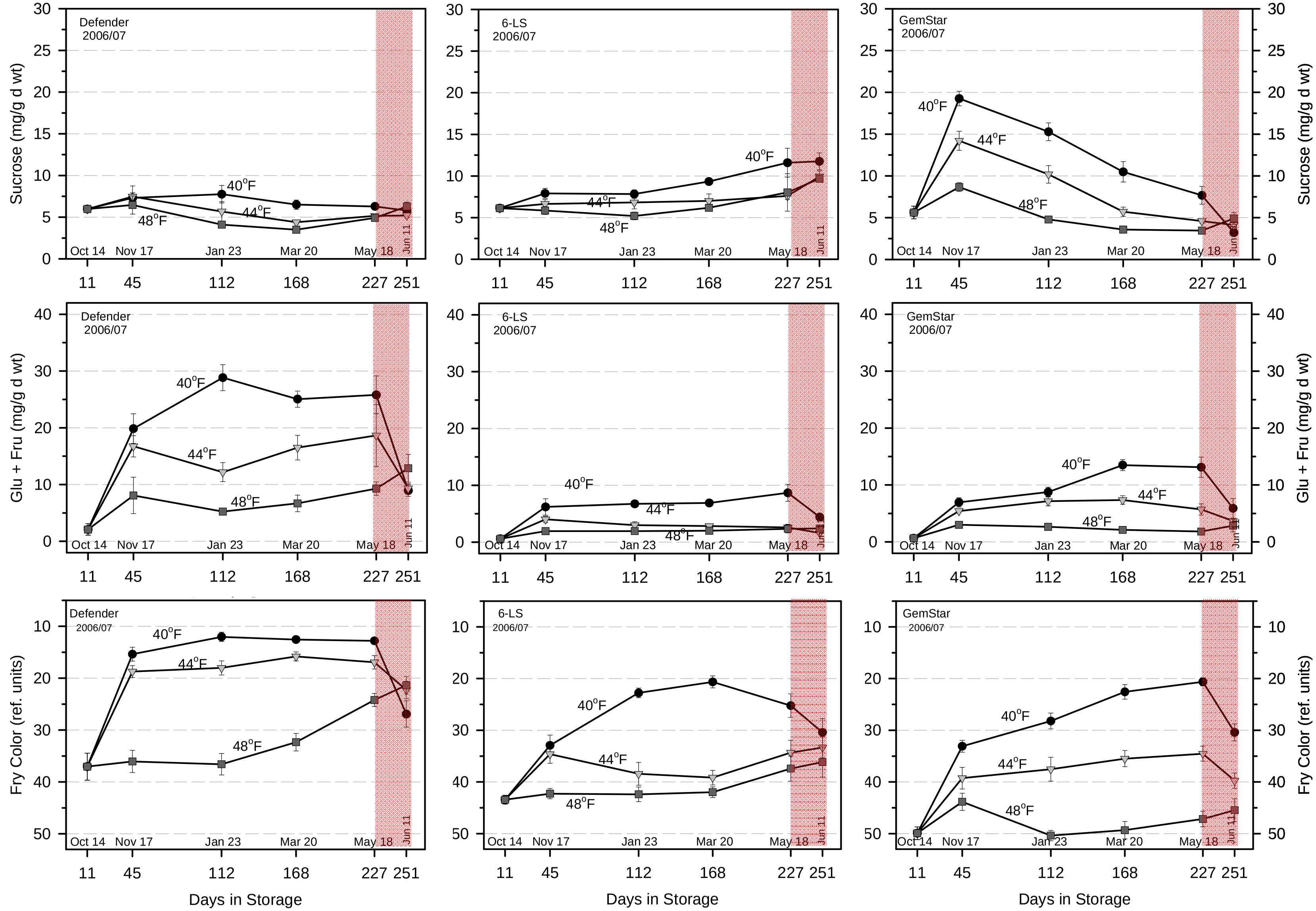


Fig. 13. Temperature-induced changes in sucrose (top row), reducing sugars (middle row), and fry processing quality (bottom row) during storage of Defender (left column), 6LS (middle column), and GemStar (right column) tubers grown in **2006** at Othello, WA. The tubers were wound-healed at 54°F for 11 days prior to storage at the indicated temperatures and reconditioned at 60°F from May 18 to June 11 (shaded). Note the inverted scale on the fry color axis (bottom row). Low photovolt reflectance (ref) values indicate darker fries. A photovolt reflectance ≤19 is a USDA 3 or greater French fry, which is unacceptable by industry standards. USDA 2 = 20-24 ref. units, USDA 1 = 25-30 ref. units, USDA 0 ≥31 ref. units. Each point is the average of 12 tubers ±SE.

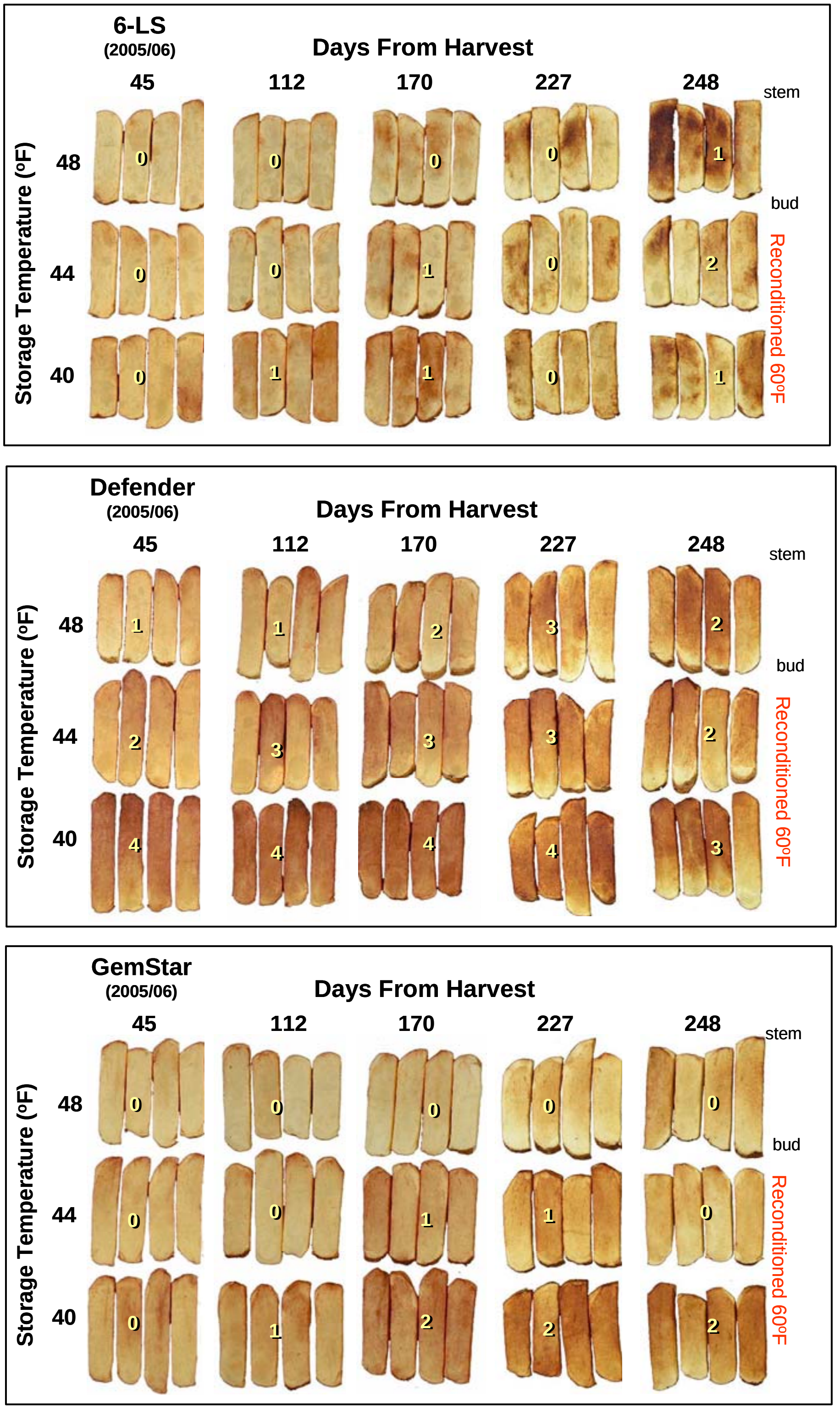


Fig. 14. Changes in processing quality of 6LS, Defender, and GemStar Russet over 227 days of storage at 40, 44 and 48^{o}F (2005 crop). Tubers stored at each temperature were reconditioned for 21 days at 60^{o}F from 227 to 248 days after harvest. Each fry plank is from a different tuber selected to represent the average fry color in a 12-tuber sample. Numbers on the fries indicate the average USDA values of the stem (darkest) ends of the 12-tuber samples. Note the progressive mottling of fries from 6LS tubers starting about 170 days after harvest. The disorder is characterized by localized pockets of reducing sugars that darken during frying. Similar results were obtained for all three cultivars during the 2006/07 storage season. Fry colors are plotted in Figures 12 and 13.