Optimizing Crop Development & Process Quality of Clearwater Russet in the Columbia Basin

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The objectives of this 3-yr study were to define the growth and yield responses of Clearwater Russet to nitrogen (N) fertility, model the attainment of tuber physiological maturity (PM), and determine subsequent effects on retention of process qualities during storage. Clearwater was grown with four rates of seasonal N – 150, 250, 350, and 450 lb/A (avg over 3-yr period) (Table 1). The N was applied with a custom flood sprayer designed to deliver the desired amount of N in a volume of water consistent with fertigation through a center pivot. Plots were fertigated with solution 32 (urea and ammonium nitrate) starting 14 days after emergence (DAE) according to the schedule shown in Table 1 (avg dates over the 3-yr study period). On average, N applications ceased at the end of July. Petiole NO₃-N levels were comparable across the four rates of N fertility early in the season but then declined as the season progressed; the rate of decline was inversely related to N rate (data not shown). Petiole NO₃-N levels thus correlated well with N fertility rates.

Foliar & Tuber Growth Profiles

Averaged over the N rates, maximum foliar growth was achieved at ~100 DAP (Figs. 1 & 2). Maximum foliar biomass increased 31% (from 14.0 to 18.3 T/A) as N increased from 150 to 450 T/A. The duration of foliar growth was also extended late in the season with increasing N (Fig. 2). Total yield of Clearwater increased (11%, 3.9 T/A) from 150 to 350 lb/A N, then fell by 1.4 T/A at the highest N rate (450 lb/A). Similar yield responses were characterized for Mtn Gem Russet, Castle Russet, Targhee, A03921-2, A06084-1TE, A02424-83LB, GemStar, and Payette Russet over these N rates (2-3 seasons each, depending on cultivar) (data not shown). Maximum yields of these cultivars/clones were achieved at ~350 lb/A N and the increase in yield from 150 to 350 lb/A N averaged 2.8 T/A (8.2%).

An economic analysis of the Clearwater yield data conducted by Bolding (2017) and Pavek showed adjusted gross returns at 350 to 375 lb/A N under the late management conditions of this study (Fig. 2). They recommend that soil and petiole analyses be used as a guide to achieve the 350-375 lb/A seasonal target for N fertility. In a ‘typical season’ petiole NO₃-N should be between 21,000-26,000 ppm.

Table 1. Fertigation schedule for Clearwater Russet N rate trials averaged over 3 years (2014-16, Othello, WA). Planting dates averaged April 15. Plots contained 120 lb/A residual N at planting. Fertigation began approximately 14 days after emergence (DAE) on June 1 (47 DAP). Row closure occurred about 59 DAP (28 DAE). Fertigation ceased after the July 8 application (84 DAP) for the 150 lb/A treatment and after July 28 (104 DAP) for all other treatments.
with soil N >50 lb/A until early bulking (~90 DAP). Soil N should then decrease along with petioles to 15,000-23,000 ppm through mid-bulking (~115 DAP), and then decrease further to 11,000-19,000 ppm at late bulking (~125 DAP). However, in a season with an unusually warm spring (e.g., 2016), petiole NO₃-N can fall to very low levels due to rapid foliar growth and should not be relied upon to steer weekly application rates (Pavek et al., 2018). Instead, rely on calendar scheduling (historical records) along with soil analysis to guide weekly application rates to achieve seasonal targets (see Pavek et al., 2018).

**Fig. 1.** Three-year average foliar, tuber, and total biomass (foliar + tuber yield) yield profiles for Clearwater Russet under four levels of nitrogen (N) at Othello, WA (2014-16). Planting and harvest dates averaged April 15 and Oct. 14 (183 DAP), respectively, over the 3 growing seasons. Cumulative degree days (DD) are shown on the top axis of each graph. The red line marks the maximum foliar yield at 150 lb/A N. Note that maximum foliar growth increased with increasing N as did foliar duration (see also Fig. 2 below).

**Fig. 2.** Effects of seasonal N rates on foliar growth (left), total tuber yield, and adjusted gross value (right) of Clearwater Russet. Data are averaged over three growing seasons (2014-16). Maximum foliar growth and duration of foliar growth increased with N. Adjusted gross value (minus N cost) increased 10% from 150 to 350 lb/A N (Bolding, 2017). The green shaded area indicates the ideal seasonal N fertility range (350-375 lb/A N) for maximizing yield and gross return.
Tuber Physiological Maturity

A major objective was to determine how N fertility influenced the attainment of tuber physiological maturity at season end to subsequently affect retention of process quality in Clearwater tubers during storage. Tuber physiological maturity was calculated as the average days after planting to reach (1) maximum yield, (2) maximum specific gravity, (3) minimum sucrose, and (4) minimum reducing sugars in the stem ends of tubers (Wohleb et al., 2014). Tuber specific gravity, sucrose, and reducing sugars were quantified at ~15-day intervals from 55 to 183 DAP and compared with the foliar and tuber growth profiles to estimate PM as affected by N fertility over the 3-year study period (Fig. 3).

Average tuber fresh weight of Clearwater increased 11% (6.6 to 7.4 oz/tuber) as N increased from 150 to 350 lb/A (Fig. 3, middle row). No additional increase was observed at 450 lb/A N. Tuber sucrose levels fell rapidly from 60 to 100 DAP and then remained at relatively low levels during late bulking and maturation (Fig. 3). The attainment of maximum specific gravity was delayed with increasing N rate. Tubers grown with 150 and 350 lb/A N had final gravities averaging 1.095 and 1.088, respectively, over the 3-yr study period. Similar to sucrose, reducing sugar (RS) concentrations were highest at 60 DAP (data point not shown in Fig. 3) when tubers were less than 1 oz in weight. Tuber RS concentrations at 60 DAP decreased with increasing N rate (data not shown), a consequence of the more advanced early tuber development at the higher N regimes. Tuber RS concentrations fell from 60 to 100 DAP, remained low and constant through 130 DAP, then increased in the stem end of tubers through 183 DAP (Fig. 3).

Tuber physiological maturity (PM) was delayed by 12 days (from 133 to 145 DAP) with increasing N rate (Figs. 3 and 4). Most importantly, the end-of-season post-PM upswing in stem-end RS increased with tuber maturation period beyond PM (Fig. 4) and is an indicator of tuber physiological age. Physiological aging of tubers under dead vines following PM is accelerated by exposure to fluctuating soil temperatures (e.g., Fig. 5). We demonstrated this phenomenon in separate studies with Clearwater, where tubers harvested at PM were stored for 32 days with oscillating temperatures (24-h cycle, 50 to 72 to 50°F) to mimic the effect of fluctuating soil temperatures. The oscillating temperature regime accelerated the aging process, resulting in tubers averaging 9% higher respiration rates ($P<0.001$) following treatment and over a subsequent 2-week storage period at 44°F, 35% greater buildup in reducing sugars ($P<0.001$) over full-season storage at 44°F, and 16% darker fry color ($P<0.001$) when compared with tubers held at a constant 61°F (mean of daily cycling temperature) over the same 32-day period directly following PM (data not shown).

Reducing sugar concentrations in tubers from the 2014 and 2015 N trials (Fig. 6) increased during the first month of storage at 44°F and then remained constant or decreased over the remainder of the 7.5-month storage period depending on N rate (Fig. 6). By 229 days of storage, tuber RS concentrations in tubers grown with 350 and 450 lb/A N were 23 and 52% lower, respectively, than the average of tubers grown with 150 and 250 lb/A N (Fig. 6) and this resulted in up to 23% lighter process fry color, as shown for the physiologically mature tubers that had been subjected to oscillating temperatures in the postharvest study described above. By influencing the timing of tuber PM and thus the post maturation period under dead vines prior to harvest at 183 DAP (exposed to fluctuating soil temperatures), N fertility affected the physiological age of tubers at harvest, their rate of aging during storage, subsequent reducing sugar buildup, and retention of process quality (fry color). Therefore, to maximize retention of process quality during storage, in-season management (e.g., fertility, irrigation, etc.) should be tailored to allow proper maturation of tubers at season end. Management inputs should be adjusted to permit the crop to complete its annual growth cycle within the available growing season, which will differ with production region. Harvesting too early when the crop is actively growing, or maintaining N fertigation late in the season (e.g., well beyond 1st week in Aug.) in an attempt to get the highest possible yield will likely produce physiologically immature tubers with lower gravity that will lose process quality relatively early in storage. Conversely, exposure of tubers to oscillating soil temperatures for an extended period under dead vines after physiological maturity accelerates tuber aging and will also compromise the ability of tubers to maintain process quality during full-season storage.
Summary & Recommendations

- Consider physiological maturity (PM) when deciding when to harvest:
  - Recognize that PM in Clearwater (grown with 350-375 lb/A N) occurs when the crop still has ~60% green vines (~145 DAP; 3,000 growing degree days (GDD); 60/40 green vines/dead vines).
  - At PM, approximately half the crop will be in late stage bulking and the other half will be under dead vines in the skin-set phase of maturation where physiological age is accelerated by temperature.
  - The challenge is to minimize tuber exposure to diurnal fluctuations in soil temperature under dead vines without sacrificing the yield potential for tubers still bulking under green vines.

- To maximize both yield and storage potential in a ‘green vine’ harvest scenario, plan to lift the crop within 10-18 days of PM (145 DAP) = 155-163 DAP; 3,100-3,300 GDD (45°F base); 35-40% green vines. Adhere to best management practices (BMP) for minimizing bruise/mechanical damage during harvesting.

- For a ‘vine-kill’ harvest scenario, desiccate at ~155 DAP (~40-45% green vines) and harvest 7-14 days later.

- Adhere to best management practice recommendations for minimizing bruise and other mechanical damage for bruise-free incentives and to minimize dry rot potential.

- Prolonged maturation period under dead vines (PM to harvest) subjects the crop to diurnal fluctuations in temperature that accelerates tuber aging, which can affect retention of quality – dormancy length, weight loss potential, sugar buildup.

- Clearwater is inherently resistant to low temperature sweetening (LTS) (Novy et al., 2010) and this trait confers increased tolerance of delayed harvest beyond PM for maintaining low sugars and process quality during storage compared with LTS-susceptible cultivars. Nonetheless, our research has demonstrated that tubers should be harvested as close to PM as possible (e.g., within 10-18 days of PM) to maximize retention of process quality during long-term storage.

Literature Cited

Bolding, Kathryn R. 2017. Fine-tuning the cultural management of Russet Burbank and Clearwater Russet potatoes by investigating in-row spacing, seed-type, and/or nitrogen rate. MS Thesis, Washington State University, Pullman, WA. pp. 43-64.


Fig. 3. Foliar and tuber growth (top row), average tuber weights and sucrose concentrations (middle row), and reducing sugars (glucose + fructose) and specific gravity (bottom row) were profiled as components of physiological maturity (PM). PM was estimated at 133, 135, 141, and 145 DAP as N rate increased from 150 to 450 lb/A (bottom row) and is plotted vs N in Fig. 4. Note the increase in reducing sugars in the stem end of tubers following PM.
Increased N Delays the Attainment of Tuber Physiological Maturity

Stem End Reducing Sugars Increase after Physiological Maturity

Fig. 4. (left) Effects of N fertility on days after planting to tuber physiological maturity (PM) of Clearwater Russet (2014-16). PM is the average DAP to reach max yield, max specific gravity, minimum sucrose, and minimum reducing sugars in tubers (see Fig. 3). Yield and value were maximized at 350-375 lb/A N (green shaded area). This coincided with ~2,950-3,000 growing degree days (GDD) (45°F base). Past work with many cultivars has demonstrated that tubers should be harvested within 10-14 days of PM for longest retention of process quality during storage. (right) Delaying harvest well beyond PM (i.e. extending the maturation period from PM to harvest) exposes tubers to fluctuating soil temperatures (see Fig. 5) that can accelerate aging, resulting in physiologically older tubers that contain higher concentrations of stem end reducing sugars. The reducing sugars often continue to increase in storage, which will negatively affect process quality.

Fig. 5. Daily fluctuation in soil temperature (5-inch depth) during the late bulking and maturation phases of crop development (2016 season). Physiological maturity (PM) for Clearwater was reached at ~141-145 DAP (shaded). Exposure of tubers to fluctuating soil temperatures following the attainment of PM accelerates physiological aging, which can ultimately lead to buildup in reducing sugars earlier in storage, with associated negative consequences for process quality (see Fig. 6).
**Fig. 6.** *(Left)* Changes in tuber reducing sugar concentrations during storage at 44°F averaged over the 2014 and 2015 seasons. Representative fry planks from tubers grown with 450 lb/A N are shown at the beginning (9 DAH) and end (229 DAH) of storage compared with tubers grown with 250 lb/A N. Note the sugar end development in tubers grown with lower N fertility. This was likely a consequence of longer maturation of tubers in the field post-PM (see Figs. 3 and 4) compared with tubers from the 450 lb/A N regime. *USDA fry color. *(Right)* Effects of nitrogen on retention of process quality of Clearwater Russet tubers following wound healing at 54°F and 234 days of storage at 48°F (2015 trial). Processing quality deteriorated noticeably by 234 days after harvest, even though average fry color was still acceptable by industry standards. The maturation period (PM to harvest) for tubers grown with higher N rates was shorter (= longer retention of lighter fry color) than for tubers grown with lower N rates. The percent values indicate the average improvement in fry color relative to tubers grown with 150 lb/A N. Each fry plank is from a different tuber selected to represent the average fry color in a 12-tuber sample.