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Contents

Understanding the resistance response to *Meloidogyne chitwoodi* introgressed from *Solanum bulbocastanum* into cultivated potato

Sapinder Bali, Kelly Vining, Cynthia Gleason, Chuck Brown, Hassan Mojtahedi, Vidyasagar Sathuvalli

Meloidogyne chitwoodi (Columbia root-knot nematode; CRKN) is one of the most devastating pest of potato in the Pacific Northwest region of the United States. CRKN is a soil-borne pest that infects potato roots as well as tubers. Tuber damage is evident in the form of internal (blemishes) as well as external (bumps) defects that make the crop unfit for commercial use (Figure 1). Currently, soil fumigation is the preferred method to control this nematode. However, host resistance is viewed as one of the most effective and environmentally friendly approaches to control nematode damage but no commercial potato variety is known to harbor CRKN resistance. CRKN resistance was first identified in the wild diploid species *Solanum bulbocastanum* (clone SB22), and this resistance was introgressed into a tetraploid selection, PA99N82-4 by using protoplast fusion and conventional breeding. A single dominant gene mapped onto Chromosome 11 (Brown et al 1996) controls this resistance but the underlying resistance mechanism is still unknown. In order to unveil the molecular events leading to resistance response, we used RNAseq technology to study the differential gene expression between CRKN resistant PA99N82-4 and a susceptible cultivar Russet Burbank. The resistant and susceptible clones were challenged with 1200 CRKN juveniles and the response to nematode infection was studied at four time points: 48 hours post inoculation (hpi), 7-, 14- and 21 days post inoculation (dpi). RNA sequencing resulted in an average of 33 million reads for each time point, out of which an average of 79% sequence reads mapped to *Solanum tuberosum* reference genome. An average of 3000 genes were differentially expressed between PA99N82-4 and Russet Burbank at each time point, out of which ~50% were up-regulated in the resistant clone. Differentially expressed data showed the genes that are usually triggered in response to the external stimuli were up-regulated in the resistant clone. Most of these genes are known to be involved in transcription factor activity, DNA binding, transporter and kinase-like activity, which in turn are known to trigger various host-pathogen interaction pathways, plant hormone signaling pathways, antioxidant activity, cell wall re-enforcement and polyamine biosynthesis. Based on our gene expression data (fold change $\geq$1), we hypothesize that CRKN presence in and around the root tissue triggers pathogen associated molecular patterns (PAMP)-triggered immunity (PTI) as an early response. Once the nematodes secrete effectors into the root tissue after their successful penetration, the R-gene mediated effector-triggered immunity (ETI) is initiated in the resistant clone that might be responsible for inhibiting the feeding site formation, an important event for the nematode to reproduce and complete its life cycle. The resistance response is due to the accumulation of reactive oxygen species (ROS) and hypersensitive response (HR) leading to rapid cell death causing localized lesions around the site of nematode infection. The plant hormone salicylic acid (SA) seems to play a significant role in ETI based HR activity, which is indicated by the up-regulation of SA marker, (pathogenesis related) PR-1 gene in PA99N82-4. The ROS scavenging system is also activated in order to prevent further host tissue damage. In addition, polyamines (spermine and spermidine) are up-regulated in the resistant clone, indicating their role in the resistance mechanism. An active ingredient of the root cell wall re-enforcement, suberin is also playing prominent role in strengthening the host cell wall to protect the tissue from further nematode attacks. The present study is the first ever description of the molecular crosstalk between *M. chitwoodi* and the resistant potato. However, the major genes involved in the defense pathway warrant further validation. The data repository thus generated could be used in breeding for CRKN resistant potato varieties.

Figure 1: *Meloidogyne chitwoodi* infected potato tubers showing external (left) and internal (right) defects.

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Am I Applying too much P? The Complicated World of Phosphorus Recommendations

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Introduction: Washington State produces an estimated 105,600,000 CWT of potatoes and its growers have a yield average of 640 CWT/A (USDA, 2018). Washington State produces the highest yields per acre in the world and is an essential provider to the global potato industry. High yields are made possible from the long growing season (150+ days of growth following emergence) and through the use of inputs such as fertilizers, water, and pesticides. Along with nitrogen and potassium, phosphorus (P) is one of the most commonly used macronutrients required for optimal plant growth and development. Phosphorus contributes to increase in tuber yield and maturation, plays a role in respiration and photosynthesis reactions, and is important for processes related to carbohydrate formation and its storage in the tubers. However, P exists as an anion in the soil and has a low water solubility making it immobile. Furthermore, factors such as pH can limit how much phosphorus is readily available to the plant. For example, in the Columbia Basin, where pH is typically alkaline (pH > 7.0), P is likely to precipitate with calcium making P unavailable to the plant. In order to overcome these factors, growers tend to use excessive supplies of P to help the plant utilize the nutrient efficiently (Hopkins et al., 2014).

Using inordinate amounts of P to fertilize potatoes can increase the chances of losing the nutrient through erosion or runoff. Key legislation in a Washington law (ESHB 1498) enacted on April 15, 2011, prohibits the display and retail sale of turf fertilizers that contain phosphorus and the use of such fertilizers on turf (WSDA, n.d.). It is possible that future regulations could limit or prohibit growers on P use in an effort to reduce P runoff into waterways (Thornton et al., 2014). The potato industry needs to be proactive and establish improved guidelines for P use to reduce chances of environmental contamination.

Since P recommendations only exist for one cultivar (Russet Burbank) in the Columbia Basin, the first objective of this study was to evaluate and determine phosphorus rates for six different russet varieties when grown in the Columbia Basin with pre-plant soil levels at or slightly above 20 ppm of P. The second objective was to determine whether or not higher rates of P have an impact on post-harvest quality retention of tubers.

Materials and Methods: Trials were conducted at the WSU Research Farm located near Othello, Washington (2017-2018) under Shano silt loam soil conditions with soil P levels of 20-25 ppm of P. The experiment was planted into a randomized complete block design with four replications. Six cultivars: Russet Burbank, Ranger Russet, Umatilla Russet, Clearwater Russet, Castle Russet, and Mountain Gem Russet were grown using four rates of monoammonium phosphate (MAP) (125, 250, 375, and 500 lbs/A). Treatments were broadcasted as a pre-plant fertilizer and incorporated six inches into the soil with a rototiller. Since MAP adds 11% nitrogen (N), extra N was applied to each plot as needed to balance N across treatments. All nutrients other than P were applied to be non-limiting to plant growth. Plots were 15.58 ft. by 3 rows and managed using cultural management practices typical for long-season russet-type potatoes in the Columbia Basin. In-season soil and petiole samples were taken to monitor P levels within each of the four treatments.

Potatoes were harvested using a custom-built one-row harvester, following harvest, tubers were washed and electronically weighed and sorted into categories: U.S. No. 1, U.S. No. 2, and culls. Tubers were categorized into undersized tubers, growth cracks, knobs, greening, rot and malformed. Market yield was classified as U.S. No. 1 and 2 grade tubers > 4 oz. Specific gravity (SG) (weight in air/ (weight in air – weight in water)) and internal defects were also obtained. A mock processing contract and harvest data were used to conduct an economic analysis for the processing industry in the Columbia Basin. The cost of P fertilizer for each treatment was subtracted from the gross return to establish an adjusted gross return.

A post-harvest study was conducted on all varieties that were grown with the low (125 lbs/A) and high (500 lbs/A) treatments of phosphorus. All varieties were harvested at 150 days after planting (DAP) and stored for 30 days at 44°F. French fry color of Clearwater, Umatilla, Ranger, and Castle Russet tubers from the low and high P treatments was measured at zero days after harvest (DAH) using a photovoltaic machine (model 577, Photovolt Instruments Inc., Inc., Indianapolis, IN). Twelve tubers were cut longitudinally and one fry plank of 3/8" x 1 1/8" from each tuber was obtained. Vegetable oil was heated to 375°F and the fries placed into a fryer (model PFA570, Perfect FRY Company) for 2 minutes, and then refried for 1.5 minutes (Knowles and Pavek, 2004). After the initial fry analysis, the remaining tuber samples were placed at a cold storage temperature of 39°F and fried at 10 DAH, 20, DAH, and 30 DAH.

Tuber tissue P content analysis was conducted on all seven clones following harvest for the high and low treatments (125 and 500 lbs/A P). Similar to the fry analysis, 12 longitudinal slices were taken from each variety and placed in petri dishes. The tuber slices placed into petri dishes were then freeze-dried. The freeze-dried samples were ground into fine powder and 10 grams of sample from each variety and treatment were collected, placed in culture tubes, and analyzed for a macro element screen (Calcium, Potassium, Magnesium, Sodium, Phosphorus, and Sulfur) at the University of Idaho Analytical Sciences Laboratory located in Moscow, ID.

A SAS ANOVA regression analysis was used to analyze data and the means statistically separated using Fisher's Protected Least Significant Difference Test at the 0.05 and 0.01 level of significance.

Results/Discussion: Averaged across varieties, total yields ranged from 850 to 890 CWT/A (Figure 1) but the differences between treatments were not significant. Varieties responded similarly and were therefore averaged together. Adjusted gross return ranged from -2% to 3% relative to the non-treated control (Figure 2). When values were averaged across varieties, no significant differences were seen; however, the 125 and 250 lbs/A treatments appeared to at least pay for the additional P.

Although the yield and economic data were similar across treatments, the soil and petiole P values appeared to respond well to the different P application levels; the P high rates produced numbers above those from of the lowest rates (Figures 3 and 4).

The post-harvest analysis of four clones treated with high phosphorus (500 lbs/A) and low P (125 lbs/A) did show indications of fry quality differences. Averaged across the four clones tubers from the higher phosphorus treatments produce significantly darker fry color at 0 DAH than those from lower rate treatment (Figure 5). At 0 DAH, however, the fry colors were still acceptable to processors with a rank of USDA 0. There was a cultivar specific response from

Umatilla Russet which fried significantly darker across all fry dates when treated with 500 lbs/A of phosphorus (Figure 6). Tubers of Ranger, Umatilla, and Russet Burbank from the high P treatment contained significantly more P than those from the low P treatment (Figure 7).

Conclusion When soil P levels are above 20 ppm and pH between 7.5-7.9, similar to this study, growers may not benefit from the application of P. Economically, however, it appears to be safe for growers to apply upwards of 250 lbs/A P across these six varieties as the adjusted return at least covered the expense of the added P. Growers should use caution, however, if their soil is such that they expect a high amount of P to be tied up due to high pH. In high pH situations, it is possible that rates above 250 lbs/A P may have to be used to combat the tie-up with calcium. Although fries darkened slightly from the high rate of P, the fries were still acceptable to the quick service industry, based on their USDA 0 rating. It is something to consider, however, because as fries darken due to other issues, like cold temperature sweetening, high P may exacerbate the situation and leave fries darker than if lower rates of P were used in the field. Because these results are from only two years of research, readers should use caution until more data becomes available after an additional year of research.

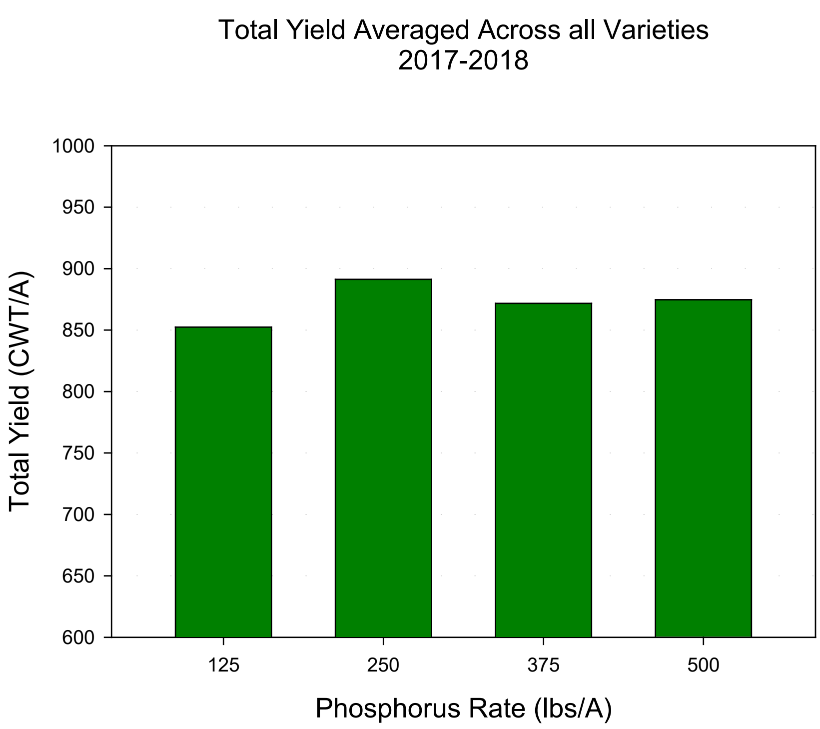

Figure 1 Total yield averages across six varieties for each treatment for the years 2017-2018, displayed in CWT/A.

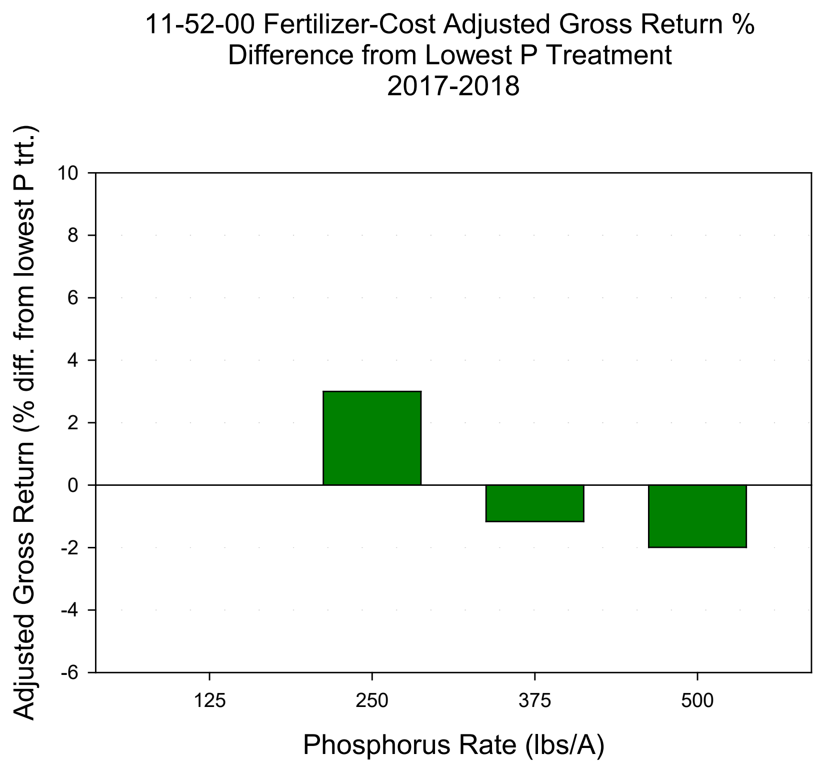

Figure 2 Phosphorus adjusted processing gross return (percent difference from 125 lbs/A P treatment) for all six varieties averaged across 2017-2018.

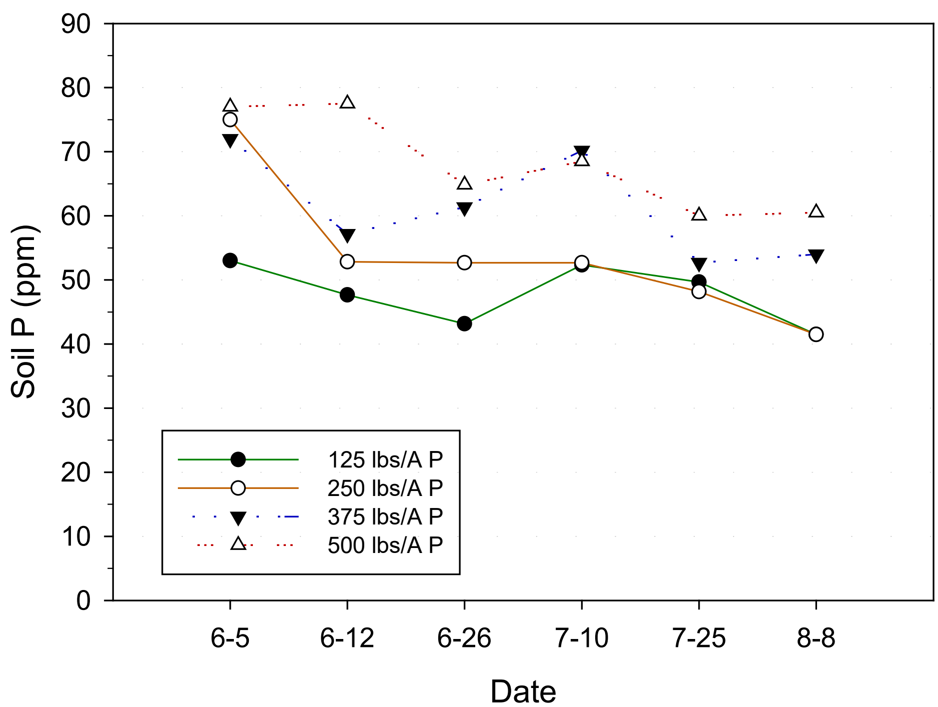

Figure 3 Soil graphs from 2018 depicting the concentration of phosphorus in the soil (1ft depth) for ranges 125-, 250-, 375-, and 500- lbs P/A.

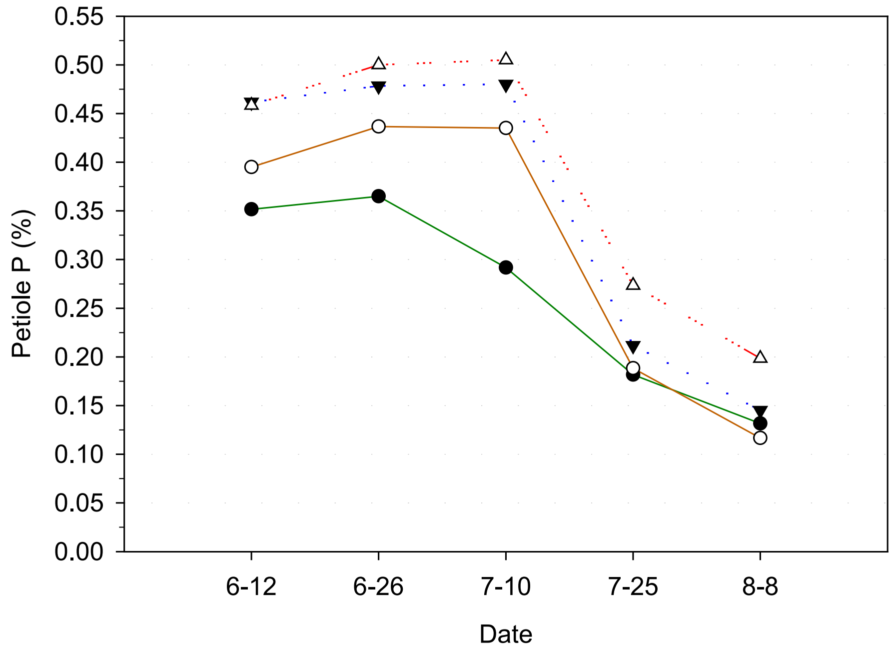

Figure 4. Petiole graphs from 2018 depicting the concentration of phosphorus in petiole for ranges 125-, 250-, 375-, and 500- lbs P/A

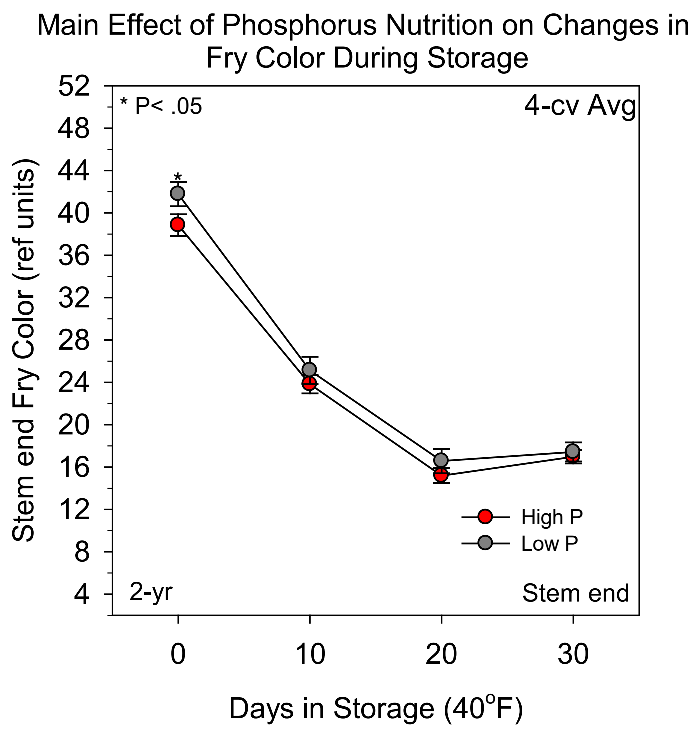

Figure 5. Reflectance units of fry color obtained from four varieties (Clearwater, Castle, Ranger, and Umatilla) between low (125 lbs/A P) and high (500 lbs/A) treatments, averages across 2017-2018.

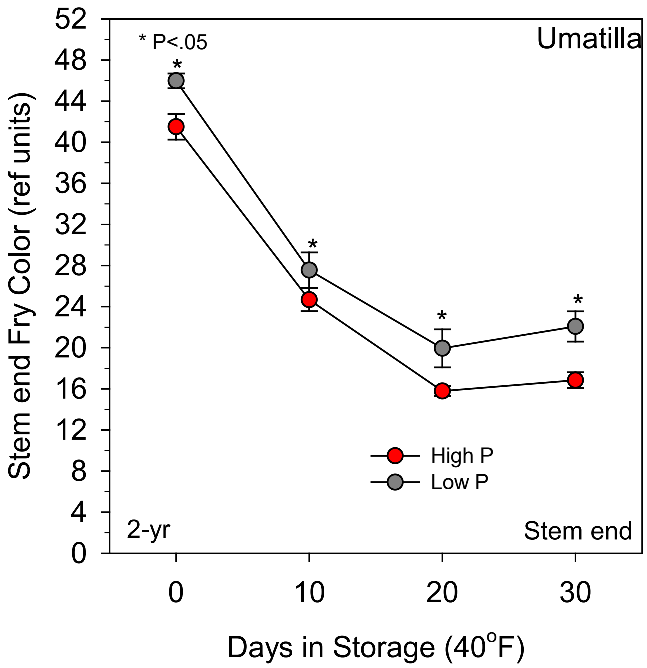

Figure 6. Umatilla French fry analysis response for both high and low treatments (125- and 500 lbs/A P) reflectance units, averages for both 2017-2018.

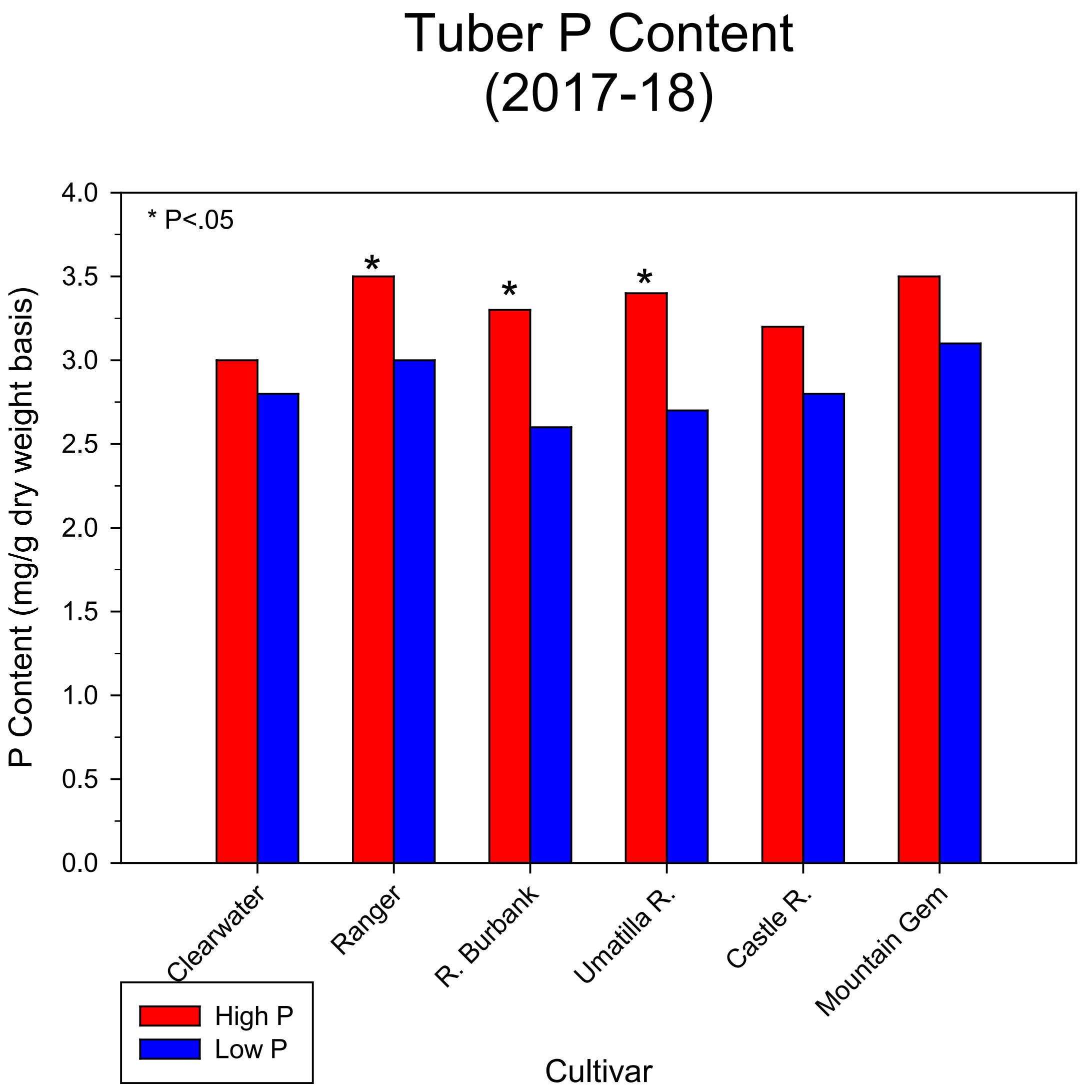

Figure 7. Tuber tissue P content averages from 2017-2018, displayed in mg/g dry weight for Clearwater, Ranger, Burbank, Umatilla, Castle, and Mountain Gem.

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Tolerance to Heat Stress in Cold-Sweetening Resistant Cultivars

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Introduction and Background

A major focus of the Northwest Potato Variety Development Program (NWPVDP) is to breed, select, and release new cultivars for frozen processing. Developing late season russet cultivars that can resist sweetening when stored long-term at low temperature (e.g., 40-44^{o}F) is a priority of the program. Clearwater Russet is an excellent example of one such cultivar that has cold-sweetening (CS) resistance (Novy et al., 2010). The recent acceptance of Clearwater Russet by McDonald's in 2016 has spurred a significant increase in Pacific Northwest acreage devoted to this cultivar.

We recently demonstrated that the CS-resistant phenotype of many cultivars (e.g., Clearwater, GemStar Russet, Premier Russet, Castle Russet, Sage Russet) is heat labile. Sufficient heat stress (HS), either in-season or postharvest, can abolish CS-resistance, rendering these cultivars CS-susceptible (like Russet Burbank and Ranger Russet). Ideally, new cultivars should be heat tolerant for retention of their CS-resistant phenotype. We, therefore, seek to identify genotypes that can tolerate heat stress for use as parental material in the breeding program, and further studies focused on the metabolic basis of heat tolerance. Accordingly, clonal entries and parental material from the NWPVDP were screened to determine the effects of heat stress on cold sweetening resistance. Five distinct phenotypes were identified: (1) HS exacerbates the extent of CS of CS-susceptible clones (e.g., Russet Burbank, Ranger Russet); (2) HS has no effect on CS of CS-susceptible clones (e.g., A02516-102LB); (3) HS abolishes CS-resistance (e.g., Clearwater Russet, GemStar Russet, Castle Russet, A06030-23, AOR06070-1KF, A03921-2); (4) HS partially attenuates CS-resistance (AO02183-2); and (5) HS has relatively little effect on the cold sweetening responses of CS-resistant cultivars/clones (e.g., Payette Russet, EGA09702-2, A07548-2LB, A12406-2sto, Innate® Gen 2). This latter phenotype (heat tolerant for retention of CS-resistance) is the most desirable. Details of the studies are described below.

Results

A postharvest heat stress (PHHS) protocol (Herman et al., 2017) was used to characterize the tuber phenotypes of newly developed clones/cultivars. This protocol assesses the extent of cold-sweetening (CS) that occurs after tubers have been given a heat stress (HS) treatment (90^{o}F, 21 days). Thus far, Payette Russet is the only conventionally bred cultivar (>30 clones/cultivars tested) that tolerated HS for retention of its CS-resistant phenotype (Figs. 1 & 2). Evaluation of several siblings of Payette Russet and its parents (EGA09702-2 and GemStar Russet) demonstrated that Payette's heat tolerance was likely inherited from its maternal parent, EGA09702-2 (Herman et al., 2017). However, one full-sibling (A02507-3LB) of Payette Russet had neither CS-resistance or heat-tolerance (similar to Russet Burbank) (Fig. 1). Two half-siblings (A02515-2 & A01432-44LB) had CS-resistance but were susceptible to HS. Two other half-siblings (A12406-2sto & A07548-2LB) were heat-tolerant/CS-resistant, supporting EGA09702-2's potential (and perhaps that of its F1 lineage) for introgressing this complex trait into future clones. The clones/cultivars expressing the distinctive physiological phenotypes should be investigated further to resolve the molecular basis of the heat tolerant/CS-resistant trait.

The sweetening responses of additional clones from the 2017 and 2018 Regional Trials to these temperature stresses were also evaluated (Fig. 1) and several distinct phenotypes were characterized (Fig. 2). Numerous Regional Trial clones (A06030-23, AOR07781-5, AOR06070-1KF, A03921-2) had CS-resistance (Figs. 1 & 3) but were heat intolerant for retention of the CS-resistant phenotype. AO02183-2 had partial tolerance to heat stress for CS-resistance (Fig. 3).

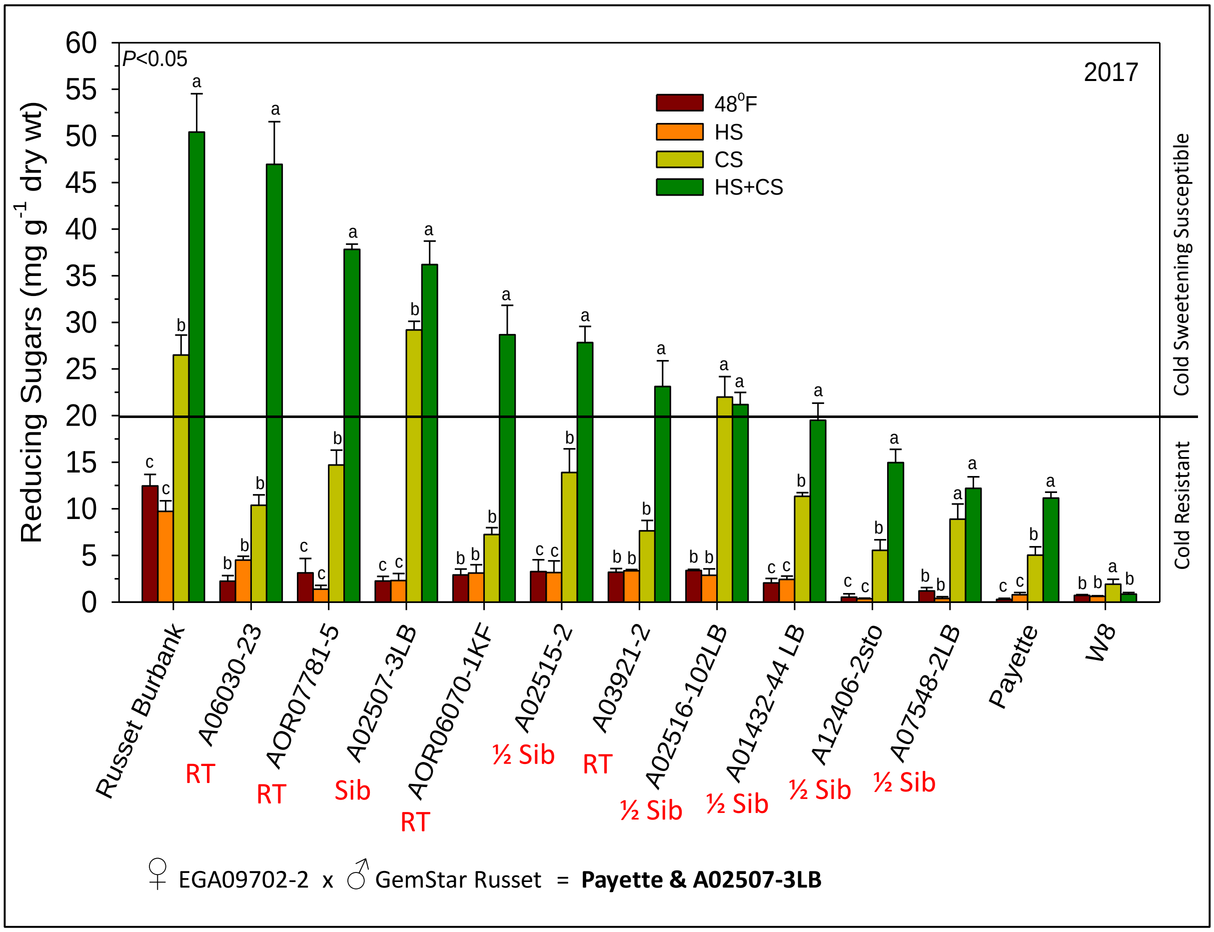

Fig. 1. Changes in tuber reducing sugar concentrations from CS-susceptible and resistant cultivars/clones as affected by HS (storage for 21 d at 90ºF), cold-storage (32 d at 39ºF), and the sequential combination of HS plus cold-storage. Control tubers were stored at 48ºF for 53 days. HS exacerbated the accumulation of reducing sugars in CS-susceptible clones, Russet Burbank and A02507-3LB. A06030-23, AOR07781-5, AOR06070-1KF, A02515-2, and A03921-2 had CS-resistance that was abolished by prior exposure to HS. A02515-102LB is CS-susceptible, but HS did not exacerbate sweetening like for Russet Burbank. A12406-2sto, A07548-2LB, Payette Russet, and Innate® W8 were tolerant of HS for retention of their CS-resistant phenotype. These clones maintained USDA 2 or lighter fry color when stored cold, regardless of prior exposure to HS. Letters indicate LSD ($P<0.05$) for comparison of PHHS treatments within a clone. Each bar represents the average reducing sugar concentrations in 12 tubers. RT, regional trial; Sib, sibling or ½ sibling (same maternal parent) as Payette Russet.

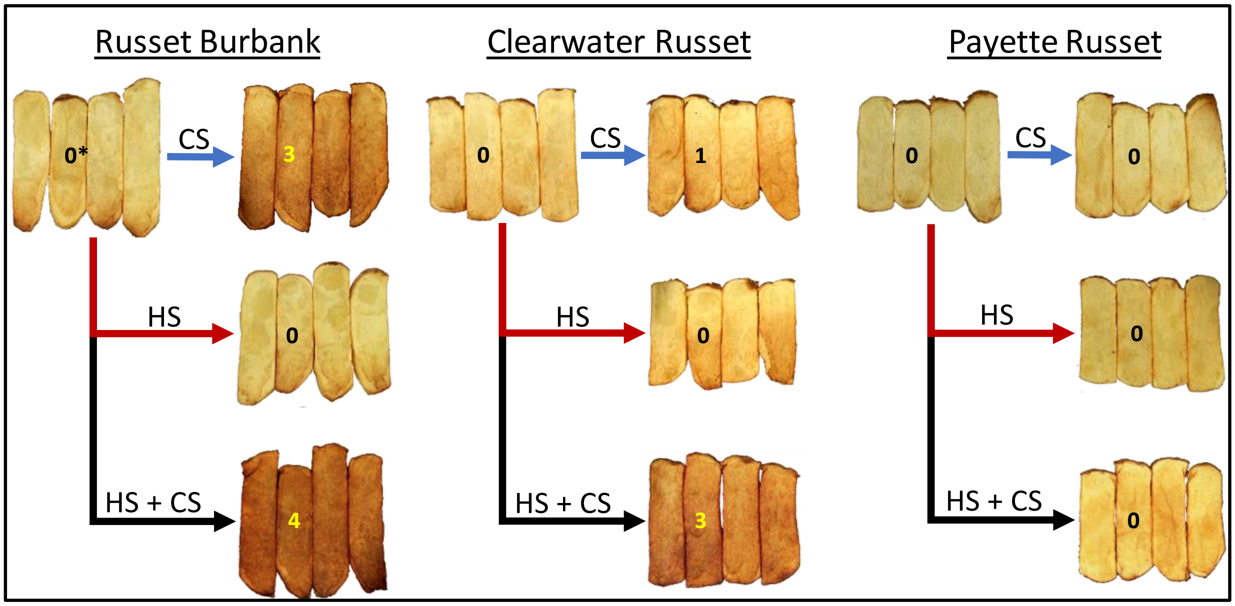

Fig. 2. Russet Burbank, Clearwater Russet, and Payette Russet tubers were fried in October following storage for 53 days at 48ºF, or 32 days of cold-storage at 39ºF, or 21 days of heat stress (HS) at 90ºF, or the sequential combination of HS followed by cold-storage. The cultivars display distinct CS phenotypes with respect to the effects of HS. Russet Burbank is CS-susceptible and heat intolerant. HS exacerbates its CS-susceptible phenotype. Prior exposure of tubers to HS abolish the CS-resistant phenotype of Clearwater Russet. By contrast, heat-stressed tubers of Payette Russet retain their CS-resistant phenotype. Each fry plank is from a different tuber and the four fries depict the average color from a 12-tuber sample. Numbers indicate USDA fry colors.

In 2018, the PHHS protocol was modified to evaluate the effects of heat dosage (Fig. 3). Tuber samples of 6 clones/cultivars were harvested at physiological maturity and subjected to 0, 7, 14, and 21 days of HS (90ºF) before cold-storage (32 days, 39ºF). An additional phenotype was identified - AO02183-2 (the best-performing entry in the 2018 Regional postharvest trials) had partial tolerance to HS for retention of its CS-resistant phenotype (Fig. 3). Moreover, seven days of HS modified the CS phenotype of each clone/cultivar to the same extent as 21 days of HS (Fig. 3). The CS-resistant phenotypes are thus more sensitive to heat than initially thought. This finding simplifies the screening process for heat tolerance and underscores the importance of avoiding HS to ensure retention of cold-sweetening resistant phenotype during storage. Studies in 2019 will evaluate the effects of even shorter doses of HS (2, 4, 6 days at 90ºF) to better resolve heat tolerant phenotypes.

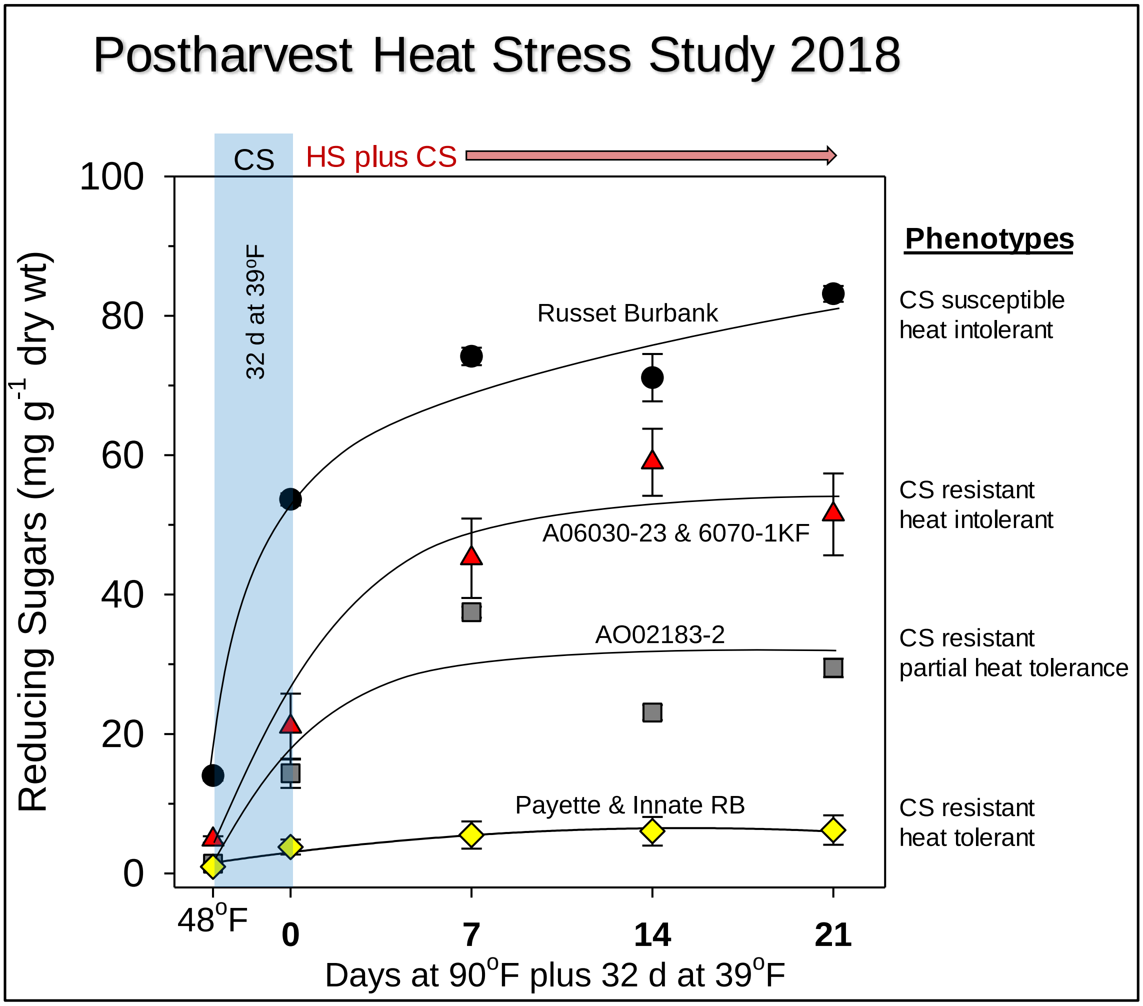

Fig. 3. Changes in tuber reducing sugar concentrations from CS-susceptible and resistant cultivars/clones as affected by dose of heat stress (HS, storage for 0, 7, 14, or 21 days at 90ºF) prior to cold-storage (32 d at 39ºF). Tubers were initially stored at 48ºF directly following harvest. The CS response of each cultivar/clone is indicated by the increase in reducing sugars during storage of tubers for 32 days at 39ºF (shaded area, zero days of HS). Four distinct phenotypes were characterized: (1) Russet Burbank is CS-susceptible but heat intolerant (7 d of HS at 90ºF prior to cold-storage exacerbated its CS-susceptible phenotype); (2) A06030-23 and AOR06070-1KF are CS-resistant but heat intolerant (7 d of HS prior to cold-storage abolishes the CS-resistance of these clones and they sweetened to the same extent as non-heat stressed RB stored at 39ºF); (3) AO02183-2 is CS-resistant with partial tolerance to HS (7 d of HS prior to cold-storage partly attenuated CS-resistance); (4) Payette Russet and Innate® RB are CS-resistant and heat tolerant (7 d of HS prior to cold-storage had little effect on reducing sugar content). Note that 7 days of HS produced the same effect on subsequent sweetening at 39ºF as the 14- and 21-day HS treatments. Each point represents 12 tubers ±SE.

Summary and Conclusions

- More than 30 advanced clones, parental breeding material, and cultivars from the NWPVDP have been screened for effects of heat stress on CS-resistant phenotype.
- To date, Payette Russet is the only conventionally bred cultivar identified that can maintain its CS-resistant phenotype following exposure to considerable heat stress. Innate® engineered cultivars also have robust CS-resistance with tolerance to heat stress by virtue of their silenced invertase.
- Payette likely inherited heat tolerance from its maternal parent, EGA09702-2; the CS-resistance of Payette's paternal parent, GemStar Russet, is abolished by prior exposure to heat stress (Herman et al., 2017), similar to Clearwater Russet (see Fig. 2).
- This work has identified additional clones (siblings of Payette Russet that share the maternal parent, EGA09702-2) that are heat tolerant/CS-resistant, making them good candidates as parental material in breeding for the heat tolerance trait.
- Five distinct tuber physiological phenotypes were identified: (1) cold-sweetening susceptible, heat intolerant; (2) cold-sweetening susceptible, heat tolerant (3) cold-sweetening resistant, heat intolerant; (4) cold-sweetening resistant, partial heat tolerance; (5) cold-sweetening resistant, heat tolerant.
- Clones/cultivars within each of the five phenotypes provide an opportunity to determine the mechanism of heat tolerance and its inheritance in relation to cold-sweetening resistance/susceptibility.
- Heat dosage studies demonstrated that 7 days of heat stress increased cold sweetening the same as 21 days of HS in the tested CS-susceptible and CS-resistant clones/cultivars.

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Modern Soil Moisture Monitoring Methods

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Introduction

Potatoes (*Solanum tuberosum* L.) are susceptible to soil moisture stress due to their shallow root system and high water consumption (Powelson and Rowe, 1993). As a result, knowing the soil moisture status of the potato crop is crucial for maximizing marketable yield. For the past several decades, irrigators have used the "hand-feel," and hand-push probe method to monitor soil moisture status and schedule irrigation (Morris, 2006). However, these methods are time intensive, lack accuracy, and continuous monitoring. In the past three decades, new soil moisture monitoring methods have been changing how irrigators monitor soil moisture status and have potentially improved water use efficiency. According to the USDA, approximately 40% of irrigators in Washington State schedule irrigation by monitoring soil moisture status using the "hand-feel" method, and only about 10% monitor soil moisture status using soil moisture sensing devices (NASS, 2013).

It is estimated that by 2050, the world's population will reach 9 billion, which means more food will need to be produced ("FAO's Director-General on How to Feed the World in 2050," 2009). In addition, water is a limited resource and its use may rise in conjunction with the exponential population growth. Because of these major concerns, irrigation-dependent agricultural producers will need to maximize production and water use efficiency. To improve water use efficiency, irrigators must have methods to track soil moisture for irrigation scheduling.

Today, irrigators have many options for monitoring soil water status and a choice of whether to monitor soil water status quantitatively and or qualitatively. This paper will describe two approaches used to describe soil water status, and four non-destructive soil moisture monitoring methods that have been in development for as long as 70 years and are now readily available.

Neutron Scattering Method

The next three methods will describe how soil water status is determined using a quantitative approach, which describes water content as the volume of water within a volume of soil (V_w/V_s), usually reported as a fraction in m^3/m^3. This fraction is referred to as volumetric water content (VWC, Cooper, 2016). In the United States, when water is applied to cropland by irrigation or rainfall, the quantity is usually reported as depth in "inches of water." Similarly, the soil water content is reported in "inches of water per foot of soil" by multiplying the VWC by 12 (Gardner, 1965; Cooper, 2016; Datta et al., 2017).

Determining the optimal VWC range in the soil to maximize potato yields requires a soil texture analysis to establish the upper and lower range. The upper limit is called field capacity (FC) and is defined as the fraction of water held in soil after excess water has drained after a rain or irrigation event (Hillel, 1998). The lower limit is called management allowable depletion (MAD) which is the percent soil moisture from the FC allowed to deplete without causing yield reductions. In the case of potatoes, MAD is 35 percent. For example, soil with an FC of 3 inches will have a lower limit/MAD of 1.95 inches.

The neutron scattering method is implemented by a device called a neutron probe, first used in the 1940s to measure soil water content in the lab (Brummer and Mardock, 1945). Neutron probes determine soil water content indirectly by measuring the thermalized ion cloud density formed around the probe, which is created by the collision of hydrogen nuclei with fast neutrons emitted by a decaying radioactive source. Since water is the primary source of hydrogen in most soils, the thermalized ion density is proportional to the volumetric water content present in the soil (Fityus et al., 2011; Couchat, 1967).

In order to use a neutron probe (Fig.1), it must first be calibrated to account for the different soil textures at each of the depths, following the instructions provided by the manufacturer. Secondly, access tubes must be installed following the recommendations of Ward and Wittmans (2009) to avoid air gaps. Lastly, measurements are made by placing the neutron probe over the access tube and lowering the probe to the desired depth (InstroTek Inc., 2019; Ward and Wittmans, 2009).

The main advantages of this method include ease of use, a large sphere of influence (15 cm in wet soils) that is not influenced by salinity, temperature, and soil cracking. On the other hand, this method does require special licensing to implement, equipment is heavy, continuous field measurements are not allowed, and near-surface measurements are challenging to make (Washington, 2019; Cooper, 2016).

There are two leading suppliers of neutron probes in the US, InstroTek (Research Trial Park, NC), which offers the CPN503 Hydroprobe (Fig. 2), and Troxler labs (Research Triangle Park, NC) which, offers the Model 4300 soil moisture gauge (Fig. 3). However, the process of acquiring one is relatively complicated due to the regulations on the radioactive material used in neutron probes (WSDH, 2019). The alternative is to hire a neutron probe services if one is available in your area. However, this type of service is disappearing rapidly due to new, less regulated technology.

Figure 1 *Image depicting the CPN503 Hydroprobe neutron probe from InstroTek implemented in the field. Courtesy of InstroTek Inc., TRC, USA*

Figure 2 *Image of CPN503 Hydroprobe Elite. Courtesy of InstroTek Inc., TRC, USA*

Figure 3 *Model 4300 Soil Moisture Gauge. Courtesy of Troxler Inc., TRC, USA*

Time Domain Reflectometry

Time domain reflectometry (TDR) was first used for measuring soil water content by Topp et al. (1980), their work paved the way for what we know today as TDR (Cooper, 2016). TDR relies on the dielectric constant of soil and water to determine soil water content, which is described merely by the capacity of soil [the capacitor] to hold on to a larger charge by adding additional water [the dielectric] to the soil (Cooper, 2016). Soil water content is indirectly determined by measuring the time it takes for a generated electromagnetic pulse (EMP) to travel the length of parallel rods inserted in soil. Since plain water is a great conductor, additional water in the soil increases the speed of the pulse. Thus, the travel time of the electromagnetic pulse is a function on the dielectric constant of the soil and proportional to the squared travel time of the pulse (Dalton and Van Genuchten, 1986; Jones et al., 2002)

In the field, TDR system installation is relatively simple (Fig 4). Probes consisting of two or more metal prongs are inserted in the soil and connected to a pulse generator and a data logger (Patterson and Smith, 1981). Measurements can be scheduled manually or via a telemetry option, including cellular and GPS (Campbell Sci., 2019).

The TDR method has many advantages, amongst the best include excellent accuracy and precision, and the ability to choose how much of the soil depth to measure. For example, a 30 cm probe installed on a 30-degree angle will measure a depth of 15 cm; the same probe installed vertically will measure a depth of 30 cm (Campbell Sci., 2019; Jones et al., 2002). Disadvantages include high initial capital cost, errors caused by improper installation, and the instruments may be difficult to configure (Campbell, 2014). However, TDR-probe variations are being made available by companies like Campbell Sci., which simplify configuration and installation, as well as reduce cost.

The leading supplier of TDR systems in the US is Campbell Scientific Inc., located in Logan, Utah. They offer a number of TDR system variations, "true" TDR systems, reflectometer TDR systems, and multi-depth systems (Fig. 7). Reflectometer and multi-depth probes are equipped with all the necessary electronics to excite an EMP and measure the travel time of the pulse within.

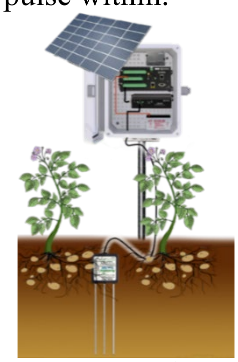

Figure 4 *Image depicting a TDR system implemented in the field. Courtesy of Campbell Sci. Inc., Utah, USA; and, Acclima, Meridian, USA, respectively.*

Figure 5 *Image of a TDR system is characterized as a "true" TDR system, and is comprised of a CR1000X data logger, a TDR200 pulse generator, and a CS605 probe. Courtesy of Campbell Sci. Inc., Logan, USA.*

Figure 6 *Image of a TDR system comprised of a CR310 data logger, and a CS625 probe. Courtesy of Campbell Sci. Inc. Logan, USA.*

Figure 7 *Image of a TDR system comprised of a CR1000X data logger, and a SoilVUE10 multi-depth probe. Courtesy of Campbell Sci. Inc., Logan, USA.*

Capacitance

This method is also referred to as frequency domain reflectometry (Cooper, 2016). The idea to measure soil water content using capacitance was conceived in the 1950s and 1960s. However, the technology was not available for practical use until the late 1970s when high-frequency electronics became available (Grant et al., 1957; Summerhill, 1967; Cooper, 2016). The principle of capacitance probes is relatively modest, it relies on the same principle as TDR, which states that with an increase of water in the soil, there is also an increase in the charge-capacity of the soil (Dalton and Van Genuchten, 1986; Jones et al., 2002). In this case, the soil water content is determined indirectly by measuring the capacitance of the soil [which acts as the capacitor] after being polarized by an electromagnetic field created by two plates. The capacitance measured in the soil is a function of the water content in the soil and is thus proportional to the soil water content (Bell et al., 1987).

Implementing a capacitance system to monitor soil moisture in the field is relatively easy. Capacitance systems with multi-depth probes may require access tubes (Fig. 8). If this is the case, users should install them using the manufacturer's instructions. Single-depth probes can be installed in any direction. However, precaution must be taken to avoid preferential flow by packing the soil that was removed to its original bulk density. This method allows for continuous monitoring, which means that the user can choose how often measurements are made. Moreover, this method allows for the use of telemetry, which gives users the capability of managing their system from anywhere.

The main advantages of this method are lower cost per unit, simple readout devices, easy to install/use, low power consumption, multi-depth devices available, and the best resolution of any method. However, it also has several disadvantages which include sensitivity to soil texture and temperature, fluctuations at different frequencies, and sensitivity to air gaps (Baumhardt et al., 2000; Campbell, 2014).

Capacitance probes are extremely popular, and as a result, there are many companies that retail these devices. There are three main suppliers of capacitance probes, Meter Group Inc., located in Pullman, WA, USA, Delta-T Devices, located in Cambridge, UK, and Sentek, located in Stepney, AUS. Some of the most popular setups offered by these three companies are as follows: Meter Group offers the ZL6 data logger equipped with the TEROS 12 probe (Fig. 9), or the portable ProCheck equipped with the TEROS 12 probe (Fig. 10); Delta-T Devices offers the GP2 data logger equipped with the Theta Probe (Fig. 11) or the portable HH2 reader equipped with the PR2 Profile probe (Fig. 12); and, Sentek offers the portable Diviner 2000 equipped with a multi-depth probe (Fig. 13) or the drill n' drop multi-depth probe connected to a CR310 Campbell Sci. data logger (Fig. 14).

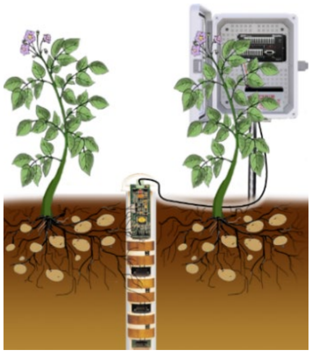

Figure 8 *Image of capacitance soil moisture monitoring system implemented in the field, using a data logger, and a multi-depth probe. Courtesy of Campbell Sci. Inc., Logan, USA; and, Sentek, Stepney, AUS, respectively.*

Figure 9 *Image of capacitance soil moisture monitoring system comprised of a data logger and probe. Courtesy of METER Group Inc., Pullman, USA.*

Figure 10 *Image of the handheld ProCheck reader equipped with a TEROS 12 probe. Courtesy of METER Group Inc., Pullman, USA.*

Figure 11 *Image of the handheld HH2 reader equipped with the PR2 Profile Probe. Courtesy of Delta-T Dev., Cambridge, UK.*

Figure 12 *Image of the handheld HH2 reader equipped with the PR2 Profile Probe. Courtesy of Delta-T Dev., Cambridge, UK.*

Figure 13 *Image of the handheld Diviner 2000 reader equipped with depth probe. Courtesy of Sentek, Stepney, AUS.*

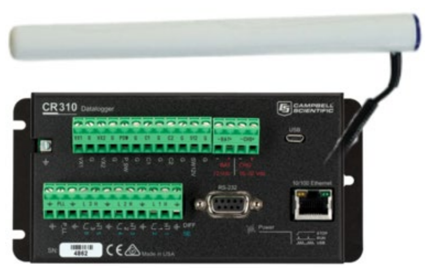

Figure 14 *Image of capacitance soil monitoring system comprised of a data logger from Campbell Sci., and a multi-depth probe. Courtesy of Campbell Sci. Inc., Pullman, USA; and, Sentek, Stepney, AUS, respectively.*

Capacitance with Calibrated Medium

The methods previously discussed determine soil water status quantitatively. In contrast, this method measures soil water status qualitatively in terms of soil water potential (SWP) in kPa, which is a measurement of the work required to overcome the forces that adhere water molecules to the soil particle. Moreover, soil water potential is an excellent indicator of plant stress (Hillel, 2004).

It is the consensus that most plants cannot extract water from the soil when the soil water potential is above -1500 kPa, a reference point referred to as wilting point (Andraski and Scalon, 2002). In the case of potatoes, it is recommended to maintain SWP below -60 kPa to optimize production (Kang et al., 2004), regardless of soil type. Additional information on managing soil water potential for potatoes can be found in Shock and Wang (2011).

Capacitance probes with calibrated media determine SWP using the same dielectric constant principle that is used by TDR and capacitance probes. However, this method has two additional components, a porous medium [usually ceramic], and a soil water characteristic curve (SWCC, Fig. 15), which describes the relationship between soil water content and potential (Whalley et al, 2001; Or et al, 1999).

A SWP device is merely a capacitance probe modified so that the electrodes and porous medium (Fig. 16) are amalgamated to each other (Whalley et al, 2001). To determine SWP, capacitance probes determine the percent water content of the porous medium [which is in equilibrium with the soil] and converts it into an SWP value, using the SWCC (Hilhorst and De Jong, 1988; Whalley et al, 2001).

Since this system uses the same data loggers as their capacitance probe counterparts, the same procedures are followed (Fig.17). Also, the same telemetry options are available for this system, since this system uses the same data loggers as capacitance systems.

The main benefits of measuring soil water potential using this method include, easy to use/install, low maintenance, long-lasting, low power consumption, relatively accurate, excellent resolution, excellent range, and provide temperature readings (Delta-T Dev., 2019; METER, 2019). This methodology, however, can be more complex to comprehend than other systems.

The two main suppliers of capacitance probes with calibrated medium are METER Group located in Pullman, WA, and Delta-T Devices located in Cambridge, UK. Meter group developed and retails the TEROS 21soil water potentiometer, which is connected to their ZL6 data logger (Fig. 18). Delta-T Devices manufactures and retails the EQ3 Equitensiometer soil water tensiometer, which is connected to their GP2 data logger. (Fig. 19).

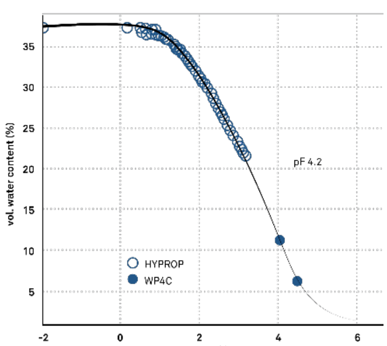

Figure 15 *Image of a soil water characteristic curve, (METER Group B, 2019)*

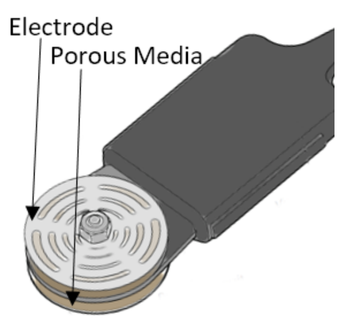

Figure 16 *Diagram of capacitance probe with calibrated media, TEROS 21, (METER Group, 2019)*

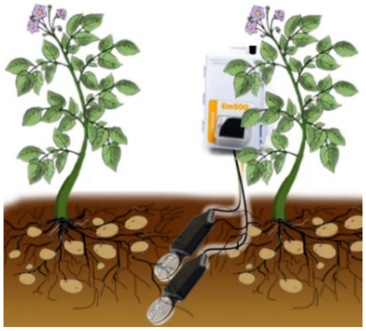

Figure 17 Image depicting a SWP monitoring system, using capacitance probes with calibrated. Courtesy of Meter Group Inc., Pullman, USA.

Figure 18 Image of SWP monitoring system is comprised of a data logger, and a capacitance probe w/ calibrated. Courtesy of METER Group Inc., Pullman, USA.

Figure 19 Image of SWP monitoring system comprised of a GP2 data logger, and an EQ3 Equitensiometer capacitance probe with calibrated media. Courtesy of Delta-T Dev., Cambridge, UK.

Discussion

The WSU Potato Research Group has had the opportunity to work with all of the aforementioned methods. In their opinion, the capacitance method for determining VWC is the most effective method today, because capacitance systems are more affordable than others, more readily available, easiest to implement, and are offered in the most configurations.

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Aphids, Their Biology, Relationship to Virus, the Value of Neonicotinoids

Andy Jensen, Manager of the Northwest Potato Research Consortium, entomologist, and aphid enthusiast

The 2019 Washington-Oregon Potato Conference was marked by the absence of several USDA Agricultural Research Service scientists and their presentations due to the 'partial government shutdown.' The material below was compiled and presented as one of the necessary substitutes. I had hoped to review four subject areas relevant to aphids:

1. Key biological features, excerpted from a recent *Potato Progress* article (Volume 18, Number 12).
2. The important biological relationships between aphids and potato viruses.
3. Some key points about aphid management, including the value of neonicotinoid insecticides in aphid and virus management since the mid-1990s.
4. Monitoring aphids in potato.

The emphasis here is on the commercial crop. Covering aphid and virus management in potato seed is a book-length subject and beyond the scope of this article.

General aphid biology review.

Quite a lot of pest management effort is directed toward aphids on potato. Therefore, as a review for many of you, and to provide a learning resource for people new to aphid biology and their interaction with potato, I thought I would prepare the following primer.

Facts of aphid biology

Aphids have several unusual or unique biological features that are useful for pest managers and crop producers to understand.

Aphids are all parthenogenetic and viviparous, with telescoping generations and seasonal polyphenism.

- Parthenogenesis is the reproductive strategy wherein females produce offspring that are genetic copies of themselves without mating with males. All aphids display parthenogenesis, but most also have one generation per year of sexual reproduction (see below).

- Viviparity is the practice of giving birth to live young. It is in contrast to oviparity, which is the practice of laying eggs. All aphids display at least one generation per year of viviparity, but most also have one generation per year of oviparity (see below).
- Telescoping generations refers to the fact that aphids are developing young inside them from a very early age. In fact, most aphids are pregnant when they are born! In many species, therefore, a female aphid begins to deposit offspring within a few hours of molting to the adult stage.
- Seasonal polyphenism refers to aphids' ability to produce multiple types of adults through the course of the season. Most aphids are completely without wings and are known as apterous. Almost all aphid species can also produce winged females, known as alate. Remember parthenogenesis? It's interesting to bear in mind that a single female aphid can produce offspring that are genetically identical but are a mix of wingless and winged. Other specialized forms include the viviparous female that hatches from the egg in spring, which is known as the fundatrix; the fundatrix can be similar to others of her species or have bizarre morphology and extreme reproductive capacity. Finally, most aphid species can produce males and egg-laying females; males can be either winged or wingless depending on the species, and egg-laying females are almost always wingless.

Figure 1. *Uroleucon sonchi* giving birth on sow thistle. Photo by the author.

Aphid species are generally divided into three life cycle strategies known as heteroecious, autoecious, and anholocyclic.

- Heteroecious aphids are also known as migratory or host-alternating. These species overwinter as eggs on a woody shrub, vine, or tree. Eggs hatch and two or a few generations develop on that host. Then, a generation will form that is mostly or entirely winged, and those females will migrate to completely unrelated species of plants and reproduce on them all growing season. Finally, a special kind of winged female and winged males are produced, which migrate back to the woody host. There, the males mate with egg-laying females. Both common aphids affecting potato in the Northwest are heteroecious:

Figure 2. A *Nearctaphis* fall migrant on mountain ash with her new born young. Photo by the author.

green peach aphid (*Myzus persicae*) and potato aphid (*Macrosiphum euphorbiae*). Green peach aphid uses peach (and some close *Prunus* relatives) as winter host, while potato aphid uses roses, both wild and cultivated, as winter host.

- Autoecious aphids lack this alternation between unrelated host plants, but otherwise have a similar biology of overwintering eggs, wingless and winged females throughout the growing season, then males and egg-laying females in the fall.
- Anholocyclic aphids survive completely without sexual reproduction, having only wingless and winged females. Species with this strategy live in warm climates or indoors. Some aphids can be anholocyclic when living in warm places. For example, both green peach aphid and potato aphid can be anholocyclic in places such as the Willamette Valley of Oregon, and even in the Columbia Basin or southwestern Idaho during mild winters.

Aphids feed on plant sugary sap, which is known as phloem sap (in contrast to the watery sap in the xylem). A few species of aphids feed on non-vascular plants such as mosses. Phloem sap is high in energy but low in nitrogen, a crucial element for production of protein. This means the aphid must process large volumes of sap and excrete the excess sugar in its honeydew.

Most aphids are very host-specific, able to feed and reproduce on only one or a handful of plant species. The most familiar pest aphids, however, are examples of 'polyphagous' feeding biology, that is, they can develop on many plant species. Both potato aphid and green peach aphid are examples of polyphagy and are known to accept hundreds of plant species as hosts.

Some favorite host plants for green peach aphid and potato aphid are also common weeds in potato production (e.g. nightshades, lamb's quarters, pigweeds, tumble mustards and other weedy mustards, stork's bill) or crop plants (e.g. canola and other cole crops). Both species are known to develop on grains like corn or wheat, or legumes like beans, peas, or alfalfa, but do so only **very rarely**.

Important biological relationships between aphids and potato viruses.

Aphids are important pests of potato because they can transmit two important viruses: *Potato leafroll virus* (PLRV) and *Potato virus Y* (PVY). The biology of these two systems differs in extremely important ways that cannot be reviewed often enough. The first of these viruses can be controlled by eliminating or prohibiting aphids from reproducing in the potato crop, while the latter virus *cannot be controlled using insecticides alone*. Below I will explain some of the biology underpinning this difference.

The situation with PLRV.

PLRV is in the category of viruses known as persistent and circulative. This phrase describes the transmission biology of the virus by the aphid, illustrated and described in Figure 3. Briefly, PLRV lives in the phloem system of the plant, a phenomenon called phloem-limited. This means that for an aphid to acquire the virus from an infected plant, it must feed in the phloem system of the plant. Contrary to what might be intuitive, it takes aphids many minutes, up to half an hour or more, to reach the phloem of their host plants. The process is not unlike drilling an oil well, the aphid stylets winding their way among the other kinds of plant cells between the surface of the leaf or stem and the phloem. Once the virus has been consumed by the aphid, it must circulate through the gut wall, into the "blood" (a.k.a. hemolymph) and from there into the salivary glands. This process takes several hours, during which the aphid is exposed to any insecticides present in or on the plant. Once thus infected, an aphid can transmit PLRV for the rest of its life.

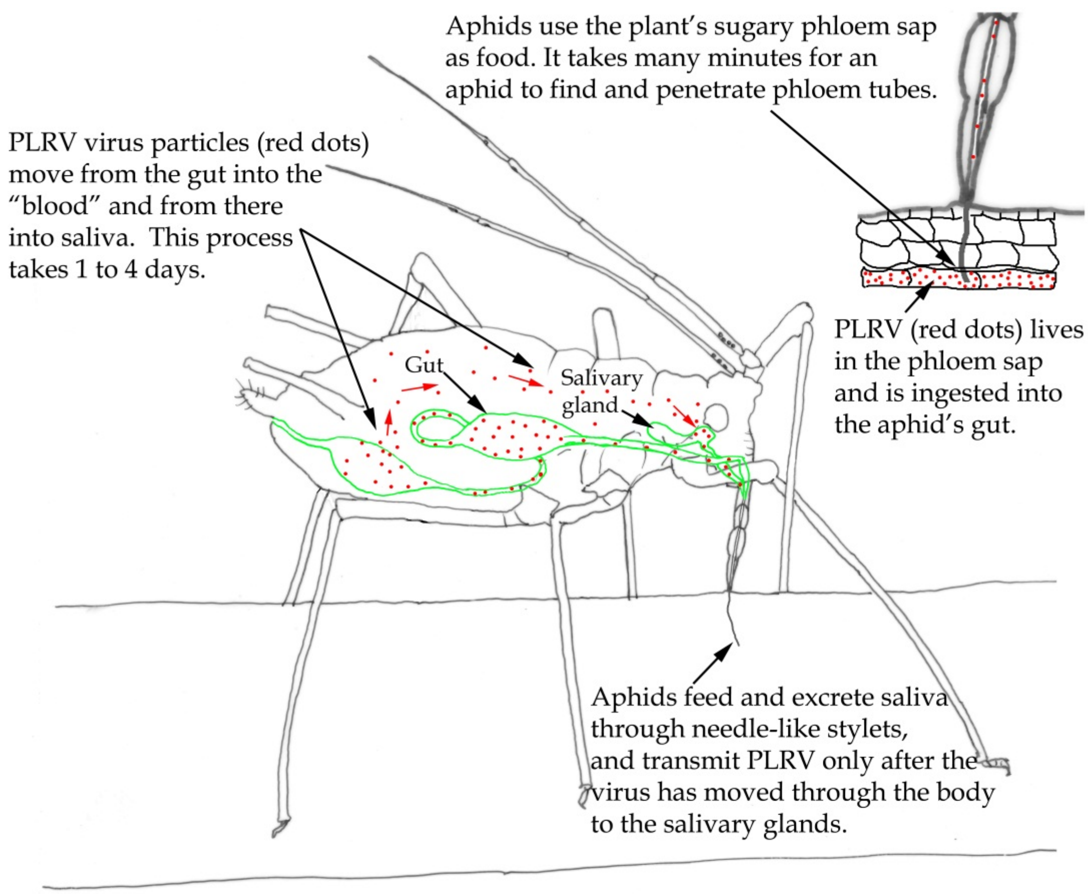

Figure 3. Details of PLRV transmission biology. The most important fact here is that from acquisition to transmission, an aphid must feed on potato for a period measured in days. This means that only aphids that can tolerate potato as food and reproduce on it can transmit PLRV. It also means that insecticides have plenty of time to act before an infected aphid can transmit PLRV. Illustration by the author.

<u>The situation with PVY.</u>
Transmission of PVY, on the other hand, is rapid and infected aphids lose the virus very quickly, a transmission style known as non-persistent (Figure 4). It relies on the fact that as aphids settle on a plant they test it for suitability as a reproductive host by briefly probing the leaf cells with their needle-like mouthparts called stylets. PVY is taken up during these brief tasting probes, adheres to the inside of the stylets and other foregut parts with the help of a specialized viral protein known as helper component, and can immediately be discharged into a plant the next time the aphid probes. It takes only a few probes after acquisition for the aphid to lose all its attached virus particles and become non-infective. The key points here for PVY management include, 1) aphids unable to colonize potato can transmit PVY, but only those aphids whose stylets and foregut can effectively interact with PVY's

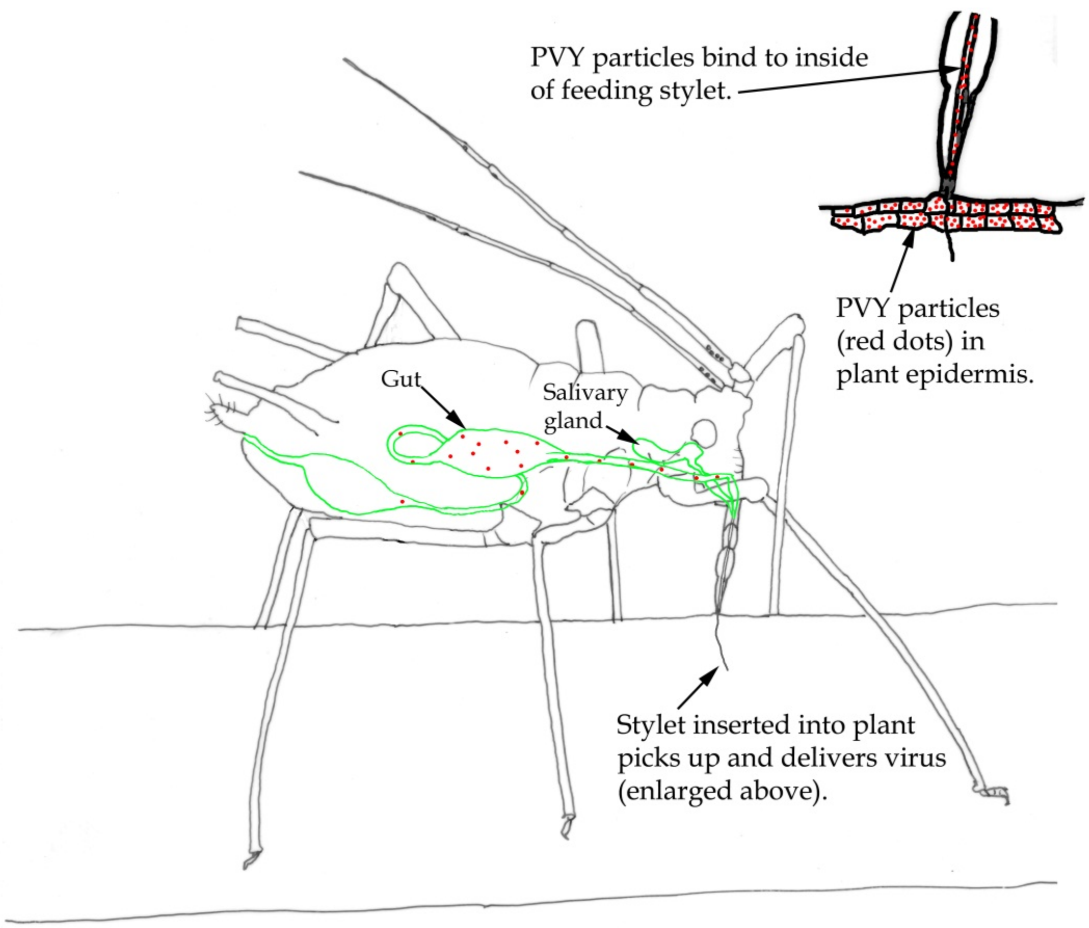

Figure 4. Important aspects of PVY transmission by aphids. Note that in most cases PVY will be transmitted by winged aphids only briefly visiting the crop. A crucial point is that PVY lives in the leaf cells near the surface, as opposed to deep in the phloem, which makes acquisition and transmission of PVY very quick processes. Illustration by the author.

helper component protein; 2) this transmission happens very quickly, much more quickly than any insecticide can act to kill the aphid. PVY management, therefore, must rely on tactics other than aphicides. One common approach in recent years has been mineral oils, sometimes known as stylet oils. The fact that oils at low rates can reduce PVY transmission was discovered in the 1960s (Bradley, Moore, & Pond 1966) and only recently has become commonplace. It is, like all PVY management tools, not a panacea. All tools in PVY management must be considered incremental improvements and must be used carefully and deliberately. For commercial growers by far the best way to control PVY in their harvested crop is to buy seed with little or no PVY.

Key points about aphid management.

Aphids are often managed in commercial potatoes based on a threshold at or near detection – in other words, very aggressively. The key reasons for this risk-averse approach are to 1) control the spread of PLRV and tuber net necrosis it can cause, and 2) limit the spread of PVY and the yield and quality losses it can cause. As many of you know, PLRV used to be common in seed potato, and was a major issue every year in commercial potato production. A look back at the potato conference proceedings and similar publications in the 1970s to early 1990s will show just how serious this problem was. Net necrosis and PLRV, however, have become extremely rare during the 21st century. Why is this? The extreme efficacy of neonicotinoid insecticides such as imidacloprid and thiamethoxam are usually given all the credit, and rightly so. These products can control colonizing aphids in potato almost all season, and extremely effectively (see the red line Figure 5). As described above, keeping colonizing aphids out of potato can and does prevent PLRV infection. The widespread adoption of powerful neonicotinoids in the seed industry has almost eliminated PLRV from seed. Research by Pete Thomas and colleagues in the 1990s showed that by far the most important source of PLRV in the commercial crop is what comes in the seed, as opposed to PLRV that may exist in surrounding environment, weeds, etc. If the seed is free of PLRV, very little will occur in the crop at harvest (Thomas, Pike, and Reed 1997). With neonicotinoids in the commercial crop as well, PLRV is practically eliminated. I should note that although non-colonizing aphids are crucial vectors of PVY, green peach aphid is incredibly capable, and any resident population in your crop can spread PVY.

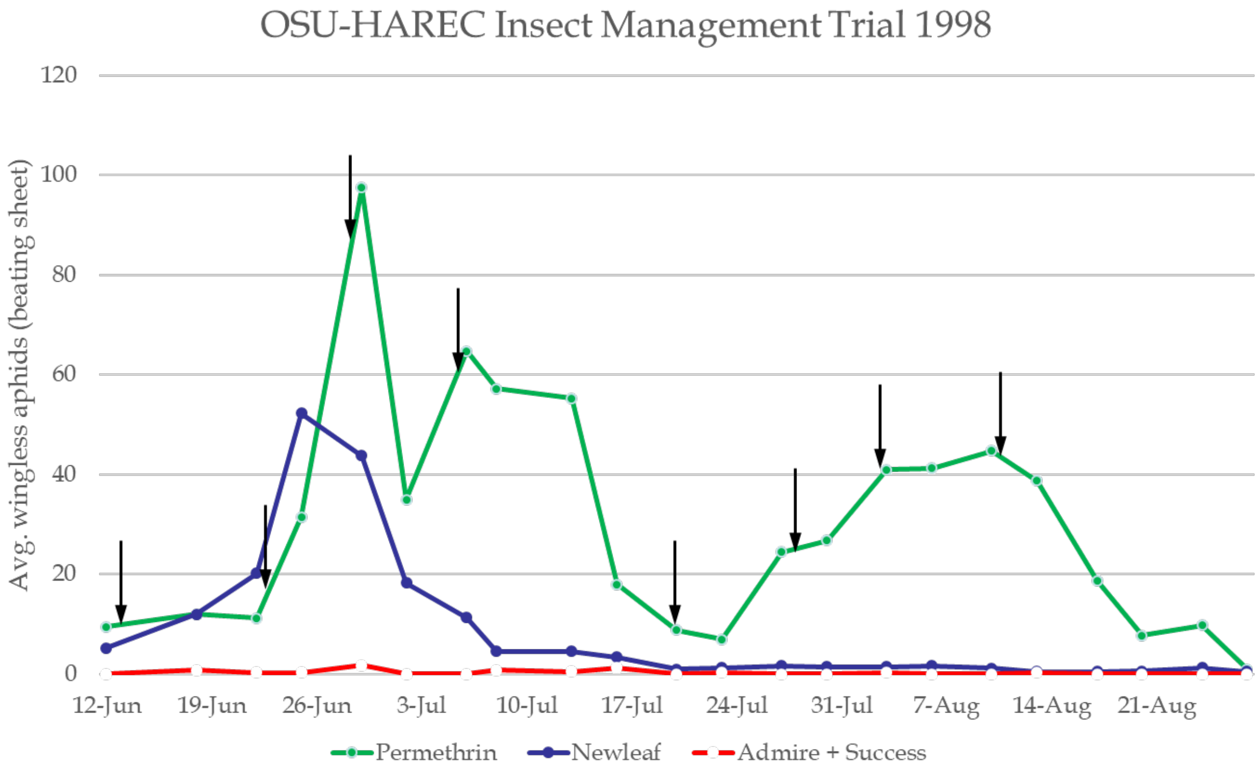

Figure 5. A selection of insecticide treatments from a research report by Gary Reed, OSU Hermiston, 1998. The red line shows the incredible aphid control of imidacloprid applied at planting (Success was used to control beetles). The green line shows what can happen with frequent applications of pyrethroid insecticides (the black arrows showing permethrin application dates): aphid population explosion followed by consistently high numbers. The blue line here is especially interesting. It shows what happened with aphid populations that received no insecticides at all, in plots of the now-defunct transgenic plants called Newleaf that were resistant to beetles. The beating sheets used here were large, so the aphids per sheet represent the number shaken from about 2 plants.

Figure 5 shows two other very important and common phenomena:

1. Pyrethroid insecticides lead to “flaring” of aphid populations. This is almost certainly due to the complete elimination of predators and parasitoids by the insecticide and the fact that pyrethroids are only partially effective at killing aphids. The net result is aphids reproducing faster than can be controlled by the insecticide. Figure 5 is a great illustration of why entomologists constantly discourage the use of pyrethroids!
2. Very often aphid populations that are left untreated will rise briefly early in the season and then drop off to very low numbers. This is the normal course of aphid populations in natural systems. Spring brings on large numbers of aphids as they exploit high quality host plants and low numbers of predators. During summer, predators, parasitoids, heat, and lower host plant quality typically cause aphid populations to crash. When lay people learn that I am an aphid expert, they almost invariably ask me how to control the aphids on

some plant or other in their yard. My first answer is always to wait a week or two and see if they disappear without any control effort. The blue line in Figure 5 shows that this can happen in a potato crop as well.

Monitoring for aphids in potato.

There are no formal treatment thresholds for aphids in commercial potato, but it is still important to look for them in your crop. Reasons include:

1. Determine when/if to spray for aphids. If you did not apply a neonicotinoid at-planting, it will be important to monitor the crop to detect and then track the early season flush of aphids. If you can be patient, you can then follow the population and see if the early flush dies back quickly, thus allowing you to avoid insecticide application.
2. Confirm (or not) that your insecticide program is working. If a neonicotinoid is used at planting, it is likely to eventually lose effectiveness and aphids may start to build up. It is important to be in the crop to detect this change and track whether aphid numbers are building.
3. Keep an eye on predator populations. Aphids are sometimes referred to as the corn flakes of the insect world because so many insects like to eat them. It is definitely worthwhile to watch potato fields for the presence and abundance of the many common predators of aphids, some of which are shown in Figure 6. Watching predator numbers throughout the season allows you to have a sense of whether they will be able control any nascent aphid resurgence.

Figure 6. Common predators of aphids. <u>Top row left to right:</u> damsel bug (a.k.a. 'nabid'), two big-eyed bugs feeding on an aphid under the dry flower, a big-eyed bug (a.k.a. *Geocoris*), a lady beetle larva. <u>Middle row left to right:</u> three kinds of adult lady beetles (a.k.a. 'ladybugs'), a minute pirate bug (a.k.a. anthocorid). <u>Bottom row left to right:</u> larva of a brown lacewing, larva of a lady beetle, and pupa of a lady beetle.

How to look for aphids in a potato crop? There are strong opinions and two main camps: 1) leaf picking, and 2) beating sheet/tray/bucket methods. As an aphid specialist I have a definite preference: a 1 square foot plywood beating tray (Figure 7) combined with leaf picking. Why both methods, you might ask? I have learned from experience that beating trays like mine are good at detecting aphid populations on many kinds of plants. But, the best place to find aphids in potatoes is often the lower yellowing leaves inside the canopy, which are not easy to sample using a beating tray technique. Therefore, I recommend quick beating tray samples of the upper parts of the plants to detect recent colonists of all aphids plus established populations of potato aphid (potato aphid often prefers the upper stems, as in Figure 8a), and leaf picking deep inside the canopy to detect established populations of green peach aphid (Figure 8b).

Figure 7. My plywood beating tray, paint stirring stick for tapping on the plants, plus a hand lens and reading glasses for seeing the insects.

<u>Summarizing:</u>

- Aphids have unique biology that helps them be resilient, ubiquitous pests.
- PLRV and tuber net necrosis it causes can be controlled using insecticides aimed at aphids.
- PVY is transmitted mostly by transient, non-colonizing aphids, and insecticides are only a minor player in PVY control. For commercial growers, the best approach is to by seed with low PVY content.
- Neonicotinoids have apparently solved the PLRV/net necrosis problem by allowing production of virus-free seed.
- Avoid pyrethroids (IRAC Group 3), which can lead to aphid population buildup.
- It is important to scout for aphids and their predators. Bear in mind that sometimes aphid populations will drop off to near-zero naturally.

A

B

Figure 8. Photo A is a group of potato aphids on the upper foliage of potato. This is the red color form of potato aphid, which is more often green. Photo B is the kind of slightly yellow leaf to focus on when picking leaves for green peach aphids; this leaf has many aphids that would commonly be caused by over-use of pyrethroid insecticides early in the season.

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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 NO_3-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 NO_3-N levels thus correlated well with N fertility rates.

Fertigation Schedule for Clearwater N Study
(3-yr avg., 2014-16)

28 DAE approximate row closure

	Date	Seasonal N Rates (lb/A)* 150	250	350	450
		In-season N (lb/A)			
14 DAE	6/1	7	19	26	41
21 DAE	6/8	5	26	33	41
28 DAE	6/13	5	21	31	37
	6/18	3	18	24	37
	6/23	3	14	24	37
	6/30	3	10	24	36
	7/8	3	7	23	36
	7/14	0	7	18	26
	7/21	0	5	16	24
	7/28	0	3	11	15

*Plus 120 lb/A N residual at planting.

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.

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 NO_3-N should be between 21,000-26,000 ppm 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 NO_3-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).

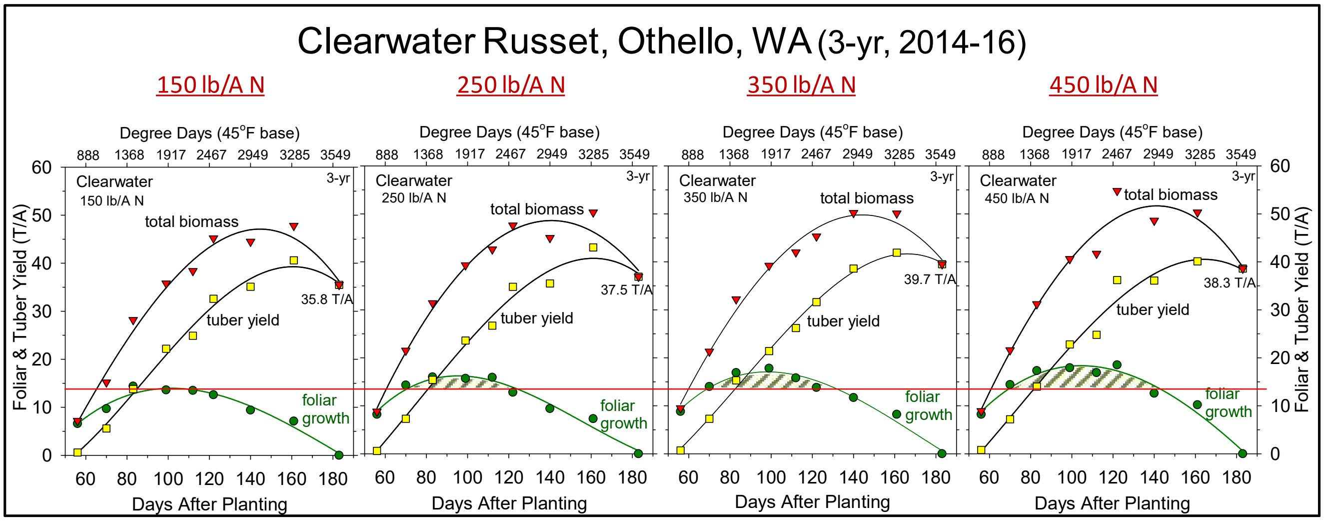

Fig. 1. Three-year average foliar, tuber, and total biomass (foliar + tuber yield) yield profiles for **Clearwater Russet** under four levels of nitrogen (N) at Othello, WA (2014-16). Planting and harvest dates averaged April 15 and Oct. 14 (183 DAP), respectively, over the 3 growing seasons. Cumulative 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).

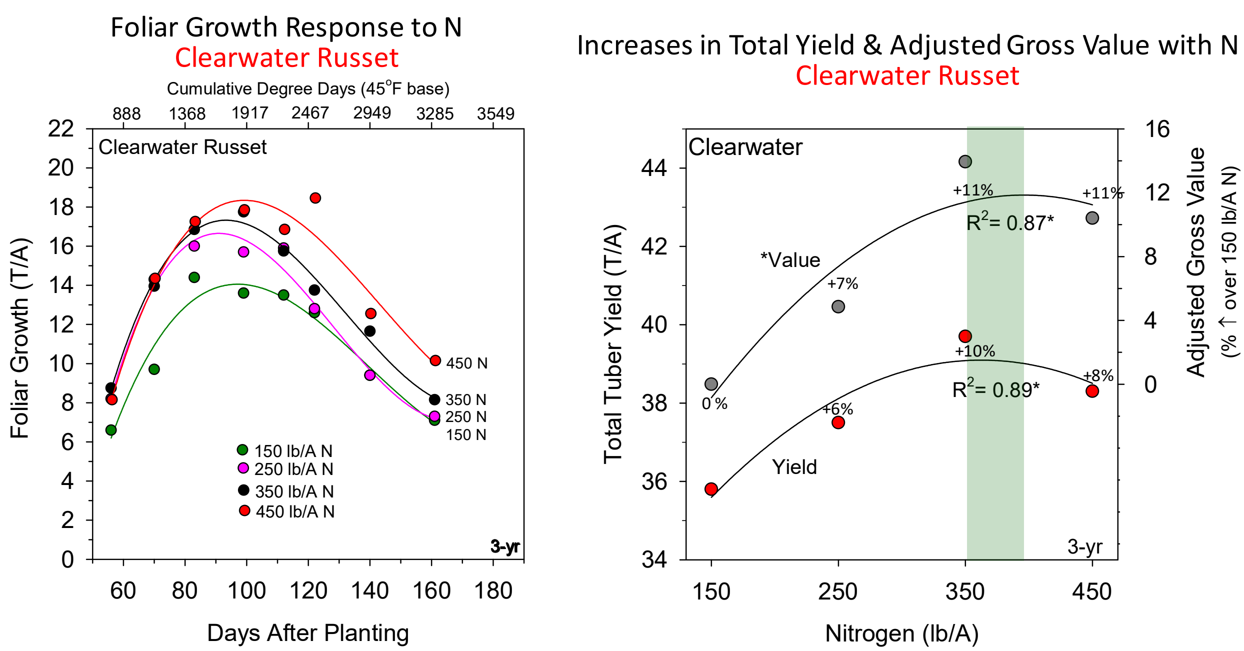

Fig. 2. Effects of seasonal N rates on foliar growth (left), total tuber yield, and adjusted gross value (right) of **Clearwater Russet**. Data are averaged over three growing seasons (2014-16). Maximum foliar growth and duration of foliar growth increased with N. Adjusted gross value (minus N cost) 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.**

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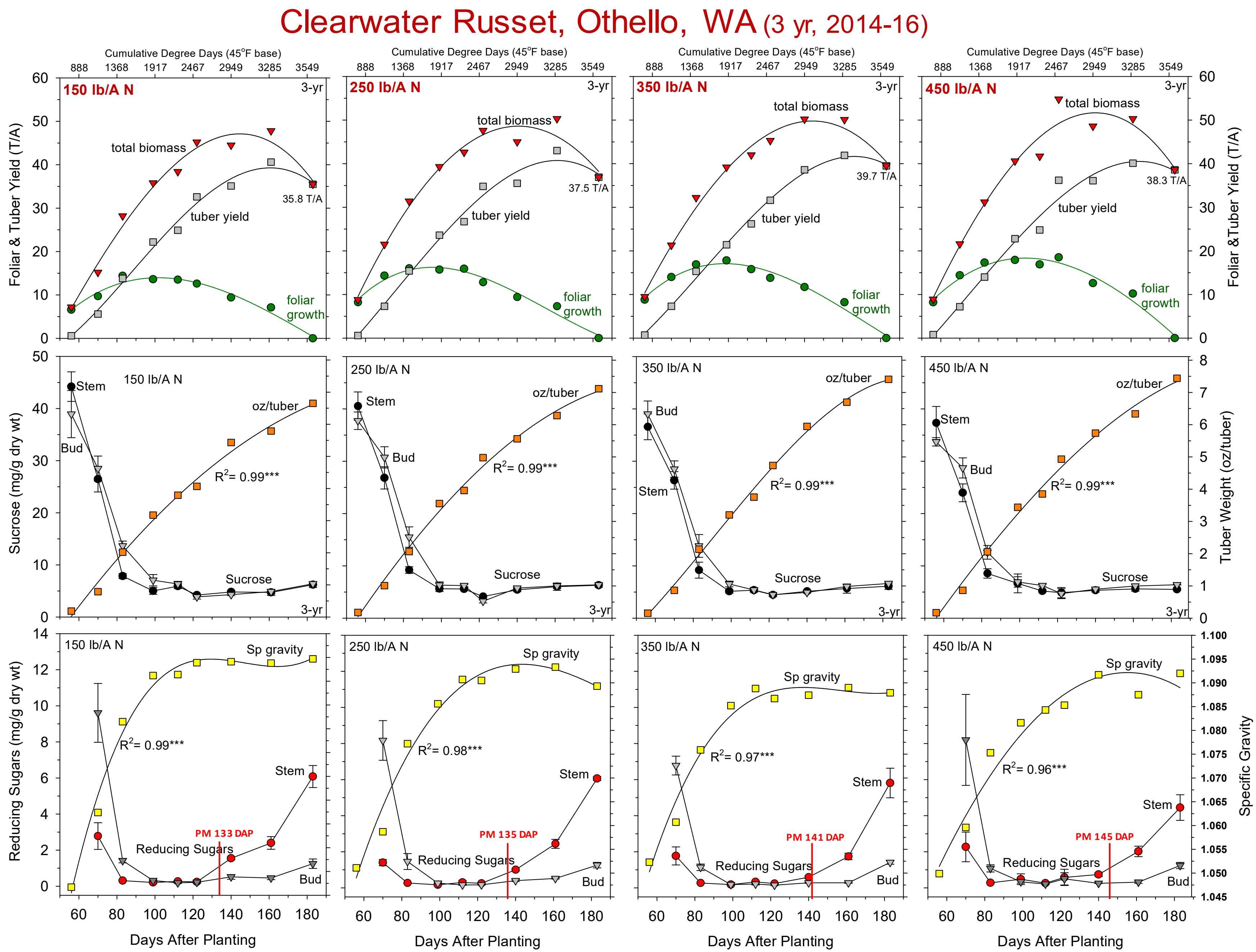
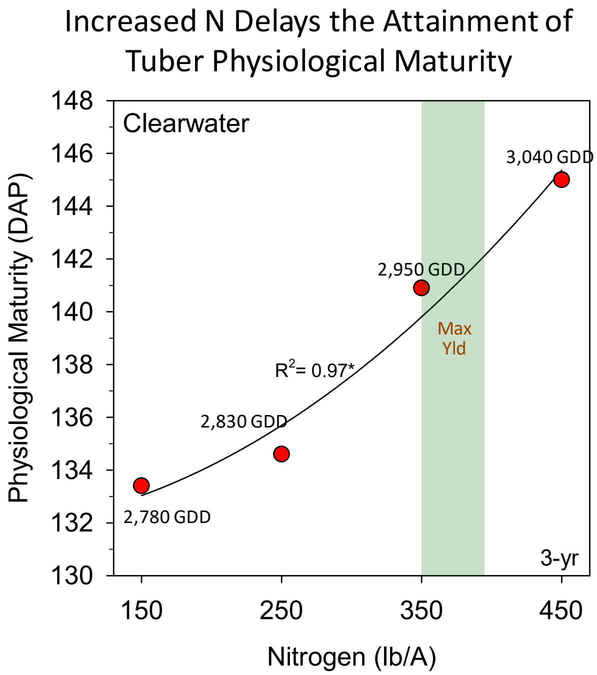


Fig. 3. Foliar and tuber growth (top row), average tuber weights and sucrose concentrations (middle row), and reducing sugars (glucose + fructose) and specific gravity **(bottom row)** were profiled as components of physiological maturity (PM). PM was estimated at 133, 135, 141, and 145 DAP as N rate 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.



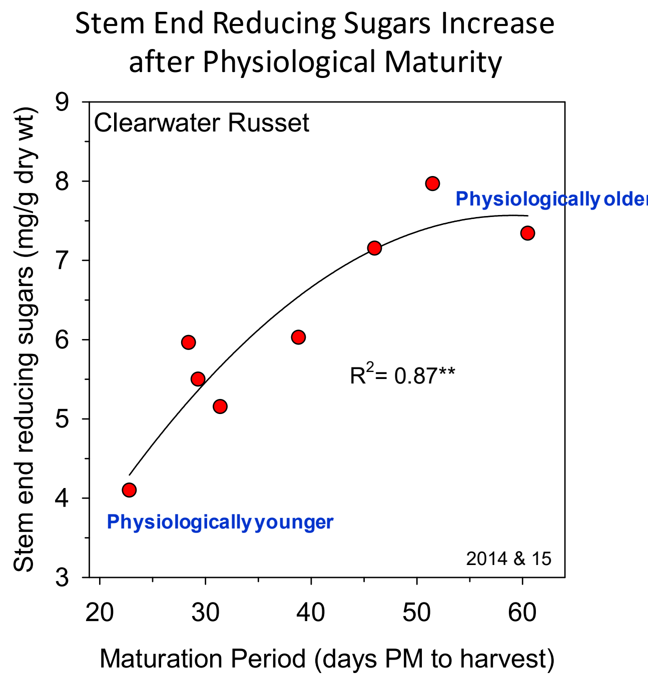


Fig. 4. (**left**) Effects of N fertility on days after planting to tuber physiological maturity (PM) of Clearwater Russet (2014-16). PM is the average DAP to reach max yield, max specific gravity, minimum sucrose, and minimum reducing sugars in tubers (see Fig. 3). Yield and value were maximized at 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.

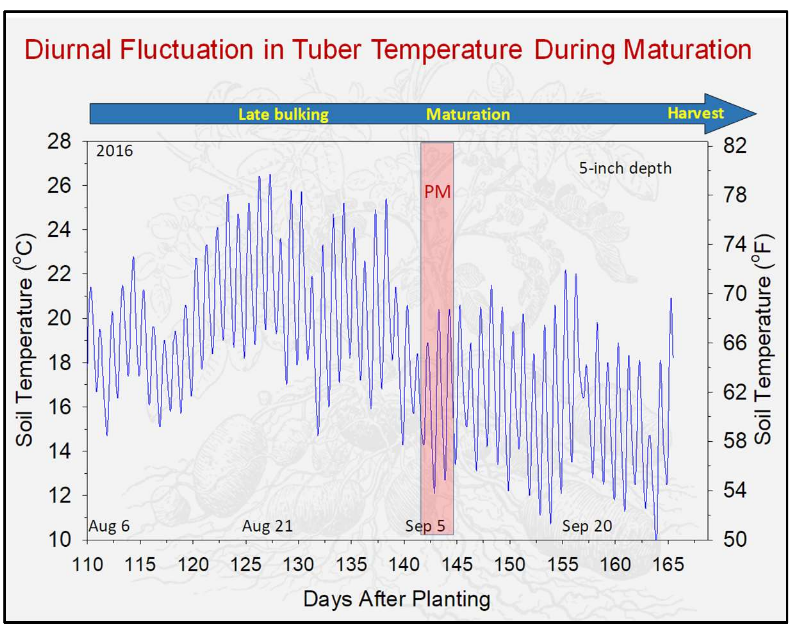


Fig. 5. Daily fluctuation in soil temperature (5-inch depth) during the late bulking and maturation phases of crop development (2016 season). Physiological maturity (PM) for Clearwater was reached at ~141-145 DAP (shaded). Exposure of tubers to fluctuating soil temperatures following the attainment of 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).

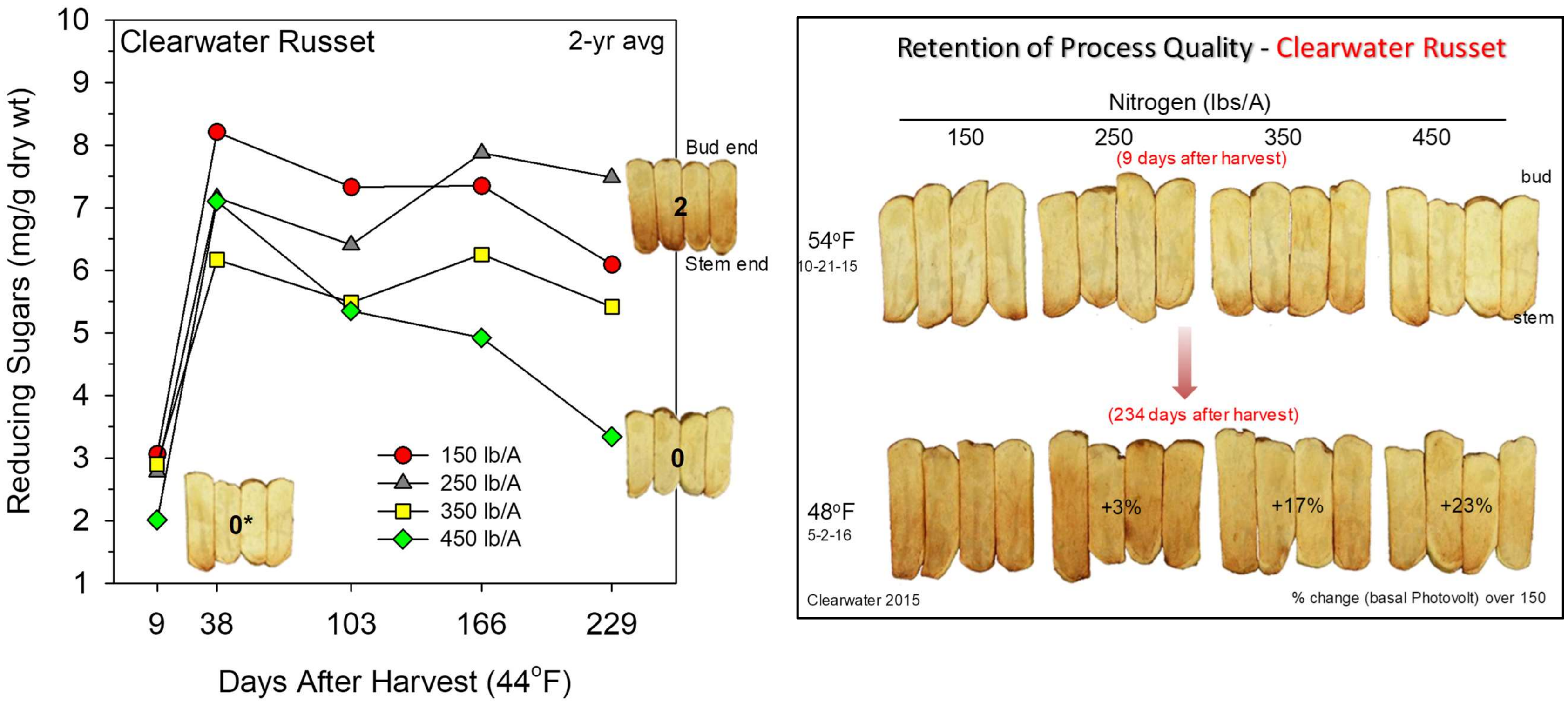


Fig. 6. (**Left**) Changes in tuber reducing sugar concentrations during storage at 44°F averaged over the 2014 and 2015 seasons. Representative fry planks from tubers grown with 450 lb/A N are shown at the beginning (9 DAH) and end (229 DAH) of storage compared with tubers grown with 250 lb/A N. Note 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.

Direction of Planting: Does It Matter?

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No previous research on direction of planting exists for potatoes in the Columbia Basin. The purpose of this trial was to investigate if there is a difference in economic return to growers for planting in one direction or another.

Methods and Materials: In 2015-18, Umatilla Russet and Payette Russet (2018 only) were planted in four directions north to south (N to S), northeast to southwest (NE to SW), west to east (W to E), and northwest to southeast (NW to SE) and grown using standard practices (Figure 1). Each direction was replicated 4 times in a strip-plot design. These varieties were chosen because of their non-uniform emergence and dormancy issues (Payette R.). Soil temperature was measured for each treatment, 2 inches above the seed piece. Solar radiation was collected in 2018 only. Yield, size profile, US grade, tuber quality, and gross return were measured and calculated. Data were combined across years and cultivars for the summary in Table 1.

There were no differences in soil temperature based on row orientation. Rows planted N to S, NW to SE, and NE to SW collected more solar radiation during the day then those planted W to E (data not shown). Photosynthetic photon flux (PPF) measurements indicated that the north side of rows planted west/east failed to collect as much PPF during a typical summer day than other planting directions simply due to their orientation relative to the sun (data not shown). A significant shadow was always present on the northern side of the rows. Figure 2 demonstrates this relationship. Although the canopy eventually covers 100% of the ground after potato row-closure, the plants are less dense between rows compared to within-row plants and sunlight is still able to make its way into the canopy. Because of this, rows should be oriented to absorb as much solar radiation on all sides of the plants throughout the day (N toS, NW to SE, NE to SW). The row planting directions that absorbed the most solar radiation also produced the highest gross return and yield (Table 1). Based on four years of research, planting from or to N to S, NW to SE, or NE to SW (vice versa) is better for plant growth and economic return than planting W to E, vice versa. (Table 1).

When planted in a tight row (spaced about 10 inches apart in-row) and planted W to E, one side of the row tends to be shaded more than the other. Think about what side of the tree the moss typically grows in the northern hemisphere – north. In a row planted W to E or vice versa, the north side of the row is more shaded than the south. When planted N to S or close, the tightly spaced side of the row is on the W and E. As the sun moves from sunup to sundown (Figure 3), the W and E sides get close to equal exposure to the sun during the day – maximizing the capture of solar radiation. If plants were spaced in a perfectly square pattern, say 17 x 17 inches, as opposed to the typical row, say 10 x 34 inches, planting direction would not matter. Remember, results may vary if the field is sloped one direction or another. We hope to continue this research for one more year with more than one variety to proof the data before we make recommendations to growers. For many situations, growers must plant in the direction that is logical with the lay of the land.

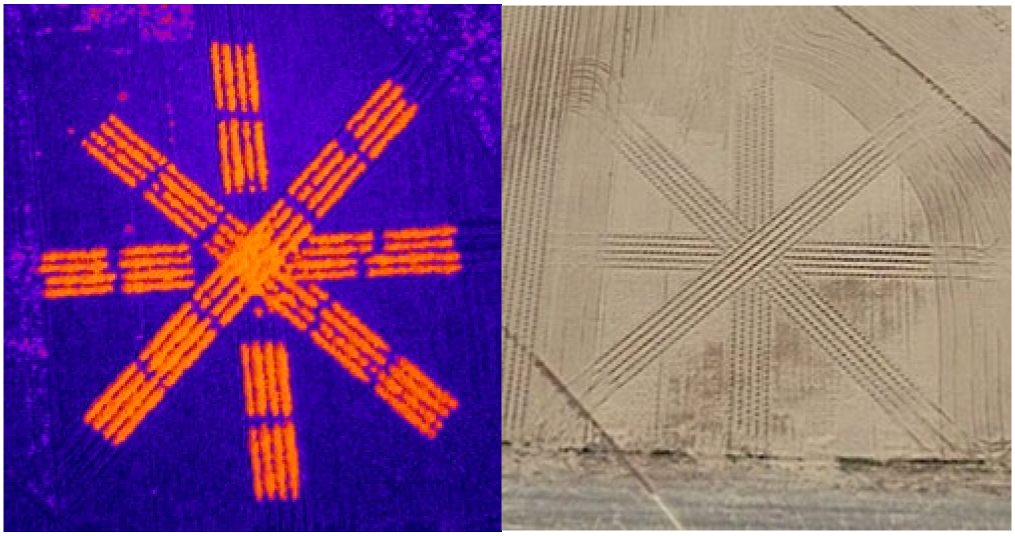

Figure 1. A near-infrared photo of the Direction of Planting trial taken by a drone (left) compared to a Google Earth snapshot (right). The photo on the left was taken near the end of June after potato plants had emerged. The photo on the right was taken after the trial had been planted and dammer-diked. The trial was located on the WSU Othello Research Farm.

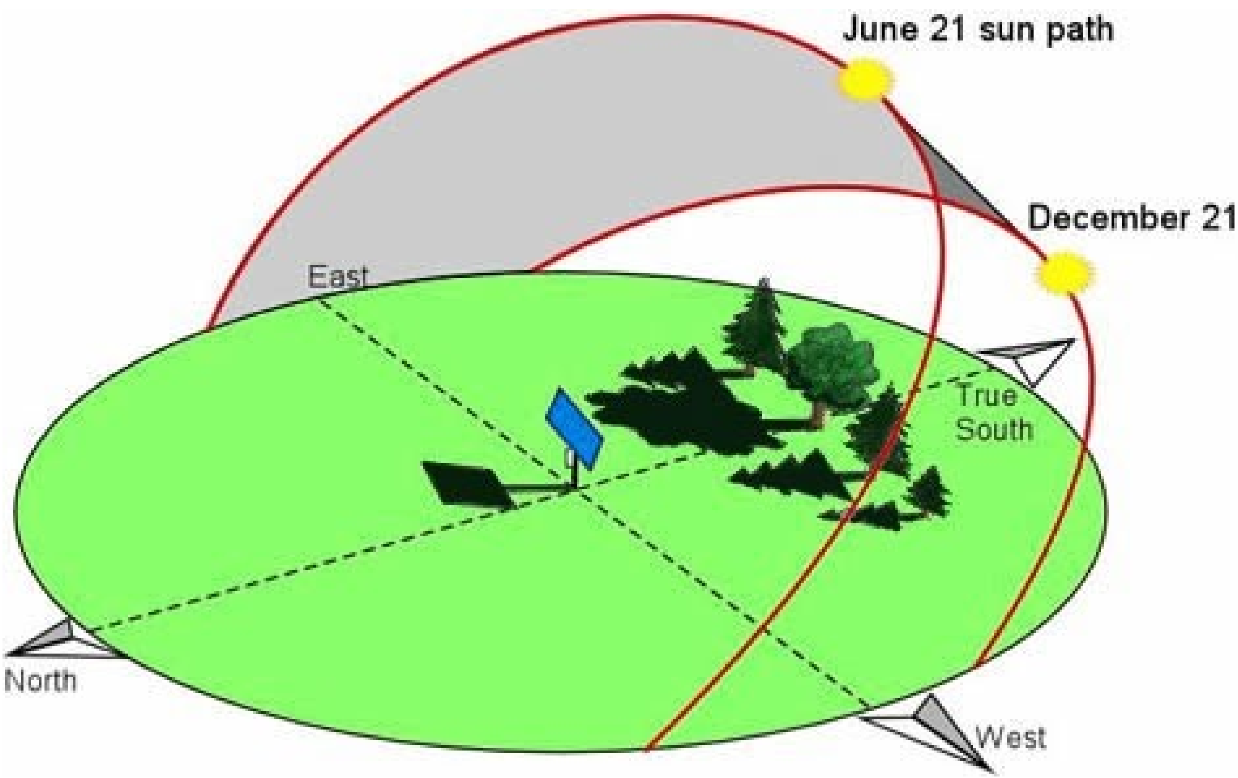

Figure 2. The sun's movement during summer and winter soltice. Note the shadow on the north side of a tree line planted due west/east. The shadow is similar on potato hills and plants when planted west/east.

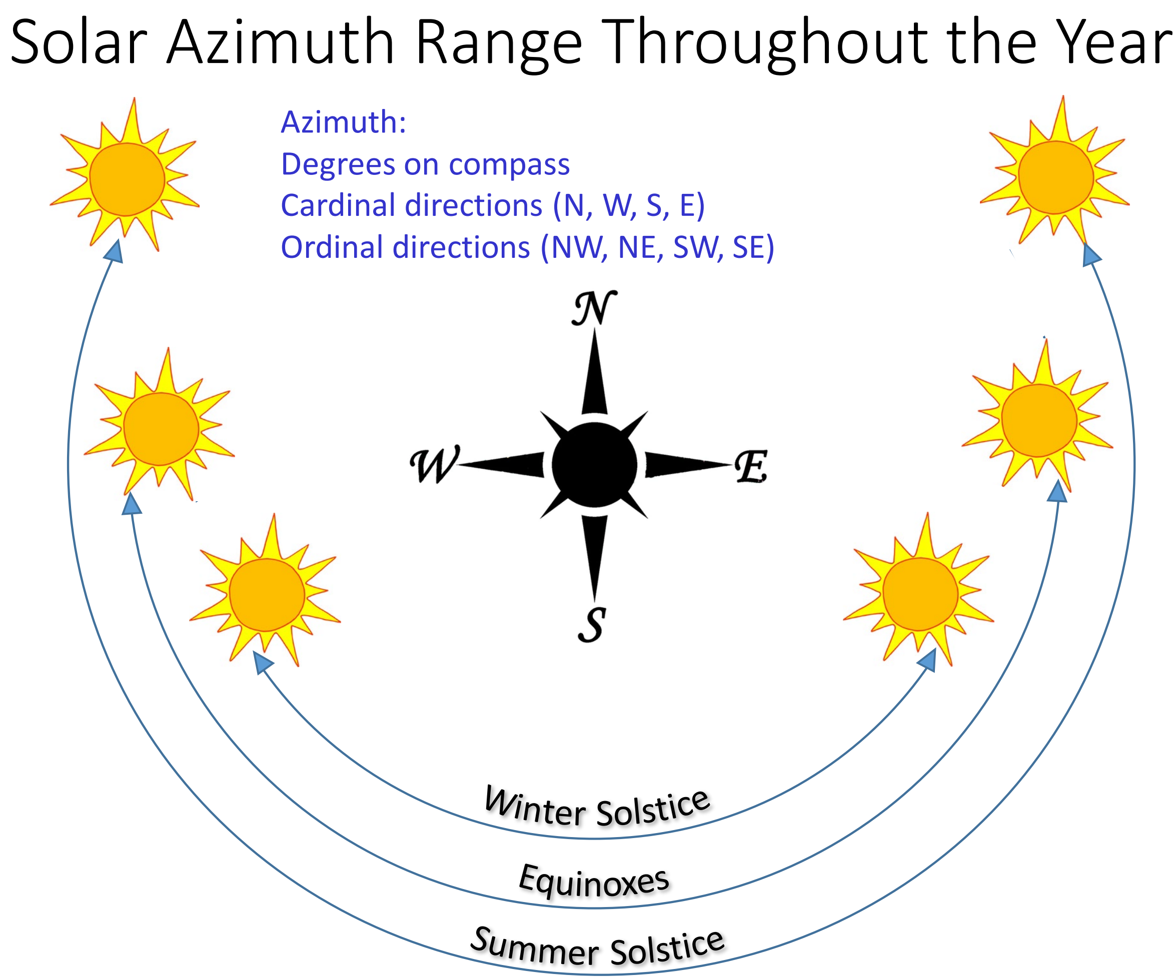

Figure 3. Solar azimuth range throughout the year for the Northern Hemisphere

Table 1. Yield, economics and tuber information from the 2015-18 Direction of Planting trial.

2015-18 WSU DIRECTION OF PLANTING TRIAL SUMMARY

Treatment	Process Adjusted Gross $/A	Total Yield CWT/A	Total Market Yield	US 1s > 4 oz %	US 2s > 4 oz %	Culls & < 4 oz %	Process Yield US 1 & 2s > 6 oz %
N to S	4690	776	737	78	2	21	58
NW to SE	4900	768	721	78	3	19	64
NE to SW	4590	751	718	76	2	22	57
W to E	4280	722	674	75	2	24	57
LSD	480	54					4.9
Pvalue	0.0484	0.0578	ns	ns	ns	ns	0.0067

Treatment	Average Tuber Weight oz	Tuber Number Per Plant	Specific Gravity	Market Yield (Percent of Market Yield) CWT/A 0-4	4 to 8	8 to 12	12 to 16	> 16
N to S	7.1	10.7	1.089	129	300	168	70	69
NW to SE	8.1	9.3	1.089	104	254	169	103	91
NE to SW	7.1	10.3	1.089	128	290	156	75	69
W to E	7.3	9.8	1.089	121	266	155	78	54
LSD		0.8		19	37		21	21
Pvalue	ns	0.0051	ns	0.0057	0.0343	ns	0.0037	0.0279

ns = values within the same column are not signficantly different based on Fisher's Least Signficant Difference Test

LSD values not shown when treatment values are not significantly different

Potatoes. Real Food. Real Performance.™
WHAT ARE YOU EATING?™

Potatoes USA

STRATEGY AND CAMPAIGN KEY MESSAGES

Performance Strategy

For years we've talked about why you *can* eat potatoes. From now on we're talking about why you *should*— because *potatoes fuel performance*.

- Extensive research led us to conclude that this is the best possible positioning to pursue.
- Most people don't consider the potato a performance food and are surprised when they learn it is. That surprising truth is our big opportunity.
- The point is to deliver a nutrition-based lifestyle benefit that positively challenges consumers' preconceived notions about potatoes.
- Moving from "*you can*" to "*you should*" is a huge marketing shift for us that can fundamentally change how people perceive potatoes.

Potato Nutrition

Potatoes contain the complex carbohydrate, potassium, and energy people need to perform at their best.

- Potatoes are a naturally nutrient-dense complex carbohydrate. *(26 gm/5.3 ounce skin-on potato)*
  - ✓ Carbohydrate is the primary fuel for your brain and a key source of energy for muscles.
  - ✓ Our body's own stores of carbohydrate are limited and may be depleted, even in a single session of intense and/or prolonged exercise. It's important to replenish them.
- Potatoes with skin on have more potassium than a medium-sized banana and more than any other 20 top-selling fruits and vegetables. *(620 mg/5.3 ounce skin-on potato)*
  - ✓ Potassium is an important electrolyte that aids in muscle, cardiovascular and nervous system function.
- Potatoes are more energy-packed than any other popular vegetable. *(110 cal./5.3 ounce skin-on potato)*
  - ✓ It's critical to take in enough quality calories to match the demands of your day.
- Potatoes contain many other important nutrients that athletes seek, including vitamin C (27 mg), fiber (2g), and complete protein (3g).

What Are You Eating? Campaign

The performance strategy is coming to life in a new campaign that shows how potatoes fuel athletic performance and poses the question: "What are *you* eating?"

- The campaign is based on the idea that consistently beating your personal best isn't just about how you train; it's about what you eat.
- It is designed to provoke a "moment of re-evaluation," among consumers with a clear message: If potatoes can fuel elite athletes, they can fuel your active life too.
- The campaign is NOT about marketing only to athletes. It IS about using athletes to illustrate the power of the potato, to influence consumers to think about potatoes differently, and to amplify our message to all audiences.
  - ✓ For its first year, the campaign will come to life through social media, advertising, influencer marketing, industry engagement and events (Rock 'n Roll Marathon, Shape America, Collegiate & Professional Sports Dietician Association, Produce for Better Health, etc.).

Call to Action

Every member of the potato industry can — and should — get involved.

- Visit PotatoesUSA.com/grower and look for the "What are you eating?" portal to buy gear, download an event toolkit or request activation equipment and materials.

USE THE PRIMARY MESSAGES IN SEQUENCE FOR AN "ELEVATOR SPEECH"

Start by "headlining the headlines" and then put the primary (bolded) messages together in your own words. You can use one or two of the "proof points" (those bullets under the bolded messages that help flesh things out) if you like. This will result in a conversational "elevator speech" that fits your personal style but also ensures the industry speaks with one voice. Here's an example:

> *"Potatoes USA is undertaking a major marketing shift based on our new 'performance strategy.' It's rooted in nutrition facts, of course, and it comes to life in a cool new campaign.*
>
> *"In a nutshell, for years we've talked about why you can eat potatoes. But from now on we're talking about why you should — because potatoes fuel performance. That's the strategy, and it's a bit of a surprising truth for some people, but it's based in sound nutrition science. It's pretty simple actually: Potatoes contain the energy, potassium, and complex carbohydrate people need to perform at their best. With that in mind, the strategy is coming to life in a new campaign that shows how potatoes fuel athletic performance and poses the question: 'What are <u>you</u> eating?' This is a big deal and I think it's a smart move every member of the industry can get behind — and, in my opinion, should get directly involved with."*

BRING OUR MESSAGES TO LIFE WITH REAL-WORLD STORIES

Anytime you get the chance, try to bring our messages to life with stories about things you've experienced first hand or examples from other people's lives that you've heard or read about. Potatoes USA will share particularly strong stories with the industry as they become available, but be on the lookout for your own.

Invasive colonization of Lygus: How can we manage the spread?

Silvia I. Rondon
Hermiston Agricultural Research and Extension Center, Crop and Soil Sciences, Oregon State University, Hermiston, OR. Email silvia.rondon@oregonstate.edu

Lygus bugs (Hemiptera: Miridae) are insects that feed on a wide range of crops including strawberries, a variety of berries, apples, peaches, nectarines, pears, legume seed crops such as alfalfa or clover seed, canola, vegetables like carrots, radish, beans, and quinoa in the Pacific Northwest. Although seldom a pest on potatoes, Lygus bugs abundance and distribution are an increasing concern to potato growers as too many unknowns are still present in regards to the effect of Lygus on potatoes which besides causing direct feeding damage, Lygus bugs can carry pathogens potentially causing a decrease in tuber quality.

Damage by Lygus on potatoes was reported as early as 2007. However, it was in 2014, when we were able to identified the different faces of the damage. Both, adults and immature Lygus bugs, feed on potato plants by inserting their piercing-sucking stylets causing laceration of leaves, stems, and bud ends. Lygus bugs prefer to feed on terminal leaves or upper foliage of potatoes and they do have potato varietal preference. Affected tissue does not grow

Fig. 1. leaf flagging (top left); oozing (right); plant desiccation (bottom left). Photos credit. Irrigated Agricultural Entomology Rondon Program.

normally and ultimately desiccates and dies. Feeding usually results in 3-stages: (1) leaf flagging, caused by direct puncturing of the plant tissue, (2) oozing, a plant physiological response, and (3) plant desiccation, caused by the lack of moisture due to the rupture of phloem channels (Fig. 1).

Lygus complex in the Columbia Basin

In general, Lygus bugs adults are about ¼ inch long and are recognized by the presence of a conspicuous heart shape on the upper center of the back known as scutellum. Immature Lygus bugs look similar to adults, except immatures are smaller, do not have wings, and do not reproduce. Newly hatched Lygus look like aphids, but and can be distinguished from aphids by their lack of cornicles (Fig. 2). Lygus bug eggs are difficult to see with the naked eye because females insert the entire egg into plant tissues.

Fig. 2. Inmature Lygus (left); aphids (right). Photos credit. Left, Irrigated Agricultural Entomology Rondon Program; right, K. Pike WSU.

It was determined, based on morphological and molecular studies, that the species composition of the Lygus complex in the Columbia Basin included *L. hesperus* (western tarnished bug), *L. elysus* (pale legume bug), and *L. keltoni*. The first one, *L. hesperus*, is the most abundant season long in potato fields (˜ 82%) (Fig. 3).

Lygus hesperus **Lygus elysus** **Lygus keltoni**

Molecular and Morphological Identifications Reveal Species Composition of *Lygus* (Hemiptera: Miridae) Bugs in Potatoes Fields in the Lower Columbia Basin of the United States

Josephine Antwi, Silvia I Rondon

Journal of Economic Entomology, toy314, https://doi.org/10.1093/jee/toy314

Published: 13 October 2018 **Article history ▾**

http://v3.boldsystems.org/index.php/Taxbrowser_Taxonpage?taxon=Lygus&searchMenu=taxonomy&query=Lygus

Monitoring Lygus bugs

There are different techniques available for sampling Lygus bugs including sticky cards, insect nets or vacuums. Based on our experiments, the inverted leaf blower (ILB) is the most effective sampling tool. Currently we recommend using the ILB for 5 minutes, 5-10 feet inside fields. Presently, there is no economic threshold for Lygus bugs on potatoes in the PNW but in Canada, where *L. lineolaris* is prevalent on potatoes, 25 adults per 25 sweeps over crop foliage seems to be the established threshold. Regardless, it is very important to monitor Lygus bugs on the field throughout the growing season starting at the vegetative growth stage. Lygus surveys conducted by the Irrigated Agricultural Entomology Program yielded high numbers of Lygus from June to August, with population peaks occurring in July.

Management of Lygus bugs

Monitoring Lygus populations on surrounding vegetation has been suggested because crops such as alfalfa, beans, or quinoa can serve as a source for Lygus bugs in potato fields; however, the source of Lygus in potato fields will be investigated in the upcoming seasons. Preliminary results indicate that as alfalfa is harvested, Lygus bugs migrate to nearby potato fields. Border crops of alfalfa have proven successful in controlling Lygus bug populations in cotton fields in southeast and southwest US. In potatoes, chemical products such as Vydate Cl-V or permethrin keep immatures and adults at low levels. It is easier to control immatures rather than adults but it is difficult to have long residual chemical effect.

There is the sense that this emerging pest of potato can potentially be serious, but efforts to determine the consequence of Lygus damage on potato yield and quality should be further investigated.

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How Taters Trot the Globe

John Tullis, Business Development Manager
The Northwest Seaport Alliance

Once a potato is harvested, where does it go?

If its destination lies overseas, it will almost certainly pass through one of the 10 container terminals of The Northwest Seaport Alliance (NWSA). And from here, most travel to Asia: Nearly a third to Japan, but South Korea, China, Taiwan, the Philippines, Malaysia, Hong Kong and Singapore are also hungry for the potatoes exported through the NWSA.

From French fries to chipper potatoes to fresh, whole potatoes, roughly three-quarters of the nation's potato exports pass through NWSA terminals. And demand is growing: Consumers in Central and South America want more potatoes, and the NWSA is looking at how best to meet that demand through our terminals.

The NWSA is positioned to compete in a volatile market

The Northwest Seaport Alliance is a partnership between the Ports of Seattle and Tacoma to move marine cargo both into and out of the U.S. The partnership formed in 2015 as a response to changes across the maritime sector where fierce competition has driven prices downward.

In recent years, ocean carriers began to invest in larger ships because they cost less to operate, using less fuel per unit and benefiting from other economies of scale. But with larger ships came excess capacity, and many ocean carriers have since had to consolidate. These volatile market conditions brought a critical choice for the Ports of Seattle and Tacoma: continue to compete against each other and watch their revenues tank or join forces and invest in terminal modernizations to handle the larger ships.

Fast forward to today. As the NWSA approaches its fourth anniversary this summer, the final investments are underway to upgrade Husky Terminal in Tacoma to accommodate not one but two super-post-Panamax ships end-to-end. And construction is set to kick off on similar upgrades to Terminal 5 in Seattle as soon as this summer. With the capacity to handle large volumes effectively, we are anchoring our ability to continue connecting exporters across the Northwest with markets overseas, particularly in Asia.

To learn more about The Northwest Seaport Alliance, visit nw.sa.com.

Do Lygus Cause Economic Damage to Potatoes?

Tim Waters, Washington State University Extension, 509 545-3511, twaters@wsu.edu

REPORTING PERIOD: March 1, 2018 – January 1, 2019 (2018 Growing Season)

ACCOMPLISHMENTS:
Two species of Lygus were found predominately on potatoes, and there was some variability by location, but the most prevalent species is *L. hesperus* in the majority of the Washington Columbia Basin while *L. elisus* is common, but typically in a smaller proportion. *L. elisus* appears to be more common when flowering seed crops are close to potato fields.

We were able to design a method by which to cage Lygus in plots that are large enough to perform studies on the economic impact of Lygus and other insect pests. Damage to potato plants that is associated with Lygus feeding occurred in infested cages. In plots where Lygus were introduced, overall yield was not impacted, but potato quality was reduced, mostly in terms of specific gravity and tuber greening. Future studies hope to further quantify the impact Lygus feeding has on potato quality.

PROCEDURES:
Species Identifications
Hypothesis: Lygus species vary by growing location and nearby host crops.
Lygus were collected from various commercial fields during the growing season and species will be determined, with the growing region and potato cultivar noted.

For this objective, 18 fields were selected across the Columbia Basin, and the collections occurred. Adult Lygus were collected using a bucket sampling method whereby the tops of potato plants were shaken over an 8.5-inch diameter, two-gallon plastic bucket. The specimens were then kept on ice and shipped next day to the USDA Wapato laboratory for morphological identification. For some specimens, the morphological features presented subtle nuances making identification difficult. For those specimens, Dr. Cooper's lab performed molecular analysis to determine the species. A voucher of the collected specimens is stored at the USDA facility in Wapato.

Economic Injury
Hypothesis: Lygus cause economic damage to potato crops in the Columbia Basin.
We will evaluate if Lygus impact yield and quality of potatoes grown in the Columbia Basin. Lygus populations will be documented for the growing season, and the yield and quality of the tubers assessed at the end of the growing season.

Field cages were constructed with input from several sources in three commercial fields near Plymouth, WA, at the WSU Research Farm in Pasco, and at the USDA Station in Wapato, WA. Cages were 8.5 feet wide and 25 feet in length and consisted of a wood base frame with ¾ inch pvc pipe arches. The frame was covered with a mesh fabric (0.03 by 0.03 Mesh high density polyethylene netting AgFabrics, Vista, CA) that allowed water and light to infiltrate but would not allow entrance or exit of larger bodied insects (those larger than thrips), including Lygus. The fabric was attached to the frame with lath and staples, and a door fashioned on the end to allow entry for infestations and sampling of insects. Three rows of potatoes (Umatilla Russet cv.) were grown in each cage, with the yield and quality measurements taken on fifteen feet of the middle row. For the commercial field, there were three treatments 1) Caged plots infested with Lygus beginning at bloom, 2) Caged plants with no Lygus and 3) Uncaged plots. At the WSU and Moxee sites, there were three treatments 1) Caged with no Lygus, 2) Caged with Lygus introduced at bloom (10 per cage 4 times), and 3) Caged with Lygus introduced at tuber bulking (10 per cage 3 times). The plots near Plymouth were harvested September 7, 2018, the Pasco plots were harvested October 3, 2018 and the Moxee plots were harvested October 19, 2018. The only complications with the cages were birds and aphids, both were dealt with in a rapid manner.

RESULTS/DISCUSSION:

Species Identifications

295 Lygus from 18 different field locations were identified mostly by morphology and a handful of specimens by molecular analysis. Overall, 77% were identified as *L. hesperus*, 20.5% as *L. elisus*, and the remaining 2.5% were *L. robustus*. In the Northern Columbia Basin of Washington, two instances occurred where *L. elisus* was the predominant species, and two instances contained a nearly 50:50 ratio of the two species (Figure 1). *L. hesperus* represented more than 50% of the population at the remaining 14 sites, and oftentimes represented 85 to 100% of the species collected (Figure 1). The difference in species ratios could be the result of numerous factors including nearby adjacent plant species, when during the season the specimens were collected, and collection methods. At the North Columbia Basin sites where *L. elisus* was the predominant species collected, flowering seed crops were near the potato field. In the sites where *L. hesperus* was the predominant species, fields were mostly surrounded by potatoes and various weedy habitats. It does not appear that potato cultivar has an impact on species constituency. Further assessments will be conducted in 2019.

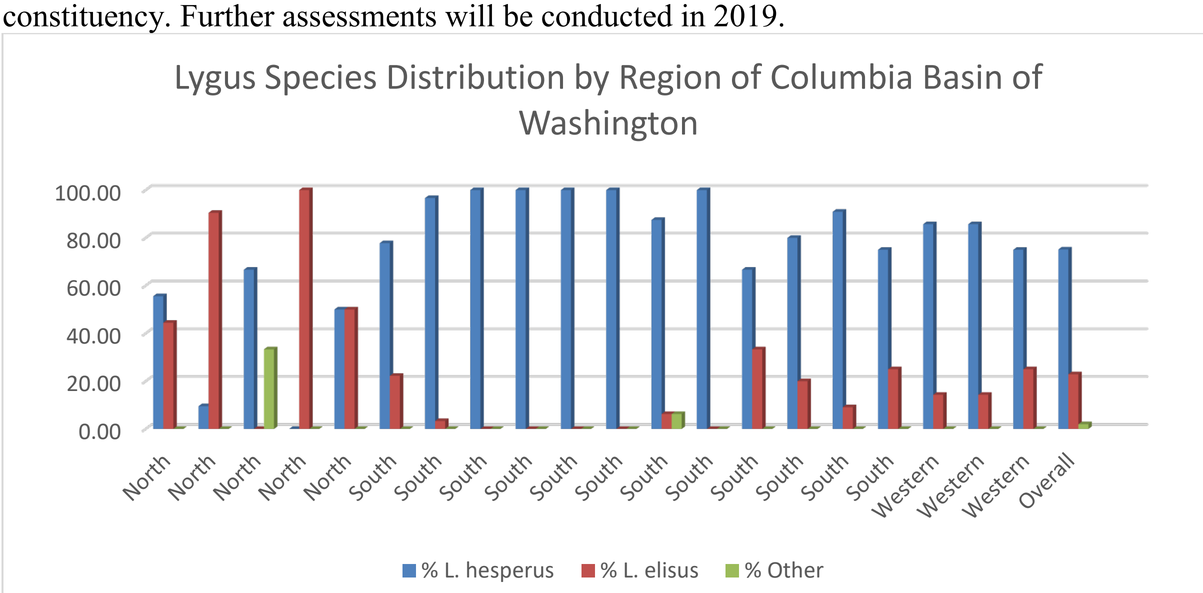

Figure 1. Lygus species proportion by collection location. North, South and Western refer to general local within the Columbia Basin of Washington State.

Economic Injury

In the commercial field, caged plots yielded less than adjacent plots that were not caged (Table 1). This result is not surprising due to the interference of light and other environmental factors associated with caging potato plants. Potato quality was adversely impacted by infesting cages with Lygus whereby more green tubers were found in cages infested with Lygus (Table 1). Specific gravity, tonnage and gross returns were reduced, but not significantly in caged plots with Lygus infested compared to caged plots without Lygus. These plots were not replicated in an individual field but are data from three fields. Replication within individual fields may have yielded more discernable results. The plots that were free of Lygus tended to be green longer than the surrounding field and caged plots with Lygus introduced (Figure 2). When the plots were harvested, the soil in the plots that were free of Lygus was dry, since the plants had not senesced and were using water more than the surrounding field. It seems likely that if the field had been irrigated longer, these plots would have continued to bulk for much longer than the adjacent areas, likely resulting in greater yield and tuber quality.

Trt.	Specific Gravity	Fry Col. 0	Fry Col. 1	Fry Col. 2	Fry Col. 3	Fry Col. 4	Ext. Def.	Green	Tot. Def.	Mis-shap	Ton/A	Gross $
No Cage	1.08220a	24.33a	0.50a	0.20a	0.0a	0.0a	1.773a	0.000b	1.867a	10.00a	41.85a	5915a
Cage – Lyg	1.08341a	23.17a	1.83a	0.0a	0.0a	0.0a	1.583a	0.183b	1.657a	22.33a	32.74b	4566b
Cage + Lyg	1.07771a	24.50a	0.50a	0.0a	0.0a	0.0a	3.953a	0.483a	3.953a	21.17a	31.80b	4470b

Table 1. Potato quality and yield data from the commercial field plots. Fry Col=Number of fry slices of 25 test stripes that were in that USDA fry color class. External Defects, green, total defects, and misshapen are all in pounds per sample based on 15 foot of row. Means followed by same letter or symbol do not significantly differ (P=.10, Student-Newman-Keuls).

Figure 2. Commercial Umatilla Russet Field with Lygus cages. Left side was kept free of Lygus until harvest, while cage on right was infested at bloom stage. Notice surrounding field is similar to the cage on the right.

At the Moxee USDA site, USDA No. 2 fry color was adversely impacted by early Lygus introductions at tuber bulking (Table 2). Plots that were infested with Lygus early (bloom) also tended to yield less and produced less gross value, but not at a statistically significant level. Specific gravity was significantly reduced in plots that were infested with Lygus at tuber bulking (Table 2). It should be noted that yields were extremely low at the Moxee site, and in fact the fry color scores would have resulted in contract rejection for all treatments. The plots were planted much later than is commercially done and were irrigated with drip irrigation. In 2019, we will correct these issues or plant at a different site that can accommodate more suitable conditions.

Trt.	Specific Gravity	Fry Col. 0	Fry Col. 1	Fry Col. 2	Fry Col. 3	Fry Col. 4	Ext. Def.	Green	Tot. Def.	Mis-shap	Ton/A	Gross $
– Lyg	1.08853a	6.5a	8.5a	4.0b	3.8a	1.4a	x	x	x	30.8a	17.3a	2451a
+ Lyg Bloom	1.08515a	2.3a	8.8a	9.3a	4.0a	0.4a	x	x	x	36.5a	13.8a	1956a
+ Lyg Bulk	1.07858b	5.3a	7.0a	5.8ab	5.0a	1.4a	x	x	x	29.9a	15.0a	2183a

Table 2. Potato quality and yield data from the USDA Moxee Site. Fry Col=Number of fry slices of 25 test stripes that were in that USDA fry color class. External Defects, green and total defects were not evaluated for these plots mistakenly. Misshapen are in pounds per sample based on 15 foot of row. Means followed by same letter or symbol do not significantly differ (P=.10, Student-Newman-Keuls).

At the Pasco site, overall yield and gross return did not differ significantly by treatment, but the trend of lower yield and return was consistent with the Moxee site (Table 3). Specific gravity was low at this site overall and did not differ significantly, but lowest in the plots that were infested at tuber bulking with Lygus, again mimicking the trend from the Moxee site (Table 3). Fry color was not impacted by treatment.

Trt.	Specific Gravity	Fry Col. 0	Fry Col. 1	Fry Col. 2	Fry Col. 3	Fry Col. 4	Ext. Def.	Green	Tot. Def.	Mis-shap	Ton/A	Gross $
– Lyg	1.0762a	11.25a	11.88a	1.75a	0.1a	0.0a	3.66a	0.87a	3.73a	26.3a	26.1a	3551a
+ Lyg Bloom	1.0765a	9.88a	10.00a	5.13a	0.0a	0.0a	4.68a	0.23a	4.70a	38.8a	25.8a	3485a
+ Lyg Bulk	1.0756a	13.38a	8.13a	3.50a	0.0a	0.0a	3.21a	0.57a	3.26a	28.5a	27.2a	3604a

Table 3. Potato quality and yield data from the WSU Pasco Site. Fry Col=Number of fry slices of 25 test stripes that were in that USDA fry color class. External Defects, green, total defects, and misshapen are all in pounds per sample based on 15 foot of row. Means followed by same letter or symbol do not significantly differ (P=.10, Student-Newman-Keuls).

With the Lygus cage studies, it was apparent that Lygus impact plant health, and more so when plants were infested at tuber bulking than at bloom. There was some variability from one site to another in regard to which factors were most influenced, but some of those details should be resolved with refinement to the experimental protocol and agronomic practices required to grow potatoes under large cages. We evaluated Lygus populations in the cages, but numbers of nymphs recorded was low. We do find Lygus nymphs in commercial potato fields, but not to the same level that is commonly observed in other host plants such as alfalfa. Many of the adult Lygus would be commonly found at the top of the cages several days after being released. Perhaps Lygus do not prefer to continually inhabit potatoes, but rather feed for a short period of time then migrate to more suitable hosts. The above studies will be repeated, but further studies may focus on the ability of Lygus to reproduce on potatoes in comparison to other hosts and additional infestation timings in order to determine the potato growth stages that are most susceptible to injury from Lygus feeding.

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Neonicotinoid Longevity in Potato Production Systems of the Northwest

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REPORTING PERIOD: March 1, 2017 – January 1, 2019 (2017 & 18 Growing Season)

ACCOMPLISHMENTS:
Potato cultivars differed in canopy weight early in the growing season as expected in 2017 but did not differ significantly in 2018. We detected a difference in plant foliar weight from season to season which impacted insecticide concentration in the leaves and therefore psyllid control. Tissue weights were lower in 2018, and insecticide concentration was higher resulting in improved psyllid control for longer into the season. Seed treatment with insecticide did reduce canopy weight in one cultivar in 2017 but not in 2018.

The slip cages were used in hopes to determine how long the at-plant neonicotinoids would be effective at controlling potato psyllids. The data from the cages were highly variable, making it difficult to confidently predict days of control of psyllids. Since the tissue weights and pesticide concentrations vary so much from year to year and one cultivar to another, it is highly unlikely that we could ever make that assessment. Rather, we can say that under conditions where plant canopy weights are high, psyllid control is likely to be much shorter than in conditions where plant foliar growth is reduced. For example, in 2017 and 2018, marginal psyllid control was only achieved for Alturas for up to 56 and 70 days after planting respectively for any of the three insecticide treatments. In Norkotah insecticide treated plots, adequate psyllid control was never achieved with any of the three insecticides. In some instances, the layby application of thiamethoxam appeared more effective than the at-plant treatments. Other data from this study suggest that aphid control is realistically achieved with the insecticides evaluated for 75 to 80 days. Colorado potato beetle was not evaluated as part of this study, but observations in the experimental area strongly indicate that the at-plant and layby treatments of neonicotinoids are highly effective at controlling the first generation of Colorado potato beetle.

This project demonstrates that neonicotinoid concentration in the potato plant, and therefore effectiveness in suppressing pest insects, varies by cultivar and growing season. In rapidly growing cultivars such as Norkotah, at-plant neonicotinoid treatments may not be effective for psyllid control. For practical purposes, prescriptive prophylactic use of at-plant neonicotinoid insecticides does not make sense for all cultivars and all growing conditions, especially in consideration for psyllid control. Neonicotinoids are an effective tool for managing early season aphid and Colorado potato beetle. These data call into question, however, how effectively systemic pesticides mobilize in different cultivars and different growing seasons. Scouting is still the best method to ensure that potato psyllids and other insect pests do not build up to numbers where they cannot be controlled.

PROCEDURES:
An experiment was conducted at the WSU research site in Pasco, WA and maintained mimicking commercial potato production in the Columbia Basin. All plots received a fungicide in-furrow treatment (Ridomil Gold at 6.5oz per acre and Quadris F at 8oz per acre), post-plant pre-emergence herbicides, applications of Coragen for Colorado potato beetle control, and foliar fungicides as needed to avoid disease outbreaks (Table 1a and 1b). The plots were arranged in a

randomized complete block design with four replications. Each plot was four rows wide and twenty-five feet in length.

Treatments included neonicotinoids applied in three ways: in-furrow with imidacloprid (Admire Pro 8.7 fl oz/A), seed piece with thiamethoxam (Cruiser Maxx 0.23 fl oz/100 lbs. seed), and a banded lay-by application with thiamethoxam (Platinum 8 fl oz/A). Cruiser Maxx and Platinum contain the same insecticide active ingredient, thiamethoxam, and with the rates that were used, were applied in equal amounts of active ingredient per acre. The in-furrow and seed piece treatments were made at planting (April 17, 2017 and April 20, 2018), and the lay-by treatments were made at the six to eight-inch rosette stage (May 22, 2017 and May 21, 2018). The in-furrow and layby treatments were applied with 5 and 10 gallons of water per acre, respectively. All the treatments were applied to two different cultivars. One cultivar was an abundant early-season foliage determinant cultivar (Norkotah), and the other of an indeterminant cultivar with typically sparse, early-season foliage (Alturas). Untreated check plots of both cultivars were also planted and evaluated.

Samples of the potato foliage were collected seven times during the growing season (43, 49, 56, 70, 84, 98, and 112 days after planting). Leaf samples consisted of one-gallon bags of foliage collected from at least twenty different plants per plot. On each plant, the most recent fully developed leaf was collected. Samples were collected at the same time of day for each sampling period, placed in a container with ice packs, and sent next day shipping to Pacific Agricultural Laboratories (PAL). PAL evaluated the samples for the amounts of thiamethoxam, its metabolite (clothianidin), and imidacloprid present utilizing liquid chromatography mass spectroscopy. At the designated dates as detailed above, we performed destructive plant sampling on three plants in each plot. Destructive whole plant sampling (a wet-weight measurement) provided a relative assessment of the canopy size of the two cultivars at the time the concentration of the pesticide was measured. The aboveground portion, roots, and tubers were all weighed separately for each three-plant sample.

Date	Pesticide	Rate	Unit
5/3/2017	Boundary	2	pt/A
5/3/2017	Eptam	3.5	pt/A
5/3/2017	Tricor	0.35	lbs/A
6/6/2017	Coragen	5	oz/A
6/10/2017	Luna	11	oz/A
6/10/2017	Equus	1.3	pt/A
6/20/2017	Bravo	1.5	pt/A
6/29/2017	Luna	11	oz/A
6/29/2017	Equus	1.3	pt/A
7/19/2017	Zing	34	oz/A
7/18/2017	Zing	34	oz/A
7/25/2017	Revus	7	oz/A
8/1/2017	Revus	7	oz/A
8/8/2017	Zing	34	oz/A
8/19/2017	Luna	11	oz/A
9/4/2017	Zing	34	oz/A
9/8/2017	Reglone	2	PT/A

Date	Pesticide	Rate	Unit
5/5/2018	Boundary	2	PT/A
5/5/2018	Eptam	3.5	PT/A
5/5/2018	Tricor	0.35	LB/A
5/15/2018	Boundary	2	PT/A
5/15/2018	Eptam	3.5	PT/A
5/15/2018	Tricor	2	LB/A
5/29/2018	Coragen	5	FL OZ/A
6/15/2018	Luna	11	FL OZ/A
6/15/2018	Bravo	1.5	PT/A
6/29/2018	Luna	11.5	FL OZ/A
7/5/2018	Coragen	7.5	FL OZ/A
7/9/2018	Zing	32	FL OZ/A
7/19/2018	Vertisan	24	FL OZ/A
7/23/2018	Zing	34	FL OZ/A
8/3/2018	Luna	4	FL OZ/A
8/13/2018	Revus Top	7	FL OZ/A
8/16/2018	Blackhawk	3	FL OZ/A
9/20/2018	Reglone	2	PT/A

Table 1a (2017) and 1b (2018): The maintenance pesticides applied to the Neonicotinoid Trial.

Additionally, we determined efficacy of the insecticides by enumerating key Columbia Basin region potato pests and beneficial insects. Insects were evaluated weekly from emergence to harvest using three different types of insect sampling methods: bucket samples, leaf samples, and vacuum samples with pest and beneficial insect counts performed at each assessment. Bucket samples are collected by shaking the tops of five potato plants over an 8.5-inch diameter, two-gallon plastic bucket and evaluating the contents. Leaf samples are taken by collecting ten of the newest fully developed leaves from the perimeter of the plots and placing them in a labeled zip top plastic bag to be quantified in the laboratory. Vacuum samples are collected by operating a Stihl leaf vacuum, with a mesh fabric affixed to the front of the vacuum, around the perimeter of each plot while brushing the plant tops with the apparatus. The mesh bag was then emptied into a labeled Ziploc bag for quantification in the laboratory.

In addition to evaluating the resident insect populations, slip cages with potato psyllids were utilized to assess the efficacy and residual effects of the insecticides. Each plot was infested with three second instar psyllid nymphs using a slip cage (6 x 9-inch mesh fabric) on a single potato leaf. They were placed on plants on the same seven dates that the foliage tissue samplings for the insecticide concentration levels were procured. The slip cage remained on the leaf for seven days. The cages were then removed, and mortality of the psyllids was assessed. At the end of the season, the potato tubers were dug from a ten-foot section of row from the middle of each plot and evaluated for yield and quality.

RESULTS/DISCUSSION:
Potato cultivars did not differ in leaf tissue weights early in the season in 2018, but as the season progressed, Norkotah leaf tissue weights were significantly lower than Alturas leaf tissue weights (Figure 1). This trend is somewhat different than in 2017, where early in the growing season, Norkotah leaf tissue weights were higher than Alturas, which was what we expected with the determinant cultivar. The maximum foliar weights for both cultivars differed by season, with both cultivars containing significantly higher maximum foliar weights in 2017 compared to 2018 (Figure 1). During the 2018 growing season, potato growing degree days accumulated more rapidly in May compared to 2017 which may have had an impact on the foliar growth patterns of both cultivars (Figure 2). For most sample dates, insecticide treatment did not influence leaf tissue weights (Table 2a & 2b). In 2017, during two sample periods (June 12 and 26), plots treated with thiamethoxam as a seed treatment contained lower fresh canopy weights than the untreated check, but as the season progressed, that trend was no longer present (Table 2a). On the July 5, 2018 sample date, plots treated with CruiserMax and Platinum contained lower leaf tissue weights than the untreated check (Table 2b). These data suggest there is likely some inherent cost to the plant from metabolizing the insecticide treatment in terms of reduced tissue weight, but that impact is resolved once the material is reduced in concentration in the system and does not appear to adversely impact potato yield.

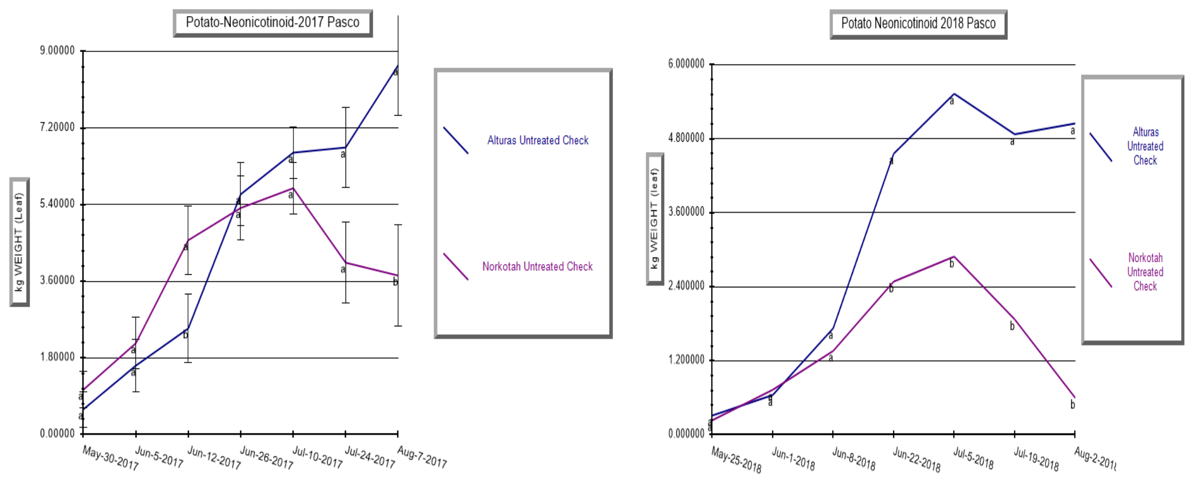

Figure 1. Fresh plant weights for three plants per plot by cultivar during the seven sample periods. Treatments with the same letters are not statistically different from one another (P=0.05 Student-Newman-Keuls test).

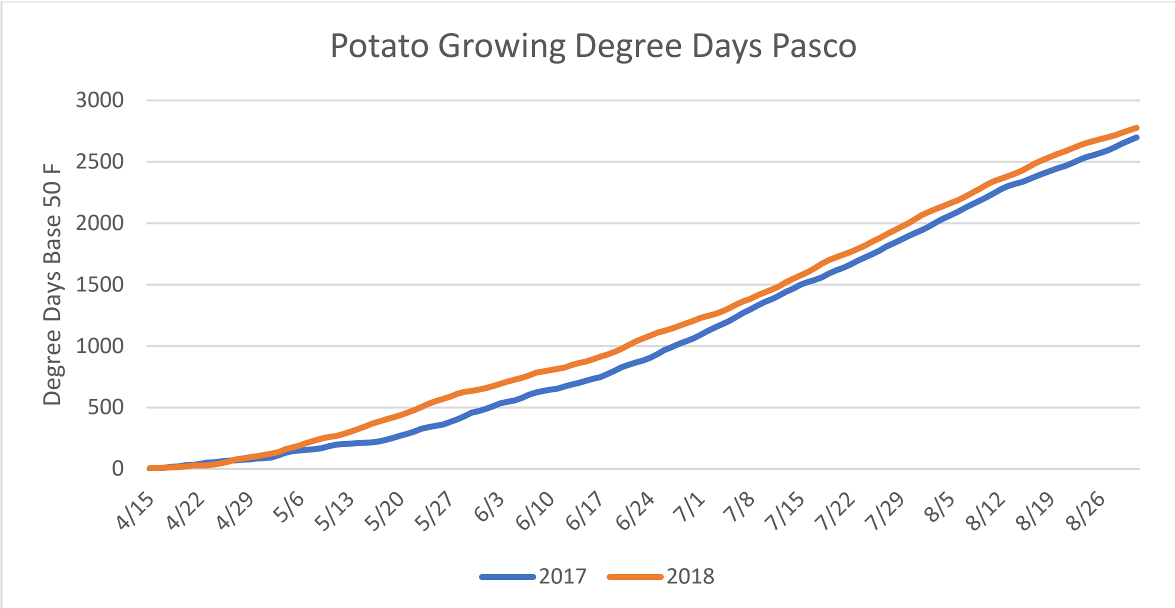

Figure 2. Potato growing degree days at the WSU AgWeatherNet weather station in Pasco, WA from when the plots were planted until harvest for 2017 and 2018.

Plant Weights	Weight in Kg						
Treatment	Date						
	30-May	5-Jun	12-Jun	26-Jun	10-Jul	24-Jul	7-Aug
Alturas	0.6801b	1.5809b	2.9238b	5.0875a	6.2778a	6.40298a	6.81135a
Norkotah	0.9789a	2.2560a	3.7333a	4.7109a	5.7154a	4.58389b	3.43961b
LSD	0.180	0.373	0.484	1.080	1.277	1.079	1.420-1.893
Untreated Check	0.8234a	1.8836a	3.5300a	5.4861a	6.2064a	5.66601a	5.57358a
Admire Pro	0.7535a	1.8595a	3.4054ab	5.0301ab	6.4460a	5.74412a	4.80971a
Cruiser Maxx	0.7645a	1.7823a	2.7644b	3.8909b	5.1873a	5.96010a	4.55911a
Platinum	0.9768a	2.1484a	3.6145a	5.1896ab	6.1466a	4.60349a	4.66473a
LSD	0.254	0.527	0.684	1.080	1.277	1.526	2.134-2.672
Alturas/Untreated Check	0.5930b	1.6208cd	2.4928c	5.6475a	6.6243a	6.74490ab	8.63111a
Norkotah/Untreated Check	1.0538a	2.1456abc	4.5673a	5.3248a	5.7885a	4.58712bcd	3.48670b
Alturas/Admire Pro	0.6403b	1.7165bcd	3.3303bc	4.9558a	6.7108a	7.02860a	6.56224ab
Norkotah/Admire Pro	0.8668ab	2.0025abc	3.4805b	5.1045a	6.1813a	4.45965cd	3.46333b
Alturas/Cruiser Maxx	0.6585b	1.1690d	2.4000c	3.9985a	5.4668a	6.56385abc	6.00997ab
Norkotah/Cruiser Maxx	0.8705ab	2.3955ab	3.1288bc	3.7833a	4.9078a	5.35635a-d	3.40853b
Alturas/Platinum	0.8288ab	1.8173a-d	3.4723b	5.7483a	6.3093a	5.27455a-d	6.29224ab
Norkotah/Platinum	1.1248a	2.4795a	3.7568ab	4.6310a	5.9840a	3.93243d	3.40046b
LSD	0.360	0.745	0.968	2.161	2.554	2.158	3.266-4.103

Table 2a. Fresh plant weights for three plants per plot by various factors during the seven sample periods 2017. Treatments with the same letters are not statistically different from one another (P=0.05 Student-Newman-Keuls test).

Plant Weights in Kg	Weight in Kg						
Treatment	Date						
	25-May	1-Jun	8-Jun	22-Jun	5-Jul	19-Jul	2-Aug
Alturas	0.3232a	0.6578a	1.6807a	4.0182a	4.1937a	4.9309a	5.3168a
Norkotah	0.2650a	0.6021a	1.4890a	2.9043b	2.7816a	1.9412b	0.6282b
LSD	0.099953	0.138679	0.245567	0.435806-0.503902	0.653244	0.702112	0.301723-0.746946
Untreated Check	0.2743a	0.6876a	1.5446a	3.4023a	4.2111a	3.3737a	2.2957a
Admire Pro	0.2554a	0.6408a	1.6908a	3.4200a	3.6073ab	3.0818a	2.4082a
Cruiser Maxx	0.2938a	0.5333a	1.5978a	3.6590a	2.9324b	3.5687a	2.5126a
Platinum	0.3528a	0.6582a	1.5061	3.2345a	3.1998b	3.7201a	2.4426a
LSD	0.141355	0.196122	0.347285	0.647563-0.683572	0.923826	0.992937	0.706451-0.786746
Alturas (Untreated)	0.3129a	0.6450a	1.7284a	4.5596a	5.5317a	4.8747a	5.0503a
Norkotah (Untreated)	0.2357a	0.7302a	1.3609a	2.4860a	2.8904a	1.8728a	0.6000a
Alturas (Admire Pro)	0.2307a	0.6291a	1.7914a	3.8714a	4.1518a	4.4645a	5.2482a
Norkotah (Admire Pro)	0.2802a	0.6525a	1.5903a	3.0103a	3.0629a	1.6992a	0.6463a
Alturas (Cruiser Maxx)	0.2787a	0.5709a	1.7433a	4.1559a	3.6660a	4.8329a	5.3680a
Norkotah Cruiser Maxx)	0.3089a	0.4957a	1.4524a	3.2099a	2.1990a	2.3044a	0.7132a
Alturas (Platinum)	0.4704a	0.7864a	1.4599a	3.5416a	3.4253a	5.5517a	5.6078a
Norkotah (Platinum)	0.2353a	0.5300a	1.5524a	2.9481a	2.9746a	1.8885a	0.5582a
LSD	0.199906	0.277359	0.491135	0.821659-1.060458	1.306487	1.404224	0.630936-1.479884

Table 2b. Fresh plant weights for three plants per plot by various factors during the seven sample periods 2018. Treatments with the same letters are not statistically different from one another (P=0.05 Student-Newman-Keuls test).

At the end of the 2017 growing season, in fact, yields did not differ between plots treated with Cruiser, Admire Pro, or the untreated check treatments (Table 3a). Plots treated with Platinum contained significantly lower overall yields in 2017. The overall yield did not differ between cultivars, but grades did where there were significantly more oversized Grade 1 tubers, fewer Grade 2 tubers, and fewer culls in the Norkotah than Alturas. Despite the differences in plant foliage weights during the growing season, yield and quality were not impacted directly by, or through interaction within, any of the main experimental factors.

In 2018, yield and quality were lower for Norkotah than Alturas, except with more culls reported in Alturas (Table 3b). Norkotah is a determinant early maturing cultivar, so this result of lower yield and specific gravity is expected. Insecticide treatment did not influence potato yield or quality factors that were evaluated in 2018 (Table 3b). There were not interaction effects of the two main factors evaluated, cultivar and insecticide treatment. When comparing 2017 and 2018, Alturas performed better in 2018 than 2017 while the opposite was true for Norkotah. This is probably a result of the growing degree day accumulation patterns of the two seasons.

Treatment	Grade 1		Grade 2							
	4 oz to >	6+ oz	4 oz	4 oz to>	6+ oz	Culls	Marketable Yield(T/A)	Specific Gravity	Solids	Total Yield
Alturas	4.834a	8.223b	2.853a	0.199a	0.420a	1.333a	19.173a	1.06753a	17.980a	32.5a
Norkotah	3.146b	13.803a	1.608b	0.002b	0.016b	0.660b	18.780a	1.06549a	17.549a	31.9a
LSD	0.6324- 0.7721	2.3578	0.3903	0.0696- 0.1485	0.189688- 0.31696	0.569431- 0.59577	3.2464	0.002212	0.4742- 0.4753	5.51
Untreated Check	3.937a	11.688a	2.214a	0.048a	0.091a	0.734a	19.195ab	1.06731a	17.921a	32.6ab
Admire Pro	4.368a	12.538a	2.421a	0.120a	0.208a	1.207a	21.761a	1.06705a	17.881a	36.9a
Cruiser Maxx	4.024a	10.098a	2.311a	0.039a	0.114a	1.014a	18.320ab	1.06536a	17.516a	31.1ab
Platinum	3.394a	9.728a	0.051a	0.051a	0.205a	0.946a	16.630b	1.06633a	17.739a	28.2b
LSD	0.9764- 0.9769	3.3344	0.5519	0.1189- 0.2205	0.493944- 99999.217629	0.752524- 0.89743	4.5911	0.003129	0.6650- 0.6745	7.79
Alturas/Untreated Check	4.885ab	8.723bcd	3.023a	0.118ab	0.365ab	0.843a	19.093a	1.07038a	18.589a	32.4a
Norkotah/Untreated Check	3.142d	14.653a	1.405c	0.009b	0.000b	0.631a	19.298a	1.06425c	17.276c	32.7a
Alturas/Admire Pro	5.863a	9.185bcd	3.033a	0.480a	0.517a	1.717a	22.425a	1.06925ab	18.360a	38.0a
Norkotah/Admire Pro	3.199d	15.890a	1.810c	0.000b	0.037ab	0.792a	21.098a	1.06485bc	17.414b	35.8a
Alturas/Cruiser Maxx	4.710abc	7.668cd	2.683ab	0.154ab	0.437a	1.397a	18.720a	1.06455c	17.336c	31.8a
Norkotah/Cruiser Maxx	3.421cd	12.528ab	1.940bc	0.000b	0.000b	0.694a	17.920a	1.06618ab	17.697a	30.4a
Alturas/Platinum	4.023bcd	7.315d	2.673ab	0.127ab	0.127ab	1.470a	16.455a	1.06595bc	17.662a	27.9a
Norkotah/Platinum	2.843d	12.140abc	1.278c	0.009b	0.009b	0.533a	16.805a	1.06670ab	17.816a	28.5a
LSD	1.2618- 1.6963	4.7155	0.7806	0.4167- 99999.2056	0.512819- 99999.438965	1.210710- 1.232171	6.4928	0.004425	0.9486- 0.9665	11.02

Table 3a: The yield and grade data for both the Norkotah and Alturas varieties 2017. Treatments with the same letters are not statistically different from one another (P=0.05 Student-Newman-Keuls test). Yield and grade data expressed in kg per plot and ton per acre in total yield.

Treatment	Grade 1		Grade 2							
	4 oz to >	6+ oz	4 oz	4 oz to>	6+ oz	Culls	Marketable Yield(T/A)	Specific Gravity	Solids	Total Yield
Alturas	5.778a	15.136a	1.803a	0.184a	0.669a	2.489a	23.570a	1.07750 a	20.178 a	39.9a
Norkotah	1.842b	9.511b	1.100b	0.015b	0.147a	0.569b	12.643b	1.07064 b	18.676 b	21.4a
LSD	0.8154	2.3821	0.3614	0.137	0.5163	0.8872	2.4116	0.002766	0.6022	4.08
Untreated Check	3.757a	11.919a	1.358a	0.086a	0.599a	1.576a	17.740a	1.07505 a	19.641 a	30.0a
Admire Pro	3.772a	11.323a	1.550a	0.081a	0.260a	1.384a	16.984a	1.07250 a	19.084 a	28.8a
Cruiser Maxx	3.728a	14.104a	1.401a	0.068a	0.329a	1.804a	19.664a	1.07548 a	19.736 a	33.3a
Platinum	3.984a	11.946a	1.498a	0.164a	0.445a	1.352a	18.038a	1.07325 a	19.246 a	30.6a
LSD	1.1531	3.3688	0.511	0.1937	0.7301	1.2546	3.4106	0.003911	0.8517	5.78
Alturas/Untreated Check	5.636a	15.218a	1.474a	0.148a	0.885a	2.699a	23.360a	1.07880 a	20.463 a	39.6a
Norkotah/Untreated Check	1.878a	8.621a	1.242a	0.025a	0.313a	0.454a	12.120a	1.07130 a	18.820 a	20.5a
Alturas/Admire Pro	5.851a	13.846a	2.109a	0.125a	0.306a	2.211a	22.238a	1.07603 a	19.855 a	37.7a
Norkotah/Admire Pro	1.692a	8.800a	0.990a	0.036a	0.213a	0.556a	11.731a	1.06898 a	18.313 a	19.9a
Alturas/Cruiser Maxx	5.398a	17.497a	1.815a	0.136a	0.658a	2.767a	25.503a	1.07910 a	20.530 a	43.2a
Norkotah/Cruiser Maxx	2.058a	10.711a	0.988a	0.000a	0.000a	0.840a	13.825a	1.07185 a	18.943 a	23.4a
Alturas/Platinum	6.226a	13.982a	1.814a	0.329a	0.828a	2.279a	23.179a	1.07608 a	19.863 a	39.3a
Norkotah/Platinum	1.742a	9.911a	1.182a	0.000a	0.062a	0.425a	12.897a	1.07043 a	18.630 a	21.8a
LSD	1.6309	4.7642	0.7228	0.274	1.0326	1.7743	4.8232	0.005532	1.2045	8.17

Table 3b: The yield and grade data for both the Norkotah and Alturas varieties 2018. Treatments with the same letters are not statistically different from one another (P=0.05 Student-Newman-Keuls test). Yield and grade data expressed in kg per plot and ton per acre in total yield.

In 2017, the neonicotinoid concentration differed between cultivars with the lay-by application of thiamethoxam and imidacloprid, but not with seed treatment of thiamethoxam for a majority of the sample periods (Table 4a). The imidacloprid concentration was higher in the Norkotah plots than in Alturas for the second sample period, then lower on the third and fourth sample periods (Table 4a). This trend was opposite of what we hypothesized, where the faster growing Norkotah cultivar contained higher concentrations of insecticide than the slower growing Alturas cultivar early in the growing season. If you compare these data with the plant tissue weights during the same time period, the tissue weights did not differ significantly until June 12 (Figure 1a). Perhaps the plant began to grow rapidly prior to the sample weights being obtained and therefore the imidacloprid had systemically moved into the rapidly growing leaf tissue. The same trend is not observed with the other insecticides. All the insecticides evaluated are moderate to highly soluble (340, 610 and 4100 mg/kg for clothianidin, imidacloprid, and thiamethoxam respectively), so if the plant is growing quickly and requiring more water, the neonicotinoid is more likely to be drawn up into the leaf tissue through the xylem. Thiamethoxam by the lay-by application contained significantly higher concentrations of active ingredient in the plant tissue than the application by seed treatment (Table 4a). The Norkotah plots had a lower concentration of thiamethoxam when applied by seed treatment as compared to the Alturas plots (Table 4a). The treatment of thiamethoxam by lay-by application did not differ by cultivar (Table 4a). Clothianidin is a biologically active (as an insecticide) metabolite of thiamethoxam and was, therefore, analyzed in the tissue tests. Clothianidin followed the same trend of lower concentrations in the faster growing Norkotah cultivar, but results were not statistically significant (Table 4a). The clothianidin concentration did differ in the lay-by application where there was a higher concentration of the compound in the faster growing Norkotah plots, following the same unexpected trend realized on the plots treated with imidacloprid (Table 4a).

In 2018, the concentration of imidacloprid did not differ significantly between the two cultivars, except for one sample date (July 20) where there was no detectible level in the Norkotah plots (Table 4b). The level of imidacloprid was numerically lower for the entire sample season in Norkotah for 2018, but varied more in 2017. The overall level of imidacloprid started at a much higher concentration early in 2018 compared to 2017 but reduced more dramatically (Table 4a and 4b). Leaf tissue weights were much higher in 2017 compared to 2018 and likely explain the initial higher titer level of imidacloprid in 2018 since there was less leaf tissue for the product to be diluted in. This supports the hypothesis that under conditions conducive for more foliar growth that the pesticide concentration would be reduced due to dilution. A similar trend occurs in relation to clothianidin and thiamethoxam, whereby concentrations were higher in 2018 than 2017 (Table 4a & 4b). The concentration of thiamethoxam and clothianidin remained at a higher concentration consistently over time in 2018 than in 2017 (Table 4a & 4b). This demonstrates that neonicotinoid concentrations can fluctuate significantly from one season to the next and from one cultivar to another but is largely impacted by plant foliar growth as larger canopies tended to have reduced pesticide concentrations. In 2018, the level of clothianidin differed by cultivar on June 22 where Alturas plots contained higher concentrations of the compound than Norkotah (Table 4b). For the other sample periods there was no significant difference in the concentration of clothianidin. The concentration of thiamethoxam was generally higher in plots treated by lay-by application, but not significantly different.

A great amount of variability occurs with consideration to titer level of the pesticides in the leaf of the plant at the same dose at the same number of days after planting. Regularly, individual plants in fields are detected with enormous populations of Colorado potato beetles while adjacent plants contain no beetles. This is likely due to the differences in titer level and could be attributed to pesticide application inaccuracies or plants that were inadvertently not treated.

Treatment		5/30/2017	6/5/2017	6/12/2017	6/26/2017	7/10/2017	7/24/2017	8/7/2017
Alturas (Admire Pro)	Imidacloprid (mg/kg)	0.2891a	0.1350a	0.2173a	0.1365a	0.0563a	0.0360a	0.0165a
Norkotah (Admire Pro)	Imidacloprid (mg/kg)	0.2000a	0.3473a	0.0623ab	0.0768ab	0.0615a	0.0368a	0.0215a
Alturas (Platinum)	Clothianidin (mg/kg)	0.0218bc	0.0338b	0.0616b	0.0768a	0.1297a	0.0303a	0.0220a
Norkotah (Platinum)	Clothianidin (mg/kg)	0.0445a	0.0725a	0.1284a	0.1008a	0.0945a	0.0354a	0.0215a
Alturas (Platinum)	Thiamethoxam (mg/kg)	0.1010b	0.1162a	0.1151a	0.1230a	0.1028a	0.0435ab	0.0338a
Norkotah (Platinum)	Thiamethoxam (mg/kg)	0.1352ab	0.0808ab	0.1024a	0.1415a	0.1122a	0.0753a	0.0595a
Alturas (Cruiser Maxx)	Clothianidin (mg/kg)	0.0415ab	0.0470b	0.0366bc	0.0295b	0.0217b	0.0029b	0.0000b
Norkotah (Cruiser Maxx)	Clothianidin (mg/kg)	0.0433a	0.0403b	0.0254c	0.0220b	0.0122bc	0.0033b	0.0025b
Alturas (Cruiser Maxx)	Thiamethoxam (mg/kg)	0.2475a	0.0888a	0.0677b	0.0473b	0.0008b	0.0186bc	0.0064b
Norkotah (Cruiser Maxx)	Thiamethoxam (mg/kg)	0.0847b	0.0479a	0.0270c	0.0299b	0.0000b	0.0074bcd	0.0079b
Alturas (Platinum)	Combined (mg/kg)	0.0338bc	0.1393a	0.1053bc	0.2028a	0.2445a	0.0843a	0.0563a
Norkotah (Platinum)	Combined (mg/kg)	0.0725a	0.0895a	0.0528c	0.2545a	0.2300a	0.1233a	0.0858a
Alturas (Cruiser Maxx)	Combined (mg/kg)	0.0470b	0.1508a	0.1805ab	0.0773a	0.0253a	0.0250a	0.0085a
Norkotah (Cruiser Maxx)	Combined (mg/kg)	0.0403b	0.1590a	0.2395a	0.0528a	0.0123a	0.0215a	0.0130a
LSD Value p=0.05	Imidacloprid	0.02026-0.10503	0.19212	0.15689	0.10177	0.0115	0.00935	0.00862
	Clothianidin	0.02011	0.02178	0.00689-0.03567	0.01615-0.06767	0.01212-0.05476	0.00806-0.02101	0.00912
	Thiamethoxam	0.04651-0.12074	0.0141-0.05486	0.01085-0.04938	0.03986	0.01950-0.06375	0.02404-0.05476	0.01375-0.02641
	Combined	0.07305	0.08269	0.07878	0.12975	0.11418	0.06888	0.03788

Table 4a. Residue values by treatment. Values expressed in milligrams of pesticide per kilogram of plant fresh weight. Treatments with the same letters are not statistically different from one another (P=0.05 Student-Newman-Keuls test).

Treatment		5/25/2018	6/1/2018	6/8/2018	6/22/2018	7/5/2018	7/20/2018	8/2/2018
Alturas (Admire Pro)	Imidacloprid (mg/kg)	0.5570a	0.2375a	0.0800a	0.0864a	0.0205a	0.0115a	0.0030a
Norkotah (Admire Pro)	Imidacloprid (mg/kg)	0.3139a	0.0763a	0.0319a	0.0628a	0.0070a	0.0000b	0.0000a
Alturas (Platinum)	Clothianidin (mg/kg)	0.2568a	0.1330a	0.1675a	0.0900a	0.0338a	0.0483a	0.0315a
Norkotah (Platinum)	Clothianidin (mg/kg)	0.0850a	0.1468a	0.1425a	0.0610b	0.0218a	0.0263a	0.0298a
Alturas (Platinum)	Thiamethoxam (mg/kg)	0.4020a	0.2250a	0.3395a	0.0723a	0.0365a	0.0208ab	0.0155b
Norkotah (Platinum)	Thiamethoxam (mg/kg)	0.1825a	0.2480a	0.1861a	0.0675a	0.1570a	0.0143bc	0.0438a
Alturas (Cruiser Maxx)	Clothianidin (mg/kg)	0.5125a	0.1175a	0.0865a	0.0809ab	0.0248a	0.0340a	0.0210a
Norkotah (Cruiser Maxx)	Clothianidin (mg/kg)	0.2925a	0.1025a	0.0873a	0.0363c	0.0228a	0.0213a	0.0155a
Alturas (Cruiser Maxx)	Thiamethoxam (mg/kg)	1.4500a	0.4950a	0.1201a	0.0588a	0.0238a	0.0290a	0.0090b
Norkotah (Cruiser Maxx)	Thiamethoxam (mg/kg)	1.0300a	0.1980a	0.0561a	0.0483a	0.0203a	0.0108c	0.0085b
Alturas (Platinum)	Combined (mg/kg)	0.6588a	0.3580a	0.5200a	0.1623a	0.0703a	0.0690a	0.0470a
Norkotah (Platinum)	Combined (mg/kg)	0.2675a	0.3943a	0.3325a	0.1285a	0.1788a	0.0405a	0.0735a
Alturas (Cruiser Maxx)	Combined (mg/kg)	1.9625a	0.6125a	0.2083a	0.1083a	0.0485a	0.0630a	0.0300a
Norkotah (Cruiser Maxx)	Combined (mg/kg)	1.3225a	0.3000a	0.1438a	0.0845a	0.04300a	0.0320a	0.0240a
LSD Value p=0.05	Imidacloprid	0.43263- 99999.0882	0.17686	0.04504- 99999.01812	0.04157- 99999.01426	0.00934	0.00491	0.0031
	Clothianidin	0.12601	0.12208	0.04125	0.02122	0.01543	0.01196	0.01215
	Thiamethoxam	0.2399	0.1907	0.11084- 99999.01988	0.02171	0.16611	0.00889	0.01561
	Combined	0.48244	0.38292	0.15522	0.05697	0.22035	0.02015	0.03011

Table 4b. Residue values by treatment. Values expressed in milligrams of pesticide per kilogram of plant fresh weight. Treatments with the same letters are not statistically different from one another (P=0.05 Student-Newman-Keuls test).

The potato psyllid slip cage assays are difficult to interpret due to the high mortality rates in the untreated check plots during some assay periods. Cages were placed too high in the canopy during one sample period in 2017, leading to high mortality in the untreated check plots (June 19th). Psyllids were reared in a laboratory, and then transferred to the field. This did not appear to impact survivorship during the cooler days but appeared to be problematic during warmer weather. The raw percent mortality was subjected to a correction formula to account for natural mortality attributed to the insects being caged on the plants. The raw data was subjected to the following formula: Schneider-Orelli Formula (the mortality % in treated plot minus the mortality % in the control plot, all of that divided by 100 minus the mortality % in the control plot. The result of that equation is then multiplied by 100). For all sample periods in 2017 except the last one, cultivar did not impact psyllid survivorship significantly (Table 5a). In 2017 there was a strong numeric trend for mortality rates being higher in Alturas plots, and if you look at the interaction of the two main factors, Alturas plots treated with either thiamethoxam application (Cruiser Maxx and Platinum) routinely recorded higher mortality rates for psyllids. Insecticide treatment did impact psyllid survivorship, where during all but one sample period in 2017, plots treated with lay-by thiamethoxam (Platinum) had higher mortality rates for psyllids than the untreated check plots and were more often numerically higher than the other insecticide treatments (Table 5a).

Alturas plots tended to have higher psyllid mortality rates in slip cages in 2018, similar to what was observed in 2017 and in fact were significantly higher on June 8, July 26, and August 9

(Table 5b). This once again is likely attributed to the different growth patterns of the two cultivars. Norkotah is a determinant cultivar and it is likely, especially toward the end of the sample period, that most of the plants' resources were being directed toward the tubers, resulting in generally reduced insecticide concentration in the leaves and subsequently lower mortality rates to potato psyllids. For efficacy against potato psyllids, based on the slip cages, adequate control was never achieved in Norkotah plots irrespective of insecticide treatment or insecticide titer level. In both seasons, control of potato psyllids in slip cages in Norkotah plots was only above 33% twice, both instances in 2018 with lower canopy weights. In Alturas plots, control was achieved (75% and above) on numerous occasions, but more-so in 2018 than 2017 and in plots treated with Cruiser Maxx or Platinum than with Admire Pro. Insecticide treatment influenced mortality rates in psyllid cages in 2018, but the insecticides did not differ between one another (Table 5b). Mortality rates of psyllids in slip cages in 2018 were greater than in 2017 (Tables 5a & 5b). The lower tissue weights recorded in 2018 resulted in higher insecticide titer levels which resulted in the increased mortality. This supports the overall hypothesis that under fast growing conditions, potato plant canopies are larger, and the concentration of the pesticide is reduced leading to lower psyllid mortality compared to seasons where canopy growth is reduced.

How long are at plant neonicotinoid treatments effective for insect control? This project supports the idea that the control period is dependent upon foliar growth of the crop, whereby when foliar growth is greater, neonicotinoid concentration is diluted and therefore control is less. The slip cages were used in hopes to determine how long the at-plant neonicotinoids would be effective at controlling potato psyllids. The data from the cages were highly variable, making it difficult to confidently predict days of control of psyllids. Since the tissue weights and pesticide concentrations vary so much from year to year and one cultivar to another, it is highly unlikely that we could ever make that assessment. Rather, we can say that under conditions where plant canopy weights are high, psyllid control is likely to be much shorter than in conditions where plant foliar growth is reduced. For example, in 2017 and 2018, adequate psyllid control was only achieved for Alturas for up to 56 and 70 days after planting respectively for any of the three insecticide treatments. In Norkotah insecticide treated plots, adequate psyllid control was never achieved with any of the three insecticides. In rapidly growing cultivars such as Norkotah, at plant neonicotinoid treatments may not be effective for psyllid control. Scouting is still the best method to ensure that potato psyllids and other insect pests do not build up to numbers where they cannot be controlled.

Treatment	Date						
	6-Jun	12-Jun	19-Jun	3-Jul	17-Jul	31-Jul	7-Aug
Alturas	55.92a	43.45a	31.70a	40.60a	26.80a	23.90a	41.83a
Norkotah	33.75a	19.82a	33.30a	24.60a	19.60a	21.90a	15.55b
LSD	24.53	24.23	27.91	30.05	27.46	24.15	24.99
Untreated Check	0.00c	0.00c	0.00b	0.00b	0.00b	0.00b	0.00b
Admire Pro	52.00ab	26.13bc	46.90a	29.0ab	18.40ab	37.50a	45.13a
Cruiser Maxx	45.88b	39.52ab	29.00ab	55.30a	52.50a	10.30ab	18.69ab
Platinum	81.46a	60.88a	54.00a	46.30a	22.00ab	43.80a	50.94a
LSD	34.68	34.26	39.47	42.5	38.84	34.16	35.34
Alturas/Untreated Check	0.00c	0.00c	0.00b	0.00b	0.00b	0.00b	0.00c
Norkotah/Untreated Check	0.00c	0.00c	0.00b	0.00b	0.00b	0.00b	0.00c
Alturas/Admire Pro	62.50ab	27.27bc	43.80ab	25.00ab	8.30ab	25.00ab	71.50a
Norkotah/Admire Pro	41.50bc	25.00bc	50.00ab	33.00ab	28.50ab	50.00a	18.75bc
Alturas/Cruiser Maxx	68.42ab	54.05ab	33.00ab	75.00a	55.00a	20.50ab	33.33abc
Norkotah/Cruiser Maxx	23.35bc	25.00bc	25.00ab	35.50ab	50.00ab	0.00b	4.06c
Alturas/Platinum	92.75a	92.50a	50.00ab	62.50a	44.00ab	50.00a	62.50ab
Norkotah/Platinum	70.17ab	29.27bc	58.00a	30.00ab	0.00b	37.50ab	39.38abc
LSD	49.05	48.46	55.82	60.11	54.92	48.3	49.98

Table 5a. Percent mortality of psyllids in slip cages 2017. Mortality corrected using the Schneider-Orelli Formula. Treatments with the same letters are not statistically different from one another (P=0.05 Student-Newman-Keuls test).

Treatment	Date						
	1-Jun	8-Jun	15-Jun	29-Jun	12-Jul	26-Jul	9-Aug
Alturas	64.10a	70.80a	18.70a	63.20a	50.00a	45.30a	50.00a
Norkotah	45.30a	13.90b	37.50a	59.40a	32.70a	0.00b	0.00b
LSD	24.42	19.88	24.54	19.76	30.28	20.61	18.27
Untreated Check	0.00b	0.00b	0.00a	0.00b	0.00b	0.00a	0.00b
Admire Pro	68.80a	46.50a	43.70a	87.50a	46.70a	31.30a	34.40a
Cruiser Maxx	78.10a	60.40a	29.10a	81.30a	62.50a	25.00a	31.30a
Platinum	71.90a	62.50a	39.60a	76.50a	56.30a	34.40a	34.40a
LSD	34.53	28.12	34.7	27.95	42.82	29.15	25.84
Alturas/Untreated Check	0.00a	0.00b	0.00a	0.00a	0.00a	0.00a	0.00b
Norkotah/Untreated Check	0.00a	0.00b	0.00a	0.00a	0.00a	0.00a	0.00b
Alturas/Admire Pro	75.00a	87.50a	31.10a	87.50a	62.50a	62.50a	68.80a
Norkotah/Admire Pro	62.50a	5.60b	56.30a	87.50a	31.00a	0.00a	0.00b
Alturas/Cruiser Maxx	93.80a	95.80a	8.30a	100.00a	75.00a	50.00a	62.50a
Norkotah/Cruiser Maxx	62.50a	25.00b	50.00a	62.50a	50.00a	0.00a	0.00b
Alturas/Platinum	87.50a	100.00a	35.40a	65.50a	62.50a	68.80a	68.80a
Norkotah/Platinum	56.30a	25.00b	43.80a	87.50a	50.00a	0.00a	0.00b
LSD	48.83	39.76	49.07	39.53	60.56 a	41.22	36.54

Table 5b. Percent mortality of psyllids in slip cages 2018. Mortality corrected using the Schneider-Orelli Formula. Treatments with the same letters are not statistically different from one another (P=0.05 Student-Newman-Keuls test).

Pest and beneficial insects were also enumerated in the test plots. In 2017 insects were not as abundant in potatoes compared to previous seasons. Lygus counts were significantly impacted by cultivar, where early in the season, more were captured in Norkotah plots, but as the season progressed, significantly more Lygus were captured in Alturas plots (Figure 3). It can be assumed that this difference is a result of the overall plant health and vigor. Norkotah is a determinant cultivar, and as the crop reached its maturity, leaves began to senesce, and fewer Lygus were captured in those plots. Lygus counts were not impacted by the neonicotinoid insecticides used in this study.

Psyllid counts were extremely low during 2017 and rarely encountered in these experimental plots. Aphid counts were also relatively low in 2017. During one sample period at the beginning of July, wingless aphid counts increased in untreated check plots, but remained low in treated plots (data not shown) indicating that the neonicotinoids were still impacting aphid counts nearly 80 days after planting.

Insect were more abundant in plots in 2018 than in 2017. Beneficial insects were not adversely impacted by insecticide applications at planting or lay-by. In fact, minute pirate, damsel, and big-eyed bugs were abundant in all treatments for the first four sampling periods, and sometimes more abundant in treated plots (Figures 4, 5 & 6). Big-eyed bugs were the most common beneficial insect encountered; both damsel and minute pirate bugs were encountered ten times less frequently. Beneficial insects tended to occur more frequently in Alturas than Norkotah (Figures 4, 5 & 6).

Beet leafhoppers were not impacted by insecticide treatment at the dates they appeared in the plots in significant numbers (74 DAP) (Figure 7a & 7b). Beet leafhoppers were more abundant in Norkotah plots than in Alturas. This trend could be attributed to the relative location of the experimental blocks whereby the Norkotah plots were closer to the adjacent upland vegetation that is oftentimes attributed to hosting large populations of beet leafhopper.

During 2018, Lygus were not impacted by insecticide treatment, but were more abundant in Alturas plots than Norkotah plots (Figure 8). During most sample periods, nearly twice as many were detected in Alturas plots. This trend differs slightly from 2017 where initially more lygus were found in Norkotah plots. The number of Lygus was higher overall in 2018, except during the peak Lygus flight during 2017 where more were recorded. Lygus have been noted to exhibit preference for some cultivars over others on farms, and these data seem to corroborate that trend. This information, while not impactful in terms of insecticide efficacy of this study, could be useful in understanding cultivars to utilize in future studies.

The occurrence of potato psyllids outside of the slip cages was rare in 2018 and did not present an opportunity to determine efficacy. Colorado potato beetle was abundant, but in order to preserve potato foliage and not confound other data collection for the experiment, they were controlled with a narrow spectrum insecticide (Coragen, chlorantraniliprole). Aphid numbers were also relatively low and only appeared in untreated check plots until around 75 days after planting, when numbers were not impacted by treatment (Figure 9).

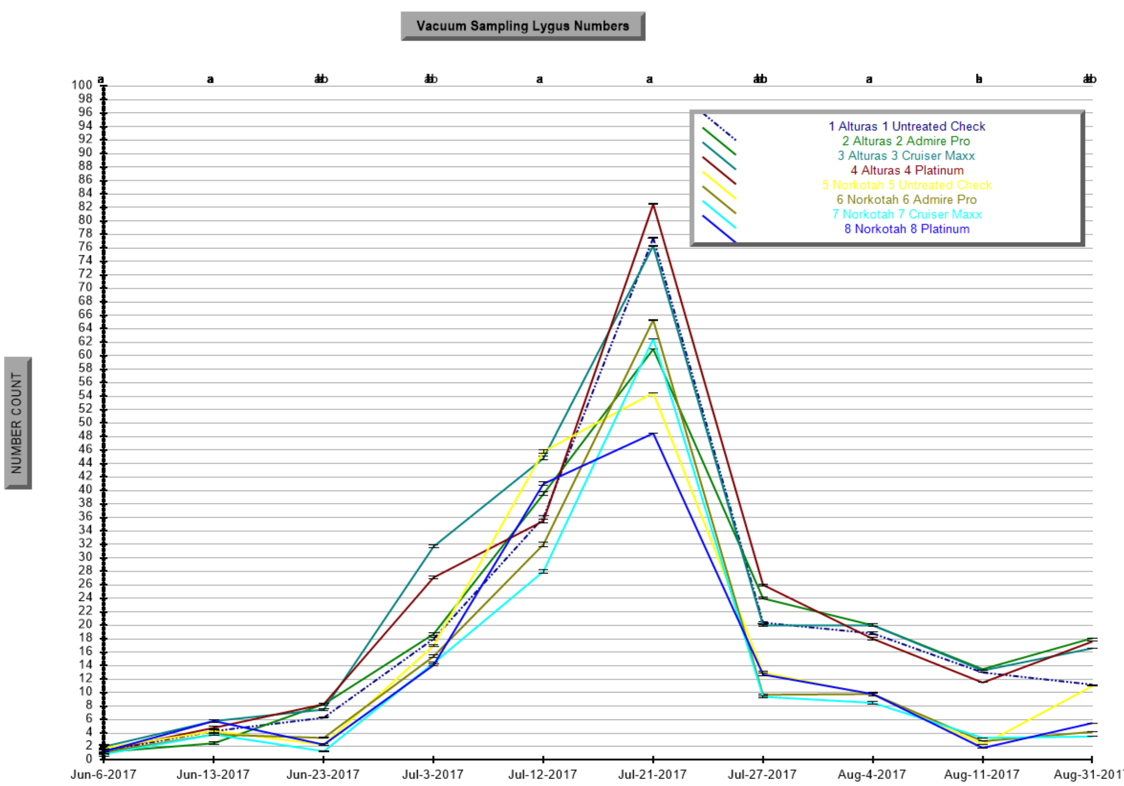

Figure 3. Lygus per vacuum sample by treatment 2017. Treatments with the same letters are not statistically different from one another (P=0.05 Student-Newman-Keuls test).

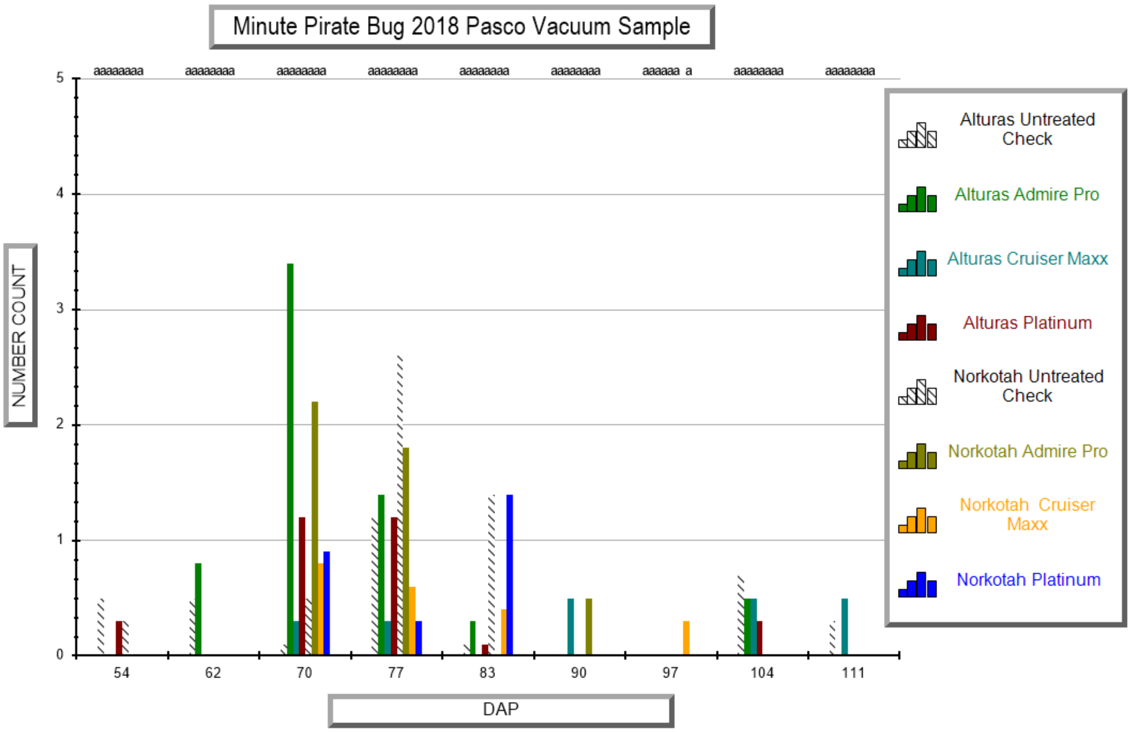

Figure 4. Minute pirate bugs per vacuum sample by treatment 2018. Treatments with the same letters are not statistically different from one another (P=0.05 Student-Newman-Keuls test).

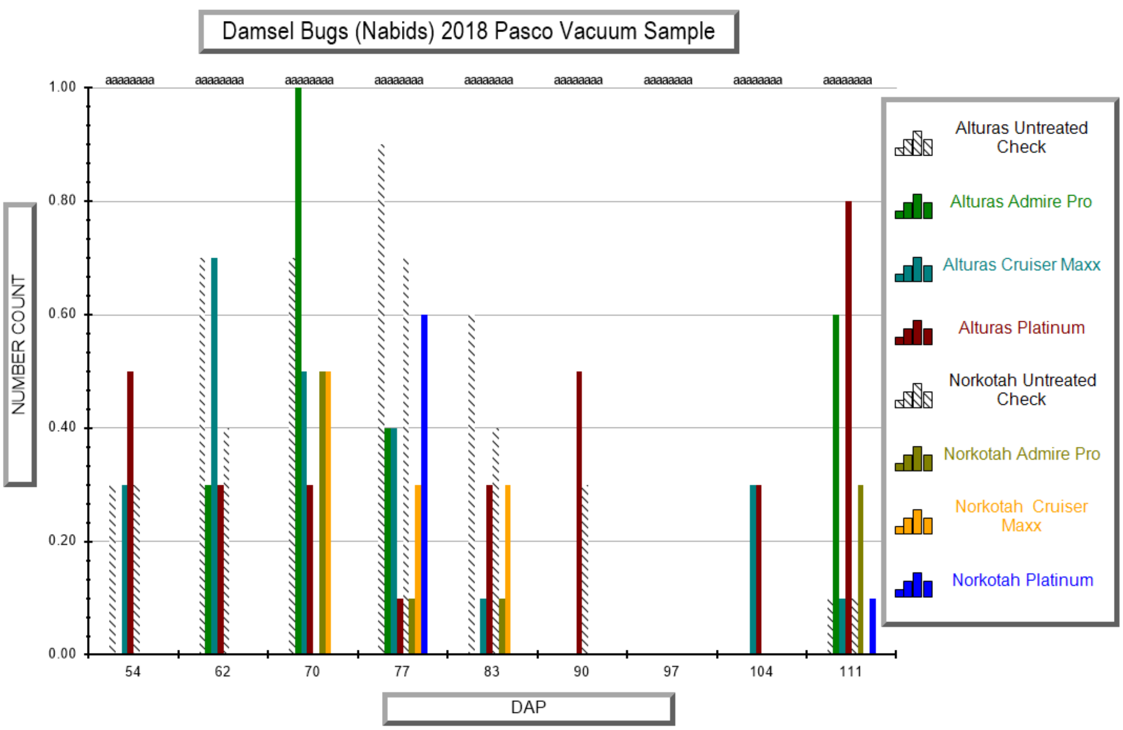

Figure 5. Damsel bugs per vacuum sample by treatment 2018. Treatments with the same letters are not statistically different from one another (P=0.05 Student-Newman-Keuls test).

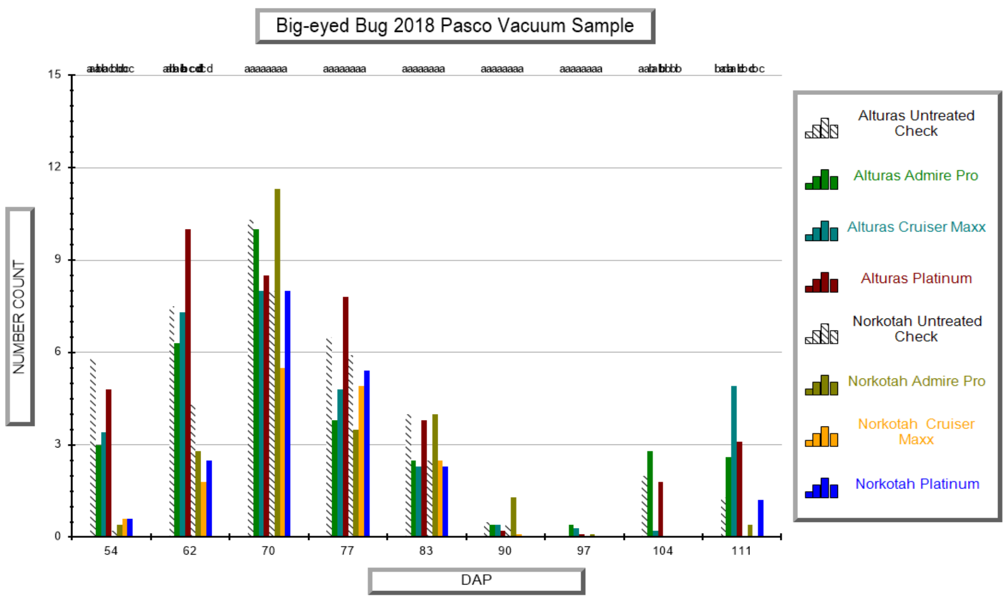

Figure 6. Big-eyed bugs per vacuum sample by treatment 2018. Treatments with the same letters are not statistically different from one another (P=0.05 Student-Newman-Keuls test).

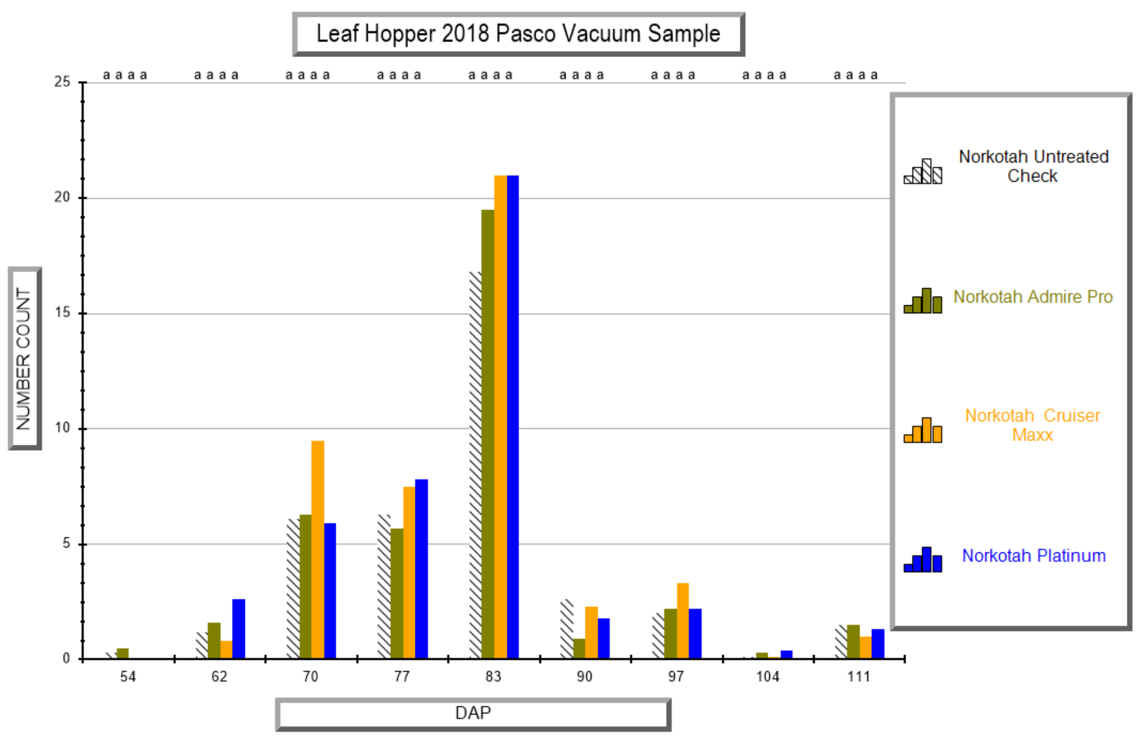

Figure 7a. Beet leafhoppers per vacuum sample by treatment, Norkotah plots 2018. Treatments with the same letters are not statistically different from one another (P=0.05 Student-Newman-Keuls test).

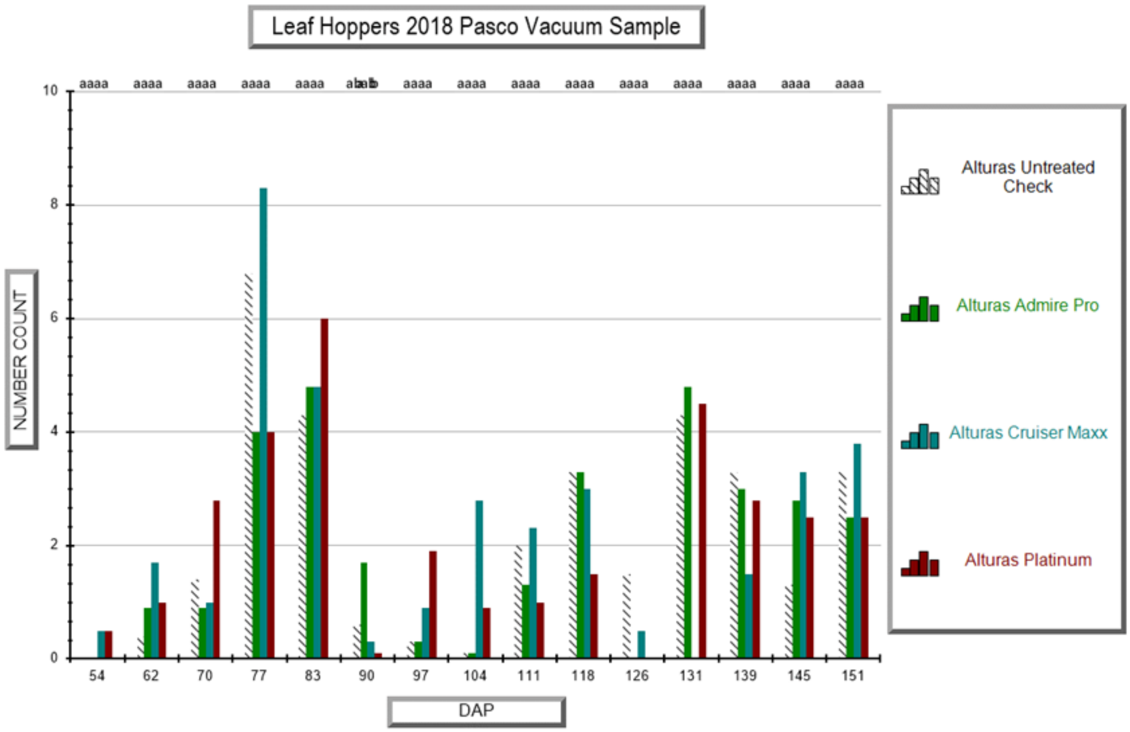

Figure 7b. Beet leafhoppers per vacuum sample by treatment, Alturas plots 2018. Treatments with the same letters are not statistically different from one another (P=0.05 Student-Newman-Keuls test).

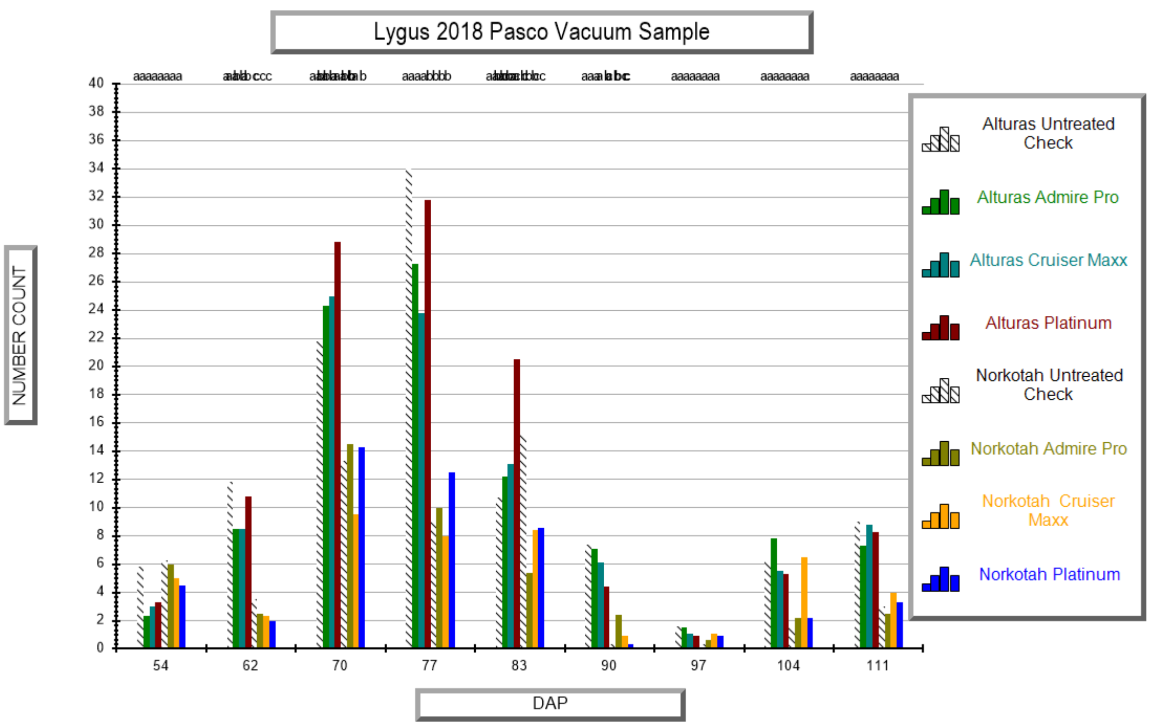

Figure 8. Lygus per vacuum sample by treatment, Alturas plots 2018. Treatments with the same letters are not statistically different from one another (P=0.05 Student-Newman-Keuls test).

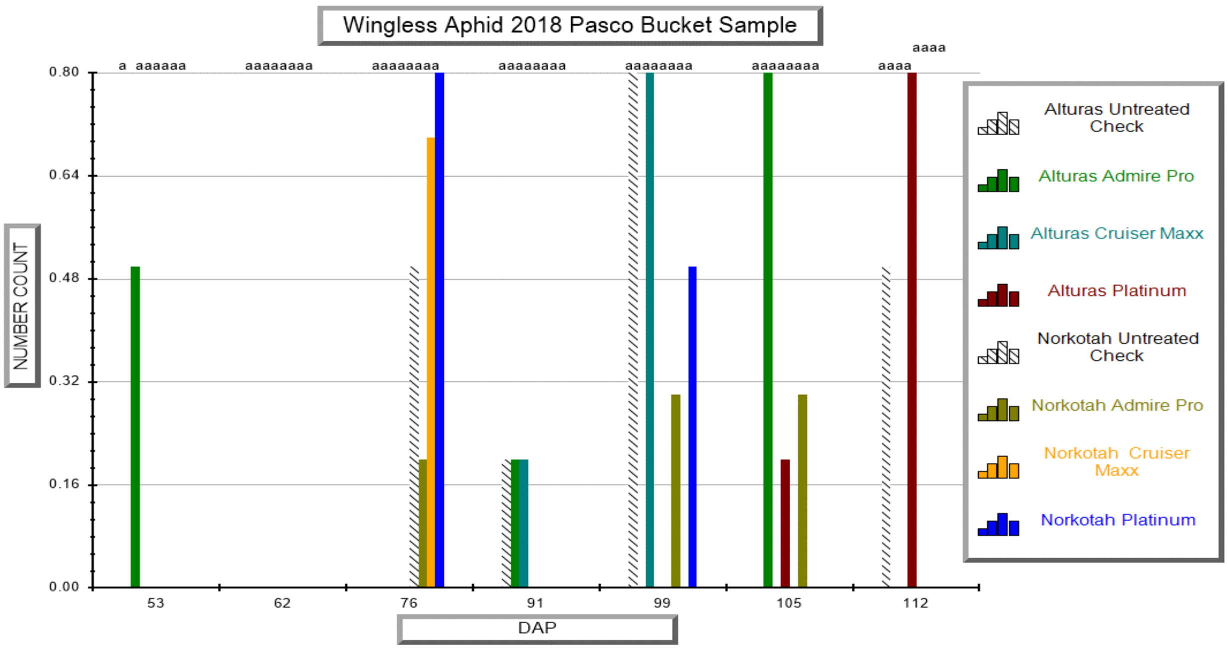

Figure 9. Wingless aphids by bucket sample by treatment, Alturas plots 2018. Treatments with the same letters are not statistically different from one another (P=0.05 Student-Newman-Keuls test).

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