Proceedings

of the

1st ANNUAL WASHINGTON OREGON POTATO CONFERENCE 2010

January 26-28, 2010
Three Rivers Convention Center
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Proceedings of the 1st Annual Washington-Oregon Potato Conference

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Identifying Potato Germplasm Resistant or Tolremic to Black Dot and Powdery Scab

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Introduction

Black dot is a fungus (*Colletorichum coccodes*) that invades the vascular system of the potato plant and causes death later in the growing season. It is a component of early dying affecting plant growth later in the season. Is it a saprophyte feeding on dead tissue that was killed by other organisms or is it triggered during the foliage senescence process to become an active pathogen and shorten the viability of the foliage, curtailing the yield? Powdery scab (*Spongospora subterranea*) is also a fungus with unusual properties. It spends part of it life cycle in the potato root system and most obviously damages the plant by causing galling on the roots and scabby lesions on the tubers. However, its yield-robbing facility really lies in the dysfunction of the roots that it causes. This is difficult to assess visually, but the size and the functionality of the root system are sharply reduced in susceptible varieties. These two pathogens have several facts in common: 1) they are easily transmitted and spread as viable infections of seed tubers, 2) they are maintained for years in the soil ready to become active the next time potato is planted in the field, 3) they are relatively new to many areas, but have become widespread and predominant in cropping zones, and 4) they frequently occur together in the field.

During 2009 we planted a large number of varieties and breeding lines in three separate trials in a grower's field with a history of both organisms. We made two harvests of the trials, the first while the foliage was still green to evaluate powdery scab and black dot damage on the on the roots and presence of the black dot fungus in the stems, and the second harvest was to obtain measurements of yield components. Previous years' studies had made one thing obvious - identifying specific traits that predicted resistance that were consistent year after year did not occur. The expression of both diseases varied greatly with year. Even our "reliable" susceptible trial entries did not behave that way year after year.

The traits that we measured are presented in Table 1

Table 1. Traits measured in the three trials.

• Total Yield	• Over 14 oz.
• Marketable yield	• Root fresh weight
• Cull weight	• Root dry weight
• Under 4 0z.	• Percent root dry matter
• 4 to 6 oz.	• Powdery scab rating fresh root
• 6 to 9 oz	• Black dot rating fresh root
• 8 to 10 oz.	• Cultured black dot
• 10 to 12 oz.	• Sclerotia expansion dry stem
• 12 to 14 oz.	

The nature of the three trials is depicted in Figure 1. The PV Trial consisted of varieties offered for commercialization by the Plant Variety Management Institute. The GN trial consisted of clones in the Tri-State and Western Regional trials. The RR set consisted of clones with a history of demonstrated resistance. The PV, GN, and RR sets were most available for rapid commercialization in the order PV>GN>RR (Figure 1). Sclerotia appear as discrete black bodies often on the epidermis of the stem about the size of pencil tip (Figure 2). As stems dry out slerotia appear in sequence up the stem in relation to the prevalence of fungus in the stem. We measure from the ground level to the furthest appearance of sclerotia on the stem (Figure 3)

Results

One of the more consistent linkages we found was the relationship between yield of tubers over 14 ounces and the expansion of black dot sclerotia up the stem of green harvested stems that were allowed to air dry.

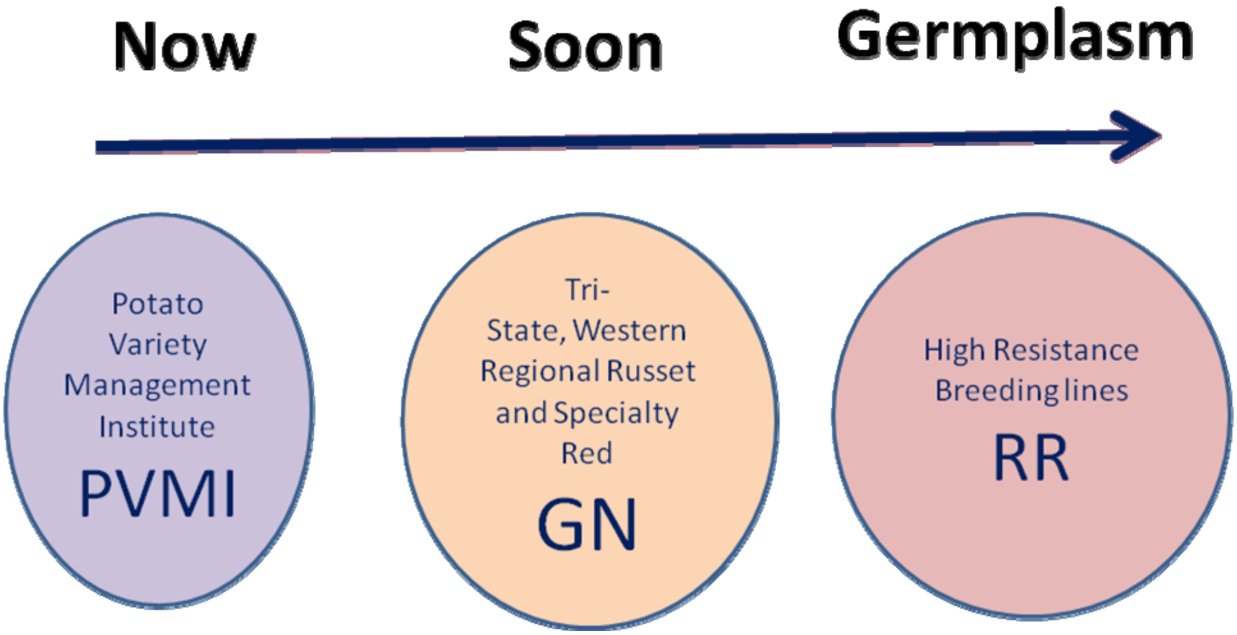


Figure 1. Germplasm under evaluation in field trials in 2009

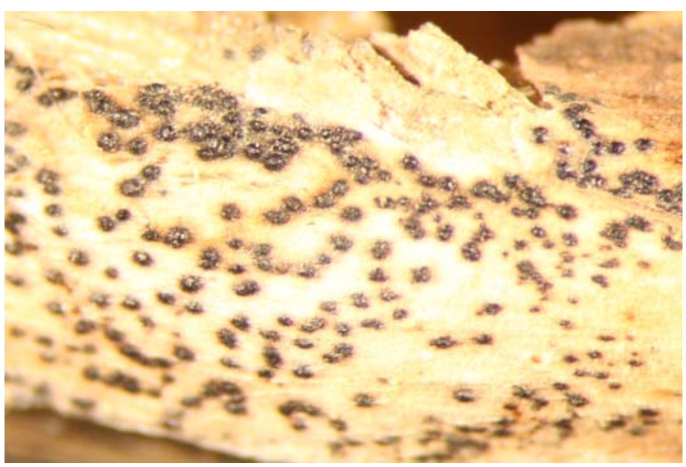


Figure 2. Sclerotia expansion up drying stems in the GN trials

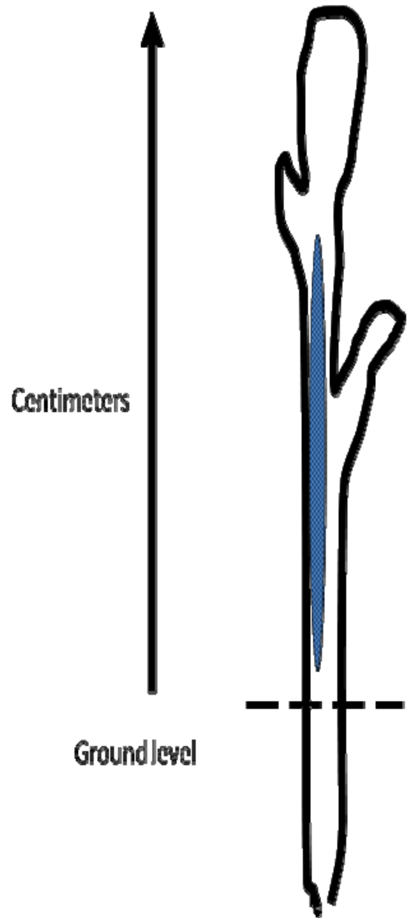


Figure 3. Method of measuring black dot sclerotia expansion on dried stems.

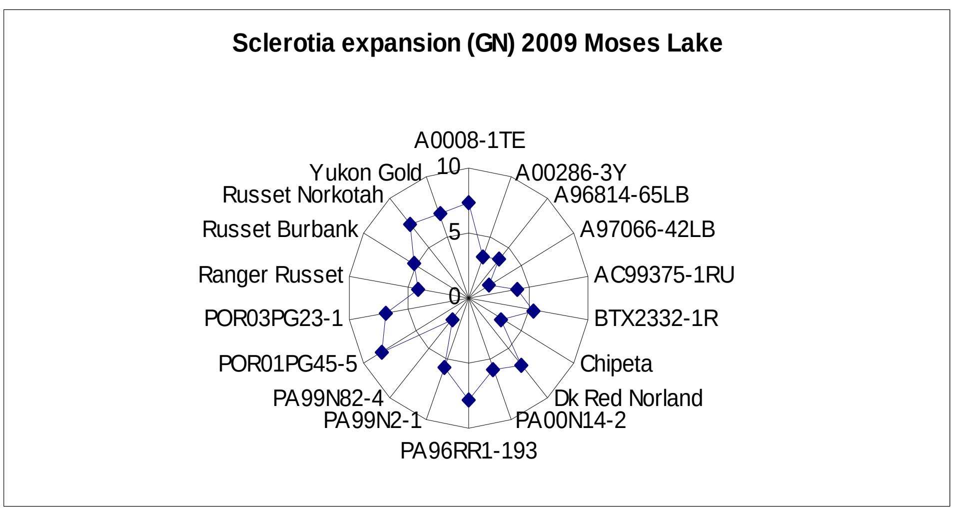


Figure 4. Sclerotia expansion in GN trial.

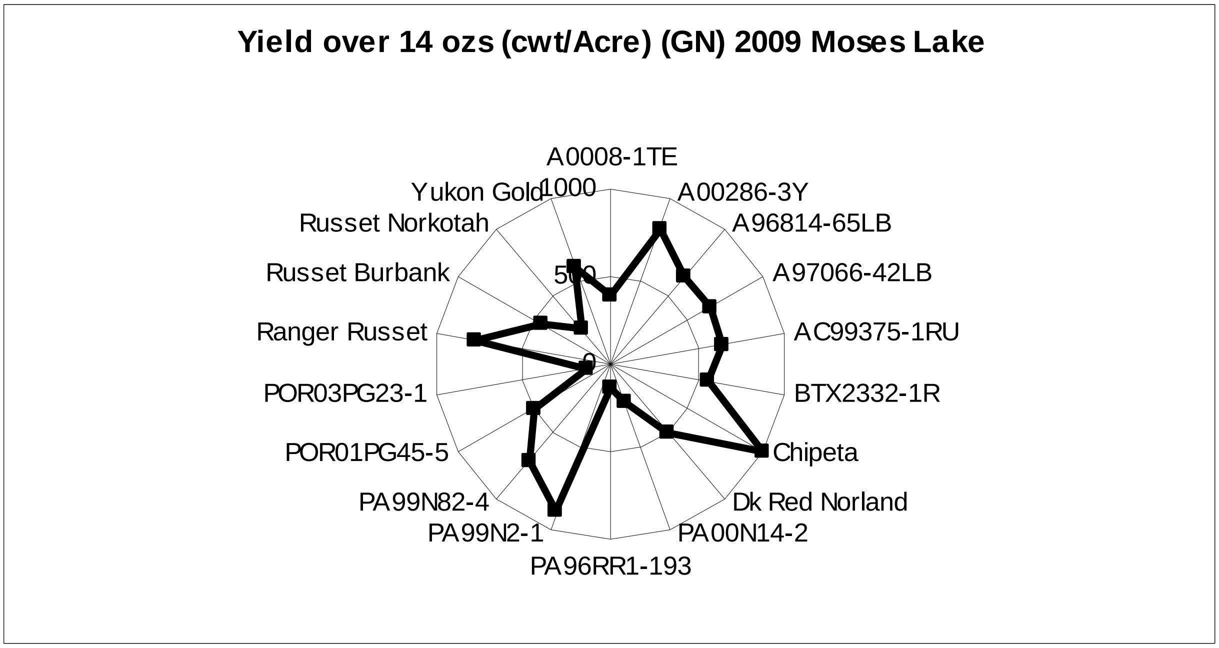


Figure 5. Yield over 14 ounces in GN trial.

The sclerotia expansion indicated strong differences between genotypes (Figure 4). The yield over 14 ounces, indicating the ability of the genotype to produce large size tubers in the face of the pathogen challenge, is almost a mirror image of sclerotia expansion (Figure 5). This relationship is also described by the regression of yield over 14 ounces against sclerotia expansion. A significant negative correlation was found (Figure 6).

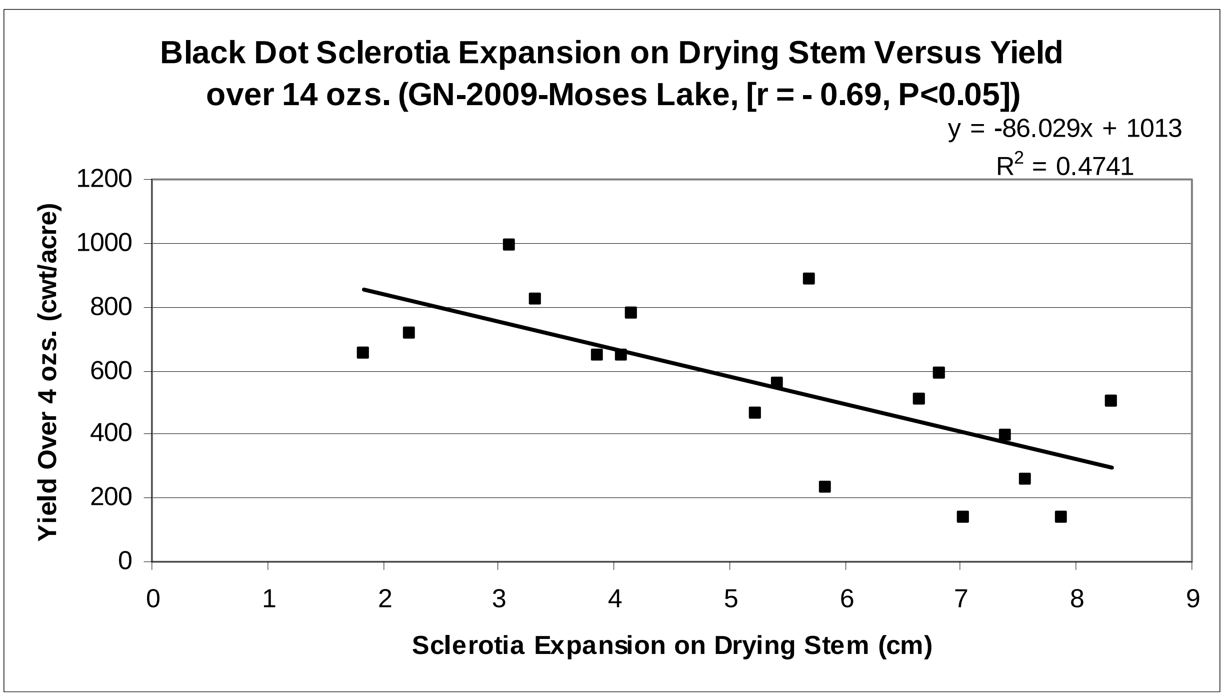


Figure 6. Negative correlation between sclerotia expansion and yield over 14 oz (r = -0.65, P, 0.05).

The most powerful message that emerges from this relationship is that it is possible to predict ability of clones to resist damage from black dot and powdery scab with direct measures of progress of black dot appearance on the stem. However, this is an indirect method. The most direct method is to measure yield directly under severe challenge by the pathogens.

BiPlot Analysis:

Plant breeders are often forced to consider numerous traits simultaneously and to make simple decisions based on complex performance. Biplot analysis is a technique which adds to the decision making power. This is a type of multivariate analysis that identifies which traits are explaining the majority of variation and then presents the breeding clones performance on a two-dimensional display. This method of summarizing results is useful because among other things it identifies a new genotype with unique combinations of characteristics, or, alternatively, identifies new genotypes with performances similar to already established cultivars. We applied this analysis to the GN, PV, and RR trials. The analyses are presented as Figures 7 through 9 on the following pages.

The biplot analyses assist in the identification of clones which perform well on resistance traits or have a high yield of large size tubers, or both. It is apparent that a few clones have high yield profiles while not having resistance to black dot as determined by the disease severity index or by sclerotia expansion.

These clones are tolremic, i.e. they are able to perform well despite the fact that they are diseased. Examples of these are A00286-3Y and Premier Russet. Clones which are apparently resistant to invasion by black dot are Sage Russet, Yukon Gem, and Alturas. It is noteworthy that this is the first determination that Sage Russet may be a promising new candidate for the processing industry with considerable resistance to both black dot and powdery scab. This is based on only the first year of data. Subsequent tests will provide data with greater credibility.

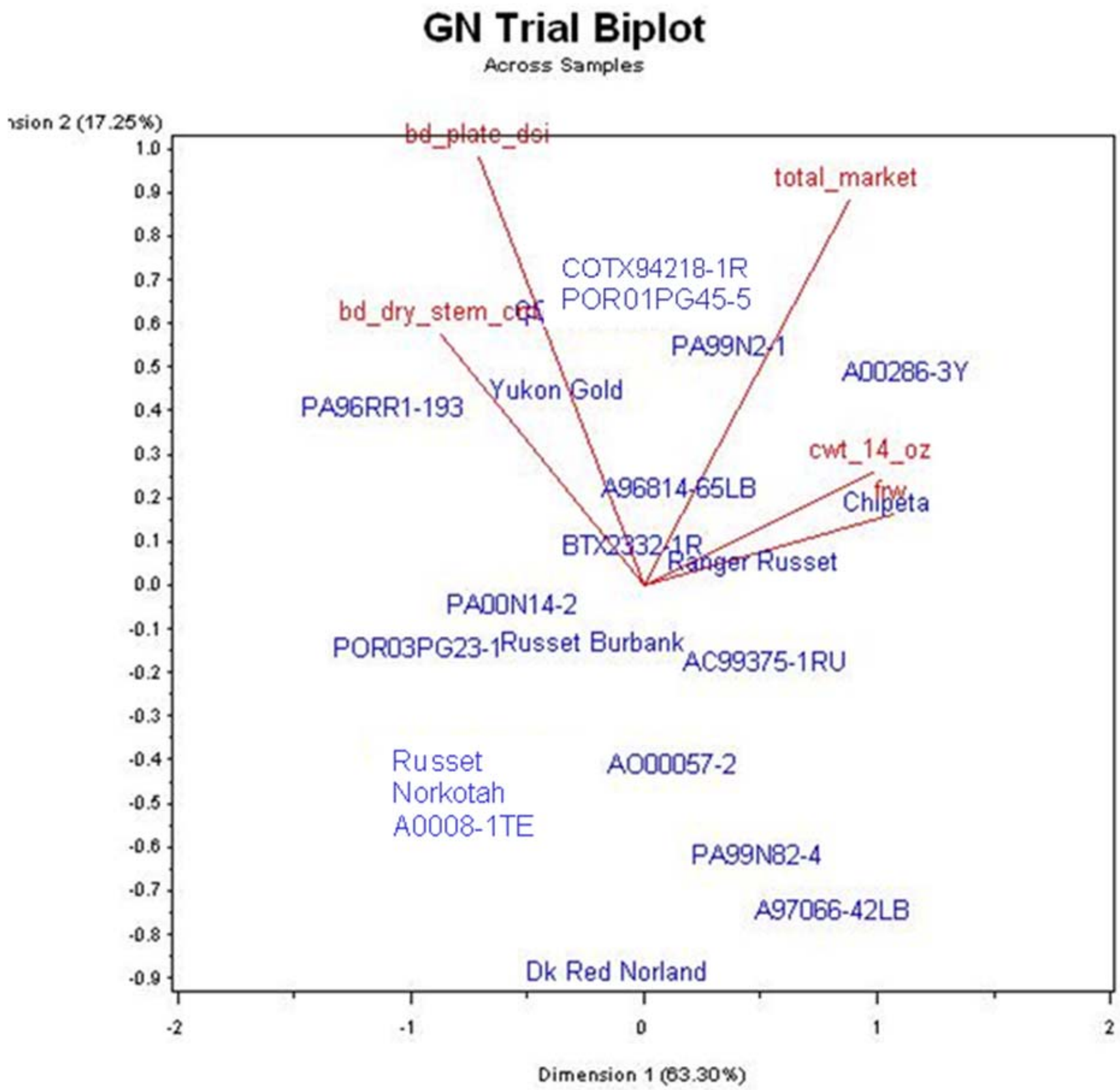


Figure 7. The Biplot analysis of the GN trial. The five lines represent the directionality of five traits: bd_dry_stem = sclerotia expansion up dried stems, bd_plate_dsi = detection of black dot fungus at increasing heights in the stem by plating out on medium, total_market = total yield excluding culls, cwt_14_oz = yield of non-cull tubers over 14 ozs, and frw = fresh weight of roots. Traits whose lines are at acute angles to each other are correlated, at right angles are independent and at obtuse angles are negatively correlated. The traits were picked out by the program as those which explain most of the variation in the data.

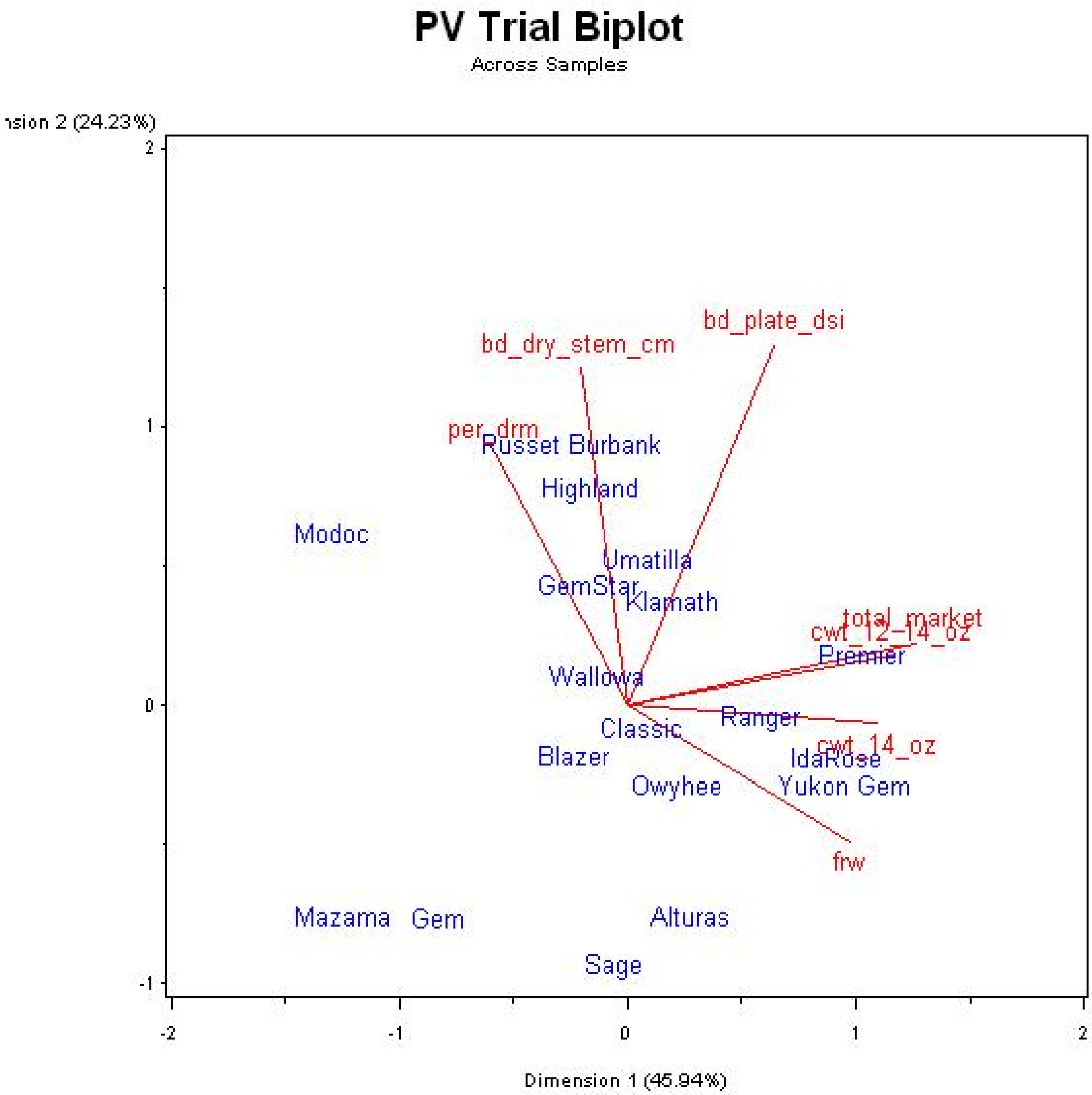


Figure 8. The Biplot analysis of the PV trial. The seven lines represent the directionality of seven traits: per_drm = percent root dry matter, bd_dry_stem = sclerotia expansion up dried stems, bd_plate_dsi = detection of black dot fungus at increasing heights in the stem by plating out on medium, total_market = total yield excluding culls, cwt_12-14_oz = yield of 12-14 ozs size tubers, cwt_14_oz = yield of non-cull tubers over 14 ozs, and frw = fresh weight of roots. Traits whose lines are at acute angles to each other are correlated, at right angles are independent and at obtuse angles are negatively correlated. The traits were picked out by the program as those which explain most of the variation in the data.

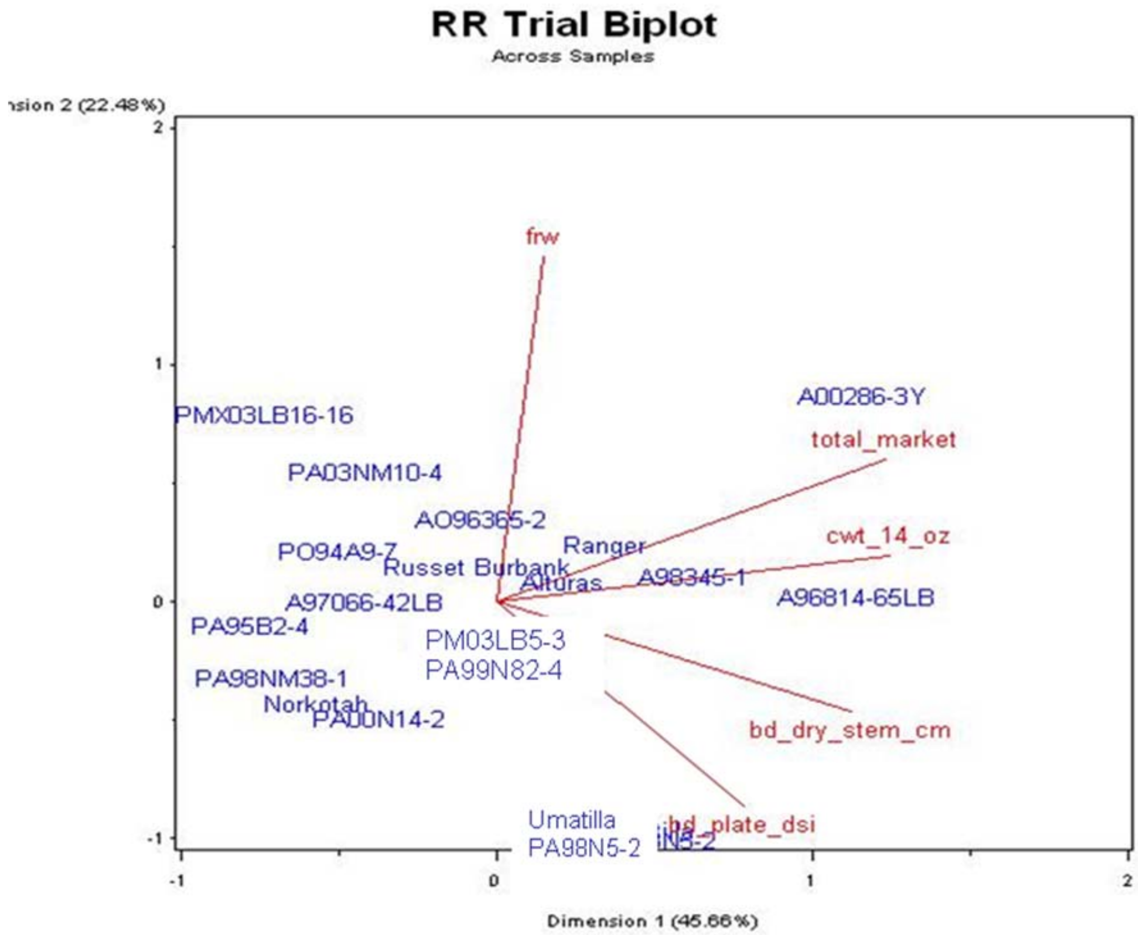
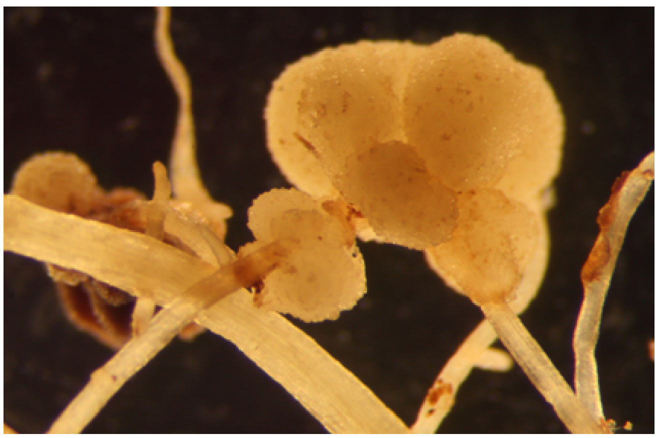


Figure 9. The Biplot analysis of the RR trial. The five lines represent the directionality of five traits: per_drm = percent root dry matter, bd_dry_stem = sclerotia expansion up dried stems, bd_plate_dsi = detection of black dot fungus at increasing heights in the stem by plating out on medium, total_market = total yield excluding culls, cwt_14_oz = yield of non-cull tubers over 14 ozs, and frw = fresh weight of roots. Traits whose lines are at acute angles to each other are correlated, at right angles are independent and at obtuse angles are negatively correlated. The traits were picked out by the Biplot program as those which explain most of the variation in the data.

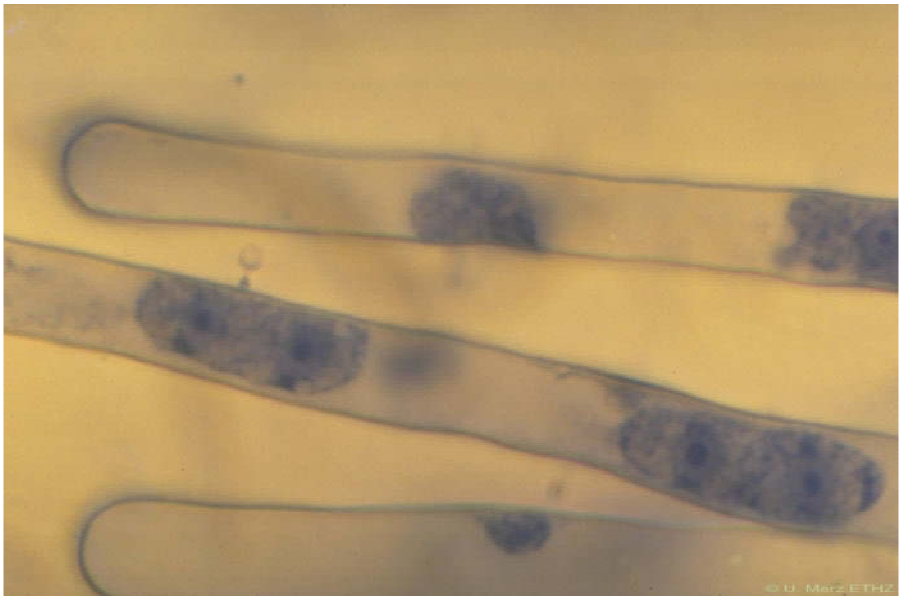
Summary

In the future we will always take detailed yield data on clones that we are evaluating for resistance. All other traits that we measure will be compared to these. Also it has been shown that tolremia is a real phenomenon when it comes to resistance to black dot and powdery scab. Measurements of the amount of disease organism present in the plant will, therefore, mislead us in those cases. Tolremic clones can yield despite being diseased. So far tolremia appears to be accompanied by large root mass. This may be a key to coping with these diseases, i.e., we must find root systems that resist or outgrow the damage caused by the diseases.

Appendices



Appendix 1. Root galls caused by powdery scab organism. Galls remain in the soil after the roots decompose and serve as a source of future inoculums.



Appendix 2. Powdery scab takes the form of plasmodia that inhabit the interior of the roots. This stage of the pathogen may be the most damaging to the roots, per se, although little information is available on the topic .

Appendix 3. Powdery scab lesions on tubers. Worldwide this is the most recognizable form of powdery scab disease. However, russeted skin tubers rarely show this type of lesion in a noticeable way. Powdery scab is therefore primarily a root damaging disease in processing russeted skin varieties destined for processing in the Pacific Northwest. An exception to this is Shepody which suffers from large and deep lesions on the tuber (it is not russeted, either). Powdery scab is often present on seed tubers which provides for ever-present inoculums. Powdery scab infection on seed may be barely noticeable.

An Update on PVMI, the Potato Variety Management Institute

Jeanne Debons, Executive Director, PVMI
January 27, 2010

PVMI was started as a non-profit organization in 2005 by the three potato commissions of Idaho, Oregon and Washington. Its job is to promote the new potato varieties developed by the Tri-State Research and Breeding Program, and also collect license and royalty fees based on the amount of seed grown.

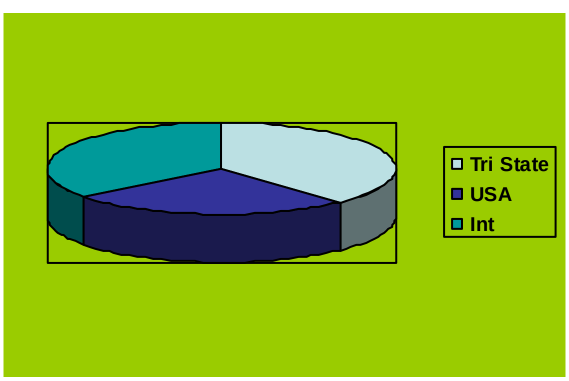
In 2009, PVMI collected sufficient royalty fees to send a check for $100,000 to the university programs. This amount was divided by four institutions: the University of Idaho, Oregon State University, Washington State University and the USDA Agricultural Research Service.

Early in 2010 the PVMI Board, which is made up of a single representative from each of the three states potato commissions as well as two growers from each state, decided to reduce the license fees to $250 per year for all seed growers outside the Tri-State area and to $100 per year for seed growers located in the Tri-State area. A single annual license covers all 24 varieties that PVMI administers on behalf of the program. The reason for the Board's decision is that they do not want the license fee to act as a deterrent for growers to evaluate the new varieties. It is the royalties from good new potato varieties that will ultimately make the money for the grower and PVMI.

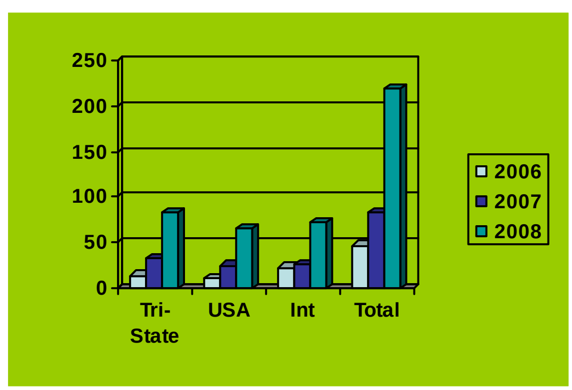
Royalties are due when seed is sold off the farm and are $0.25/CWT for Tri-State growers, $0.50/CWT for U.S. growers outside the Tri-States and $1.00/CWT for all seed growers outside the U.S.

Since January 2006 almost $600,000 in license and royalty fees have been collected. The breakdown of these fees is approximately 35% collected from Tri-State growers, 34% collected from seed growers in the U.S. and 31% collected from outside the U.S. In the future, royalties will become the larger proportion of funds collected not only because the annual fee has been reduced but also because a successful variety will generate much more income. The breakdown in licenses and royalties overall collected to date is 42% licenses and 58% royalties. In the 2008 seed crop year, i.e. prior to the decrease in license fees, the proportion was 35% from license and 65% from royalties, so we are beginning to see the trend.

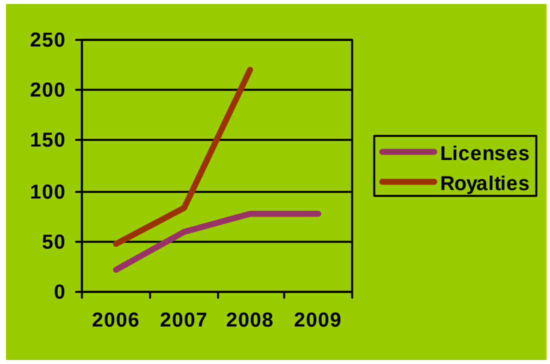
Total Royalty Contribution



Royalty Breakdown 2006 -2008



Collection of Fees to Date



Alturas and ***Ivory Crisp*** have now both received PVP (Plant Variety Protection) status and as such will have royalties collected. That means for seed grown in 2009 for ***Ivory Crisp*** and for seed grown in 2010 for ***Alturas,*** royalties will be due.

Premier Russet was expected to be a potential "silver bullet" potato so that many seed growers have had acreage during the last couple of years. During the past year, as has been the case with several successful varieties in the past (***Ranger, Umatilla***) there were some problems associated with its growth (hollow heart), bruising and/or storage. There are management methods to avoid all or most of these issues and growers in the future need to consult the agronomy and management notes put out by both the University of Idaho team at Aberdeen as well as the WSU researchers. These are available at www.pvmi.org. With the new varieties one needs to remember one is dealing with the equivalent of a high performance race car. One can not just put gas in it and go. Specifically the nitrogen requirements can be very different. My opinion is that these are still early days on these and other new varieties and we need to proceed cautiously. Unexpected crop performance requires one to examine the assumptions used (fertility, water, spacing, harvest qualities, etc). These varieties have excellent qualities (cold sweetening resistance, long storage, low sugars, high protein, PVY resistance, etc.), so it would be better to see if we can manage their idiosyncrasies, rather than give up on them.

Gallatin Russet (A88338-1) was released in 2009 as a non-PVP, free public variety. Anyone can have access to it without requiring a license or royalties. This variety is prone to hollow heart but field management can overcome this problem.

Severe cuts to the Tri-State Research and Breeding Program have been made by both state and federal governments. This means that experiment stations are under threat. PVMI hopes to provide enough income in the future so that this will be less of a threat, but in the meantime the program is struggling financially. The new varieties need to perform and be adopted by the processors and Quick Service Restaurants so that PVMI, and return of funds back to the program, is a success. Without PVMI we risk that only private companies will be able to afford the high cost of breeding, and the Pacific Northwest would not have the dedicated program they deserve.

PVMI publishes a semi-annual newsletter ***Variety News*** on paper and on-line versions as well as providing Agronomy Notes and Management Bulletins produced by the Tri-State Breeding and Research Program. There are links to many of the important potato places as well as descriptions of the new varieties and a place to find information about buying or selling your PVMI varieties seed. **www.pvmi.org**

Thiamine and Folate in Potato: Targets for Increased Nutritional Value and Enhanced Disease Resistance

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Abstract

The development of more nutritious potato varieties would *(1)* benefit those for which it is a diet staple, *(2)* help the potato industry cope with negative publicity associated with glycemic index and acrylamide issues, and *(3)* open up new economic opportunities for growers and processors. Thiamine and folate are essential micronutrients in the human diet. These water-soluble B vitamins are great targets for nutritional enhancement of potato because *(1)* thiamine and folate deficiencies are still common throughout the world, even in developed countries, and are responsible of various serious diseases, *(2)* the potato is relatively poor in thiamine and folate compared to rich sources such as beans and lentils, and *(3)* there is little loss of thiamine and folate during cooking and processing. In addition, there is increasing evidence that higher thiamine content correlates with increased resistance to biotic and abiotic stresses in plants. Unfortunately, the natural variation of thiamine and folate concentrations in potato has not been extensively studied. Therefore, the author measured thiamine and folate concentrations in various potato genotypes in order to evaluate the potential for increase of these vitamins in new varieties. Field-grown tubers from commonly grown varieties and advanced breeding lines contained between 410 and 871 ng thiamine per g fresh weight (FW). The higher ones would qualify as good or excellent sources of thiamine. Wild species grown in a greenhouse had even higher variation in thiamine content, ranging from 476 to 2104 ng per g FW. Primitive cultivars contained between 600 and 1264 ng thiamine per g FW, and had between 159 and 385 ng folate per g FW.

Introduction

Potatoes with improved nutritional qualities offer a more appealing product for consumers and help offset negative publicity associated with glycemic index and acrylamide issues. In particular, there is an increased demand for specialty potatoes which is partially due to the higher demand from consumers for more colorful, tastier, and more nutritious potatoes, and partially due to the pro-active small-scale farmers who are trying to diversify their production and marketing to provide economic stability. To answer this demand, varieties such as Purple Pelisse, a dark purple flesh potato high in antioxidants selected by the Pacific Northwest Tri-State Breeding Program, was recently released. The identification of genotypes high in phytonutrients is the starting point to developing commercially available high-phytonutrient potato varieties. The potato possesses a tremendous genetic diversity that has only just begun to be utilized. Amongst the thousands of existing potato accessions, some will hopefully be rich in thiamine and folate, the vitamins currently being investigated.

Thiamine and folate are essential micronutrients in the human diet. Thiamine deficiency is still common throughout the world [1], even in the U.S. where cases of thiamine deficiency are reported every year, and are linked to various diseases such as heart failure and bladder dysfunction [2]. A deficiency of folate in the diet is associated with the increased risk of neural tube defects, strokes, cardiovascular diseases, anemia and some cancers. Unfortunately, current folate intake is suboptimal in most of the world's populations, even in developed countries [3]. Every year, ca. 500,000 newborns are affected by birth defects due to inappropriate prenatal folate intake by their mothers. Unfortunately, potato varieties currently consumed are relatively low in folate and thiamine. Concentrations in modern potato varieties are four to ten times lower than in sources such as beans or lentils (The USDA Nutrient Database SR20). Despite its relatively low thiamine and folate content, potato has two major advantages over other foods in its capability of being developed as a major source of these vitamins: *(1)* it is the third most consumed vegetable worldwide; and *(2)* when cooking or processing potatoes there is little loss of thiamine and folate. Thus, the introduction of new potato varieties high in thiamine and/or folate could significantly decrease the incidence of diet deficiencies.

In addition to its importance in nutrition, thiamine exhibits potential for increased disease resistance in crops. Thiamine has been shown to stimulate the plant's inherent defense mechanisms which lead to protection against bacterial, viral, and fungal diseases [4]. Plants sprayed with thiamine and then infected with pathogens either showed significantly decreased or no disease symptoms. Rice with lower thiamine content has been shown to be more susceptible to bacterial blight and blast [5]. These results suggest that cultivars with higher thiamine content could be more resistant to select pathogens.

The natural variation of thiamine and folate concentrations in potato has not been extensively studied. This project was focused on determining the range of thiamine and folate concentrations amongst potato genotypes from the Northwest breeding programs, some popular varieties, and a series of wild species and primitive cultivars. Here, the author reports on thiamine and folate concentrations in these various potato genotypes.

Materials and Methods

Potato Material. During the 2009 season, tubers were harvested from 46 breeding lines or cultivars grown at the Hermiston Agricultural Research and Extension Center (HAREC). These included 16 varieties selected by the Pacific Northwest Tri-State Breeding Program, 20 advanced breeding lines from the Tri-State Breeding Program, and 10 commonly grown varieties. Tubers were harvested by hand early in the growing season (mid-June) and weighed 16 g on average. A small collection of wild potato species accessions were grown in a HAREC greenhouse in 2008 and were harvested mid-November under short-day conditions. Primitive cultivars were field-grown at Sturgeon Bay and were harvested mid-September. Tubers weighed 36 g on average. These tubers were a kind gift from Dr. John Bamberg. All tubers were frozen in liquid nitrogen at harvest or one day post-harvest.

Thiamine Assay. Thiamine concentrations were measured by using a microbiological assay employing *Lactobacillus viridescens* grown in thiamine deficient medium. Total thiamine was extracted by acid hydrolysis and enzymatic treatment with takadiastase. After extraction, the solution was adjusted to pH 6.5 and centrifuged. Assays were performed on 96-well microtiter plates. Plates were incubated at 30°C for ca. 18 h. Bacterial growth was measured at 650 nm on a BioTek Instrument EL 311 SX microplate autoreader and analyzed with the KCJr EIA application software. Thiamine concentrations were calculated by reference to a standard curve using known amounts of thiamine. Concentrations are the average of two independent measurements performed on at least two extracts from each of three independent biological samples.

Folate Assay. Folates were extracted by a tri-enzyme treatment (protease, amylase, and deconjugase) in 10 mL of extraction buffer (50 mM HEPES/50 mM CHES, pH 7.85, containing 2% (w/v) sodium ascorbate and 10 mM 2-mercaptoethanol, deoxygenated by flushing with nitrogen). After centrifugation for 10 min at 3000*g*, the supernatant was transferred to a new tube. The residue was re-suspended in 5 mL of extraction buffer and re-centrifuged for 10 min. The combined supernatants were adjusted to a 20-mL final volume with extraction buffer, flushed with nitrogen, frozen in liquid nitrogen, and stored at -80°C until analysis. *Lactobacillus rhamnosus* was used to determine total folate content of tri-enzyme-treated samples. Assays were performed on 96-well microtiter plates. Plates were incubated at 37 °C for 18 h. Bacterial growth was measured at 650 nm on a BioTek Instrument EL 311 SX microplate autoreader and analyzed with the KCJr EIA application software. Results were calculated by reference to a standard curve using 5-formyl-tetrahydrofolate. Concentrations are the average of two independent measurements performed on at least two extracts from each of three independent biological samples.

Results and Discussion

Thiamine concentrations in tubers from field-grown varieties ranged between 410 and 871 ng thiamine g^{-1} FW (ca. 2.2-fold variation) (Table I). Amongst all these genotypes, twelve would provide over 10% of the Recommended Daily Allowance (RDA) based on mid-size tuber servings (175 g) and would qualify as a “good source” of thiamine according to the USDA grading system. Previous reports have shown that thiamine retention during cooking is high, 95% and 100% for microwaved and boiled unpeeled potatoes, respectively [6]. Therefore we expect that values reported here on raw tubers would be about the same or slightly lower after cooking.

Wild species grown in a greenhouse showed a higher variation in thiamine content than established cultivars, ranging from 476 to 2104 ng g^{-1} FW (Fig. 1). The two highest thiamine genotypes had more than double the amount of thiamine than that of Russet Burbank and could therefore be used as source of genes to introgress into domesticated cultivars for nutritional improvement.

We also determined thiamine and folate concentrations in a small set of primitive cultivars. Thiamine concentrations ranged between 600 and 1264 ng g^{-1} FW (ca. 2.1-fold variation) (Fig. 2). Thiamine concentrations differed significantly between field and greenhouse grown Russet Burbank tubers as well as between field locations (Table I, Fig. 1 and 2). This could be due to differences in environmental conditions under which potato plants were grown and/or the stage of development at which tubers were harvested. We observed a significant increase in thiamine concentrations during tuber enlargement (data not shown). Folate concentrations ranged between 159 and 385 ng g^{-1} FW (Fig. 3), the highest genotype containing 2.4-fold more folate than Russet Burbank. A mid-size tuber serving of the highest folate genotype would provide ca. 17% of the RDA and would qualify as a “good source” of folate. The highest folate genotype was also the highest thiamine genotype.

Conclusions

Thiamine and folate concentrations varied substantially amongst potato genotypes grown under the same environmental conditions (one location/one year). In particular, wild species and primitive cultivars showed the greatest range of vitamin concentrations. Potato genotypes identified to have high levels of thiamine and folate could provide genes to introgress into modern cultivars for nutritional enhancement and possibly increased disease resistance.

References

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Table I: Thiamine concentrations in tubers from 46 potato varieties field grown at HAREC. The Recommended Daily Allowance (RDA) for a healthy male adult is 1.2 mg per day. The percentage of the RDA provided by a raw potato serving is indicated in the last two columns. Food servings which provide over 10% of the RDA are qualified as a "good source"; those which provide over 20% of the RDA are qualified as an "excellent source" according to the USDA grading system. SE, Standard Error.

	ng/g FW	SE	%RDA (175 g serving)	%RDA (300 g serving)
A00286-3Y	410	23	6	10
Umatilla Russet	428	18	6	11
Yukon Gold	432	27	6	11
Wallowa Russet	460	17	7	12
Shepody	465	16	7	12
Abnaki	475	21	7	12
Klamath Russet	483	17	7	12
PA96RR1-193	496	37	7	12
Ranger Russet	508	66	7	13
R. Burbank	510	37	7	13
POR01PG22-1	514	32	7	13
Russet Norkotah	515	40	8	13
POR03PG23-1	523	27	8	13
Purple Majesty	538	33	8	13
A96814-65LB	543	17	8	14
Achirana	545	17	8	14
Dark Red Norland	564	21	8	14
AO96160-3	577	26	8	14
Modoc	578	19	8	14
Alturas	583	20	9	15
Mazama	589	23	9	15
POR02PG26-5	590	19	9	15
Clearwater Russet	599	26	9	15
Classic Russet	602	37	9	15
Defender	607	24	9	15
All Blue	619	45	9	15
POR03PG80-2	620	26	9	16
A99331-2RY	624	21	9	16
POR01PG20-12	635	38	9	16
POR01PG10-1	636	37	9	16
Highland Russet	640	26	9	16
POR01PG45-5	642	37	9	16
Gem Russet	643	30	9	16
AOR00681-15	644	21	9	16
COO86107-1	656	39	10	16
POR02PG37-2	658	45	10	16
POR01PG1-6	660	52	10	17
A97066-42LB	663	19	10	17
OR00068-11	669	27	10	17
Purple Pelisse	680	42	10	17
Blazer Russet	688	27	10	17
Red Sunset	732	60	11	18
Red LaSoda	754	29	11	19
GemStar Russet	840	32	12	21
Premier Russet	856	36	12	21
AOA95155-7	871	35	13	22

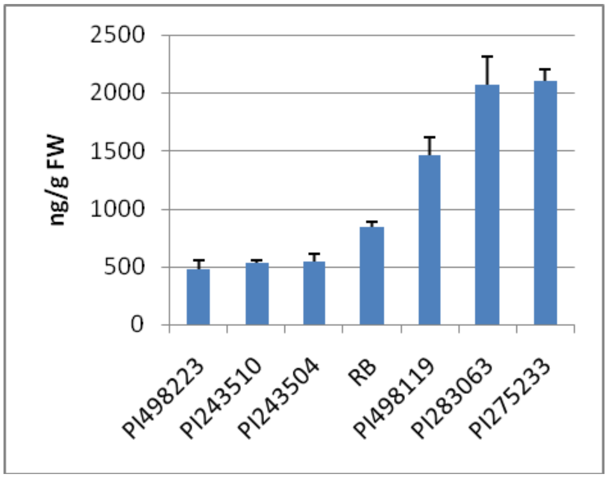

Figure 1: Thiamine concentrations in tubers of six wild potato species. All plants were grown in a greenhouse in 2008 at HAREC. RB, Russet Burbank; *Solanum bulbocastanum*: PI498223, PI243510, PI243504; *S. circaeifolium*: PI498119; *S. cardiophyllum*: PI283063; *S. pinnatisectum*: PI275233.

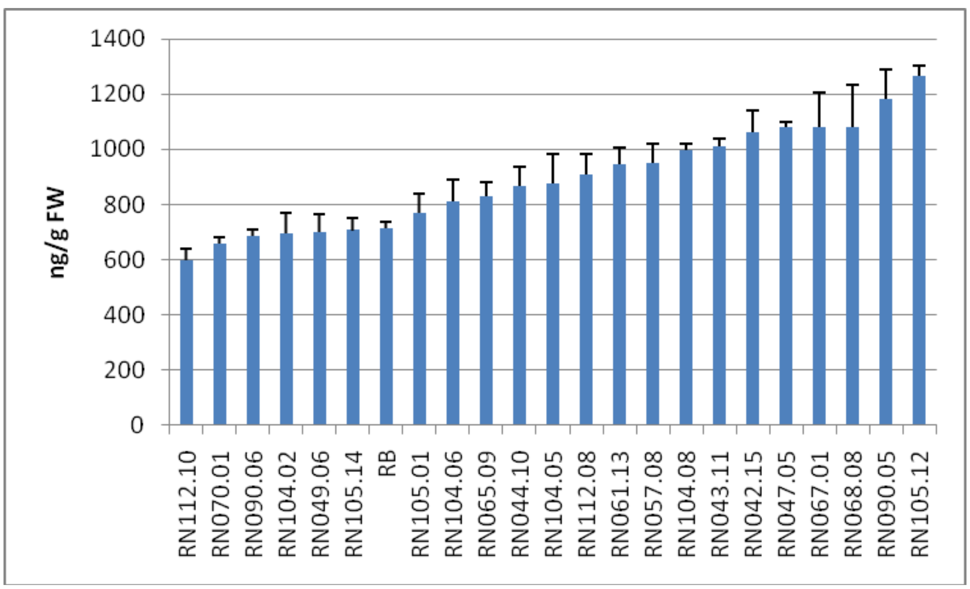

Figure 2: Thiamine concentrations in tubers of primitive cultivars. All plants were field grown in 2009 at Sturgeon Bay, WI. RB, Russet Burbank.

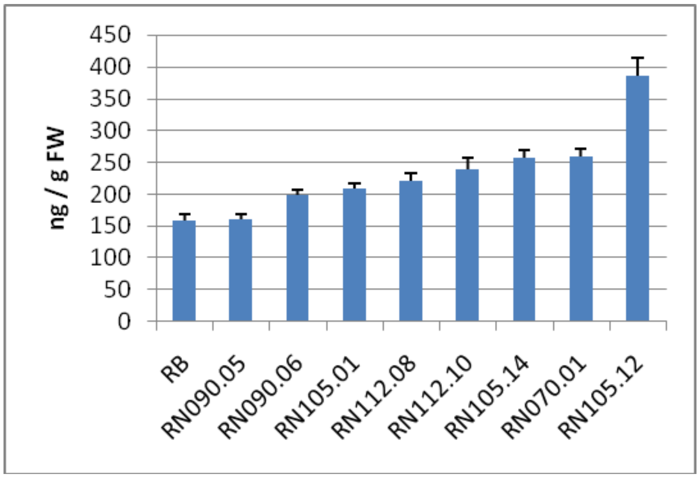

Figure 3: Folate concentrations in tubers of primitive cultivars. All plants were field grown in 2009 at Sturgeon Bay, WI. RB, Russet Burbank.

Fumigant Application Efficacy Trials in Light of Potential EPA Changes

PERSONNEL:

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Introduction:

Pre-plant center pivot fumigation with metam sodium is an effective means for controlling economically important soil borne pathogens in potato production (Triky-Dotan et al., 2007; Tsror et al., 2005). Other putative reduced air emission application methods (specifically shank and low drift drizzle boom (Smart Drop)) are receiving favorable buffer zone consideration as part of EPA-OPP's July 2008 Reregistration Eligibility Decision (RED) document (USEPA 2008). To better ascertain if product efficacy is affected by changing to reduced-emission application technologies, two pre-plant center pivot field fumigation efficacy studies were initiated in Franklin County WA; the first in the fall of 2008 followed by a more comprehensive field examination initiated in the fall of 2009.

2008-2009 Efficacy Demonstration: The goal of the 2008-2009 field-scale efficacy examination is to provide growers with efficacy information that directly compares water run to shank and low drift drizzle-boom chemigation (also marketed as Smart Drop) when using Sectagon 42® (Tessenderlo Kerley Inc.) at conventional application rates of 40 gallons per acre (GPA). For this single field 2008-2009 efficacy demonstration, pre and post fumigation soil borne pathogen soil core assays, visual plant evaluations at harvest, and harvest yield and quality determinations were evaluated at nine randomized sampling locations (3 application treatments x 3 replicate plots/treatment).

2009-2010 Efficacy Demonstration: In October 2009, we repeated randomized block Sectagon efficacy trials at 40 GPA rates. However, we also expanded the program to investigate product efficacy through harvest at lower (20 GPA) and higher (60 GPA) Sectagon 42 application rates to ascertain if there can be differences in product efficacy relative to application rate.

The over-arching objective is to provide growers and field men with tangible application practice options and information to support product efficacy for informed management decision-making. Application-based efficacy information will be important to provide growers in view of imminent buffer designation label language changes in spring 2011.

Study Overview:

2008-2009 Single Application Rate Efficacy Evaluation:

Ranger Russet potatoes were planted in April 2009 and harvested in late August 2009 from a 122 acre circle provided by Schneider Farms, Pasco WA. Pre-fumigation, post fumigation, pre-harvest soil-borne pathogen assays, in-season plant evaluations, and harvest yield and quality of potatoes were conducted in a randomized replicated design to compare application practice treatments (Figure 1). To avoid possible field application edge effects, the nine sampling positions (+) were located equidistantly between the individual tower treatments.

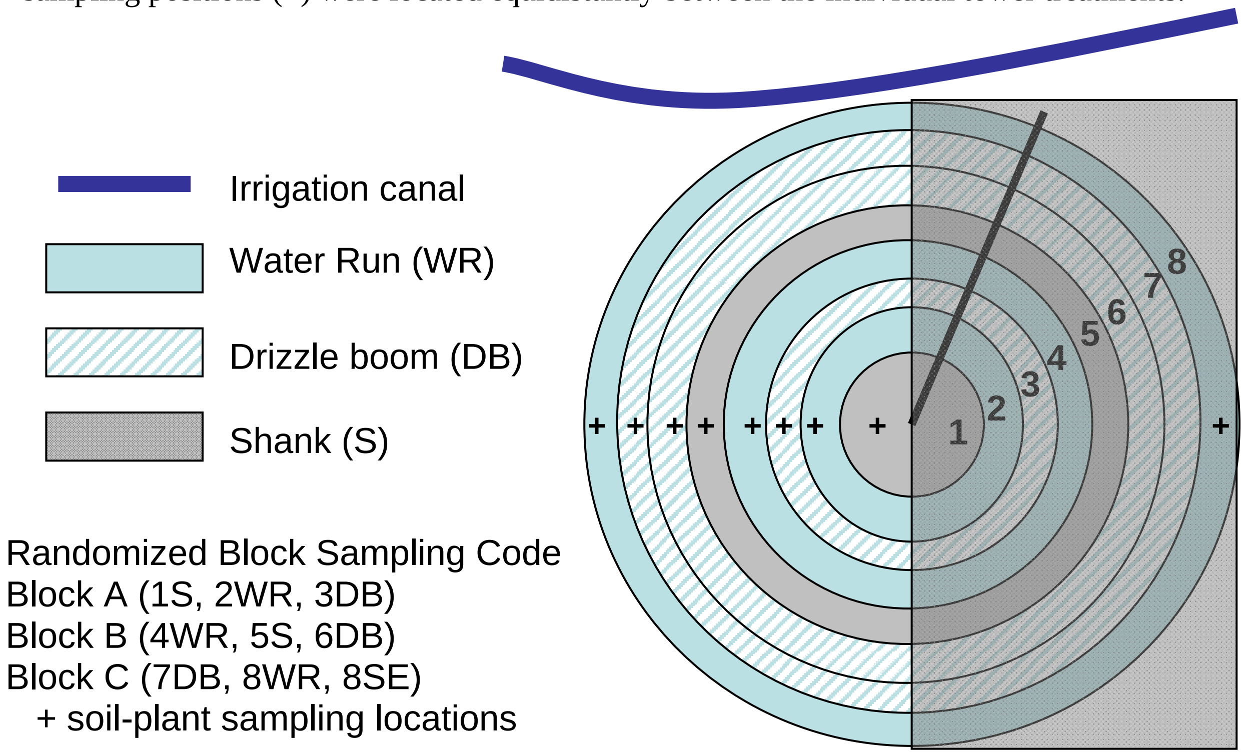

Figure 1: 2008-2009 Field Efficacy Layout

<u>Soil borne pathogen soil assays</u>: Before field fumigation in the fall 2008 and just before planting in 2009, soil cores were taken and segregated into two soil depths (0-12 and 12-24 inches) then composited from each of the treatment plots pre and post fumigation. The composited soil core samples (9 treatment plots x 2 depths) were assayed for *Verticillium dahliae, Pythium* spp., and *Fusarium* by OSU HAREC.

<u>Visual plant evaluations:</u> Field visual examinations were conducted in late August 2009 to document foliage symptoms just before harvest. Stems (15-17) were pulled from the ground within center of each of the nine replicated treatments and assayed for *Colletotrichum coccodes* and *Verticillium dahliae*. Stems were air dried in 48^{o}F storage held at 90% relative humidity and evaluated by WSU Plant Pathology for sclerotia incidence and severity of *Colletotrichum coccodes* and *Verticillium dahliae*.

<u>Yield and grade assessments</u>: Tubers were harvested in mid-August 2009 from 40 foot row sections at the nine treatment plot locations and transported to OSU HAREC where yield and grade assessments were conducted.

2009-2010 Multiple Application Rate Efficacy Evaluation:

In October 2009, a 148 acre eight tower circle with corner catchment (courtesy of Schneider Farms) was used for the second-year application based efficacy demonstration (Figure 2). *Ranger Russet potatoes were planted in April 2010.*

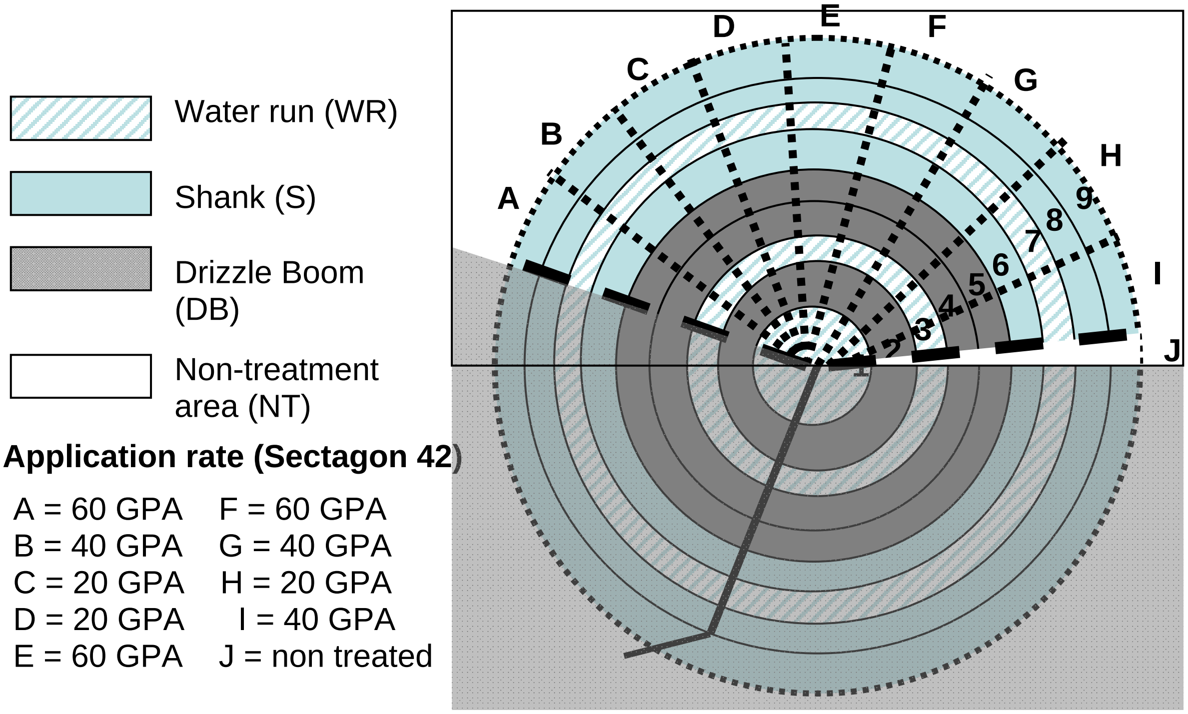

Figure 2: 2009-2010 Field Efficacy Layout

As in the 2008-2009 field study, this second year work was developed to compare water run to shank and to drizzle-boom when using Sectagon 42 at regional application rates of 40 GPA. This program has been expanded to also investigate product efficacy through harvest at lower (20 GPA) and higher (60 GPA) application rates. The three application rates were randomly assigned (in triplicate) among the nine ca. 12^{o} wedge sections within the test field. A tenth wedge (J) was set aside as an untreated control (Figure 2). The field study was developed in a manner similar to the 2008-2009 randomized block study. To avoid edge effects, the ninety GPS positions (81 application rate-practice treatment plots and 9 untreated control plots) were equidistantly positioned between treatment tower rows and application rate sections.

Set-up, field conditioning, and applications: For the water run application, low elevation drop nozzles (ca. 5ft from ground level) were retrofitted by Windflow Fertilizer Inc. (WFI) to tower rows 1, 3, and 7. The drizzle boom assembly was positioned at tower rows 2, 4, and 5. Towers rows 6, 8, and the corner catcher (row 9) were capped off for subsequent Sectagon 42 ground application by tractor-drawn shank injection. Enough water was applied to bring the entire field test sections to ca. 70-80% moisture content before conducting the fumigation treatments. The drizzle boom-water run center pivot chemigation was completed by WFI one-day before conducting the shank application. During the center pivot application, line pressure was carefully monitored for sections “A” through “I” (Figure 2) to assure even Sectagon 42 application rate coverage at either 20, 40, or 60 GPA. Figure 3 shows center pivot water run-drizzle boom operations during the fumigation period.

Figure 3: Sectagon 42 Center Pivot Application

Shortly after completion of the field center pivot chemigation, tractor drawn shank injections at 20, 40, and 60 GPA were performed by Crop Production Services to a depth of ca. 9 inches within tower rows 6, 8 and 9 (catchment area) according to the "A" to" I" section rates in Figure 2.

Soil borne pathogen soil assays: Pre-fumigation (October 2009) and post-fumigation soil cores (March 2010) were taken and segregated into two soil depths (0-12 and 12-24 inches) then composited from each of the ninety treatment plots by OSU HAREC and WSU staff. The composited soil core samples were transported OSU HAREC and are awaiting determination.

RESULTS AND DISCUSSION:

2008-2009 Single Application Rate Efficacy Evaluation:

OSU-HAREC Soil borne pathogen soil assays: Below is reported colony forming units (CFU) and statistical treatment from composited soil samples for the three application treatments.

		Pythium CFU		Fusarium CFU		Verticillium CFU	
Treatment	Sample Depth	Pre	Post	Pre	Post	Pre	Post
Drizzle boom	12	62 a	45 a	2201 a	1073 a	9 a	18 a
	24	24 b	18 a	1003 b	596 a	3 b	3 a
Shanked	12	47 a	39 a	2794 a	1687 a	2 a	4 a
	24	16 a	20 a	1440 a	824 b	1 a	3 a
Water Run	12	57 a	13 a	2804 a	2295 a	5 a	13 a
	24	22 b	5 a	861 b	492 b	5 a	2 a

Values in columns within treatments followed by the same letter are not significantly different; P<0.05.

Pythium and *Fusarium* CFUs were present in pre and post fumigation in treatments and at the two depths investigated. Although there were some observed differences with depth within treatments, there were no strong significant differences observed among the treatment applications. Low observed *Verticillium* counts both pre and post fumigation makes it problematic to draw conclusions regarding differences with depth or among treatment applications.

OSU-HAREC Yield and grade assessments: Below are the yield and specific gravity for potatoes collected from the three application treatments (n=3 for each treatment).

		Yield (lbs)					
Treatment	Specific Gravity	Under 4 oz	Culls/ 2's	4-8 oz	8- 12 oz	Over 12 oz	Total Yield
Drizzle Boom	1.082	20.9	5.7	57.6	42.1	33.7	159.9
Shanked	1.084	18.8	9	49.3	39	32.9	148.8
Water Run	1.082	22	6.7	55.3	41.9	25	150.8

There were no observed significant differences ($p < 0.05$) in total yield, size, and specific gravity among the application treatments.

WSU-Plant Pathology visual plant evaluations: There was gradual increasing emergence of early die syndrome (random plant necrosis) towards the center of the pivot. The necrosis was not bounded by treatment boundaries and was measurable within the three closest tower plots to center of the pivot (Block A: 1S, 2WR, 3DB) and around the one distal plot (8 SE) on the opposite side of field (see Figure 1). Covariant analysis was used to weight data for this necrotic factor (5-15%). All treatments had increased incidence and severity of disease within these necrotic areas. Overall there was not a strong presence of disease within the treatments. There were no significant differences ($P=0.05$) between methods of application for the incidence and severity of sclerotia on potato stems for black dot (*C. coccodes*) or Verticillium (*V. dahliae*). Except for some necrosis proximal to center of pivot the canopy was physiologically young at harvest, which would have reduced expression of disease in stems compared to what would have been obtained later in the season, just before or at senescence.

On-going 2009-2010 Multiple Application Rate Efficacy Evaluation:

To complete this work, plant observations will be conducted as before by WSU Pathology with harvest/yield and soil assays being conducted in fall 2010 by OSU HAREC. WSU-FEQL will oversee the completion of this 2-year study with outputs in the form of an informational extension bulletin. This bulletin will address the comparative efficacy of conventional water run to reduced emission technologies to aid growers when deciding on application practice and product rate.

Acknowledgements:

This proceeding represents an on-going collaboration to provide regionally specific application-based metam sodium efficacy information. Special thanks must go to many for providing their continued *in-kind* support. Particularly, we wish to thank Ed Schneider of Schneider Farms for donating use of his land-chemigation equipment for two planting seasons, Monte Spence and his crew at WindFlow Fertilizer for retrofitting, center pivot drizzle boom operations/mult-application rate oversight, Jim Ossman and his group at Crop Production Services for their efforts in performing shank application. We also wish to express our thanks to

Jim Owens and Kurt Volker from Tessenderlo Kerley for product support and field oversight for the 2008 and 2009 field efficacy demonstrations.

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Defining In-Season Nitrogen Management Needs for Alturas and Premier Russet

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Managing nutrient inputs properly, especially nitrogen (N) is essential for maximizing tuber quality and yield (Rowe 1993). Improper N management can significantly compromise yield and quality (Rowe 1993). Insufficient N can lead to reduced growth (Harris 1992), reduced light interception, limited yield (Chase et al. 1990; Laurer 1986; Munro et al. 1977; Santerre et al. 1986; White et al. 1974) delayed tuber set (Harris 1992), reduced dry matter content (Love et al. 2005; MacKerron and Davies 1986; McDole 1972; Painter and Augustin 1976; Westermann et al. 1994; Yungen et al.1958) and an increase in diseases such as early die, late blight, and Verticillium wilt (Davis et al. 1990; Rowe 1993). In contrast, excess N may reduce tuber N uptake efficiency, delay tuber initiation (Westermann and Kleinkopf 1985), and promote overgrowth of vines which can reduce the effectiveness of vine desiccants (Pavlista and Blumenthal 2000) and create a humid environment that promotes diseases associated with moisture such as aerial stem rot, Sclerotinia stem rot, pink rot, and other foliar and tuber diseases (Rowe 1993). Excess N may also affect storability (Long et al. 2004) and have adverse environmental effects such as groundwater run-off and leaching (Rowe 1993), which increases the risk of environmental pollution.

In light of the importance of N management, there is considerable need in the potato industry for cultivar specific N recommendations that reduce excess N applications while returning maximum economic value to the grower. Standard industry fertilization practices for potato are generally driven by published regional fertilization guidelines. However, these guidelines are often based on the nutrient requirements of the well-studied Russet Burbank cultivar (Kleinkopf and Westermann 1986; Lauer 1986; Roberts and Dow 1982; Roberts et al. 1982; Rykbost et al. 1993; Westermann and Kleinkopf 1985; Westermann et al. 1988), which has demonstrated maximum yields with applied N rates from as little as 45 kg ha^{-1} following red clover (*Trifolium pratense* L.) to as much as 400 kg ha^{-1} (Lauer 1986; Porter and Sisson 1991*b*). Different potato cultivars have unique morphological, physiological and developmental characteristics that may differ from Russet Burbank in response to N fertilization (Arsenault et al. 2001) and as such may differ in their N requirements. Therefore, fertilizing cultivars other than Russet Burbank with typical Russet Burbank rates may not be the most effective strategy. In addition to being of limited value when a cultivar other than Russet Burbank is being produced, regional guidelines are rarely accompanied by a thorough economic analysis. Economics take into account the price/cost ratio of N fertilizer and potato value in a particular year and help quantify the true efficiency of a grower's fertilizer regime. Nitrogen affects a number of key processing characteristics in potato that directly relate to economic return. Processing contracts include economic penalties and incentives for processing parameters such as tuber size, internal and external quality, and specific gravity, all of which can be affected by N (Knowles et al. 2009). Without examining the economics related with a particular N rate, a grower is not getting the whole picture. To further complicate the issue, N recommendations in potato are generally performed with the main goal of maximizing total yield. However maximum biological yield does not always equate to maximum economic yield (Pavek and Holden 2008) and there may be a large disparity between the two. Thus, a grower fertilizing a new cultivar in accordance with standard Russet Burbank fertilization practices may be compromising yield, quality, and net income.

The recent release of two new cultivars from the Tri-State Breeding Program and the USDA/ARS, Alturas and Premier Russet (Premier), has necessitated the development of appropriate in-season N fertilizer recommendations tailored to each cultivar. The reported research examines in-season N rates that are associated with maximum economic return and tuber quality for these two cultivars with the following specific objectives: 1) assess a new research method for N application that closely mimics commercial fertigation and allows for a large number of treatments, 2) develop a cultivar-specific understanding of N response as it relates to yield, quality, and economics of these cultivars, 3) define specific petiole and soil critical concentrations for each cultivar for maximum economic returns and 4) increase grower bottom line.

MATERIALS AND METHODS

This experiment was conducted at the WSU Othello Research Station in Othello, WA, on a Shano silt loam during the 2007 through 2009 growing seasons. Each cultivar was planted in a randomized complete block design with five-row plots, 25 ft long, with 5 ft borders and 10 inch spacing between plants. Plots were treated with five in-season N rates: 0%, 25%, 50%, 100%, and 150%. Treatments are expressed as a percentage of the current in-season N recommendations for Russet Burbank. All treatments received the same pre-plant fertilizer during a particular year. Pre-plant, in-season and total season N rates and associated in-season N expense are shown in Tables 1-4.

In-season N (UAN-32) was applied weekly between 50 days after planting (DAP) and 100 DAP via a custom designed fertigation simulator that delivered 0.15 in. of water (Figure 1; Table 3). Petioles were collected weekly from center data rows between 60 DAP and 120 DAP and soil samples were collected bi-weekly at one and two foot levels. Hand digs were initiated at 70 DAP and performed every eighteen days. Data on stem number, tuber number, vine weight, tuber weight and tuber number were collected. At the end of the season, tubers were harvested via a two row digger and graded and sized using a custom two lane electronic sizer. An economic evaluation was performed on both cultivars via a mock processing contract modeled after contracts currently in use in the Columbia Basin.

RESULTS

Petiole and Soil Nitrogen Trends

Treatment differences were evident and distinct in the petiole NO_3-N analyses for both cultivars, especially as each season progressed (Fig. 2). As expected, increasing N rates typically led to increased N concentration in the plant tissue and the soil (Fig. 2) throughout the growing season. Petiole differences were evident within ten days of the first in-season application across all years for both cultivars. As N applications began for both cultivars, petiole values typically climbed and eventually peaked between 70 and 80 DAP. Following the peak, petioles declined steadily as the season progressed. For both cultivars, treatment differences in soil N were not as defined or obvious as with the petioles (Fig. 3). Often, the soil N levels appeared to reflect the rates being applied. Occasionally, however, the soil values from the treatments intertwined and trends were not clear. During mid to late season, the highest N rate could typically be resolved from the other treatments, with soil values far in excess of the other treatments.

Vine Weights, Senescence and Harvest Index

The effects of N became somewhat apparent within 10 days after the first in-season N application. The two highest N treatments of both cultivars typically started to develop the heaviest overall canopy weights, which continued throughout most of the season (Fig. 4). Vine weight differences between the lowest three N rates, and occasionally all N rates, were not always apparent. For the most part, however, the 0% treatments of both cultivars produced the lowest vine weights. As the season progressed, fresh vine weights of Premier typically peaked close to 100 DAP while Alturas vine weights appeared to have peaked 20 to 40 days later. Although the vine weights did not always appear to correlate with the in-season N treatments, the differences between the lowest and highest treatments were typically quite pronounced and indicated that much of the additional N available to the plants in the high N treatments was directed toward vine production in both cultivars. Beyond 100- to 120-DAP, vine weights across most treatments of both cultivars began to decline due to the onset of natural vine senescence, suggesting a changing source/sink relationship between the vines and tubers.

In-season N rate substantially affected the harvest index for both cultivars across years (Fig. 5). By the time foliar weight had peaked during the season, those plants receiving lower N rates had partitioned more fresh weight to tubers than plants receiving higher amounts of N. In essence, plants receiving less N favored tuber production and plants receiving virtually unlimited N favored vine production as a percentage of whole-plant fresh weight at this point in the growing season.

When vine senescence was regressed against N rate, highly significant non-linear trends were revealed (Fig. 6). Lush growth was seen across all Alturas treatments for most of the year during 2009. As a result, the trend that existed in the previous years was not seen, and treatments were not different at 140 DAP (data not shown).

Tuber Quality and Specific Gravity

In-season N rate did not significantly affect blackspot bruise, stem end discoloration, shatter bruise, hollow heart, internal brown spot, length-to-width ratio or brown center (data not shown). Overall, incidences of these tuber defects were very low with the exception of shatter bruise in Premier. Though treatments were not statistically different, Premier appeared to be genetically susceptible to shatter bruise averaging 70%, 77%, and 88% in 2007, 2008, and 2009, respectively, across all treatments.

Tuber specific gravity was highly correlated with N rate for both cultivars across all years (Fig. 6), with the exception of Premier in 2009 (data not shown). Specific gravity increased as in-season N rate decreased. Because there were highly significant trends during the previous years for both cultivars, it is plausible that climate and/or field variability during 2009 complicated the otherwise typical specific gravity x N rate trend seen in Premier (data not shown). Relative to the mock processing contract parameters, the specific gravity values for all treatments of both cultivars were well within the range where the maximum incentives could be achieved.

Stem Number, Tuber Number, and Average Tuber Weight

Stem and tuber number per plant were not significantly different across treatments and years for either cultivar (data not shown). Stem number averages across three years were 2.5 stems per plant for Premier and 3.04 stems per plant for Alturas.

Total Tuber Yield and Size Distribution

In-season N levels had a significant and substantial affect on total tuber yields in both cultivars in all years of the study. As in-season N rates increased, total yield of both cultivars increased in a highly significant non-linear trend (Fig. 6). Alturas maximum yield occurred when the highest rate of N was applied (approximately 355 lbs in-season N/A). Premier total yield peaked at 123% (approximately 295 lbs in-season N, Fig. 6). The difference in total yield between the 0% and 100% treatment of Premier was approximately 100 CWT/A. Based on the decline in total yield beyond 123%, it appears as though excess N did not contribute to a corresponding yield response in Premier. Total yields in both cultivars were substantially lower in 2008 than in 2007 or 2009 (data not shown).

In-season N level influenced tuber size distribution for both cultivars across all years. Significant correlations were obtained when market yields of >4 oz (data not shown) and >6 oz (Fig. 7) tubers were regressed against in-season N. The trends and responses to applied in-season N were similar for both cultivars, differing only in the amount of in-season N required to reach maximum yields in the size categories examined.

For Alturas, maximum yields of marketable tubers >6 oz peaked, at 160% of the typical in-season N rates (384 lbs in-season N/A, Fig. 7). >12 oz tubers peaked at 120% of the typical Russet Burbank in-season rate (approximately 288 lbs N/A; Fig. 7). In Premier, yield of tubers >6 oz reached a maximum at 108% (259 lbs in-season N/A, Fig. 7). Maximum yield of >12 oz tubers occurred at 117% of typical Russet Burbank in-season rates (Fig. 7).

Economics

With the exception of Premier in 2007, adjusted gross processing income reached a maximum at in-season N rates at, or slightly above, the 100% rate (Fig. 7). Too much N (150%) was typically detrimental to the grower's bottom line (Fig. 7). In Alturas, revenue was optimized at 108% of the typical in-season N rate (259 lbs in-season N/A) and Premier revenue was optimized at in-season N rates of 100% (240 lbs in-season N/A). During 2007-09 in Alturas and 2008-09 in Premier, the marginal revenue gains from in-season N declined as the total amount of N increased beyond the maximum. Beyond the optimal rates of 108% for Alturas and 100% for Premier, additional in-season N only served to reduce revenue, despite any marginal gains in yield. Adjusted gross income was maximized at the various rates for both cultivars due to a mix of optimizing incentives within the processing contract, producing relatively high market yields, and minimizing N expense per unit of production. Importantly, the economic analyses for both cultivars demonstrated that maximum biological yield was typically not synonymous with maximum economic yield.

Nitrogen response patterns were established for both cultivars by dividing the total yield (tons/A) associated with the N rate that provided maximum economic returns (423 lbs total season N for Alturas and 392 lbs total season N for Premier) by the pounds of N required to reach that yield. Both cultivars required 11 pounds of total season N/A to produce one ton of fresh tuber weight.

DISCUSSION

Current Columbia Basin nutrient guidelines recommend optimum petiole NO_3-N values for Russet Burbank of 1.5 to 2.6%, 1.2 to 2.0% and 0.6 to 1.0% during tuber initiation (45-60 DAP), tuber bulking (60 DAP), and tuber maturation (120 DAP), respectively (Lang et al. 1999). The petiole values from the 100% treatment of both cultivars were typically within these recommended Russet Burbank ranges, while the 150% treatment values were significantly higher for much of the season. Similar to the 100 and 150% treatment, the reduced N treatments (0%, 25%, and 50%) produced petiole NO_3-N levels that appeared to be largely dose-dependent. Petiole values from these treatments fell in line with the lowest in-season N producing the lowest overall petiole levels. According to Pavek and Holden (2008), petiole NO_3-N concentrations for Alturas and Premier typically exceed those of Russet Burbank early to mid season but track closer to Russet Burbank mid to late season. They also found that Alturas petiole levels tend to be similar or slightly above Russet Burbank's near the end of the season while Premier's petiole NO_3-N values are typically lower.

Tested and proven previously by Pavek and Holden (2008), the fertigation simulator appeared to be an extremely effective method for testing the five water-applied fertilizer treatments, as evidenced by the distinct petiole and soil trends among treatments (Figs 2 and 3). The unique design allowed precise and accurate applications of in-season N and, similar to commercial potato production, utilized water as the fertilizer carrier. There is the potential to utilize the fertigation simulator for further research into water-applied pesticides, fungicides, and miticides in a variety of field crops outside of potatoes.

Both Alturas and Premier responded somewhat uniquely yet appeared to share a common trend relative to adjusted gross returns. Except for Premier in 2007, the adjusted gross returns for both cultivars followed the classic "law of diminishing returns" across all years; adjusted gross returns increased steadily as in-season N rates increased, eventually reaching a maximum (Fig. 7). Beyond this maximum, the marginal increase in yield was offset by a disproportional increase in N expense, resulting in a decline of adjusted gross returns. For Alturas, maximum economic yield was found at 108% of the typical in-season N rate for Russet Burbank (approximately 258-280 lbs/A in-season N, 405-410 lbs/A total season N, including residual and pre-plant). For Premier in 2008-09, maximum economic yield was achieved with 100% of the typical in-season Russet Burbank rate (approximately 240 lbs/A in-season N, 390 lbs/A total season N).

Alturas total yield from the 100% treatment was 756 CWT/A across years and total yield from the 150% treatment was 781 CWT/A, a difference of 25 cwt. Although the 150% treatment had higher total yields, the fertilizer-cost-adjusted base price/CWT after contract incentives/decentives was higher at the 100% treatment ($7.50/cwt at 150% vs $7.56/CWT at the 100% treatment), an increase of $0.06/CWT; N cost per acre was $54/A higher for 150% treatment than for the 100% treatment. To produce potatoes at the 150% rate, it cost more but returned less than at the 100% treatment. A closer look at the economics reveals that the proportion of 6 oz and greater tubers was higher at the 100% treatment than the 150% treatment (32% vs 29%) and the proportion of culls and tubers <4 oz was less at the 100% treatment than the 150% (12% vs 14%). Though these differences appear minute, the extra $0.06/CWT multiplied by a yield of 750 CWT/A translates into an extra $5,625 in processing contract incentives per 125 acre pivot.

Economics for Premier were quite similar to those of Alturas, with the exception that the 100% treatment in Premier had higher total yields than the 150% treatment (719 CWT/A vs 714

CWT/A, respectively). Similar to Alturas, the percentage of undersize tubers was less at the 100% treatment (7.56%) than the 150% treatment (7.92%) and the percentage of > 6oz tubers was higher at the 100% treatment (79%) than the 150% treatment (77%). This combination led to a contract-adjusted base price of $7.59/CWT at the 100% and $7.58 for the 150% treatment. For a standard sized pivot, the extra $0.01 incentive resulted in an $875 gain (per 125 acre pivot), illustrating again that a fractional shift in tuber size distribution can affect the growers bottom line. These data suggests that the appropriate amount of in-season N management is essential for producing tuber size profiles of maximum economic value.

Increasing N resulted in depressed specific gravities in both cultivars in a highly significant non-linear trend (with the exception of Premier in 2009; Fig 6). Although specific gravity decreased as N increased, the gravity values for both Alturas and Premier remained within the acceptable range for processing at all in-season N levels. This demonstrates that even at multiple levels of in-season N (0% and 150%), these cultivars will likely be eligible for specific gravity incentives.

Prior to the initiation of this study, it was common knowledge within the industry that many Alturas and Premier growers were applying 50% of the N typically (full season) used to produce Russet Burbank. It is now apparent that these growers may have been losing more than $250/A of potential profits in Alturas due to insufficient N. This equates to a loss of over $31,000 per average size center pivot (125 acres). Following the Columbia Basin guidelines for Premier (Novy et al. 2008), growers could have lost as much as $390/A in 2007 and $57/A in 2008-09 compared with the economically optimum rates determined in this study. The resulting loss in grower adjusted gross income could have been as high as $48,750 per pivot during 2007 and $7,125 in 2008-09.

Data from these experiments confirm the well known but often forgotten concept that maximum biological yield is not always the same as maximum economic yield. For potato growers growing a new cultivar for the first time, maximum economic return, as opposed to maximum yield, should be the most important consideration in determining optimum fertilizer rates (Love et al. 2005). An understanding of a cultivar's nitrogen response pattern (lbs of N required to produce each unit of yield) and how it relates to economics is an important contributor to maximum economic return and should also be evaluated when considering growing a new cultivar. Cultivars can vary significantly in the amount of N required per unit of final yield and N costs related to production will vary as well. For example, a study by Pavek and Holden (2008, unpublished) showed that Alturas was 26% more efficient in nitrogen use (yield per pound of N required) than Russet Burbank while Premier was 13% more efficient. Indeed, maximum total yields for Alturas and Premier were obtained with 150% and 125% of the typical Russet Burbank in-season N rate, respectively. For both cultivars, however, *revenue* was generally optimized at a rate closer to 100% of typical for Russet Burbank. In addition to revenue loss from the costs associated with higher N rates, some reduction in economic return came from a shift in tuber size profile. Contract incentives were reduced on yields from the higher N rates because there were fewer tubers within the desirable size range (6-12 oz). This is of special concern to producers who enter into processing contracts with deductions for oversize tubers.

. In order for Columbia Basin growers to minimize risk and maximize returns when producing Alturas and Premier, we recommend that petiole and soil N concentrations be maintained within the ranges found in Tables 5 and 6. These values were established following a detailed review of data from all years for both cultivars with the goal of finding ranges that were relatively low-risk, yet profitable. Due to all the different elements involved in crop production, it is difficult to recommend a specific N fertilizer regime that will work for all growers across all situations and seasons. Soil type, organic matter content, previous crop residues, weather and other factors all affect N availability; producers may find they can apply less N than levels found in this study and still produce profitable yields. However, coarse textured soils, prevalent in many parts of the Columbia Basin, may require slightly higher rates of N if leaching is prevalent. In addition, as input costs and potato prices changes the amount of in-season N required to maximize profits may change.

By utilizing the recommended petiole NO_3-N and soil N ranges, growers can adjust their inputs as needed for each situation, thereby maintaining plant growth and health that is necessary to produce a profitable crop. It is essential for growers to keep all other nutrients at appropriate levels, according to Columbia Basin Russet Burbank recommendations (Lang et al. 1999). Although it may be possible to make a profit with in-season N rates and petiole and soil values lower or higher than those found in this study, our intent was to identify N management that would lead to the maximum economic yields for these cultivars. As with any research and crops, these recommendations may be modified in the future as the management of these two cultivars becomes better understood.

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Figure 1. Chemigation simulation unit applying in-season fertilizer treatments on the Othello Research station.

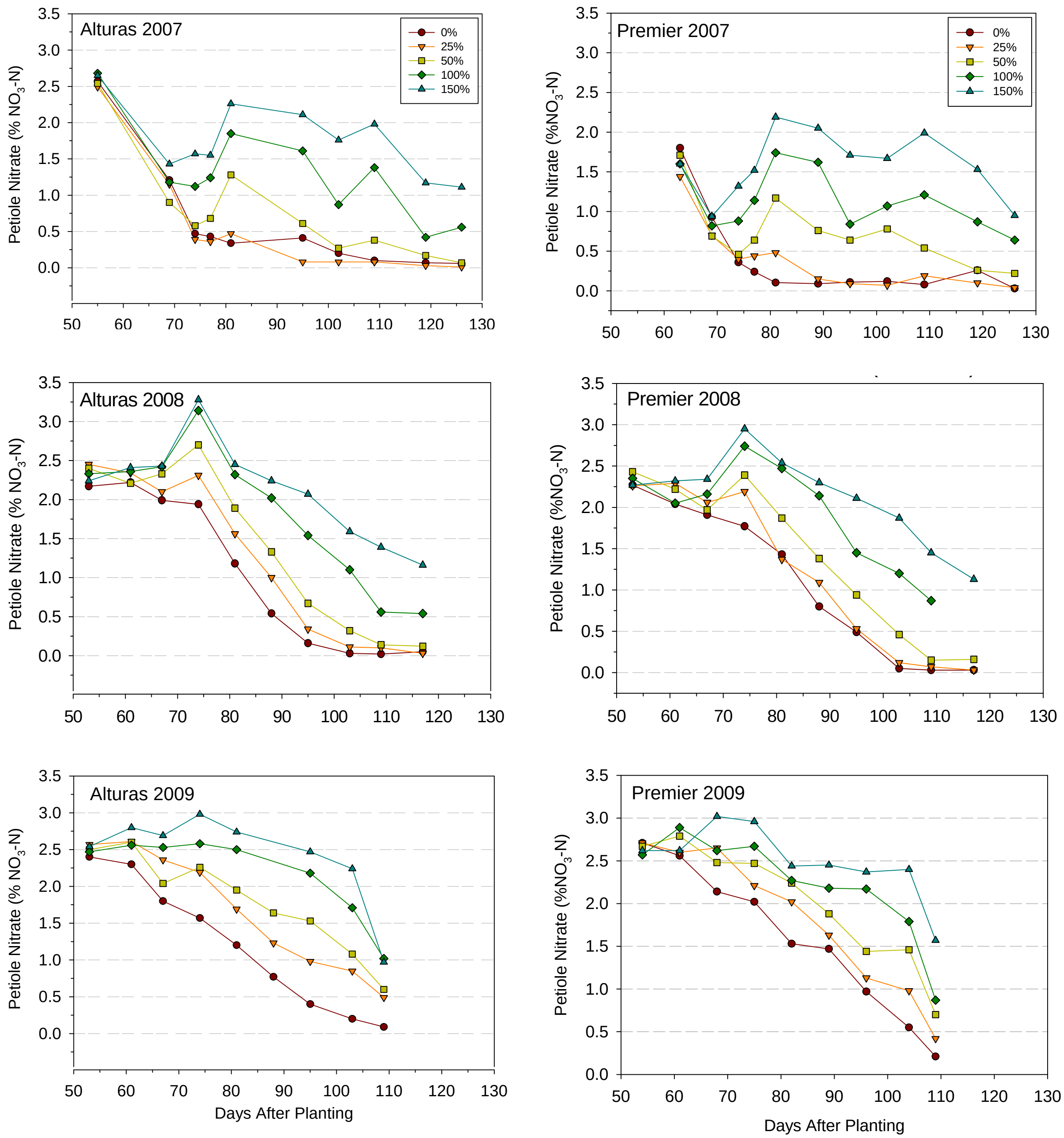

Figure 2. Alturas and Premier petiole NO_3-N trends across 5 different in-season N rates for 2007-09.

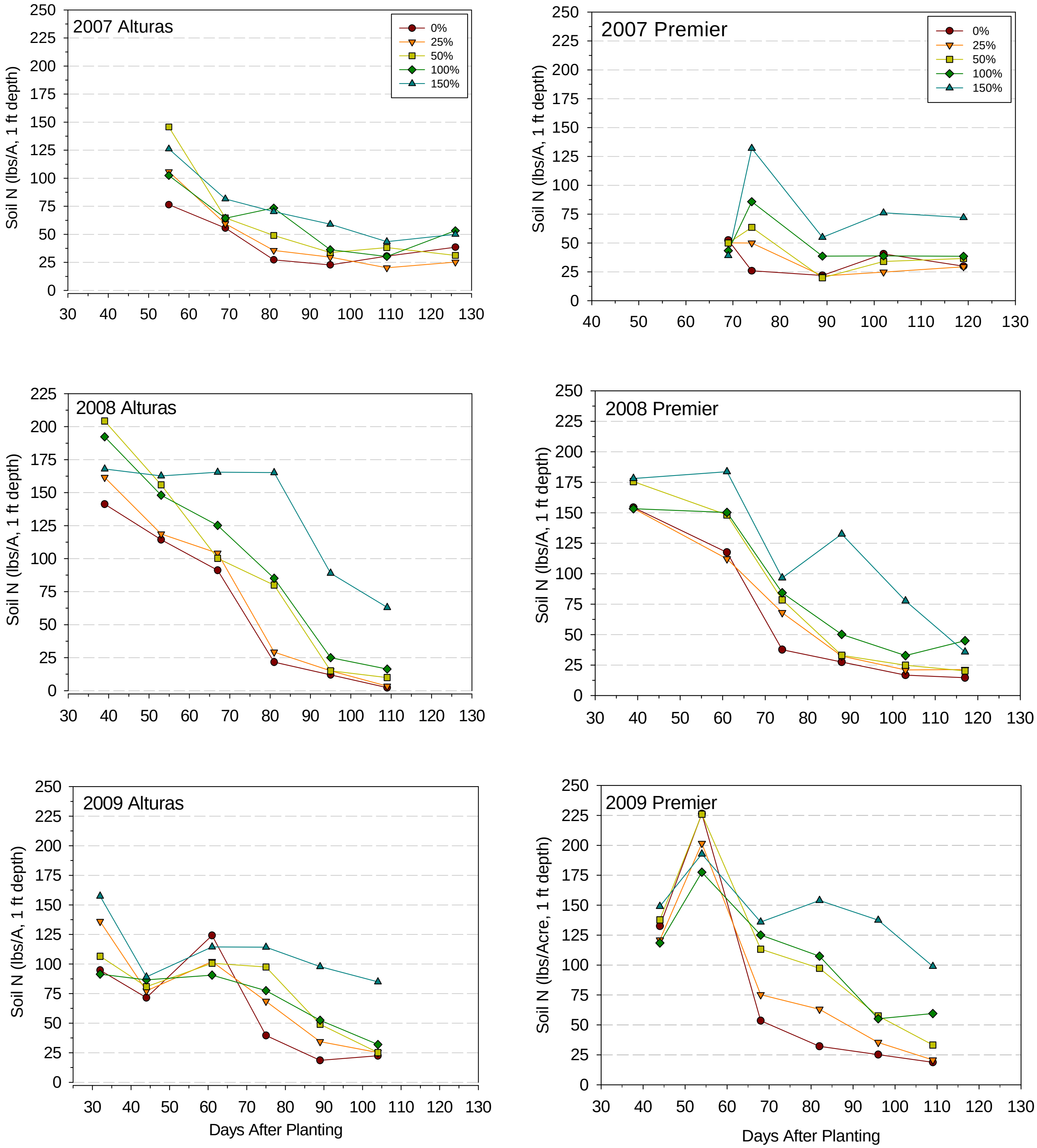

Figure 3. Alturas and Premier soil total N (NO_3 + NH_4) levels across five different in-season N treatments during 2007-09.

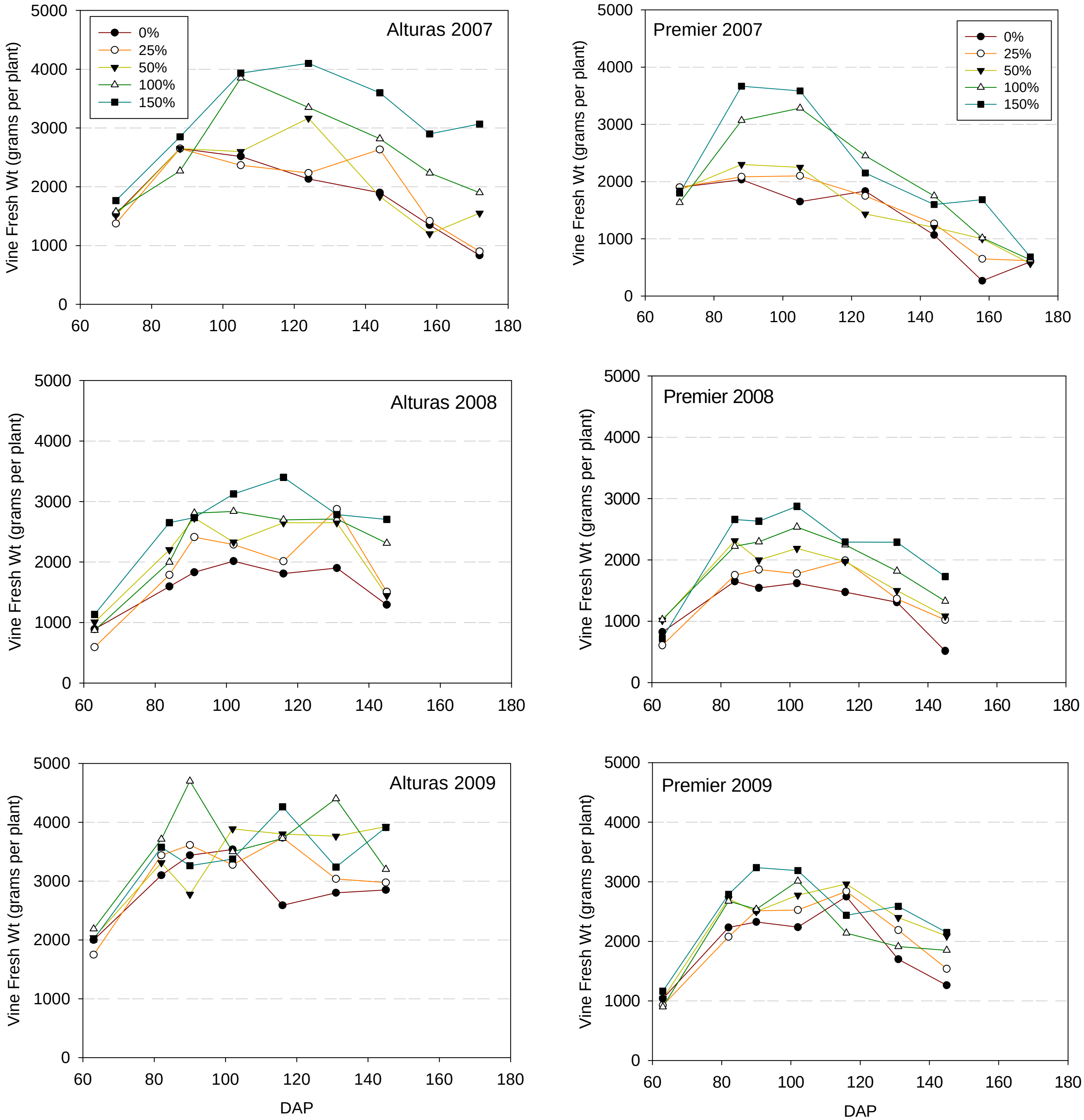

Figure 4. Alturas and Premier fresh vine weights across the growing season for five different in-season N rates during 2007-09.

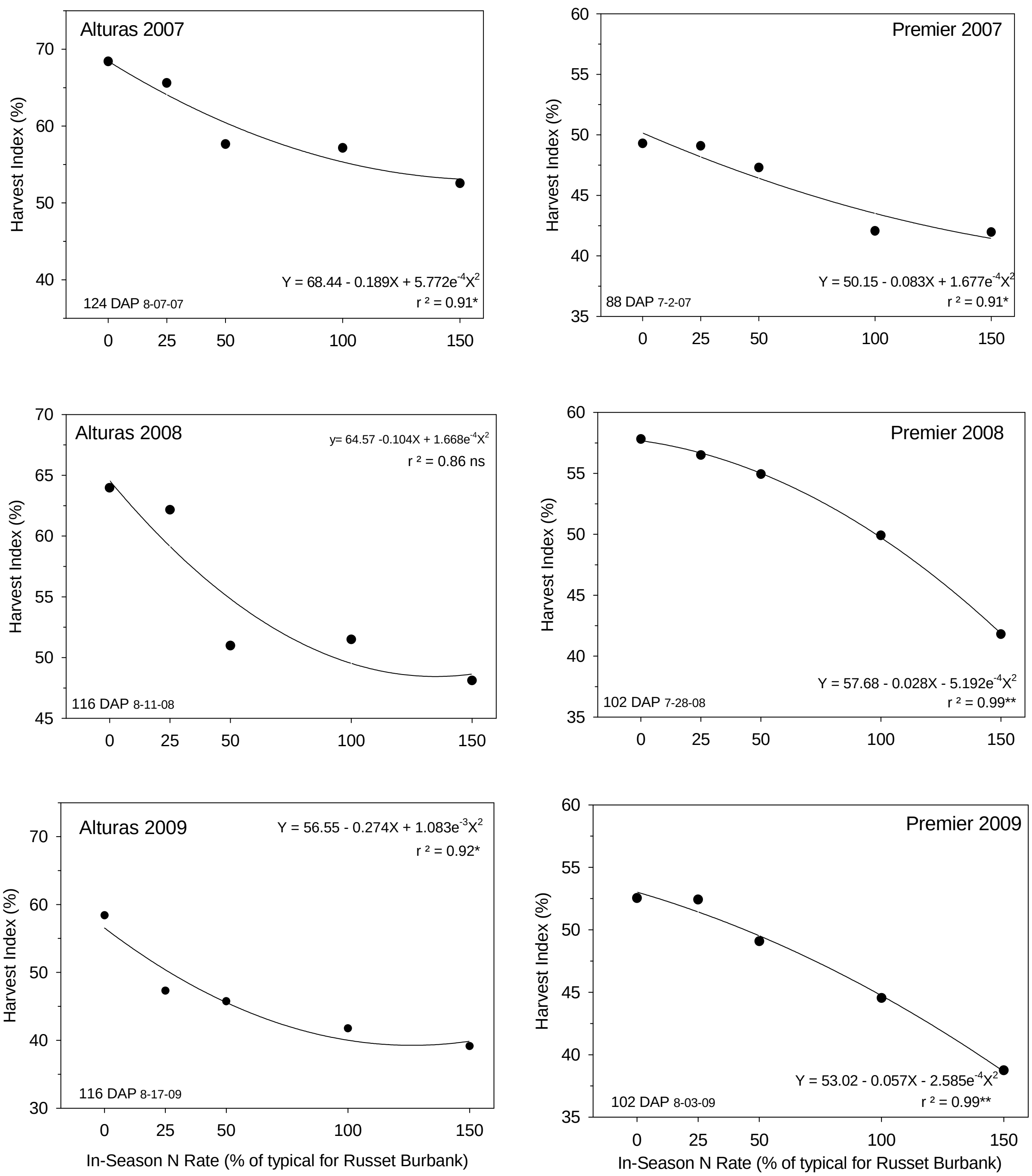

Figure 5. Alturas and Premier harvest index (calculated as tuber weight/tuber weight + above ground-fresh plant weight x 100) at 124 DAP (2007) and 116 DAP (2008-09).
*, **, ***, ns: significant at P ≥ 0.05, 0.01, or 0.001 respectively, or non-significant.

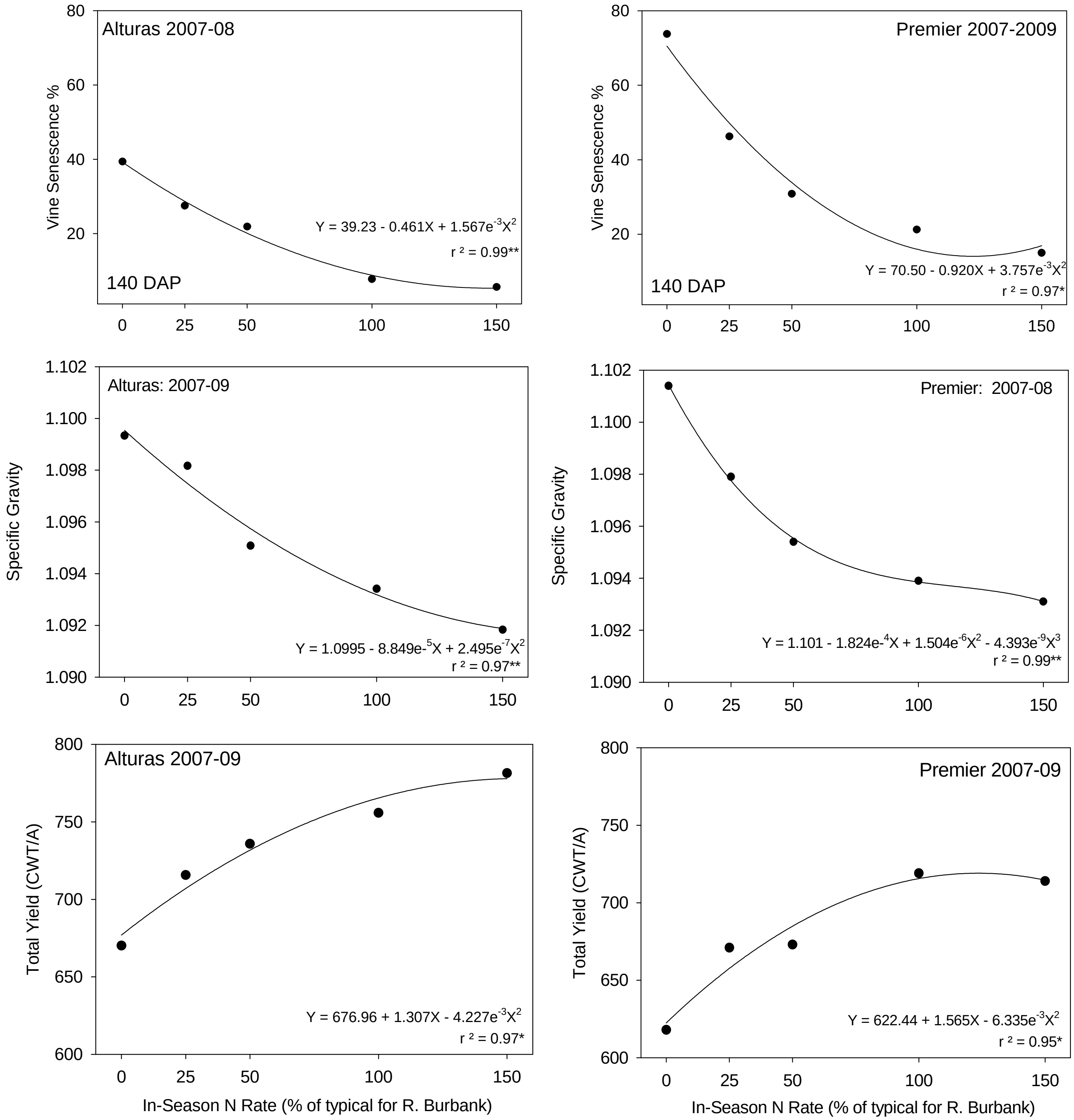

Figure 6. Vine senescence, specific gravity and total yield for Alturas and Premier across five in-season N rates in 2007-09. Data on vine senescence for Alturas in 2009 and specific gravity for Premier in 2009 were non-significant.
*, **, ***, ns: significant at P ≥ 0.05, 0.01, or 0.001 respectively, or non-significant.

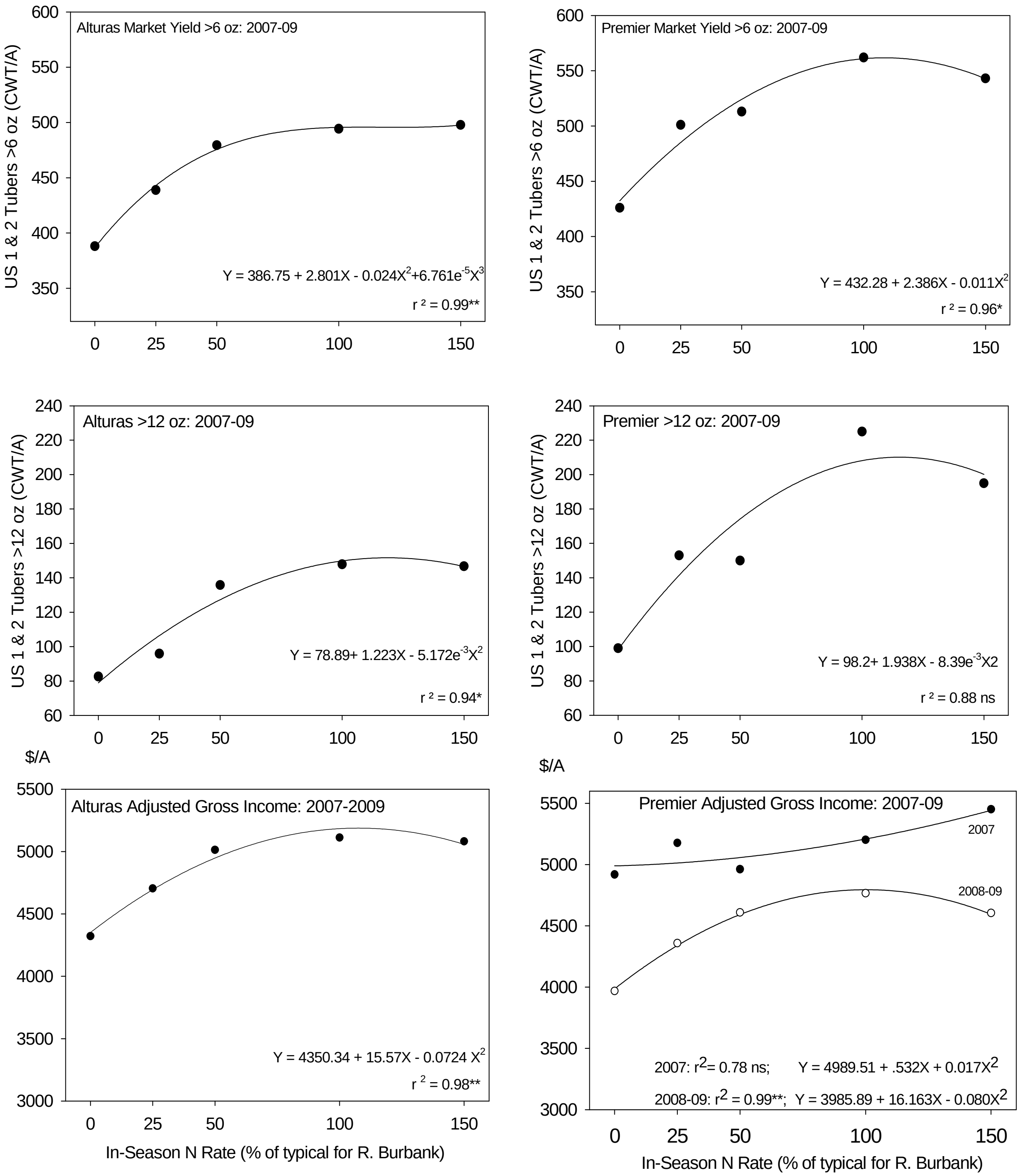

Figure 7. US 1 and 2 tubers greater than 6 and 12 oz and nitrogen-cost adjusted gross income for Alturas and Premier during 2007-09. The economic evaluation was based on a mock processing contract modeled after contracts currently in use in the Columbia Basin of Washington and Oregon with the cost of N set at \$0.44/lb.
*, **, ***, ns: significant at $P \geq 0.05$, 0.01, or 0.001 respectively, or non-significant.

Table 1. Preplant, in-season, and total season nitrogen for 2007 and associated in-season N expense for five rates of in-season N applied to Premier and Alturas

Treatment As a % of Standard RB Rate	Applied Pre-plant N + Soil Residual[a]	Measured At-Emergence Soil N[b]	Applied In-Season N	Applied In-Season N Via Phos Applications	Total Applied In-season N	Total N Applied in 2007	In-season N Fert Expense ($0.44/lb)
%	--			lbs/A		--	$/A
0	125	127	0	30	30	155	0
25	125	127	58	30	88	213	23
50	125	127	115	30	145	270	46
100	125	127	230	30	260	385	92
150	125	127	345	30	375	500	138

[a]Soil residual values derived from a composite of twenty, 1 ft soil samples across trial location prior to planting; urea application (75 lbs/A) plus soil N (NO_3-N 8 lbs/A, NH_4 42 lbs/A) = 125 lbs/A.
[b]At-emergence soil N values derived from 120, 1 ft soil samples across trial location upon >90% plant emergence (NO_3 100 lbs/A, NH_4 27 lbs/A).

Table 2. Preplant, in-season, and total season nitrogen for 2008 and associated in-season N expense for five rates of in-season N applied to Premier and Alturas

Treatment As a % of Standard RB Rate	Applied Pre-plant N + Soil Residual[a]	Measured At-Emergence Soil N[b]	Applied In-Season N	Applied In-Season N Via Phos Applications	Total Applied In-season N	Total N Applied in 2008	In-season N Fert Expense ($0.44/lb)
%	--			lbs/A		--	$/A
0	152	168	0	9	9	161	0
25	152	168	58	9	67	219	23
50	152	168	115	9	124	276	46
100	152	168	230	9	239	391	92
150	152	168	345	9	354	506	138

[a]Soil residual values derived from a composite of twenty, 1 ft soil samples across trial location prior to planting; urea application (80 lbs/A) plus soil N (NO_3-N 24 lbs/A, NH_4 48 lbs/A) = 152 lbs/A.
[b]At-emergence soil N values derived from 120, 1 ft soil samples across trial location upon >90% plant emergence (NO_3 159 lbs/A, NH_4 9 lbs/A).

Table 3. Preplant, in-season, and total season nitrogen for 2009 and associated in-season N expense for five rates of in-season N applied to Premier and Alturas

Treatment As a % of Standard RB Rate	Applied Pre-plant N + Soil Residual[a]	Measured At-Emergence Soil N[b]	Applied In-Season N	Applied In-Season N Via Phos Applications	Total Applied In-season N	Total N Applied in 2009	In-season N Fert Expense ($0.44/lb)
%	--			lbs/A		--	$/A
0	152	171	0	10	10	162	0
25	152	171	58	10	68	220	23
50	152	171	115	10	125	277	46
100	152	171	230	10	240	392	92
150	152	171	345	10	355	507	138

[a]Soil residual values derived from a composite of twenty, 1 ft soil samples across trial location prior to planting; urea application (90 lbs/A) plus soil N (NO_3^- 30 lbs/A, NH_4^+ 32 lbs/A) = 152 lbs/A.
[b]At-emergence soil N values derived from 120, 1 ft soil samples across trial location upon >90% plant emergence (NO_3 163 lbs/A, NH_4 8 lbs/A).

Table 4. Rate scheme for five in-season N rates for 2007-2009

Treatment as a % of RB standard	Number of Applications*			
	Two	Four	Two	Two
%	----------------------------N lbs/A----------------------------			
0	0	0	0	0
25	5	7.5	6	3
50	10	15	13	5
100	20	30	25	10
150	30	45	38	15

***Applications started approximately 10 days after >90% emergence**

Table 5. Recommended petiole values at 60-, 90-, and 120-days after planting (DAP) for Alturas and Premier Russet.

Variety	End Tuber Initiation Mid June 60 DAP	Mid Bulking Early July 90 DAP	Late Bulking Late July 120 DAP
	(ppm NO3)	ppm (NO3)	(ppm NO3)
Alturas	23-26,000	17-20,000	<8,000
Premier	23-26,000	17-20,000	<10,000

Table 6. Recommended total soil N values (N03-N + NH4) at 60-, 90-, and 120-days after planting (DAP) for Alturas and Premier Russet in the top 12".

Variety	End Tuber Initiation Mid June 60 DAP	Mid Bulking Early July 90 DAP	Late Bulking Late July 120 DAP
	(lbs/A)	ppm (NO3)	(ppm NO3)
Alturas	90-150	50	<50
Premier	90-150	50	<50

Effect of Plant Stress on Development of Potato Black Dot

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Roots, stolons, tubers, below ground stems and foliage of potato are all infected and colonized by the soil borne fungus *Colletotrichum coccodes.* Infected tissues characteristically develop small black sclerotia as they senesce, giving the name 'black dot' to the disease on infected potato plants. Black dot is common in most potato growing areas in the world and may cause up to 30% yield reduction.

In the Columbia Basin of central Washington, *C. coccodes* can be isolated relatively early in the growing season from below- and above-ground potato stems and from a high proportion of plants by mid-season. Stem infections are initially latent in that disease symptoms often do not become evident until late in the growing season and sclerotia generally do not develop until plants begin to senesce and die. Leaves low in the canopy on infected plants may turn chlorotic and drop before plant senescence. Initial infections are latent, but the fungus rapidly expands within stem tissues during senescence and also during times of plant stress. The internal colonization of stems has a greater affinity towards the roots, stolons and tubers than towards the foliage.

Infection of potato plants by *C. coccodes* can be caused by soil-borne, tuber-borne or air-borne inoculum. Soil-borne and tuber-borne inocula are the main inoculum sources in the Columbia Basin. Soil-borne inoculum has recently been shown to have a greater disease-causing potential than tuber-borne inoculum. Air-borne infection may be an important contributor to the initial development of the disease. A high potential for foliar infection is present in the Columbia Basin because wounds from blowing sand provide entry avenues for the fungus and sprinkler irrigation may disseminate conidia and sclerotia via splashing, and contribute the needed moisture for inoculum germination and infection.

Potato roots and stolons are susceptible to infection from soil-borne inoculum. Lesions on below-ground plant parts may resemble those caused by Rhizoctonia. The cortical tissue is invaded causing a sloughing of the periderm. As stems dry, cortical tissue is easily scaled away and an amethyst color may be common inside the vascular cylinder. Sclerotia develop in infected tissues. Lesions develop on foliage from air borne inoculum and are dark brown to black and similar in appearance to early blight, except concentric rings within the lesion do not develop. Infection of potato tubers by *C. coccodes* results in the development of lesions on the tuber surface, characterized by the production of small, black sclerotia. Symptoms are commonly observed at the stem end of the tuber and the lesions can appear silvery to brown, generally with a poorly defined margin. In contrast, silver scurf lesions are silver, with a clearly defined margin. Confirmation of these two diseases requires examining tubers with a hand lens or microscope to observe the characteristic black sclerotia of black dot, or conidia (spores) of *Helminthosporium solani*, the causal agent of silver scurf.

Effect of Rotation on Incidence of Black Dot

The black dot fungus can be initially isolated from tubers in the field when tubers are about 3 inches in diameter. Incidence of tubers with the black dot fungus increases as the growing season progresses (Fig. 1). In a study in 2009, detection of the black dot fungus increased sharply at approximately 130 days in field. Black dot symptoms were not present on tuber's periderm collected from the field before tuber maturation, indicating that the tubers were latently infected in the field. In studies in the Columbia Basin the 2008 and 2009 growing seasons, incidence of black dot significantly decreased as the number of years between potato crops increased (Figs. 2, 3, 4). A sharp decline in incidence of black dot occurred at three years out of potato production (Fig. 3 & 4). Black dot and silver scurf decreased 10% and 6%, respectively, per increasing year between potato crops (Fig. 3). The black dot fungus was detected in fields out of potato for 10 and 15 years, but incidence of detection of the fungus was generally low after 6 or more years out of potato production (Figs. 2, 3, 4). Black dot also significantly increased as the number of previous potato crops increased (Fig. 5). Both factors, years between potato crops and number of previous potato crops, accounted for a large proportion of disease incidence for black dot ($P < 0.0001$, $R^2 = 0.87$) with multivariate analysis. Weed hosts may account for long term persistence of the fungus in soil.

Effect of Nutrient Stress on Black Dot Development

Plant stress from nutrient deficiency increases colonization of potato roots by the black dot fungus. In recent experiments, Russet Burbank plants produced in tissue culture were grown in a hydroponic solution in growth chambers under temperature and light conditions favoring potato growth. Plant nutrients were supplied at a level where there were no deficiencies or toxicities except for nitrogen. Nitrogen (ammonium nitrate and ammonium phosphate) was supplied at 5, 40, 160, and 640 ppm to create plant stress from a nitrogen deficiency and excess. Established plants were inoculated with a spore suspension of *C. coccodes* and allowed to grow. Plants were then destructively sampled at 1, 2 and 3 weeks after inoculation and roots were assayed for *C. coccodes*. Nitrogen treatments were arranged as a Latin square design with three replicates and two subsamples per replicate. Infection severity was assessed by plating roots on modified potato dextrose agar and then determining the extent of infection. The experiment was expanded to test for the effects of potassium (0, 10, 80, and 160 mg K/l potassium nitrate) and phosphorous (0.032, 0.128, 1.00 and 8.2 ml phosphoric acid/liter) on black dot development.

Colonization of root systems was greatest at the lowest level of nitrogen (5 ppm). Root colonization decreased as nitrogen concentration increased to 160 ppm, which was the optimum level of N, and then increased as nitrogen increased to 640 ppm (Fig. 6). When potassium was tested, greatest root colonization occurred at the lowest level of potassium (0 mg MgK) and decreased as potassium concentration increased to 80 mg (the optimal level of K) and then slightly increased as potassium concentration increased to 160 mg Mg K (Fig. 7). The same pattern was seen when phosphorous was tested. The greatest root colonization occurred at the lowest level of phosphorous (0.032 ml) and then decreased as phosphorous concentration increased to the optimal level of P (1.00 ml) (Fig. 8).

Effect of Water Stress on Black dot Development

Plant stress from over irrigating increases the severity of black dot on potato plants. The effects of water levels from irrigation on black dot development in potato were investigated under a greenhouse environment in 2009. Two separate trials were completed using certified G2 Umatilla Russet potato seed that was assayed free of black dot. The first trial had 2 oz seed pieces planted in 2 gal pots of greenhouse mix soil with a pre-plant 16-16-16 NPK. One of three irrigation levels was applied to each pot and each irrigation level contained a pot where soil was infested with inoculum of *C. coccodes* or not infested. Each treatment and irrigation level was replicated eight times (n = 48 plants). The irrigation levels were defined as 1). High – plants were watered to keep the soil surface moist; 2). Medium – surface of soil was allowed to dry but plants never exhibited wilt symptoms; 3). Low – plants were irrigated only when 50% of leaflets showed loss of turgor. Due to excessive irrigation of plants receiving high irrigation there was typically 200 – 400 ml of drainage which depleted the nutrient reservoir of these plants. To remove the nutrient factor among irrigation levels, NPK was added to the high irrigation treatment to maintain similar nutrient reservoirs between treatments. Nutrient levels were monitored both by chlorophyll meter and petiole assays. The second trial had the same treatments as the first except an added high treatment of irrigation that received no extra nutrients and thus was susceptible to effect of nutrient leaching. Each treatment was replicated four times in the second trial. Weight of roots, density of sclerotia of *C. coccodes* on stems, density of sclerotia on roots as measured with a disease severity index (DSI) and incidence of infected progeny tubers were used to determine effect of irrigation on incidence and severity of the disease.

Root weight, density of sclerotia on roots (root DSI), density of sclerotia on stems and infection of progeny tubers were all negatively affected by black dot at the high water irrigation treatment in both trials (Figs. 9, 10). Plant height, SPAD chlorophyll, tuber number and yield were not affected by *C. coccodes*.

Conclusions and Management of Black Dot

Incidence of tubers in which the black dot fungus can be detected increased as the growing season progressed. Tubers were latently infected in the field and disease symptoms of blemishes and lesions and disease signs of sclerotia became evident in storage. Incidence of black dot significantly decreased as the number of years between potato crops increased. Potato roots were more extensively colonized by the black dot fungus when plants were stressed by both a lack and excess of nitrogen, potassium and phosphorous than when optimum levels of each nutrient were available to plants. Severity of black dot was greater when plants were stressed by excessive irrigation water than when plants were optimally watered.

No single management tactic will successfully reduce the effects of black dot on potato growth. Therefore several tactics must be integrated to successfully manage the disease. Lengthening the time between potato crops reduces the effect of soil borne inoculum and can be a helpful disease management tactic. Data from recent studies suggest that more than four years out of potatoes are needed to appreciably reduce the effects of the disease from soil borne inoculum. Incidence of infected tubers decreased 10% per year out of potatoes after the first three years in a field study in the Columbia Basin in 2009. An application of a strobilurin at 40-62 DAP can significantly reduce black dot sclerotia in upper and lower stems and tubers which may reduce soil inoculum in subsequent years.

Even though soil borne inoculum has a higher potential to cause severe disease than tuber borne inoculum, potato seed lots with a high incidence of black dot should be avoided. Recent research demonstrated that *C. coccodes* grows from infected seed piece to roots, stolons and tubers at a rate of approximately 1 mm/day. The fungus can easily colonize roots and stolons, and reach daughter tubers from an infected seed piece during a long growing season. Reducing plant stress is an important management tactic for black dot. A balanced plant nutrition program is important in reducing the effects of black dot on plant growth. Adequate nutrients may especially be important into the bulking phase of plant growth. Plant stress from over irrigation should be avoided. Not only does water saturated soil favor spread and development of *C. coccodes*, but oxygen is displaced in the soil which is needed for oxidative respiration by roots. Other causes of plant stress including blowing sand, which may increase the incidence of foliar infections, should be avoided. Co-infection with other pathogens, especially the Verticillium wilt fungus will increase damage in many potato cultivars. Consequently, black dot management also includes managing Verticillium wilt and other potential causes of early crop death.

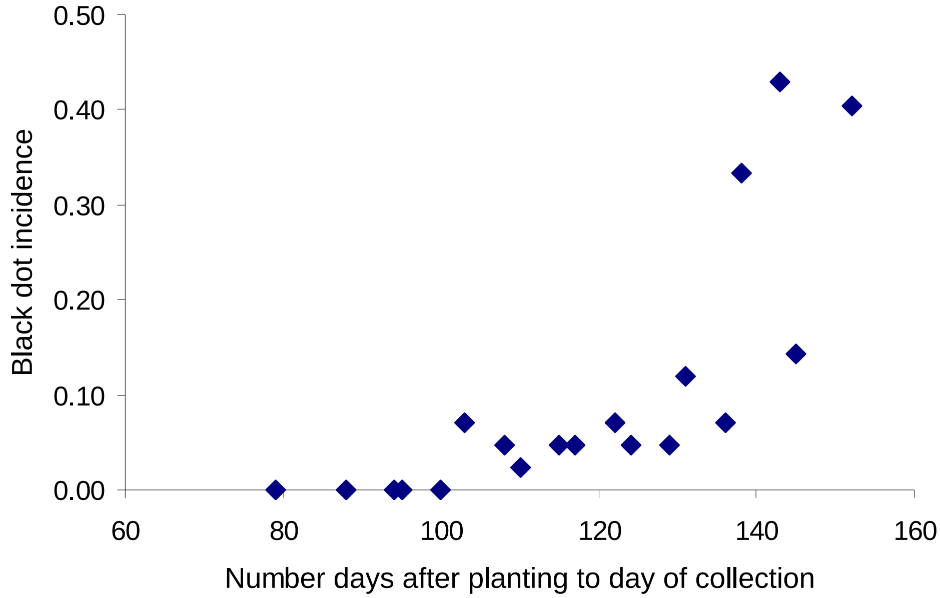

Figure 1. Incidence tubers with the black dot fungus for four fields during the growing season.

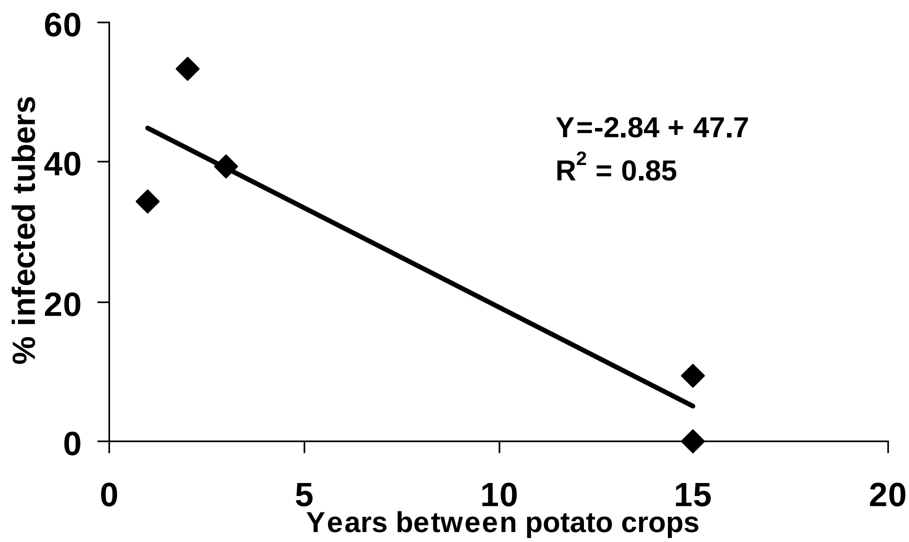

Figure 2. Percent progeny tubers that assayed positive for *Colletotrichum coccodes* in fields in the Columbia Basin with different potato rotations in 2008.

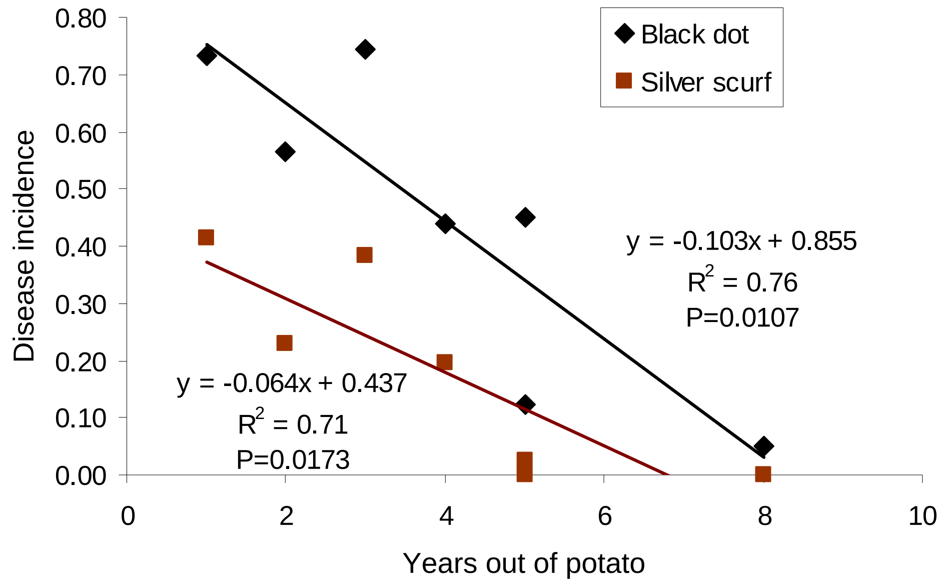

Figure 3. Incidence of black dot and silver scurf on potato tubers from seven fields from commercial storage relative to number of years potatoes were out of rotation.

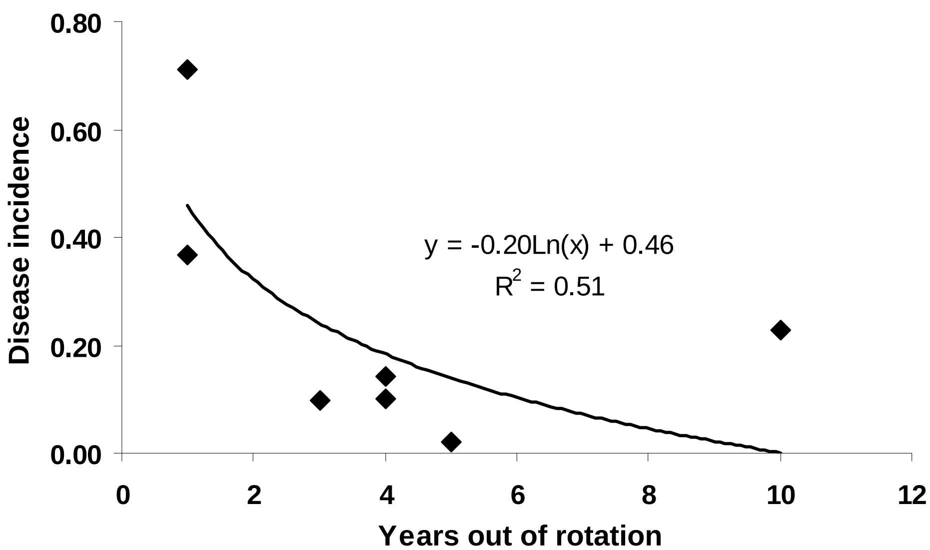

Figure 4. Black dot incidence on potato tubers out of commercial storage compared to number of years potatoes were out of rotation.

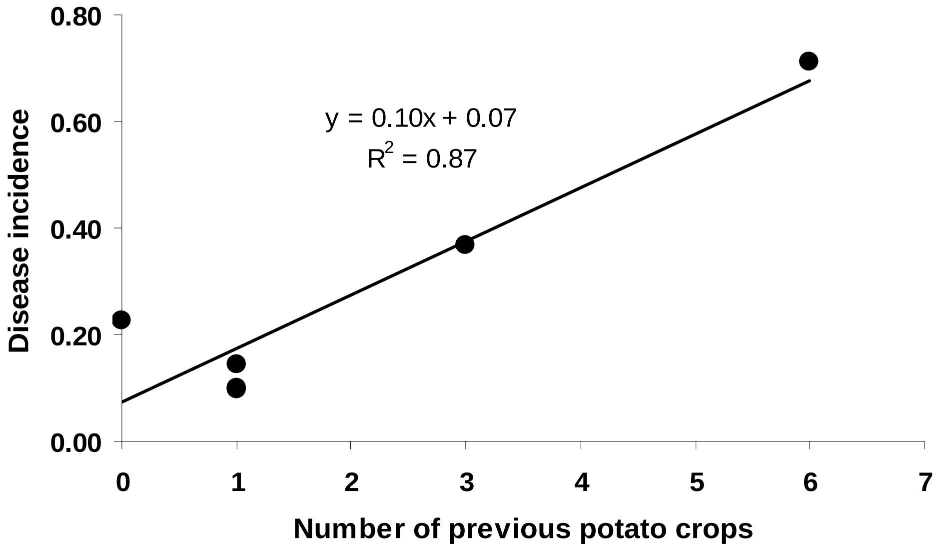

Figure 5. Black dot incidence on potato tubers out of commercial storage compared to number of previous potato crops grown.

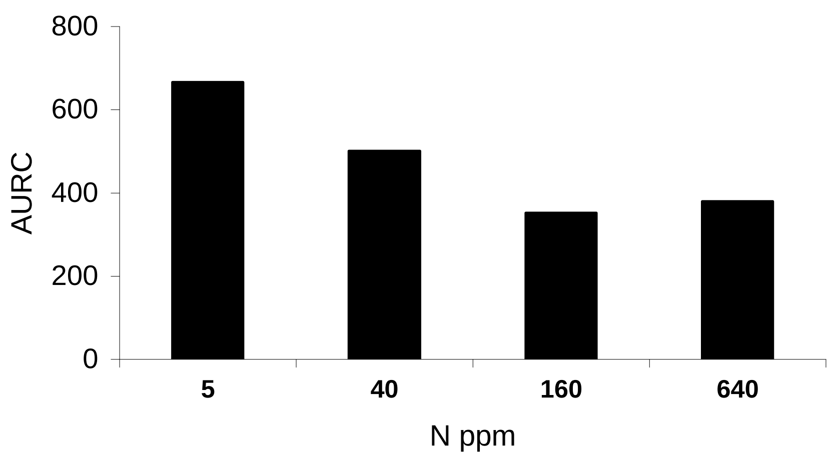

Figure 6. Root colonization curve for black dot (AURC) on RB grown in hydroponic culture with various levels of nitrogen.

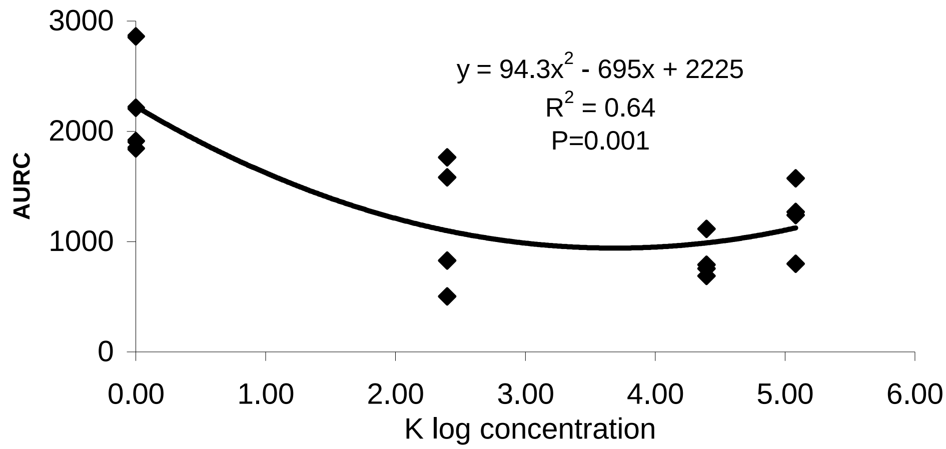

Figure 7. Root colonization curve for black dot (AURC) on RB grown in hydroponic culture with various levels of potassium. Non-transformed values of K were 0, 10, 80 and 160 mg.

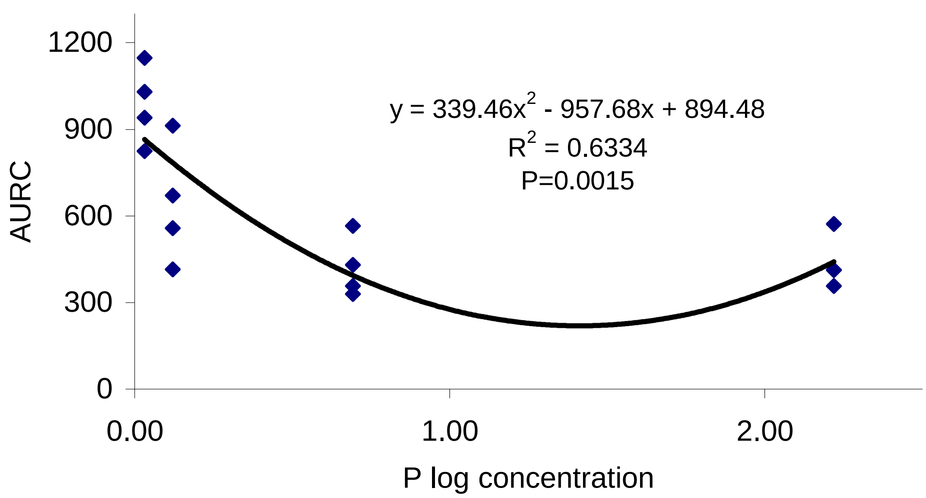

Figure 8. Root colonization curve (AURC) for black dot on RB grown in hydroponic culture with various levels of phosphorous. Non-transformed values of P were 0.032, 0.128, 1.00 and 8.20 ml.

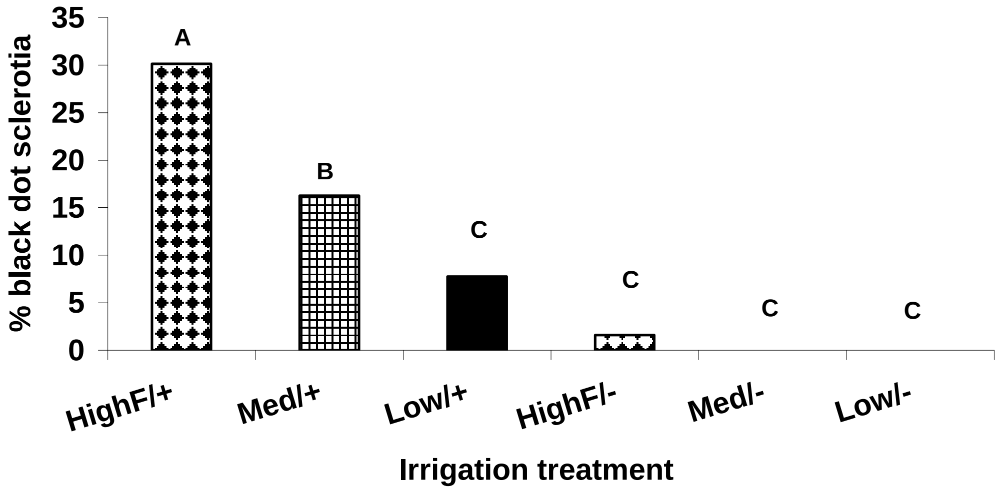

Figure 9. Percent of black dot sclerotia on potato stem in greenhouse with three levels of irrigation with (+) and without (-) soil infested black dot.

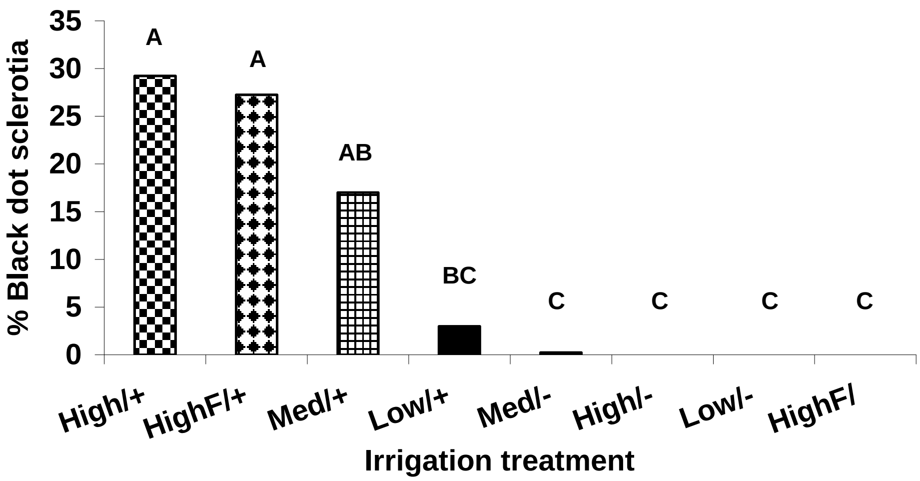

Figure 10. Percent of black dot sclerotia on potato stem in greenhouse with three levels of irrigation with (+) and without (-) soil infested black dot where the high irrigation had nutrients (F) or not.

WSDA's Implementation of the Soil Fumigant Mitigation Measures

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Good Morning, I am out of the Olympia Office of the Department of Agriculture and I am one of the people who have been tasked with trying to figure out how we are going to implement the changes to the soil fumigant labels. The Department appreciates that EPA has used a public process and sought stakeholder input over the last couple years, but we are having a big problem with how they are going about implementation. These will be the most complicated and extensive label changes I've seen in the 19 years I've worked for the Department. A couple weeks ago at the Consultant's meeting I read a letter that we intended to send to EPA. We did send that letter a few days ago and I would just like to read the first paragraph. This letter was sent by WSDA Director Dan Newhouse to Steve Owens, the Assistant Administrator, Office of Pesticide Programs, in Washington DC:

Dear Mr. Owens,

The Washington State Department of Agriculture (WSDA) is requesting that EPA delay implementation of changes to the labels of the soil fumigant products…WSDA supports adopting measures to protect people and the environment; however the scheduled 2010 mitigation measures do not allow sufficient time for training of enforcement personnel or education and outreach to the pesticide user community. Based upon the magnitude of fumigation regulatory changes, the preferred outcome would be to delay implementation until the 2012 growing season. However, an alternative that would delay changes slated for…2010 until 2011 would allow state lead agencies time to prepare enforcement staff and educate end users on the specifics of the upcoming label changes. I am greatly concerned that adherence to the current timelines will be counterproductive and not allow for successful implementation of the soil fumigant mitigation measures….

The letter goes on to cite all the difficulties and uncertainties that State lead agencies are trying to deal with. EPA is not providing answers to our questions. WSDA has yet to see the final labels, and we should ALREADY have a good grasp on the new requirements. We should be training the industry now and yet we have numerous unanswered questions. I know that AAPCO, the Association of American Pesticide Control Officials, has sent a very similar letter, and if they haven't done so already, Oregon and some other states also intend to send a similar letter.

We don't know whether EPA will actually delay implementation so assuming that EPA decides to forge ahead, let's take a look at some of the things that we think are going into place this year and then how WSDA will be dealing with them.

EPA has decided to delay some of the measures until 2011. Here is a list of what they are planning to implement this year, and we will go over most of these…

Restricted-Use Designation
Site Monitoring
Handler PPE
5-Day entry prohibition
Good Ag Practices
Fumigation Management Plan
Registrant Training for Handlers

And the list of what they intend to delay until 2011, including the buffer zone requirements…

Buffer Zones
Sensitive Site Restrictions
Applicator Training
First Responder and Community Outreach
Emergency Preparedness

Restricted Use Classification - In 2010 all of the soil fumigants will become restricted use, which means that you will have to be licensed to purchase and use them. If you are on the commercial side of things you will need our current soil fumigant category on your Commercial Applicator or Commercial Operator license. If it is a non-commercial application then, at least for this year, you will just need a Private Applicator license. It is quite possible that will change in the next year or two if EPA decides to require a special examination for soil fumigations. It may be that you will have to take an exam and add a soil fumigant category to your Private Applicator license.

"Fumigant Safe Handling Information" - WSDA has no idea what this safe handling information is, and where applicators/employers are supposed to obtain it. This could be a 50 page safety manual or it could be information taken from the label and provided verbally to handlers by the certified applicator. This is an example of the kind of problems we are having with implementation – the use season will be upon us in a short time and we don't have the specifics!

Site Monitoring - The State Chemigation rules already require monitoring every 4 hours. The new labels will require monitoring every 2 hours if you are fumigating a field that is 80 acres or larger. This does not over-ride the WSDA chemigation rules so when a sensitive area is at risk of being exposed, the application must be continuously monitored. Until the buffer zone requirements go into effect, sensitive areas must still be continuously monitored.

Worker Entry - Entry will be prohibited for all workers from the start of the application until 120 hours after the application is complete. This includes all workers, even if they are wearing all of the PPE that handlers are required to wear. Only trained and equipped handlers may be in the treated area and only to perform handler tasks.

Handler Training - There is supposed to be handler training that will be required this year (this would be handlers who are directly supervised by a certified applicator), but again, we have no idea what this entails. We have asked EPA about this but they have not responded. As of a couple weeks ago at the Consultant's meeting, WSU was not aware of the requirements for this training. Here you have the organization that is responsible for pesticide education in this state wanting more information so they can best serve their customers. We also will continue to work with EPA to clarify our areas of concern.

Good Agricultural Practices - Some of the label statements that were previously "advisory" in nature will now become mandatory. So that you're not applying during inversion conditions, wind speed must be at least 2 mph at the start of the application, or forecast to reach 5 mph during the application. The maximum wind speed is 10 mph for mid to high release applications and 25 mph for low release height solid stream (drizzle boom) types of application.

Checking weather forecast for low-level inversions – This is a requirement that has been giving me a lot of problems. Applicators are supposed to check the weather forecast and, if a shallow, compressed (low level) inversion is forecast for more than 18 consecutive hours during the 48 hour period <u>after the start of</u> the application,* they cannot make the application. I've spent a considerable amount of time on the National Weather Service website and I can't even find the word "inversion" let alone a forecasted period when one is supposed to occur. This is one of the questions we posed to EPA in early November and we have yet to receive a response.

**author's note: In the presentation I indicated the 48 hour period from the start of the application through the 48 hour period <u>after completion</u> of the application, which is not correct.*

Soil Conditions – Soil must be in good tilth and free of large clods (whatever that means) and crop residue must lie flat, not interfere with the soil seal. Like many label requirements it is a matter of degree to be considered a violation. The conditions will be pretty drastic before we cite this as a violation. We have the "burden of proof" and we have to assume that you will take us to a hearing on this. We understand, too, that residues are left for erosion control and because of minimum tillage practices. I don't have a real good idea at this point how we will pursue this label requirement.

Temperatures – The maximum air temperature and soil temperature is 90°, and if the air temperature has been above 100° in the three days prior to the fumigation, the soil temperature must be measured and recorded in the Fumigation Management Plan. This is probably not going to affect the applications in the Columbia Basin much since most of them occur in October, but it's just another example of details that we do not yet know.

Does the application need to be shut down if the air or soil temperature reaches 90°? Or is the 90° mark only applicable at the start of the application?

Soil Moisture - Immediately prior to application the soil moisture must be 60 - 80% of field capacity in top 6 inches of soil. It must be measured by appropriate equipment or USDA *Feel Method.* Obviously we are not going to be able to tell after the fact what the soil moisture was at the start of the application so how will we know if you were in compliance? Because you will record it in the Fumigation Management Plan.

Application and Equipment Conditions - There will be a number of other requirements that will be specific to the method of application (For example, shank vs water run).

Site Specific Fumigation Management Plan (FMP) and **Post Application Summary Report –** Applicators will need to fill out an FMP prior to the application and then note any changes in a post application summary report. At this point EPA has produced an FMP template for methyl bromide applications, but not yet for metam applications. There is not a required form or format so you can make your own. Creating an FMP would probably be a good place for applicators to start since the FMP really addresses most of the label changes that are coming. One of the questions that has not been answered is whether you still need to fill out a post application summary report if there were no changes to the application. The items that will be covered by the FMP include:

- Applicator Information
- Site information
- Soil Conditions
- Weather Conditions/Forecast
- Buffer Zones
- Handler PPE
- Handler Information
- Emergency Procedures
- Posting Procedures
- Site Specific Response & Mgt (Neighbors)
- Communications
- Air Monitoring (for handlers)
- GAPs
- Hazard Communications

Note that some of these items, such as buffer zones, will not be a requirement until 2011, but they will still be included on any FMP template that is developed.

Okay, how is WSDA going to implement all these changes? At least for the first couple years we intend to provide a lot of technical assistance. In most cases we will likely not even be issuing Notices of Correction, But… Applicators must still apply in a careful and safe manner. Applicators must still continuously monitor when sensitive sites are at risk, and then shut down when necessary. If houses, businesses, etc. are nearby,

Tuber Maturity & Postharvest Behavior

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Background and Objectives

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

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

The objectives of this work were three-fold:

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

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

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

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

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

Key indices of crop development included:

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

  Tuber physiological maturity was estimated as the average of DAP to achieve these indices.
- Max. foliar biomass (T/A)
- Max. tuber yield (T/A)
- Specific gravity at harvest

Results – Alturas & Premier Russet

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

Foliar & Tuber Growth

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

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

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

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

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

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

<u>Retention of Processing Quality</u>

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

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

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

Results – Ranger Russet

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

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

Summary

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

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

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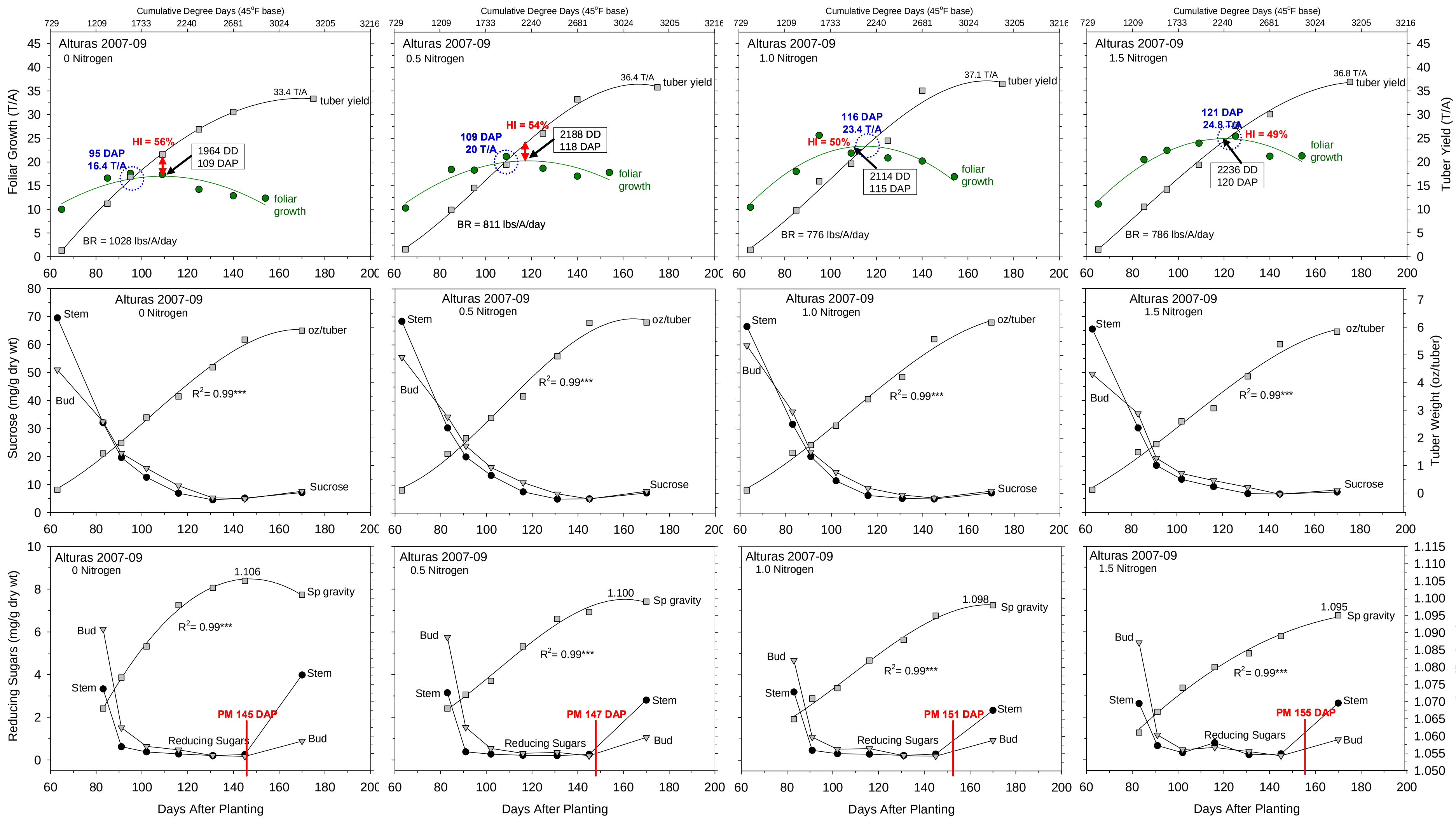


Fig. 1. Foliar and tuber growth (top row) responses of **Alturas** to four levels of in-season nitrogen (N) at Othello, WA averaged over 3 seasons (2007-09). The N levels (0, 0.5, 1.0, and 1.5) equal 0, 50%, 100%, and 150% of recommended in-season rates. See table 1 for planting and harvest dates. Changes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

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

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

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

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

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

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

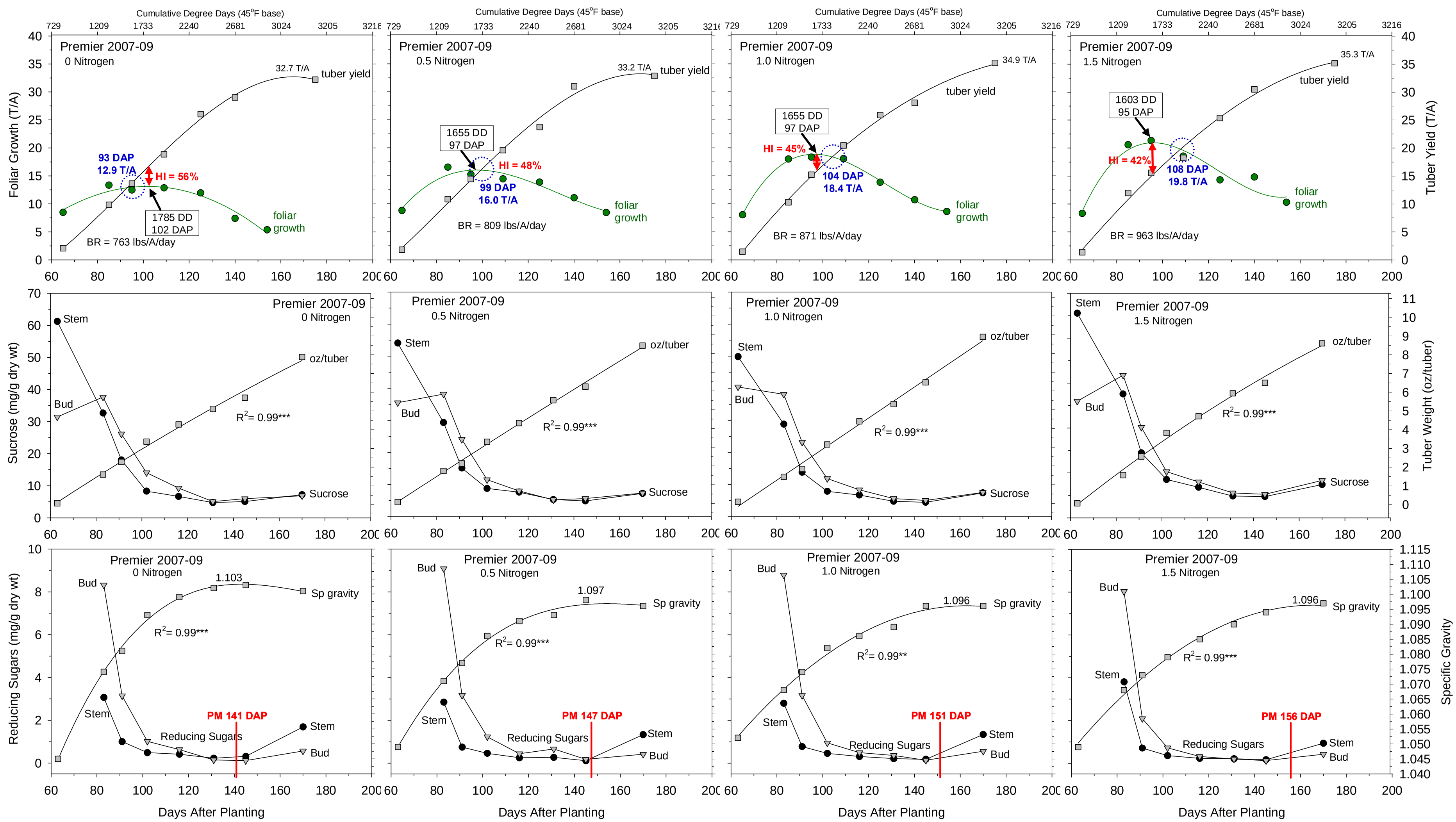


Fig. 3. Foliar and tuber growth (top row) responses of **Premier Russet** to four levels of in-season nitrogen (N) at Othello, WA averaged over 3 seasons (2007-09). The N levels (0, 0.5, 1.0, and 1.5) are equivalent to 0, 50%, 100%, and 150% of recommended in-season rates. See table 3 for planting and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

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

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

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

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

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

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

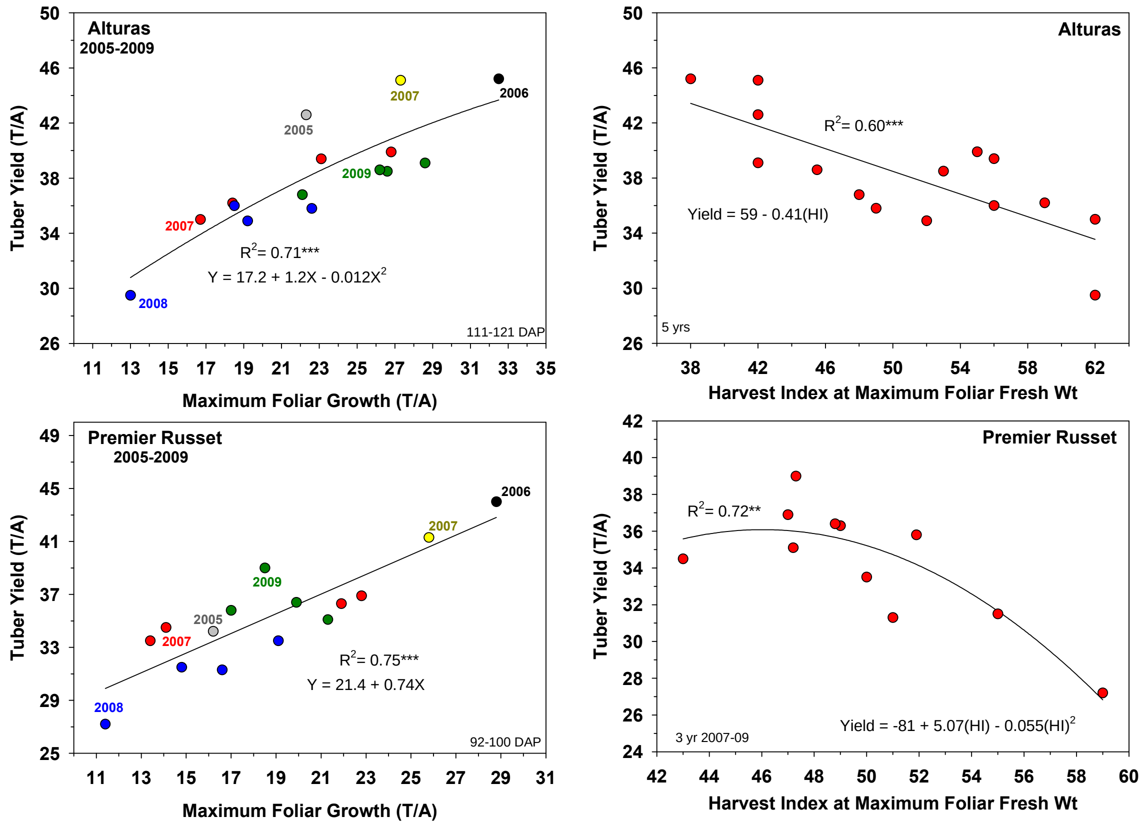


Fig. 3. Left: Dependency of tuber yield on foliar growth in Alturas (top left) and Premier Russet (bottom left). The yield (T/A) of above ground foliage at maximum foliar development was estimated from regressions of foliar fresh weight vs. days after planting (see foliar growth curves in Figs. 1 & 2).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

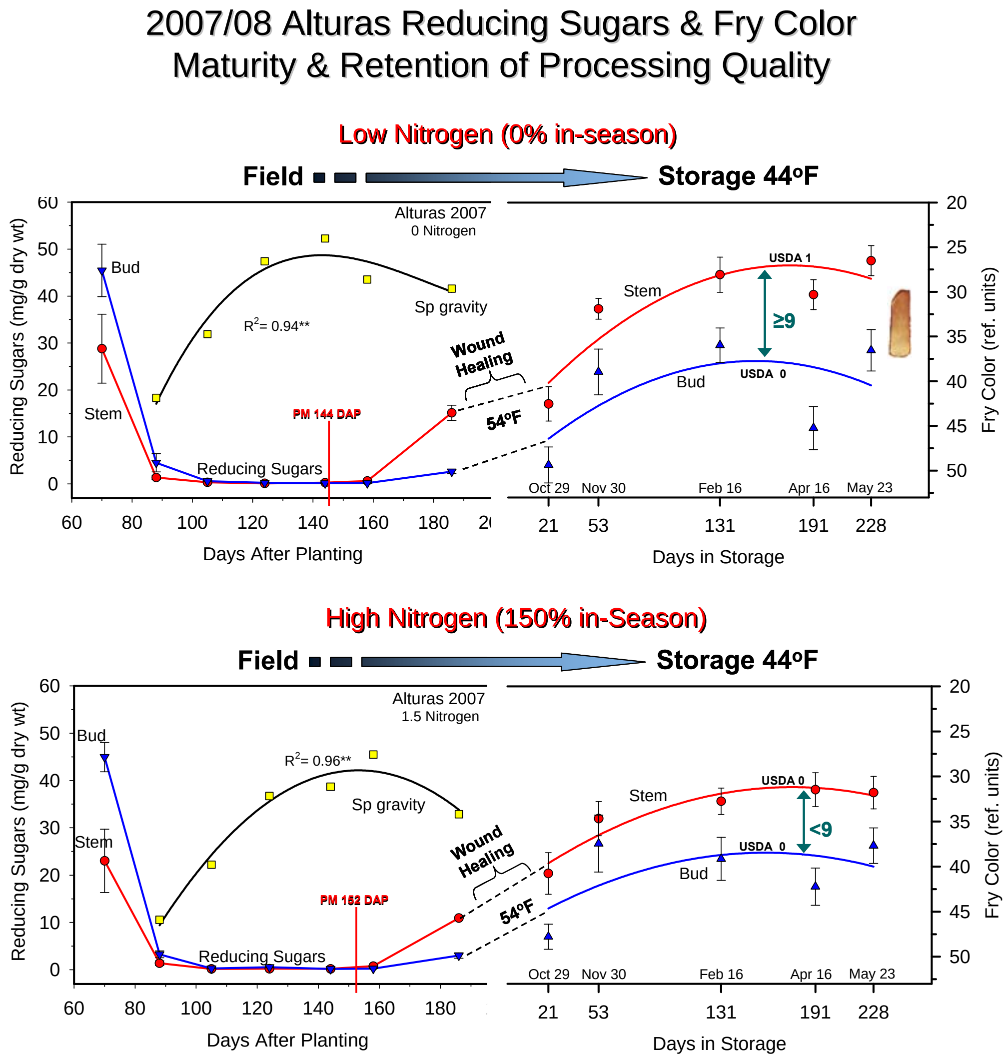


Fig. 4. Changes in reducing sugars (glucose + fructose), specific gravity and fry color of Alturas tubers during development and in storage (2007 growing season and 2007/08 storage season). The crop was planted April 5, 2007 at Othello, WA and grown with 0% (top) and 150% (bottom) of the recommended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

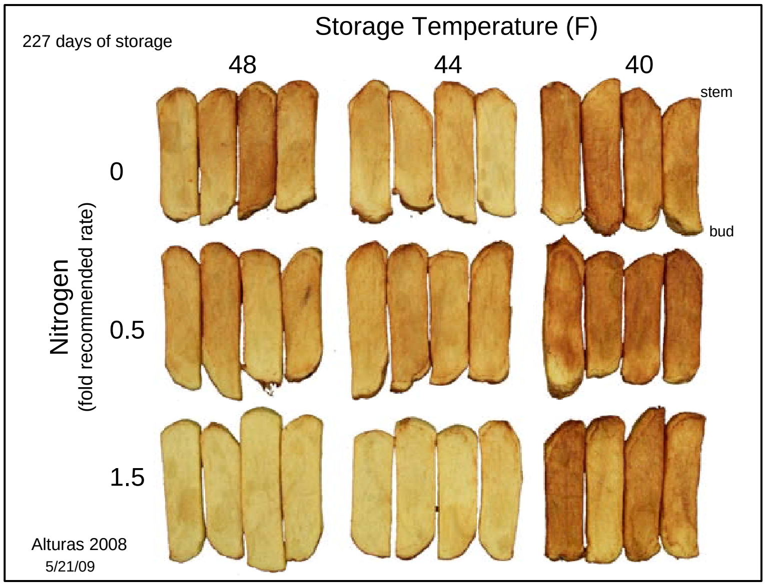


Fig. 5. Effects of in-season N and storage temperature on processing quality of Alturas following 227 days of storage (**2008/09** storage season). Planting date was April 17. The N levels (0, 0.5, and 1.5) are equivalent to 0, 50%, and 150% of recommended in-season rates. Physiological maturity (PM)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

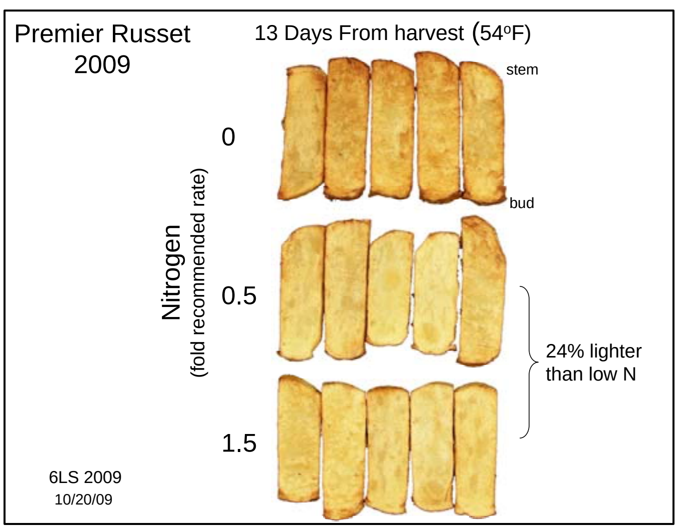


Fig. 6. Effects of in-season N on processing quality of Premier Russet 13 days after wound-healing at 54^{o}F following harvest in **2009** (Oct. 20). Planting date was April 23. The N levels (0, 0.5, and 1.5) are equivalent to 0, 50%, and 150% of recommended in-season rates. Physiological maturity (PM)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

Ranger Russet - Tuber Maturity Affects Fry Color During Storage

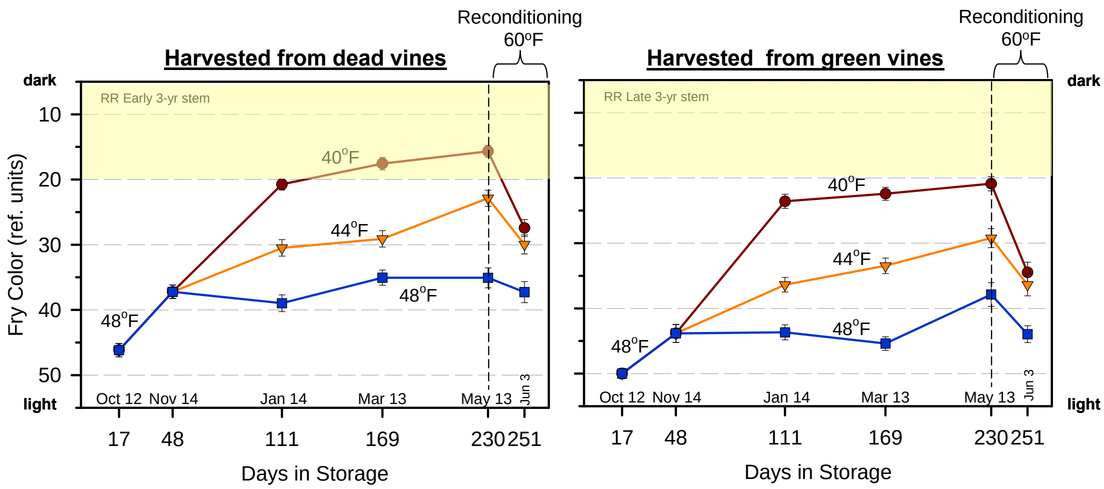
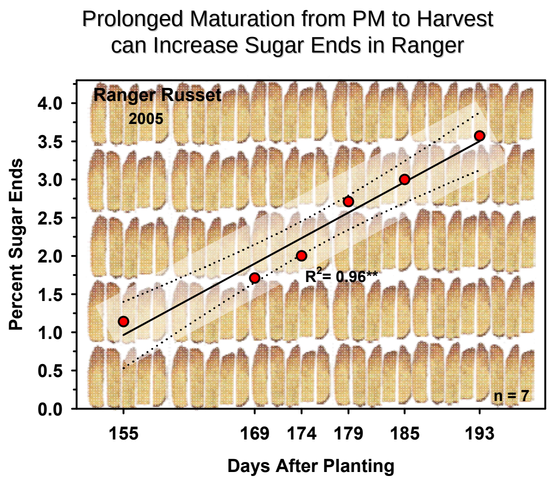


Fig. 7. Changes in the processing quality of French fries (photovolt reflectance units of the stem ends of fries) prepared from Ranger Russet tubers harvested overmature from dead vines (left) and from partially green vines (right) in response to different combinations of conditioning (initial), holding,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

Ranger Russet CT/HT Storage Regime Options

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

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



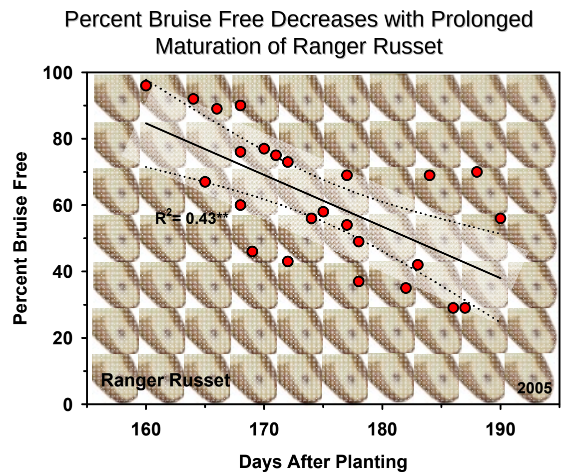


Fig. 8. Trends in the percentage of tubers with sugar ends and percentage bruise free with increasing days after planting for Ranger Russet in the Columbia Basin during the 2005 growing season. Ranger Russet tubers reach maturity approximately 145 to 155 days after planting. Sugar end and bruise free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

Microbial Control of Potato Tuberworm in Potato Plants and Tuber Storage with Emphasis on Research Conducted in the Pacific Northwest of the United States

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Introduction

Potato tuberworm (PTW), *Phthorimaea operculella* (Zeller) (Lepidoptera: Gelechiidae), is widely recognized as a potato pest of global importance (Radcliffe 1982, Trivedi and Rajagopal 1992, Kroschel and Lacey 2008). Larvae mine in potato leaves and stems, but more important is the feeding damage in potato tubers, which also can cause rapid rotting in non-refrigerated storage. In the tropics and subtropics it is primarily a serious pest of stored tubers (Raman et al. 1987). If left untreated, PTW infestation of tubers stored under rustic conditions can be extremely high. When populations of PTW are very high, they can also be debilitating to potato plants. Although it is less commonly a potato pest in temperate regions, it can have periodic outbreaks causing significant damage to tubers (Sporleder et al. 2004, 2008a, De Bano et al. 2010). Because there is zero tolerance for insect parts in processed tubers, infestations, even relatively small ones, can result in substantial economic losses. For example, damage caused by PTW in the Pacific Northwest was especially high in 2003-2005 (Jensen et al. 2005, Rondon et al. 2006, 2008, De Bano et al. 2010), often requiring frequent application of broad spectrum insecticides (Schreiber and Jensen 2005).

Several natural enemies are reported from PTW including insects (parasitoids and predators) (Briese 1981, Horne 1990, Kroschel and Koch 1994, Kroschel 1995, Herman 2008a, Horne and Page 2008) and pathogens (Kroschel and Lacey, 2008, Lacey and Kroschel 2009). Naturally occurring and inundatively applied entomopathogens (biopesticides) can significantly contribute to control of PTW within an integrated control management (IPM) strategy. The advantages and disadvantages of using insect-specific pathogens as microbial control agents (MCAs) are presented by Kaya and Lacey (2007). In addition to efficacy, two important advantages of MCAs are their selectivity for targeted insects and safety for natural enemies and vertebrates (Laird et al. 1990, Hokkanen and Hajek, 2003). In this paper we review the most researched and practically used pathogens for control of PTW i.e. a granulovirus and the bacterium *Bacillus thuringiensis* (Bt).

Potato tuberworm granulovirus

The most effective MCA for PTW is a granulovirus (PoGV) in a family of viruses, the Baculoviridae (granuloviruses and nucleopolyhedroviruses), that infect and kill insects. The granuloviruses exclusively infect and kill several species of Lepidoptera. The name granulovirus is derived from their granular appearance under high magnification. Each granule contains a single viral rod. After the granules, also known as occlusion bodies (OBs), are ingested by lepidopteran larvae, they dissolve in the alkaline midgut freeing the viral rods which attach to and pass through the membrane of the midgut epithelial cells. From there they invade a variety of host cells and produce hundreds of millions of rod-containing OBs per larva. Several strains of PoGV have been isolated from PTW worldwide (Reed 1969, Broodryk and Pretorius 1974. Hunter et al. 1975, Briese 1981, Alcázar et al. 1991, 1992a, Vickers et al. 1991, Setiawati et al. 1999, Zeddam et al. 1999, Laarif et al. 2003) including the United States (Hunter et al. 1975). The virus is very selective and infects only PTW and some closely related species, such as the Guatemalan tuber moth, *Tecia solanivora* (Povolny). PoGV is prepared as an MCA by infecting PTW larvae with virus-treated tubers, after death grinding them for use in a diluted aqueous suspension for spraying or drying (Reed and Sringett 1971, Matthiessen et al. 1978, CIP 1992, Kroschel et al. 1996, Sporleder 2003). For dry application, the virus suspension is mixed with talc or another carrier and dried for application onto stored tubers (CIP 1992). A substantial amount of successful testing of PoGV has been conducted on stored tubers in Peru (Alcázar 1992b), Ecuador (Zeddam et al. 2003), Bolivia (Kroschel, personal communication), in the Middle East (Salah et al. 1994, Moawad et al. 1997, Farrag 1998), Northern Africa (Lagnaoui et al. al. 1997), Asia (Amonkar et al. 1979, Ali 1991, Kurhade and Pokharkar 1997, Das et al. 1992, Setiawati et al. 1999, Islam et al. 1990, Chandel et al. 2008), Australia (Hamilton and Macdonald 1990), and more recently the Pacific Northwest of the United States (Arthurs et al 2008a, 2008b, Lacey et al. 2010). In developing countries, it has been used primarily for control of PTW in the tuber storage. Research on the virus has also been conducted in potato plantings (Reed and Springett 1971, Briese and Mende 1981, von Arx et al. 1987, Salah and Aalbu 1992, Salah et al. 1994, Kroschel 1995, Kroschel et al. 1996, Arthurs et al. 2008a). Salah et al. (1994) tested a combination of Bt, PoGV and extra irrigation for integrated control of PTW in Tunisian field trials. In some cases, the integrated controls proved to be more efficacious than conventional insecticides. Factors that determine the larvicidal activity of PoGV have been presented by Pokharkar and Kurhade (1999), Sporleder (2003), Sporleder and Kroschel (2008), Sporleder et al. (2007, 2008b). The principal limiting factor under field conditions is solar degradation of the virus (Sporleder 2003, Sporleder and Kroschel 2008). Consequently, in areas on the plant that are not protected from direct sunlight, such as the surface of leaves, the virus can be deactivated within a few days.

Bacillus thuringiensis

Bt is the only bacterium that has been evaluated for PTW control. The crystal toxins produced at the time of sporulation act as stomach poisons. After ingestion by targeted insects, the toxin is solubilized and causes the lysis of midgut epithelial cells and ultimately death of the insects. Although there are several different strains of Bt, each with specific toxicity to particular groups of insects, Bt subsp. *kurstaki* (Btk) is most commonly used against Lepidoptera (Beegle and Yamamoto 1992, Garczynski and Siegel 2007). Btk has been reported to be effective for control of PTW infestations in field tests (Broza and Sneh 1994, Salah et al. 1994). However, repeated applications have been required because the toxin responsible for activity is inactivated by UV light from the sun, and rain washes it onto the soil. Btk has also been widely tested to control PTW infestations tuber storage (Kroschel and Koch 1996, Salama et al. 1995a, 1995b, von Arx and Gebhardt 1990, Hernandez et al. 2005, Arthurs et al. 2008a). In Tunisia, an integrated control approach comprising Bt applied at the beginning of the storage period in combination with cultural control (early harvest) eliminated the reliance on parathion sprays (von Arx et al., 1987).

Potato tuberworm granulovirus and *Bacillus thuringiensis* research in Washington State. **Field studies.** There are few insecticidal options for PTW control late in the growing season. We evaluated PoGV and Btk for season-long control of PTW on potato foliage in 2006 and 2007 (Arthurs et al. 2008a). Compared to untreated controls, 10 weekly applications of 10^{13} PTW occlusion bodies (OBs) per hectare (4 x 10^{12} OBs/acre) reduced PTW populations in replicated 1-m^3 field cages by 86–96% on pre-harvest foliage and 90–97% on tubers added to cages shortly before harvest. Infection rates of 82–95% of fourth instar larvae by PoGV were noted within individual larval cohorts. Equivalently timed Btk treatments (1.12 kg product/ha; one lb/acre) were significantly less effective at population suppression, with a only 36–76% reduction in larvae recovered from tubers added to cages. A PoGV/Btk alternation was significantly more effective than Btk alone and as effective as PoGV in 2007, but not in 2006. There was some evidence that reduced rate PoGV treatments (10% rate or 50% application frequency) were less effective than the standard program. There were no treatment effects on percentage of tubers growing in the ground that were infested at harvest, which remained comparatively low at ≤8.1%.

Bioassays were conducted to evaluate the residual activities of foliar deposits. Early-season applications were highly effective for the first 24 h (≥93% mortality) with a steady decline in activity over 10 days. A second application, applied later in the season, showed similar patterns, although in this case Btk was less persistent than PoGV, whereas both agents provided significant larval mortality compared with controls over 14 days. Both PoGV and Btk provide alternatives to manage field infestations of PTW prior to harvest, thus reducing the risk of tuber infestations in storage.

In 2008 we conducted large plot trials of PoGV against natural populations of PTW in potato plantings in Eltopia, WA and continued with caged tests in Moxee, WA (Lacey 2009). Large plot field trials in Eltopia assessed the efficacy of PoGV and combination of half rate PTW virus (820 virus infected larvae per acre) with half rate imidacloprid, virus alone and imidacloprid alone. The rationale of combining PoGV and imidacloprid was to investigate the possibility of the synergistic effect of the nicotinal insecticide and entomopathogens reported by other authors (Quintela and McCoy 1997). Tests started in mid growing season consisted of 5 bi-weekly applications of the virus until 2 weeks before vine kill. Results showed an 86% reduction of mines in plants treated with PTW virus, but only a 46% reduction of mines in imidacloprid treated plots. Tuber infestation was reduced by 90% in plots treated with PTW virus. There was no synergistic or additive activity of PTW virus and imidacloprid. We also monitored non-target impacts of the treatments. Figures 1 and 2 show the average numbers of beneficial and pest insects, respectively throughout the sampling period (July 1-September 19, 2008). No apparent effect of most of the treatments on beneficial insects was observed. None of the predators (big eyed bugs, damsel bugs, spiders) or parasitoids (Braconidae) in virus treated plots was negatively affected by virus. However, plots that received imidacloprid showed some decline in big eyed bugs. The gradual decline of parasitoids in all plots after July 21 and predators after August 20 is typical of natural enemies whose hosts have been reduced. The average numbers of pest insects (aphids, thrips, Colorado potato beetle [CPB], leafhoppers and other Homoptera) on each sampling date was somewhat reduced in the imidacloprid plots predominantly due to the suppressing effect of the pesticide on the large population of CPB.

Small plot field evaluation of reduced applications (three) of PTW virus (full rate, 1645 infected larvae per acre) and Bt at the USDA research farm in Moxee started at mid-season. The highest mortality of PTW larvae (81%) in tubers was observed in plots treated with virus. Mortality of larvae in Bt-treated plots was negligible. Despite the high level of larval mortality within infested tubers in virus-treated plots, the infestation rate was not significantly different from controls.

Figure 1. Average number of predators and parasitoids on each of six sampling dates in control plots and in plots treated with PoGV, imidacloprid or an imidacloprid-PoGV combination. Eltopia, WA 2008.

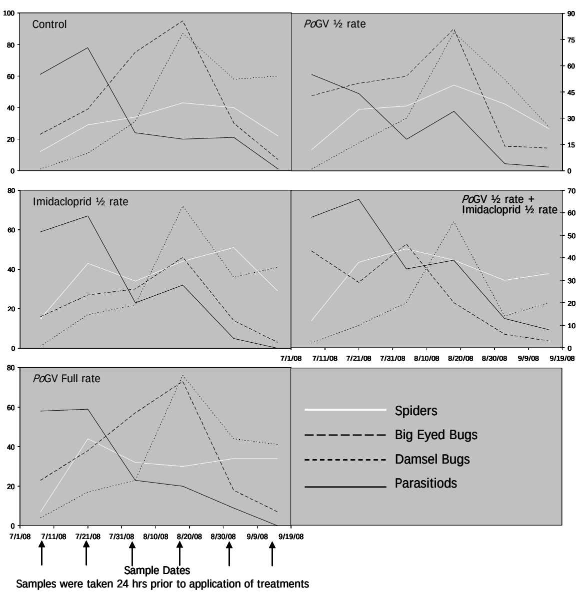
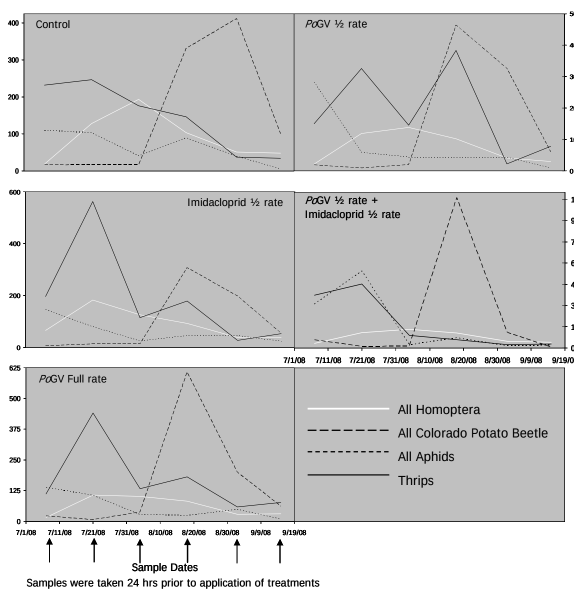


Figure 2. Average number of pest insects on each of six sampling dates in controls and in plots treated with PoGV, imidacloprid or an imidacloprid-PoGV combination. Eltopia, WA 2008.



PTW granulovirus and *Bacillus thuringiensis* research in Washington State. Storage studies. Liquid suspensions and dry formulations of PoGV derived from infected larvae and Btk were evaluated for control of the PTW in stored tubers (Arthurs et al. 2008b). Laboratory bioassays at 25°C demonstrated that both PoGV and a wettable powder (WP) formulation of Btk incorporated with carriers (water, talc, sand, diatomaceous earth, and kaolin clay), were effective against neonate larvae. Depending on the technique, 100% larval mortality was achieved at concentrations as low as 0.025 infected larval equivalents (LE) PoGV per kg tuber and 150 mg Btk WP per kg tuber. However, 100% mortality was never achieved with tests on pre-infested tubers, ostensibly due to the higher dosage required to kill older instars inside tubers. The most effective PoGV formulations were dipping (water) and talc, with dipping most effective for postinfestation treatments, causing up to 91.6% mortality at 0.4 LE per kg. There was no significant effect of formulation in the Btk treatments. The protective effects of residues were also evaluated under longer-term storage conditions. Batches of tubers treated with PoGV or Btk via dipping (up to 0.1 LE and 150 mg WP per kg tuber) were stored in cages containing an initial potato PTW infestation (10% of tubers). Although potato PTW populations were reduced by up to 98.4% after 2 months at 25°C, no treatments prevented the development and reproduction of the F1 generation. The sprouting of stored tubers seemed to be a limiting factor for sustained control. No significant treatment effects were detected in similar cages held at 12°C for 4.5 months.

Treatment of tubers in rustic stores with the PoGV has been demonstrated to provide considerable protection of tubers. Research conducted by our group was the first to show the effects of PoGV for protection of tubers stored in refrigerated warehouse conditions (Lacey et al. 2010). Tubers were treated by dipping in aqueous suspensions of PoGV or water. An estimated 0.0819 LEs of virus or 1.88×10^9 OBs were deposited on each kg of tubers. They were held at 16°C for 11 days before lowering the temperature by 0.5°C per day until 10°C was reached. The tubers were stored at this temperature for 53 days. Mean numbers of infested tubers at the end of the assay was dependent upon both pre-infestation rate and virus treatment. Mean numbers of infested tubers in the control treatment was three tubers per chamber higher than in the virus treatment demonstrating that PoGV controlled larvae and minimized spread into un-infested tubers. Of the larvae that were retrieved in virus-treated infested tubers, the mean mortality was 87% compared to 37 % in controls.

Entomopathogenic fungi

Fungal MCAs and botanical insecticides have been investigated to a lesser extent than PoGV and Bt for control of PTW (Kroschel and Koch 1996, Hafez et al. 1997, Sewify et al. 2000, Sabbour and Ismail 2002, Chandel et al. 2008, Lacey and Arthurs 2008). An endophytic fungus, *Muscodor albus,* isolated from the bark of cinnamon trees was discovered to have biofumigant properties (Strobel et al. 2001).The fungus produces several volatile compounds (alcohols, esters, ketones, acids and lipids) that are biocidal for a wide range of pest organisms including plant pathogenic bacteria and fungi, plant parasitic nematodes, and insects (Strobel et al. 2001, Mercier and Jiménez 2004, Mercier and Manker 2005, Lacey et al. 2008, Riga et al. 2008). We studied the effects of these volatiles on 3 day old potato tuberworm larvae within infested tubers inside sealed chambers (Lacey et al. 2008). The length of exposure to *M. albus* significantly affected mortality of larvae, calculated as percentage of larvae failing to survive to the adult stage. For example, exposure durations of 3, 7, or 14 days at 24°C followed by incubation in fresh air at 27°C until emergence resulted in mortalities of 84.2, 95.5 and 99.6%, respectively. However, the longer exposures also increased levels of carbon dioxide (CO_2) that are unacceptable for tuber storage. Effects of *M. albus* on larval survival were also monitored at 10, 15 and 24°C, using an exposure duration of 7 days followed by incubation in clean air at 27°C to monitor moth emergence. Mortality of larvae was sharply reduced at the lower temperatures resulting in 50.8, 76.8, and 95.4% mortality, respectively. Tuber storage conditions, especially cooling rates, are discussed by Lacey et al. (2008) with respect to using *M. albus* as a fumigant without simultaneously producing unacceptable levels of CO_2 for tuber storage.

Conclusions

The biopesticides evaluated in our studies and in those of other researchers demonstrated effective control of PTW in storage and in the field under certain conditions. PoGV and Bt are safe to application personnel and the food supply and do not affect beneficial insects and other nontarget organisms. The further development and use of biopesticides will ultimately provide components for the integrated and sustainable control of PTW and other insect pests of potato (Cloutier et al. 1995, Lacey and Kroschel 2009, Lacey et al. 2009) and insect and mite pests in other agroecosystems (Lacey et al. 2001). In agroecosystems with a complex of insect and mite pests, highly specific biopesticides, such as PoGV will require combination with other methods of control, such as conservation and augmentation of natural enemies (Briese 1981, Horne 1990, Kroschel 1995, Herman 2008a), cultural control (Foot 1976, von Arx et al. 1987, Strand 2006, Chandel et al. 2008, Clough et al. 2008), use of soft pesticides (Nouri and Arfaoui 2008, Gentz et al. 2010), and judicious use of conventional chemical pesticides, especially the timing of applications (Strand 2006, Herman 2008b, Gentz et al. 2010). Although factors limiting the adoption and use of microbials include higher cost and requirement for repeated applications compared to most chemicals presently used, these costs could be offset by the premium price paid for food produced using a greener approach with concomitant environmental and food safety benefits. The implementation of biopesticides will ultimately depend on an increased awareness of their attributes by growers and the public, which will be the main drivers for their commercialization and use.

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Heat Necrosis: A Hot Topic

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Introduction

Internal heat necrosis (IHN), also known as internal brown spot (IBS), is a physiological disorder of potato tubers. It is characterized by brown patches of tissue within the border of the vascular ring. The severity of IHN can vary, from small flecks that are difficult to distinguish from other internal disorders (such as virus-induced net necrosis), to large blotches encompassing nearly the entire tuber. Neither the tuber skins nor the vines of potatoes with IBS display any symptoms; tubers must be cut to observe IBS. The brown patches of tissue darken when potatoes are fried, making affected tubers unsuitable for processing into chips or fries. IBS is more of a problem in the mid-Atlantic and southeastern United States, but can also be a concern in the Pacific Northwest, particularly the southern Columbia River Basin. Many varieties have been shown to be susceptible to IBS in at least some years and locations, including the well-known 'Russet Burbank', 'Chieftain', 'Yukon Gold', and 'Atlantic', and the newly released 'Clearwater'.

Causes

Environment

The causes of IBS have been difficult to determine. The growing environment is certainly a major factor. High temperatures, particularly at night, seem to play the biggest role, although dry conditions, particularly early in the growing season, have also been implicated. Later harvests tend to have higher levels of IBS than earlier ones, suggesting that the stresses leading to IBS are cumulative. However, the research in this area is incomplete, and a reliable temperature screening regime would help breeders identify potential new varieties that are resistant to IBS. In any case, the environmental causes are the most difficult for the grower to control.

Calcium

A significant amount of research has been done on the role of calcium in the development of IBS. To date, the results have been rather conflicting. This is at least partly the result of using different varieties, different soils, and different methods of applying calcium. Recently, a genetic engineering approach was used to measure the effect of calcium on IBS. A calcium-binding protein (CBP) from corn has been shown to act as a calcium 'sponge', allowing plants to retain calcium, and better cope with certain types of stress. The gene for this protein was incorporated into 'Atlantic' potato through the use of *Agrobacterium tumefaciens*, a soil-dwelling bacterium that can insert DNA into the genomes of plants. Unexpectedly, CBP-transformed plants tended to have higher yields than normal 'Atlantic' potato (Figure 1). Two lines showed higher concentrations of calcium in *leaves* (Figure 2), but no differences were seen in tuber calcium levels. In addition, CBP-transformed lines tended to have *higher* levels of IBS (Figure 3). While further research is underway with the CBP plants, this experiment has certainly not been able to put the calcium question to rest. Calcium does seem to be involved in the development of IBS, but the mechanism is unclear, and supplementing commercial plantings with calcium to avoid IBS is not recommended.

Genetics

The fact that some varieties are frequently observed to develop IBS, while others do not, suggests that genetics is an important factor. Recently, a three-year study was undertaken at North Carolina State University to attempt to quantify the genetic factors involved in IBS. In a breeding population derived from an IBS-susceptible and an IBS-resistant parent, the vast majority of progeny showed little to no symptoms, suggesting that development of IBS-resistant varieties should not be too difficult. In addition, we observed that early maturity (as measured by vine senescence) was associated with lower levels of IBS. Along with these encouraging signs, we also noted that some clones displayed significant yearly variability in IBS symptoms. Therefore, although genetic resistance to IBS should be relatively easy to incorporate into new varieties, screening in multiple years is important.

Conclusion

IBS can be a significant problem in certain production areas, especially with susceptible varieties. While all three factors (environment, nutrition, and genetics) influence the disorder, it is difficult to modify the growing conditions, and nutrient management is poorly understood, and may not have significant impact. For the grower, the genetic solution (i.e. resistant varieties) is the best option for limiting the potential impact of IBS. Information on the performance of various varieties and advanced breeding lines vis-à-vis IBS can be found at http://www.ars.usda.gov/main/docs.htm?docid=3019.

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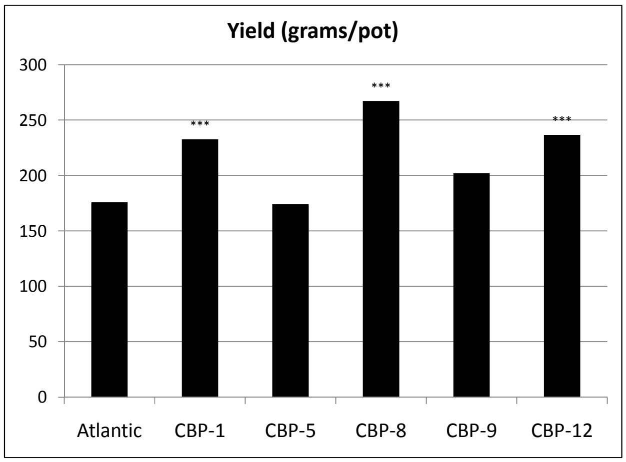
Figures



*** Significantly different from Atlantic

Figure 1. The effect of the calcium-binding peptide on yield.

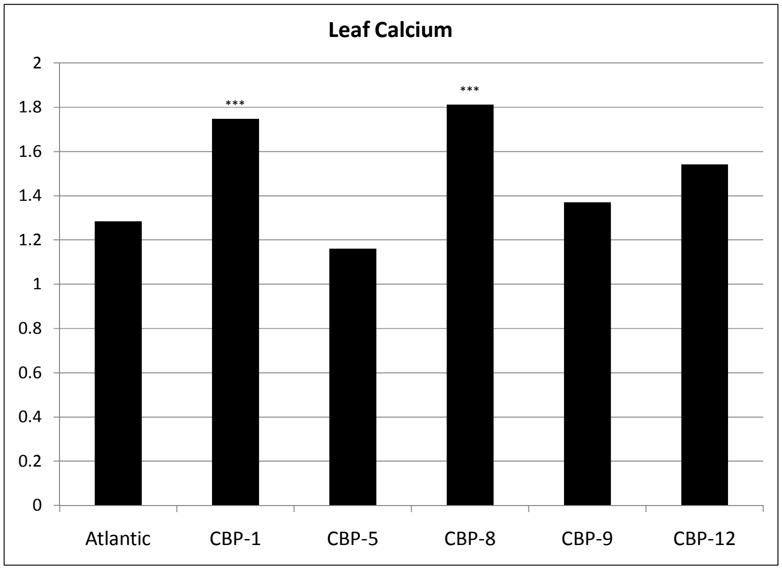


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Figure 2. Effect of the calcium-binding peptide on *leaf* calcium.

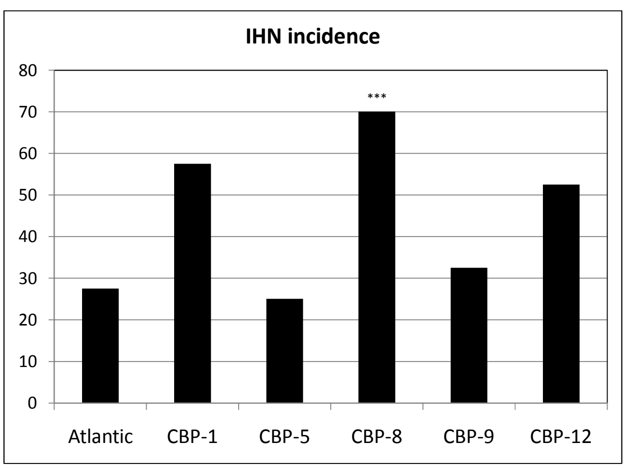

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Figure 3. Levels of IHN incidence in normal and CBP-transformed 'Atlantic' tubers. Incidence is the percentage of a group of potatoes with IBS symptoms.

The Potato Seed Lot Trial: What the Past 46 Years Tell us about the Future

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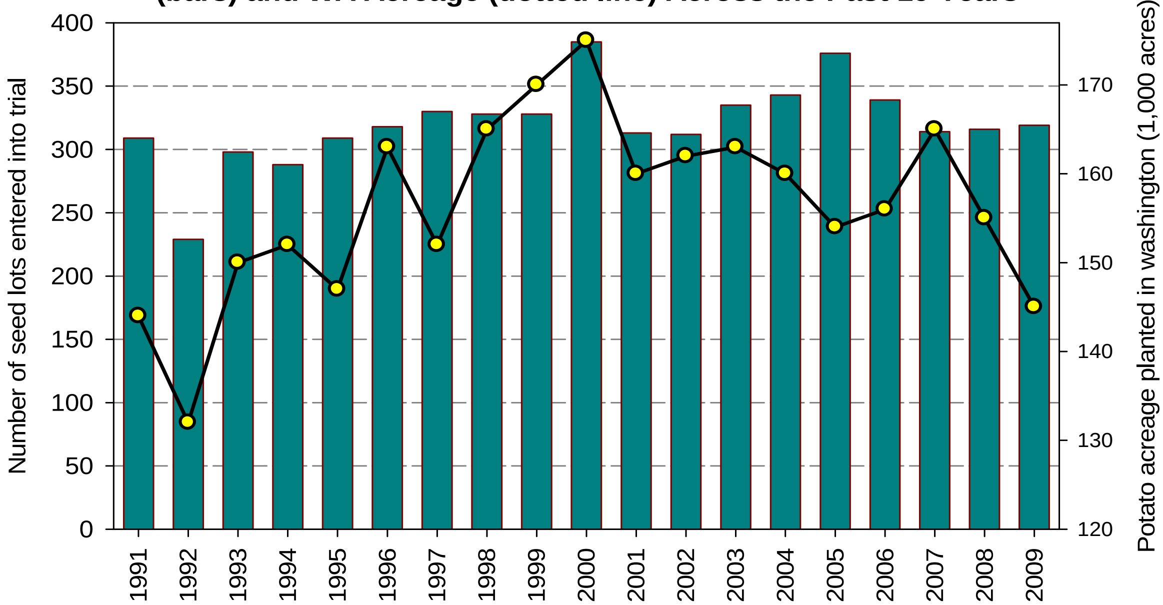
INTRODUCTION

Poor quality potato seed will impact commercial grower income. Major quality factors are disease, virus, herbicide damage, frost damage, and seed-piece handling. Commercial potato growers typically purchase their seed potatoes from seed-growing regions which typically lie outside of Washington. For quality control, it is essential that each seed lot be grown under controlled conditions for approximately 70 days and evaluated by professionals. The Seed Lot Trial provides Washington potato growers, seed suppliers and handlers a side-by-side comparison of seed lots utilized by Washington commercial potato producers. The potato field day provides potato buyers and sellers an opportunity to observe performance of seed lots of common interest and discuss results. To improve field disease diagnostic skills, WSU, USDA and potato industry personnel exchange ideas and share expertise on field diagnosis of disease symptoms and other seed tuber quality factors. Demonstration trials provide an opportunity for individuals of the Washington Potato Industry to evaluate new and/or different varieties and technology for potential use in their operation.

We continue to improve our seed lot reading accuracy. Our plant readers utilize real-time in-field test kits for PVY. The PVY tests allow readers the opportunity to “gauge their eyes” for each cultivar and to test plants exhibiting less-than-obvious symptoms. We continue to incorporate a virus/disease reading training session into our program as a routine requirement prior to the first field reading. The goal of the training session was to utilize expertise from experienced pathologists and seed certification and industry personnel in an effort to aide all who participated in the Washington State potato seed lot screening. All plants in the trial are “proof read” by professionals following general seed lot readings to further reduce false readings and improve the quality of the seed lot trial. The results are available “Washington Commercial Seed Lot Trials" at www.potatoes.wsu.edu.

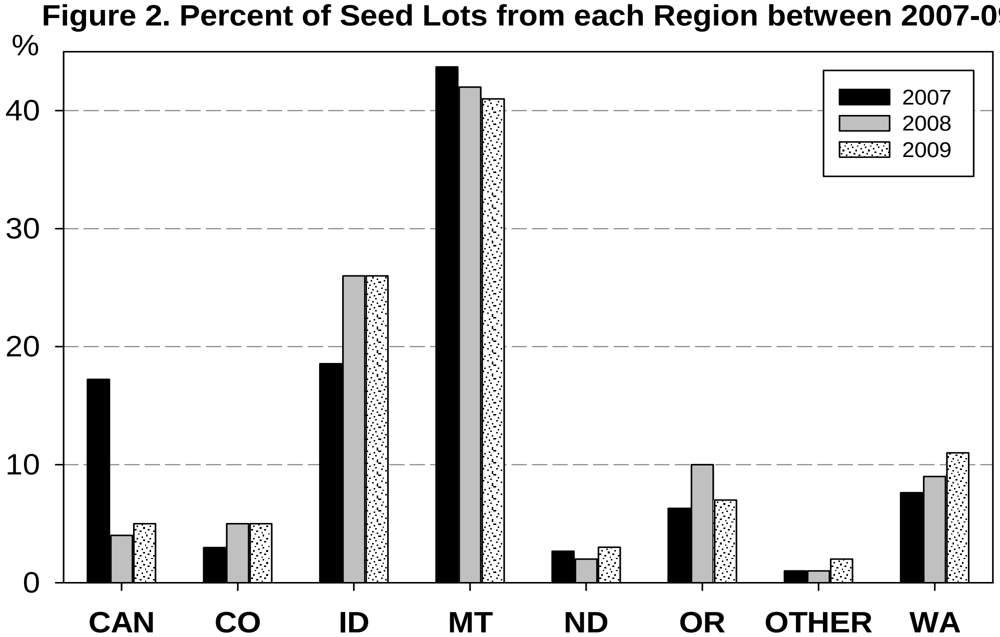
Potato seed lot samples entered into the commercial seed lot trial were up slightly from the previous two years. There were 319 seed lots submitted this year, compared with 316 in 2008 and 314 in 2007 (Figure 1, bars). Potato acreage in 2009 was down 6% from 2008 and 9 percent from 2007 (Figure 1, dotted line).

Figure 1. Number of Potato Seed Lots Entered into the WSU Seed Lot Trial (bars) and WA Acreage (dotted line) Across the Past 19 Years



Canada-supplied seed lots are on the increase following the 2008 reopening of the U.S./Canadian border to Alberta-grown seed potatoes (Figure 2). MT seed lot numbers have declined steadily over the past three years, while WA, ND, and "Other" regions have increased slightly. The interest in new varieties is on the rise and some of these other regions may be experiencing growth as growers search for and buy any and all available seed.

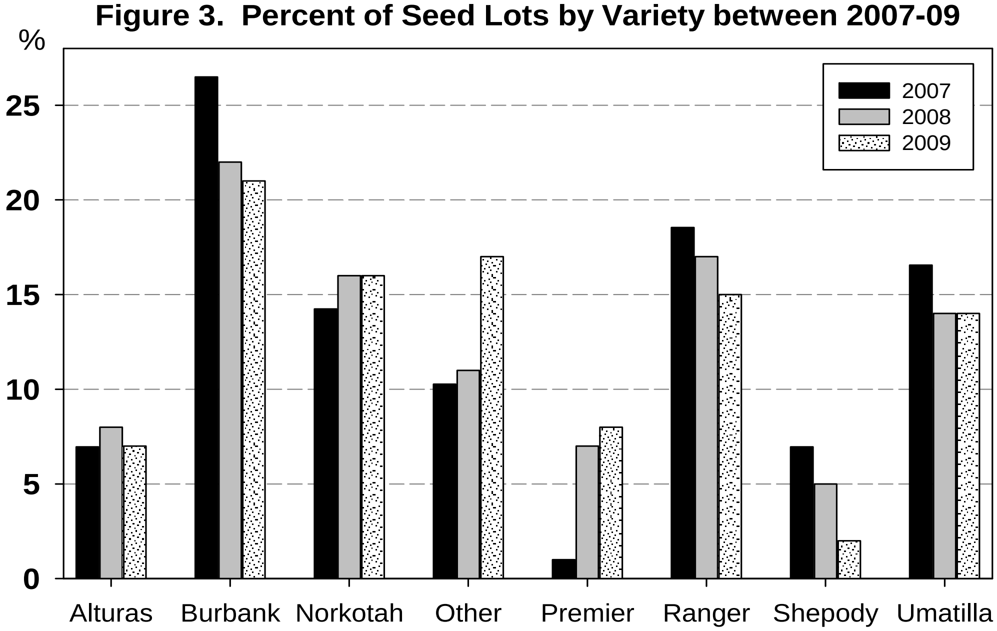
Figure 2. Percent of Seed Lots from each Region between 2007-09



Russet Burbank, Ranger, and Shepody seed lots have experienced a steady decline over the past several years while samples of Premier Russet and "Other" varieties have jumped dramatically (Figure 3). Alturas, Norkotah, and Umatilla seed lot numbers remained mostly unchanged.

Varieties developed by the Northwest Potato Variety Development Program/PVMI accounted for 49% of the seed lots entered into the 2009 trial and included: Premier Russet, Classic Russet, Alpine Russet, Blazer Russet, Clearwater Russet, Highland Russet, Yukon Gem, Western Russet, Alturas, Ranger, Umatilla, and A88338-1.

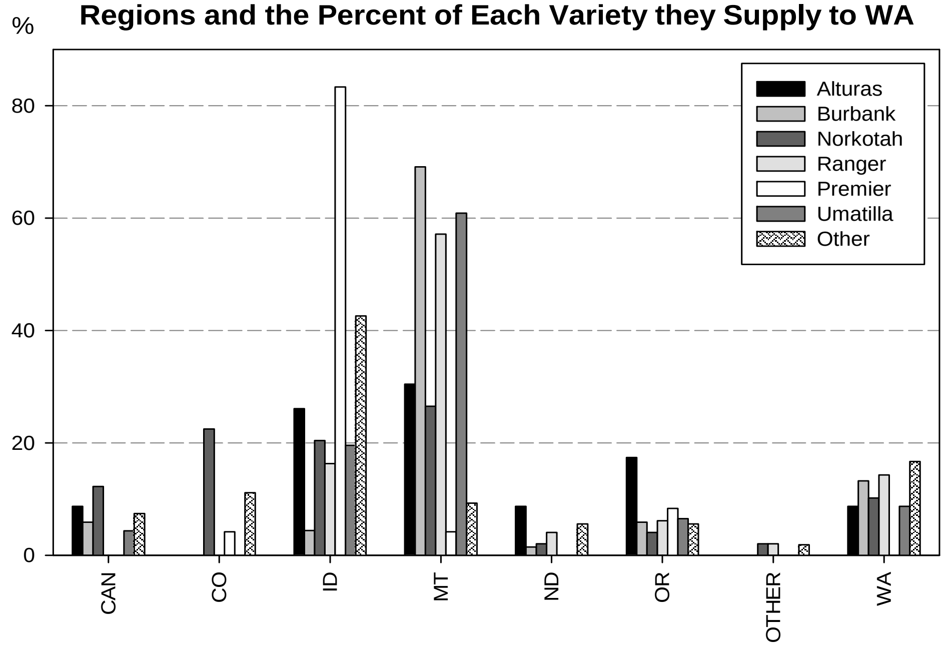
Figure 3. Percent of Seed Lots by Variety between 2007-09



Russet Burbank, Shepody, and Ranger Russet seed lot numbers dropped over the past two years, while Premier Russet and "Other" varieties increased (Figure 3). The "Other" variety category has continued to increase over the past 3 years, possibly indicating an increase in the number of attractive, new cultivars being offered on the market place. For the first time, the "other" category makes up 17% of the varieties entered in the seed lot and is second only to Russet Burbank.

Based on the seed lots received in 2009, Montana, Idaho, Oregon, Washington and Canada continue to provide Washington growers with a wide selection of varieties (Figure 4), while Colorado and the "other" regions appear to specialize by offering fewer varieties. Idaho appears to have contributed the lion's share of Premier Russet. Although it's important to note that the seed lot samples may not provide a fair representation of what is actually available from each seed region. It does, however, represent what many Washington growers purchased from each region.

Figure 4. 2009 Washington Seed Lot Profile - Seed Growing Regions and the Percent of Each Variety they Supply to WA



Disease Content (Tables 1-3, Figures 6 & 7)

Leaf Roll – Leaf Roll continues to decline in incidence and is becoming rare (Table 1). This is likely due to the use of new pesticide chemistries in the seed growing regions. Leaf Roll appears to have become a non-issue in the commercial seed lots.

Table 1	**Percent of Seed Lots Containing Disease by Year**				
	2005	2006	2007	2008	2009
Disease	%	%	%	%	%
Leaf Roll	4	5	3	3	0.6
Black Leg	11	10	14	23	10
Mosaic	45	42	42	39	30

Black Leg – Ten percent of the 319 seed lots in the 2009 trial contained one or more plants showing black leg symptoms, compared to 23% in 2008 (Table 1). Only 1% of the seed lots had 10 or more Black Leg infected plants (Table 2). Similar to 2008, many Premier Russet contained black leg in 2009 (Figure 5) and 5% of the Premier seed lots had severe black leg (>10 plants) (Figure 6.) Because the variety is somewhat new to the system, seed growers may need a few years of trial and error before they determine the best way to grow and harvest Premier while also reducing black leg. Already, we see improvement in Premier when the 2009 seed lot readings are compared to 2008. Idaho and Oregon had the highest occurrence of severe black leg (Figure 7). None of the other regions provided seed lots with severe black leg infection.

Table 2.	2009 Seed Lots with Severe Disease Loads (>10 Plants)	
	Total Lots with Disease	Lots with >10 Infected Plants
Disease	------------------------------%------------------------------	
Leaf Roll	0.6	0
Black Leg	10	1
Mosaic	30	5

Figure 5. For Each Variety, The Percentage of Seed Lots that Contained One or More Infected Plants in 2009

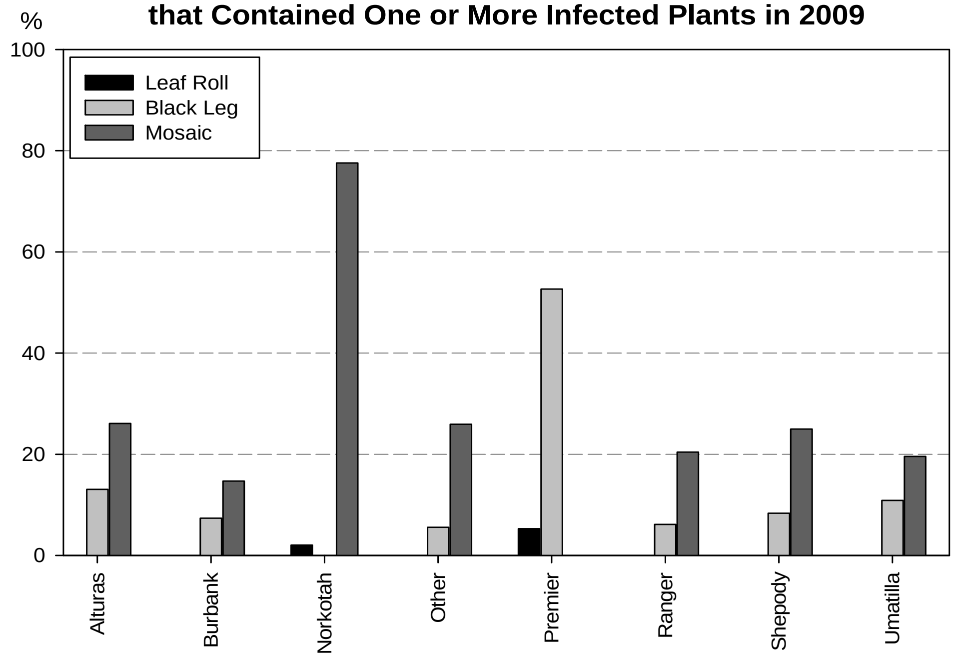


Figure 6. For Each Variety, The Percentage of Its Seed Lots that had Severe Infection - 2009

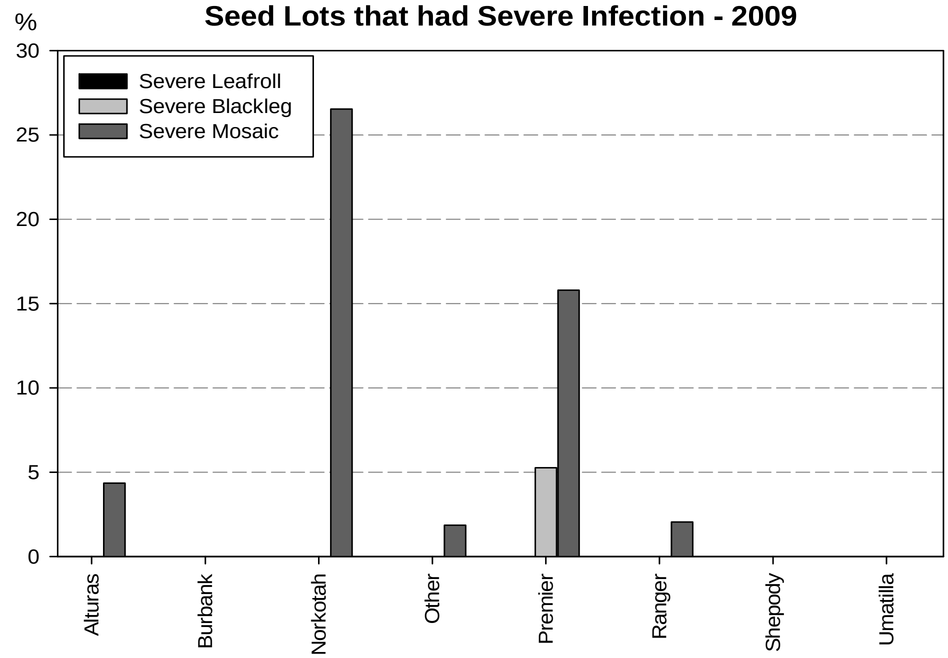
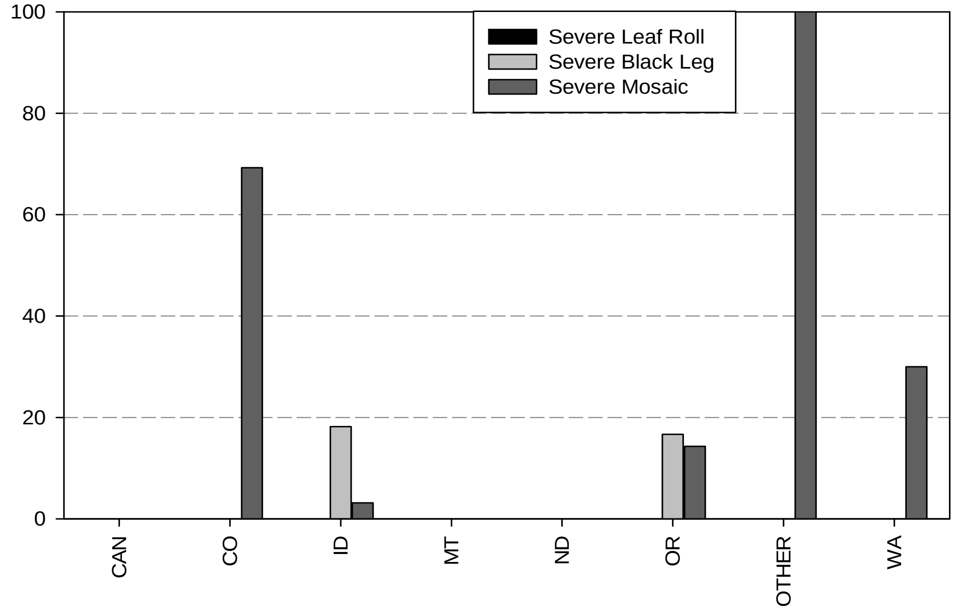
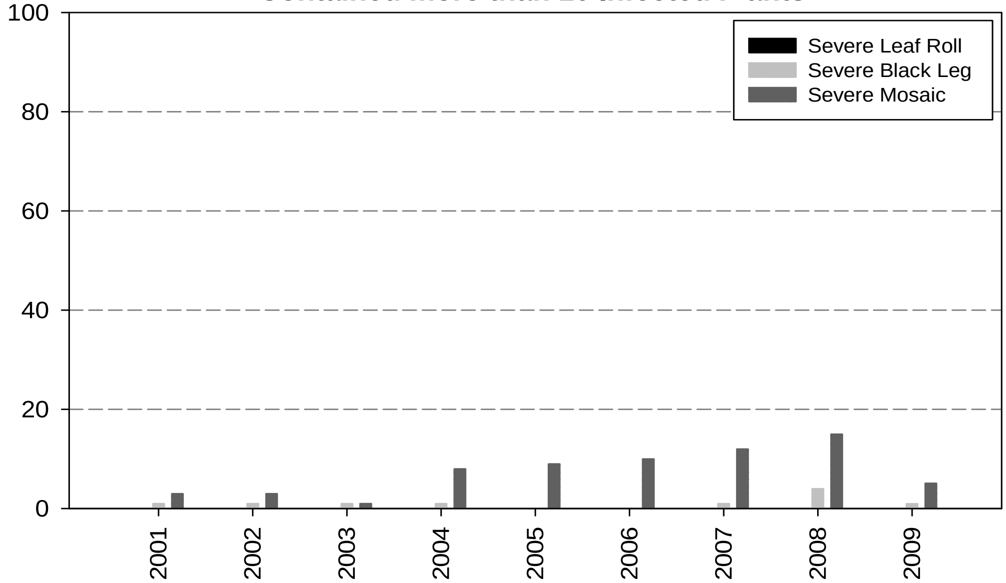


Figure 7. For Each Region, The Percentage of Its Seed Lots that have Severe Infection - 2009



Mosaic – Mosaic remains a concern (Tables 1-2, Figures 5, 6 & 7) but appears to have declined in incidence and severity from the previous five years. Thirty percent of the 2009 seed lots had some level of mosaic (Table 1). However, only 5% of the 2009 seed lots had severe infection compared with 15% in 2008 (Table 2, Figure 8). The increase over the past several years was likely due to the increase in PVY-sensitive varieties like Norkotah and the Norkotah strains and perhaps a change in pesticides and their management. The sudden decrease from 2008 may be the result of intense efforts from state certification agencies and the Western Regional Coordinating Committee for Potato Virus and Disease Control (WERA-89). Both these sets of organizations have been working together to combat all potato diseases, especially PVY. A huge drop in PVY was seen between the 2008 and 2009 Idaho seed lots (data not shown). This is most likely due to an overhaul of their testing procedures. Colorado, WA, and the "Other" locations provided the most seed lots with severe mosaic (>10 plants) in 2009 (Figure 7).

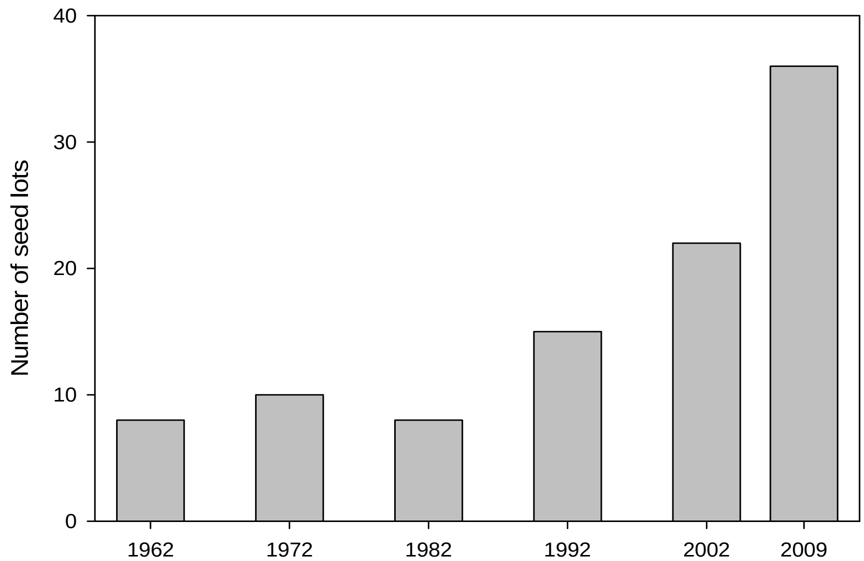
Figure 8. Percent of Total Seed Lots that Contained more than 10 Infected Plants



HISTORICAL DATA

Washington State University has conducted the seed lot trial in cooperation with the Washington State Potato Commission and industry for 45 years (1961-78, 1982-2009). The number of varieties entered in to the trial over the project's duration is shown below (Figure 9). Below, we list the top six cultivars from 1962-2009, listed in 10 year increments, or less. The data showed us what we already suspected – we are growing a lot more varieties now than we were in the past. In 1962, only eight varieties were entered into the trial. In 2009 there were thirty six entries.

Figure 9. Number of Potato Varieties and Variety Strains entered into the WSU Seed Lot Trial Since 1962.



TOP SIX VARIETIES ENTERED INTO THE SEED LOT TRIAL EACH YEAR

1962 : Russet Burbank 84%, White Rose 5%, Early Gem 4%, Dazoc 2%, Others 2%, Norland 1%.

1972: Russet Burbank 66%, Norgold 28%, Kennebec 3%, Others 2%, Red Pontiac 1%, Norchip 1%, Norland 1%.

1982: Russet Burbank 70%, Norgold 15%, Lemhi 7%, Others 2%, Kennebec 2%, Nooksack 2%, Butte 1%.

1992: Russet Burbank 45%, Russet Norkotah 26%, Shepody 13%, Ranger 6%, Others 6%, Nooksack 3%, Yukon Gold 2%.

2002: Russet Burbank 31%, Ranger 24%, Russet Norkotah 13%, Umatilla 13%, Shepody 8%, Others 7%, Alturas 5%.

2008:Russet Burbank 22%, Ranger 17%, Russet Norkotah 16%, Umatilla 14%, Others 11%, Alturas 7%, Shepody 7%.

2009:Russet Burbank 22%, Others 17%, Ranger 16%, Russet Norkotah 16%, Umatilla 15%, Alturas 7%, Premier 8%.

SUMMARY:

Seed lots planted in Washington are entered into the seed lot trial and examined for seed-borne diseases and chemical carry-over. In essence, the seed lot trial serves as a quality control instrument for Washington growers and associated seed producers. It also provides a historical gauge of the health of the seed growing industry.

Overall, PVY incidence and severity dropped from last year. This is likely due to intensive efforts by state certification agencies and the Western Regional Coordinating Committee for Potato Virus and Disease Control (WERA-89). The true test will be whether or not the lower level can be maintained, or even reduced. **Norkotah continues to contain unacceptable levels of PVY**; close to 80% of the seed lots containing one or more plants displaying PVY symptoms. In addition, more than 25% of the infected Norkotah seed lots were loaded with severe PVY infection. Out of all of the main seed contributors to Washington, **Colorado continues to provide the most seed lots infected with PVY**. Potato breeding projects are aware of the problem and are focusing on developing PVY resistant varieties.

On the upside, leaf roll has virtually disappeared. This decline is likely due to better pesticides, management, and certification. The public exposure coming from the Washington State seed lot trial has likely helped "push" many of the seed producers into top-tier crop management; and for that, we are thankful. All other diseases and conditions seem to be acceptably low, although blackleg is still a concern.

Due to successful breeding programs and the on-set of the Plant Variety Protection Act (PVP), seed growers – now more than ever - need to make sure they do their homework before committing to a new variety.

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Disease Resistance in New Tri-State Potato Varieties

Vales, M. Isabel, N. Rick Knowles, Mark .J. Pavek, Jeff .C. Stark, and the Northwest Potato Variety Development Team

The use of disease-resistant potato varieties is an important control method in the context of an integrated pest management strategy. Growers should be able to easily implement this control method by just planting resistant varieties; this would subsequently eliminate or significantly reduce the application of expensive and at times toxic chemicals resulting in cost reductions and protection of the potato crop and the environment. The Pacific Northwest "Tri-State" Potato Variety Development Program is increasingly emphasizing disease/pest resistance in its breeding and selection efforts. The hard work is beginning to pay off by generating new potato varieties that allow growers to diversify their potato crop and at the same time address disease resistance. From 2005 through 2009 the Tri-State Program has officially released 13 new Potato varieties: Blazer Russet, Premier Russet, Highland Russet, Yukon Gem, Gallatin Russet, A84180-8, Classic Russet, Alpine Russet, Clearwater Russet, Owyhee Russet, Red Sunset, Crimson Red, and Purple Pelisse. All varieties developed by the Tri-State Program have been licensed to the Potato Variety Management Institute (PVMI), a non-profit organization working on behalf of the program since 2005, with the goal of enhancing promotion and marketing efforts. Detailed information about these potato varieties can be found at the PVMI website, www.pvmi.org. The main strengths and weaknesses, related with diseases, of potato varieties recently released by the Tri-State Program are highlighted below.

Blazer Russet is an early to mid-season variety notable for its high yield of oblong-long, medium-russeted tubers and resistances to sugar ends, tuber malformations and most internal and external defects. It shows good potential for both processing and fresh markets, with the processing industry viewing Blazer Russet as a replacement for Shepody—an early harvest variety widely grown in the U.S. It is resistant to common and powdery scab and PVX, moderately resistant to tuber late blight and net necrosis, and moderately susceptible to PVY.

Premier Russet is a mid- to late-season variety notable for its high yield, high percentage of U.S. No. 1's, attractive tuber appearance, high specific gravity, excellent fry color from cold storage and resistances to sugar ends, tuber malformations and most internal and external defects. Premier Russet is highly resistant to the accumulation of reducing sugars following long-term storage at 40-45^{o}F, resulting in a low acrylamide-forming potential. Its cold-sweetening resistance allows storage at colder temperatures, thereby prolonging tuber dormancy and quality for processing or fresh pack use. Premier Russet should be useful in both tablestock and processing markets. It is resistant to PVY^{O}, common and powdery scab, moderately resistant to early dying, tuber early blight and soft rot, and susceptible to dry rot.

Highland Russet is a mid- to late-season variety notable for its high yield of large, uniform tubers, moderately high specific gravity and resistances to tuber malformations and most internal and external defects. It has been successfully grown and processed in commercial trials. Fry recovery from the field and storage has been high and it shows good potential for the processing market. Currently, it is being processed by Lamb Weston and J.R Simplot Co. to meet the specific product needs of several of their QSR customers. It is resistant to PVX, moderately resistant to PVY^{O}, common scab, early and late tuber blight, and it is more susceptible to powdery scab than Russet Burbank.

Yukon Gem is a yellow skinned variety with light-yellow flesh and higher yield potential than Yukon Gold (its paternal parent). Total yield across all Western regional sites was significantly greater than Yukon Gold and its merit for fresh pack is comparable to that of Yukon Gold. It is currently being processed into specialty fry products by Lamb Weston and also is being marketed for tablestock use in the Northwest and upper Midwest. Yukon Gem is resistant to PVX, moderately resistant to PVY^O, common scab, early and late tuber blight, and more susceptible to powdery scab than Russet Burbank.

Gallatin Russet is a late maturing selection with medium to heavy russet skin. Compared to Russet Burbank, Gallatin Russet produces substantially greater U.S. No. 1 yields, with similar specific gravity and processing quality. It has much better resistance to Verticillium wilt, PLRV, common scab and soft rot than Russet Burbank, making it a good candidate for organic production, which is its primary use at this point.

A84180-8 is a late maturing, medium-russet cultivar with good culinary quality and good potential for the fresh market. U.S. No. 1 yields for A84180-8 were 26%, 11% and 10% higher than Russet Burbank in eastern Idaho, western and central Idaho, and Washington, respectively. It has good resistance to internal and external defects and has high vitamin C content. A84180-8 has been licensed by a major fresh pack company for production under a trademarked name. It is resistant to common scab, moderately resistant to Verticillium and susceptible to PLRV.

Classic Russet is an early to medium maturing variety with early bulking potential and high yields of oblong-long, medium-russeted tubers having higher protein content than those of standard potato varieties. It produces a very high proportion of U.S. No. 1 tubers, which are very smooth and attractive. It also has moderate specific gravity and resistances to sugar ends, tuber malformations and most internal and external defects. Classic Russet has excellent culinary qualities that are comparable to Russet Burbank. It shows good potential for early processing and fresh markets, with the fresh industry viewing Classic Russet as a potential replacement for Russet Norkotah. In a recent survey, 87% of growers who responded said that they are interested in growing Classic Russet. It is resistant to common scab, moderately resistant to dry rot, and susceptible to PVY.

Alpine Russet is a high yielding, medium to late maturing cultivar with oblong tubers, light russet skin and excellent processing quality following long-term storage. It has moderately high specific gravity, good resistance to sugar ends, and produces significantly lighter colored fries than either Ranger Russet or Russet Burbank out of 45^{o}F storage. Alpine Russet has exhibited lower susceptibility to growth cracks and secondary growth than Ranger Russet and Russet Burbank, particularly under high stress conditions. Alpine Russet is notable for tuber dormancy similar to that of Russet Burbank, making it an excellent candidate for long-term storage, with processing characteristics superior to that of Russet Burbank. It is resistant to common scab, moderately susceptible to dry rot, and susceptible to PVY.

Clearwater Russet is a moderately high yielding, medium-late maturing variety, with oblong-long tubers and an attractive medium-russet skin. Tubers of Clearwater Russet exhibit excellent fry color out of storage which, coupled with their attractive appearance, makes this variety suitable for both processing and fresh market usage. It has high specific gravity and is resistant to cold-induced sweetening and sugar ends as well as most internal and external tuber defects. Clearwater Russet is also notable for having a protein content that is 35% higher than Russet Burbank. It is resistant to tuber late blight and PVX, moderately resistant to Verticillium, common scab and PVY^O, and moderately susceptible to tuber early blight and dry rot.

Owyhee Russet is a medium to late maturing potato clone with long, medium-russeted tubers suitable for both the fresh and processing markets. Owyhee produces total yields that approach those of Russet Burbank, but U.S. No. 1 yields are significantly higher. Owyhee has medium specific gravity, light fry color, few sugar ends, and attractive tuber type. It is less susceptible to black spot bruise than Russet Burbank. Owyhee demonstrates resistance to common scab and moderate resistance to Verticillium wilt, foliar early blight and bacterial soft rot, and is susceptible to PVY.

Red Sunset is a medium maturity potato clone with red skin/white flesh and round tubers suitable for fresh market. It has high yields of U.S. No. 1 tubers, bright skin color, high iron levels, few internal and external defects, low specific gravity and high fresh market merits. A potential weakness is its moderate potential for skinning. It is resistant to common scab, and susceptible to foliar and tuber late blight.

Crimson Red is a medium maturing potato clone with red skin/white flesh and round tubers suitable for fresh market use. The U.S. No. 1 yields of Crimson Red are similar to Dark Red Norland and Red LaSoda; specific gravity is medium but significantly higher than the controls. Crimson Red has bright red skin, few internal and external defects, and high fresh market merits. This cultivar was a retread variety and has been exclusively sub-licensed. It is susceptible to foliar late blight.

Purple Pelisse was competitively sub-licensed by PVMI in 2009 to a southern-Oregon based potato cooperative, Klamath Basin Fresh Direct, with the goal of maximizing the promotion and marketing of this unusual potato. Purple Pelisse is a mid season specialty potato with purple skin, dark purple flesh and high levels of antioxidants. This selection is unique among commercially available purple varieties in that plants set a large number of smooth, small, fingerling-shaped tubers. Tubers have medium specific gravity and are ideal for boiling or roasting whole. Chips made from Purple Pelisse tubers retain their bright purple color and resist fading. It is moderately resistant to common and powdery scab, PVY and net necrosis, and susceptible to PLRV, and foliar and tuber late blight.

Breeding efforts focused on crosses to introgress genetic resistance to diseases: late blight, corky ringspot, PLRV, PVY, PVX, verticillium wilt, early blight, common scab, and zebra chip; nematodes: Root-knot and potato cyst nematodes; and insects: aphids, wireworms, and tuber moth will soon generate additional Tri-State disease/pest resistant potato varieties that would increase the catalog of available options for growers in the U.S. Pacific Northwest and worldwide. Molecular breeding approaches are being implemented to complement and enhance conventional breeding efforts. Resistance traits targeted by the Tri-State Program via marker-assisted selection (MAS) include PVY (Ottoman et al., 2009, Vales et al., 2010 and Whitworth et al., 2009), PLRV (Kelley et al., 2009), Columbia root knot nematode (Zhang et al., 2007), and late blight (*RB* gene). Our conventional disease/pest breeding efforts will benefit tremendously from international and national efforts to implement molecular breeding. It is expected that with the sequencing of the potato genome (http://www.potatogenome.net/ and translational genomic projects (i.e. SolCAP, http://solcap.msu.edu/), biology-based solutions will enhance potato breeding activities.

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applicators must take measures to protect occupants. If you're applying under inversion conditions when there is a house nearby and someone gets sick, we're going to pursue penalties against you. So, you still need to take necessary precautions.

Buffers in 2011 – Buffers won't be required until 2011 but just to give you an idea… at 140# a.i. and 120 acres, the following buffers will be required:

- High Release Ht (over 8'), = 900' buffer
- Medium Release Ht (4 – 8') = 700' buffer
- Low Release Ht solid stream (drizzle boom) <4' = 525'
- Shanked = 225'

EPA has indicated that "credits" might be available that will reduce buffer size, but as far as I can tell most of the conditions and/or practices that could reduce buffers will not be applicable to the Columbia Basin. Let's hope that some of the work that Vince Hebert is doing will justify smaller buffers.

Thank you