WASHINGTON OREGON POTATO CONFERENCE 2017

January 24, 25 & 26, 2017

Three Rivers Convention Center & Toyota Center

Kennewick, WA

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Proceedings of the

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January 24, 25 & 26, 2017

Kennewick, Washington

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Contents

Farming for flavor: The New Potato Imperative

Leif Benson, Oregon's International Culinary Ambassador, four Time Chef of the Year and Chef emeritus

Today we will explore why great culinary qualities in potatoes are important. You could call it "Food for thought." Today's consumers want to know more and more about their food and how and where it's grown, along with a great eating experience.

Potato Sensory Evaluation at Le Cordon Bleu

So, the question is "**What is new with potatoes?**"
Well, for the past 7 years the Oregon Potato Commission and I have conducted sensory evaluations on potatoes at Le Cordon Bleu Culinary School in Portland. We then assembled a panel of professional chefs who have been trained on how to evaluate culinary qualities in potatoes. Since chefs value flavor and culinary qualities, I created a flavor lexicon to help chefs evaluate potato flavors, and I hope it can influence consumer decisions when purchasing potatoes. We gathered a group of up to twenty chefs, growers, and researchers to participate in this program using the flavor lexicon to evaluate taste, texture, aroma and appearance. It is a rare opportunity to taste 50 potato entries side by side all in one sitting. Yet, every potato sensory event that we have done, the panel of chefs and growers has been amazed to find that each potato tastes different, and also has its own culinary qualities.

Goodness Unearthed Award

After these sensory evaluations, the Oregon Potato Commission presented a "Goodness Unearthed Award" for the best tasting potatoes. These potatoes were broken down into four categories: Russet, Red, Yellow, and Specialty. We also evaluated some experimental varieties. These awards can have promotional potential in the market place.

Peruvian/What is Flavor?

A little background
There are about 4,000 Peruvian native varieties that grow on the planet and about 600 varieties grown in the United States. For centuries potatoes have been selected for their taste, texture, shape, and color. Yet all potatoes are not created equally in taste and texture.

So what is flavor exactly? Flavor is made up from **taste and smell.**

Taste is broken down into four parts: **sweet, sour, bitter, and salty**. You could also include a **5th element called umami, which means savory**.

Smell is actually the main determinate of food flavor and the smells of food are potentially limitless. And, there is recent research of a 6th taste category called "**Kokumi**" from a study at Oregon State University at Corvallis, which suggest that we also have taste receptors on our tongue, roof of the mouth, and back of the throat, that allow us to taste starch or carbs. This may explain why potatoes are so cravable, and why we love bread, pasta, and of course potatoes.

Other factors are **temperature and texture** in the perception of flavor. "Terroir," meaning "soil or land" which refers to the environment that the potatoes are grown in, including **soil type, water, and temperature**, can also influence flavor. Potatoes have a very special flavor profile, and every grower has had an opinion about their favorite potatoes to eat.

Types of Flavors/Textures

Some potatoes have many flavor textures; I have listed 50 flavors including: **earthy, soil, herbaceous, celery, toast, astringent, buttery, nutty, smooth creamy, and/or gummy**. Some flavors are desirable and some are not. But we cannot underestimate the satisfaction and the power of potato flavor. The better eating experience consumers have, the more they will buy potatoes.

Remembering Great Taste

Remember when supermarket tomatoes used to taste juicy and strawberries were full of flavor? Potatoes should never go the way of the often tasteless strawberries or tomatoes. Potatoes are one of the most craved foods of all, and are the third most important consumed food on the planet. Supermarkets in Europe have been very active in the attempt to de-comodify and glorify the humble potato. They do this with more attractive packaging as well as guidance on which variety is best for which use. This is vital knowledge for anyone who has accidentally selected a waxy potato when they should have had a non-waxy variety for their purpose.

Potato Flavor/ Culinary Branding

Variety branding is becoming more important, and successful branding can command a premium price. We need to encourage groceries to enhance informational signs instead of specifying them just as red, white, new, russet, or Yukon to avoid making potatoes seem too ordinary. They could potentially sell more potatoes to the public by using different variety names as well as culinary preparation suggestions to go with them. Russet potatoes are wonderfully familiar and comforting. Moving forward I encourage the variety selection process and growers to place high value on flavor and culinary qualities of potatoes that are being considered for the market place.

We are investing in the future of driving consumer interests into choosing to eat potatoes more frequently. I contend that great tasting potatoes do not need many additions to make them taste better. If I have a great tasting potato then all it needs is just a little bit of extra-virgin olive oil, garlic, and a little bit of salt and pepper. Depth of potato flavor is always important. From subtle chestnut to buttery sweet. It doesn't have to be complicated to be delicious. In fact, newly dug potatoes generate a "fresh from the ground flavor" that just can't be beat, and it's a mystery why that is.

Robuchon Potatoes

Chef Joel Robuchon of France, has a number of 3-star Michelin restaurants in France and Las Vegas. He has been called the chef of the century by a French travel guide and is most famous for his mashed potato dish called by his namesake, Robuchon potatoes (using French LaRatte potatoes).

Likewise, with Chef Thomas Keller of the French Laundry and many other top chefs in the United States, almost every chef will have their favorite potatoes for their various dishes.

You can guess that they want great-tasting potatoes. Yet, sometimes potatoes get a bad rap for not being healthy, but we know that potatoes are an excellent source of high-value nutrients. **It's not the potato that's bad, it what we do to them that makes them unhealthy**.

In the spirit of innovation I think there is money to be made in high value gourmet-flavored potatoes. They have outstanding culinary qualities that satisfy chefs and the consumer segment. As farmers markets have become more popular and accessible to the public there is a frenetic burst of interest from growers and the public for more interesting fresh food that is full of flavor! Perhaps we can create the first potato to go viral for its flavor and culinary qualities. That being said, we could use more social media such as Twitter and Facebook to encourage the new generation to consume more potatoes. Consumer education is an ongoing concern, Younger consumers often overlook potatoes due to prep time and negative health concerns brought on by the media. However, progressive growers have come a long way from the days of "one variety fits all." Regarding today's potatoes, will they stand the test of time in terms of taste and versatility?

"Small Potatoes Go Big"

Growers have also made great varieties like small potatoes which have landed among the top 10 food trends for 2017. This could be for many reasons: they're shareable, sociable, and are an innovative platform. There are also many different types within this category like **minis, marbles, and fingerlings**, all of which respond well to roasting, blistering, smoking, and smashing. Small potatoes are perfect for their **skin to flesh ratio**. They generally have a more concentrated flavor. It's not surprising they are included in the **2017 food trends;** they make great bar snacks! Plant based cuisine is a major food trend, few things are better than perfectly salty crisp on the outside and creamy on the inside, the taste of potato goodness.

Heirloom Ozette Potatoes

Many great tasting heritage variety potatoes have disappeared from the market shelves because of, poor yields, disease resistance and long term storage issues, but have been kept alive by specialty growers and home gardeners. Rare old varieties such as Makah Ozette, also known as Anna Cheeka's Ozette, have been resurrected by these specialty growers. The Makah Indians have grown these potatoes for over 200 years, right in Washington State. It is the only potato to be recognized by the **slow food movement** in the United States, and has earned a place in the **Ark of Taste** as an heirloom potato favorite. These heirloom potatoes are revered by chefs for their unique nutty earthy flavor reminiscent of cooked dry beans; they taste like a good earthy smell. Chefs treat them as if they were fine wines.

Al's Place and Smoke's Poutinerie

Undoubtedly chefs have played their part in the potato revival or we would not have seen the addition of rarified items like bulk duck fat in specialty stores that we love for making potato confit or duck fat fries and poutines.

Al's Place in San Francisco is making red skin potato brined French fries that have become a hit, while "**Smokes Poutinerie**" is using yellow flesh potatoes for poutine fries with great flavors and has opened 150 locations in Canada and in the U.S. These are great examples of some of the endless possibilities where potatoes are making their mark. As long as you have a great potato flavor to start, the rest is golden.

The Power of Potato Flavor

As a chef, I believe flavor is one of the most important elements in food. When we consume potatoes, we want to enjoy them for what they are, not for what we put on them. I contend that as we educate consumers on this concept they will respond to taste and potato goodness. After all, we cannot underestimate the satisfaction and the power of potato flavor.

Bottom Line

We want great tasting food, and potatoes play a major role in our food choice satisfaction. We love potatoes.

I would like to close with expressing my gratitude to all farmers and the potato industry for providing high quality produce to chefs and consumers, and carrying on this great tradition of family farming in the Pacific Northwest.

Phosphorus Fertility and Its Effects on the Commercial Production of Potatoes in the Columbia Basin

Chandler J. Dolezal, R.N. Knowles, Zach J. Holden and Mark J. Pavek
Department of Horticulture, Washington State University, Pullman, Washington, 99164-6414, USA

Introduction: Phosphorus (P) is one of the three essential macronutrients required for plant growth and development. Specifically, phosphorus is key in the production of a healthy potato crop where as much as 1 lb P/ac per day is taken up by the plant. Within the plant, phosphorus is used for many basic functions such as protein synthesis, adenosine diphosphate (ADP) phosphorylation to adenosine triphosphate (ATP), and as a key component of cell structure. Due to its relative immobility in the soil and potential to bind with free cations, deficiency can be a common occurrence.

Key legislation has been passed that prohibits the sale of fertilizers that contain phosphorus for homeowner use in Washington. Concern of future legislation that may impact agriculture has spurred the potato industry to be proactive in seeking out options to better manage phosphorus, as well as understand its effect on overall growth, development, and storage characteristics. Through the use of alternative P sources (Microessential Sulfur and Zinc) and P enhancers (Accomplish, Avail), differing application techniques (band, broadcast, fertigation, split application), current season destructive dig surveys, and full term storage analysis, better management of P in potato production can be achieved.

Materials and Methods: All trials conducted used the clone Umatilla Russet with the exception of the post-harvest analysis trial, which included Ranger Russet, Russet Burbank, Sage Russet, Teton Russet, Alpine Russet, and Alturas. Trials conducted during the summers of 2014, 2015, and 2016 investigated the use of alternative products and sources as well as differing application methods to improve phosphorus use efficiency (PUE) in potato production in the Columbia Basin of Washington. The products used were Avail, Accomplish, and Micro Essentials Sulfur and Zinc (MESZ). The differing application methods used were banding, broadcast, fertigation, and split application. Ammonium polyphosphate (10-34-0) was also used as an industry standard with the exception of the broadcast applications that used monoammonium phosphate (11-52-0), to compare to the alternative products and differing application methods along with an untreated control, which did not receive any phosphorus input.

Avail and Accomplish were mixed at the prescribed rates with 10-34-0 and banded shortly after planting, as was the standard 10-34-0. The band consisted of two lines of fertilizer applied via CO_2 injection 2 inches to either sides of the seed piece and 2 inches above it. MESZ was broadcast applied and rototill incorporated into the top 6 inches of soil prior to planting. All products, including the standard, were applied at rates of 50 and 100 lbs of actual phosphorus per acre with exception of the standard, which also included a 200 lbs of actual phosphorus per acre. Nitrogen was added to balance all treatments to account for amounts added from the various products.

For the application methods experiment, banding of 10-34-0 was conducted in a similar manner to that of the Avail and Accomplish treatments via CO_2 injection. Broadcast applications were made via a Gandy fertilizer spreader using 11-52-0 as the standard product. All treatments consisted of a 100 lbs and 200 lbs of actual P per acre along with an untreated control. Treatment took place prior to planting with the fertilizer being incorporated shortly after application through the use of a rototiller in the top 6" of the soil profile. Fertigation (the application of 10-34-0 through irrigation water) was conducted through the use of a mock fertigator system pulled by a tractor. Applications started at 60 days after planting (DAP) and continued until 110 DAP. Split application was a combination of band application and fertigation with 75% of total P being applied via banding and the remaining 25% via fertigation.

The post-harvest analysis study was conducted on tubers that were grown without the input of P as well as the addition of 200 lbs of actual P per acre. Tubers were harvested at 150 DAP and entered into a full term storage analysis. Storage temperature was maintained at 44°F for the length of the study. Tubers were analyzed for tuber P content upon entering storage along with an initial fry analysis. Four subsequent fry analyses were conducted over a six-month storage span at two-month intervals. At each harvest interval, tubers were removed from storage at a sample size of 12 tubers per treatment and cut into fries. An individual fry was selected from each tuber, fried, and then a photovolt reading taken from the stem and bud end of the fry.

A destructive dig trial was conducted during the growing seasons of 2014 and 2015 on the clone Umatilla Russet. Treatments consisted of 0, 50, 100, and 200 lbs of actual P per acre. Digs were started at 60 DAP and continued every other week until 150 DAP. During each dig session, four plants per rep were excavated and canopy mass, root mass, combined tuber mass, tuber number per plant, specific gravity of tubers, stolon number, and stem number were recorded.

During the growing season, petiole and soil samples were collected to assess plant phosphorus status. Along with these samples, emergence counts, stems count, and vine senescence was evaluated during the growing season. Each treatment consisted of 4 reps arranged as a randomized complete block design (RCBD). Three-row plots were used consisting of a border, petiole, and a final harvest row. Plots were 16.67ft long with 34 inch row spacing, except for 2016 when row spacing was changed to 32 inches, and 10 inch seed spacing with a planting depth of 8 inches. All other management practices were conducted consistent with industry standards to ensure no limiting factor was introduced.

Plots were harvested 150 DAP and assessed for total yield, marketable yield, #1 and #2 yield, and culls. Samples were also taken to assess specific gravity and screen for internal defects. Economic return was than determined based on the yield assessment while also incorporating the cost of the individual products.

Results: Data collected from the 2014-16 growing seasons did not demonstrate any significant difference between the products Avail, Accomplish, and MESZ from the industry standard 10-34-0 or the untreated control at either the 50 or 100 lbs P/ac rate. Figure 1 illustrates the main effect of product. When rates of 50 and 100 lbs P/ac were combined, all products provided a significant return over the control (not applying any phosphorus). When economic return was analyzed (Figure 2), all products with the exception of MESZ and Avail provided a greater return than the control, but not from the industry standard 10-34-0.

Data collected for the method of application study for the growing seasons of 2015-16 did not demonstrate a benefit of one application method over another, but applying phosphorus via banding, broadcasting, or split applied provided greater yields than not applying phosphorus at all (Figure 3). Fertigation failed to provide a greater yield than not applying phosphorus at all (Figure 3). All methods of application except for broadcast and fertigation provided a significantly greater return than the control (Figure 4).

In-season destructive digs of plants indicated that all rates increased yield compared to not applying phosphorus at all (Figures 7 and 8). Differences among the rates were not noted and therefore are not displayed.

The post-harvest analysis of seven clones either treated or not treated with phosphorus during a growing season did indicate fry quality differences. Those clones that did receive phosphorus on average accumulated a greater amount of tuber tissue P, with 5 of the 4 significantly so (Figure 9). The average of all clone stem-end fry color demonstrated a trend for those clones that did receive phosphorus to fry darker than those that did not receive any phosphorus (Figure 10). A cultivar specific response was noted, though, as seen in Figures 11 and 12 where Umatilla Russet was frying darker when treated with phosphorus and Alpine Russet fried the same regardless of phosphorus level.

Conclusions: Yield data collected for both the alternative products and method of application trials indicated no advantage to one particular product or application method. In the alternative product study, MESZ, Accomplish, and Avail provided similar yields to those attained by industry standard 10-34-0. The use of any of the products did provide for a greater return than not using anything at all, reaffirming that some amount of phosphorus is required to produce a healthy, productive crop.

Varying the method of application failed to increase PUE in any form. All methods provided a greater yield than not applying phosphorus at all with the exception of fertigation. This would indicate that applying all phosphorus via fertigiation is not a beneficial practice from an economical and sustainability standpoint. Applying phosphorus via banding or broadcast would allow all phosphorus to be put on the crop at the beginning of a season without the need for supplemental applications.

Although it was noted that the general application of phosphorus was beneficial, the destructive digs carried out failed to illicit any differences between rates. This may indicate that current suggested application rates need to be reanalyzed with current cultivars as some form of efficiency might exist within current clones.

The postharvest study did illustrate that those clones receiving phosphorus on average did fry darker than those not receiving phosphorus. Regardless, the phosphorus treated tubers were still at a USDA 0 indicating no economic loss. The response does indicate a physiological response of which the mechanisms need to be further investigated.

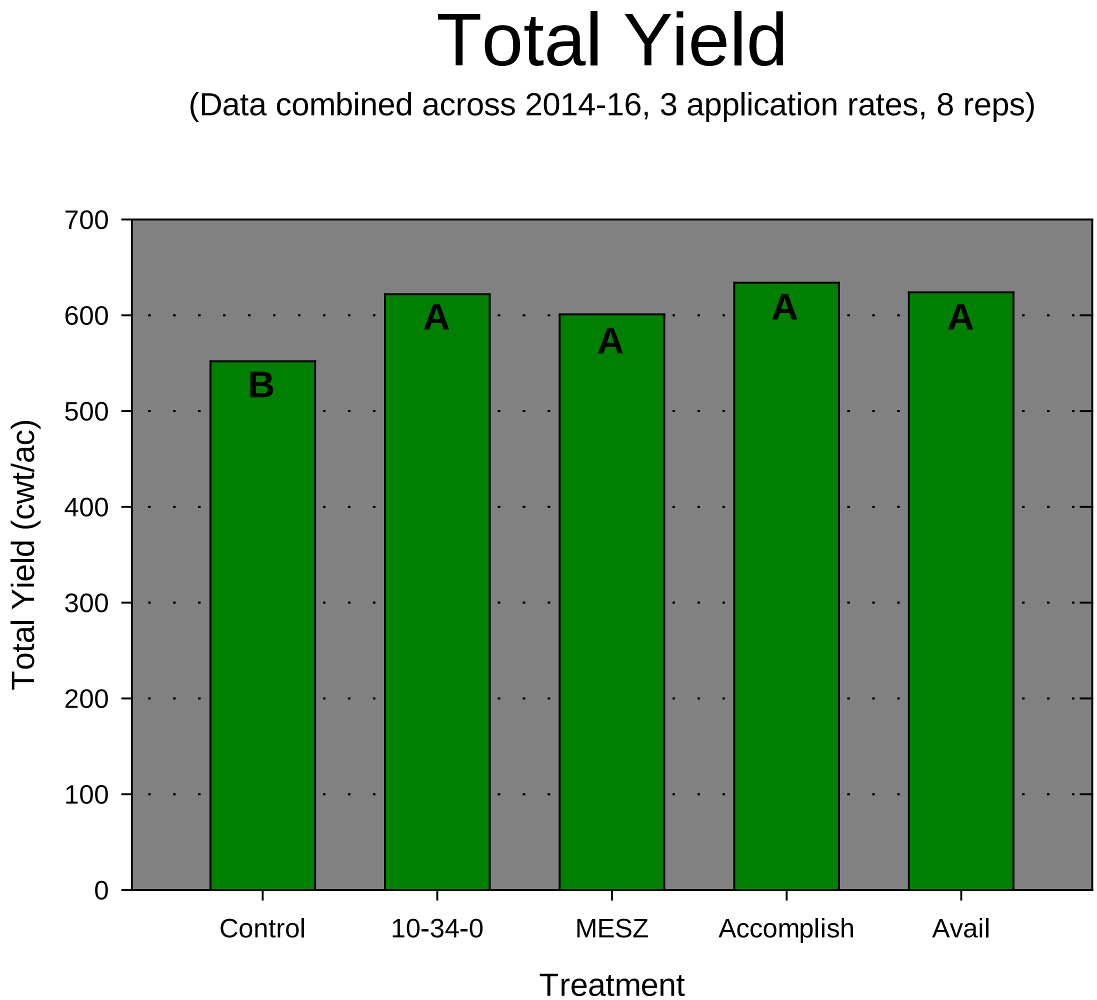

Total Yield
(Data combined across 2014-16, 3 application rates, 8 reps)
Total Yield (cwt/ac)
700
600
500
400
300
200
100
0
B
A
A
A
A
Control
10-34-0
MESZ
Accomplish
Avail
Treatment

Figure 1

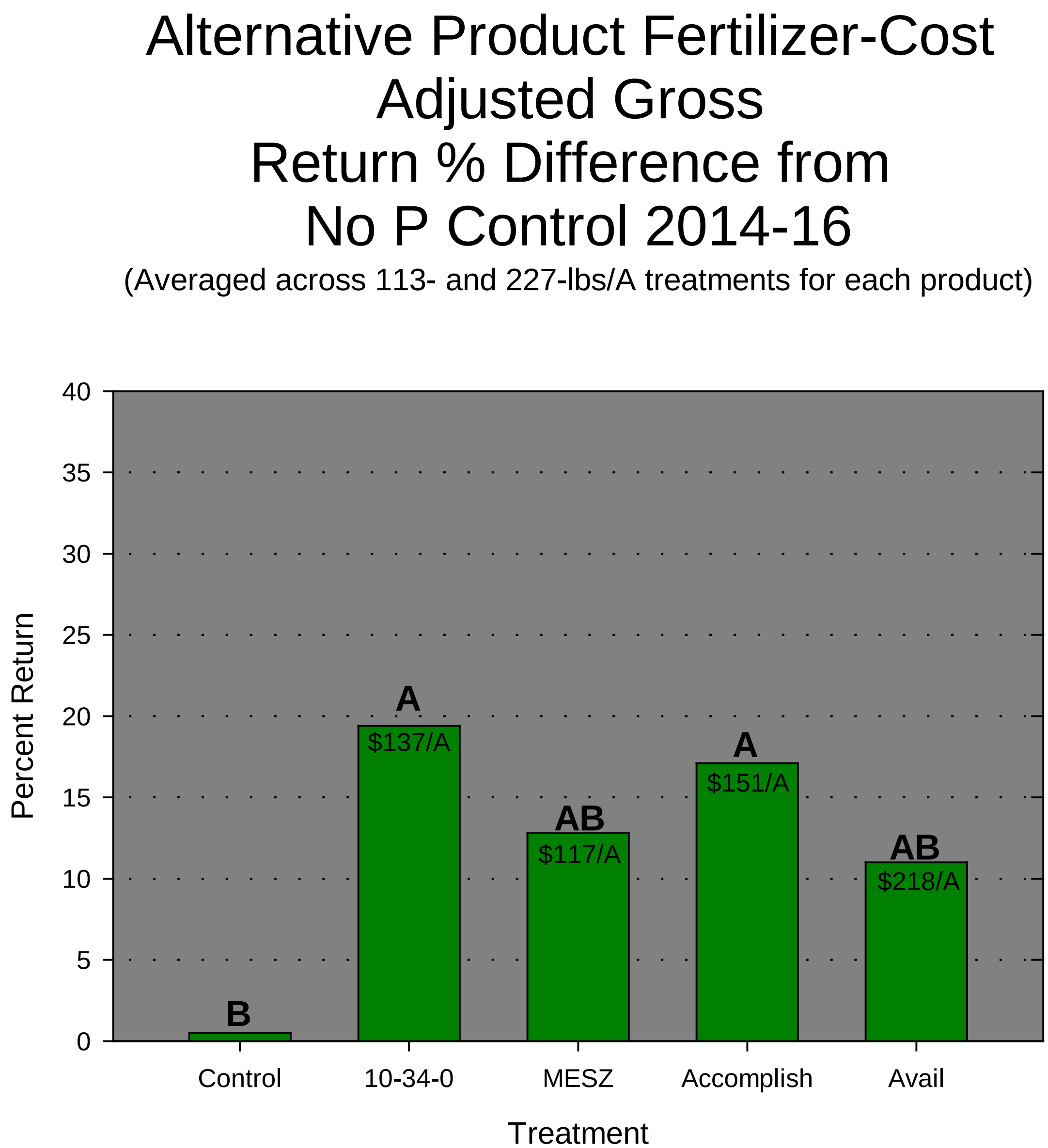

Alternative Product Fertilizer-Cost
Adjusted Gross
Return % Difference from
No P Control 2014-16
(Averaged across 113- and 227-lbs/A treatments for each product)
Percent Return
0
5
10
15
20
25
30
35
40
B
A
$137/A
AB
$117/A
A
$151/A
AB
$218/A
Control
10-34-0
MESZ
Accomplish
Avail
Treatment

Figure 2

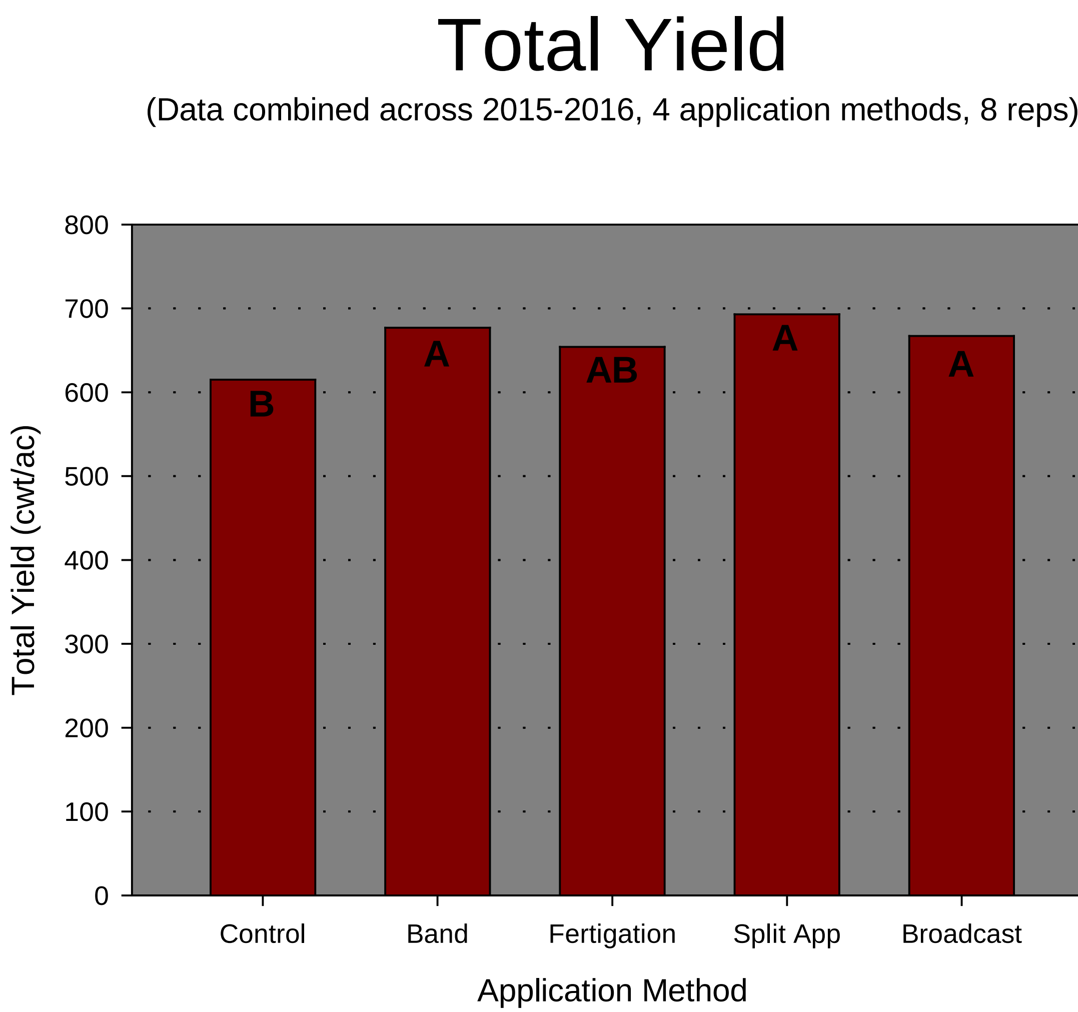

Total Yield
(Data combined across 2015-2016, 4 application methods, 8 reps)
Total Yield (cwt/ac)
800
700
600
500
400
300
200
100
0
B
A
AB
A
A
Control
Band
Fertigation
Split App
Broadcast
Application Method

Figure 3

Application Method Fertilizer-Cost Adjusted Gross Return % Difference from No P Control

(2015-16 data averaged across 227- and 454-lbs/A treatments for each application method)

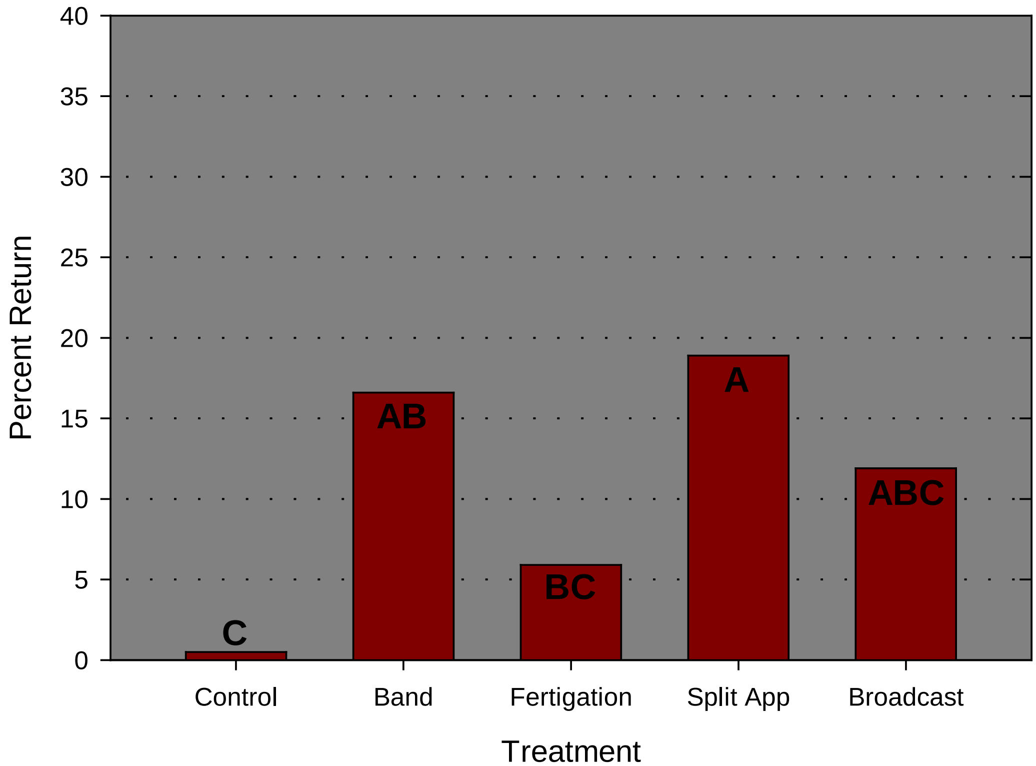


Figure 4

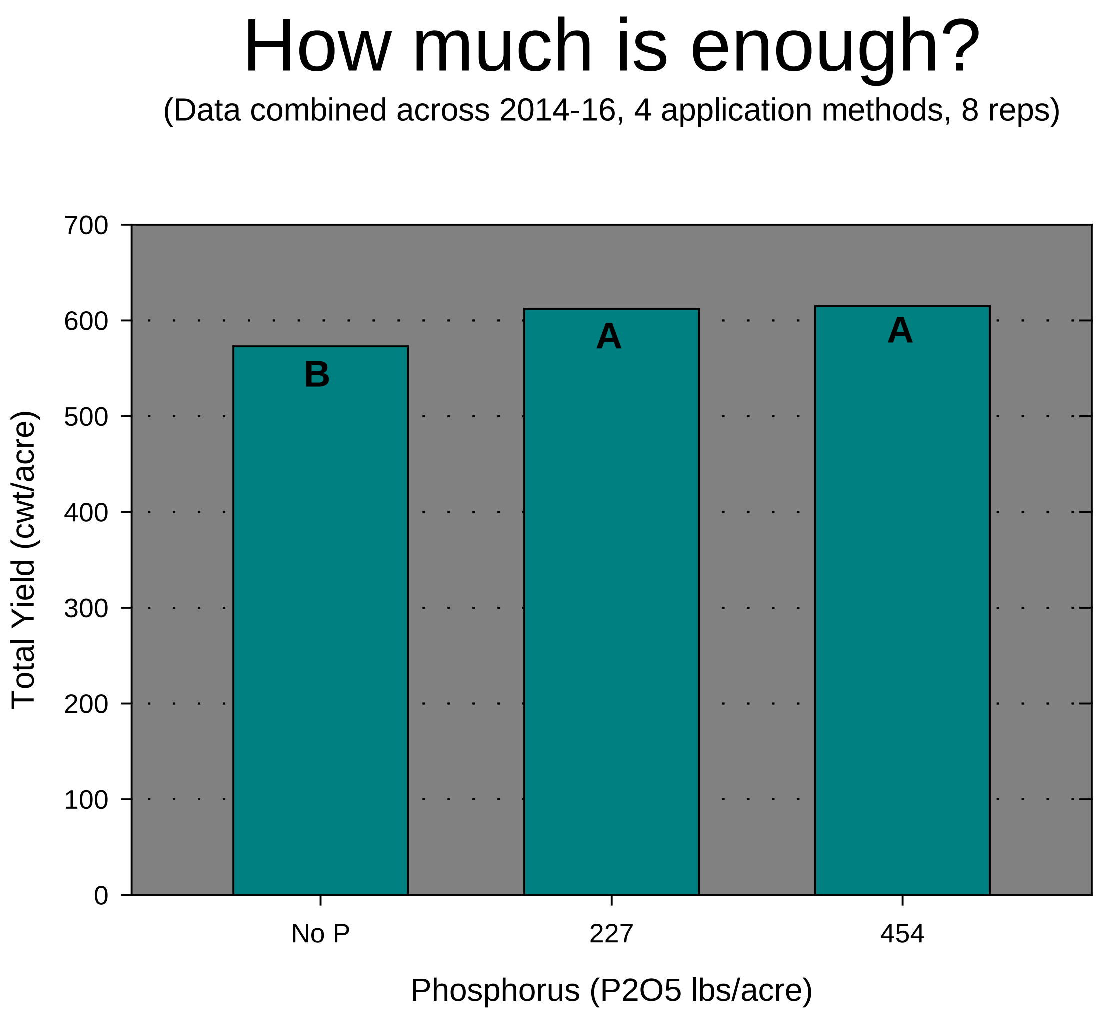
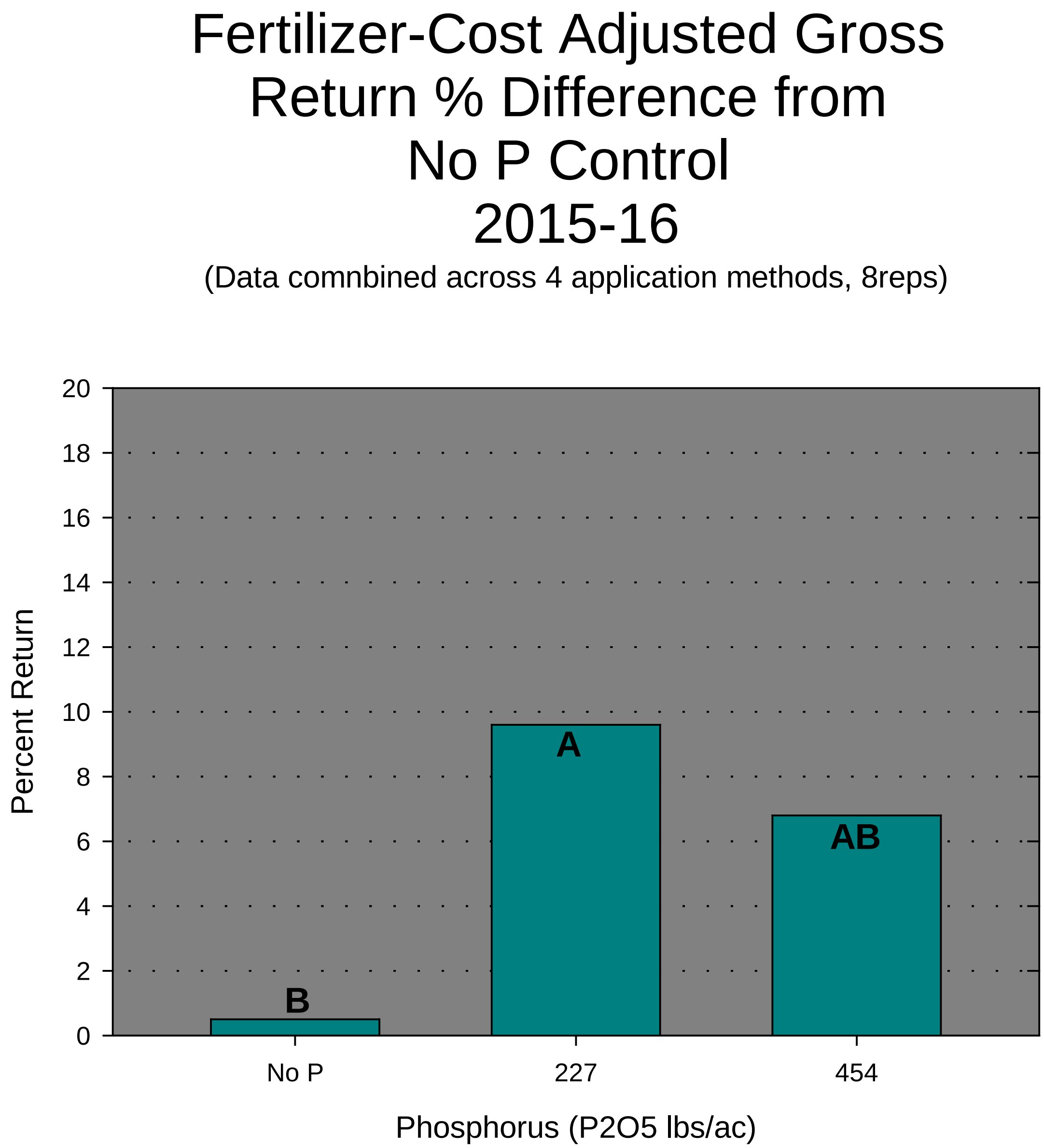

How much is enough?
(Data combined across 2014-16, 4 application methods, 8 reps)
700
600
500
400
300
200
100
0
Total Yield (cwt/acre)
B
A
A
No P
227
454
Phosphorus (P2O5 lbs/acre)

Figure 5



Fertilizer-Cost Adjusted Gross Return % Difference from No P Control 2015-16
(Data comnbined across 4 application methods, 8reps)
20
18
16
14
12
10
8
6
4
2
0
Percent Return
B
A
AB
No P
227
454
Phosphorus (P2O5 lbs/ac)

Figure 6

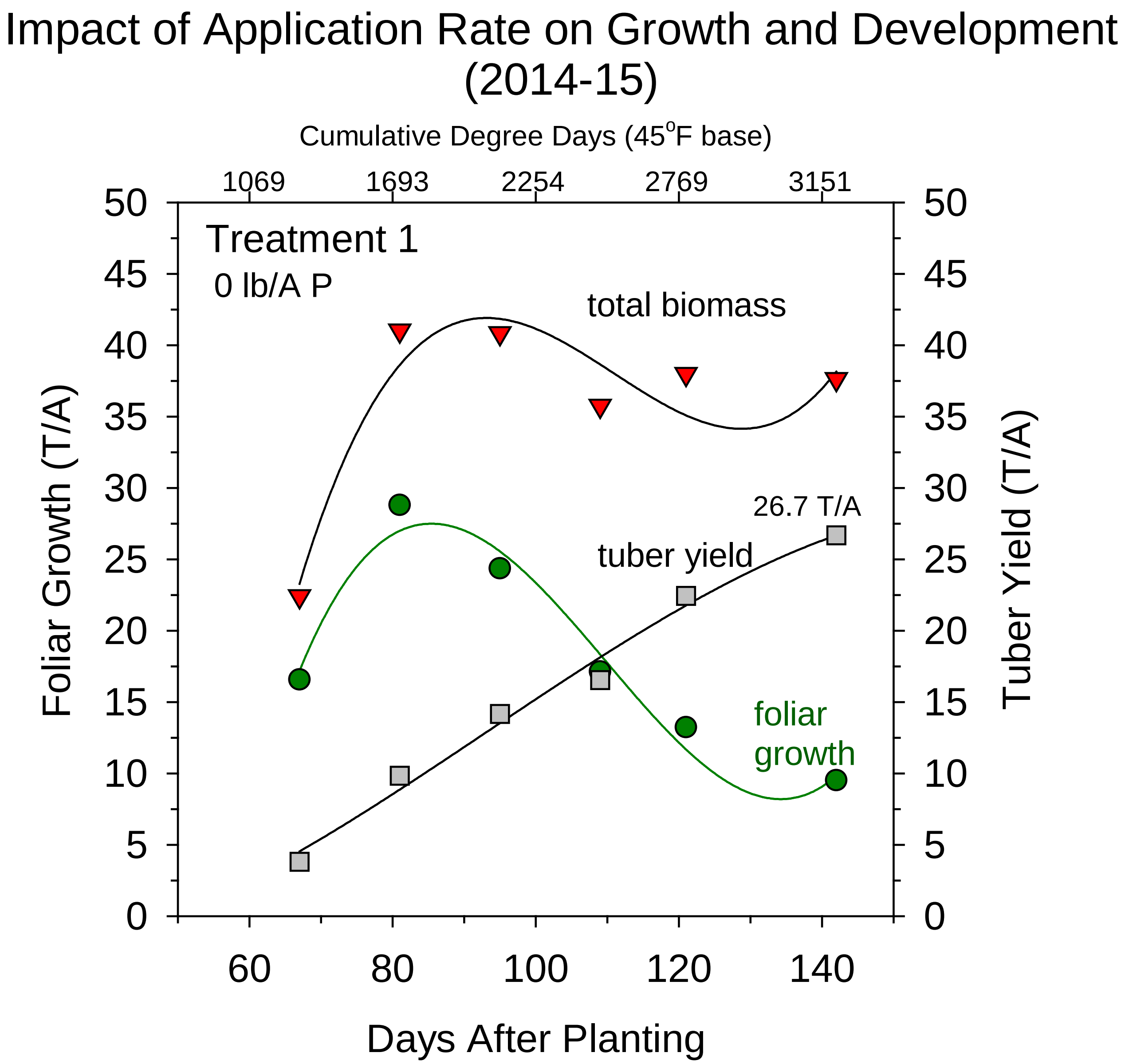

Impact of Application Rate on Growth and Development
(2014-15)
Cumulative Degree Days (45°F base)
1069
1693
2254
2769
3151
Treatment 1
0 lb/A P
total biomass
26.7 T/A
tuber yield
foliar
growth
Foliar Growth (T/A)
Tuber Yield (T/A)
Days After Planting

Figure 7

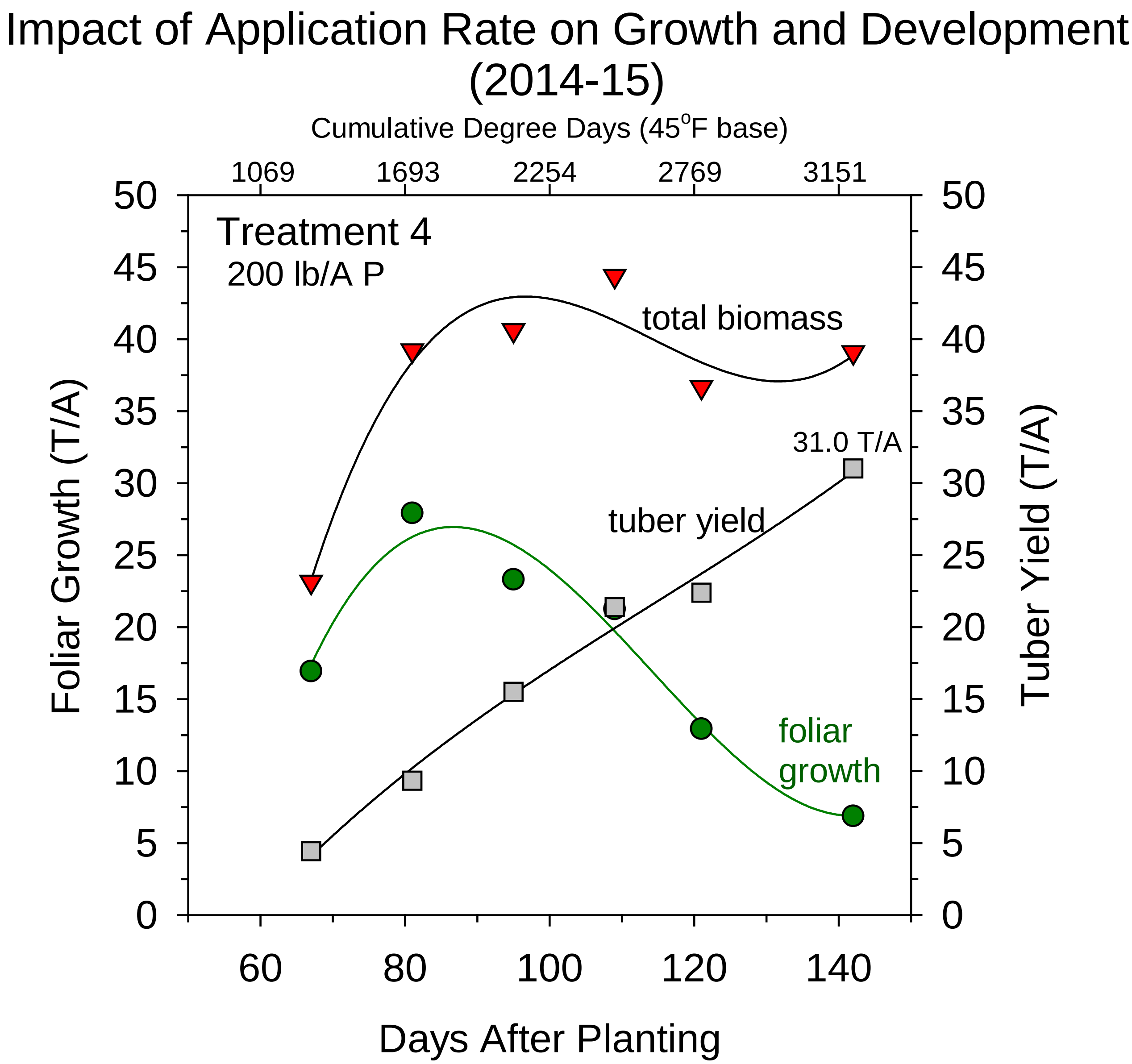

Impact of Application Rate on Growth and Development
(2014-15)
Cumulative Degree Days (45^{o}F base)
1069
1693
2254
2769
3151
Treatment 4
200 lb/A P
total biomass
31.0 T/A
tuber yield
foliar
growth
Foliar Growth (T/A)
Tuber Yield (T/A)
Days After Planting
0
5
10
15
20
25
30
35
40
45
50
60
80
100
120
140

Figure 8

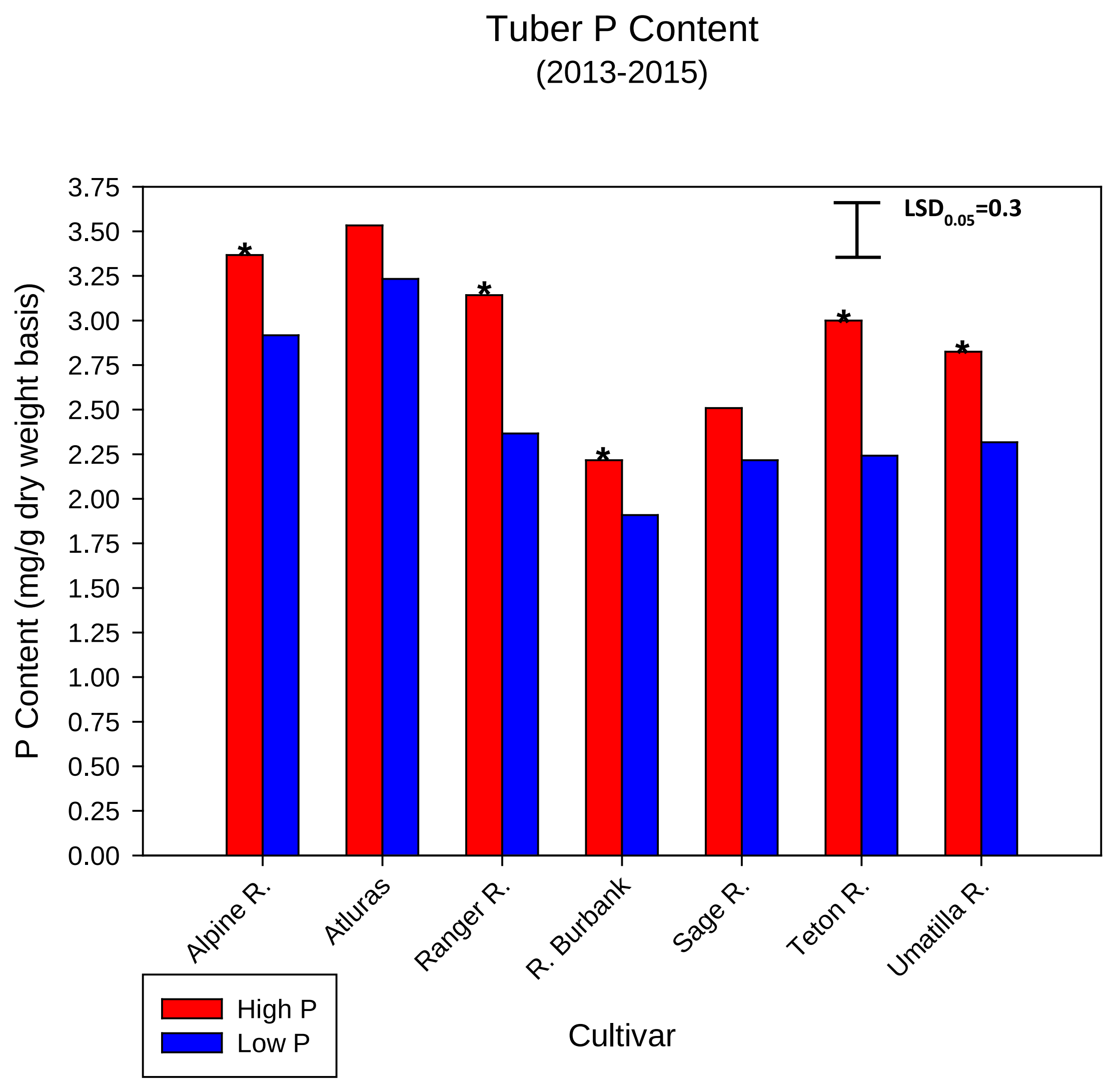
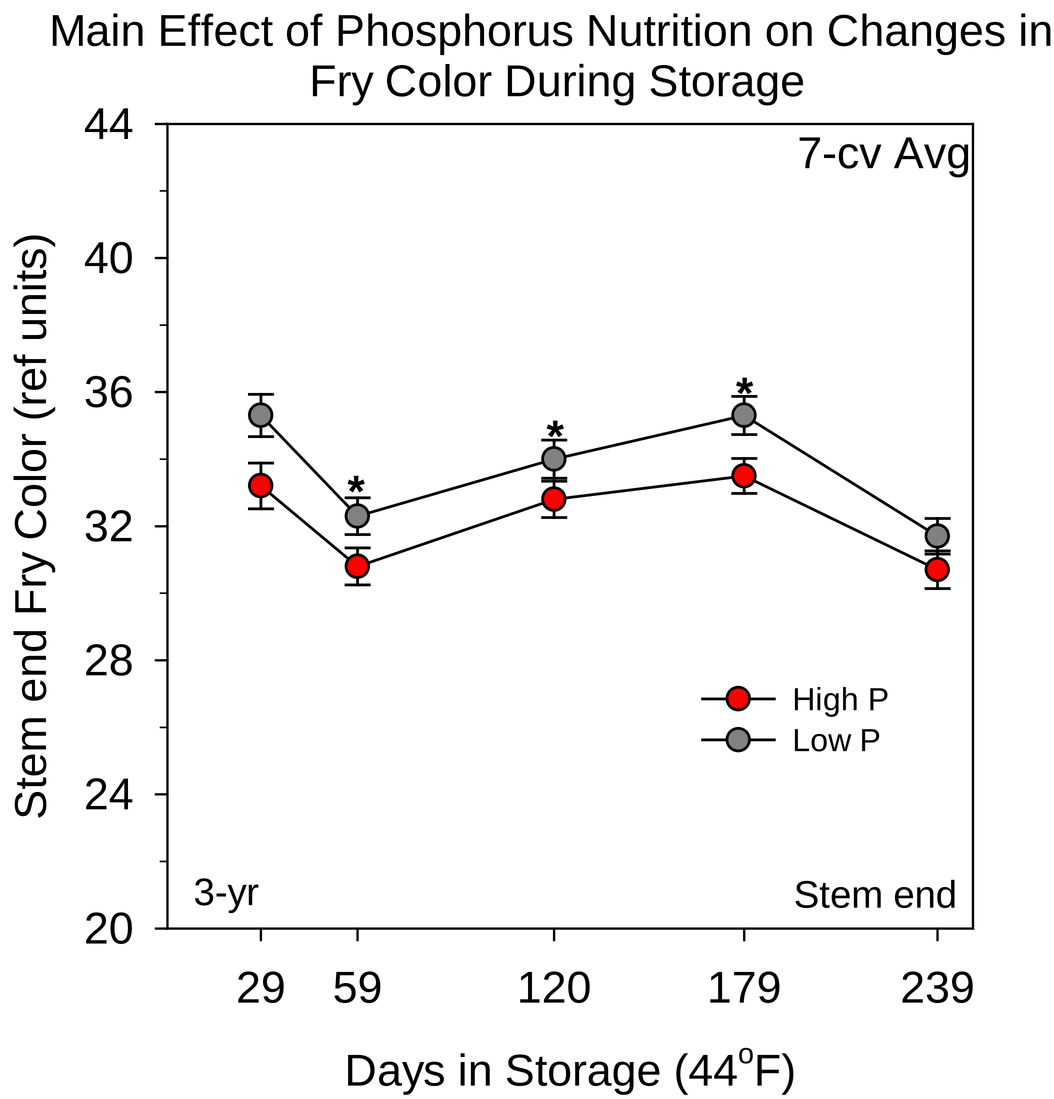

Tuber P Content
(2013-2015)
P Content (mg/g dry weight basis)
3.75
3.50
3.25
3.00
2.75
2.50
2.25
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
LSD$_{0.05}$=0.3
Alpine R.
Atluras
Ranger R.
R. Burbank
Sage R.
Teton R.
Umatilla R.
High P
Low P
Cultivar

Figure 9



Main Effect of Phosphorus Nutrition on Changes in Fry Color During Storage
7-cv Avg
Stem end Fry Color (ref units)
44
40
36
32
28
24
20
*
*
*
High P
Low P
3-yr
Stem end
29
59
120
179
239
Days in Storage (44°F)

Figure 10

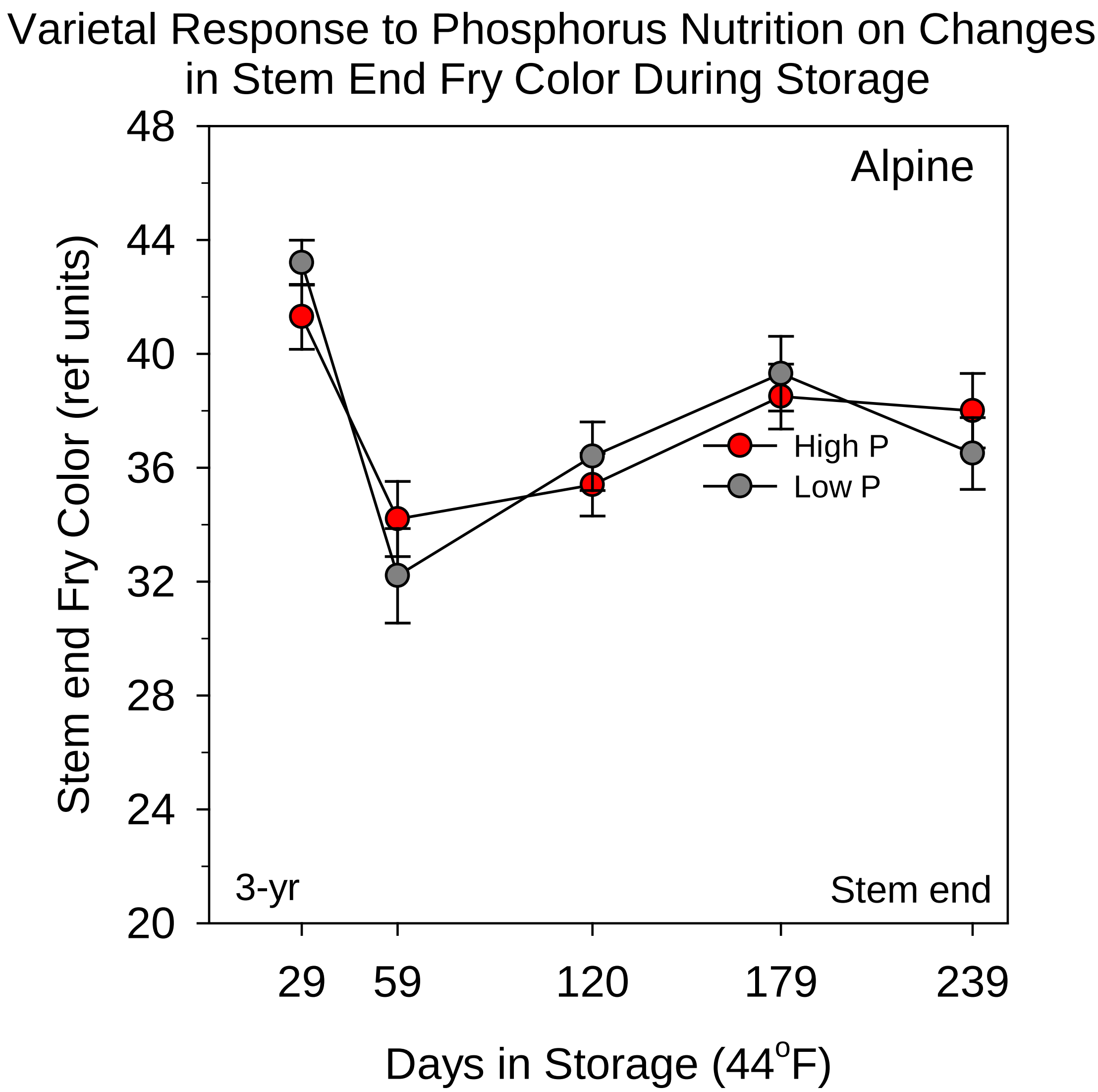
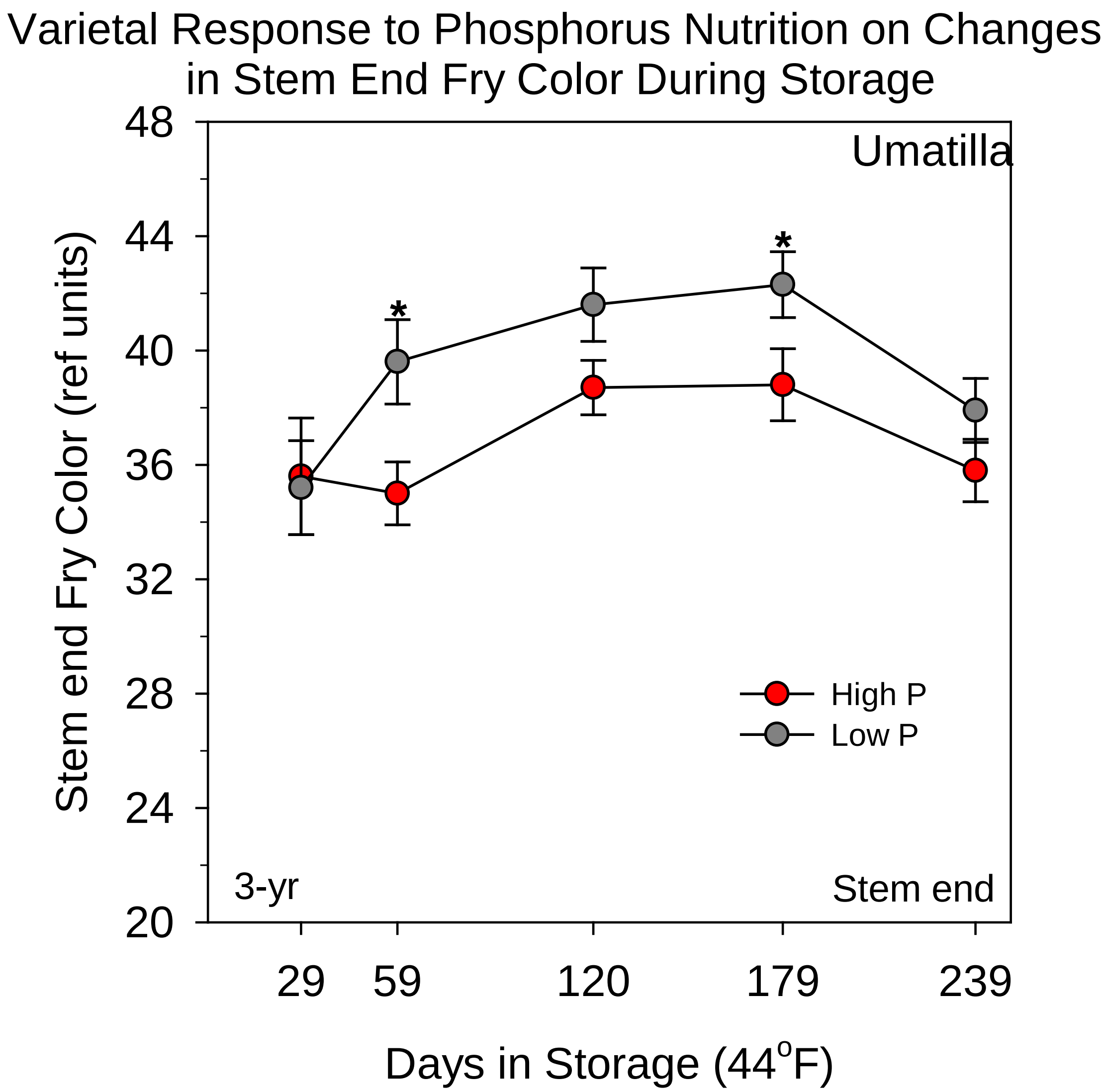

Varietal Response to Phosphorus Nutrition on Changes in Stem End Fry Color During Storage
Alpine
High P
Low P
3-yr
Stem end
Stem end Fry Color (ref units)
Days in Storage (44^{o}F)
48
44
40
36
32
28
24
20
29
59
120
179
239

Figure 11



Varietal Response to Phosphorus Nutrition on Changes
in Stem End Fry Color During Storage
Umatilla
Stem end Fry Color (ref units)
48
44
40
36
32
28
24
20
*
*
High P
Low P
3-yr
Stem end
29
59
120
179
239
Days in Storage (44°F)

Figure 12

Susceptibility of Litchi Tomato and Weedy Hosts to Crop-aggressive Isolates of *Verticillium dahliae* and *Colletotrichum coccodes*

Z.A. Frederick, T.F. Cummings, C.R. Brown, R.A. Quick, and D.A. Johnson

Verticillium wilt, caused by the soil-borne fungus *Verticillium dahliae*, is one of the most important diseases of potato in North America (Agrios 2005; Omer et al. 2008). Development of Verticillium wilt outbreaks depends on the number of microsclerotia in potato field soil prior to planting, the presence of a susceptible host, and an environment conducive to infection (Schnathorst 1981). Reducing the number of *V. dahliae* microsclerotia, or limiting their ability to germinate, is an important consideration prior to planting potatoes (Mace, Bell, and Beckman 1981).

Successful Verticillium wilt management hinges on the combined effects of chemical treatments (soil fumigants), suppressive soils, the use of resistant or moderately resistant cultivars, and irrigation management (where applicable) (Johnson and Dung 2010; Pegg and Brady 2002). *Verticillium dahliae* infection can occur whenever microsclerotia are present in soil, but epidemics of Verticillium wilt of potato typically arise when a minimum of 5 to 30 viable microsclerotia per gram of soil are present (Powelson and Rowe 1993). The disparity in Verticillium wilt severity and the number of microsclerotia in soil has been attributed to *V. dahliae* aggressiveness (Mace, Bell, and Beckman 1981; Schnathrost 1981).

Certain *V. dahliae* isolates are considered more aggressive than other isolates when more severe symptoms or greater numbers of microsclerotia are produced within one host compared to other plants (Douhan and Johnson 2001). Repeated infection of the same host by the same *V. dahliae* isolate is thought to accentuate aggressiveness (Bhat and Subbarao 1999). Individual *V. dahliae* isolates that are aggressive to a particular host, such as potato, are called host-adapted pathotypes (Dung et al. 2013; Pegg and Brady 2002), and is sometimes abbreviated to pathotype for ease of explanation.

Weedy hosts such as black nightshade and hairy nightshade are important to potato production in the Pacific Northwest because of their ability to directly compete for resources and space (Alvarez and Hutchinson 2005). These weedy hosts are also known hosts for *V. dahliae* (Woolliams 1966). An understanding of the interaction of aggressive isolates of *V. dahliae* with weedy hosts is unknown, yet important to successful long-term management of Verticillium wilt of potato because locations where *Verticillium*-susceptible weedy hosts grow in the potato field could pose greater risk of increased initial inoculum from *V. dahliae* aggressive to potato in subsequent years. Knowledge of the location of microsclerotia from aggressive *V. dahliae* isolates are likely to be distributed in a field could be used to direct management strategies to provide greater Verticillium wilt control.

The Pale Cyst Nematode (PCN, *Globodera pallida*) is also an important soilborne potato pathogen (Dandurand 2013; Timmermans et al. 2007). PCN is a regulated pathogen under a Federal Domestic Quarantine Order from USDA Animal and Plant Health Inspection Service and the Idaho State Department of Agriculture (Dandurand 2013, https://www.aphis.usda.gov/aphis/ourfocus/planthealth/plant-pest-and-disease-programs/pests-and-diseases/SA_Nematode/sa_potato/ct_pcn_home). Litchi tomato (*Solanum sisymbriifolium*) is a trap crop for PCN (Dandurand 2013; Scholte and Vos 2000; Timmermans et al. 2007). Trap crops are defined as plants that release root exudates that stimulate nematode egg hatch but are not a host to the nematode (Dandurand 2013; Timmermans et al. 2007). Understanding the interaction of litchi tomato and soilborne potato diseases such as *V. dahliae* and *C. coccodes* is important to potato crop rotation sequences if litchi tomato is going to be as a PCN trap crop to avoid increasing soilborne potato pathogen inoculum.

The objectives of this study were to: (i) identify the susceptibility of 16 weedy hosts from the Columbia basin to eight *V. dahliae* isolates and (ii) identify weedy hosts where the potato or mint pathotype produce greater numbers of microsclerotia compared to the other *V. dahliae* isolates. The objectives of this study were to also (i) quantify inoculum production density of two pathotypes of *V. dahliae* and an isolate of *C. coccodes* in stems and roots of greenhouse-grown litchi tomato plants to potato cvs. that differ in susceptibility to *V. dahliae*, and (ii) evaluate litchi tomato grown in tandem with potato in field soils infested with endemic *C. coccodes* and *V. dahliae* populations to determine if microsclerotia are formed within stems and roots.

Susceptibility of weedy hosts to crop-aggressive isolates of *V. dahliae* under greenhouse conditions.

Methods. Four greenhouse trials were established in 2014 to 2016 to determine the susceptibility of weedy hosts to crop-aggressive isolates of *V. dahliae*. Sixteen weedy hosts were evaluated for susceptibility to *V. dahliae* and number of microsclerotia produced when infected with one of eight *V. dahliae* isolates (Table 1). The eight *V. dahliae* isolates were from six different crop hosts and included isolates that were aggressive on mint or potato, called the mint and potato pathotypes, respectively. Two crop hosts were also employed: eggplant as a universally susceptible control to ensure isolate infectivity was maintained and potato to confirm the aggressiveness of the potato pathotype was maintained. Weedy hosts and potato seedlings no greater than 8 cm in length were inoculated by submerging the hypocotyl and primary root in agitated conidial suspension of one *V. dahliae* isolate at a concentration of approximately 1.0 X 10^6 colony forming units (CFU)/ mL for 2 to 3 seconds. Weedy and crop host seedlings were then directly transplanted into moistened soilless potting medium in 3.79 liter pots and arranged in a randomized complete block design with three blocks. The plants were allowed to grow for four months before stems and roots were harvested separately and were dried to facilitate the formation of microsclerotia. Dried stems and roots were ground separately and one gram of dried, ground plant parts were placed on a semiselective medium designed for *V. dahliae*. Colony Forming Units derived from microsclerotia of both pathogens were counted.

Results. The *V. dahliae* potato pathotype (isolate 653) produced more microsclerotia than other *V. dahliae* isolates within black nightshade in three of four trials (Fig. 1). The *V. dahliae* isolate from tomato (isolate 461) produced more microsclerotia than other *V. dahliae* isolates within wild oats in two of three trials (Fig. 1). Greater numbers of microsclerotia from the *V. dahliae* isolate from tomato (isolate 461) were observed than other *V. dahliae* isolates in pigweed tumble, large crabgrass, and henbit (Fig. 1) but only in one trial each. Other nightshade weedy hosts, such as bittersweet nightshade, did not produce many microsclerotia (<5 microsclerotia) when infected with any of these *V. dahliae* isolates in either trial (data not shown). Conversely, weedy hosts such as eastern black nightshade and hairy nightshade were susceptible to infection by six of eight and all eight *V. dahliae* isolates, respectively, although no one isolate produced more microsclerotia than the seven other isolates (data not shown).

Susceptibility of Litchi Tomato to Crop-aggressive Isolates of *Verticillium dahliae* and *Colletotrichum coccodes* under greenhouse conditions.

Methods. Greenhouse trials were established in 2013 and 2014 to determine the response of litchi tomato to *C. coccodes* and aggressive pathotypes of *V. dahliae* from the Columbia Basin. Two isolates of *V. dahliae* (potato and mint pathotypes) and an isolate of *C. coccodes* were selected for experimentation, as well as the potato cultivars Russet Alturas, Ranger Russet, and Russet Norkotah as resistant, moderately resistant, and susceptible hosts, respectively, to *V. dahliae*. Microsclerotia (30 microsclerotia/g) of *V. dahliae* or *C. coccodes* were mixed with soilless potting mix and litchi tomato seedlings and sprouted potato tubers were planted into the infested potting mix. Plants were arranged in the greenhouse in a completely randomized design and allowed to grow for four months before plants were dried to facilitate the formation of microsclerotia. Dried plants were ground and one gram of dried, ground plant parts were placed evenly on the surface of a semiselective medium designed for *V. dahliae*. Colony forming units derived from microsclerotia of both pathogens were counted.

Results. Greater numbers of microsclerotia were observed for the *V. dahliae* potato pathotype than the mint pathotype for all potato cultivars (Ranger Russet, Russet Alturas, and Russet Norkotah) in the greenhouse the in 2013 ($P \leq 0.05$, Fig. 2). The number of *V. dahliae* microsclerotia of the potato pathotype was less in litchi tomato than each of the potato cultivars Ranger Russet, Russet Alturas, and Russet Norkotah the in 2013 ($P \leq 0.05$, Fig. 2). Litchi tomato planted in soilless mix infested with either pathotype of *V. dahliae* was infected, but the number of microsclerotia did not differ between either *V. dahliae* pathotype in litchi tomato (Fig. 2).

Greater numbers of microsclerotia for the potato pathotype of *V. dahliae* than mint pathotype were observed from Russet Norkotah and Ranger Russet roots in 2014 ($P \leq 0.05$, Fig. 3). Otherwise, there were no differences in the number of *V. dahliae* microsclerotia in Russet Alturas, Russet Norkotah, and Ranger Russet stems, regardless of pathotype, which is inconsistent with results in 2013 (Fig. 2). Greater numbers of *V. dahliae* potato pathotype microsclerotia were observed in stems and roots of Russet Norkotah than litchi tomato ($P < 0.0001$, Fig. 3). Otherwise, the amount of *V. dahliae* microsclerotia did not differ between any potato cultivar and litchi tomato, regardless of *V. dahliae* pathotype. This is in contrast to Litchi tomato having fewer *V. dahliae* CFU of either pathotype than all potato cultivars in 2013 (Fig. 2). Symptoms of Verticillium wilt on litchi tomato were not observed in either greenhouse trial (data not shown).

The number of microsclerotia of *C. coccodes* from stems was significantly lower in litchi tomato than Ranger Russet, Russet Alturas, and Russet Norkotah in 2013 ($P \leq 0.05$, Fig. 4). No differences were noted between the *C. coccodes* microsclerotia from stems or roots of any of the potato cultivars and litchi tomato in 2014 (Data not shown). No symptoms of black dot were observed on litchi tomato grown in the greenhouse (data not shown).

Evaluation of litchi tomato susceptibility to *V. dahliae* and *C. coccodes* under field conditions.

Methods. A field trial was conducted to confirm the susceptibility of litchi tomato to *V. dahliae* and *C. coccodes*, and the relative amounts of microsclerotia produced from infection in litchi tomato compared to potato cultivars. Field soil was naturally infested (5 to 15 *V. dahliae* or *C. coccodes* microsclerotia/g). Litchi tomato transplants were planted in a randomized complete block design in Prosser, WA with potato cultivar Russet Burbank in 2015. Litchi tomato and potato plants were allowed to grow from April to August, and were harvested in August and dried. Dried plants were ground and the number of microsclerotia of both *V. dahliae* and *C. coccodes* were determined by plating dried, ground plant matter on a semiselective medium as previously described.

Results. Greater numbers of *V. dahliae* microsclerotia were observed in stems and roots of Russet Burbank than litchi tomato at Prosser, WA in 2015 ($P < 0.05$, Fig. 5). The number of *C. coccodes* microsclerotia did not differ between stems of either plant at Prosser, WA. Greater numbers of *C. coccodes* microsclerotia were observed in roots of Russet Burbank than litchi tomato at Prosser, WA in 2015 ($P < 0.05$, Fig. 6). No symptoms of Verticillium wilt and black dot were observed on litchi tomato grown in the field (data not shown).

Discussion:

Litchi tomato was confirmed as a host for both *V. dahliae* and *C. coccodes*, as indicated by the presence of both pathogens in stems and roots of test plants. Microsclerotia production of *V. dahliae* in litchi tomato was consistently less than in Russet Norkotah and equivalent to less than the production in Ranger Russet. There was no difference in the number of microsclerotia between the mint and potato pathotypes of *V. dahliae* when infecting litchi tomato in the greenhouse. Infected litchi tomato contained fewer *V. dahliae* microsclerotia than Russet Burbank potatoes planted next to them in the field in Prosser, WA. Consequently, if litchi tomato is used in rotation with potato production, more microsclerotia of the potato pathotype would not be produced than the mint pathotype. Widespread planting of litchi tomato will likely return some microsclerotia of *V. dahliae* to soil, but less than susceptible potato cultivars and not necessarily of a pathotype that is aggressive on potato.

The observation of few *C. coccodes* microsclerotia generated in infected litchi tomato and absence of black dot symptoms on inoculated plants in the greenhouse was consistent with the same observations of few *C. coccodes* microsclerotia and no black dot symptoms in field-grown litchi tomato. Widespread planting of litchi tomato will likely return some microsclerotia of *C. coccodes* to soil, but less than susceptible potato cultivars.

Different sets of litchi tomato plants were evaluated in the experiments in 2013 and 2014, and they likely varied in resistance to the two pathotypes of *V. dahliae*. The difference in litchi tomato susceptibility to the *V. dahliae* potato pathotype could be attributed to the lack of genetic uniformity in seed. Each litchi tomato plant is unlikely to be genetically uniform because the litchi tomato seeds used for the experiment were from open pollinated plants grown in the field.

A broad range of weedy hosts was evaluated for *V. dahliae* susceptibility in the first two trials. The third and fourth trial focused on nightshades because of the interesting result of the interaction of black nightshade with the potato pathotype of *V. dahliae*, and questions were raised if that observation was consistent with other nightshades. Every weed tested in this study was confirmed (or re-confirmed) as a host for *V. dahliae* as indicated by the recovery of *V. dahliae* from plants grown in greenhouse settings.

The weedy hosts evaluated for *V. dahliae* susceptibility in this experiment were not expected to be genetically uniform because the seeds used to produce them were from open pollinated plants. The difference in *V. dahliae* susceptibility, especially to different pathotypes, in these weedy hosts may have varied between years due to the genetic variability in seed. Each plant evaluated in each trial was genetically distinct and possibly more or less susceptible to this *V. dahliae* isolate. Even though the weedy hosts are genetically diverse, consistent observations of increased microsclerotia production by aggressive isolates of *V. dahliae* within one weedy hosts means this weedy hosts could pose a potential threat to potato production.

The consistent observation of black nightshade being susceptible to the potato pathotype of *V. dahliae* is important in managing Verticillium wilt of potato because locations where black nightshade are prevalent in the potato field may have greater inoculum pressure from *V. dahliae* aggressive to potato in subsequent years. Linde et al. (2016) highlighted that management of disease where pathogen aggressiveness can be maintained from a crop to weedy host and then back to the original crop must include an understanding of two important factors: (i) the maintenance of pathogen aggressiveness and (ii) ultimately control of the weed host. These greenhouse trials have highlighted how black nightshade could be an important source of microsclerotia the potato pathotype of *V. dahliae*, which is the first factor for what Linde et al. (2016) described. Further research can link the field location of weedy hosts such as black nightshade and the distribution of *V. dahliae* microsclerotia in potato fields with the goal of improving Verticillium wilt disease management by simultaneously decreasing weedy competitors and eliminating alternative hosts for potato-aggressive isolates of *V. dahliae*.

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Table 1. Weedy and crop hosts, number of trials, and isolate characteristics of *Verticillium dahliae* used to determine microsclerotia production when potential host plants were inoculated with *V. dahliae* host-adapted isolates in four trials in 2014-2016.

Common Name	Latin Binomial	No. of Trials
Annual Bluegrass	*Poa annua*	2
Annual Sowthistle	*Sonchus oleraceus*	2
Barnyard Grass	*Echinochloa crusgalli*	2
Bittersweet Nightshade	*Solanum dulcamara*	2
Black Nightshade	*Solanum nigrum*	4
Common Lambsquarters	*Chenopodium album*	2
Downy Brome	*Bromus tectorum*	2
Eastern Black Nightshade	*Solanum ptycanthum*	2
Eggplant (cv. 'Night Shadow')	*Solanum melongena*	3
Green Foxtail	*Setaria viridis*	2
Hairy Nightshade	*Solanum physalifolium*	2
Large Crabgrass	*Digitaria sanguinalis*	2
Litchi Tomato	*Solanum sisymbriifolium*	2
Pigweed Powell	*Amaranthus powellii*	2
Pigweed Tumble	*Amaranthus albus*	1
Potato (cv. 'Russet Norkotah')	*Solanum tuberosum*	2
Rattail Fescue	*Vulpia myuros*	2
Wild Oat	*Avena fatua*	3

V. dahliae Isolate Name	VCG [a]	Pathotype	Original Host [b]
111	2B	Mint	Mint
155	2B	Mint	Mint
381	2 A/B	-	Watermelon
461	2	-	Tomato
625	2B	-	Sugar Beet
653	4A	Potato	Potato
SF	2A	-	Sunflower
Vmd-4	2 A/B	-	Tomato

[a] VCG: vegetative compatibility group
[b] Host of origin for the *V. dahliae* isolate. Strains originating from potato or mint are the potato or mint strains, respectively.

Fig. 1. Summary of the number of trials where a *V. dahliae* isolate had a differential effect on inoculum production because of greater number of microsclerotia than the other seven isolates for a specific weedy or crop host. The host of origin or the pathotype of the *V. dahliae* isolate is written within or above each bar, and the weedy host is along the horizontal axis.

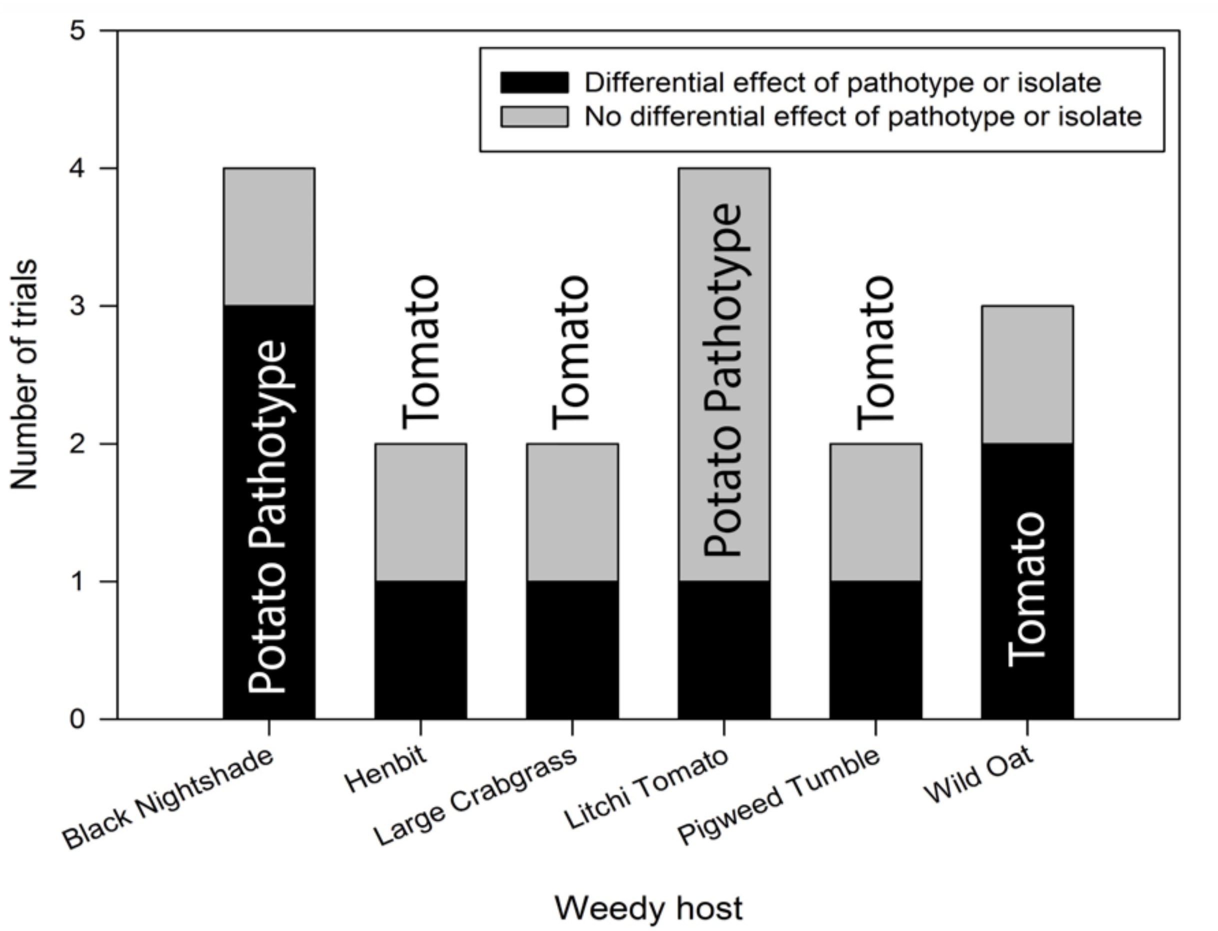


Fig. 2. Mean number of *Verticillium dahliae* microsclerotia from stems of three potato cultivars Alturas, Russet Norkotah, and Ranger Russet, and litchi tomato in a greenhouse experiment in 2013.

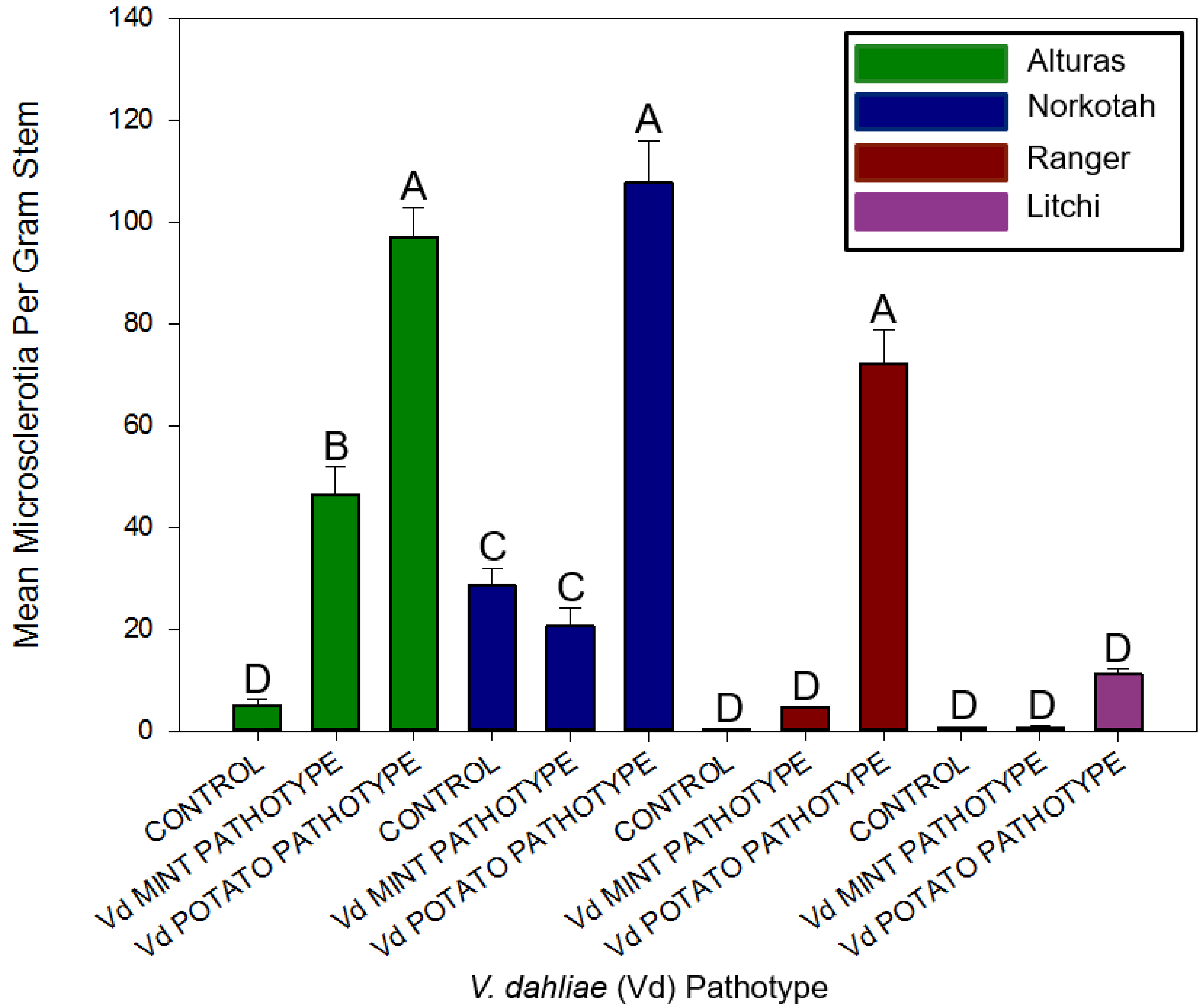


Fig. 3. Mean number of *Verticillium dahliae* CFU from roots of three potato cultivars Alturas, Russet Norkotah Ranger Russet, and litchi tomato (*Solanum sisymbriifolium*) in a greenhouse in 2014.

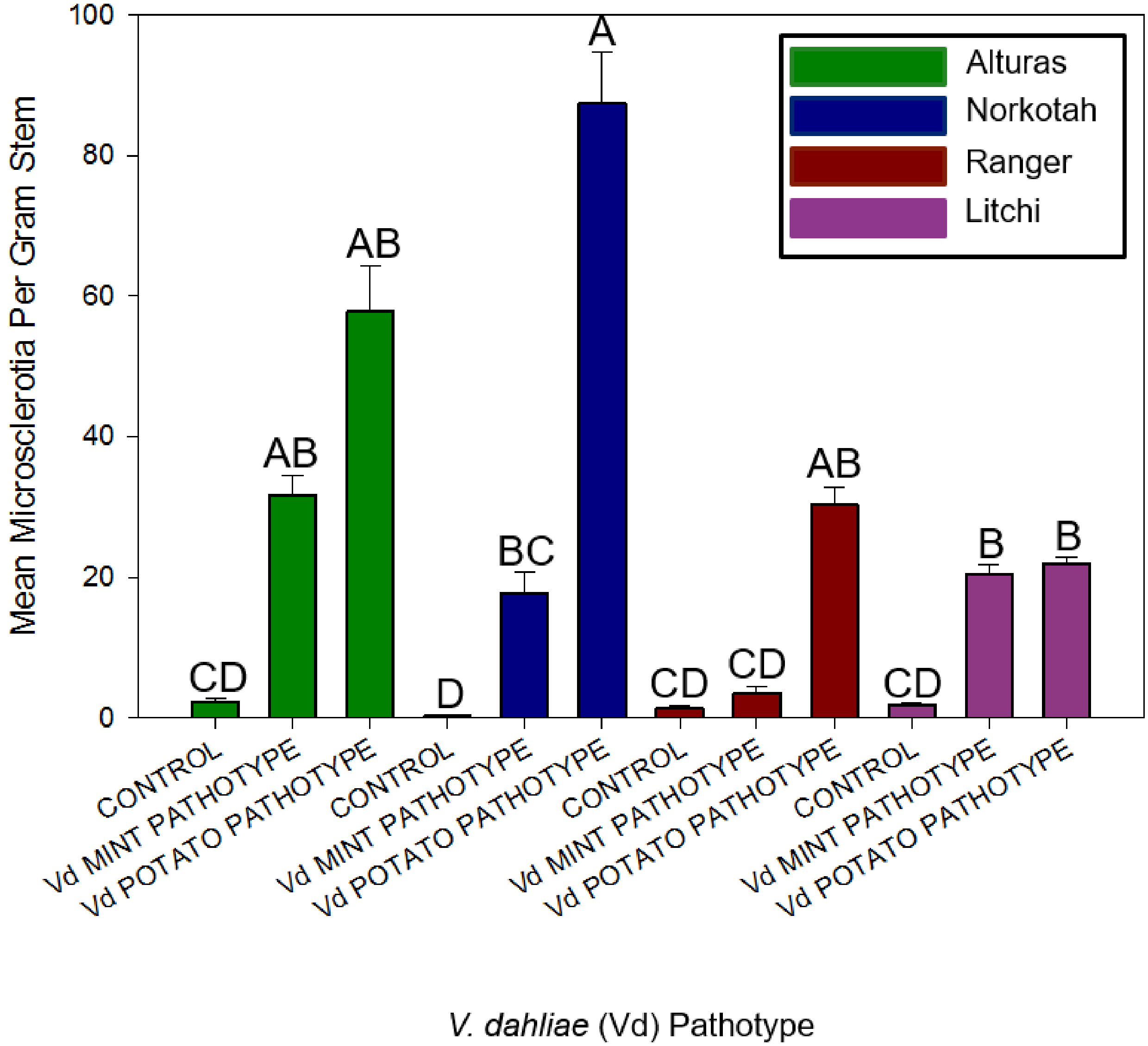


Fig. 4. Mean number of *Colletotrichum coccodes* microsclerotia from stems of three potato cultivars Alturas, Russet Norkotah, and Ranger Russet, and litchi tomato in a greenhouse experiment in 2013.

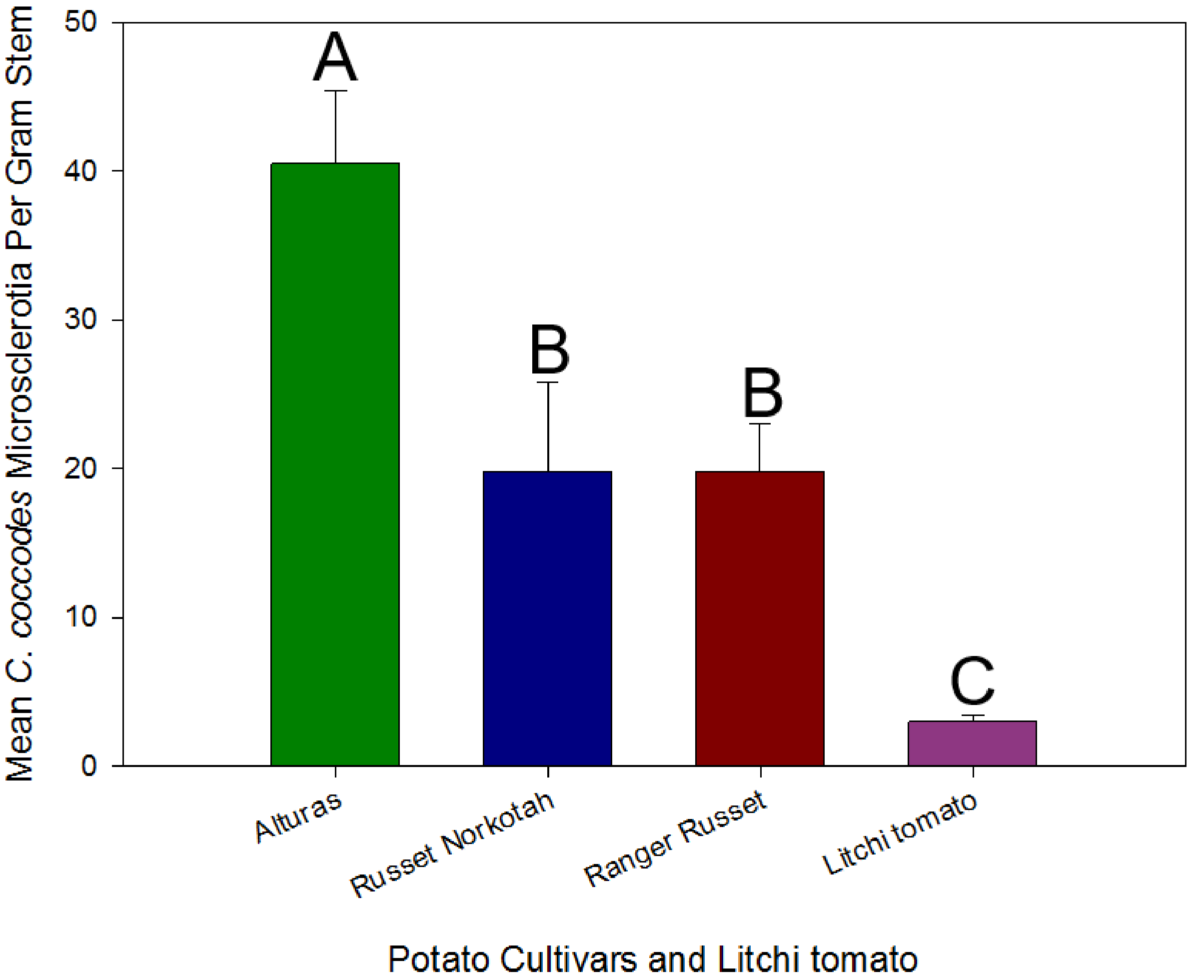


Fig. 5. Mean number of *Verticillium dahliae* microsclerotia from stems and roots of potato and litchi tomato (*Solanum sisymbriifolium)* in the 2015 field trial in Prosser, WA.

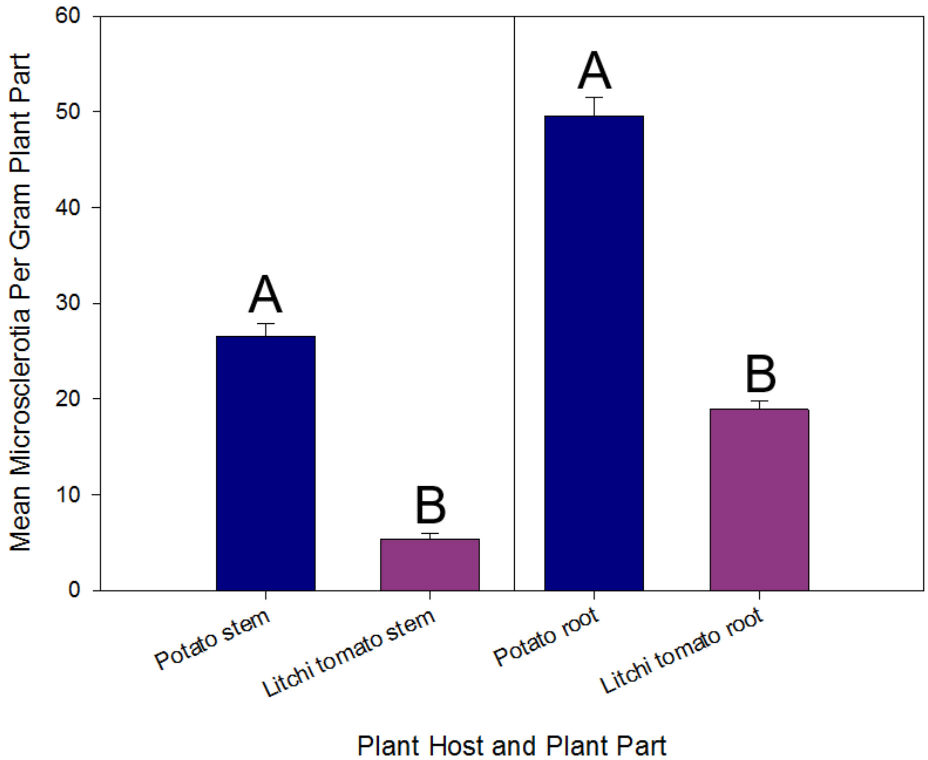
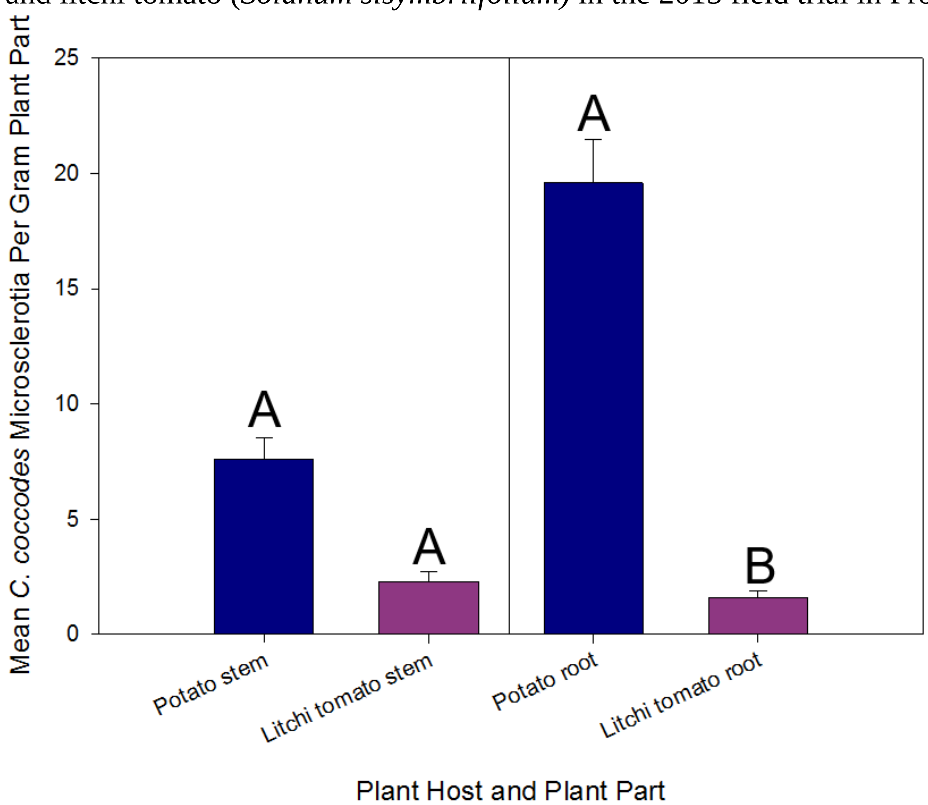


Fig. 6. Mean number of *Colletotrichum coccodes* microsclerotia from stems and roots of potato and litchi tomato (*Solanum sisymbriifolium)* in the 2015 field trial in Prosser, WA.



Dickeya Species Affecting Potato: Current Distribution in the U.S. and Outlook for 2017

Kenneth Frost

Assistant Professor, Oregon State University, Department of Botany and Plant Pathology & Hermiston Agricultural Research and Extension Center, 2121 S 1st ST, Hermiston OR 97838
kenneth.frost@oregonstate.edu (541) 567-8321.

Soft rot, aerial stem rot, and blackleg of potato are caused by multiple species of *Pectobacterium* and *Dickeya*. Several species within the genus *Pectobacterium* are endemic in U.S. potato production and it appears one or two *Dickeya* species are rapidly increasing in prevalence, becoming an expensive problem for the potato industry. For example, *Dickeya dianthicola* was first reported the northeastern U.S. in 2015 and was later reported in 10 different states at the end of 2015, including states that produce seed potatoes. By the fall of 2016, *D. dianthicola* was detected in 23 states and two Canadian provinces. Based on testing of seed potatoes from affected states, *D. dianthicola* will likely cause losses again in 2017. Given the difficulty of eliminating bacterial pathogens from seed potato, this bacterial pathogen will continue to be a problem for many years.

Pectobacterium atrosepticum, *P. carotovorum*, and *P. wasabiae* are also present in U.S. potatoes and cause soft rot diseases. In addition to *D. dianthicola*, two other species of *Dickeya*, *D. dadantii* and *D. chrysanthemi*, are present in U.S. potato but their impact on production has not been documented. It is common to find multiple species of these two bacterial genera in a single field or a single plant. Thus, the observed disease problems in the field may be a result of a pathogen complex. While not all of these species are equally aggressive on potato, it is not known how new species may interact with those soft rot pathogens that are endemic. Therefore, it is important to study the biology of both genera including the potential interactions that may occur among all species of the pathogen complex.

Multiple pathogenic species of *Dickeya* and *Pectobacterium* can cause seed piece decay, blackleg, stem rot and wilt, and tuber soft rot. Disease losses can occur at planting, during the growing season and in storage. Current management options rely primarily on cultural practices and no commercial potato varieties are resistant. No systemic antibacterial compounds are registered for use in potato and since the pathogens colonize the plant vascular system, contact materials are of limited use after the pathogens colonize the plant or tuber. Currently, the best management practice is exclusion, to exclude the pathogens from the farm, but complete exclusion is a nearly impossible task. Disease management also relies on sanitation and proper handling of potatoes before and during planting, and at harvest and during storage. Accurate diagnosis and detection of the pathogen at key points of seed potato production can also help to reduce the impact soft rot bacteria.

It appears that the potato industry will be dealing with soft rot diseases caused by both *Pectobacterium* and *Dickeya* species for a long time to come. This is not a reason for panic, but a reminder to be vigilant when it comes to management of bacterial diseases. Researchers are currently seeking funding to develop improved management strategies for this pathogen complex and economic analysis tools to guide the implementation of the management strategies.

Nematode Management in the Face of Short Supply of Telone and Vydate

Russ Ingham
Department of Botany and Plant Pathology
Oregon State University
Corvallis, OR

Columbia root-knot nematode (CRKN, *Meloidogyne chitwoodi*) infects potato tubers and causes quality defects such as external bumps on the surface and small brown spots that can be as deep as ¼ inch under the surface. Most root-knot nematodes penetrate roots and cause the root to swell around the infection site producing a gall. The female nematode continues to grow, with her posterior close to the root surface. Once eggs are formed they are laid in an egg mass on the root surface surrounded by a jelly-like substance called a gelatinous matrix. When CRKN infect tubers, galls are formed under the skin causing the bumps seen on the surface. When females mature and lay their eggs in an egg mass in the tuber the gelatinous matrix is brown in color forming the noticeable brown spot about the size of a pinhead. Some discoloration also occurs as the tuber tissue reacts to presence of the foreign substance of the egg mass and walls it off. Another species, the Northern root-knot nematode (*M. hapla*) also infects tubers and causes small brown spots around the egg mass but does not cause bumps/galls on the tuber surface. Even light external or internal symptoms of root-knot nematodes make tubers unacceptable for domestic markets. This can lead to devaluation or rejection of the crop affected. Furthermore, in export markets where CRKN is considered a quarantined pest, a single female found in one tuber can result in the rejection of a shipment of potatoes from entry into that country. CRKN becomes active at 41 °F (5 °C) so it infects roots early in the season and produces a large number of offspring. Without treatment, densities of 1/250 g soil can result in crop rejection. Low tolerances for symptoms from infection plus low damage thresholds and rapid reproduction rates make damage a certainty if CRKN is not managed adequately.

Stubby-root nematodes (SRN, primarily *Paratrichodorus allius* in the Northwest) feed on root tips but cause little damage to potato. However, in some fields, SRN carries *Tobacco rattle virus* (TRV) which it vectors to potato plants by feeding on roots causing a disease called corky ringspot (CRS). Presence of TRV in tubers causes necrotic areas in the form of diffuse brown spots, that can be quite large, or arcs and rings. Symptoms can vary by variety. For example, symptoms in Russet Burbank tend to be diffuse spots while those in Yukon Gold are primarily arcs and rings. These necrotic spots, arcs, and rings are considered to be quality defects and tubers with even a small amount of symptoms are considered culls. Crops with as few as 6% culls can be downgraded or rejected. This can occur at densities of SRN as low as 3/250 g soil so SRN needs to be managed in any field with a history of CRS.

Over the last several years CRKN and SRN have been managed with the fumigants Telone and metam sodium and the nonfumigant nematicides Mocap and Vydate C-LV. However, there was an accident at the plant where Vydate was made and it is no longer available. Loss of Vydate has increased demand for Telone which was already in short supply due to a shortage in raw materials and demands from other markets. Managing nematodes in potato when these two key products are in short supply will likely require a combination of several strategies such as crop rotation, green manure crops, nematicide combinations, careful crop management to reduce symptom development, and combinations of these tactics.

Management with Reduced Rates of Telone

If a grower cannot obtain all the Telone that his farm requires his options are to use a full labeled rate on as many acres as he has sufficient product for or to treat more acres at a reduced rate and run the risk of inadequate control. The recommended rate for using Telone alone is 20 gpa. With reduced supply available, rates as low as 11 gpa are being proposed. Few studies have been done with rates lower the 20 gpa. In a trial completed in the Columbia Basin during 1994, 10 gpa of Telone reduced culls due to CRKN from 88% in the check to 14% which may not have been acceptable to processors (Ingham et al., 2000a). Telone at 15 and 20 gpa each reduced culls to 2%. In trials done in 1998 (Ingham et al., 2007a) and 1999 (Ingham and Hamm, 2000), Telone at 15 and 20 gpa reduced culls from 66 and 22 in non treated plots to 1% and 0%; (1998) and 5% and 5% (1999), respectively. However, in 1993, 15 gpa and 20 gpa of Telone only reduced culls from 57% to 8% and 23%, respectively, (Ingham et al 2000a), and in 2000 from 94% to 11% and 20%, respectively (Ingham et al., 2007a). Therefore, in some trials even the recommended rate had unacceptable levels of tuber damage.

In contrast, several trials in the Columbia Basin found that Telone alone was effective at controlling SRN and CRS at rates of 10 gpa or higher (Ingham et al., 2000b, 2007b). The discrepancy in the effectiveness of Telone alone between these two nematodes may be due to the fact that most CRKN are found in the top foot of soil whereas SRN are more evenly distributed with depth. This means that getting a good seal at the surface during Telone application is more critical for controlling CRKN to prevent survival. Therefore, when using reduced rates of Telone it is all the more critical to make certain conditions are optimal to maximize results. Shanks should be set 18 inches apart and set to inject at 18 inches deep. Soil moisture should be slightly below field capacity and temperature should be 50-60 °F. The soil should be worked up early to encourage the breakdown of roots and expose nematodes and their eggs and then worked into a good seed bed condition to provide a good seal after injection.

Using Mocap or Metam Sodium with Telone

Adequate control of CRKN with reduced rates of Telone may be achieved by using another product in combination with Telone. In a 1990 trial in the Klamath Basin, Telone at 15 gpa only reduced culls due to CRKN from 59% to 30% (Ingham and Rykbost, 1991) and in 1991 Telone at 20 gpa only reduced culls from 52% to 20% (Ingham, 1992). However, in both studies addition of a broadcast preplant incorporated (PPI) application of Mocap at 6 lb a.i./acre reduced culls to zero. While we have no data on combinations of Mocap with rates of Telone less than 15 gpa, it is probable the there would be a benefit of Mocap to reduced rates of Telone as well, especially if the rate of Mocap was increased to 12 lb a.i./acre.

In the 1994 Columbia Basin study mentioned above in which Telone at 10 gpa reduced culls from 88% to 14%, addition of a water-run application of metam sodium at 38 gpa reduced culls to 1%. While these are the only data we have with metam sodium and Telone at 10 gpa we have several trials with combinations of Telone at 15 gpa and water-run or shanked-in metam sodium at 30 gpa and culls were reduced to 2% or less in all cases. Therefore, it is safe to assume that Telone at 11 gpa plus metam sodium at 38 gpa would be an effective treatment in most instances. It is speculated that the reason the addition of Mocap and metam sodium improve control of CRKN is that they help reduce nematode populations near the surface that may not be adequately controlled if there is not a sufficient seal during the Telone application. Since Mocap also persists in the soil for an extended period it may also help control nematodes migrating up from deeper depths. All these treatments would be effective for controlling CRS as well.

Using Shanked-in Metam Sodium

For fields in which there is not sufficient Telone available to treat in any fashion the choices are not to grow potatoes in those fields or to treat with some product other than Telone. While water-run metam sodium helps control nematodes when used in combination with Telone it is generally not effective as a stand-alone treatment. Over five trials, tubers culled from CRKN in non treated plots averaged 58% while those in plots treated with water-run metam sodium at 38 gpa averaged 30% (Ingham and Hamm, 2000, Ingham et al., 2000a, Ingham et al, 2007a, Rykbost et al., 1995). Tubers with CRS in six trials averaged 46% and 30% in non-treated and metam sodium treated plots, respectively (Ingham and Hamm, 2000, Ingham et al., 2000b, Ingham et al, 2007b, Rykbost et al., 1995). However, shanking metam sodium can be effective in suppressing nematode damage to tubers under low to moderate pressures. For example, in 1996 shanking in 30 or 38 gpa of metam sodium at 16 inches reduced culls due to CRKN from 47% in untreated plots to less than 1%. In a 2001 trial, metam sodium shanked-in at 6 and 12 inches (30 or 38 gpa) or at 6, 12, and 18 inches (50 gpa) reduced the percentage of culled tubers from 53% in non treated plots to 1% or less. This application procedure has not been adequate under high pressure situations where a higher percentage of tubers in untreated plots were culls (Ingham et al., 2007a). Tubers with CRS in 1996, 1999, and 2000 averaged 28%, 72%, and 24% in nontreated plots and 1%, 8%, and 3% in plots treated with shanked-in metam sodium at 38 gpa, respectively (Ingham et al., 2007b).

Using Mocap with Shanked-in Metam Sodium

Mocap can be used in combination with shanked-in metam sodium either as a broadcast PPI application or shanked-in with metam sodium as a tank mix. In a high CRKN pressure situation in 2000, check plots had 94% culls from CRKN (Ingham et al., 2007b). Metam sodium (38 gpa) shanked-in at 6 and 12 inches had 35% culls. Shanked-in metam sodium plus Mocap (PPI) at 12 lb a.i./acre had 15% culls while an injected metam sodium/Mocap tank mix at the same rates reduced percent culls to zero. Reducing the rates in this application method to 30 gpa of metam sodium and 9 lb a.i./acre of Mocap did not provide adequate control (12% culls). Metam sodium and Mocap tank mix applications would likely be effective for controlling CRS as well, provided that the disease pressure is not too high.

Managing Nematode Populations before Treatment

Without access to the highly effective fumigant nematicide, Telone, growers will need to be aware of the nematode population levels in their fields and reduce densities with cultural methods as much as possible. This may require sampling fields during the rotation in addition to the fall before planting potatoes. Discovering that a field has a high population level in the fall may not provide any option other than to not plant potatoes in that field the coming year. When high densities are present growers should use poor or non-host rotation crops and green manure crops to reduce populations. This will help the products that are available to be more effective. Management of CRKN populations for the next potato crop should begin as soon as the current crop is harvested. Densities of CRKN after potato should be low if they were managed successfully to prevent damage to the crop that was just harvested. However, some level of CRKN will still be present. Growing rotation crops that are hosts will increase population densities making future control more difficult, while growing crops that are poor or non hosts will decrease population densities making control more likely.

The host status of crops is determined by calculating the reproductive factor (Rf) which is equal to the final population density divided by the initial population density. For example, the population density at harvest divided by the population density at planting. Crops with an Rf value greater then l.0 are defined as good hosts (Rf greater than 10 = excellent hosts). Under good hosts populations will increase. Crops with Rf values from 0.1 and 1.0 are considered poor hosts. Populations are supported but at slowly declining levels. Crops with an Rf less than 0.1 are non-hosts where populations are not supported and densities decline rapidly.

Growing crops that are poor or non hosts can be effective at reducing populations of CRKN because it has no long-lived resistant stage. Second stage juveniles (J2) hatch from eggs and if they do not find a suitable host to infect they die. Unfortunately, most crops grown in rotation with potato tend to be hosts for CRKN although the Rfs can vary between different varieties. There is a high acreage demand for crops that are good hosts so growers need to grow both good hosts and poor or non-hosts in rotation in order to meet market demands and suppress CRKN. Cropping sequences should be designed to grow the best host crops early in the rotation reducing the subsequent population increase with poor or non-hosts later. Long-season host crops like field corn can increase CRKN to 10,000/250 g soil. If this increase happens late in the rotation it may not be possible to escape tuber damage if potatoes are the next thing to be planted. However, if this increase occurs early in the rotation it may be possible to reduce those populations again before potatoes are planted. For example, potatoes grown without nematicides after a cropping sequence of field corn-field corn-wheat had 68% less tuber damage than those grown after wheat-field corn-field corn (Ingham, unpublished data). In the latter case, high population densities were produced at the end of the rotation with no opportunity to reduce densities. In the former case wheat did not sustain the high population densities produced under field corn so numbers declined even though wheat is a host. In addition, because wheat is harvested earlier in the year there was time to plant a mustard blend green manure crop for the late summer and fall which suppressed population densities further. Whenever possible, short season crops with low Rf values such as sweet corn or peas followed by a non host green manure crop should be grown in the last year before potato. For example, a field corn crop grown in 2001 increased CRKN to nearly 11,000/250 g soil. However, by growing wheat followed by a radish green manure crop in 2002 and a green pea-lima bean-mustard green manure crop (Caliente 61) sequence in 2003, population levels were reduced to 3/250 g soil. When potato was grown without nematicides in these plots in 2004 only 2% culled tubers were observed at the end of the season. A conventional rotation of wheat–field corn-field corn had 100% culls (Ingham, unpublished data).

The best options for cover crops to suppress CRKN are the sudangrass hybrid cv Trudan 8 or the sorghum-sudangrass hybrid Sordan 79, radish cv Terra Nova, and the mustard blend Caliente 61. For the most part, green manure crops need to be chosen by variety as well as plant type as host status can vary by variety. In one study, a numbered line of hybrid sudangrass increased CRKN 9.5 fold over five months while Trudan 8 reduced population levels by 96% (Mojtahedi et al., 1993). However, while Trudan 8 and Sordan 79 are good for suppressing CRKN they are excellent hosts for SRN and should not be grown in a field with a history of CRS (Charlton et al., 2010). SRN and CRS are much more difficult to control with rotation since most plants, including weeds, are hosts to the nematode and the virus. Using green manure crops is one of the few options. Radish cvs Terra Nova and Doublet have been demonstrated to suppress CRKN, SRN and CRS (Charlton et al., 2010, O'Neill, 2016).

Minimizing CRKN Damage in a Current Potato Crop.

Several cultural procedures can be used to minimize tuber damage in a potato crop that has not received adequate treatment. Plant the shortest season cultivar as possible. The longer a crop remains in the field the more degree-days will accumulate resulting in more CRKN generations, greater population increase, tuber infection, and symptom expression. Harvest as soon as possible and do not leave tubers in the ground longer than necessary. Once vines are killed, soil and tuber temperatures rise, increasing the rate of development for nematodes that have infected tubers and resulting in more extensive symptom expression. This has been substantiated in a number of studies. In one case the percentage of tubers culled from CRKN increased from 18% to 72% when harvest was delayed by three weeks (David and Ingham, unpublished data). Since CRKN in tubers continues to develop at temperatures above 41 °F, store tubers as cool as possible and have the crop processed as soon as possible.

Summary

In summary, in order to successfully manage nematodes when key products are in short supply growers should:

1) Use a reduced rate of Telone with full rate of metam sodium or Mocap
2) Make sure conditions are optimal for Telone
   considering shank spacing, temperature, moisture, seal
3) Shank in metam sodium at full rate
   with Mocap broadcast ppi or, preferably, as a tank mix
4) Manage nematodes with rotation crops and green manure crops
5) Manage potato crop to minimize damage should infection occur
   This is more relevant for root-knot than for corky ringspot.
   Once tubers are infected with TRV there is little that can be done.
6) Sample so they know what they have

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Progress in Developing PGR Seed Treatments to Modify Plant Establishment, Tuber Set, Size & Shape of Selected Cultivars

Rick Knowles, Cody Dean, and Lisa Knowles
Department of Horticulture, Washington State University
(Proceedings of the Annual Washington and Oregon Potato Conference, Jan. 25, 2017, Kennewick, WA)

Introduction & Background

The relationship between the tonnage yield of tubers and the yield of acceptable raw product for frozen processing (≥3-inch-long French fries) can differ greatly among cultivars. Tuber size distribution and length-to-width (L/W) ratio (i.e. tuber shape) interact to dictate the yield of fresh-cut French fries. Therefore, for a 35 T/A U.S. No. 1 tuber yield produced by two cultivars, the yield of usable French fries will differ due to variation in these factors.

On average, yield of fries increases with tuber L/W ratio but the increases are much greater for smaller tubers (e.g., 4-10 oz) than larger tubers (≥12 oz) (Fig. 1). Tubers greater than 12 ounces produce about 95% raw product regardless of shape (Fig. 1b). Conversely, the recovery of 3-inch or longer fries from tubers less than 4 ounces is negligible. The models presented in Fig. 1b are being used to compute and compare the yields of usable raw product from tuber yields and L/W ratios for selected cultivars, and to evaluate the efficacy of management techniques designed to maximize the recovery of raw product for frozen processing. Ideally, tubers for frozen processing should have a L/W ratio of 1.8 or higher for maximum fry yield.

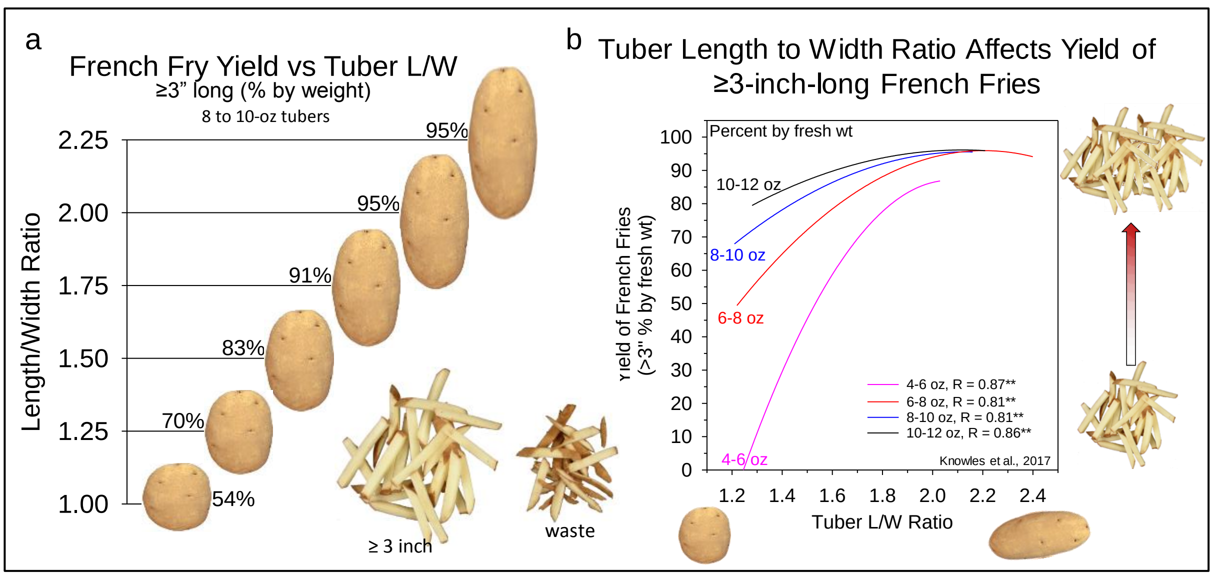


Fig. 1. (a) Changes in percent recovery of 3-inch or longer French fries by weight from 8-10 oz tubers with increasing tuber length to width (L/W) ratio. The tubers shown are in scale with the indicated L/W ratios. **(b)** Changes in yield of 3-inch or longer French fries with increasing tuber L/W ratios for 4-6, 6-8, 8-10, and 10-12-oz tubers.

Payette Russet and Alturas are frozen-processing cultivars released from the Northwest Potato Variety Development program. Strengths of Payette (released in 2015) include high late season yield, resistance to late blight, Verticillium wilt, pink rot, black dot, and all known strains of PVY, excellent gravity for frozen processing, cold sweetening resistance, heat tolerance, low acrylamide formation, and long dormancy (Novy et al., 2017). Alturas (released in 2002) produces high yields of cold-sweetening resistant tubers with significantly less nitrogen than Russet Burbank, and is resistant to Verticillium wilt and early blight (Novy et al., 2003). In 2016, Alturas was the 5th and 7th most widely grown cultivar (acreage basis) in the Northwest and U.S., respectively (NASS, Crop production, December 2016).

Despite their strengths, the round tuber phenotype of these cultivars (Table 1) and Payette's long dormancy are characteristics that can negatively affect yield and limit the recovery of raw product for frozen processing. The long dormancy of Payette slows emergence and plant establishment (Novy et al., 2017), which in short growing season areas will ultimately limit the time devoted to tuber bulking, and potentially result in lower yields.

Tuber Shape
8-10 oz tubers

Clone	L/W ratio		
	WA	OR	ID
R. Burbank*	1.77	1.99	2.11
A03141-6*	1.52	1.60	1.64
Alturas	1.40	1.50	1.54
Payette**	1.41	1.40	1.71

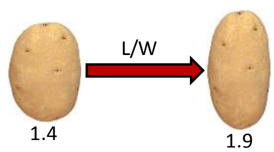


Table 1. Length to width (L/W) ratios of 8-10-oz tubers of Russet Burbank, A03141-6, Alturas, and Payette Russet. Data are from the regional trials of the Northwest Potato Variety Development Program. Note that tubers have a rounder phenotype (lower L/W ratio) when grown in the Columbia Basin of WA and OR compared with southern Idaho. This regional effect on tuber shape has been consistent across genotypes for many years.

Our preliminary work has demonstrated that these weaknesses can be corrected by treatment of seed with gibberellin (GA) and/or auxin (NAA). GA hastens emergence and plant establishment and increases tuber L/W ratio, which can substantially increase the yield of raw product for frozen processing. However, GA also decreases apical dominance, resulting in more stems, increased tuber set, and smaller tubers. NAA can be used to modulate GA's effects. The effective relative concentrations of these potent growth regulators depend on the desired effect, cultivar, and mode of application. Management techniques that can mitigate slow emergence and round tuber phenotype will facilitate wider adoption of newly developed cultivars by industry.

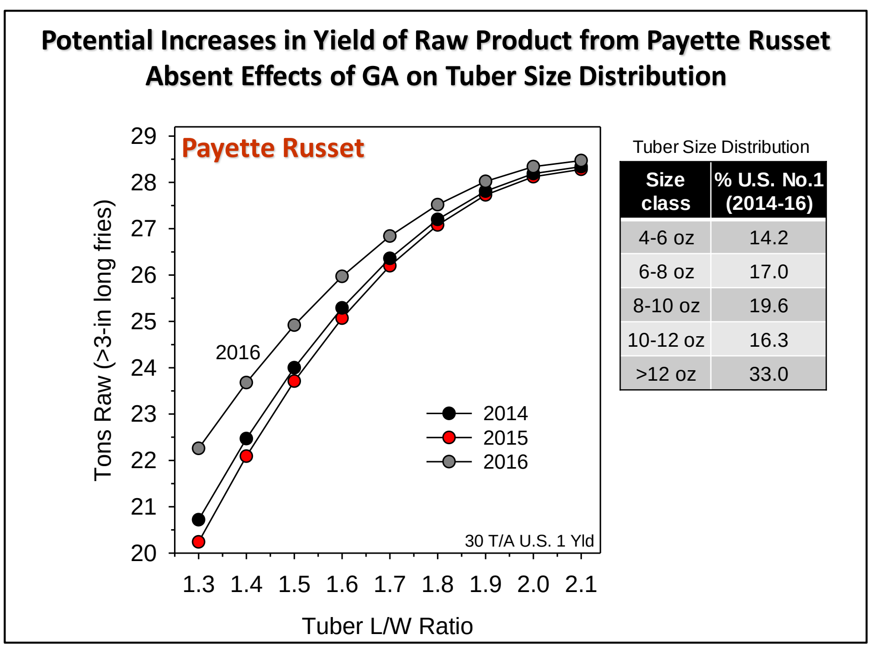


Fig. 2. Expected changes in yield of 3-inch or longer French fries (raw product) with increasing tuber length to width (L/W) ratio for a 30 T/A U.S. No. 1 tuber yield of Payette Russet produced in each year. Fry yields were calculated based on the actual tuber size distributions produced in 2014, 2015, and 2016 at Othello, WA. Tuber size distributions were relatively consistent over the 3-year period (3-yr average is shown in the table).

Results

Trials in 2015 showed that GA effectively hastened emergence and increased L/W ratios of Payette Russet tubers from 1.3 to 1.7, which boosted total fry yield from the 4-12-oz tubers by 36% (+456

T per 120-acre pivot) (Knowles et al., 2016). However, GA also increased stem numbers per seed piece and tuber set, thereby shifting tuber size distribution away from ≥10-oz tubers that yield high percentage raw product toward ≤6-oz tubers (including <4-oz tubers that yield no raw product), resulting in only 0-5% increase in fry yield when all size classes constituting U.S. No. 1 yield (>4 oz) were considered. Based on the tuber size distributions produced by Payette Russet from 2014-16, we estimated that French fry yields could be increased as much as 38% by selectively abolishing the GA-induced shift in tuber size distribution while retaining the GA-induced increase in L/W ratio across all size classes (Fig. 2).

Since the effects of GA and NAA on stem numbers and tuber size distribution are opposite (Herman et al., 2016; Knowles and Knowles, 2016), and the two growth regulators have different modes of action, there is potential for a combination seed treatment that would isolate and thus capitalize on the effects of GA on accelerating emergence and increasing tuber L/W ratio. We postulate that NAA in the combination treatment would reduce GA's effect on increasing stem and tuber numbers, thus maintaining tuber size distribution, but GA would still hasten emergence and potentially (see below) increase tuber L/W ratio. Accordingly, we tested a broad range of GA and NAA concentrations in combination applied as dip or spray to seed for Payette Russet and Alturas in 2016.

When combined with GA, NAA only partly moderated the GA-induced stimulation of plant emergence (Fig. 3a), maintained apical dominance (Fig. 3b), and had no effect on the GA-induced increase in tuber L/W ratio (Fig. 3c). GA alone or in combination with NAA increased the yield of ≥3-inch-long fries from the 4 to 12-oz tubers by 43% (726 T per 120 A pivot) (Fig. 3d schematic).

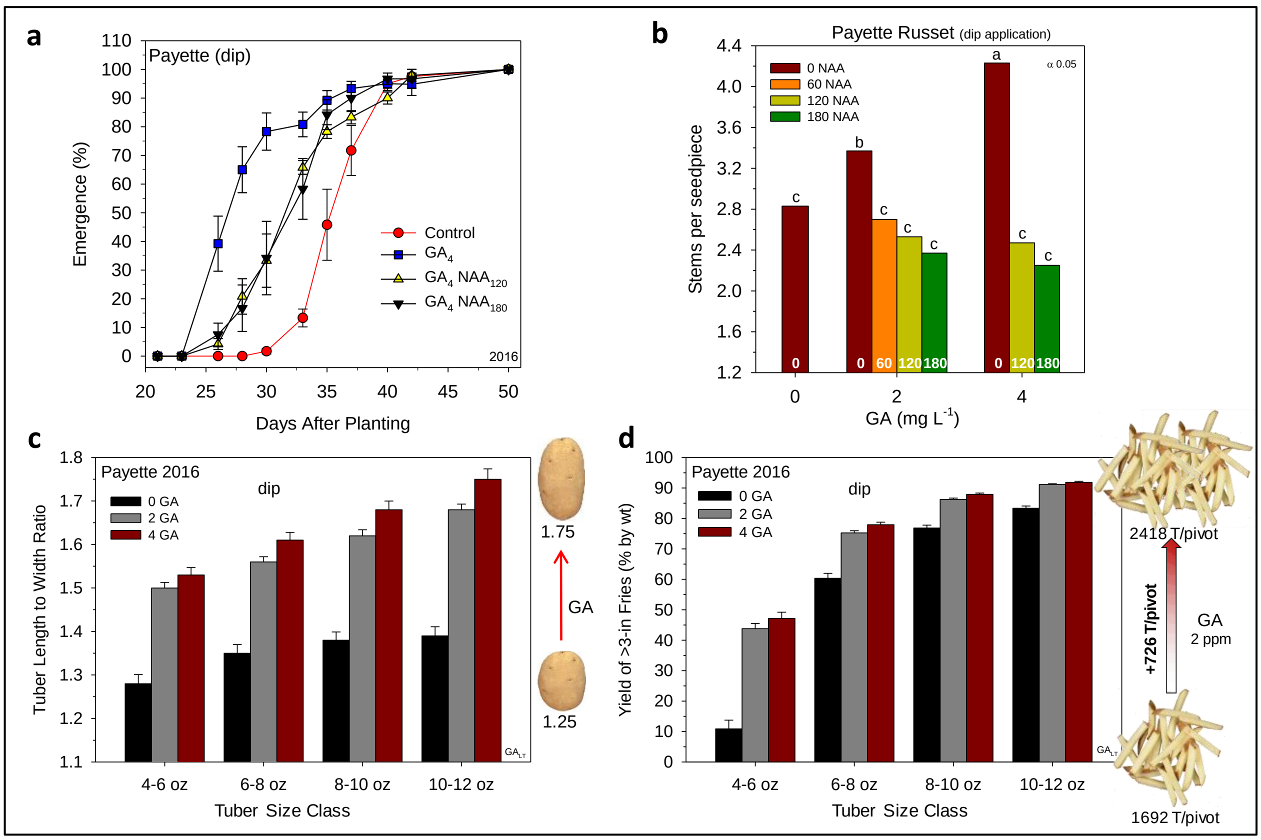


Fig. 3. (a) Plant emergence from Payette Russet seed treated with GA (4 ppm) alone or in combination with NAA (120 and 180 ppm) as a dip application. **(b)** Stem numbers produced by the GA and GA + NAA treated seed. **(c)** GA-induced changes in tuber length to width (L/W) ratios of 4-12 oz U.S. No. 1 tubers by size class. Data are averaged over all treatments since NAA in combination with GA had no effect on L/W ratio beyond that attributable to GA alone. **(d)** Percent recovery of 3-inch or longer French fries by weight from 4-12 oz tubers by size class. Fry yield from the 4-12 oz tubers increased 43% due to the GA-induced (2 ppm) increases in tuber L/W ratio. This increase equated to an additional 726 tons of raw product per 120 A pivot as portrayed in the schematic.

However, when all tuber size classes (>4 oz) were considered, the increases in fry yield attributable to GA alone averaged -2.6% in the 2016 dip application trials, due to the GA-induced shift in tuber size distribution toward 10-oz and under tubers (including increased yield of undersize tubers (<4 oz) that do not contribute to fry yield) (Fig. 4a). When combined with 2 ppm GA in dip application trials, NAA (180 ppm) partly reduced the GA-induced shift toward smaller tubers (Fig. 4b), resulting in a marginal increase in fry yield (6%; 204 T per pivot) over non-treated seed.

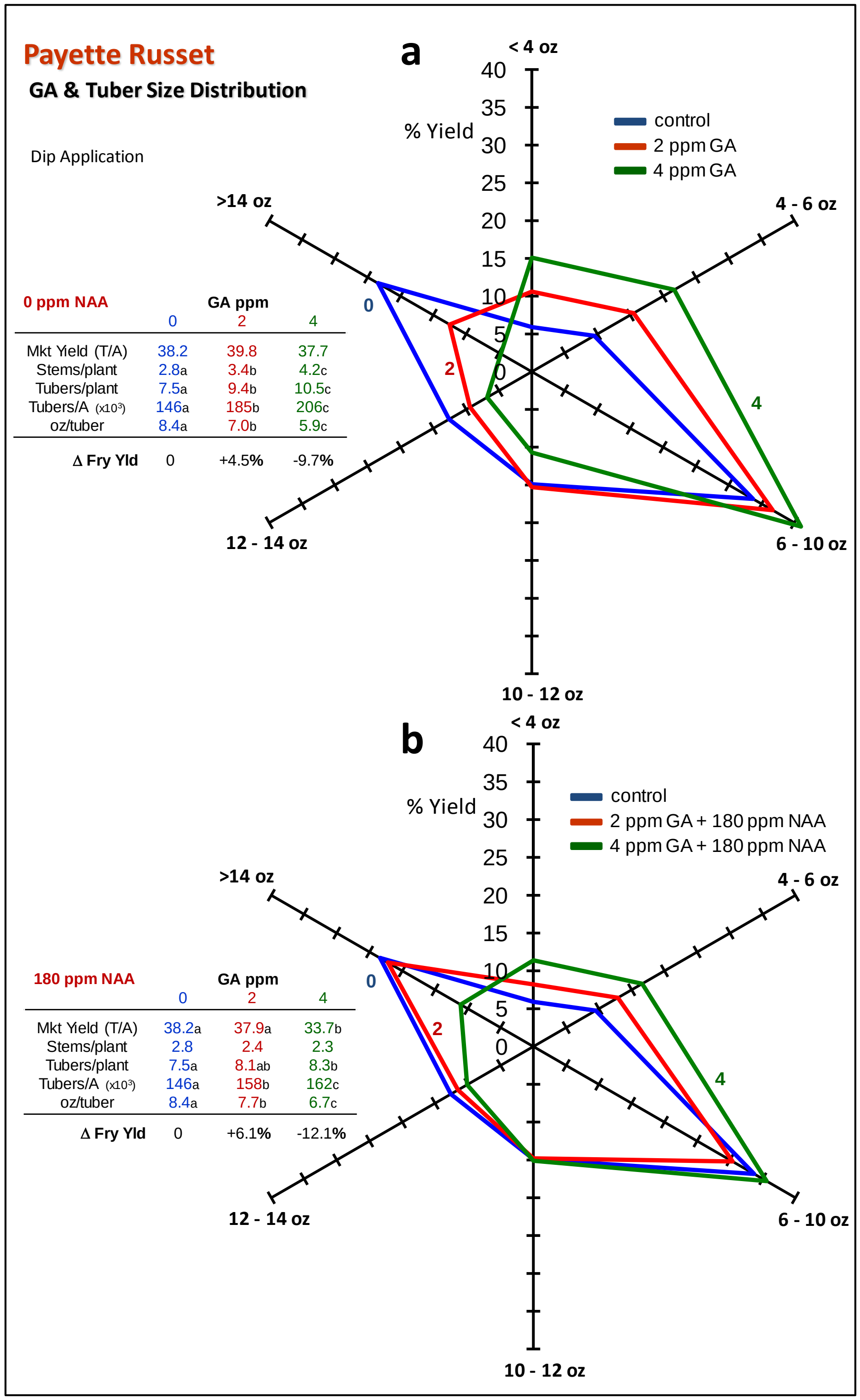


Fig. 4. Tuber size distributions of Payette Russet as affected by 2 and 4 ppm GA applied alone **(a)** or in combination with 180 ppm NAA **(b)**. Cut seed was treated by immersing in treatment solutions prior to air drying and planting several days after treatment. Tuber yields for each size class are expressed as percent marketable yields (U.S. No. 1 + <4 oz). Marketable (Mkt) yields, stems per plant, tubers per plant and per acre, and average tuber fresh weights are compared in the inset tables. Letters indicate LSD *P*<0.05. Note that GA increased stems (a) and shifted tuber size distribution toward smaller tubers, effectively reducing the percentage of 12-oz and over tubers that yield 95% usable raw product (French fries). The magnitude of these effects was concentration-dependent. GA at 4 ppm was excessive and in combination with 180 ppm NAA, decreased tuber yield, size, and the yield of French fries by 12.1% (b, inset table). However, when combined with 2 ppm GA, NAA inhibited the GA-induced shift in size distribution. This effect, coupled with the GA-induced increase in tuber L/W ratios (Fig. 3), effectively increased the yield of raw product by 6.1% (+204 T of French fries per pivot when compared with control).

As expected, spray application (~0.6 gal/ton) to seed was less effective than dip application for a given concentration of plant growth regulator. However, raw product yield (i.e. T/A French fries) from Payette was increased as much as 16% (540 T per pivot) by using NAA in combination treatments to confine the effect of GA to tuber shape (Fig. 5).

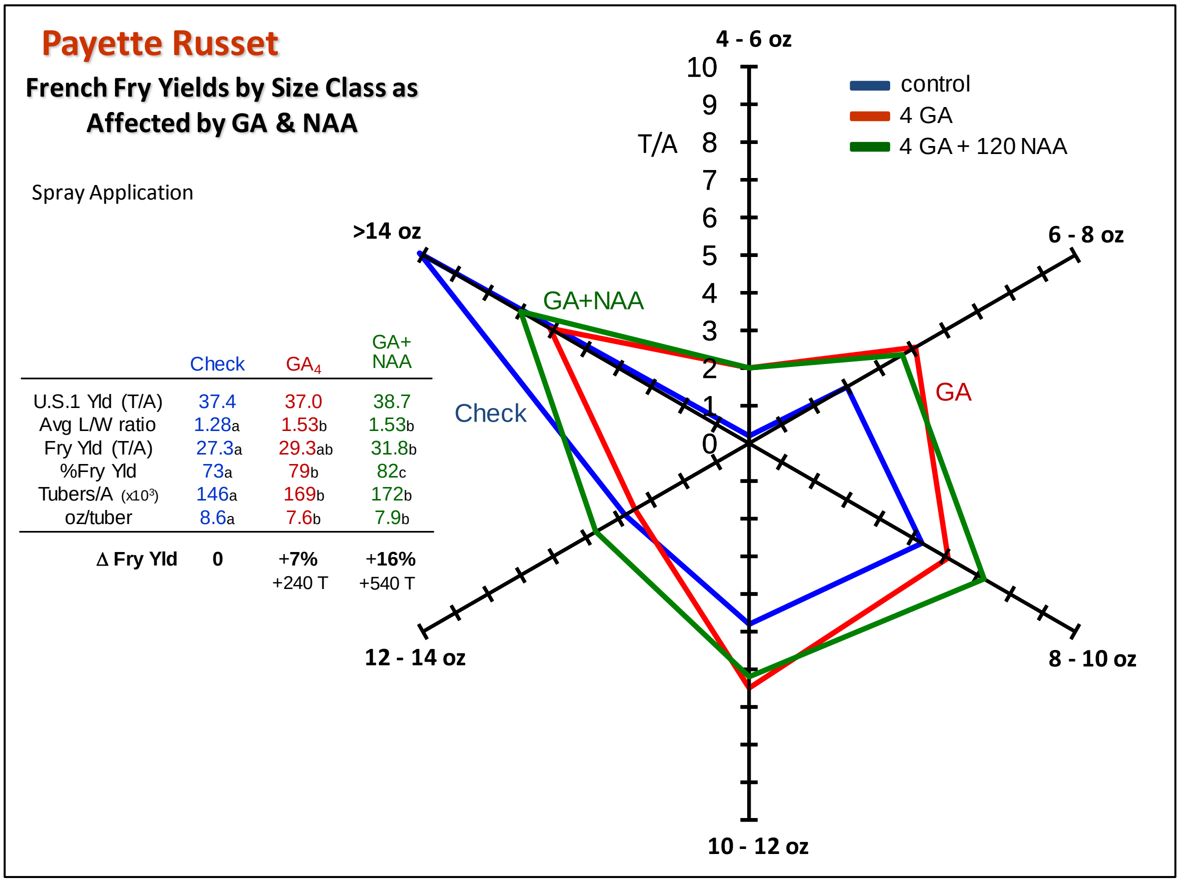
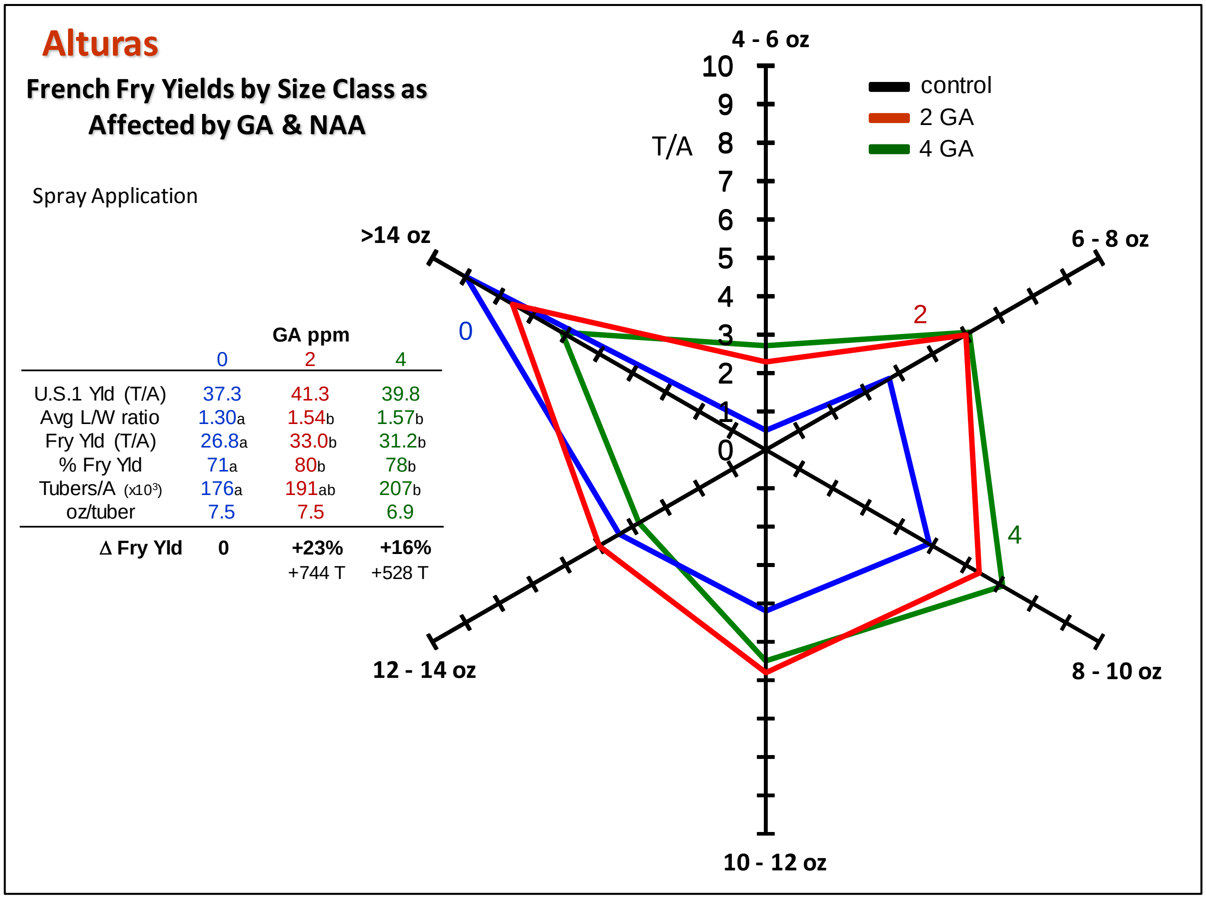


Fig. 5. Yields (T/A) of 3-inch or longer French fries by tuber size class from **Payette Russet** as affected by spray treatment of seed with GA alone (4 ppm) or in combination with NAA (120 ppm). GA alone decreased the yield of French fries from >12-oz tubers but increased the yield of fries recovered from 4-12-oz tubers. This latter effect was attributable to GA-induced increases in L/W ratios (inset table) and yields of the 4-12-oz tubers. The increased yield of fries from <12-oz tubers exceeded the loss of fry yield from >12-oz tubers, resulting in a 7% net increase in total fry yield over all U.S. No. 1 size classes, which equated to 240 T more fries per 120 A pivot than control (inset table). In the combined treatment, NAA attenuated the GA-induced shift in tuber size distribution (data not shown) and associated loss of fry yield from >12-oz tubers. This effect, coupled with the increased L/W ratios of 12-oz and under tubers, further increased overall net fry recovery relative to the GA alone and control treatments, resulting in 16% increase (+540 T more fries per pivot) in yield of raw product over non-treated seed (inset table).

In contrast to Payette, Alturas was substantially less sensitive to GA for shifts in tuber size distribution but not shape, resulting in 23% increase in raw product recovery (744 T per 120 A pivot) with 2 ppm GA alone (Fig. 6).



	GA ppm		
	0	2	4
U.S.1 Yld (T/A)	37.3	41.3	39.8
Avg L/W ratio	1.30a	1.54b	1.57b
Fry Yld (T/A)	26.8a	33.0b	31.2b
% Fry Yld	71a	80b	78b
Tubers/A (x10³)	176a	191ab	207b
oz/tuber	7.5	7.5	6.9
Δ Fry Yld	0	+23% +744 T	+16% +528 T

Fig. 6. Yields (T/A) of 3-inch or longer French fries by tuber size class from **Alturas** as affected by spray treatment of seed with 2 and 4 ppm GA. In contrast to Payette Russet, Alturas is less sensitive to GA for shift in tuber size distribution (i.e. reduction in yield of >12-oz tubers and increase in yields of <12-oz tubers including undersize). Therefore, GA at 2 ppm increased the net yield of French fries by 744 T per pivot (23%) (inset table) primarily by increasing L/W ratios of the 4-12-oz tubers, despite a 16% GA-induced decline in yield of >14-oz tubers (data not shown). The increased yield of fries from <12-oz tubers thus greatly exceeded the loss of fry yield from >14-oz tubers, resulting in 80% fry recovery across all size classes (inset table). GA at 4 ppm decreased the yield of >12-oz tubers by 26% (data not shown) and associated fries by 27%. However, this effect was offset by 29% increase in yield of 4-10-oz tubers (data not shown) and when coupled with the increased L/W ratios of 4-12-oz tubers, resulted in 16% net increase in yield of raw product (+528 T more fries per pivot).

Increases in tuber L/W ratio induced by GA/NAA seed treatments maximized yield of raw product only when the relative concentrations were adjusted to minimize shifts in tuber size distribution, as dictated by cultivar sensitivity to GA. While results from the 2016 studies were encouraging, the 1-year data sets were variable. An expanded array of trials is underway in 2017 to define optimum GA/NAA concentrations and application techniques to effectively control apical dominance, tuber set, size distribution and shape for increased yield of raw product from frozen processing cultivars.

Summary and Final Thoughts

- We need to be thinking about fry yield per acre for existing and new cultivars (the tonnage tuber yield vs fry yield are two different things). There is opportunity for developing cultivars and management techniques that effectively maximize French fry yield per acre.
- U.S. No. 1 tuber yields are not all created equal – a 35 T/A yield for two cultivars can translate to substantially different yields of raw product depending on tuber size distribution, shape, and the extent of culling for defects and bruise.
- Tuber shape (L/W ratio) and size distribution interact to affect the yield of 3-inch and longer French fries. Increasing the L/W ratio of 4-10-oz tubers has the greatest effect on recovery of French fries.
- Twelve ounce and over tubers produce 95% fry yield regardless of shape…. however, large tubers can often have greater incidence of defects (e.g., hollow heart, brown center) and bruise (=penalties); this incentivizes limiting oversize in favor of 4-12 oz tuber yield (with high L/W ratio) to maximize raw product recovery.
- Treatment of seed with GA will hasten emergence, increase stem numbers and tuber set, decrease average tuber size, and increase tuber L/W ratio. Optimum rates of GA depend on cultivar sensitivity and the desired effect (outcome). Concentrations too high will produce many stems that lack vigor, and can substantially reduce yield and alter tuber shape (Blauer et al., 2013; Herman et al., 2016).
- The effects of GA on emergence and tuber shape can potentially be isolated from its effects on increasing stem numbers and shifting tuber size distribution by combining with NAA. In combination, NAA attenuates GA's effects on increasing stem numbers and shifting tuber size distribution, while retaining the GA-induced effects on quicker emergence and shape.

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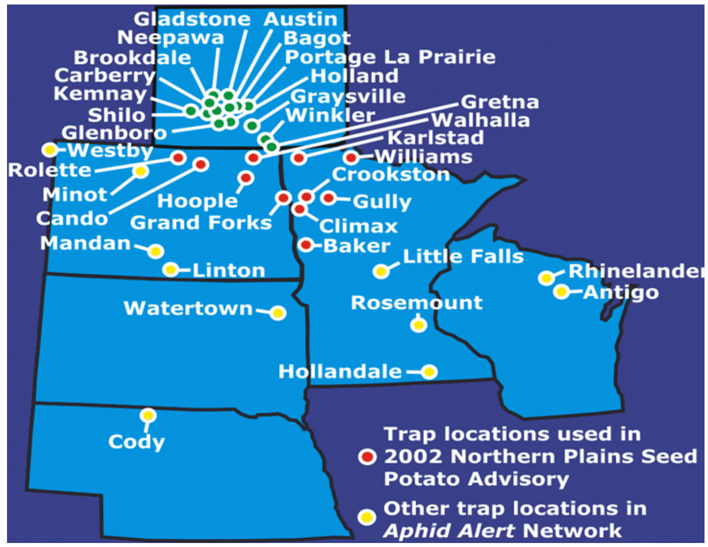
Aphid Alert: A Brief History of Apprehending Aphids.

Ian MacRae

Dept. of Entomology, Univ. of Minnesota, NWROC, Crookston, MN 56716.
Address correspondence to: imacrae@umn.edu

Aphid Alert 1992-2003



Aphid Alert trap sites run from 1992-2003. Not all sites were run in each year.

Just like comedy, in pest management appropriate timing is everything; applying management tactics at the right threshold can prevent significant loss. When dealing with insects that transmit diseases, these thresholds are generally very low, so information on the numbers of these disease vectors is doubly important. In Minnesota and North Dakota a system of suction traps called the ***Aphid Alert Network***, has been used to monitor the regional presence of aphids that can transmit PVY in seed potatoes. The system was first established in 1992 and in that iteration ran until 2003. At its height in this period it became a cooperative effort incorporating trap sites that monitored populations of the aphid species that vector PVY in Minnesota, North Dakota, Manitoba, South Dakota, and Nebraska. The project involved grower hosts, provincial and state personnel from the Depts of Agriculture in each state and university personnel from the University of Minnesota. Each trap site hosted 2 pan traps that held a yellow-green tile and a 3m tall suction trap powered by a 12V deep cell marine battery. These traps were changed weekly by an employee of the University of Minnesota or the cooperating state/province. Employees would make the rounds each week, collecting the trap samples, replacing trap pans, jars and batteries. The trap material and batteries would be returned to the MN Dept. of

Traps and reports used in Aphid Alert 1992-2003.

Agriculture's Seed Potato Certification lab in East Grand Forks, MN. Batteries would be recharged for re-use and UMN graduate students would sort and identify the aphids and prepare a weekly report on trap catch at each location.

The system was the basis for the research that led to many aphid management advances including: the use of border crops, the effect of fungicides on aphids, refining the use of refined oils, the role of aphid behavior on PVY epidemiology, transmission efficiencies of certain aphid species, and identification of PVY strains then present in MN.

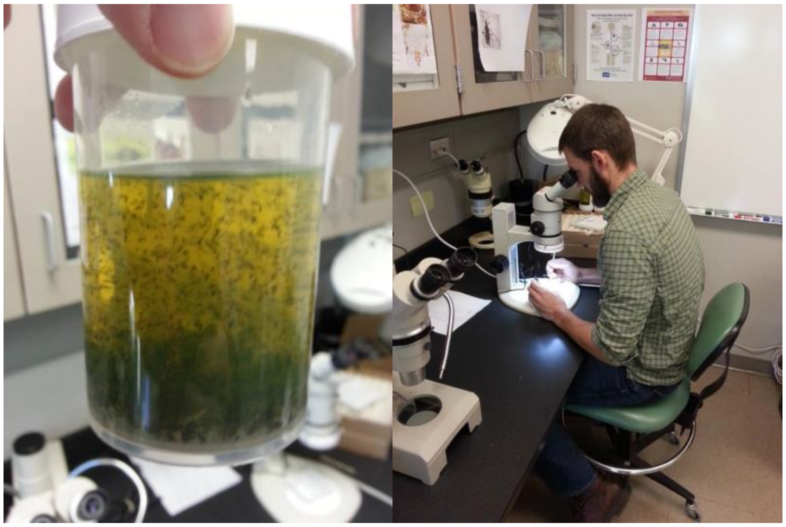
Eventually, however, the system became unsustainable for a number of reasons. PVY is a difficult problem to solve and while trap data can support management decisions, impacts can still occur. In addition, the information was distributed as a printed newsletter sent out via mail, making the information less timely. The bulk of the work, including servicing the traps, also fell to graduate students whose tenure with the university is limited, leading to turnover in staff. And because the identification of the winged aphids required specialized training and knowledge, transferring the project to a different entity was problematic.

Solar powered suction trap in use 2012-present.

Aphid Alert 2011-2017

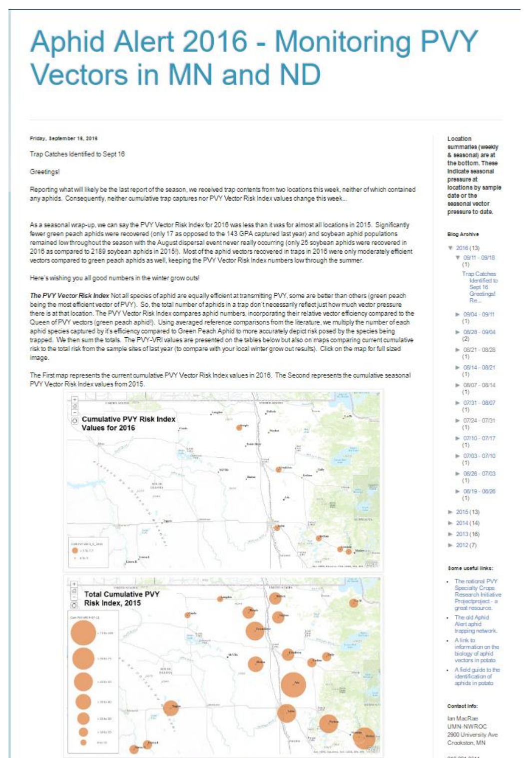
In 2011, MN and ND seed potato growers indicated they were interested in re-establishing the ***Aphid Alert Network***, but the system would have to be more sustainable over the long term. After discussion with seed potato growers and the Seed Certification directors of both states, it was decided to develop a collaborative system that would be maintained and serviced by volunteer grower-cooperators, with identifications and information distribution coming from the University. The ready support of grower-cooperators was a major factor in improving the sustainability of the system and there is a growing waiting list of volunteers wanting to host a trap site in the network.

Traps themselves were also made more sustainable. Solar panels were incorporated meaning batteries wouldn't require weekly replacement and weekly charging. The grower-cooperators change the trap jars weekly and use pre-paid, pre-addressed mailers to send the trap contents to the Entomology lab at the UMN Northwest Research & Outreach Center, where the aphids are sorted out and identified by lab personnel. We focus identification on the 15 most important PVY vector species in the NC States, but report other vector and non-vector species as well. Pan traps have not yet been used as there was no way to conveniently send the contents of such traps back to the lab. However, modified pan traps have been developed that can easily be emptied into jars and mailed with the suction trap contents. These traps will be included in the growing season of 2017.



Trap contents prior to sorting (left) and UMN Entomology technician identifying aphids.

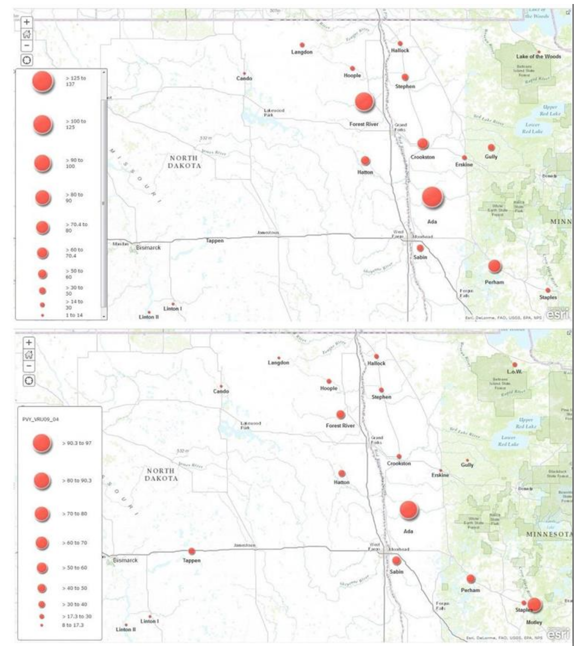
The details of regional aphid population distribution and density is distributed electronically via email, ListServe, websites (aphidalert.blogspot.com and aphidalert.umn.edu), Twitter (@MNSpudBug), and the Northern Plains Potato Growers Assoc. electronic newsletter (**Potato Bytes**), Updates to the electronic sites occur as samples are identified and past issues are archived and available. The hard copy versions were nice to have as reading, but digital delivery means the previous week's aphid population information is available to growers within 3-4 days of the trap being emptied (as opposed to 2 weeks with printed newsletters).



Aphid Alert blog post, including maps of aphid pressure.

Our digital reports include both the number of aphids that are PVY vectors at each trap location for that week and the running total of the season's catch at each trap location. But not all species of aphid are equally efficient at transmitting PVY, some are better than others (Green Peach Aphid is the most efficient vector of PVY). So, the total number of aphids in a trap doesn't necessarily reflect just the potential for PVY transmission at that site.

We developed the *PVY Vector Risk Index* which compares the numbers of each aphid species, incorporating their relative transmission efficiency (i.e. how well an aphid species can transmit the virus). There's been considerable research published comparing transmission efficiencies, mostly comparing to Green Peach Aphid. We averaged the comparisons (e.g. most publications show Soybean aphid is about 10% as efficient as Green Peach Aphid in transmitting PVY while Pea Aphid is considered to be about 20% as efficient). By multiplying the number of various species by their proportional efficiency, we estimate the risk of PVY transmission as if all aphids were Green Peach. We then total across all vector species at a site to get the total PVY Vector Risk Index value for that location. For example, if a trap captures 1 Green Peach Aphid, 10 Soybean Aphids (only 10% as efficient) and 3 Pea Aphids (only 20% as efficient, the total PVY Vector Risk Index value for that trap at that date would be 1+(10 x 0.1) + (3 x 0.2) = 2.6.



Cumulative PVY Vector Risk Index maps for 2015 (top) and 2014 (bottom).

The Index values are used to create maps in ESRI ArcGIS Online. Symbols representing the magnitude of the cumulative PVY Vector Risk Index values at each site are used to create a quick and easy to understand visual reference of current and previous years' transmission risk. This allows growers to estimate this year's risk of PVY transmission given the previous year's aphid numbers and the resulting winter rejection rates.

Conclusions

The ***Aphid Alert Network*** continues to be a successful collaboration between University researchers and the seed potato producers of Minnesota and North Dakota. The system's sustainability has been increased through the participation of grower cooperators who monitor the traps, by adapting traps so they require less maintenance, distributing information in a timely manner via digital communications and supplying data that is meaningful and accurately reflects the potential risk of PVY transmission.

Potato Nutrient Use and Management Tips across Varieties

Mark J. Pavek, N. Richard Knowles, Zachary J. Holden

Department of Horticulture and Landscape Architecture, Washington State University, Pullman, Washington, 99164-6414, USA

Introduction

Time, and time again, research has demonstrated that the addition of fertilizer to nutrient deficient soils is beneficial for crop growth and production. Application rates and petiole and soil sufficiency ranges for nitrogen (N), phosphorus (P), and potassium (K), and some micronutrients like sulfur, zinc, boron, and magnesium have been established for most crops in most primary production regions. The difficulty for commercial crop producers is determining proper nutrient input levels when production or plant growth conditions are non-typical. The difficulty is compounded as one ponders whether growing conditions are really ever "typical".

Prior to making important production decisions, growers should remember a few concepts. One has to do with yield potential – what is the actual attainable yield, given the land, potato variety, environmental limitations, etc.? Yield can be put into several categories:

- Potential Yield
  - no restrictions except genetics, absolute maximum
- Attainable Yield
  - maximum yield grower can attain in a given situation
- Economic Yield
  - yield that maximizes grower return
- Actual Yield
  - actual yield a grower attains in a given situation
- Primitive Yield
  - no inputs used, environment not manipulated

The ultimate goal of all producers should be to produce the yield that maximizes grower return, or the economic yield. All too often, their goal is to produce the maximum yield for the given situation, or the attainable yield. Because sufficient economic return is key for businesses to remain competitive and maintain production, the second concept growers should embrace is "the law of diminishing returns". At some point, higher yields from additional inputs (more fert, protectants, etc.) become too expensive to achieve. The potential economic gain in yield increase from each additional input is eventually offset by the cost of those inputs. In other words, when one maximizes yield, they are not always maximizing economic return. Following years of nitrogen and phosphorus research on many potato varieties and having experienced production years with rather extreme variations in ambient temperatures and heat unit accumulation, we provide recommendations for Columbia Basin potato producers based on previous and ongoing research and economic analyses.

Materials and Methods

Nitrogen Trials

Across 10 years (2007-16), eighteen potato varieties were tested under four full season nitrogen N) rates, typically 150-, 250-, 350-, and 450-lbs N/acre. Approximately 75- to 125-lbs N/acre was available in the soil prior to planting (soil residual + pre-plant urea broadcast). The remaining N (UAN, Soln 32) was applied once to twice weekly at rates between 0- and 35-lbs/A via a flood sprayer (overhead irrigation fertigation simulator) between tuber initiation (early June, 50-60 days after planting) and the mid to late tuber bulk (late July, 100-110 DAP). Petiole and soils samples were collected weekly or bi-weekly between June and early August. The crop was allowed to grow between 150- and 180-DAP prior to harvest. Following harvest, tubers were separated into typical US yield and cull grades and internal and external quality was evaluated. Nitrogen fertilizer cost-adjusted gross return was calculated for either the fresh (baked potato) or process (french fry) market.

Phosphorus Trials

Across 6 years (2011-16), up to eight potato varieties were tested under three full season phosphorus rates, 0-, 227-, and 454-lbs P/acre. Phosphorus was applied in a variety of manners: all pre-plant broadcast, split applications of 75/25 pre-plant broadcast, banded (liquid and dry), and 100% applied via the irrigation water. Phosphorus sources include 11-52-0 and 10-34-0.

Results and Recommendations

Nitrogen

Ten years of research revealed that over 90% of the time the nitrogen rate required to maximize tuber yield was greater than that used to maximum economic yield. Alturas is shown as an example in Figure 1. Twenty nine percent of the 18 varieties tested produced maximum economic returns using with less than 350 lbs/A of N, 53% used between 350- and 400-lbs/A, and 23% used more than 400 lbs/A. Averaged across all varieties, the maximum tuber yield required 399 lbs/A of N while the maximum economic yield was realized with 348 lbs/A of N. The maximum economic yield was achieved with 51 lbs/A less N, or 15% less, than was required to maximize tuber yield.

We recommend applying pre-plant or at-planting nitrogen so there is 125- to 150-lbs/A of available N (soil residual + applied) in the root zone at emergence. Petiole and soils during the growing season should be used as a guide, however, growers should strive to hit the season total N targets (Table 1). Petiole and soil samples should be collected prior to row closure and continue through the season until late bulking (once every 2 weeks is adequate). Soil N should be at or below 50 lbs/A by mid-July and plants kept healthy via “spoon-feeding” of nitrogen. With low soil N and the cessation of N applications prior to mid-August, plants will be able to adequately mature during August and September.

Phosphorus

There was typically significant benefit from applying 227 lbs P2O5 on 8 varieties compared to the NO-P control; on rare occasion, 454 lbs P2O5 was also beneficial (Figures 2 and 3). When averaged across years, the 454 lbs/A appeared to be detrimental to economic return (Figure 3). Based on this and other recent research, we recommend Columbia Basin growers have at least 227 lbs of P2O5 (soil available +

applied) available in the soil at or soon after plant emergence. Application of excessive P2O5 (454 lbs or greater) has the potential to reduce grower yield and economic return.

For nutrient recommendations other than N and P, growers should follow the nutrient management guidelines established for Russet Burbank (Lang et al. 1999).

Table 1. Full season nitrogen target rates for the Columbia Basin of Washington and Oregon along with target petiole rates during June and July. Growers should strive to have 125- to 150-lbs/A of nitrogen in the soil (residual + applied) at emergence and apply the remainder during the season via irrigation (fertigation). To ensure plant maturity, stop nitrogen applications prior to mid-August.

Variety	Full Season Nitrogen Target Rate	Petiole Nitrate Target Concentrations June 15	June 30	July 15	July 30
Process Market Recommendations	lbs/A	-----------------% NO_3-N------------------			
Alpine Russet	370	2.9	2.3	2.0	1.7
Alturas	360	2.6	3.0	2.2	1.5
Classic Russet	360	2.7	2.5	2.3	2.0
Clearwater Russet	375	2.4	2.3	1.9	1.5
Mountain Gem Russet	340	2.6	2.3	2.0	1.8
Owyhee Russet	325	2.8	2.5	2.1	1.7
Payette Russet	425	2.5	2.8	2.2	1.6
Ranger Russet	360	2.8	2.6	2.4	2.3
Russet Burbank	350	2.6	2.2	2.0	1.7
Sage Russet	375	3.1	2.8	2.6	2.4
Teton Russet	350	2.7	2.5	2.2	2.0
Umatilla Russet	400	3.0	2.8	2.5	2.1
Fresh Market Recommendations					
Classic Russet	330	2.7	2.3	2.0	1.8
Mountain Gem Russet	300	2.6	2.1	1.8	1.6
Teton Russet	325	2.7	2.3	2.0	1.8

Figure 1. Adjusted gross return ($) and total tuber yield for Alturas averaged across three years of research. Note that the Adjusted gross return (economic yield) was maximized with 366 lbs/A of nitrogen, while the tuber yield was maximized with 435 lbs/A of nitrogen.

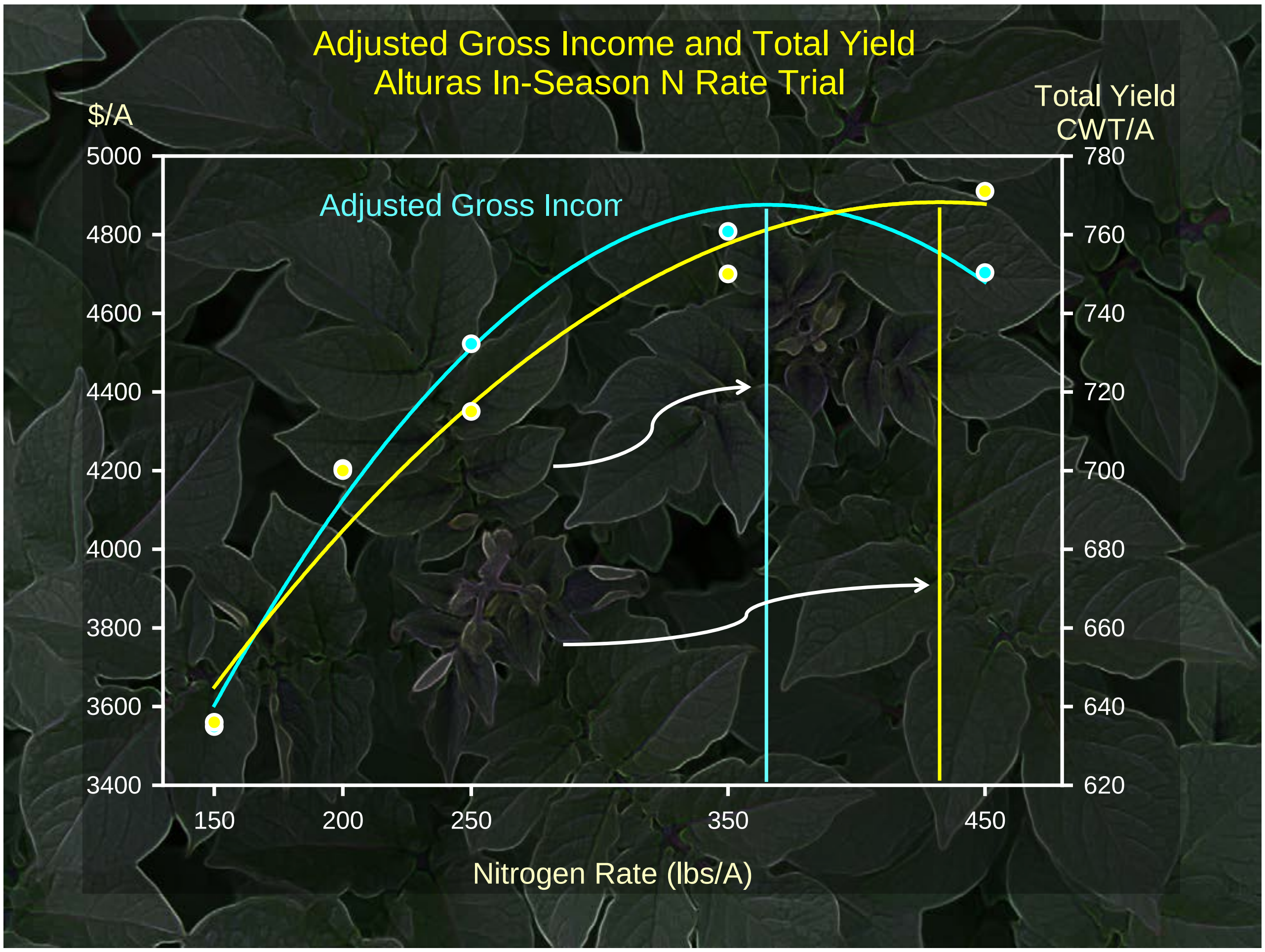


Figure 2. Adjusted gross return ($) for eight potato varieties when 0- or 227 lbs/A phosphorus was added to the soil. Soil ppm of phosphorus was typically between 10 and 14, with pH > 7.0.

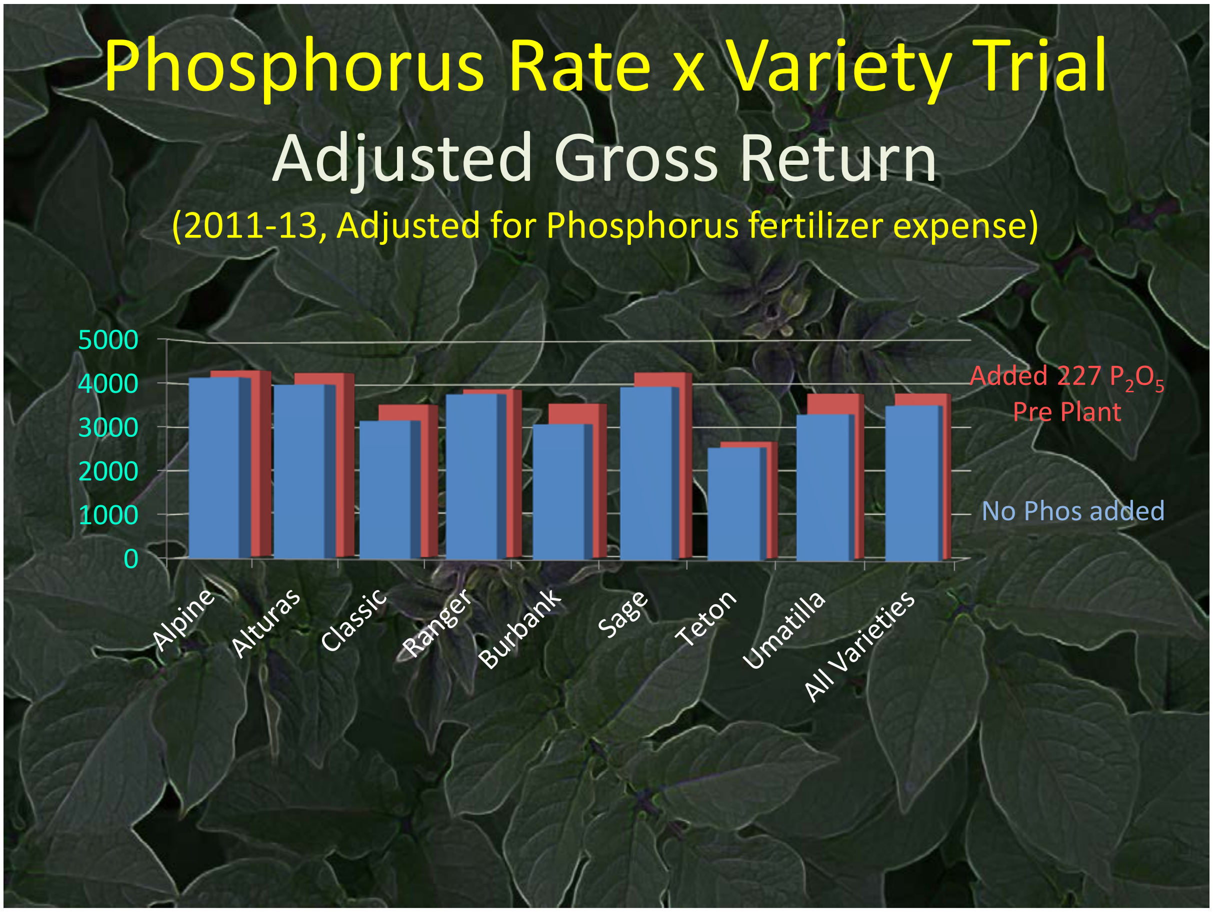
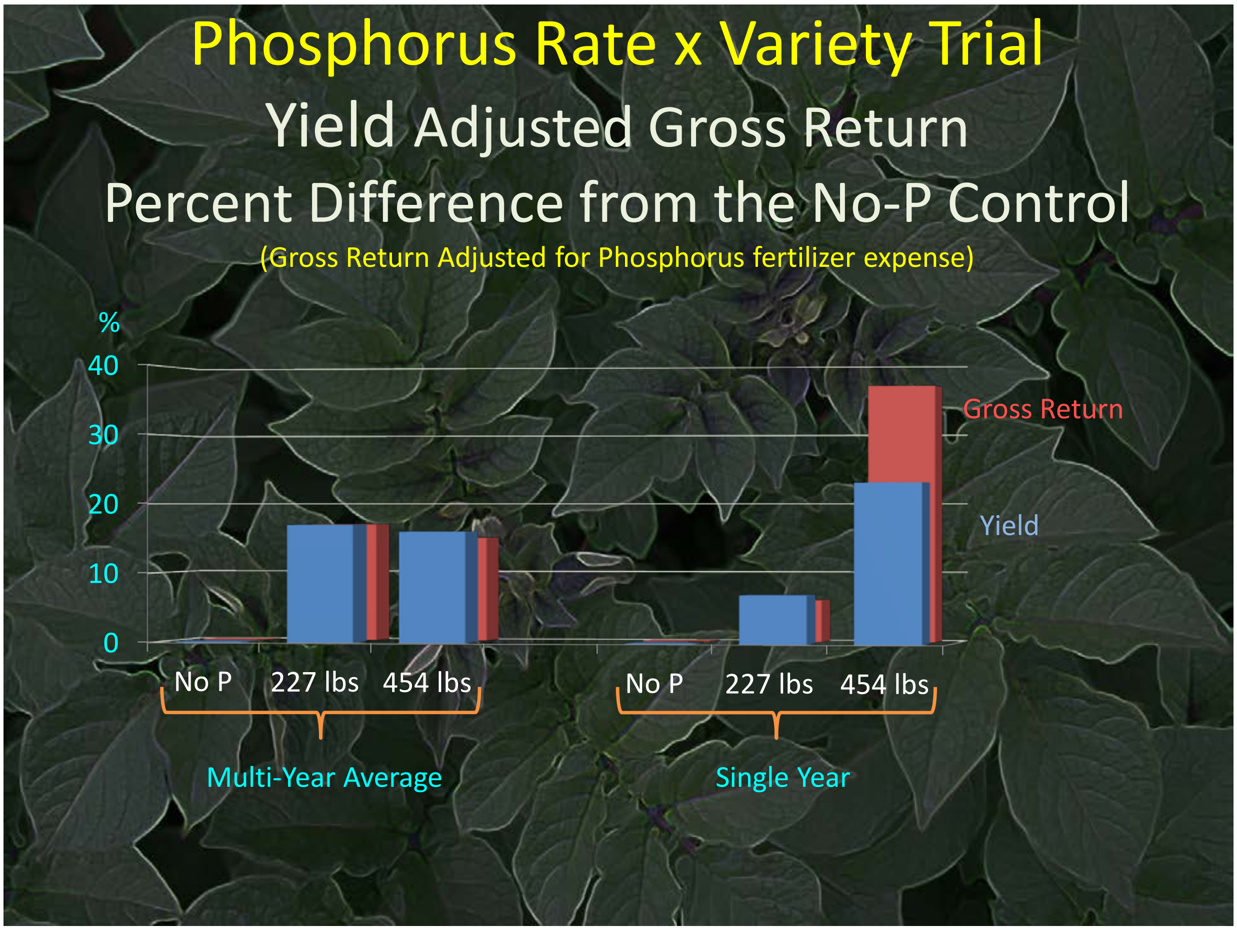


Figure 3. Adjusted gross return, percent difference from the non-treated control NO-P or 0 rate averaged across Russet Burbank, Ranger Russet, and Umatilla Russet and years 2011-13 or 2013 only (single year). Rates were 0- 227- and 454-lbs/A of phosphorus. All P was applied pre-plant broadcast (11-52-0). Soil ppm of phosphorus was typically between 10 and 14, with pH > 7.0



Managing Lygus on potatoes in the Columbia Basin: should we care?

Silvia I. Rondon and Josephine Antwi

Hermiston Agricultural Research and Extension Center, Crop and Soil Sciences, Oregon State University, Hermiston, OR

Lygus bugs are insects that feed on a wide range of cultivated crops including strawberry, apple, peach, nectarine, pear, legume, carrots, radish, and other crops. Although rarely a pest on potatoes, Lygus bugs abundance and distribution are causing apprehension to potato growers in the PNW, particularly those in the lower Columbia Basin, suggesting that in addition to causing direct feeding damage, Lygus bugs may vector pathogens.

Lygus bugs are insects with characteristic piercing-sucking mouthparts. Adults are about ¼ inch (6mm) long, somewhat hunchback and are recognized by the presence of a conspicuous heart shape on the upper center of the back known as scutellum. Immature Lygus bugs look somewhat similar to adults, except immatures are smaller, do not have wings, and do not reproduce (Figure 1). Lygus bug eggs are difficult to see with the naked eye because females insert entire eggs into plant tissues exposing only the flat cap cover of the egg (Figure 2).

Figure 1. Left, Lygus adult; right, nymph. Pictures not scaled. Photos credit: Rondon's Irrigated Agricultural Entomology Program (by J.A.)

Figure 2. Lygus egg in a green bean. Magnification 10X. Photo credit: Rondon's Irrigated Agricultural Entomology Program (by J.A.)

Lygus bug damage

Both adults and immatures feed on plants by inserting their piercing-sucking stylets into leaves and stems of host plants. Lygus bugs digest their food extra-orally by secreting enzymes through saliva producing a liquefied "plant soup" before ingestion. In potatoes, tissues at the site of Lygus feeding do not grow normally (Figure 3A). Feeding usually results in leaf flagging, and

Figure 3. Lygus damage caused by feeding and oviposition (A); close up of a dead leaf. Photos credit: Rondon's Irrigated Agricultural Entomology Program (by J.A.)

leaf deformation; also feeding injury often appears as brown lesions or dead tissue (Fig. 3B) Much of their feeding damage can be seen at the terminal region of potatoes.

Lygus bugs as potential vectors of potato pathogens

The extent to which Lygus feeding damage affects potato tuber yield is still unknown. But there are concerns that Lygus bugs could transmit potato pathogens – specifically the Beet Leafhopper Transmitted Virescence agent (BLTVA) – causal agent of potato purple top disease (Figure 4). The pathogen is transmitted to potato primarily by the beet leafhopper (BLH), *Circulifer tenellus* Baker. However, Lygus bugs have been observed in association with potato plants expressing purple top symptoms and some growers have a firm belief that Lygus vectors this pathogen. Preliminary results prove that Lygus can carry the pathogen but the efficiency of transmission is under investigation.

Figure 4. Purple top disease on potatoes. Photo credit: Rondon's Irrigated Agricultural Entomology Program.

Management of Lygus bugs

Monitoring Lygus populations on surrounding vegetation has been suggested because crops such as alfalfa can serve as a source for Lygus into potato fields. Preliminary field studies suggest that as alfalfa is harvested, Lygus bugs migrate to nearby potato fields. There are different techniques available for sampling Lygus bugs including sticky cards, insect nets or vacuums. Based on our studies, the inverted leaf blower (a.k.a. DVAC) is the most effective tool to sample this insect (see YouTube video https://www.youtube.com/watch?v=dLpI3jkCjXQ). Currently we recommend to use the vacuum for 5 minutes, 5-10 feet from the border of the fields. Presently, there is no economic threshold for Lygus bugs on potatoes in the PNW.

The rising numbers of Lygus bugs on potato fields in the PNW in recent years suggests that Lygus bugs are emerging pests of potato. Lygus feeding is quite significant and there are efforts ongoing to determine the consequence of such damage. Additionally, we know that Lygus bugs carry the potato pathogen, BLTVA, but the efficiency and rate of transmission is currently under investigation. There is an urgent need for more research in order to identify effective pest management programs against the insect.

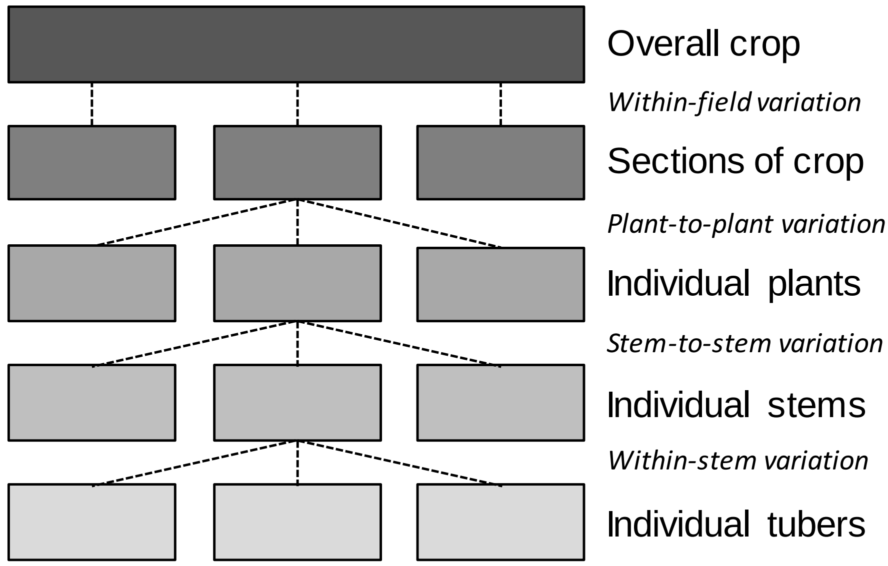
Variation in Tuber Size: Multiple Scales, Myriad Causes

S.E.H. Smart. NIAB CUF, 219b Huntingdon Road, Cambridge, United Kingdom
simon.smart@niab.com

Variation in tuber size within crops can affect marketable yield by increasing the proportion of under- and over-size tubers. Different mathematical models have been used to describe tuber size or tuber weight including Weibull distributions (Bussan *et al*. 2007), gamma distributions (Marshall 2000) and normal distributions (Travis 1987). These methods are preferable to analysing the yield within individual size grades as fewer spurious significant effects occur and more subtle differences in tuber size can be detected (Hall & Glasbey 1993). The method of Travis (1987), who described the tuber size distribution with a normal curve, describes the tuber size distribution with two parameters; mean tuber size where 50 % of yield consists of smaller tubers and 50 % consists of larger tubers, and standard deviation where 68 % of yield is within one standard deviation of the mean tuber size. The standard deviation increases as yield and mean tuber size increase, but the ratio between the standard deviation and the mean tuber size remains stable. This ratio is the coefficient of variation (COV) and is a measure of uniformity. Typical values of the COV of tuber size range from *c.* 12-20 %, which for a typical UK crop at the optimum mean tuber size equates to marketable yields of *c.* 98-84 %. Although tuber weight distributions are not normally distributed, cubic transformations can be used to convert between size and weight, and in turn predict the percentage of yield in any weight grade.

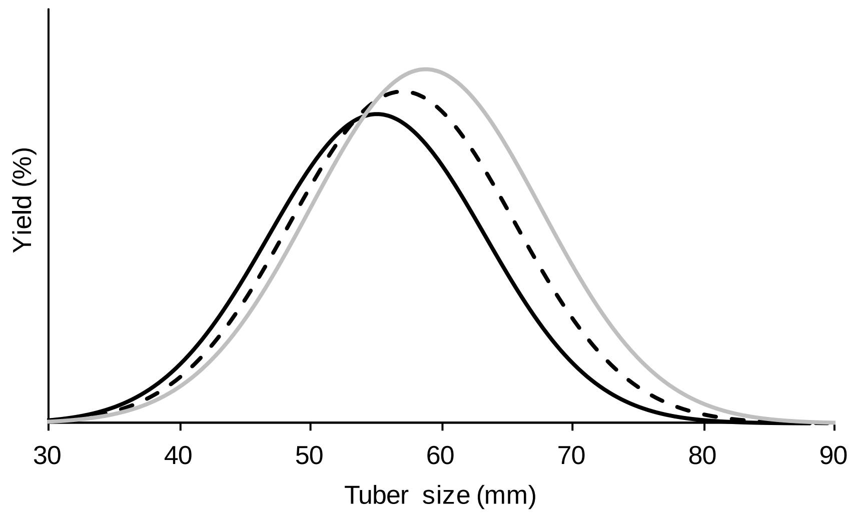
Achieving the target mean tuber size is critical to having a large proportion of the yield within the required grades and is determined by yield and number of tubers. The processes governing each of these are well understood (Allen & Scott 1980; Firman & Daniels 2011) and mean tuber size can therefore be manipulated by varying seed size and spacing (Allen & Wurr 1992). During the season, with knowledge of yield formation, mean tuber size can be predicted in order determine when the optimum economic yield will be achieved, depending on the value of different grades (Stalham 2017). However, variation in tuber size is more difficult to predict and manipulate, with many factors potentially affecting the extent of variation. Variation in tuber size occurs at different levels within a crop (Figure 1) and understanding the mechanisms determining this variation will aid in producing more uniform crops. Analogous to the processes determining mean tuber size, variations in tuber size are caused by variations in yield and the number of tubers.

Figure 1. Different scales at which variation in tuber size occurs within a crop.



At the largest scale, variations in the yield and or number of tubers at different locations within a crop can result in the mean tuber size varying. Factors that affect the yield and number of tubers between crops (e.g. soil type, nutrition, irrigation, pathology) will also affect variation within a crop. The effect on uniformity will depend on the extent of the variation in mean tuber size and currently, there is little quantitative information available on how this varies within crops. Models indicate that some variation in the mean tuber size can be tolerated with only a small effect on uniformity (Figure 2) but more data are required to establish how realistic this is. Technological innovations such as unmanned aerial vehicles and yield mapping may allow us to characterise within-field variations more precisely but these variations would need to be predictable and consistent in order to be managed.

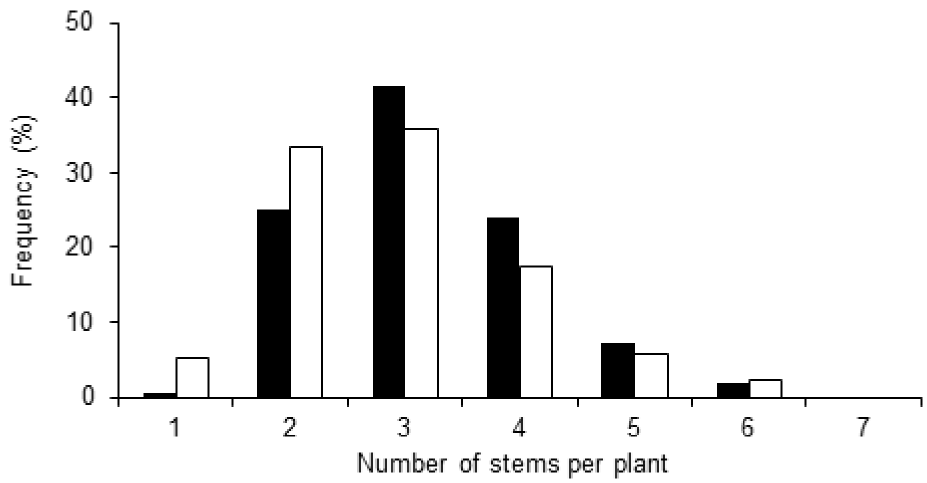
Figure 2. Modelled tuber size distributions for a typical crop with a yield of 60 t/ha, 500k tubers/ha and a COV of tuber size of 15.0 % (- - - -). Areas producing a 10 % lower yield (———) or a 10 % higher yield (———) produce smaller and larger tubers respectively, but the overall COV of tuber size of the entire crop is only moderately increased to 15.4 %.



Plant-to-plant variation has long been noted to occur within potato crops (Stewart 1921; Svensson 1966), but the causes of this variation have been uncertain and whether it has any effect on uniformity has not previously been investigated. Surveys of commercial crops found that plants with a higher yield per stem produced larger tubers, consistent with how for a given yield, the stem density determines the mean tuber size of crops. Several experiments were conducted to establish how variation in seed tuber weight, emergence and within-row spacing affected variation in the yield, number of stems and number of tubers per plant and how these variations affected the overall variation in tuber size. Theoretically, the most uniform crop would consist of evenly spaced, single-stemmed plants that emerged evenly. In reality, crops are far from this ideal, but there would be advantages in manipulating crops to be closer to this situation.

Considering that the mean seed tuber weight affects the number of stems per plant (Firman & Daniels 2011; Allen & Wurr 1992), variation in seed tuber weight was expected to affect variation in the number of stems per plant, which has previously been shown to influence the mean tuber size of plants (Firman and Shearman 2006). Reducing variation in the number of stems per plant would reduce variation in mean tuber size per plant and improve uniformity. However, it was found that reducing variation in seed tuber weight had no significant effect on the variation in the number of stems per plant (Figure 3) and did not affect uniformity. Although the experiments were conducted with Maris Piper, similar relationships between the weight of individual seed tubers and the number of stems per plant were found in other varieties. There are clearly other factors besides seed tuber weight which determine the number of stems per plant and establishing these merits further attention.

Figure 3. The number of stems per plant for crops grown from tightly graded seed (35-45 g) and widely graded seed (25-45 mm, 12-82 g) with the same average weight. Tightly graded seed, ■; widely graded seed, □.



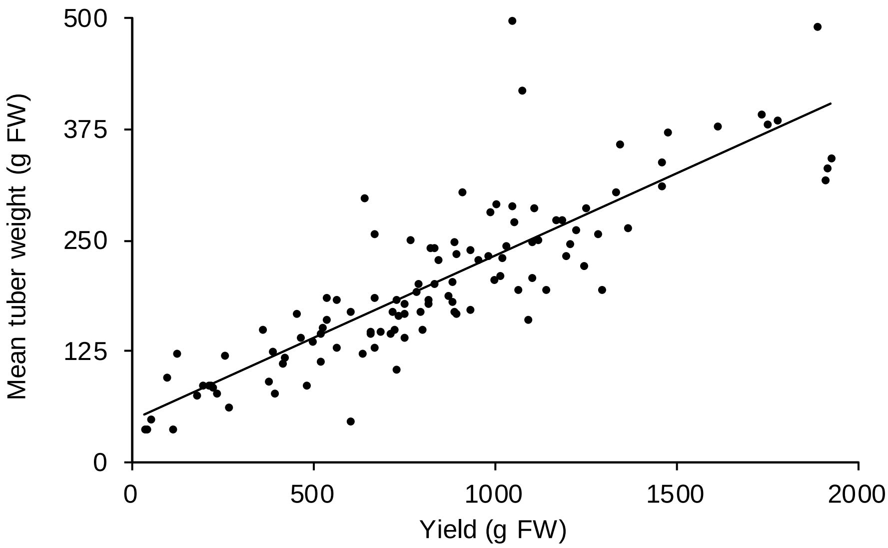
Variation in emergence is known to be important in influencing the uniformity of root vegetable crops, with earlier emerging plants out-competing later-emerging plants and producing larger roots (Benjamin 1990). While emergence is routinely recorded in experiments, it is uncertain whether variation in emergence contributes to causing variation in tuber size. Seed tubers were sprouted prior to planting and split into two groups, one containing evenly sprouted tubers

(2-4 mm long) and the other containing tubers with long and short sprouts (< 2 mm and > 4 mm long). The evenly sprouted seed tubers emerged more uniformly and decreased variation in yield per plant, but did not significantly affect uniformity. However, the differences in emergence between treatments were relatively small in comparison to those that occur between stocks of the same variety grown in different years. Had emergence been more protracted, the results may have differed. Information on the typical duration of emergence in commercial crops is required to establish how substantial any decreases in uniformity that it causes are.

Variation in within-row spacing results in plants growing at different densities which would be expected to cause plants with more space to produce larger tubers than those with less space. While previous experiments (Pavek & Thornton 2006) have found irregular planting can decrease marketable yields, they did not distinguish between whether this was due to differences in the mean tuber size or variation in tuber size. Other experiments have found no influence of variation in within-row spacing on the tuber size distribution (Jarvis *et al.* 1976; Entz & LaCroix 1984; Booth & Allen 1989, 1990). It is necessary to establish what extent of variation in within-row spacing can be tolerated without increasing variation in tuber size. In 2013, seven treatments were examined with levels of variation in within-row spacing ranging from completely uniform to four seed tubers planted within 40 cm of each other, followed by an 80 cm gap. Increasing variation in within-row spacing did not affect overall yield, variation in yield per plant or variation in tuber size. This demonstrated that the growth of the canopy was plastic and compensated for differences in space per plant, so that large differences in space per plant had minor effects on yield per plant. In 2014, the most extreme treatment from the 2013 experiment was compared with uniform spacing in an experiment in Maris Piper and in a separate experiment in Marfona and Markies. In Maris Piper, the COV of tuber size increased by *c.* 1 % by the higher variation in within-row spacing, resulting in a *c.* 2 % decrease in the yield of marketable tubers. The treatment had a much larger effect in Marfona and Markies, increasing the COV of tuber size by *c.* 3 % resulting in a 5 % decrease in the yield of marketable tubers. Yield was decreased by variable spacing in both experiments by *c.* 5 t/ha but the differences could not be explained by differences in ground cover and may have been caused by neighbouring rows compensating and producing a higher yield. Further work is required to establish the varietal traits responsible for the different responses to variation in within-row spacing.

In addition to the experiments, surveys were conducted to examine how seed tuber weight, number of stems per plant and date of emergence affected stem-to-stem variation. As the true unit of population within the potato crop (Allen & Wurr 1992), it is crucial to understand the growth of stems in order to understand the variation that occurs within crops, but no descriptions of stem-to-stem variation exist. It was consistently found that the yield of individual stems was more variable than that of individual plants, and that as the yield of stems increased, they were more likely to produce larger tubers (Figure 4). Within crops, higher yielding stems produced more tubers, but the increase in the number of tubers was not proportional to the increase in yield and therefore was not sufficient to counter the effect of yield per stem on mean tuber weight per stem. Although there was considerable variation in the size of tubers on each stem (the causes of which are uncertain), the consequence of the relationships between yield per stem and mean tuber weight, was that reducing variation in the yield of stems would result in a more uniform crop.

Figure 4. Relationship between the yield of individual stems and the mean tuber weight per stem in Russet Burbank. Mean tuber weight was derived in an analogous way to the mean tuber size of crops, accounting for the distribution of yield between different tubers.



Variation in tuber size is a complex trait with numerous physiological and agronomic causes. This work has made progress towards understanding the underlying causes but there remain many uncertainties, in particular at the level of individual stems. Future work will continue to characterise stem-to-stem variation and will begin to examine variation in tuber size on individual stems, which is a further component of variability that was not explored in the current study.

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Potato Crop Modelling: The Way to Eliminate Unnecessary Digging?

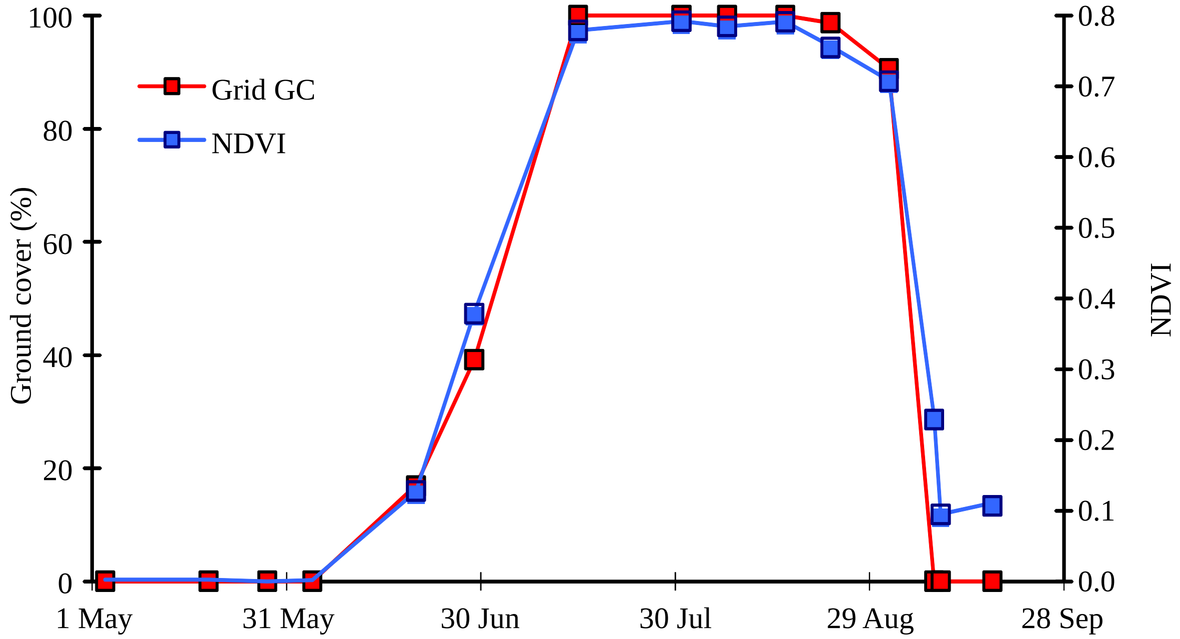
Mark A. Stalham & Marc. F. Allison
NIAB CUF, Agronomy Centre, 219B Huntingdon Road, Cambridge, CB3 0DL, UK
(mark.stalham@niab.com)

Hand-digging potato crops to determine their yield is labour-intensive and, unless sufficient replicated areas are sampled, can be inaccurate and imprecise owing to within-field variation. How many times do we need to sample a crop to accurately forecast its yield? To avoid the tedium of sampling, NIAB CUF has developed a yield model which has been proven to accurately estimate yield and tuber size distribution from simple measurements of canopy cover, combined with a parameterization dig taken around 50 days after emergence. The model can be used for accurate forecasts of final yield and size grading from this point onwards.

Why is it necessary to forecast yield? Firstly, for logistical reasons (e.g. balancing harvesting and store capacity with the crop production). Secondly, risk management (e.g. how much tonnage will be produced in a given season and whether contracts will be fulfilled or run short). Thirdly, by comparing against high-performing crops this allows improved crop management and performance and provides a route for improvement. Lastly, the freeing-up of labour resources by avoiding time-consuming yield digs in the lead-up to desiccation and harvesting allows more time for quality assessment, storage potential, skinset, disease loading, bruising etc.

The NIAB CUF yield model relies on the fact that total dry matter (DM) yield is proportional to intercepted radiation (Monteith 1977) and that intercepted radiation is largely proportional to green ground (canopy) cover, particularly since photosynthetically active radiation (PAR) is preferentially absorbed by leaf canopies. Canopy cover can be estimated from a range of methods. The simplest grid-based measurement systems based on visual assessment (Burstall & Harris 1983) or image analysis on smart phones (e.g. www.potatocropmanagement.com) rely on replicated estimates of *c*. 0.75 m^2 of canopy. However, these methods can lead to error owing to variation in the crop canopy within the field. Scaling up to a 125 acre (50 ha) centre-pivot field, with three replicate measurements using an iPhone (2.25m^2), only 0.00045 % of the field is sampled. For this reason, NIAB CUF has investigated aerial platforms for assessing Normalised Difference Vegetation Index (NDVI). Assessing NDVI via satellite platforms (e.g. LANDSAT, COSMO) needs cloud-free conditions, and where these occur for long periods of the day and season, good correlations have been obtained between satellite-derived NDVI and on-ground measurements of ground cover (Figure 1). Unfortunately, in many environments, the probability of a cloud-free day is too low to obtain reliable NDVI data from satellite flight passes. Other sensing methods such as radar from satellite platforms are still problematic but have the benefit of being much less affected by cloud cover. Sub-cloud level aerial platforms such as fixed-wing aircraft are currently being tested since these offer the chance to view many fields at the level of detailed required on a single flight. Drone platforms have more limited utility owing to regulations on lines of sight and privacy.

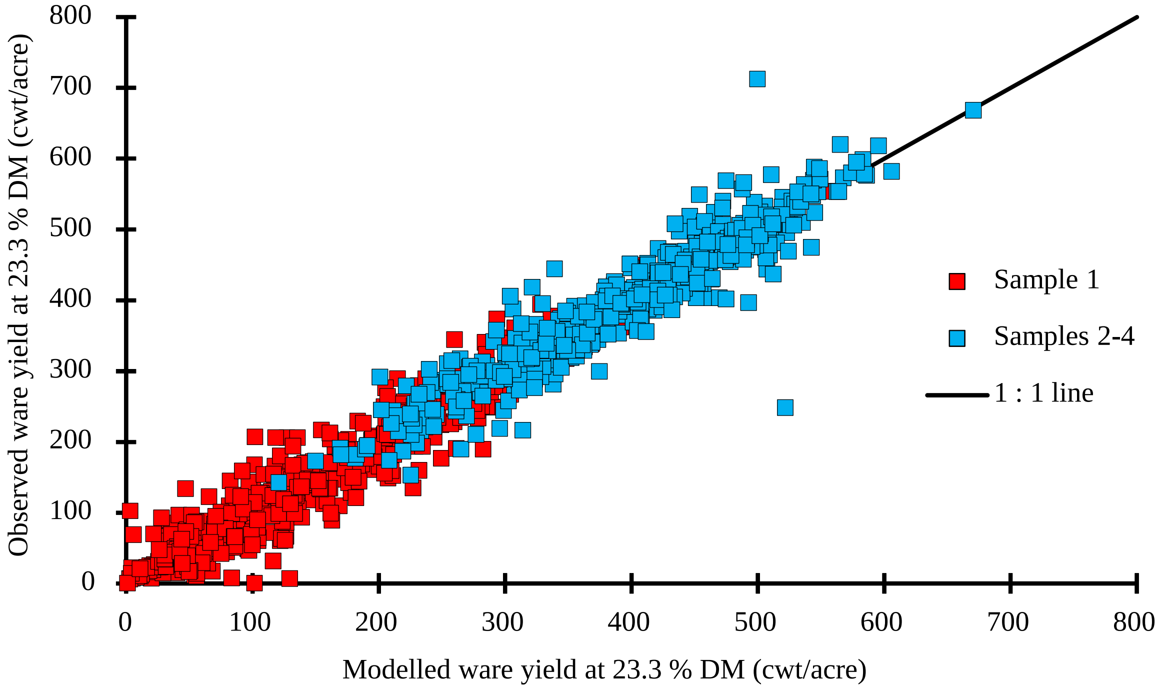
Figure 1. Relationship between grid ground cover and NDVI (from Landsat), Colorado, 2010.



The NIAB CUF model calculates the amount of DM produced each day using radiation data collected from both weather stations close to canopy level and from satellites (e.g. NASA). Radiation data are now much more widely (and freely) available for most potato growing regions in the world. The model then partitions the DM into haulm and tuber fractions and for this a replicated parameterization yield dig taken at *c*. 50 days after emergence is required. At this time, the number of tubers should have stabilized and this allows the modelling of the change in tuber size distribution as yield increases. This is a very important feature for determining the optimum desiccation date for crops where certain size fractions have much higher value than others, and the loss in value from having too much over- or under-size crops can be significantly reduced.

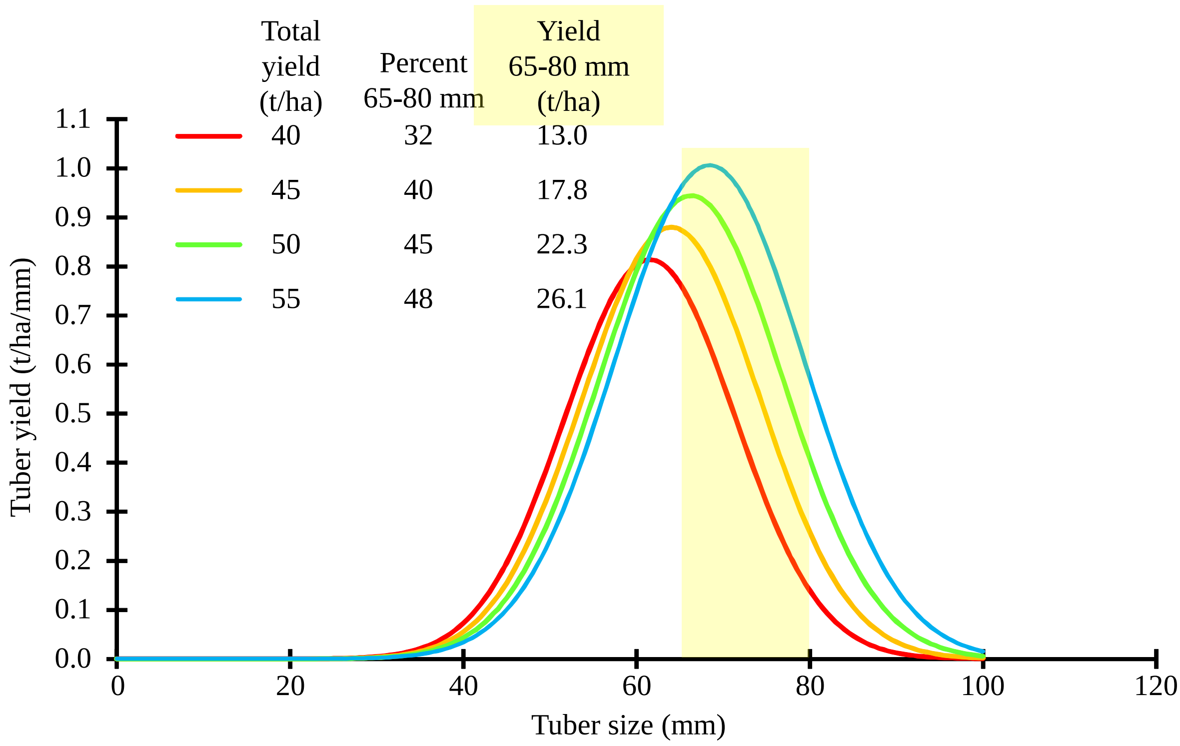
With good ground cover data, the model has been proven to provide an accurate yield prediction, even 2 months ahead. In a large validation study with chipping crops for a major international processor over the period 2010-2015, the average sampled final yield of 495 crops was 426 cwt/acre (adjusted to 23.3 % DM), whilst the mean modelled yield was calculated to be 421 cwt/acre. Also, when comparing the initial within-season forecasted yields with the retrospective modelled yields, there was little error in prediction (*c*. 13 cwt./acre). The model has now been validated in 1886 crops (Figure 2).

Figure 2. The relationship between observed ware yield and modelled ware yield in 495 chipping crops, 2010-2015.



Accurate prediction of tuber size distribution is crucial for accurate burn-down date where tuber size is critical to crop value. Two models of tuber size distribution have been used: Method 1 is based on the relationship between change in yield and mean tuber size (μ) and assumes a constant tuber population and is the method is used by the model currently (Figure 3). In order to better understand the effect of change in tuber shape in elongated varieties (e.g. French fries and fingerlings) as they grow, Method 2 has been developed which is based on the relationship between the change in mean tuber weight and μ.

Figure 3. **Relationship between 65-80 mm yield and total yield.**



Since rapid and sustained ground cover holds the key to improvements in performance, reference ground cover curves for the top 10 % of best-yielding crops have been developed based on a particular emergence date and the model therefore allows growers and agronomists to identify problems with their crops through measurement. Areas such are soil compaction, variable plant establishment and under- and over-watering have been identified for certain crops.

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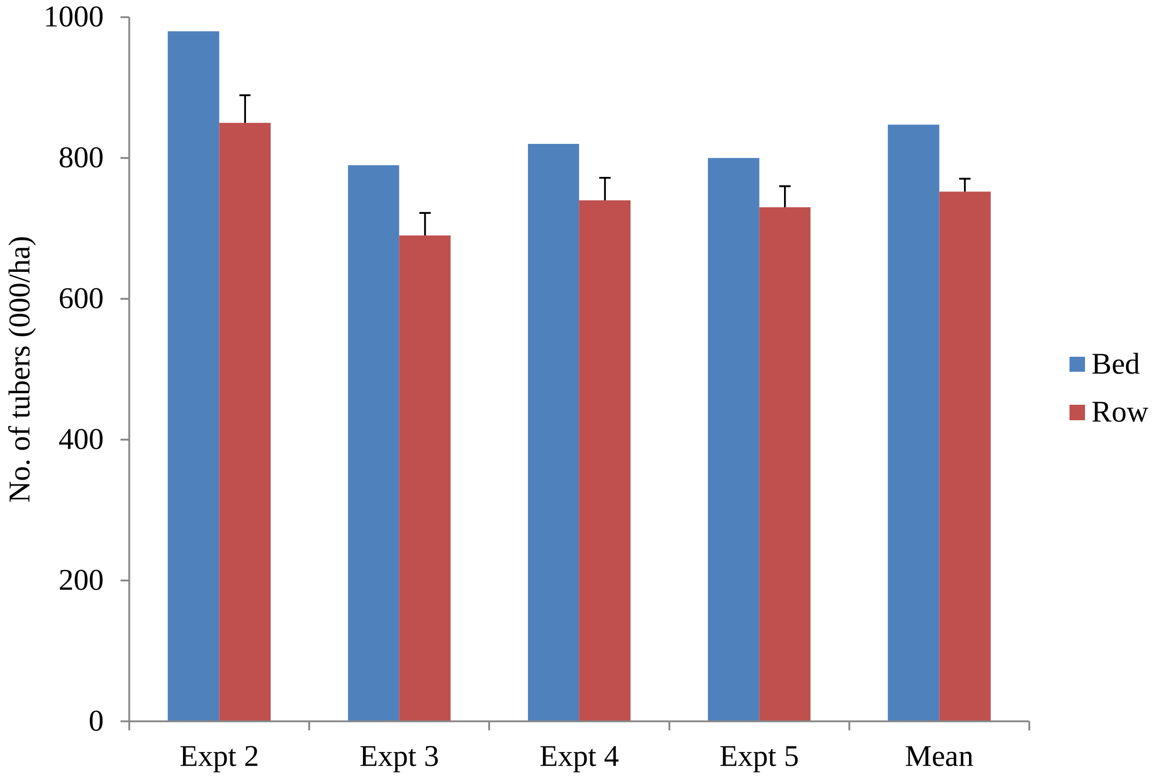
Rows vs Beds: a UK Perspective?

Mark A. Stalham
NIAB CUF, Agronomy Centre, 219B Huntingdon Road, Cambridge, CB3 0DL, UK
mark.stalham@niab.com

It is often asked by potato growers in the UK whether they should use beds rather than rows to grow their crops. There are a number of factors influencing the decision, some based on science, others based on anecdotal evidence. The most scientific reason would be the more even use of resources (soil, nutrients, water and radiation) within beds. Potatoes are almost universally grown in wide (28 to 40”) rows. With very wide row spacings, at the typical target plant populations required for economic production in terms of tuber size grading for the intended market, within-row spacing can be very close. This leads to early competition between plants within rows, particularly with respect to shading of leaves by adjacent plants. Since radiation interception by the canopy is a major determinant of the number of potential tubers set by the plant (O’Brien *et al.* 1998), this early mutual shading has the potential to reduce tuber populations in traditional row systems compared with systems where plants are spaced more uniformly and the onset of competition occurs later during the development cycle.

Fowler (1988) completed his thesis on the effect of rectangularity of spacing on crop performance. Squarer planting (i.e. bed-type systems) increased the initial rate of ground cover development compared with rectangular systems of planting (i.e. traditional wide rows), but the effect diminished as planting density increased. His work showed a 13 % increase in the number of tubers produced with beds compared with rows (Figure 1). This increase in tuber population makes beds more suitable for salad (fingerling) and seed crops. It is also a viable solution for varieties which produce few tubers per stem and/or few stems per seed tuber as it can reduce the quantity of seed required to produce small to mid-sized tubers required by certain markets. On row systems where within-row spacing exceeds 18”, a missed seed drop may be very significant as very wide gaps develop and yield loss occurs, and bed configuration reduces the effect of a miss. Conversely, attempting to grow prolific varieties for production of large processing tubers or baking outlets on beds is likely to reduce mean tuber size and make it more difficult to produce crops with a high proportion of very large tubers.

Figure 1. **Effect of rectangularity on number of tubers (Fowler, 1988).**



Although Fowler (1988) demonstrated these differences in tuber populations between beds and rows, in reality it is difficult to measure in practice, particularly as the yield may differ as well as the tuber population. He showed that at high planting densities, rate of canopy senescence was similar for bed and row configurations, leading to an increased radiation interception capacity for beds over the course of the season compared with rows. However, at low planting densities, the advantage conferred by beds was lost later in the season as beds senesced faster than row systems. The link between yield and canopy duration was close, so the effect of plant arrangement on tuber grading is heavily influenced by planting density.

Dedicated growers of salad (fingerling) crops in the UK almost universally plant in beds to take advantage of the increased tuber population, and on sandy soils this has led to configurations of three, four and even five rows in a 72” track width. Three rows per bed is by far the most common, with the ‘quad’ system gaining popularity in the 1990’s. The latter system is actually a pair of close-coupled rows, with the plant arrangement on a diamond pattern, rather than four equally-spaced rows, and therefore the effect on tuber population is actually diminished. The ‘quint’ system is a ‘quad’ plus an extra central row. As the number of rows per bed increases, soil flow around planter shoes and covering shares becomes an issue and only on the sandiest soils can four or five rows per bed become a practical solution. Where growers have both maincrop and salad crops, a compromise needs to be made for either crop as having two dedicated planters is often economically unviable.

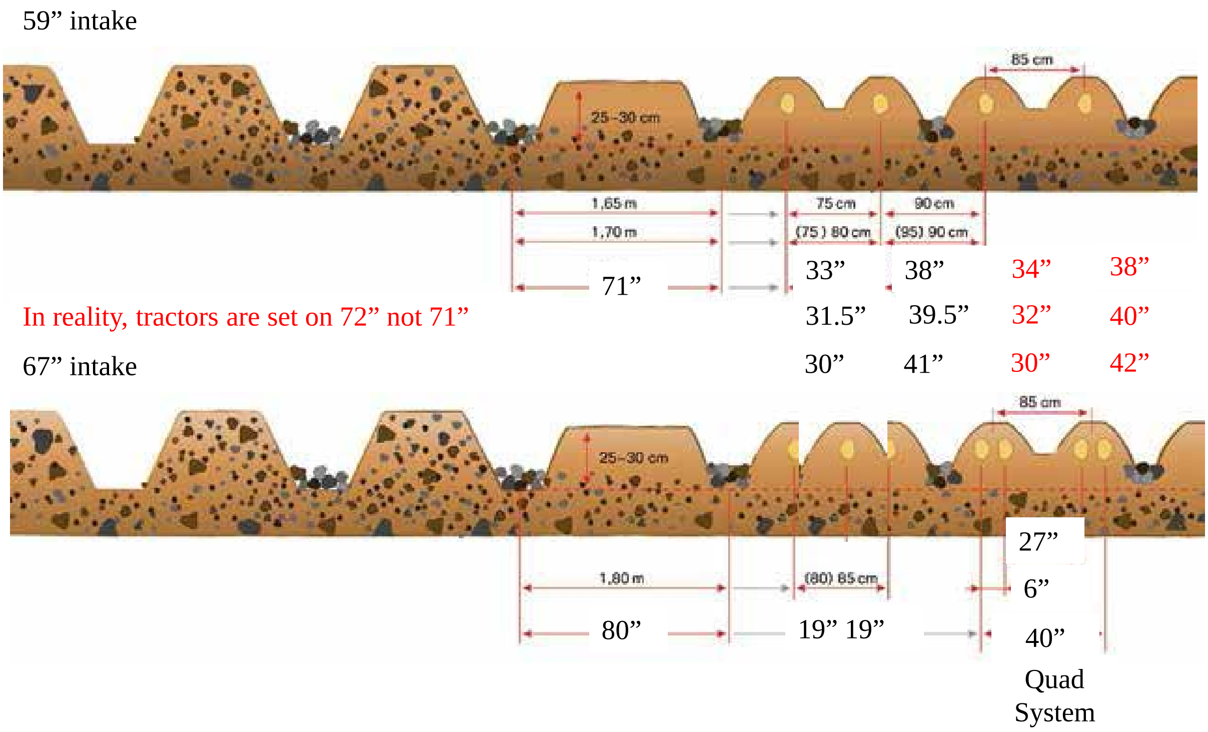
Bed systems have been proven to be more efficient at capturing water as there are 50 % less furrows for water to shed into. Measurements of water infiltration following ¾” to 1” irrigation events has shown that *c*. 15 % of water can be lost through vertical drainage in traditional ridge and furrow systems, but only *c*. 5 % in beds under the same regimes. However, this extra water capture in beds often does not translate into increased yield. As a negative, on heavier soils beds can be difficult to harvest if heavy rainfall occurs that brings the soil back to field capacity.

In the UK, the most common track width for machinery is 72”, whereas in mainland Europe it is typically 60” (two 30” equally-spaced rows). There is a misconception that narrow rows limit yield potential, as some experiments at NIAB CUF have yielded as much as 50 t/acre. Additionally, both Germany and the Netherlands plant on 30” rows and have higher average yields than the UK. What drove the change from 60” to 72” track width in the UK was the adoption of destoners in the mid-1970’s, where a bigger furrow between beds was required to bury the stone and clod removed from the bed. With harvester technology at the time, destoning was reported to improve spot harvesting rates by 40 % and reduce severe tuber damage by 30-50 % (Witney & McRae 1992), and therefore destoning (or declodding) was widely adopted. However, harvesting technology in Europe has moved on considerably in the interim period and harvesters can deal with clod far more effectively. Initially the move in wheel track for destoning systems was 68” but as tractor (and tyres) got bigger, the system settled on 72”. With the move to wider wheel tracks came the need to apparently work soils deeper to create bigger ridges, with no scientific reason. Working soil deeper results in more stone (and appreciably more clod in heavier soils) and so the wheeled trenches became fuller and the compacted area greater. Tyres on tractors towing destoners are now typically 15” wide, so the furrow must be of similar width to accommodate. This has resulted in ‘skewed inboard’ configurations being adopted, where the planter produces rows 34” apart within the bed and 38” apart between adjacent beds (Figure 2). As tyre size increased, this has moved to 32” within-bed and 40” between beds to avoid compacting the ridge flanks and reduce the proportion of green tubers that are exposed to light as the compacted soil cracks and erodes. Indeed, beds have been shown to reduce the proportion of greening as there is 10-20 % less surface area in flat-topped beds compared with ridge and furrow systems.

The idea that controlled wheelings on 72” centres reduces the effects of compaction within the zones where roots and tubers grow is therefore compromised. Using narrower (12-13”) tyres avoids the problem but the lack of traction during destoning and the lack of a firm wheeling for harvesting under wet conditions means that wide furrows and tyres are the norm rather than the exception. The majority of growers in the UK use two-row trailed harvesters and this can lead to damage at harvest owing to tractor wheels from both harvester and trailers compressing and exposing tubers in the flanks of the ridge, particularly when opening up a field. The use of self-propelled harvesters can eliminate some of these issues but not all.

One grower in the UK has successfully adopted the Grimme Maxi-Bed system, where the wheeltrack is increased to 108” (2.7 m) and three rows are planted. Theoretically, the 50 % fewer wheelings mean more useable land, though achievement of complete ground cover is often delayed by the very wide wheelings. Reportedly, output is increased by up to 150 % and fewer tractors and operators are required. However, it is a big step as growers have to convert their whole machinery system to suit the wider tramlines and therefore there is a very high initial investment in machinery There have also been problems with burying the quantity of stones in very stony conditions.

Figure 2. **Effective row and furrow widths for destoning systems.**



Summary

The more even use of resources in bed systems makes them more suitable for fingerlings and seed and for varieties which produce few tubers. Narrow rows can still produce the same yield as wider systems but the ‘controlled’ wheeling system used in the UK can actually increase compaction and greening. Soil flow and separation issues at planting and in wet harvests results in beds being largely confined to sandy soils.

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A classic yet new method for diagnosis of powdery scab disease

Kiwamu Tanaka* and Joseph B. DeShields

Department of Plant Pathology, Washington State University, Pullman, WA 99164-6430

*For correspondence: kiwamu.tanaka@wsu.edu

Abstract

Potato powdery scab disease has in recent decades insidiously spread in many regions where potatoes are grown, including most potato production areas in Washington state. It is important to forecast this disease during the pre-planting period. On-site diagnosis is important as timely decisions regarding early-stage treatment are often crucial, which can reduce secondary spread of disease in the field. Polymerase chain reaction (PCR) is currently the most sensitive and accurate method for plant pathogen detection, although standard lab-based PCRs and real-time PCRs require expensive laboratory equipment and skilled personnel. In this study, we propose a rapid and simple on-site real-time PCR method comprising of magnetic bead-based nucleic acid extraction, portable real-time PCR, and data analysis done remotely on a laptop computer. The capabilities of a portable real-time PCR were compared with a standard lab-based real-time PCR for the pathogen detection. In conclusion, the method developed in the present study enables a highly sensitive and rapid on-site detection of the powdery scab pathogen in the field.

Importance of on-site diagnosis

Accurate and rapid identification of causative pathogens significantly impacts decisions regarding plant disease management. Soilborne diseases are particularly difficult to diagnose because the soil environment is extremely large, in comparison to plant mass, and complex, making it a challenge to understand all the aspects of soilborne diseases. Moreover, soilborne diseases are sometimes symptomless during early infection stages, and some have long latent periods that result in delayed diagnoses. Many soilborne fungal pathogens have developed survival structures, such as spores or melanized hyphae, known to survive in the soil for many years even in the absence of their hosts. For example, in the case of the powdery scab disease, a causal pathogen *Spongospora subterranea* has infested a field, it remains infectious for many years (Calvert, 1968), that is, management practices, for example, crop rotations, have little impact on this disease. Effective approaches for soilborne disease management include: (1) avoiding known infested fields; (2) using pathogen-free certified seeds and seedlings; and (3) keeping equipment sanitary. In addition, in-field diagnosis can be a further effective as means for timely decisions regarding early-stage treatments or pre-plant assessments of the fields.

Available methods for molecular detection of pathogens

As shown in Table 1, recent technological advances in the molecular identification of pathogenic agents have increased the efficacy, accuracy, and speed of diagnosis, which have contributed to the detection of pre-symptomatic infections (Boonham et al, 2014).

For on-site diagnosis based on molecular detection, detection power and efficiency are the crucial factors to take into consideration. The lateral-flow assay, e.g., AgriStrip from Bioreba, is the most popular method for on-site pathogen detection because of its simplicity as a one-step assay. However, it occasionally provides ambiguous results if the target pathogen is in low concentrations and can cross react with similar species or genera. Loop-mediated isothermal amplification (LAMP) is also applicable for on-site pathogen detection and is particularly inexpensive due to low-cost reagents, reaction conditions that remain constant, and simple colorimetric visual analysis. However, both of these assays are typically used qualitatively (Hill et al, 2008), becase the specificity is relatively low, which occasionally causes misdetection of off-target microbes such common soil inhabitants. For example, there can be cross reactivity between the serological tests of *Phytophthora* spp. and *Pythium* spp. in the case of potato pathogens (Mohan, 1989), indicating that there are sometimes difficulties detecting the targeted plant pathogens.

Polymerase chain reaction (PCR) offers high specificity, sensitivity, and has quantitative capability in comparison to the aforementioned methods of detection. However, the standard lab-based PCR technology requires expensive laboratory equipment and skilled personnel, which is a major disadvantage in adopting this technology as a detection method for on-site purposes.

Classic yet new methods for molecular detection

In the present study, we propose an on-site diagnostic method using a portable real-time PCR instrument (Genesig q16; Primerdesign Ltd). Real-time PCR technology offers advantages over other methods in terms of quantitative accuracy, sensitivity, and versatility. Because of the recent trends of the fast-growing, competitive market, equipment required for PCR technology has continued to develop into a more compact and less expensive (Tomlinson, 2005), while providing high quality data. The method is composed of steps in the following order: magnetic bead-based nucleic acid extraction, portable real-time PCR, and quantitative data analysis that can be done remotely using a laptop computer (Figure 1).

Using this portable real-time PCR method, a soil sample was analyzed to detect a soilborne pathogen, *Spongospora subterranea*, which causes powdery scab disease. The pathogen was chosen as a model in this study because the disease has insidiously spread to many regions where potatoes are grown, including most potato production areas in Washington State (Johnson and Miliczky, 1993). Therefore, it is important to diagnose risk of the disease for pre-plant assessment of fields. The results suggest that the portable PCR method is able to perform accurate and relatively sensitive detection (Table 1).

The on-site detection method we developed can allow the frontline workers in agriculture to make earlier decisions regarding disease management, such as variety selections or rotations, and can quantify a plant pathogen in the sample during a field survey, prior to planting, to avoid potential disease outbreaks.

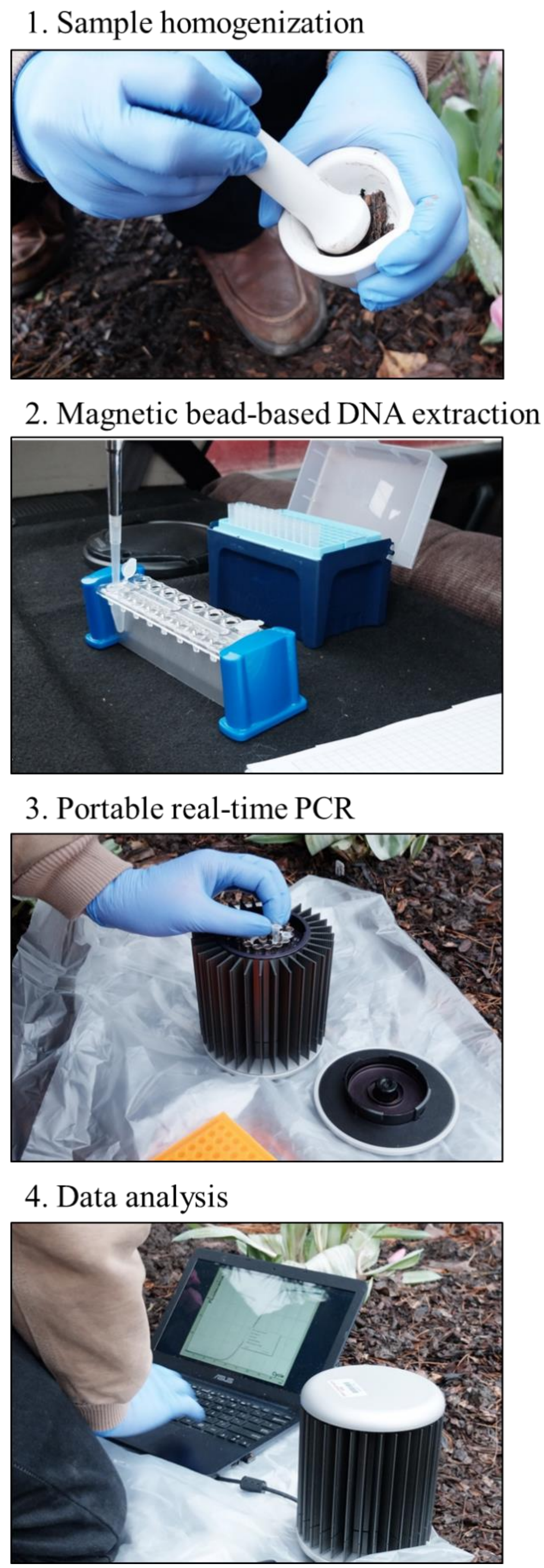

Figure 1. On-site pathogen detection based on a portable real-time PCR system.

Future prospective

In the present study, we have developed an optimized protocol for on-site molecular detection of the powdery scab pathogen using the portable real-time PCR system by comparing its capabilities with that of a standard lab-based real-time PCR system. We found that the on-site method specifically detects the powdery scab pathogen in the soil sample, while the protocol developed can be easy-to-use for any users with no prior experience in molecular diagnostics.

Conventional methods for pathogen detections are often costly, laborious, inaccurate and time-consuming. The simplicity of the on-site method we developed (Figure 1) allows operators to perform pathogen detection earlier. The promptness and sensitivity of the method can help growers avoid potential secondary infections, further reproduction of the pathogens, and inadvertent spread, thereby preventing further distribution of the pathogens. A diagnosis pipeline including an on-site method might improve the current management of crop diseases that relies heavily on synthetic chemicals and soil fumigations, which are sometimes ineffective (for example, powdery scab disease). In conclusion, the on-site method developed in the present study (Figure 1) enables the accurate and relatively sensitive detection of important soilborne pathogens in the field. This method is applicable to the detection of other pathogens for which primer sequences designed for real-time PCR are available (DeShields et al., 2017).

Table 1. Common molecular methods for pathogen detection

	Portable real-timePCR	Standard lab-based real-time PCR	LAMP	ELISA	Lateral flow (AgriStrip)
Running cost	\$0.60 - \$8.47 (Genesig)	\$0.60 (Bio-Rad)	~\$0.75 (Quant-iT PicoGreen)	\$0.60 (Bioreba)	\$4.74 (Bioreba)
Sensitivity	~50 DNA copies	~10 DNA copies	~10 DNA copies	10 sporosori/mL for *S. subterranea*	10 sporosori/mL for *S. subterranea*
Time expense	90 min	60-240 min	50-90 min	3-24 hrs	10-15 min
Preparation required	• DNA/RNA extraction • Primer design	• DNA/RNA extraction • Primer design	• DNA/RNA extraction • Primer design • DNA staining and imaging (optional)	• Protein extraction	• Not required
Resources required	• Potable real-time thermal cycler	• Standard real-time thermal cycler	• Fluorescent DNA stain • Small incubator	• Washing equipment • Plate reader • Antibodies	• Not required

Acknowledgments

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Soil-Fumigation: Discovery, Application, and Alternatives

D.L. Wheeler and D.A. Johnson

Discovery:

The first well-documented application of the scientific method to agriculture resulted in the discovery of soil-fumigants in 1869 by Baron Paul Thenard (Sagnier 1884, Wilhelm 1966). Carbon disulfide (CS_2) was identified as a candidate fumigant and application was optimized by Thenard to treat grape phylloxera (*Phylloxera vitifoliae*) infestations in wine-grape (*Vitis vinifera*) production systems in France during the late 1800s (Wilhelm 1966). Initial applications of CS_2 were delivered to soil surrounding dormant vines by teams equipped with fumigation guns, or "fumiguns", as seen in Figure 1a (Bolle 1882). As the efficacy of fumigation in reducing pest pressure and enhancing vine performance was demonstrated demand grew to fumigate larger swaths of vineyards (Peligot 1884). Mechanical injectors (Fig. 1b) were developed before the 1880s to satisfy the growing demand to fumigate (Barral 1884). Before 1900, one million acres were fumigated (Thenard 1884), often prophylactically, in areas absent of grape ghylloxera, and despite the availability of resistant root stocks (Wilhelm 1966). Other crops, including potato, were also subjected to CS_2 applications during the late 1800s (Girard 1894 a,b,c) – the benefits of fumigation were observed, interest among growers was aroused, and the era of fumigation commenced.

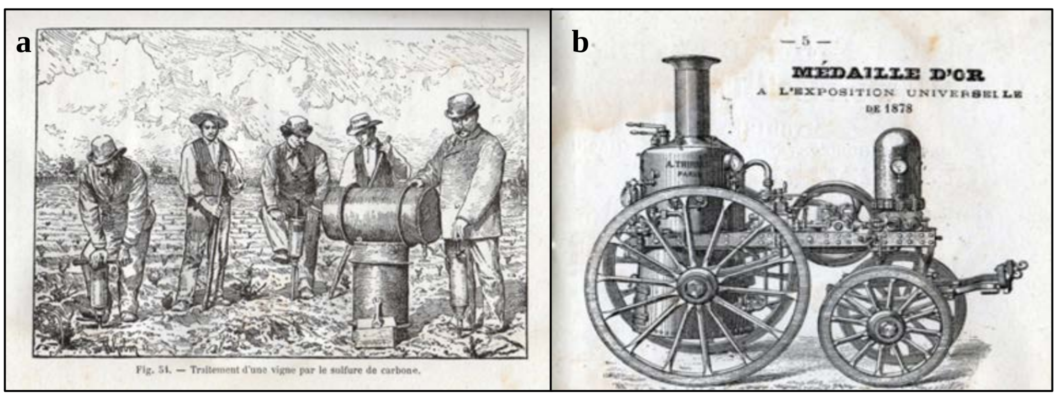

Figure 1. Application of carbon disulfide (CS_2) to dormant wine-grape vines during the late 1800's with fumigation guns (a) and mechanical injector (b). Drawings by J.A. Barral, 1884.

Application:

Since the discovery and optimization of CS_2 as a soil fumigant, various other chemistries were developed or adapted from other applications to treat soilborne pests and plant pathogens. After CS_2 and in chronological order, chloropicrin, methyl bromide, 1,3-dichloropropene, ethylene dibromide, 1,2-dibromo-3-chloropropane, and methyl isothiocynate were discovered (Lembright 1990). Of these fumigants only chloropicrin, methyl bromide, 1,3-dichloropropene and methyl isothiocynate are contemporarily applied while methyl-bromide is applied under critical and quarantine and preshipment use exemptions in accordance with the Montreal Protocol (EPA 2017). Nationally, these fumigants are applied primarily in the Northwest, Southeast, and, to a lesser extent, in the mid-Atlantic and mid-western regions of the United

States (Fig. 2). Potato, strawberries, tomato, and carrot cropping systems demand the most extensive fumigation treatment to manage soilborne pests and pathogens (Blecker and Thomas 2012). The efficacy of fumigants in reducing disease pressure in potato cropping systems has been documented observationally and experimentally (e.g. Easton et al. 1972). Likewise the off-target impacts of fumigants are documented (Sande et al. 2011) and, together with enhanced regulations, have demanded alternative management strategies to control pests and pathogens.

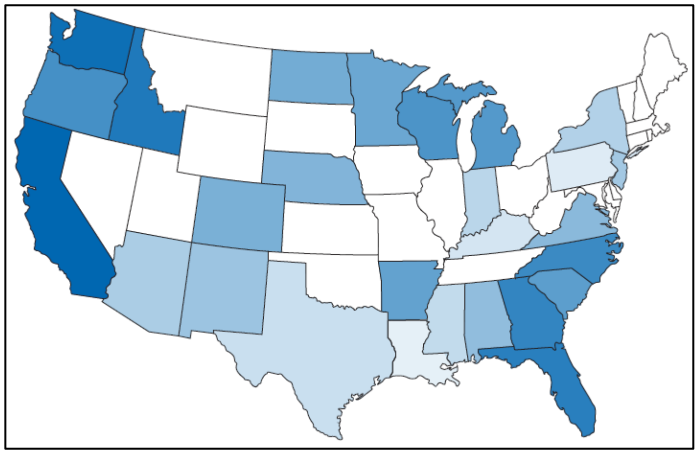

Figure 2. Distribution of fumigation applications in the continental United States. Fumigants are applied more in dark blue states than white states. Map adapted by Blecker and Thomas 2012 from EPA data.

Alternatives:

Various alternative management strategies for fumigation are available and depend on the pathogen or pest in question. For potato production systems in the Pacific Northwest, fumigants are primarily applied to reduce populations of the soilborne plant pathogen *Verticillium dahliae,* the causal pathogen of Verticillium wilt of potato. Alternative management strategies for Verticillium wilt are limited because (i) although moderately resistant cultivars are available completely resistant cultivars have yet to be developed, (ii) efficacious biocides for *V. dahliae*, other than fumigants, have yet to be identified, and (iii) the efficacy of cultural management tactics like crop rotation, cover crops and green manures is often variable. However, cultural management tactics like crop rotation and green manuring merit review here given their popularity, potential to suppress diseases, and impart desirable agronomic qualities to soils.

The effects of crop rotation and green manures on tuber yield, disease and stem incidence, and inoculum density vary from study to study (Fig. 3). Despite the variability observed in Figure 3, tuber yields generally increase, disease incidence generally decreases, stem incidence is either not affected or decreases, and inoculum density generally increases or remains the same after rotation crops are grown or green manure crops are incorporated. Several sources might contribute to the variability observed in published studies including but not limited to (i) the species and genotypes of crops planted, (ii) cultural factors (e.g. the time the crop is planted), (iii) the populations and density of the pathogen(s) present, (iv) the presence or absence of aggressive strains, and (v) environmental differences. Despite this variability, several reproducible trends can be observed in the literature: (a) suppression of wilt can be established in two-three years of green manures (Davis et al. 1996, 1998, and 2010), (b) recurrence of wilt can occur when potatoes are grown for two consecutive years (Davis et al. 2010), and (c) suppression of wilt can be restored after one year of green manures (Davis et al. 2010).

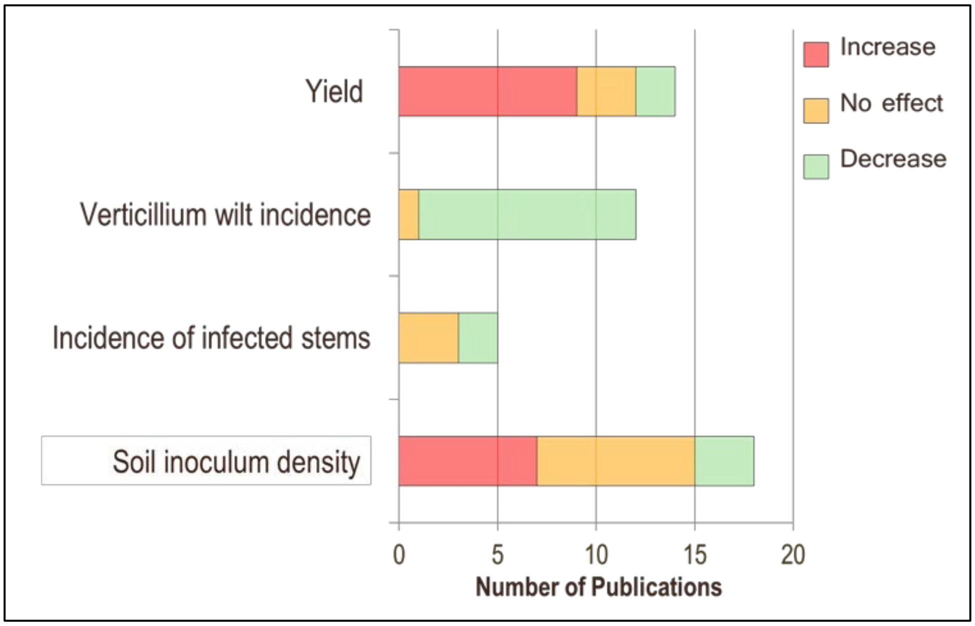

Figure 3. The effects of crop rotation and green manures on potato yield, Verticillium wilt incidence, the incidence of stems infected with *Verticillium dahliae*, and inoculum density compiled from 25 peer-reviewed publications.

Two major mechanisms have been proposed to explain the observed suppression of Verticillium wilt. Suppression may be induced, established, and maintained after a rotation or green manure crop is planted by: (i) competitive exclusion, whereby microbes selected for and propagated in response to a rotation or green manure crop outcompete *V. dahliae* and thereby exclude the pathogen from infecting potato (Qin et al. 2008) and/or (ii) biofumigation, whereby secondary metabolites, called glucosinolates, produced primarily by brassicaceous crops hydrolyze into isothiocyanates and directly inhibit *V. dahliae* or indirectly inhibit *V. dahliae* by promoting anatagonistic microorganisms (Neubauer et al. 2014). These mechanisms are not mutually exclusive or exhaustive and may operate together with other mechanisms to produce a suppressive state. For example, green manure crops can positively contribute to soil properties (Ochiai et al. 2008) and may thereby enable plants to defend against pathogens and pests while producing high-quality yields. Finally, the induction of these mechanisms by crop rotation and or green manuring appears to be specific to the Verticillium wilt pathosystem. Examples of disease suppression in other pathosystems are induced, established, and maintained by sustained monoculture of susceptible hosts which, over time, recruit microorganisms antagonistic to the pathogen and maintain a disease suppressive state despite the presence of pathogen (Raajimakers and Mazzola, 2016).

Conclusions:

Fumigants can enable production of high-quality potatoes in soils infested with plant pathogens like *V. dahliae*; however, the expenses and off-target effects of fumigants necessitate an option for effective alternatives. Resistance, biocides, and cultural management strategies should be used together to achieve optimal short and long term crop performance and profits. More research is needed to elucidate the mechanism(s) responsible for producing wilt suppressive soils. Once identified, practices which induce, establish, and maintain disease suppression can be implemented by growers.

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Demonstration Plots Show the True Nature of *Potato virus Y* Problems: A Research Update

Jonathan Whitworth, USDA-ARS, Aberdeen, Idaho

Potato virus Y (PVY) typically causes a mosaic symptom in infected potato plants. Other symptoms include necrotic tissue in the leaves, stems and tubers. If only mosaic symptoms are present, the result is a loss of yield (a quantitative loss), but with necrotic symptoms present in tubers, the loss can be more serious with a rejection of the tubers for fresh pack or processing – a quality loss. Reaction of symptoms in the plant can vary depending on the potato variety and the virus strain in the plant. This variation can range from no visual symptoms to severe symptoms that kill the plant.

PVY is mainly spread by aphids in a non-persistent manor, which means that the virus particles are on the aphid's stylet and when it probes or feeds on a plant, the virus particles are transmitted and the plant is inoculated with virus. An aphid acquires the virus from an infected plant within seconds and once it lands on a healthy plant can transmit the virus in seconds. This occurs before any insecticide can stop the feeding and transmission.

In the past, seed growers and the seed certification system have been able to control the level of PVY in seed by a system of rogueing – removing diseased plants, and inspections and tolerances to quantify the amount of virus in a seed lot. However, due to new varieties that don't express PVY symptoms very well and PVY strains that have mild expression, levels of PVY have risen.

PVY strains include PVY^{O}, PVY^{NTN}, $PVY^{N:O}$, and PVY^{NWi} among others. The O strain is referred to as the common or old strain and typically produces good visual foliar symptoms and no tuber necrosis in most varieties. The N strains typically have milder symptoms and tend to cause tuber necrosis in some varieties.

As part of a Specialty Crop Research Initiative grant by the USDA-NIFA, a demonstration plot was set up at Othello, Washington to train seed growers, inspectors, and industry in PVY symptoms. This plot consisted of 42 varieties and three PVY strains. Each plot had a healthy (non-inoculated) row, a PVY^{O} row, a $PVY^{N:O}$ row, and a PVY^{NTN} row. Varieties included all market classes such as russets, reds, and yellows.

Some examples of symptoms showed that Ranger Russet and Yukon Gold had severe reactions when infected with PVY^{O} to the point that plants were severely stunted on June 20th when the field day was held. Those same plants were dead on July 27th (Figure 1). The other rows infected with the N strains had plants with mild symptoms compared to the healthy plants. In another example, Silverton Russet showed mild symptoms on both dates (Figure 2).

A goal of potato breeding programs is to incorporate PVY (and other virus) resistance into industry ready varieties. It is important to understand the difference between resistant and tolerant. A variety that has no foliar or tuber symptoms can still be infected with PVY-this is an example of a tolerant variety. It is better to have a variety that is susceptible to PVY that doesn't produce tuber symptoms when infected than a variety that is susceptible and has tuber symptoms. Russet Burbank and Norkotah Russet are both PVY susceptible, but don't produce tuber symptoms when infected. These are PVY susceptible, but tuber necrotic tolerant. Silverton Russet also doesn't produce good foliar symptoms, so it is tolerant as well. The danger of Silverton types is that they still are a source of inoculum for more sensitive varieties planted nearby.

Figure 1. Yukon Gold PVY symptoms on June 20th (left) and July 27th (right). Rows from left to right are healthy, PVY^{O}, PVY$^{N:O}$, PVY^{NTN}.

Figure 2. Silverton Russet PVY symptoms on June 20th (left) and July 27th (right). Rows from left to right are healthy, PVY^{O}, PVY$^{N:O}$, PVY^{NTN}.

Photos courtesy M. Pavek, S. Gray

Resistance is now available in some potato varieties. There are two types, strain specific resistance and resistance against all strains. Strain specific is resistance against one strain such as PVY^{O} but susceptibility to another such as PVY$^{N:O}$. Premier Russet and Yukon Gem have strain specific resistance. Resistance against all strains of PVY is called extreme resistance and can be attributed to major genes such as *Ry*$_{sto}$ or *Ry*$_{adg}$. These genes come from the *Solanum stoloniferum* or *S. t.* subsp. *andigena* species of potato. *Ry*$_{sto}$ is in Payette Russet, a new fresh pack and processing potato that is resistant to all strains of PVY. Eva is a round white chipping variety that also has extreme resistance. More PVY resistant varieties are nearing the final stage of approval as breeding programs work to incorporate these genes, but until they are widely grown, knowing the characteristic symptoms of PVY and buying seed with no or low virus levels is critical.

Post-harvest testing is done on all seed lots destined to produce seed and on most of the lots destined for commercial production. It is critical for a buyer to know the post-harvest virus results before buying any seed. The tests are done with a sample from each seed lot being grown-out in the winter in the field or in a greenhouse. The majority of the field tests are done in Hawaii (some are done in Florida) in December and January. Results are made available by the grower to the buyer with the use of a Plant Health Certificate. This certificate includes the summer inspection results and the post-harvest test results.

While it is difficult to keep PVY out of all seed, you should expect that early generation seed has no virus or almost no virus and later generation seed has low virus. Remember that the more generations a seed lot is grown in the field means more exposure to virus. Because it is difficult to see PVY mosaic in all varieties, all states ELISA (lab test) leaves of those varieties from those grow-outs. ELISA will detect all strains of PVY. A few states ELISA test leaves of all varieties in their program. The Plant Health Certificate will show post-harvest results for visually inspected plants and/or ELISA tested plants (Figure 3).

The PVY demonstration trial was a great success with 150 people attending. Similar demonstration trials are planned for 2018 in Washington, Wisconsin, and Maine. The 2018 trials will have a core set of the same varieties and a set regional specific varieties.

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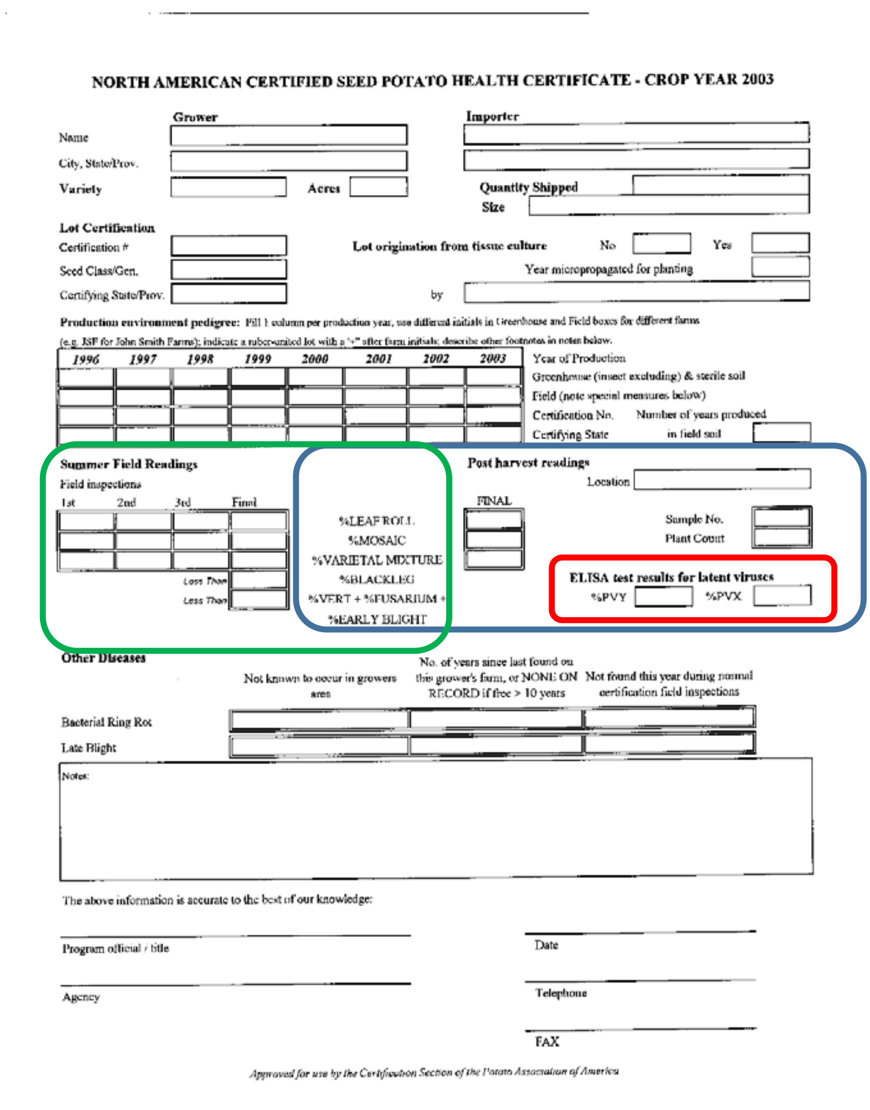
NORTH AMERICAN CERTIFIED SEED POTATO HEALTH CERTIFICATE - CROP YEAR 2003

Grower
Importer
Name
City, State/Prov.
Variety
Acres
Quantity Shipped
Size
Lot Certification
Certification #
Seed Class/Gen.
Certifying State/Prov.
Lot origination from tissue culture
No
Yes
Year micropropagated for planting
by

Production environment pedigree: Fill 1 column per production year, use different initials in Greenhouse and Field boxes for different farms (e.g. JSF for John Smith Farms); indicate a tuber-united lot with a "+" after farm initials; describe other footnotes in notes below.

1996	1997	1998	1999	2000	2001	2002	2003	Year of Production
								Greenhouse (insect excluding) & sterile soil
								Field (note special measures below)
								Certification No.
								Certifying State

Number of years produced in field soil

Summer Field Readings
Field inspections
1st
2nd
3rd
Final
Less Than
Less Than

%LEAF ROLL
%MOSAIC
%VARIETAL MIXTURE
%BLACKLEG
%VERT + %FUSARIUM +
%EARLY BLIGHT

Post harvest readings
Location
FINAL
Sample No.
Plant Count
ELISA test results for latent viruses
%PVY
%PVX

Other Diseases

	Not known to occur in growers area	No. of years since last found on this grower's farm, or NONE ON RECORD if free > 10 years	Not found this year during normal certification field inspections
Bacterial Ring Rot			
Late Blight			

Notes:

The above information is accurate to the best of our knowledge:

Program official / title
Date
Agency
Telephone
FAX

Approved for use by the Certification Section of the Potato Association of America

Figure 3. North American Plant Health Certificate. Green box shows summer field readings, blue is post-harvest readings from visual inspection, and red is ELISA test results for leaves tested in the lab.