Proceedings

of the

WASHINGTON OREGON POTATO CONFERENCE 2011

www.potatoconference.com

January 25-27, 2011

Three Rivers Convention Center

Kennewick, Washington

WASHINGTON Potatoes STATE

www.potatoes.com

Oregon POTATOES

www.oregonspuds.com

Proceedings of the Washington-Oregon Potato Conference

January 25-27, 2011
Kennewick, Washington

We would like to acknowledge sponsors of the 2011 Conference:

Underwriting Sponsors:
Oregon Potato Commission
Washington State Potato Commission

Platinum Sponsors ($5,000-$9,999):
Basin Business Journal Farm News
Columbia Basin Herald
Industrial Ventilation, Inc. / Teton West
Northwest Farm Credit Services
Spudnik Equipment Company
Two Rivers Terminal

Gold Sponsors ($3,000-$4,999):
Bayer Crop Science
ConAgra / Lamb Weston
Desert Graphics
Evergreen Implement
JMC Ventilation / Refrigeration, LLC
JR Simplot
Key Bank
McCain Foods
Produce Bagger
Syngenta Crop Protection
Wilbur Ellis - Pasco

Silver Sponsors ($2,000-$2,999):
Ag World Support Systems
AgriNorthwest
Basic American Foods
Kuo Testing Labs
Lindsay Corp.
McGregor Company
RDO Equipment
Signs Now Moses Lake
United Fresh Potato Growers of WA & OR

Bronze Sponsors ($1,000-$1,999):
Arysta Life Science
Dow AgroSciences
Gowan Company
Lever Advertising
M & M Potato, Inc.
Orv's Potato Services Inc.
Tyco, Inc.
Washington State Seed Potato Commission
Washington Trust Bank

Associate Sponsors (up to $999):
Round Butte Seed Growers
Skone Irrigation Inc.
Valent, USA

Contents

Published by: The Washington State Potato Commission
108 Interlake Road
Moses Lake, WA 98837
509-765-8845
www.potatoes.com

Producing Lower-Calorie Deep Fat Fried French Fries Using Infrared Dry-blanching as Pretreatment

Gokhan Bingol[a], Ang Zhang[b,c], Zhongli Pan[a,b*], Tara H. McHugh[a]

[a] Processed Foods Research Unit, Western Regional Research Center, Agricultural Research Service, US Department of Agriculture, 800 Buchanan St., Albany, CA 94710, USA
[b] Biological and Agricultural Engineering Department, University of California Davis, One Shields Avenue, Davis, CA 95616, USA
[c] Northwest A&F University, College of Enology, Yangling, Shaanxi 712100, China
email: Gokhan.Bingol@ars.usda.gov (Gokhan Bingol)
email: zhangang@nwsuaf.edu.cn (Ang Zhang)
email: Zhongli.Pan@ars.usda.gov (Zhongli Pan)
email: Tara.McHugh@ars.usda.gov (Tara H. McHugh)

Abstract

The main objectives of this work were to study the suitability of using infrared (IR) heating as a dry-blanching pretreatment prior to frying and to investigate its potential to reduce the oil uptake in French fry production. It was observed that by using IR heat complete inactivation of polyphenol oxidase enzyme could be achieved in 3 min with 4.7% moisture loss for 9 mm French fries. Following IR dry-blanching, the samples were fried at 146, 160, and 174°C for 1, 3, 5, and 7 min. At the end of 7 min frying, compared to unblanched samples, dry-blanched samples had 37.5, 32 and 30% less total oil at the frying temperatures of 146, 160 and 174°C, respectively. The final moisture contents of unblanched and dry-blanched samples were between 50-60% after 7 min frying. The L*a*b* color values of both unblanched and dry-blanched samples decreased initially and then increased as the frying progressed. The sensory evaluation revealed that panelists mostly favored the IR dry-blanched French fries in terms of taste, texture, color and appearance.

Highlights

- Infrared heat successfully inactivated polyphenol oxidase enzyme in 3 min.
- Oil uptake of French fries was significantly reduced.
- No significant difference in sensory properties of infrared dry-blanched and unblanched fries.

Introduction

Potatoes, available all around the world, provide a substantial contribution to the daily supply of minerals, vitamins, carbohydrates and proteins. One of the most popular processed potato products is French fries which are appreciated because of their characteristic taste and texture (Van Loon, Linssen, Legger, Posthumus & Voragen, 2005). French fries are among the major commercial fried foods and account for 44% of processed potatoes in the US (Moreira, Castell-Perez & Barrufet, 1999). The globally expanding quick-serve restaurants (QSRs) are common places for consumption of French fries. In the most popular QSRs a large serving of French fries could contain 519±30 calories, where 45.5±1.7% calories come from the fat (USDA, 2011). It has been evidenced by many epidemiological studies that the consumption of foods rich in oil causes obesity and development of many cardiovascular diseases (Kaiyala, Prigeon, Kahn, Woods, & Schwartz, 2000; Buettner, Schölmerich, & Bollheimer, 2007; USDA & USDHHS, 1990). Therefore, due to increased health awareness, the quality of food is judged by the consumers not only on the basis of color, odor, and taste, but also on the fat content.

Many QSRs seek ways to produce lower oil containing French fries and as a result, there has been a strong incentive to introduce technologies that could produce French fries with lower oil contents and with desirable sensory quality characteristics. In recent years, several new techniques have been proposed to reduce oil uptake in fried potatoes, such as dipping in sugar or salt solutions (Bunger, Moyano & Rioseco, 2003; Nonaka, Sayre & Weaver, 1977; Tran, Chen & Southern, 2007), coating with cellulose derivatives (Garcia, Ferrero, Bertola, Martino & Zaritzky, 2002; Kelleher & Williamson, 2005; Khalil, 1999; Rimac-Brncic, Lelas, Rade & Simundic, 2004), or vacuum frying (Garayo & Moreira, 2002; Troncoso & Pedreschi, 2009). However, although these proposed methods have reduced the oil content to some extent, they have found limited application due to use of synthetic chemicals, high energy consumption or unsatisfactory final product quality.

Infrared radiation is energy in the form of a band of electromagnetic wave, which is more efficient in heat transfer than convection and conduction. The efficient heat transfer can provide a high heating rate and reduce the heating time to reach the desired product temperature (Chou & Chou, 2003; Jones, 1992; Sandu, 1986). Several studies have shown that treating foodstuffs with infrared yielded higher quality products (Hebbar, Vishwanathan & Ramesh, 2004; Sharma, Verma & Pathare, 2005; Yang, Bingol, Pan, Brandl, McHugh & Wang, 2010; Zhu & Pan, 2009; Zhu, Pan, McHugh & Barrett, 2010). Up to now, the only employment of infrared technology during French fry production was reported by Lloyd, Farkas and Keener (2004) who used infrared heating to produce finished product from the deep fat par-fried French fries. The overall acceptability and final quality of French fries were reported to be comparable to that from traditional immersion frying methods.

Strong (1968) and Moyano and Pedreschi (2006) showed that the dehydration of potato strips after blanching reduced the oil uptake during frying. Furthermore, Pan and McHugh (2006) illustrated that during infrared blanching partial dehydration could also be achieved. Since infrared blanching does not need water or steam, it is also called infrared dry-blanching. Moreover, due to above-mentioned efficiencies in heat delivery, which could save time and energy, infrared technology possesses a potential for blanching potato strips prior to frying while reducing the oil uptake. However, so far, the application of infrared blanching during French fry production and its effects on final French fry quality have not been studied. Therefore, the objectives of the present work were to (i) investigate the effectiveness of infrared dry-blanching on enzyme inactivation; (ii) study the oil uptake and color change of infrared dry-blanched potato strips under different frying conditions; and (iii) evaluate the sensory quality of the French fries.

Materials and methods

Materials

Potatoes (Russet Burbank) were provided by Washington State Potato Commission. They were stored in a cold room (9±1 °C, 85±3 % relative humidity) and were taken out at least 12 h prior to experiments. The potatoes were washed and hand peeled. A French fry cutter (French Fry Cutter, Progressive International Corp., Washington, USA) was used to obtain square strips with cross section of 9.43±0.43 mm from the parenchymatous region of the potato tubers. Immediately after cutting, the strips were dipped into water mainly to prevent enzymatic browning reactions and also to remove the surface starch. The initial moisture contents (MCs) of strips before and after dipping into water were 78.75±0.20 and 82.1±0.6% (w.b.), respectively (AOAC, 1984).

Blanching pretreatment

Blanching pretreatment was done prior to deep fat drying using a pilot scale catalytic infrared device with double-sided heating (Catalytic Industrial Group Inc., Independence, KS). Infrared intensity was measured as 11080 W/m^2 using Ophir FL205A Thermal Excimer Absorber Head (Ophir Optronics Inc., Wilmington, MA). The potato strips were heated from both bottom and top for various time periods, 30, 60, 90, 120, 150, and 180 s. The samples after blanching treatment were frozen immediately for enzyme inactivation analysis. The surface and center temperatures of potato strips were measured using type T thermocouples, (response time < 0.15 s), and were recorded every 1 s with a data logger thermometer (HH147, Omega Engineering Inc., Stamford, CT, USA). Temperature measured just beneath the surface of potato strips was considered to be the surface temperature. Each experiment was repeated at least 5 times.

Polyphenol Oxidase Assay

To analyze the heating effect on polyphenol oxidase (PPO), a major enzyme that could cause browning in potatoes, the unblanched (control) and infrared dry-blanched potato strips were thawed and then were homogenized with chilled phosphate buffer solution (0.1 M, pH 6.0) in a ratio of 1:10 in a blender (Warring 38BL54 LB10, Waring Laboratory & Science, CT, USA) for 3 min. The homogenate was centrifuged at 12,000 rpm for 10 min, and stored in an ice bath until being assayed. The activity of PPO was measured by using spectrophotometer (UV-1700, Shimadzu, Kyoto, Japan) following the method of Espin, Morales and Varon. (1995). One unit of PPO activity was defined as an increase of 0.001 unit of absorbance per min.

Frying

A commercial deep-fat fryer (Professional Deep Fat Fryer, Euro-Pro Corporation, West Newton, USA) was used for the frying tests. The fryer was filled with 3.5 L of soybean oil and potatoes-to-oil ratio was maintained at 1:30 w/v. The fryer was preheated for approximately 1 h prior to frying experiments and the frying oil was discarded after 10 h of use. Only the samples blanched for 3 min were used for frying since PPO was completely inactivated. Infrared dry-blanched and unblanched samples were fried at 146, 160, and 174°C for 1, 3, 5, and 7 min. At the end of frying, the fryer basket was shaken for approximately 10 s and an additional 2 min draining was applied to remove the excess oil on the French fry surface. The samples were allowed to cool at room temperature for further analysis. A random experimental design was employed and all experiments were run in triplicate.

Total Oil Content Determination

Total oil content (TOC) was measured using the Soxhlet extraction method (AOAC, 1995). Samples were dried to a constant weight in a convection oven at 70°C for at least 12 h prior to extraction. The dehydrated French fries were ground in a blender (Warring 38BL54 LB10, Waring Laboratory & Science, CT, USA) for 2 min and were extracted by *n*-hexane for 3 h in a Soxhlet extractor. The *n*-Hexane was recovered under vacuum at 40°C by a rotary evaporator (Büchi Labortechnic AG, Flawil, Switzerland). To further remove the possible residual *n*-hexane the oil was left in a convection oven at 80°C for 1 h and then sample was weighed to determine the oil gained. TOC is expressed as g oil/g dry matter.

Color Analysis

Color is considered as an important indicator for the acceptability of French fries by consumers. For each experiment the surface colors of at least 5 samples were measured using a colorimeter (Minolta Chroma Meter CR-200, Minolta Co., Ltd., U.S.A.). For each sample the average of 8 readings along a randomly chosen face were measured and reported in CIE L*a*b* color space. The experiments were done in triplicate.

Sensory evaluation

In separate research, we have observed that the French fries produced with the industrial procedure (Sanz, Primo-Martín & Vliet, 2007), including water blanching (70°C, 14 min), air drying (60°C, 5 min), par-frying for 1 min and finish frying for 3 min at 174 °C, had MC of approximately 57 % (w.b.). The French fries had the characteristic golden-brown color when the values of a* and b* were approximately -0.8 and 15, respectively. These MC and color values were used as reference for ideal French fries. Since the required times to reach the aforementioned a*-value and the MC were similar compared to the required time to reach the b*-value, the required frying times for producing sensory evaluation samples at different frying temperatures were obtained from the average frying times to reach the a*-value and MC and are presented in Table 1.

A sensory panel evaluation was carried out for the finished fries for each frying temperature. The sensory attributes were evaluated by a total of 77 panelists. The panelists were asked whether there were differences between blanched and unblanched French fries in terms of taste, texture, color, appearance and overall. Regardless they see a difference or not, panelists were required to choose either of the treatments as their preference.

Statistical analysis

The differences between blanched and unblanched French fry color, moisture and oil content data were analyzed by Analysis of Variance (ANOVA) using Minitab® (Release 14, Minitab Inc., PA, USA) at a significance level of α=0.05. The sensory data were analyzed using binomial distribution test by using the BINOMDIST built-in function in MS Excel (Microsoft Co. Ltd., Redmond, WA, USA) to determine any significant difference.

Results and Discussion

Infrared dry-blanching

The temperature profiles of the surface and center of potato strips under infrared treatment are presented in Fig. 1. Similar to conventional blanching, in the early stage of infrared blanching surface temperatures were found to be slightly higher than the center temperatures due to high heat

delivered by infrared radiation to the surface layers which then were transferred to the center with the conduction mechanism. Due to partial shielding effect of the tray on the strips, the bottom surface temperature of potato strips rose slower than the top surface and center temperatures after 90 s. Unlike conventional blanching, after approximately 100 s of infrared treatment the center temperatures of potato strips rose slightly faster than their surface temperatures due to moisture losses at the surface layers and possibly due to changes in surface properties of the potato strips, such that swelling and slight baking of the of top surface were visually observed. It was also observed that the surface and center temperatures increased to slightly above 100°C at the end of infrared heating which could be due to dried surface and vapor pressure generated in the center, respectively.

Unlike the other blanching methods, the infrared dry-blanching combines blanching and drying into one single step, wherein the process has been named as simultaneous infrared dry blanching and dehydration by Pan and McHugh (2006). It was observed that the complete inactivation of PPO was achieved in approximately 3 min with only 4.7% moisture loss (w.b.). Therefore, the samples blanched for 3 minutes were used for further studies. It can also be seen from Fig. 1 that significant inactivation of PPO mainly occurred when the center and surface temperatures were higher than 60°C, which is in accord with the findings of Zhu and Pan (2009) for inactivation of PPO in apple slices under IR heating.

Moisture and oil contents of finished French fries

As was expected, longer frying times and higher frying temperatures led to lower moisture contents for French fries (Fig. 2). Within the frying time and temperature range of this study, two-way ANOVA revealed that frying temperature and time significantly affected ($P < 0.05$) the moisture contents of both control and blanched samples. These findings are in agreement with other authors (Garayo & Moreira, 2002; Moyano & Pedreschi, 2006).

The total oil contents of all French fry samples generally increased with the increase of frying time and frying temperature (Table 2) and with the decrease of moisture content (Fig. 3). For control samples, it was also observed that except one data point, namely 160°C 1 min, for the same frying time there were no significant ($P > 0.05$) differences between oil contents of French fries fried at 146 and 160 °C. However, at 174°C for all frying times the oil contents were significantly higher ($P < 0.05$) than those of 146 and 160°C. Moreover, inverse, almost linear, relationships were found between moisture and oil contents (Fig. 3) of control samples, with coefficients of determination of 0.98, 0.99 and 0.94 for 146, 160 and 174°C, respectively.

Significant oil uptake of infrared blanched samples took place within the first minute of frying (moisture contents less than 70%); such as, 72.5, 77.9 and 72.1% of the total oil uptake at 146, 160 and 174°C, respectively. Then the oil uptake rate was much slower during the rest of frying process. This is in accord with Moyano and Pedreschi (2006) who also found that significant oil uptake of blanched and pre-dried samples occurred within 1 and 3 min of frying at 120 and 150°C, respectively. This observation is also in agreement with the findings of Toma, Leung, Augustin and Iritani (1986) who observed that compared to untreated samples, partially (surface) frozen potato strips absorbed similar or more amount of oil during par frying.

The high oil absorption rate at the initial frying stage could be mainly due to dry-surface resulted from infrared dry-blanching. Compared the unblanched samples, which had higher moisture contents, due to reduced water vapor pressure during frying the dry surface could allow oil to quickly penetrate to the layers close to the surface of French fries. Therefore blanched samples had higher oil contents at the initial stage of frying compared to unblanched samples. During infrared blanching, the formation of an elastic whitish skin was observed when the surface temperature was higher than

60°C. Moreover, Pan, Shih, McHugh and Hirschberg (2008) showed that IR pre-treated and then freeze-dried banana slices (5 mm thick) had higher crispness than those processed only by freeze-drying. The authors related the higher crispness to the crust formation and structural changes caused during IR pretreatment. It is also reported that gelatinization of starch reduced the oil uptake during frying (Pedreschi and Moyano, 2005) and it is known that gelatinization of potato starch ranges from 65 to 75°C depending on moisture content. O'Connor, Fisk, Smith and Melton (2001) also found that after finish frying the outer layers of French fries absorbed significantly more oil compared to its inner core. Therefore, it could be concluded that the reduced oil uptake of infrared blanched samples in the later stages of frying was due to both gelatinization of the inner core and the formation of the crust which together protected the inner layers from absorbing oil and was also due to the formation of the elastic whitish skin which decreased the diffusion rate of oil. In this study only two sides of the potato strips were directly exposed to infrared emitter; however, it is expected that more oil reduction in finished French fries could be achieved if all four major sides are exposed infrared emitters to form similar skins and crusts.

Compared to unblanched samples blanched samples had significantly lower ($P < 0.05$) total oil contents after 7 min of deep-fat frying. At the end of 7 min frying, infrared blanched samples had 37.1, 32.8 and 30.2% less oil compared to control samples at 146, 160 and 174°C, respectively. This is similar to what Moyano and Pedreschi (2006) found that blanching and convective pre-drying of potato strips prior to frying reduced the total oil uptake at the end of the frying process.

Color of infrared blanched and control French fries

Figure 4 (a-f) shows the changes in L*, a*, and b* values of unblanched and blanched samples at different frying times and temperatures. The color of French fries is formed as a result of Maillard reaction which's extent is dependent on the frying time and temperature (Márquez & Añón, 1986). Although we have used parenchymatous region of potato tubers, it was observed that color distribution along the strips were not uniform, especially at longer frying times and higher frying temperatures, which could be due to heterogeneous distribution of reducing sugars in potato tissue (Talburt, Schwimmer & Burr, 1987; Thompson, Love, Sowokinos, Thornton & Shock, 2008).

At all frying temperatures, for both blanched and unblanched samples, we have observed that there was a slight initial decrease in the L* values in the first 1 min of frying; however, the L* values increased as the frying continued (Fig. 4, a and b). In literature, the L* values of French fries is reported to either decrease (Márquez & Añón, 1986) or increase that is preceded by a slight initial decrease, (Krokida, Oreopolou, Maroulis & Marinos-Kouris, 2001a; Krokida, Oreopolou, Maroulis, & Marinos-Kouris, 2001b) during the initial stages of frying and then to become constant as the frying proceeded.

The initial decrease in L* values could be due to either development of a micro-ridges or -pores on the surface, which can cause the light to scatter differently, thus causing a lower L* value. It was reasoned by Sotome, Takenaka, Koseki, Ogasawara, Nadachi, Okadome et al. (2009) that changes in surface reflectance properties of potato tubers during super heated steam blanching caused a decrease in L* values, because the authors used reflected light in the color measurement. Similarly the colorimeter used in this study also uses reflected light to measure the color values of objects. Moreover, Krokida, Oreopoulou and Maroulis (2000) showed that during frying the porosity of French fries increases. Vitrac, Trystram and Raoult-Wack (2000) reported that a large porous structure was formed inside the cassava slices after 1 min frying at 160°C. In accord with the rationale of these findings, we first measured the L* value of untreated potato strip, 60.59±0.53, and then the surface of potato strip was punctured randomly many times with a needle (diameter, 0.93 mm). The potato strip was dried at 60°C for 3 min and then the strip was dipped in oil for 1 min. It

was seen that L* value decreased significantly ($P < 0.05$) to 58.48±0.16. In another experiment, we dipped the untreated potato strips in oil and found that there was no significant difference ($P > 0.05$) in L* due to merely dipping in oil. Therefore, the initial decrease in L* value could mainly be due to the change of surface characteristics of French fries in the initial stages of frying.

For French fries, consumers mostly expect golden-brown color (Jensen, 2011). The +a* and +b* values are indicators of the redness and yellowness of the product, respectively. Higher +b* values and lower +a* values are desirable for French fries. Similar to L* values, except one treatment of blanched samples fried at 160°C, the a* values decreased within the first min of frying (Fig. 4 c and d) which was possibly due to removal of air between the cells that led to a change in the surface reflecting properties (Lau, Tang & Swanson, 2000; Brewer, Klein, Rastogi and Perry, 1994). As the frying continued due to possible conversion of chlorophyll to pheophytins the a*-value increased. In most cases, for the same frying time the higher frying temperatures led to significantly ($P < 0.05$) higher a* values for both unblanched and blanched samples. Compared to L* and a* values, the b* values considerably increased after 1 min of frying (Fig. 4, e and f.) which could be due to increase in concentration of carotenoids at the layers close to the surface as the frying progressed. The initial decrease in b* value could be due to leaching of carotenoids into oil. This rationale is in accord with assumptions of Sotome, Takenaka, Koseki, Ogasawara, Nadachi, Okadome et al. (2009).

Many authors showed that as the frying progresses the thickness of crust formed on the surface increases (Du Pont, Kirby & Smith, 1992; Ziaiifar, Courtois & Trystram, 2010). Therefore, as the crust thickness increases, which is mainly formed of oil, the concentration of dry matter components of potato could also be increasing which is resulting in an increase of a* and b* values as the frying continues.

Sensory quality evaluation

Table 1 shows the oil and moisture contents of finished fries, fried for a certain time to achieve a similar product characteristics of targeted of a MC of nearly 57 % and an a* value of approximately -0.8, used for sensory evaluation at different frying temperatures. On average, infrared blanched samples had 33.4% less oil than the unblanched samples.

The probability values of sensory attributes such as taste, texture, color and appearance of French fries and in the case of a statistical significant difference ($P < 0.05$) between unblanched and blanched samples, the percentage of panelists preferring blanched samples are given in Table 3. It is seen from Table 3 that at 174°C the texture, color and appearance of blanched samples were significantly different than those of unblanched samples wherein more than half of the panelists preferred blanched French fries. At all frying temperatures there were significant differences in textural properties and except 160°C frying temperature more than 50% of the panelists favored the texture of IR blanched samples due to their crunchier texture. There was no significant difference ($P > 0.05$) between taste and color of blanched and unblanched samples at 146°C.

Although at all frying temperatures the total oil contents of blanched samples were less than the unblanched samples, at 160°C the appearance of blanched samples was less appealing to the panelists than the control samples due to the oily appearance of surface. However, since the oil could be loosely attached to the surface of French fries the oily appearance of French fries could be eliminated by using mechanical shakers. We have experimentally observed that shaking the fryer pan for 180 s decreased the total oil content by 11.73% compared to 10 s shaking. The sensory evaluation at 3 different frying temperatures revealed that IR technology mostly improved the taste, texture and color of the French fries.

Conclusions

This study showed that infrared heating was an effective method for blanching of regular cut fries. Moreover blanching potato strips with infrared heat prior to deep fat frying significantly reduced the total oil content of French fries. The results of sensory evaluation revealed that blanching potato strips with infrared yielded a desirable taste, texture and color to the French fries, and furthermore panelists mostly preferred infrared blanched French fries. This research demonstrated that blanching of potato strips with infrared would produce lower-calorie French fries.

Acknowledgments

The authors would like to thank the Washington State Potato Commission for its partial financial support (project 5325-41000-063-05) and Mr. Donald Olson and Dr. Wen-Xian Du for their assistance.

References

Aguilera, J.M., Cadoche, L., Lopez, C. & Gutierrez, G. (2001). Microstructural changes of potato cells and starch granules heated in oil. *Food Research International*, 34, 939–947.

AOAC, (1984). The official methods of analysis. Method 28.074 (14 ed.). Arlington, VA: AOAC.

AOAC, (1995). Official Methods of Analysis. Association of Official Analytical Chemists, Washington, DC, USA.

Brewer, M.S., Klein, B.P., Rastogi, B.K. & Perry, A.K. (1994). Microwave blanching effects on chemical, sensory and color characteristics of frozen green beans. *Journal of Food Quality*, 17, 245-259

Buettner, R., Schölmerich, J., & Bollheimer, C. (2007). High-fat diets: modeling the metabolic disorders of human obesity in rodents, *Obesity* (Silver Spring), 15, 798–808.

Bunger, A., Moyano, P., & Rioseco, V. (2003). NaCl soaking treatment for improving the quality of French-fried potatoes. *Food Research International*, 36, 161–166.

Chou, K.J., & Chou, S.K. (2003). Low-cost drying methods for developing countries. *Trends in Food Science & Technology*, 14, 519–528.

Du Pont, M.S., Kirby, A.R. & Smith, A.C. (1992). Instrumental and sensory tests of texture of cooked frozen French fries. *International Journal of Food Science and Technology*, 27, 285-295

Espin, J.C., Morales, M., & Varon, R., (1995). A continuous spectrophotometric method for determining the monophenolase and diphenolase activities of apple polyphenol oxidase. *Analytical Biochemistry*, 231, 237–246.

Garayo, J., & Moreira, R. (2002). Vacuum frying of potato chips. *Journal of Food Engineering*, 55, 181–191.

Garcia, M.A., Ferrero, C., Bertola, N., Martino, M., & Zaritzky, N. (2002). Methylcellulose coatings applied to reduce oil uptake in fried products. *Food Science and Technology International*, 10, 339–346.

Hebbar, H.U., Vishwanathan, K.H., & Ramesh, M.N. (2004). Development of combined infrared and hot air dryer for vegetables. *Journal of Food Engineering*, 65, 557–563.

Jensen, A. (2011). Email correspondence: ajensen@potatoes.com

Jones, P. (1992). Electromagnetic wave energy in drying processes. In: Mujumdar, A.S. (ed). Drying ’92. Elsevier Science Publisher B.V. 114-136.

Kaiyala, K.J., Prigeon, R.L., Kahn, S.E., Woods, S.C., & Schwartz, M.W. (2000). Obesity induced by a high-fat diet is associated with reduced brain insulin transport in dogs. *Diabetes*, 49, 1525–1533.

Kelleher, S.D. & Williamson, P.G. (2005) Food product and process for reducing oil and fat content in cooked food. Patent, United States, US2005069626.
Khalil, A.H. (1999). Quality of French fried potatoes as influenced by coating with hydrocolloids. *Food Chemistry*, 66, 201–208.
Krokida, M.K., Oreopoulou, V., & Maroulis, Z.B. (2000). Effect of frying conditions on shrinkage and porosity of fried potatoes. *Journal of Food Engineering*, 43(3), 147–154.
Krokida, M.K., Oreopolou, V., Maroulis, Z.B., & Marinos-Kouris, D. (2001a). Effect of pre-drying on quality of French fries. Journal of Food Engineering, 49, 347-354.
Krokida, M.K., Oreopolou, V., Maroulis, Z.B., & Marinos-Kouris, D. (2001b). Colour changes during deep fat frying. Journal of Food Engineering, 48(3), 219-225.
Lau, M.H., Tang, J., & Swanson, B.G. (2000). Kinetics of textural and color changes in green asparagus during thermal treatments. *Journal of Food Engineering*, 45, 231-236
Lloyd, B.J., Farkas, B.E., & Keener, K.M. (2004). Quality comparison of French fry style potatoes produced by oven heating, immersion frying and controlled dynamic radiant heating. Journal of Food Processing and Preservation, 28, 460-472
Márquez, G., & Añón, M.C. (1986). Influence of reducing sugars and amino acids in the color development of fried potatoes. *Journal of Food Science*, 51, 157–160.
Moreira, R.G., Castell-Perez, M.E., & Barrufet, M.A. (1999). Deep fat frying: fundamentals and applications. Maryland: Aspen Publishers.
Moyano, P.C. & Pedreschi, F. (2006). Kinetics of oil uptake during frying of potato slices: Effect of pre-treatments. *LWT*, 39, 285-291.
Nonaka, M., Sayre, R.N., & Weaver, M.L. (1977). Oil content of French fries as affected by blanch temperatures, fry temperatures and melting point of frying oils. *American Journal of Potato Research*, 54, 151–159.
O'Connor, C.J., Fisk, K.J., Smith, B.G. & Melton, L.D. (2001). Fat uptake in French Fries as affected by different potato varieties and processing. *Journal of Food Science*, 66(6), 903-908.
Pan, Z. & McHugh, T.H. (2006). Novel infrared dry-blanching (IDB), infrared blanching, and infrared drying technologies for food processing. US Patent 0034981.
Pan, Z., Shih, C., McHugh T.H. & Hirschberg, E. (2008). Study of banana dehydration using sequential infrared heating and freeze-drying. *Lebensmittel Wissenschaft und Technologie*, 41,1944-1951.
Pedreschi, F., & Moyano, P. (2005). Oil uptake and texture development in fried potato slices. *Journal of Food Engineering*, 70, 557-563.
Rimac-Brncic, S., Lelas, V., Rade, V., & Simundic, B. (2004). Decreasing of oil absorption in potato strips during deep-fat frying. *Journal of Food Engineering*, 64, 237–241.
Sandu, C. (1986). Infrared radiative drying in food engineering: a process analysis. *Biotechnology Progress*, 2, 109–119.
Sanz, T., Primo-Martín, C., & Vliet, T.V. (2007). Characterization of crispness of French fries by fracture and acoustic measurements, effect of pre-frying and final frying times. *Food Research International*. 40, 63–70
Sharma, G.P., Verma, R.C., & Pathare, P.B. (2005). Thin-layer infrared radiation drying of onion slices. *Journal of Food Engineering*, 67, 361–366.
Sotome, I., Takenaka, M., Koseki, S., Ogasawara, Y., Nadachi, Y., Okadome, H. & Isobe, S. (2009). Blanching of potato with superheated steam and hot water spray. *LWT-Food Science and Technology*, 42, 1035-1040.
Strong, W.K. (1968). Process for preparing frozen French fry potato segments. US Patent 3,397,993.

Talburt, W.F., Schwimmer, S., & Burr H.K. 1987. Structure and chemical composition of the potato tuber. In: Talburt, W.T., Smith, O., editors. Potato processing. 4th ed. New York: Van Nostrand Reinhold Co.
Thompson, A.L., Love, S.L., Sowokinos, J.R., Thornton, M.K., & Shock, C.C. 2008. Review of the sugar end disorder in potato. *American Journal of Potato Research*, 85, 375–86.
Toma, R.B., Leung, H.K., Augustin, J., & Iritani, W.M. (1986). Quality of French fried potatoes as affected by surface freezing and specific gravity of raw potatoes. *Journal of Food Science*, 51(5), 1213-1214.
Tran, T.T.M., Chen, X., & Southern, C. (2007). Reducing oil content of fried potato crisp considerably using a 'sweet' pre-treatment technique. *Journal of Food Engineering*, 80, 719–726.
Troncoso, E. & Pedreschi, F. (2009). Modeling water loss and oil uptake during vacuum frying of pre-treated potato slices. *LWT- Food Science and Technology*, 42, 1164–1173.
USDA (2011). USDA National Nutrient Database for Standard Reference. URL: http://www.nal.usda.gov/fnic/foodcomp/search/ Last Accessed: March, 01 2011.
USDA & USDHHS. (1990). Dietary guidelines for Americans (3rd ed.). Washington, DC: US Dept. of Agric. and US Dept. of Health and Human Serv.
Van Loon, W.A.M., Linssen, J.P.H., Legger, A., Posthumus, M.A., & Voragen, A.G.J. (2005). Identification and olfactometry of French fries flavour extracted at mouth conditions. *Food Chemistry*, 90, 417–425.
Vitrac, O., Trystram, G., & Raoult-Wack, A.-L. (2000). Deep-fat frying of food: heat and mass transfer, transformations and reactions inside the frying material. *Eur. J. Lipid Sci. Technol.*, 102, 529–538
Yang, J., Bingol, G., Pan, Z., Brandl, M.T., McHugh, T.H., & Wang, H., (2010) Infrared heating for dry-roasting and pasteurization of almonds, *Journal of Food Engineering*, 101(3), 273-280.
Zhu, Y., & Pan, Z. (2009). Processing and quality characteristics of apple slices under simultaneous infrared dry-blanching and dehydration with continuous heating. *Journal of Food Engineering*, 90, 441–452.
Zhu, Y., Pan, Z., McHugh, T.H., & Barrett, D.M., (2010). Processing and quality characteristics of apple slices processed under simultaneous infrared dry-blanching and dehydration with intermittent heating. *Journal of Food Engineering*, 97, 8-16.
Ziaiifar, A.M., Courtois, F., & Trystram, G. (2010). Porosity development and its effect on oil uptake during frying process. *Journal of Food Process Engineering*, 33(2), 191-212.

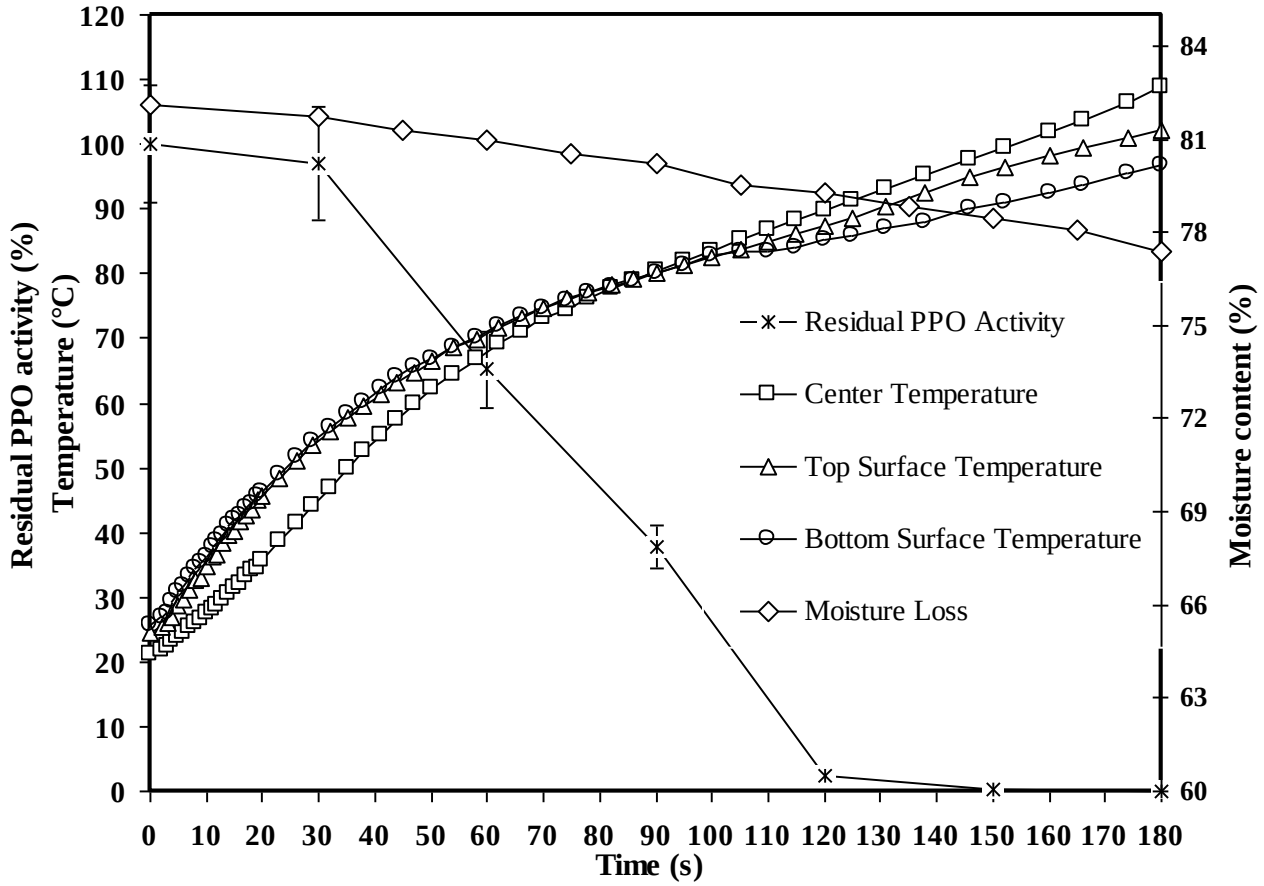


Figure 1. Residual PPO activities, temperature profiles and moisture loss of infrared dry-blanched potato strips

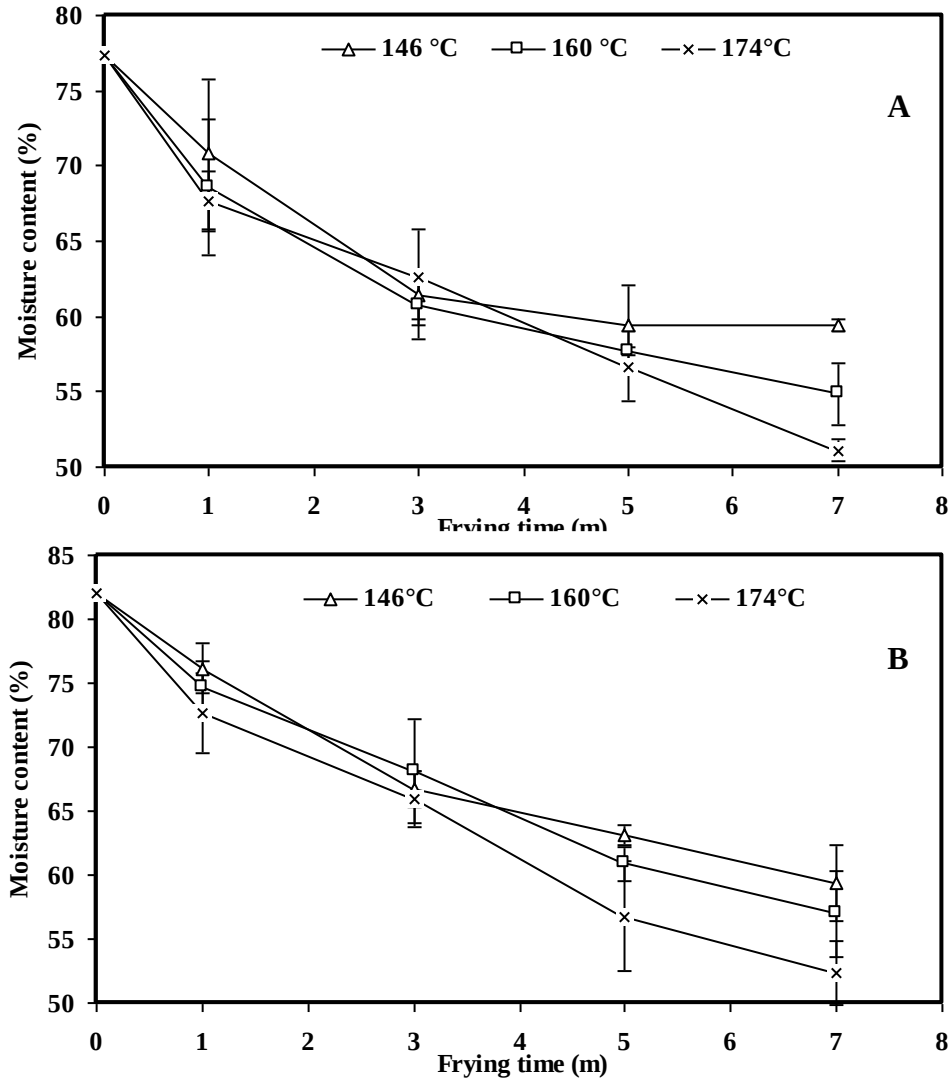


Figure 2. Moisture contents of a) infrared blanched and b) unblanched (control) French fries

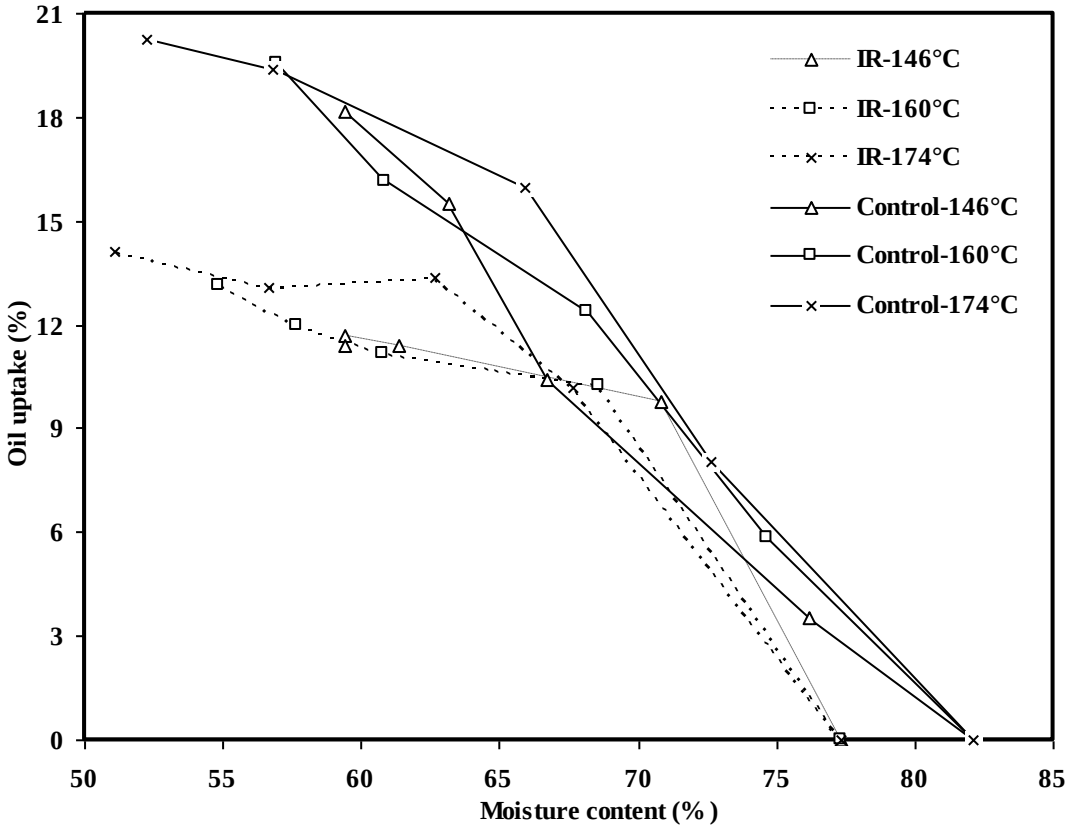


Figure 3. Relationship of oil content to moisture of infrared dry-blanched (dotted lines) and control (solid lines) French fries

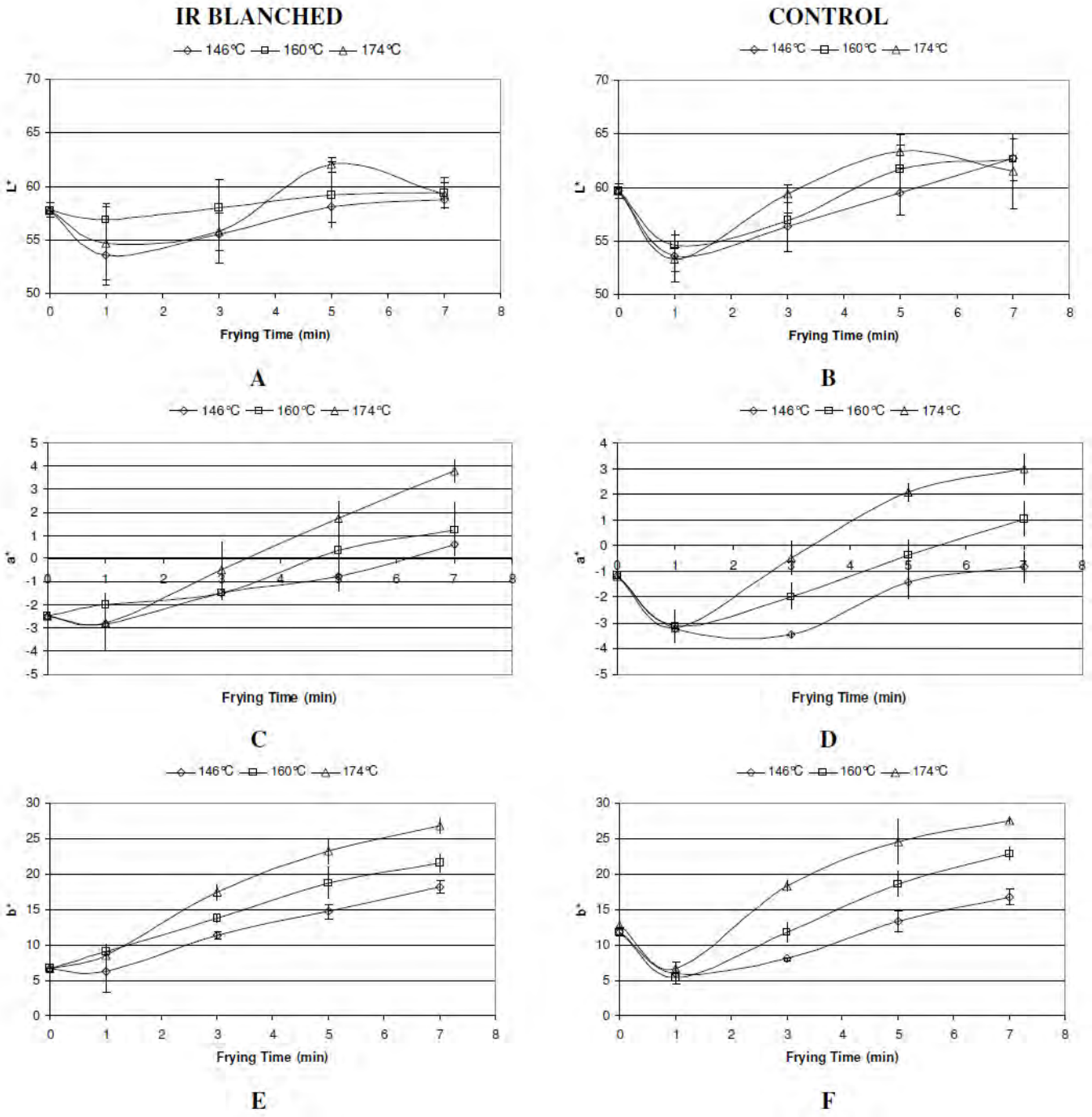


Figure 4. Color values of infrared blanched and control samples after frying

Table 1. Oil (g oil g^{-1} dry basis) and moisture (% wet basis) contents of infrared blanched and control samples prepared for sensory analysis under different frying conditions

Frying Temperature	Control			Infrared Blanched		
	Frying Time (s)	Oil Content	Moisture Content	Frying Time (s)	Oil Content	Moisture Content
146°C	447	22.77	63.89	330	13.93	58.25
160°C	333	21.74	59.13	270	15.30	60.96
174°C	241	20.79	63.1	228	14.23	57.76

Table 2. Oil contents (g oil g^{-1} dry basis) of infrared blanched and control French fries under different frying temperatures (Mean value ± S.D.)

Frying time (min)	Control			Infrared Blanched		
	146°C	160°C	174°C	146°C	160°C	174°C
1	3.51 ± 0.85a	5.82 ± 0.99b	8.05 ± 0.21c	9.75 ± 1.33a	10.25 ± 1.21a	10.19 ± 1.14a
3	10.43 ± 0.95a	12.40 ± 0.56a	15.98 ± 1.65b	11.40 ± 0.70a	11.19 ± 1.39a	13.38 ± 0.31b
5	15.49 ± 0.24a	16.14 ± 0.37a	19.37 ± 2.18b	11.67 ± 0.92a	11.95 ± 0.41a	13.05 ± 1.24b
7	18.16 ± 0.80a	19.58 ± 2.09a	20.27 ± .015a	11.42 ± 0.33a	13.16b ± 1.16b	14.13 ± 0.68b

For each treatment, means in the same row with different letters are significantly different ($P < 0.05$).

Table 3. P-values of sensory attributes and percentage preferring infrared blanched samples

Sensory Attribute / Frying Temperature (°C)	Taste	Texture	Color	Appearance
146	P=0.168	P=0.0003	P=0.118	P=0.017
	N/A	59.1%	N/A	50%
160	P=0.113	P=0.0003	P=0.113	P=0.0003
	N/A	46.4%	N/A	39.3%
174	P=0.149	P=0.0020	P=0.0001	P=0.0001
	N/A	59.3%	55.6%	51.9%

N/A: Not applicable since there is no significant difference between the blanched and unblanched samples for the respective sensory property.

Traditional Potato Breeding

Charles R. Brown, USDA/ARS, Prosser, WA

Introduction

Despite the fact that potato has been an important foodstuff in the Andes for several thousand years, and in the rest of the world for 300 years, the practice of producing new varieties through crossing has existed for perhaps 150 years. Today traditional breeding is practiced in private businesses and publically supported programs. The basic elements are the primary procedure by which almost all new varieties are derived. The purpose of this paper is to describe the mechanics of traditional breeding.

Elements of traditional breeding

The potato is a clonally propagated highly heterozygous crop. There are no inbred lines. A cross is made with the idea of approximately approaching a combination of characters from both parents, but accomplishing a certain target is usually out of the question. Selection must be embarked upon with spirit of looking for the best new clone that best approaches the improved type that one is seeking.

Mixed in with this is the fact that relatively few important traits are under simple genetic control. Indeed, total yield, yield of particular size categories, size of tuber, number of tubers, length of dormancy, sugar composition out of storage and after prolonged storage are all traits controlled by multiple genes.

A potato cross is effected by placing pollen of the paternal or staminate parent onto the stigma of the maternal or pistillate parent. The first sign of a successful cross is the swelling of the ovary of the flower. After some weeks it will appear that little green tomatoes are forming. Potato fruits never achieve the size of a large tomato. Upon harvesting and fruit ripening, seed can be expressed from the fruits and air dried to be stored for future use.

Upon germination the seedlings are separated into separate pots and handled in such a way that one tuber from each potato will be composited into a tuber family. The next growing season these tuberlings will be planted at extra large spacing to prevent mixing, allowed to grow to full maturity and then lifted with a digger. Individual clones are selected in a highly subjective manner for tuber type, skin type with some consideration for tuber size, number and yield. This newly selected clone is maintained with a unique identity and is the source of seed and the object of further selection in future plantings. Figures 1 through 10 provide a pictorial tutorial of potato breeding with explanations.

Figure 1. The potato flower has anthers and pistil, the male and female structures that contain pollen and eggs, respectively.

Figure 2. One of the first steps in the making of a cross is to remove the organs that produce pollen in the potato flower, the anthers. This is to prevent self-pollination.

Figure 3. After pollination the potato flowers produce fruits that look like little green tomatoes

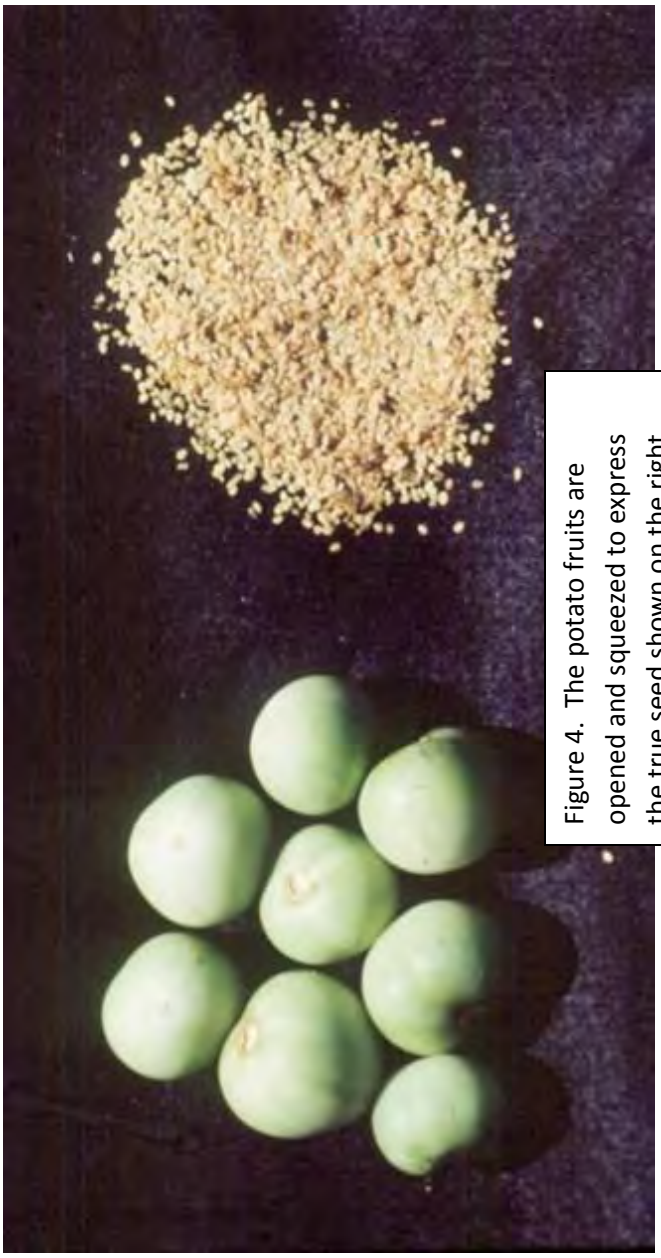


Figure 4. The potato fruits are opened and squeezed to express the true seed shown on the right. Each fruit may have as many as 200 seeds.

Figure 5. The true seed on the right is sown in soil and germinates into potato plants. These are grown individually in small pots and one tuber saved for planting in the field. At the end of the field season the plants with tubers that match a number of criteria are retained and subsequently maintained as clones.

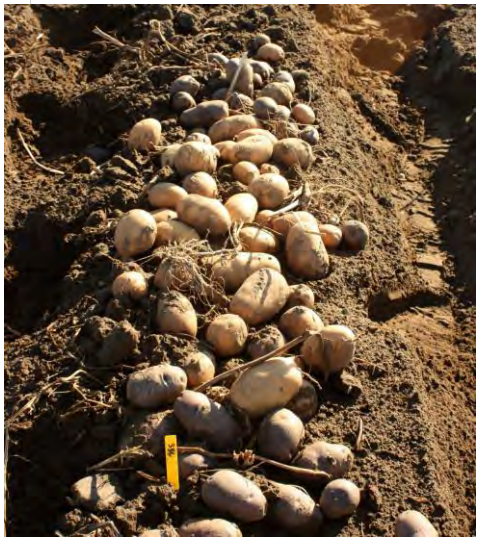


Figure 6. When the potatoes are harvested clones are selected on the basis of highly heritable characteristics like skin type and tuber shape.

Figure 7. If potato breeding were more targetable we could start with fewer seedlings and assemble traits in new genotypes with a great deal of control.

Figure 8. In reality traditional potato breeding is highly untargeted requiring us to put out large numbers of starting genotypes. It is a numbers game.

Figure 9. Because the number of seedlings must be very high, breeding programs start with from tens of thousands to hundreds of thousands of seedlings. Each breeding program has different methodologies, but within a few years the number of distinct genotypes has reached a small fraction of the original number.

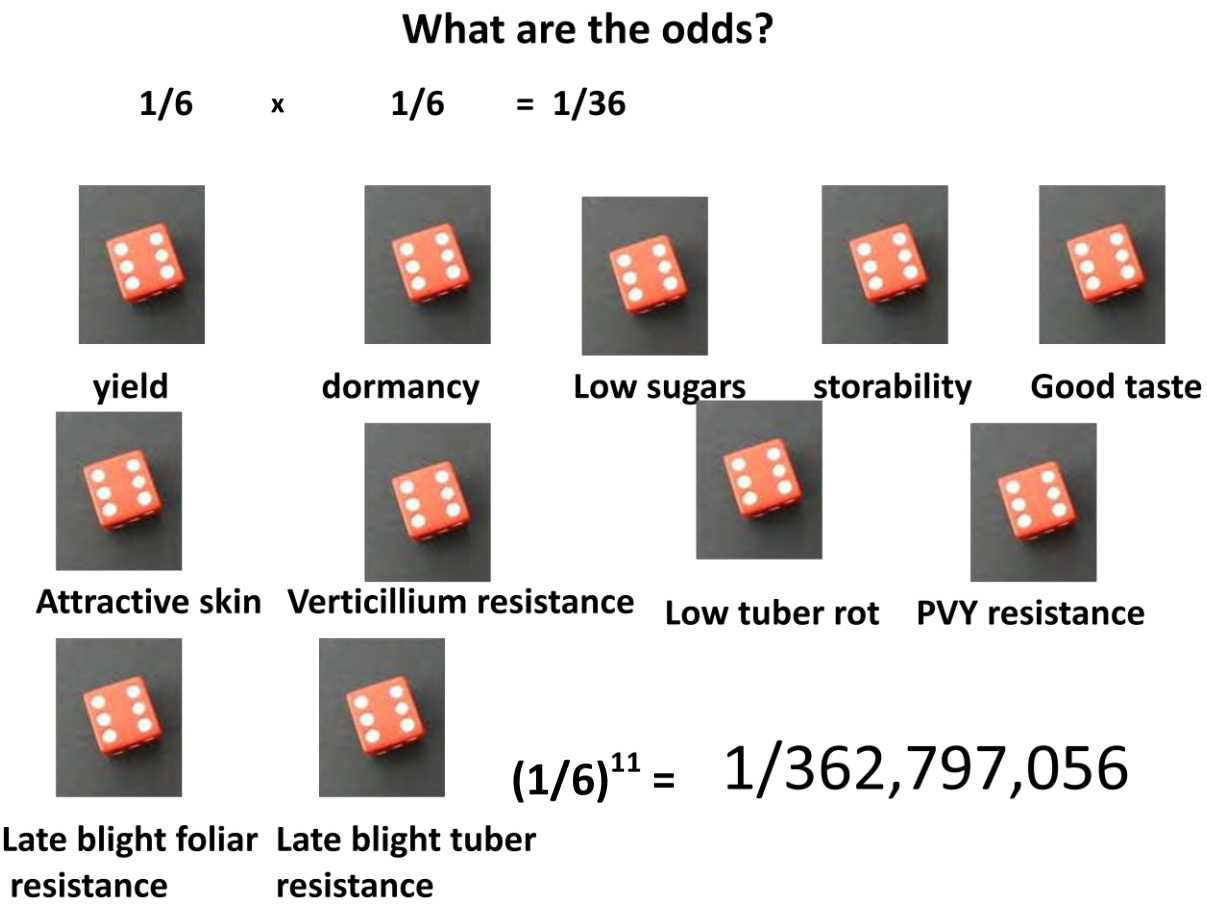


Figure 10. Here is an example of probabilities associated with finding a new potato cultivar, if we assume that all of the traits listed above have approximately 1/6 chance of being expressed at a level that would be considered high desirable. Furthermore, if we consider that the traits are independent of each other, then the probability of obtaining the best performance in just 11 characters is the same as rolling a six on a dice 11 times in a row, or a truly very low probability. In essence, this little thought exercise is telling us that in reality new potato varieties represent substantial compromises in performance, because the probability of selecting high performance becomes vanishingly small as the number of traits considered increases.

After approximately five to six years of evaluation in field trials, with increasing plot size and number of replications, advanced lines are placed in regional trials. Typically performance is tested among 10 to 15 advanced lines with the industry standard varieties for comparison.

Screening

The screening of potato germplasm has been the subject of much research. Basically the methodology employed can be separated into three broad groups 1) screening in an artificial environment, 2) screening in the field, 3) use of molecular markers associated with traits.

Artificial screening involves exposing potato plants, leaves or tubers to a challenge in a controlled environment. The challenges can be pests and pathogens, physical conditions, or chemical assays. Examples of pathogens that can be applied to potato genotypes in artificial settings are the following:

1. Late blight in foliage
2. Late blight in tubers
3. Potato virus Y
4. Potato leafroll virus
5. *Fusarium* tuber rot
6. Tobacco rattle virus
7. *Pectobacterium* bacterial soft rot
8. *Verticillium* wilt
9. Bacterial ring rot
10. Bacterial wilt
11. Columbia root knot nematode
12. Golden nematode
13. Pale cyst nematode

Examples traits best tested in the field or from field grown tubers are as follows:

1. Late blight in foliage
2. Yield
3. Black dot resistance
4. Powdery scab resistance
5. Common scab resistance
6. Culinary quality of tubers
7. Reducing sugars content in tubers
8. Fry color
9. Acrylamide content in cooked potato
10. Glycoalkaloid content

11. Protein content
12. Tyrosine content
13. Asparagine content
14. Tuber size
15. Tuber shape
16. Surface appearance of tubers (attractiveness of skin)
17. Internal defects.

Examples of molecular markers used for selection:

1. Beta carotene hydroxylase marker for yellow flesh
2. Zeaxanthin epoxidase for ultra high carotenoids
3. Potato virus Y derived from *S. andigenum*
4. Potato leafroll virus
5. Potato late blight resistance
6. Root resistance to Columbia root-knot nematode
7. Resistance to Golden nematode
8. Resistance to pale cyst nematode
9. Resistance to potato wart disease

When breeding lines reach advanced stages they are tested in multiple locations in replicated trials.

Below are two tables from the Western Regional Russet Trials. In Table 3 we see a comparison of total yield at different locations with early and late harvests. The stability of performance of breeding lines is an important determination which, of course, cannot be accomplished until there are sufficient tubers to plant at multiple sites. Very often it is the case that the breeding lines with the highest average performance are in this position because they are the highest or nearly the highest performer in most of the environments. Although many characters must have a satisfactory level of expression in a clone for it to be of interest commercially, it is rare that a lower yielding candidate would be chosen by growers. Yield is a measure of efficiency. With higher yield you can grow the same amount of potatoes on less land with less inputs. Essentially, yield is an important part of sustainability. In Table 15 a summary of the performance of the clones is given. The mean yield and percent of No 1's are imperative to judge the profitability of the clone. Processing and fresh market prices will be heavily weighted with tuber size incentives. The specific gravity will be in the processing contract because it is so crucial for the processing quality of fried products. Higher specific gravities are unavoidably associated with amount of oil that a fried product absorbs and the taste-feel of the processed and fresh market home cooked potato. Merit scores are compilations of multiple factors that give an overall idea how well the clones would perform as a fresh market or processing clones. It is noteworthy that certain clones are high performers in a number of arenas. The breeding line A01010-1 is a top yielder both in early and late harvest trials. The specific gravity, at 1.085, is

very desirable. Fry color is light out of 45 degrees storage and the merit scores are in the upper region for both fresh and processing. It would appear to be the perfect clone.

There is a bit of an internal contradiction in the evaluation of the status and future of traditional breeding. It is the major route by which new commercial varieties are developed and placed in the market. The probabilty of naming a variety out of the initial seedling population, is dauntingly low (between 1/100,000 to 1/1,000,000). Only one out 5 of released varieties gains a significant market share. The most popular varieties for processing and fresh market are quite unchanging. There is considerable resistance to learning the lessons of growing new varieties. Although it seems like a very inefficient process, with as much art as there is science, it is still the main game in town.

TABLE 3: 2010 Western Regional Potato Variety Trial - TOTAL YIELD (CWT/A) - EARLY AND LATE HARVEST

		Total Yield - Early Harvest (CWT/A)						Total Yield - Late Harvest (CWT/A)									
		ID	TX	WA	Entry			CA	CO	ID			OR		WA	Entry		
No.	Clone	PAR	SPR[1]	OTH	Mean/Rank			TUL	SLV	AB	KIM	PAR	HRM	KLA	OTH	Mean/Rank		
1	RANGER R.	493	144	578	**536**	**13**	**abc**	437	470	445	473	571	941	482	782	**575**	**7**	**bcdef**
2	R. BURBANK	523	146	636	**579**	**4**	**ab**	419	489	491	529	563	821	411	683	**551**	**8**	**cdefg**
3	R. NORKOTAH	513	134	498	**506**	**17**	**abcd**	385	382	430	414	546	399	460	532	**444**	**19**	**hij**
4	A97066-42LB	364	92	444	**404**	**21**	**d**	404	370	386	387	482	900	.	696	**518**	**13**	
5	A98345-1	496	112	663	**579**	**4**	**ab**	521	543	494	585	495	1150	482	1010	**660**	**2**	**ab**
6	A0008-1TE	529	194	584	**557**	**9**	**abc**	452	397	390	418	593	566	431	671	**490**	**16**	**efghij**
7	A00324-1	504	95	588	**546**	**11**	**abc**	388	504	494	538	562	1035	497	889	**613**	**4**	**abc**
8	A01010-1	511	78	653	**582**	**3**	**ab**	495	489	505	549	542	1224	498	931	**654**	**3**	**ab**
9	AC99375-1RU	454	59	663	**558**	**7**	**abc**	511	435	514	554	568	1185	518	1148	**679**	**1**	**a**
10	AO00057-2	428	105	527	**478**	**19**	**bcd**	454	388	466	381	497	701	474	863	**528**	**11**	**cdefgh**
11	AO96305-3	489	114	571	**530**	**15**	**abc**	370	426	392	372	551	613	432	650	**476**	**18**	**ghij**
12	AOTX95265-1Ru	566	138	550	**558**	**7**	**abc**	409	474	459	429	482	464	478	637	**479**	**17**	**fghij**
13	AOTX96216-2Ru	419	91	631	**525**	**16**	**abc**	392	398	374	455	471	976	490	772	**541**	**9**	**cdefgh**
14	AOTX96265-2Ru	455	80	615	**535**	**14**	**abc**	390	436	351	430	508	944	427	726	**527**	**12**	**cdefgh**
15	CO98067-7RU	599	69	617	**608**	**1**	**a**	383	475	439	436	473	679	443	709	**505**	**15**	**defghi**
16	CO99053-3RU	492	81	520	**506**	**17**	**abcd**	413	474	477	444	429	831	444	782	**537**	**10**	**cdefgh**
17	CO99053-4RU	469	112	453	**461**	**20**	**cd**	368	365	373	321	408	502	406	559	**413**	**20**	**ij**
18	CO99100-1RU	595	189	574	**584**	**2**	**a**	389	313	347	382	432	390	398	518	**396**	**21**	**j**
19	PA00N14-2	532	83	553	**543**	**12**	**abc**	413	452	477	477	559	601	428	665	**509**	**14**	**defghi**
20	PA99N2-1	521	42	593	**557**	**9**	**abc**	437	426	495	511	530	1071	442	898	**601**	**5**	**abcd**
21	PA99N82-4	501	53	639	**570**	**6**	**ab**	400	407	387	510	453	1007	490	1004	**582**	**6**	**abcde**
	Location Means	498	105	578	**538**			420	434	437	457	510	810	457	768	**537**		

Means followed by the same letter are not significantly different at the 5% level using Student's t test.

[1]Springlake Texas excluded from means and statistical analysis.

Indicates high or strength **Indicates low or weakness**

TABLE 15: 2010 Western Regional Potato Variety Trial - ENTRY SUMMARY[1]

No.	Clone	Year In Trial	Use	Total Yield[2]	US #1's Yield[2]	% US #1's[2]	Tuber Size (oz) Early	Tuber Size (oz) Late	Specific Gravity[2]	Fry 45 Color	%Cumulative Shrink & Sprout Rating[3]	Combined (E&L) Merit Score[4] Process	Combined (E&L) Merit Score[4] Fresh	Observations	Disposition 2011
1	RANGER R.	-	Dual	575	474	82	6.9	8.1	1.087	0.9	6.1	3.0	3.9	3.1		Check
2	R. BURBANK	-	Dual	551	409	74	5.6	6.6	1.083	1.2	7.6	4.0	3.0	2.3		Check
3	R. NORKOTAH	-	Fresh	444	361	82	6.2	5.8	1.074	1.0	7.0	3.5	3.0	3.2		Check
4	A97066-42LB	3	Proc	518	437	84	4.7	7.9	1.097	0.9	11.1	3.5	2.9	2.1	High SG; Res. to EB, VW/ED, and LB	Graduate
5	A98345-1	2	Dual	660	595	90	6.8	8.9	1.089	0.6	7.5	3.0	3.6	2.8	High US #1 & ov.size yield (E&L); CSR; VW/ED & EB Res.; Susc. to Fus(sol), scab, Rhizo,metr.	Return
6	A0008-1TE	3	Dual	490	419	85	7.2	7.0	1.081	1.2	5.7	3.0	3.3	3.5	F(sam) res.; Soft rot susc.; high protein	Graduate
7	A00324-1	1	Dual	613	535	86	7.8	9.0	1.082	0.6	-	-	3.7	3.0	Large tuber size with high % oversize and oversize yield (E&L); Soft rot res	< Seed
8	A01010-1	1	Dual	654	568	87	5.2	7.2	1.085	0.9	-	-	3.5	3.0	High total yield (E&L),vit. C, and protein; Soft ro res; tuber LB & F(sam) susc.	Return
9	AC99375-1RU	2	Dual	679	549	80	5.5	6.8	1.092	0.4	8.5	3.5	3.8	2.1	High SG & protein; Res. to V/ED,EB, LB, F(sol); CSR.	Return
10	AO00057-2	1	Dual	528	466	88	6.9	8.4	1.090	0.5	-	-	3.9	3.1	Res. to V/ED and F(sol); Possible Black Spot Bruise Res. (ID)	Return
11	AO96305-3	2	Dual	476	418	88	7.6	7.0	1.087	0.3	4.7	4.0	4.1	3.4	Long tubers (E&L); Susc to GC (E) & NN/VD (E), Cscab, S.rot, tuber EB; CSR	Return
12	AOTX95265-1Ru	1	Fresh	479	386	80	6.0	5.8	1.075	1.3	-	-	3.1	3.2	Low SG; Susc. to tuber LB, VW/ED, and soft rot	Drop
13	AOTX96216-2Ru	1	Fresh	541	434	77	13.2	14.3	1.077	1.5	-	-	1.4	1.7	V. large tuber size; susc. to GC, 2nd, HH, shatter, , B. spot; res to NN/VD, scab?; low prot.	Drop
14	AOTX96265-2Ru	1	Fresh	527	482	91	7.3	8.3	1.089	0.4	-	-	3.2	2.8	High % No. 1 (E&L); & protein; Susc. to shatter (L), c. scab; CSR yet high S. Ends	Return
15	CO98067-7RU	3	Dual	505	382	76	5.3	5.1	1.072	1.3	6.6	4.0	3.0	2.7	Small tuber size (E&L); susc to NN/VD; low protein	Graduate
16	CO99053-3RU	2	Dual	537	452	84	6.1	7.5	1.083	0.9	5.3	3.5	3.6	2.9	Susc. to H. Heart (L); res. to VW/ED & EB	Return
17	CO99053-4RU	2	Fresh	413	326	79	5.6	5.5	1.080	0.9	8.6	3.0	3.4	2.5	Low total yield (E&L); high Vit. C	Return
18	CO99100-1RU	2	Fresh	396	319	79	7.6	6.7	1.077	0.7	7.1	3.5	3.2	2.9	VW/ED & EB susc.	Return
19	PA00N14-2	2	Dual	509	424	82	5.8	5.8	1.086	1.0	5.4	4.0	3.4	3.1	Long tubers (E&L); Res to NN/VD	Return
20	PA99N2-1	3	Proc	601	526	86	6.2	7.5	1.085	1.0	5.2	2.5	2.8	2.5	Shatter Bruise (E&L); soft rot susc.	Graduate
21	PA99N82-4	3	Proc	582	491	83	6.2	7.7	1.084	0.6	6.1	3.0	3.1	2.6	Shatter Bruise (E&L); HH (L); Res to Rootknot Nematode	Graduate
	Entry Means			537	450	83	6.7	7.5	1.084	0.9	6.8	3.4	3.3	2.8		

[1] Numeric values represent means across all trial locations.

[2] Data shown from late trial results.

[3] 2009 entries at Tulelake, CA; Evaluated at 181 days after harvest. Sprout rating:1(>2 inches), 2(1-2 inches), 3(peeping to 1 inch), 4(peeping), 5(none).

[4] Data shown from combined early & late trial results.

Population Structure of *Verticillium dahliae* Isolates Collected from Potato in the Columbia Basin

Jeremiah K. S. Dung and Dennis A. Johnson
Department of Plant Pathology, Washington State University, Pullman, WA

Verticillium dahliae is a soilborne plant pathogen with a worldwide distribution. The fungus causes Verticillium wilt of potato and is a primary component in the potato early dying complex. In North America, vegetative compatibility group (VCG) 4A is found associated with potatoes and exhibits the highest aggressiveness. Primary inoculum of *V. dahliae* is composed of melanized microsclerotia, which have the ability to lie dormant in soils for long periods of time and germinate in response to host root exudates. The fungus invades the roots and colonizes the vascular system of susceptible hosts, causing wilt, chlorosis, necrosis, vascular discoloration, stunting, and premature senescence. During host senescence the fungus produces microsclerotia in colonized host tissue. The disease cycle is completed when infested host debris is incorporated back into the soil. Soilborne primary inoculum levels can increase annually if proper management practices are not observed.

Management of Verticillium wilt aims at reducing primary inoculum through pre-plant fumigation and the use of moderately resistant cultivars and disease-free planting materials. Crop rotation is of only limited benefit due to the wide host range of *V. dahliae*, its ability to colonize and persist on the roots of monocots and other nonhost crops, and its long persistence in soil. Fumigation is expensive and the practice may be eliminated in the future. The use of disease-free planting materials is an important practice, as it reduces the probability of introducing the pathogen or new genotypes (strains) of the pathogen into fields intended for potato production.

The production of potato propagative materials (seed tubers) is restricted to certain seed tubers-producing areas. Seed tubers are shipped to commercial production areas throughout the country annually and the potential exists for long-distance transport of pathogens in planting materials. It was previously shown that inoculum of *V. dahliae* can be found in the vascular system of certified tubers used for seed. Surveys of 224 seed lots intended for U.S. production fields found *V. dahliae* in 29% of the lots and 3.6% of the seed tubers in 1995 and 1996, respectively. All 162 isolates tested belonged to VCG 4, of which 64% belonged to VCG 4A, 33% to VCG 4B and 3% to VCG 4AB. Although *V. dahliae* can be transmitted in certified seed tubers, tuber-borne inoculum (internal infection of the vascular tissue of the seed) appears to have little effect on Verticillium wilt symptoms and potato yields. In a recent study, vascular infection by *V. dahliae* of seed tubers of the moderately susceptible cultivar 'Russet Burbank' resulted in a negligible effect on the development of Verticillium wilt symptoms, did not significantly contribute to aboveground stem infection or the formation of microsclerotia in debris, and did not significantly contribute to progeny tuber infection. However, tuber-borne inoculum may be an important way to introduce inoculum to soils not previously used to grow potato, or where a management practice such as fumigation has been applied to reduce soilborne inoculum.

Another potential source of *V. dahliae* inoculum is field soil associated with seed tubers, either in the form of soil attached to the surface of seed tubers or as loose soil associated with the handling and transport of seed tubers. If infested with *Verticillium*, then this soil could be another source of inoculum in commercial potato fields following fumigation. The purpose of this research was to compare the genetic diversity of *V. dahliae* isolates associated with potato

production in the Columbia Basin. A total of 27 isolates, representing 27 different seed lots from MT and ID in 2008 and 2009, were obtained from infected seed tubers sampled. Seven isolates from infested soil scraped from the surface of seed tubers were obtained from seed lots sampled in 2009. Isolates were characterized by vegetative compatibility group and using mating-type and microsatellite DNA markers. Isolates associated with 2008-2009 seed lots were compared to 15 isolates obtained in 1998 from Columbia Basin (OR, WA) field soils in potato rotations and 30 isolates collected from potato and seed potato in ID, MT, ND, NE, OR, SD, WA, WY.

Vegetative Compatibility Group (VCG) Assay

Chlorate-resistant *V. dahliae* mutants (*nit* mutants) were obtained and paired with known Nit1 and NitM VCG testers on minimal media. Plates were checked for complementation at 2-3 weeks and rated as: no complementation (no reaction), weak complementation (sparse growth of aerial hyphae but no microsclerotia formation), moderate complementation (growth of aerial hyphae and sparse microsclerotia formation), or strong complementation (full wild-type growth, with growth of aerial hyphae and microsclerotia formation). All isolates collected from infected seed tubers and infested soil scraped from seed tubers were assigned to VCG 4 and most (91%) belonged to VCG 4A (Table 1).

Mating-type (*MAT*) Gene Assay

Although the life cycle of *V. dahliae* is considered to be strictly asexual, recent work identifying mating-type (*MAT*) genes in *V. dahliae* revealed the possibility for sexual reproduction of the pathogen (8). Sexual reproduction can contribute to increased genotypic diversity of populations through genetic recombination, which can lead to novel gene combinations and new strains. Isolates of *V. dahliae* were assayed for mating-type genes using a multiplex polymerase chain reaction (PCR). All isolates tested were mating-type *MAT1-2*, indicating that sexual recombination is not likely in populations associated with potato in the Columbia Basin. However, the introduction of the other mating-type through crop rotation or future propagative materials is still a possibility.

Microsatellite Analysis

Eight microsatellite markers, previously shown to be variable in *V. dahliae* populations collected from lettuce, strawberry and other hosts from coastal California and Wisconsin (1), were used in the analysis. Fifteen additional isolates from infested soil and 30 isolates from infected potato obtained in other states were included for comparison. Genotyping was performed using a nested-PCR reaction to fluorescently label PCR products, essentially as described by Schuelke (5) and products were separated on an ABI 3100 sequencer. Genetic diversity (4) and Slatkins R_{st} (6) were calculated using the software Arlequin ver. 3.5 (2). An R_{ST} value of 0 indicates no separation; $0 < R_{ST} < 0.05$ indicates negligible differentiation; $0.05 \leq R_{ST} < 0.25$ indicates moderate differentiation; $R_{ST} \geq 0.25$ indicates high differentiation; and $R_{ST} = 1$ indicates complete differentiation. Analysis of molecular variance (AMOVA) was performed using Arlequin to test for genetic differentiation between VCG 4A and VCG 4B subgroups affecting potato. Isolates were divided into two clusters (VCG 4A and VCG 4B) with four sample populations in each (infected seed tubers, infested soil from seed tubers, Columbia Basin field soils, and potatoes and seed potatoes grown in ID, MT, ND, NE, OR, SD, WA, WY). Genetic distances were calculated using Genotype (3) and a minimum spanning network was constructed from genetic distances using HapStar ver. 0.6 (7).

A total of 14 microsatellite haplotypes (haploid genotypes, or strains) were found among the 80 isolates collected from hosts associated with potato production (seed tubers, soil scraped from seed tubers, infested field soils, and infected potato plants from various states). The potato group exhibited the greatest genetic diversity as indicated by the relative number of haplotypes to isolates sampled (Table 1), followed by infested soil scraped from seed tubers and infested field soils. A single haplotype was predominant in all VCG 4A sample populations. This haplotype made up 100% of VCG 4A isolates from seed tubers and 67% of VCG 4A isolates from infested soil scraped from seed tubers. This haplotype also accounted for 80% of VCG 4A isolates from infested field soils.

Over 63% of the genotypic variability was observed among VCG sampling groups ($P < 0.02857$), indicating significant differentiation among VCGs. Only 3% ($P = 0.17163$) of variability was explained by differences among sample populations (seed tubers, soil scraped from seed tubers, infested field soils, and potato from various states), while the remaining variability (approximately 33%) was explained by genetic diversity within sample populations ($P < 0.00001$). All VCG 4A sample populations were highly differentiated from VCG 4B sample populations ($R_{st} > 0.5$) (Table 2). Although minimum spanning network analyses differentiated two general clusters corresponding to VCG 4A and VCG 4B subgroups, some VCG 4A isolates appear to be more closely related to VCG 4B and VCG 4A/B isolates than to other VCG 4A isolates (Fig. 1).

Conclusions

The amount and distribution of genetic diversity in plant pathogen populations can directly impact disease epidemiology and management efficacy. Greater genetic and genotypic variability is often associated with an increased ability to adapt to changing environments and selective pressures. Sexual recombination increases genotypic variability by redistributing existing genetic variability into new combinations, or genotypes. All isolates characterized in this study possessed the *MAT1-2* idiomorph, indicating that the potential for sexual recombination among these populations is low.

Genotypic diversity varied among sample groups, ranging from a nearly clonal population in potato seed tubers to a relatively diverse population in potato and Columbia Basin field soils. The diversity found among potato isolates is likely due to the various states sampled, while the genetic diversity observed in the Columbia Basin field soil sample groups may be due to differences in the cropping histories of the fields. Most isolates (93%) obtained from infected seed potato were a single haplotype, indicating that genotypic diversity of *V. dahliae* isolates in seed lots is low. However, the genotypic diversity of *V. dahliae* isolates found in tare soil attached to seed tubers is relatively high. This source of inoculum may be especially important, since levels of *V. dahliae* in seed tare soil can be greater than 500 CFU/g soil (*data not shown*). Although the contribution of seed tare soil to Verticillium wilt is not known, even a small amount of infested seed tare soil (1 g soil/metric ton of seed) may be significant given the large quantity of seed (approximately 150,000 metric tons) planted in the Columbia Basin every year.

The potential exists for the exchange of heritable material between vegetatively compatible but genetically distinct isolates of *V. dahliae*. The majority of isolates characterized in this study were assigned to VCG 4A, which has previously shown to be highly aggressive on potato. The remaining isolates assigned to either VCG 4B or VCG 4A/B, which is also pathogenic on potato but to a lesser extent than VCG 4A. AMOVA and Slatkin's R_{st} values indicated that the genetic differentiation between VCG 4A and 4B subgroups was significant.

However, both subgroups contained a significant proportion of the total genetic variation, indicating genetic diversity exists within VCG 4A and VCG 4B. Although VCG 4 subgroups are genetically differentiated, the potential may exist for the exchange of genetic material between strains of VCG 4A and VCG 4B via VCG 4A/B strains.

A single microsatellite haplotype was associated with VCG 4A populations from all four sample groups and was predominant in infected seed potato. This haplotype was found in potato and field soils in rotation with potato in several states (WA, OR, SD, WY, ND, and NE), indicating a wide distribution. Several isolates of this haplotype were previously demonstrated to be highly aggressive on potato in greenhouse assays (*data not shown*). This haplotype was also isolated from *V. dahliae*-infected raspberry and blackberry (*Rubus*), watermelon (*Citrullus*), sugar beet (*Beta*), cherry (*Prunus*), and maple (*Acer*) growing in ID, OR, and WA. The exact origin of this particular haplotype is currently not known. A better understanding of the population structure of *V. dahliae* will increase the potential to better manage Verticillium wilt of potato in the future.

References

1. Atallah, Z. K., Maruthachalam, K., Toit, L. d., Koike, S. T., Michael Davis, R., Klosterman, S. J., Hayes, R. J., and Subbarao, K. V. 2010. Population analyses of the vascular plant pathogen *Verticillium dahliae* detect recombination and transcontinental gene flow. Fungal Genetics and Biology 47:416-422.
2. Excoffier, L., Laval, G., and Schneider, S. 2005. Arlequin (version 3.0): An integrated software package for population genetics data analysis. Evolutionary Bioinformatics Online 1:47-50.
3. Meirmans, P. G., and Van Tienderen, P. H. 2004. GENOTYPE and GENODIVE: Two programs for the analysis of genetic diversity of asexual organisms. Molecular Ecology Notes 4:792-794.
4. Nei, M. 1973. Analysis of gene diversity in subdivided populations. Proceedings of the National Academy of Sciences of the United States of America 70:3321-3323.
5. Schuelke, M. 2000. An economic method for the fluorescent labeling of PCR fragments. Nature Biotechnology 18:233-234.
6. Slatkin, M. 1995. A measure of population subdivision based on microsatellite allele frequencies. Genetics 139:457-462.
7. Teacher, A. G. F., and Griffiths, D. J. 2010. HapStar: automated haplotype network layout and visualization. Molecular Ecology Resources.
8. Usami, T., Itoh, M., and Amemiya, Y. 2009. Asexual fungus *Verticillium dahliae* is potentially heterothallic. Journal of General Plant Pathology 75:422-427.

Table 1. Sample groups, vegetative compatibility group (VCG), the number of individuals, and the number of haplotypes (strains) found in *V. dahliae* populations used in this study.

Sample group	VCG	No. of isolates	No. of haplotypes
Infected seed tubers[a]	4A	25	1
	4B	2	1
	Total	**27**	**2**
Infested seed surface soil[b]	4A	7	3
	4B	1	1
	Total	**8**	**3**
Columbia Basin field soils[c]	4A	11	4
	4B	3	2
	4A/B	1	1
	Total	**15**	**6**
Potato from various states[d]	4A	15	7
	4B	12	7
	4A/B	3	2
	Total	**30**	**12**

[a] Isolates from infected seed tubers were collected from seed lots intended for Columbia Basin production fields between 2007 and 2009.
[b] Isolates from infested soil on the surface of seed tubers were obtained from seed lots intended for Columbia Basin production fields in 2009.
[c] Isolates from Columbia Basin field soils were collected in 1998 from soils in OR and WA associated with potato production.
[d] The potato sample group consisted of isolates collected from infected potato and seed potato in various states (ID, MT, ND, NE, OR, SD, WA, WY) during the mid-1980's and 1990's.

Table 2. Gene diversity differentiation of *V. dahliae* VCG 4A and VCG 4B sample populations as indicated by Slatkin's R_{ST}. An R_{ST} value of 0 indicates no separation; $0 < R_{ST} < 0.05$ indicates negligible differentiation; $0.05 \leq R_{ST} < 0.25$ indicates moderate differentiation; $0.25 \leq R_{ST} < 1$ indicates high differentiation; and $R_{ST} = 1$ indicates complete differentiation.

	Sample population (VCG 4A)			
Sample population (VCG 4B)	**Infected seed tubers**	**Infested seed surface soil**	**Columbia Basin field soils**	**Potatoes**
Infected seed tubers[a]	1.00000	0.82090	0.78454	0.99648
Infested seed surface soil[b]	1.00000	0.64444	0.54571	0.99043
Columbia Basin field soils[c]	1.00000	0.81028	0.75368	0.99589
Potato from various states[d]	0.89969	0.66116	0.62440	0.73801

[a] Isolates from infected seed tubers were collected from seed lots intended for Columbia Basin production fields between 2007 and 2009.
[b] Isolates from infested soil on the surface of seed tubers were obtained from seed lots intended for Columbia Basin production fields in 2009.
[c] Isolates from Columbia Basin field soils were collected in 1998 from soils in OR and WA associated with potato production.
[d] The potato sample group consisted of isolates collected from infected potato and seed potato in various states (ID, MT, ND, NE, OR, SD, WA, WY) during the mid-1980's and 1990's.

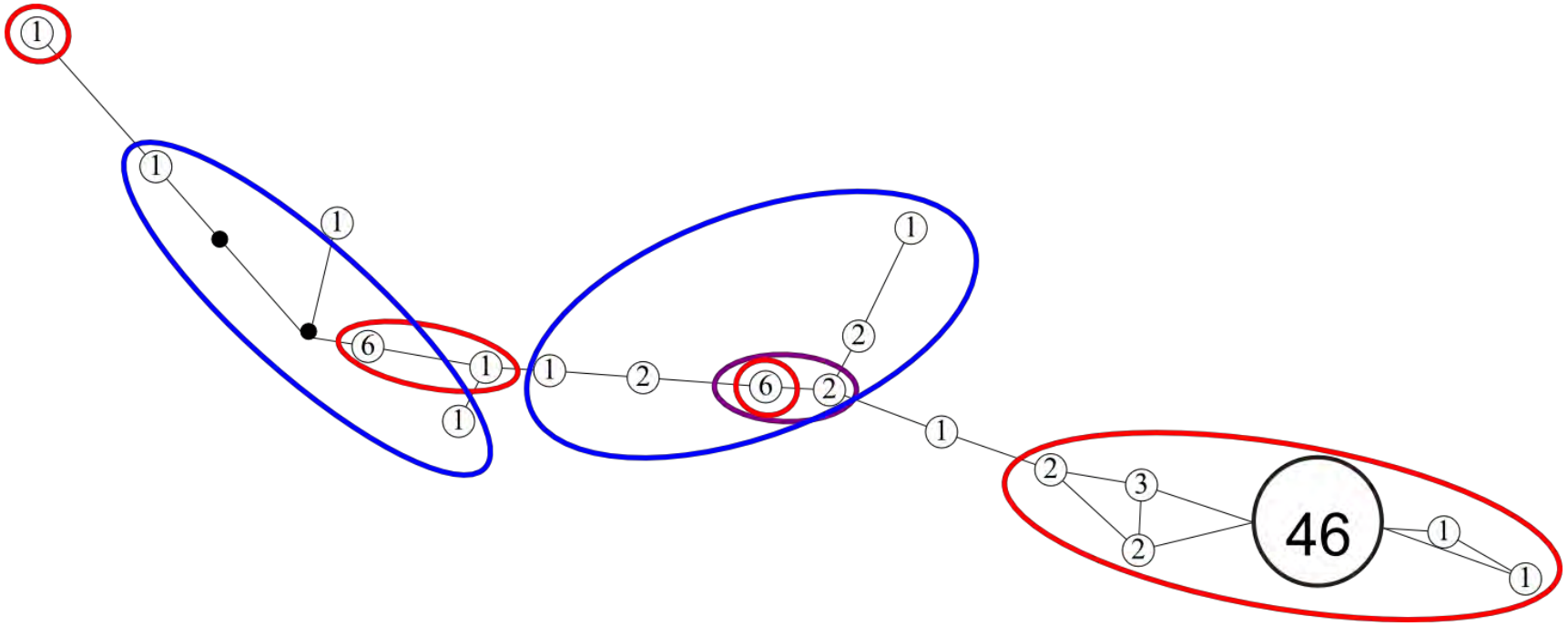


Fig. 1. Minimum spanning network showing the relationships between microsatellite haplotypes of *V. dahliae* collected from infected seed tubers, infested soil scraped from seed tubers, Columbia Basin (OR,WA) field soils, and infected potato plants and seed from various states (ID, MT, ND, NE, OR, SD, WA, WY). Numbers within circles indicate the number of isolates sampled per haplotype. Colored circles indicate the vegetative compatibility groups (VCGs) of haplotypes (red: VCG 4A; blue: VCG 4B; purple: VCG 4A/B; no circle: not defined)

Molecular Strategies to Control the Plant-Parasitic Nematodes *Meloidogyne chitwoodi* and *Pratylenchus penetrans*

Axel A. Elling

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

Introduction

Root-knot (*Meloidogyne* spp.) and root-lesion nematodes (*Pratylenchus* spp.) are biotrophic endoparasites that invade roots and tubers of host plants. They parasitize a wide variety of plant species and cause significant yield losses worldwide (Castillo and Vovlas 2007, Perry et al. 2009). In the Pacific Northwest, *M. chitwoodi* and *P. penetrans* are serious pathogens in potato. *M. chitwoodi* generally does not lead to dramatic quantitative yield losses in potato, but it causes quality defects on the tuber surface that can render entire shipments unmarketable. This species is a quarantine pathogen and hinders trade with key export markets. *P. penetrans* is a widespread pathogen in potatoes east of the Rocky Mountains, where it can lead to dramatic yield losses. *P. penetrans* is an emerging problem for potato production in the Pacific Northwest. Recently, this nematode has been found in potato fields in the Columbia Basin, where it caused yield declines of 4 tons/acre (Ingham et al. 2005). *P. penetrans* is part of the potato early dying disease complex, in which it interacts with the fungal pathogen *Verticillium dahliae* (Rowe and Powelson 2002). It is likely that *P. penetrans* will continue to spread in potato producing regions in the Pacific Northwest, which might lead to a significant increase in production costs. Both *M. chitwoodi* and *P. penetrans* have wide host ranges and are difficult to control with crop rotation. At present, there are no potato cultivars that are resistant to these nematodes. Current control strategies rely on synthetic nematicides, but increasing limitations of chemical nematode management require the development of new control tactics.

Effector Genes as Pathogen Tools

Whereas *Meloidogyne* spp. are sedentary and induce the formation of feeding sites made up of giant-cells, *Pratylenchus* spp. are migratory parasites that remain mobile upon host invasion and feed by sequential destruction of plant cells. Both nematode genera have evolved intricate molecular interactions with their host plants to overcome defense responses and to establish themselves. At the core of these interactions are nematode effector genes that encode secretions. Effector genes are active in the nematode's esophageal gland cells from where their products are released into host tissue during the infection process. Previous studies reported on the isolation of about 50 effector genes in *M. incognita* (Huang et al. 2003). To date, only very few putative *Pratylenchus* effector genes have been identified (Uehara et al. 2001, Haegeman 2011). Previous studies have demonstrated that some *Meloidogyne* effector genes aid in plant cell wall degradation or modify host cell physiology, but the function of most effector genes is unknown. It is critically important to identify effector genes in *M. chitwoodi* and in *P. penetrans* and to characterize the functions of these genes because this will enable us to devise new control strategies. Effector gene products represent the molecular interface between the nematode and its host, which makes them ideal control targets.

We are pursuing multiple strategies to identify effector genes in *M. chitwoodi* and *P. penetrans*. Previous work has led to the isolation of about 50 effector genes in *M. incognita*,

which is closely related to *M. chitwoodi*. We exploit sequence similarities between these two species to amplify homologous effector genes in *M. chitwoodi* by PCR. In addition, we are mining increasing amounts of genome data for *Meloidogyne* spp. to find effector genes. To clone effector genes in *P. penetrans*, we collect the esophageal gland regions of the nematode and sequence purified cDNA.

Effector Genes as Control Targets

Effector genes enable plant-parasitic nematodes to live a parasitic lifestyle. Their products most likely interact with host plant proteins to modulate host cell physiology. Huang et al. (2006) showed that plants that produce double-stranded (ds) RNA complementary to a *Meloidogyne* effector gene can induce RNA interference (RNAi) in the nematode and are capable of reducing reproduction of *M. incognita*, *M. arenaria*, *M. hapla* and *M. javanica* by 63-90%. Our studies show that a similar level of resistance can be achieved against *M. chitwoodi* (P. Dinh and A. Elling, unpublished). RNAi can be used as a new control strategy in its own right by generating plants that produce dsRNA complementary to nematode effector genes (Fig. 1).

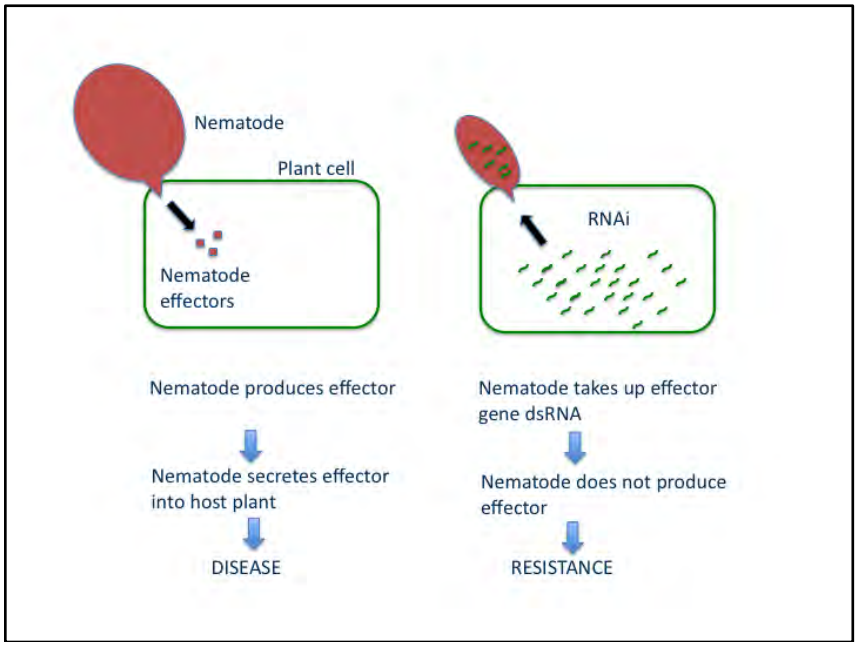


Fig. 1. *Meloidogyne* spp. secrete effector gene products into plant host cells during the infection process. Generating dsRNA complementary to *Meloidogyne* effector genes in plants leads to RNAi-induced deactivation of the respective effector gene in the nematode, thereby conferring resistance.

In addition, RNAi is a powerful tool to identify those effector genes that are indispensable for a successful infection process. If a crucial effector gene is deactivated, a reduced nematode reproduction level can be expected.

Effector gene products most likely interfere with host cell physiology by interacting with host plant proteins. We are using yeast two-hybrid assays to identify potato proteins that interact with *M. chitwoodi* effector gene products and will eventually conduct similar assays for *P. penetrans*. This is important because it will enable us to find and manipulate potato genes that are targets of nematode infection. Improving these genes through breeding could lead to new forms of resistance against *M. chitwoodi* and *P. penetrans* in potato.

Conclusions

M. chitwoodi and *P. penetrans* are serious threats to a sustainable potato production in the Pacific Northwest. Chemical nematode control adds substantially to overall production costs and will become increasingly challenging in the face of new regulations. Identifying and disabling effector genes in *M. chitwoodi* and *P. penetrans* and characterizing the function of these genes during the infection process will enable us to develop new management options for nematode pathogens in potato as part of an integrated pest management program.

Acknowledgements

We gratefully acknowledge financial support from the Washington State Potato Commission and Washington State University.

References

Castillo, P. and Vovlas, N. 2007. *Pratylenchus* (Nematoda: Pratylenchidae): Diagnosis, biology, pathogenicity and management. Nematology Monographs and Perspectives vol. 6. Brill, Leiden, The Netherlands.

Haegeman, A., Joseph, S., and Gheysen, G. 2011. Analysis of the transcriptome of the root-lesion nematode *Pratylenchus coffeae* generated by 454 sequencing technology. Mol. Biochem. Parasitol., in press.

Huang, G., Allen, R., Davis, E.L., Baum, T.J., and Hussey, R.S. 2006. Engineering broad root-knot resistance in transgenic plants by RNAi silencing of a conserved and essential root-knot nematode parasitism gene. Proc. Natl. Acad. Sci. USA 103:14302-14306.

Huang, G., Gao, B., Maier, T., Allen, R., Davis, E.L., Baum, T.J., and Hussey, R.S. 2003. A profile of putative parasitism genes expressed in the esophageal gland cells of the root-knot nematode *Meloidogyne incognita*. Mol. Plant-Microbe Interact. 16:376-381.

Ingham, R.E., Hamm, P.B., Baune, M., David, N.L., and Wade, N.M. 2007. Control of *Meloidogyne chitwoodi* in potato with shank-injected metam sodium and other nematicides. J. Nematol. 39:161-168.

Ingham, R.E., Hamm, P.B., Riga, E., and Merrifield, K.J. 2005. First report of stunting and root rot of potato associated with *Pratylenchus penetrans* in the Columbia Basin of Washington. Plant Dis. 89:207.

Perry, R.N., Moens, M., and Starr, J.L. (eds.) 2009. Root-knot nematodes. CABI, Wallingford, UK.

Rowe, R.C. and Powelson, M.L. 2002. Potato early dying: management challenges in a changing production environment. Plant Dis. 86:1184-1193.

Uehara, T., Kushida, A., and Momota, Y. 2001. PCR-based cloning of two beta-1,4-endoglucanases from the root-lesion nematode *Pratylenchus penetrans*. Nematology 3:335-341.

Foliage and Tuber Symptoms Caused by Current Season Infection by Potato Virus Y Strains in Different Potato Cultivars

Philip B. Hamm[1], Jim Crosslin[2], Jonathan Whitworth[3], and Jordan Eggers[1]

[1]Oregon State University, Hermiston Agricultural Research & Extension Center, Hermiston OR; [2]Jim Crosslin, USDA ARS Prosser WA; [3]Jonathan Whitworth, USDA ARS Aberdeen ID

Introduction

Potato Virus Y (PVY) continues to be a serious disease problem during potato production. Initially causing only yield reduction, new strains have been identified that also cause external and internal defects in tubers. These quality issues can be substantial. Researchers have seen a range of symptoms (both on foliage and in and on tubers) being produced by the different strains in different cultivars. However, documenting the symptom variation is very difficult in the field due to natural spread of the virus by aphids. Only growth chamber and greenhouse tests have successfully helped begin to document these differences. Still, greenhouse and growth chamber tests likely do not fully replicate environmental conditions potato plants experience when planted in soil in a field situation.

Field trials were attempted during the early 2000's to determine yield and quality losses due to these PVY strains. In these trials different cultivars were exposed to different PVY strains but because the different PVY strains were also spread naturally throughout the trial by local populations of aphids, mixed infections resulted. Attempts to control the aphids, by both chemical means and by planting trap crops around the plot were also unsuccessful and did not allow the collection of useful data. The building of a large screen house at the Hermiston Agricultural Research and Extension Center (HAREC) early in 2008 has allowed the study of these strains in different cultivars without virus cross contamination.

The objectives of this study were: 1) Determine the foliar and tuber symptoms produced and yield loss by cultivar when 8 cultivars are individually infected with 6 isolates of PVY (two each of PVY^{O}, PVY^{NTN}, and $PVY^{N:O}$) and 2) Determine the overall susceptibility of the 8 potato cultivars to infection by the different PVY strains.

Methods

The following PVY strains/isolates were used both years; PVY^{O} (CO35 & T1), PVY^{NTN} (T3V2 & OR0363), and $PVY^{N:O}$ (AL1 & OR2). Eight cultivars were planted; Alturas, Russet Burbank, Russet Norkotah, Premier Russet, Ranger Russet, Yukon Gem, Yukon Gold, and Blazer Russet. Yukon Gem and Premier Russet were selected due to their reported resistance to PVY^{O}. Alturas was included because of internal tuber symptoms seen previously were thought to be due to $PVY^{N:O}$. Data on symptoms, yield, and quality were obtained.

Seven blocks of potatoes were planted in the screen house during 2008 and 2009. In each block 10 nuclear seed pieces (free of virus) of each of the 8 potato cultivars were planted in 2 rows (5 seed pieces/row, 12 inches apart) in the spring of both years. When plants are approximately 8-10 inches in height, the 80 plants in each block (except the control block), were inoculated with one of the 6 PVY strains. Inoculation consisted of spraying each of the plants with a mixture of virus in a buffer solution containing Carborundum using a hand held paint applicator with 30 lbs psi. The virus inoculum was produced in tobacco plants. One week later the inoculation

procedure was repeated. The control or non-infected block was sprayed with water containing Carborundum.

Four weeks after the second inoculation all plants were tested by ELISA to confirm infection. Selected plants within each block were further tested by RT-PCR to confirm the presence of the correct virus strain. ELISA testing was done two additional times, at approximately 1 month intervals, from plants previously testing negative. Foliage symptoms were recorded at least three times and photos taken to document symptoms produced by each virus strain on each cultivar.

The exterior of each block was fenced to prevent touching of plants between blocks (this prevented mechanical spread of the virus between blocks) and each cultivar within each block was fenced to help keep plants erect and allow for easier recording of symptoms. Normal fertility and watering was done typical of potato production in the region. Weeding was by hand and insect control was aggressively maintained to ensure the enclosure was insect-free. Plants were killed down in late August/mid September each year. Individual hills of all plants were harvested, yield determined, and tubers were individually observed for symptoms. Yield for each variety was determined based on when and if plants were infected.

Results

Since data between each year was similar, only foliar symptoms from 2009 are provided. Table 1 describes foliar symptoms produced by each virus strain in each of the cultivars. The different strains produced different foliar symptoms and similar strains of each virus did not consistently cause the same foliar symptoms in the same cultivar (See Photo Plate 1).

Internal tuber symptoms were seen primarily in response to infection by $PVY^{N:O}$ in Alturas, Yukon Gold and Ranger (Table 2 &3, See Photo Plate 2). The two isolates of PVY^{NTN} produced few tuber symptoms in the cultivars tested. Similar to what resulted from foliage observations, isolates of the same PVY strain did not produce the same tuber symptoms in the same cultivar (Table 2). One isolate of PVY^{O} (T1) produced considerable symptoms in tubers while the other (C035) cause very little.

Overall infection by the different PVY isolates in the different cultivars appeared to be different over the two years of testing (Figure 1). While all potato cultivars were exposed to very high levels of virus by mechanical inoculation, Premier and Yukon Gem had less infection (they are reported to be highly resistant and resistant to PVY^{O}, respectively) as did most of the other cultivars compared to Russet Norkotah that had 100 and 95% infection in 2008 and 2009 respectively. Overall, yield was impacted by PVY infection in each cultivar except Russet Norkotah (Figure 2). Mixed yield results due to infection were seen in Premier and Blazer over the two years of the study. Virus strains and isolates appeared to differ in their ability to infect potatoes (Figure 3). Highest infection overall in cultivars occurred by isolate OR2 (an $^{N:O}$ strain) while CO35, T1, and T3V2 had the lowest overall infection percentage. The overall rate of infection was less in the PVY^{O} strains primarily due to the use of two potato cultivars that are reported to be resistant (Yukon Gem and Premier). When compared by virus, all isolates negatively impacted yield (Figure 4).

Two cultivars (Russet Burbank and Yukon Gem) were selected in this report to show the kinds of infection and yield data obtained for each potato cultivar used during this trial. Russet Burbank infection neared 100% by all the PVY isolates used except T3V2 (Figure 5). Yield in Russet Burbank was nearly always substantially reduced, regardless of PVY isolate or strain

(Figure 6), oftentimes by 50% or more. Yukon Gem is reported to be resistant to PVY^{O}. Our data confirms that information but this same cultivar is readily infected by $PVY^{N:O}$ but not PVY^{NTN} strains, at least by the PVY strains tested during this work (Figure 7). There was no yield loss in Yukon Gem due to one isolate of PVY^{O} or PVY^{NTN} because none of the plants became infected (Figure 8). Compared to controls, yield loss was substantial in infected plants compared to healthy controls. Yukon Gem has significant tuber symptoms due to $PVY^{N:O}$ infections (Table 2).

Discussion

These trials provided a means to determine impacts of three PVY strains in 8 potato cultivars, in an environment that mimicked field conditions and provided a better understanding of the differences in symptoms produced by each PVY strain in each cultivar. From this work it was learned that PVY may or may not have caused similar foliar or tuber symptoms in each cultivar. In addition, each PVY strain did not always cause the same foliar or tuber symptom in the same cultivar. Therefore symptoms are not a reliable way to distinguish the strains (^{O}, $^{N:O}$,and ^{NTN}) or isolates of the same strain. Therefore the use of symptoms may not be readily used to identify PVY strain and that further testing using ELISA and/or PCR is necessary.

Data gathered during this trial also confirmed that PVY, regardless of strain, can impact yield. Some cultivars seem to be less impacted by specific PVY strains then others. Ability of some of the PVY strains used in this trial to infect plants also appeared to be different.

The risk of reduced yields by PVY^{O} has been clearly indentified in past studies, primarily from seedborne infection. Yield loss from current season infection is not as well understood. The result of current season infection was identified during this work, not only related to yield loss but the identification of foliar symptoms by strains other than PVY^{O}. Additional loss due to tuber symptoms caused by some strains of PVY was also identified. Tuber symptoms were not limited to PVY^{NTN} or $^{N:O}$ strains since one of the PVY^{O} isolates used in this study (T1) also produced tuber symptoms.

Table 1. Foliar symptoms (2009) in eight potato cultivars growing in a screen house following inoculation with 6 isolates and 3 strains (^{O}, $^{N:O}$, and ^{NTN}) of PVY.

Virus Treatment	Cultivar Name	Foliar Symptoms
Control	Premier	NS = no symptoms[1]
T3V2 (NTN)	Premier	Mild Yellowing
C035 (O)	Premier	NS
AL1 (N:O)	Premier	Mild yellowing, mild vein clearing
OR0363 (NTN)	Premier	Mild mosaic, leaf pebbling, shiny leaves
T1 (O)	Premier	Mild yellowing to NS
OR2 (N:O)	Premier	Mild to pronounced mosaic, vein clearing, stunted leaves, leaf pebbling
Control	Alturas	NS
T3V2 (NTN)	Alturas	Wavy leaf margins, stunted leaves, mild mosaic, pebbling, vein burning
C035 (O)	Alturas	Mild Yellowing or NS
AL1 (N:O)	Alturas	Pronounced mosaic, leaf pebbling
OR0363 (NTN)	Alturas	Pronounced mosaic, sever leaf pebbling, leaf stunting
T1 (O)	Alturas	Mild yellowing
OR2 (N:O)	Alturas	NS
Control	Yukon Gem	NS
T3V2 (NTN)	Yukon Gem	NS
C035 (O)	Yukon Gem	NS
AL1 (N:O)	Yukon Gem	Mild yellowing, vein burning
OR0363 (NTN)	Yukon Gem	Leaf Yellowing
T1 (O)	Yukon Gem	Mild mosaic
OR2 (N:O)	Yukon Gem	Leaf yellowing, mild mosaic, mild pebbling
Control	Ranger	NS
T3V2 (NTN)	Ranger	Mild Yellowing
C035 (O)	Ranger	Vein Necrosis, leaf distortion, mild mosaic, mild vein clearing
AL1 (N:O)	Ranger	Pronounced mosaic, leaf pebbling, yellowing
OR0363 (NTN)	Ranger	Pronounced mosaic, leaf pebbling
T1 (O)	Ranger	Mild mosaic, yellowing, mild leaf distortion
OR2 (N:O)	Ranger	Mild mosaic, yellowing, mild vein clearing
Control	Burbank	NS
T3V2 (NTN)	Burbank	Mild Yellowing
C035 (O)	Burbank	Leaf pebbling, pronounced mosaic
AL1 (N:O)	Burbank	Leaf yellowing (spider mite damage)
OR0363 (NTN)	Burbank	Pronounced mosaic, wavy leaves, mild pebbling
T1 (O)	Burbank	Mild yellowing
OR2 (N:O)	Burbank	leaf yellowing, mild to pronounced mosaic, leaf pebbling

[1]NS= no symptoms seen in leaves due to virus infection

Table 1 Continued.

Control	Norkotah	NS[1]
T3V2 (NTN)	Norkotah	Mild Yellowing (symptoms masked by spider mite damage)
C035 (O)	Norkotah	Mild yellowing
AL1 (N:O)	Norkotah	Mild yellowing
OR0363 (NTN)	Norkotah	Mild mosaic, mild vein clearing
T1 (O)	Norkotah	Mild yellowing (major mite damage)
OR2 (N:O)	Norkotah	NS
Control	Yukon Gold	NS
T3V2 (NTN)	Yukon Gold	Mild Yellowing
C035 (O)	Yukon Gold	Mild leaf pebbling, mild yellowing
AL1 (N:O)	Yukon Gold	Mild Yellowing
OR0363 (NTN)	Yukon Gold	Mild mosaic, mild wavy leaves
T1 (O)	Yukon Gold	severe vein burning, vein necrosis, Mild yellowing (mite damage)
OR2 (N:O)	Yukon Gold	Pronounced mosaic, leaf cupping, yellowing
Control	Blazer	NS
T3V2 (NTN)	Blazer	Mild leaf pebbling, mild yellowing, mild vein clearing, leaf distortion
C035 (O)	Blazer	Mild yellowing, mild mosaic
AL1 (N:O)	Blazer	Mild Mosaic, vein clearing
OR0363 (NTN)	Blazer	Mild mosaic, mild vein clearing
T1 (O)	Blazer	Pronounced mosaic, sever leaf pebbling, wavy leaves
OR2 (N:O)	Blazer	Mild to pronounced mosaic, mild leaf pebbling

[1]NS= no symptoms seen in leaves due to virus infection

Table 2. Tuber symptoms (2009) in eight potato cultivars growing in a screen house following inoculation with 6 isolates and 3 strains (^{O}, $^{N:O}$, and ^{NTN}) of PVY.[1]

Virus Treatment	Cultivar Name	Tuber Symptoms (# tubers)	TOTAL TUBERS
Control	Premier	NS	62
Control	Alturas	NS	104
Control	Yukon Gem	NS	103
Control	Ranger	NS	102
Control	Burbank	NS	115
Control	Norkotah	NS	45
Control	Yukon Gold	NS	54
Control	Blazer	NS	53
T3V2 (NTN)	Premier	NS	57
T3V2 (NTN)	Alturas	RL (1), MSC (2), SN (1), A	134
T3V2 (NTN)	Yukon Gem	NS	110
T3V2 (NTN)	Ranger	MSC (2), A	95
T3V2 (NTN)	Burbank	MSC (1), A	102
T3V2 (NTN)	Norkotah	NS	44
T3V2 (NTN)	Yukon Gold	MRL (1), SN (2), A	38
T3V2 (NTN)	Blazer	NS	72
C035 (O)	Premier	NS	56
C035 (O)	Alturas	RL (2), MSC (3), A	84
C035 (O)	Yukon Gem	MSC (2)	129
C035 (O)	Ranger	RL (1), MSC (1), RLSE (3), A	89
C035 (O)	Burbank	MSC (4)	109
C035 (O)	Norkotah	NS	58
C035 (O)	Yukon Gold	NS	45
C035 (O)	Blazer	NS	58
AL1 (N:O)	Premier	NS	58
AL1 (N:O)	Alturas	RL (9), MSC (28), SSC (30), SN (27), SL (1), A, I	71
AL1 (N:O)	Yukon Gem	MRL (2), MSC (7), SN (7), A, I	96
AL1 (N:O)	Ranger	RL (8), MSC (59), SNSE (2), A	92
AL1 (N:O)	Burbank	NS	106
AL1 (N:O)	Norkotah	NS	62
AL1 (N:O)	Yukon Gold	RL (24), SN (39), SNSE (27), A, I	48
AL1 (N:O)	Blazer	NS	53

[1]RL = Raised lesions; MRL = mild raised lesions; RLSE = raised lesion stem end; MSC = Mild skin cracks; SSC = Severe skin cracking; SN = sunken necrotic lesion; SL = sunken lesion; SNSE = sunken necrotic stem end; A = internal symptoms associated. Numbers in parenthesis indicate the number of tubers with that symptom. Tubers could have more than one symptom.

Table 2. Continued

OR0363 (NTN)	Premier	NS	54
OR0363 (NTN)	Alturas	SN (1), A	113
OR0363 (NTN)	Yukon Gem	SNSE (4), A	102
OR0363 (NTN)	Ranger	RL (1), MSC (1), SN (1), A	84
OR0363 (NTN)	Burbank	NS	129
OR0363 (NTN)	Norkotah	NS	67
OR0363 (NTN)	Yukon Gold	RL (45),	47
OR0363 (NTN)	Blazer	NS	60
T1 (O)	Premier	NS	49
T1 (O)	Alturas	RL (28), MSC (4), SN (1), A, I	68
T1 (O)	Yukon Gem	RL (1), A	103
T1 (O)	Ranger	RL (43), MSC (21), A	82
T1 (O)	Burbank	NS	117
T1 (O)	Norkotah	NS	65
T1 (O)	Yukon Gold	RL (23), MSC (1), SSC (3), SN (12), A	50
T1 (O)	Blazer	NS	53
OR2 (N:O)	Premier	NS	57
OR2 (N:O)	Alturas	SSC (37), I	38
OR2 (N:O)	Yukon Gem	RL (9), MSC (4), SSC (22), SN (46), I	70
OR2 (N:O)	Ranger	RL (104), MSC (62), SSC (19), SN (93), A, I	128
OR2 (N:O)	Burbank	MSC (3), SN (2)	107
OR2 (N:O)	Norkotah	MSC (6), SN (2), A	45
OR2 (N:O)	Yukon Gold	RL (40), SN (42), A, I	42
OR2 (N:O)	Blazer	MSC (2), A	85

[1]RL = Raised lesions; MRL = mild raised lesions; RLSE = raised lesion stem end; MSC = Mild skin cracks; SSC = Severe skin cracking; SN = sunken necrotic lesion; SL = sunken lesion; SNSE = sunken necrotic stem end; A = internal symptoms associated. Numbers in parenthesis indicate the number of tubers with that symptom. Tubers could have more than one symptom.

Table 3. Summary of tubers with symptoms from each cultivar when infected with PVY strains, 2009.[1]

Virus	Cultivar							
	Premier Russet	Alturas	Yukon Gem	Ranger Russet	Russet Burbank	Russet Norkotah	Yukon Gold	Blazer Russet
Control	0	0	0	0	0	0	0	0
T3V2 (NTN)	0	1	0	1	1	0	1	0
OR0363 NTN)	0	1	1	1	0	0	96	0
CO35 (O)	0	1	1	1	1	0	0	0
T1 (O)	0	41	1	50	0	0	46	0
OR2 (N:O)	0	99	66	81	3	13	100	2
AL1 (N:O)	0	42	7	64	0	0	81	0

[1]Percent tubers infected

Figure 1. Overall infection in potato cultivars when inoculated individually with 3 strains and two isolates each of PVY^{O},$^{N:O}$, and ^{NTN}.

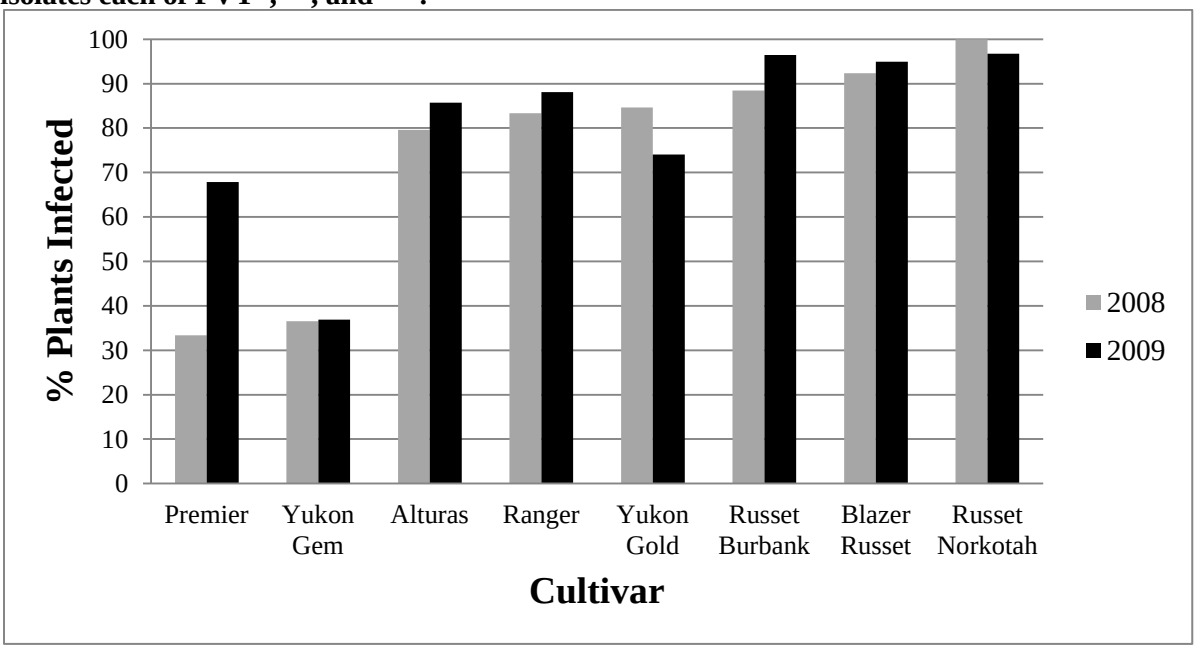


Figure 2. Overall yield of infected plants (+) by cultivar compare to healthy controls (-) inoculated with 3 strains and two isolates each of PVY^{O}, $^{N:O}$, and ^{NTN}.

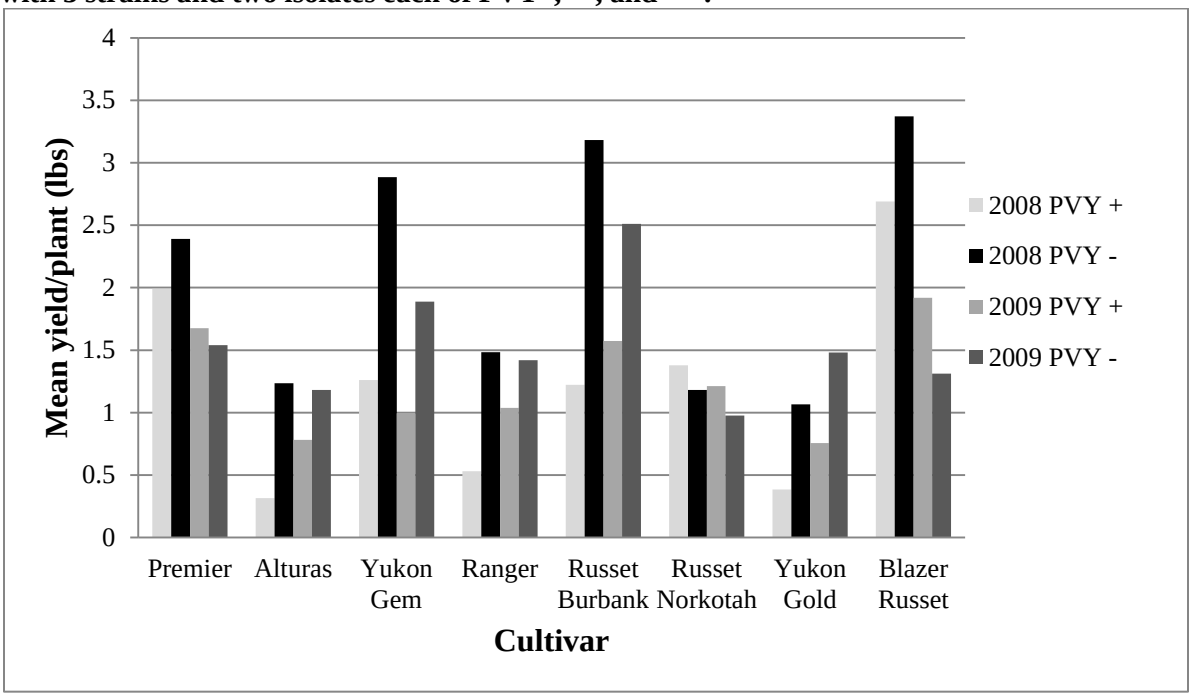


Figure 3. Overall "current season" infection by PVY strains and isolates in 8 cultivars of potato.

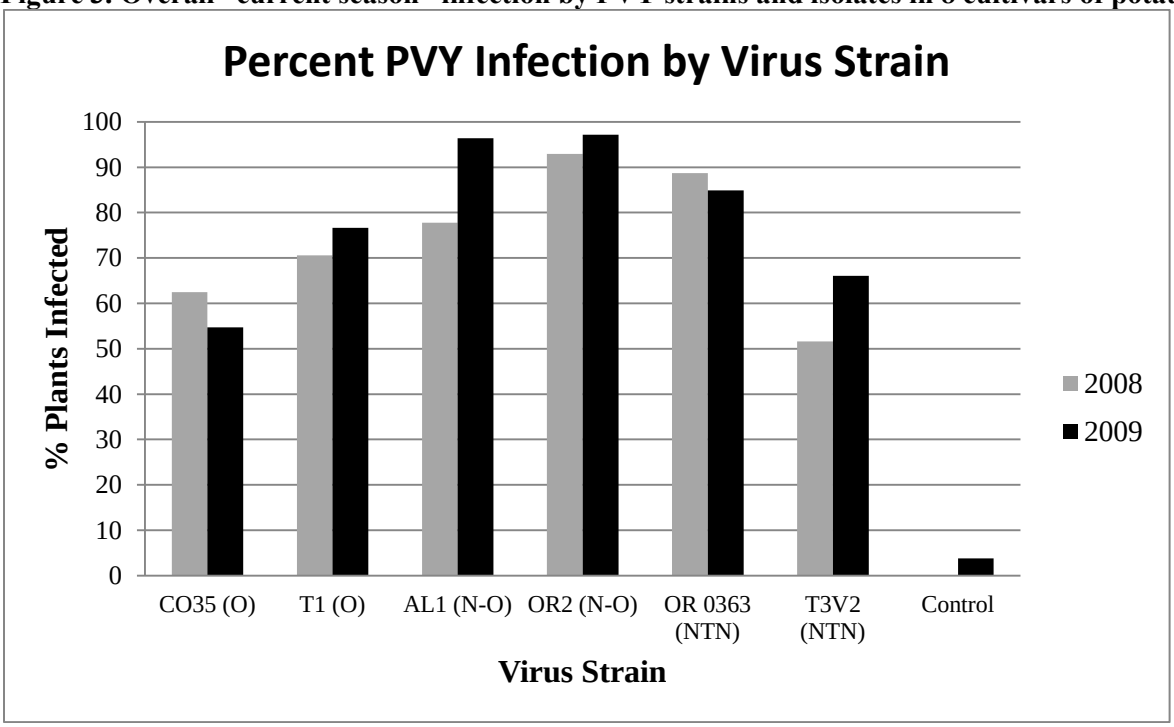


Figure 4. Overall yield from plants infected by six isolates of PVY (two each PVY^{O}, $^{N:O}$, and ^{NTN} compared to healthy plants (controls)

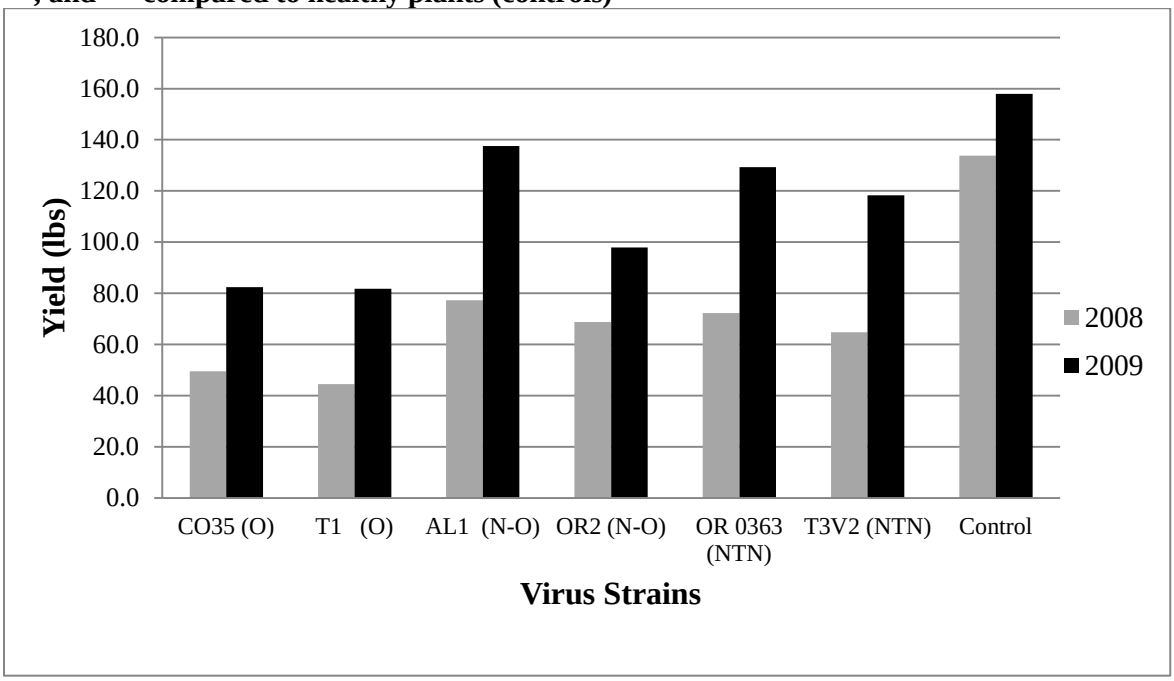


Figure 5.Infection by 6 PVY isolates and three strains in Russet Burbank.

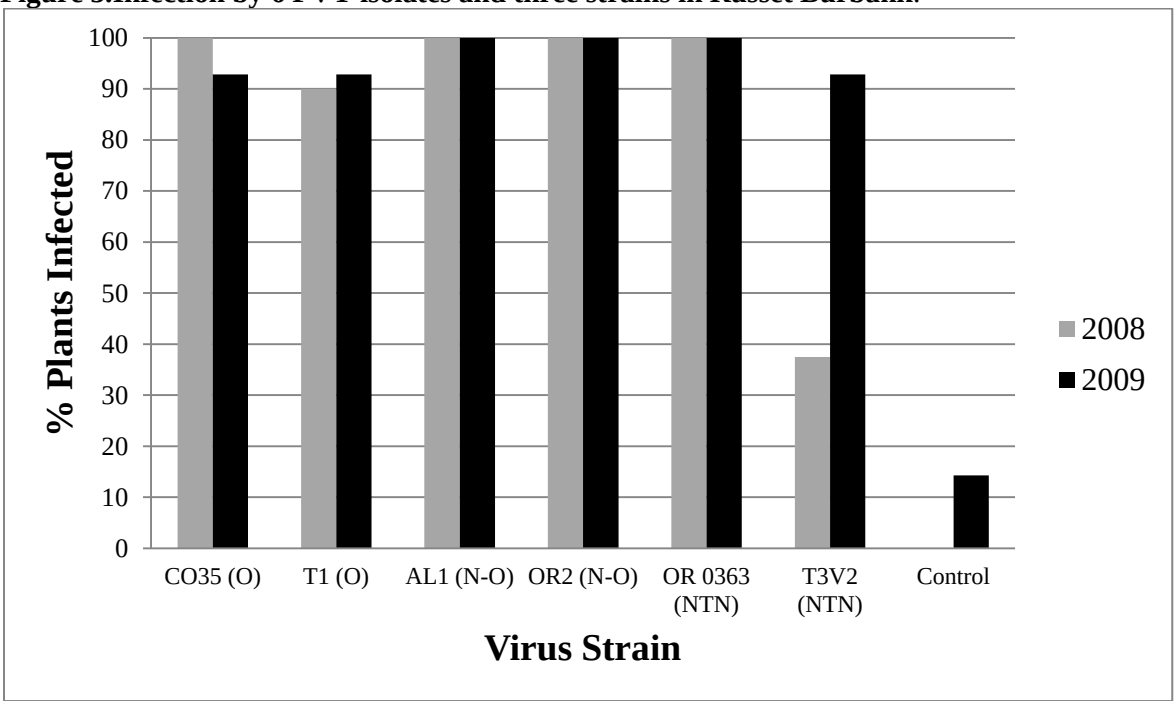


Figure 6. Yield of Russet Burbank following infection by 6 isolates (and 3 strains) of PVY.

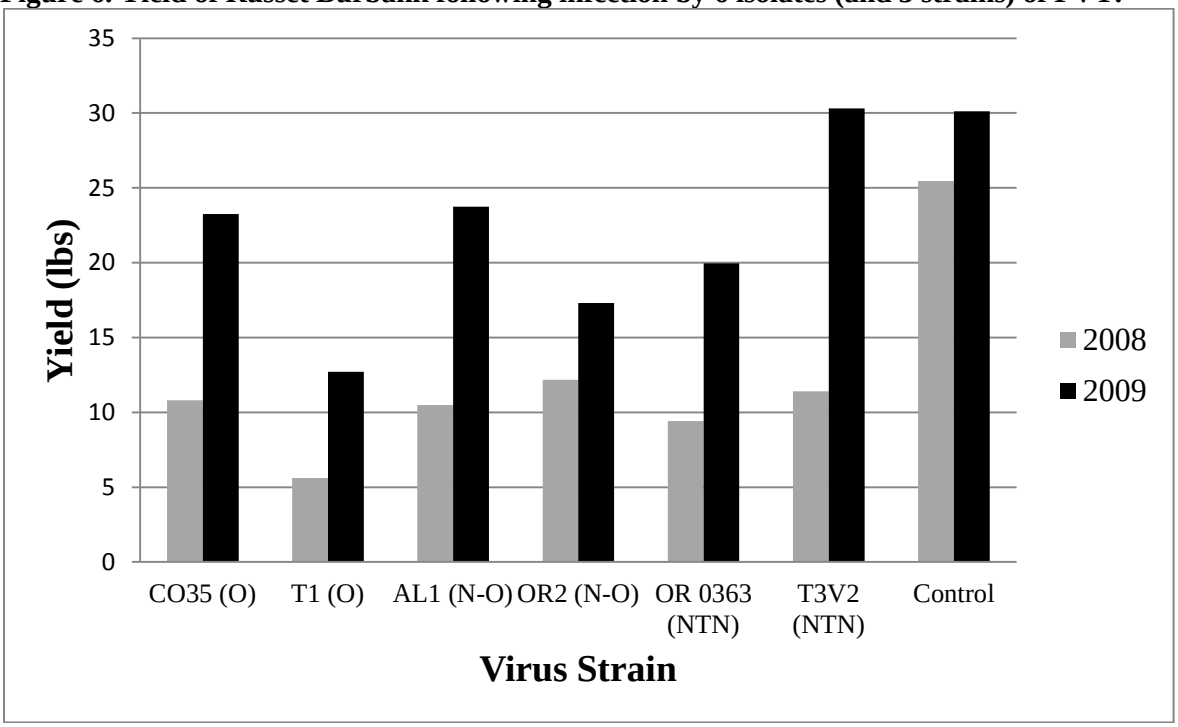


Figure 7. Infection by 6 isolates and 3 stains of PVY in Yukon Gem. No infection occurred in isolate CO35 or T3V2 either year.

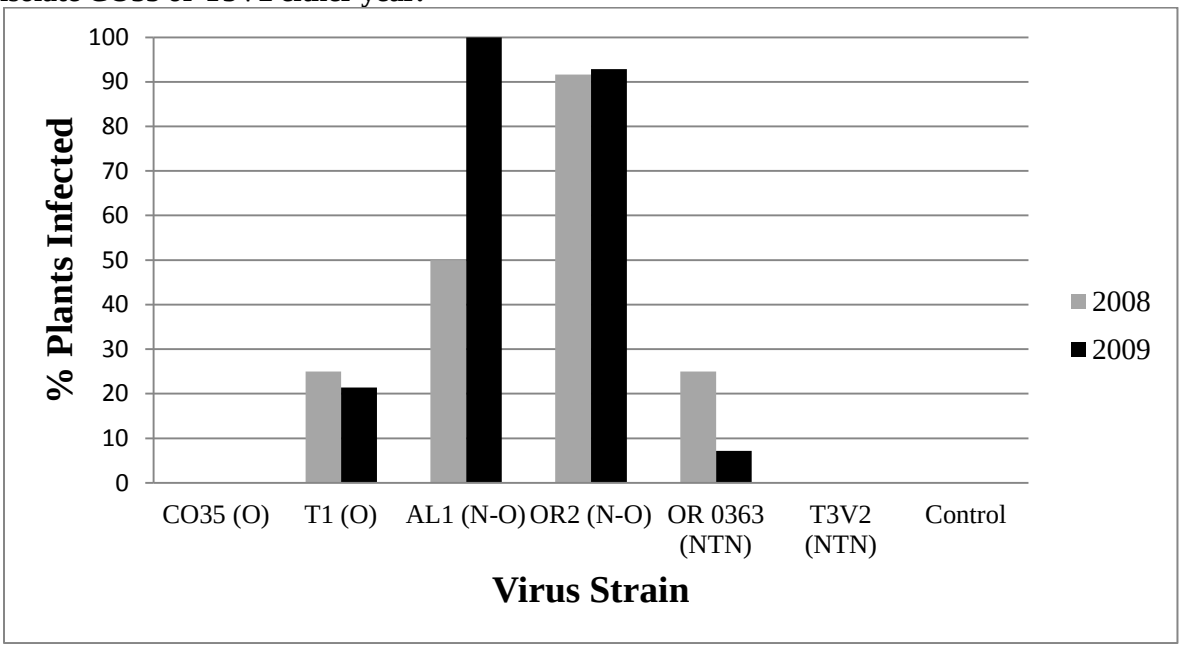


Figure 8. Yield of Yukon Gem following infection by 6 isolates (and 3 strains) of PVY compared to healthy controls. No infection occurred in isolate CO35 or T3V2 either year so no yield loss was seen.

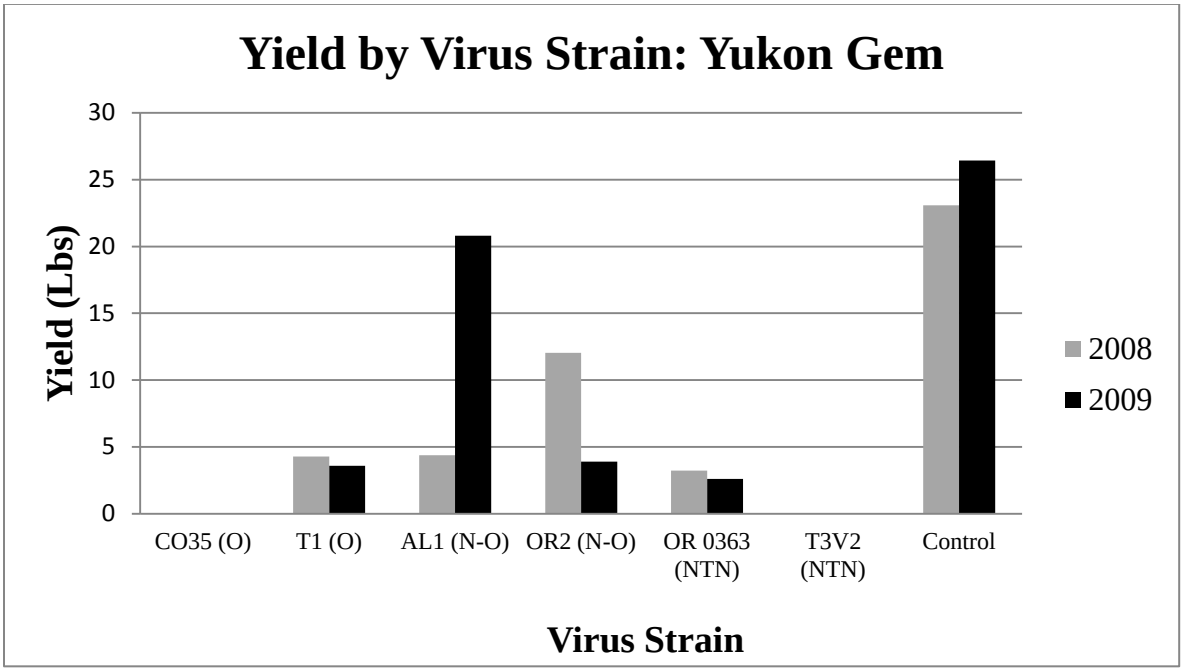


Photo Plate 1. Potato Virus Y^O (resulting from inoculations with the isolate T1) symptoms on four selected cultivars from screen house testing 2009. Photos taken on Aug 5, 2009. Notice the different symptoms produced by the same PVY^O isolate in the different cultivars. From top left clock wise: Yukon Gold (mosaic symptoms), Russet Norkotah (severe mosaic), Yukon Gem (Vein Burning), and Blazer Russet (Mosaic and "wavy leaf").

Photo Plate 2. Potato Virus $Y^{N:O}$ (resulting from inoculations with the isolate OR2) symptoms on four selected cultivars from screen house testing 2009. Notice the symptoms produced by this isolate in the different cultivars. From top left clockwise: Yukon Gold, Russet Ranger, Yukon Gem, and Alturas.

Impact of Soil Conditions on the Ability to Control *Verticillium* Wilt of Potato in the Lower Columbia Basin

Philip B. Hamm[1], Russ Ingham[2], Jordan E. Eggers[1], Donald A. Horneck[1], and Mike Madsen[3]

[1]Oregon State University, Hermiston Agricultural Research & Extension Center, Hermiston OR; [2]Oregon State University, Corvallis OR; and [3]AgriNorthwest, Paterson WA.

Introduction

In the past decade, several corporate farms in the lower Columbia Basin in both Washington and Oregon have reported decreased potato yields with each subsequent potato crop, even where metam sodium has been used. Preliminary soil sampling in Washington conducted to help determine the cause of the declining yields revealed high levels of *Verticillium dahliae* in the majority of the fields, particularly in areas with high milliequivalents of calcium. As might be expected, poor plant growth occurred where high calcium levels were found.

Research has shown no economic loss when soil-borne *V. dahliae* levels at planting are below 10 colony forming units (CFU)/gram of dry soil (number of microsclerotia), particularly for susceptible cultivars like Russet Burbank. Generally, after testing hundreds of soils from the Basin over many years, the average level of *V. dahliae* prior to soil fumigation with metam sodium was found to be approximately 20-40 CFU's/gram of dry soil or less. Following fumigation, population levels generally decrease to 0-7 CFU's/gram of dry soil. *Verticillium dahliae* levels in high calcium areas from a farm in Washington have been in the hundreds (<400) of CFUs prior to fumigation and still have substantial soil population levels following fumigation (<200). Post fumigation levels in the high calcium areas substantially exceed the 10 CFU threshold.

High calcium levels in soil are intertwined with many soil characteristics such as pH, soil texture, and calcium carbonate equivalent and soil effervescence. Many soil nutritional components are also affected by high calcium levels in the soil such as phosphorous and metal availability (Zn, Mn, Cu, Mo and Fe). Commonly, terms such as high calcium, high pH and high lime are used interchangeably, which may or may not be true depending on an individual situation.

There have been a number of reports that suggest that high levels of lime favor *Verticillium* infection and/or damage. There are at least three possible reasons as to how lime/calcium levels may influence *Verticillium* populations. One, high calcium/lime levels may have a negative impact on plant growth which may prevent the plant from being able to effectively fight the invasion of the fungus. In this situation the fungus may be able to produce higher levels of microsclerotia in the plant tissue that are then released into the soil as the organic matter breaks down. These microsclerotia can persist in the soil until the next potato crop. Poor plant growth may or may not be directly related to the elevated calcium or *Verticillium* populations, and secondary issues such as water holding capacity or metal availability may also be important. A second possibility of influence is that high levels of lime actually directly encourage development of the disease (invasion of plant tissue, production of microsclerotia, fungus growth in the plant, etc), regardless of the host plant and its health. Lastly, high pH levels may be

impacting fumigant efficacy either by deactivating the fumigant and/or influencing the penetration of the fumigant in the soil resulting in more microsclerotia surviving fumigation. Sclerotia in these areas could accumulate over time as more *Verticillium* would escape fumigation, and therefore population levels would increase to the very high numbers that have been recently tabulated.

Fumigant penetration is related to water infiltration. Soil pH can be an indicator of poor infiltration, as can several other soil properties such as bulk density, texture, organic matter content and others. Sodium (a component of metam sodium but not metam potassium) is a major contributor to poor infiltration because of its negative impact on soil structure. Water infiltration impacts may be a large contributor to poor fumigation, particularly in fields where areas of sandy and high calcareous areas co-exist. When applying water carrying metam sodium in sandy soils one might apply a different rate (less water) than to a field that has heavy soil, to get the same level of penetration. Fields that have multiple soil types may make determining the correct amount of water to use very difficult to obtain the best possible fumigation effects. In addition, infiltration issues between soil types may actually cause water carrying fumigant to "run off" and not provide an adequate fumigation.

Nematode populations may also be impacted differentially in these areas due to efficacy of the fumigant. Given the presence of *Pratylenchus penetrans* in some fields in the Columbia Basin and the direct relationship of increase levels of this nematode with increased severity of *Verticillium* infection and subsequent symptoms of early die, following the population of the nematodes is also very important. Furthermore, if calcareous soils decrease the efficacy of fumigants, nematodes, including Columbia root-knot nematode may be more difficult to control.

The specific objectives of this work were: 1) Determine if metam sodium use is as efficacious in controlling/reducing *V. dahliae* microsclerotia and nematodes in areas with high soil calcium versus areas with low soil calcium; 2) Determine if the method of application of metam sodium and the use of other fumigation products impact efficacy to reduce *Verticillium* and nematode levels in high calcium areas; 3) Determine if there is a correlation between soil properties, *V. dahliae* microsclerotia and nematode levels with potato yield; 4) Determine if microsclerotia of *V. dahliae* and nematodes are higher following a potato crop between areas of low and high soil calcium; and 5) Determine if plant nutrient status as determined by petiole analysis (first year) in mid-season or/and whole plant samples (second year) help determine whether *V. dahliae* infection is the primary problem or secondary cause of yield reductions that are occurring where high calcium soils are found.

Methods

This study was conducted over the 2009 and 2010 growing seasons. A total of six potato fields, three fields each year, were used. Selected fields had areas of both high and low calcareous soils. In the high and low calcareous soil areas of each field, 24 by 60 foot plots representing one replicate of each fumigation treatment were randomly organized within a single block. There were six fumigation treatments in 2009 (Table 1a) and eight in 2010 (Table 1b), untreated control included. Therefore in 2009, there were two main plots in each field, one in high calcareous soil the other in low calcareous soil. Within each main plot there were randomized

subplots consisting of the different fumigation treatments. Prior to treatment application, ten soil cores were collected from each treatment plot at both the 0-12 and 12-24 inch depths and bulked into one soil sample for each depth. These pre-fumigation soils were collect on October 13, 2008 for the 2009 study and October 20, 2009 for the 2010 study. Soil samples were sieved and mix thoroughly before being assayed for *Verticillium dahliae*, *Fusarium* spp., *Pythium* spp., and pathogenic and free living nematodes levels using standard laboratory practices. Soils were also analyzed for pH, OM, P, K, S, B, Zn, Mn, Cu, Fe, NO_3, NH_4, Ca, Mg, Na as well as effervescence, calcium carbonate equivalent, and texture. Fumigation was performed in the fall of 2008 for the 2009 growing season and the fall of 2009 for the 2010 growing season. Plots were resampled at both depths the following spring both years (February 16, 2009 and March 30, 2010) to determine post-fumigation soil levels of *V. dahliae*, Fusarium spp., Pythium spp., pathogenic and free living nematodes, as well as soil nutrients and characteristics. A third soil sample was collected from each sub-plot at both depths just prior to harvest of each year and assayed for *V. dahliae*, *Fusarium* spp., *Pythium* spp., and pathogenic and free living nematodes.

During the second week of August in 2009 and 2010, five potato vines were destructively sampled from each fumigation sub-plot for quantification of in-plant *V. dahliae* levels. Plant sap was extracted from surface disinfected sections of vines four inches above and below the soil line. Equal amounts of sap from the five vines were bulked, diluted in sterile water, and plated onto *V. dahliae* selective media. Total number of colonies was tabulated and the colony forming units (CFU) per milliliter of vine sap was calculated. In 2010, the causal agent of black dot (*Colletotrichum coccodes*) was quantified in addition to *V. dahliae* using the same technique.

In both years of the study, yield was determined by hand harvesting tubers from two 10-foot long hills located in the center of each treatment plot. Harvest occurred on September 22, 2009 and October 23, 2010. Tubers were sorted and weighed at the OSU Hermiston Agricultural Research and Extension Center sorting facility.

In most instances, data was analyzed three ways: comparing the average of the high and low calcareous plots, regardless of fumigation treatment; comparing the averages of the fumigation treatments regardless of soil calcium levels; and comparing the averages of each fumigation/soil calcium level combination as if each combination was a single treatment. Years were analyzed separately.

Results

Year 1 (Beginning Fall 2008)

Soil borne fungi

Overall, numbers of *Fusarium* and *Pythium* spp. did not differ between high and low calcareous areas prior to fumigation while significantly higher numbers of *Verticillium dahliae* did occur (Table 1a) at the 0-12 inch soil depth. *Fusarium* levels were significantly impacted following some fumigation treatments. No differences among treatments were evident between 13-24 inches for any fungi (Table 2a). None of the fumigation treatments significantly controlled soil borne fungi better than another, regardless of soil calcium levels, at either soil sampling depth. Numbers of *Verticillium dahliae* propagules did not increase to higher levels in the high calcareous areas at season's end compared to low calcareous levels, though the population of this fungus was still numerically higher at that sampling time. Sampling in season of sap from plant

stems from each treatment and replication found varying levels of *Verticillium dahliae* infection (Table 3a).

Yield

Total yield was always numerically lower in the high calcareous areas compared to the low calcareous areas (Table 4a), regardless of treatment. None of the fumigation treatments significantly increased yields. Total tuber count was significantly lower in the high calcareous areas.

Nematodes

Before treatment, populations of root-lesion nematodes (*Pratylenchus neglectus*) were significantly higher at both depths in areas with high calcareous soil in all three fields individually (data not shown) as well as overall (Table 5a and 6a). Effect of soil was also significant for both depths on the post fumigation sample date and for the 0-12 in. depth at harvest. Root-lesion nematode densities were not different between plots designated for the different fumigation treatments before treatment. Post fumigation populations of root-lesion nematodes from the top foot of low calcareous soils were 40%, 89%, 95%, 98% and 100% less than nontreated plots in WRMS, SHMS, WRMS + SHMS, Telone C17, and Telone + WRMS treatments, respectively. However, only the last three treatments listed were significantly different (Table 5a). There was a trend for lower populations with treatments in high calcareous soils but this was not significant. Populations in the Telone C17 treatment were significantly higher in high calcareous soil than in low calcareous soil. Root-lesion nematode densities were low in the 12-24 in. depth and there was no effect of treatment (Table 6a). By harvest, populations in the soil had declined to low levels and no effect of treatment was evident.

Before treatment, populations of free-living nematodes were not different between low and high calcareous soils at either depth, and plots designated for the different fumigation treatments were not different (Tables 7a and 8a). Effect of fumigation was significant in both soil types. In areas of low calcareous soil, densities at 0-12 in. were significantly less in the WRMS, Telone C17, and Telone + WRMS treatments. In high calcareous soils, SHMS, WRMS + SHMS, and Telone + WRMS treatments had fewer free-living nematodes than nontreated plots. After treatment, populations in the WRMS + SHMS treatments were lower in high calcareous soil than in low calcareous soil and those in the Telone C17 treatment were higher in high calcareous soil (Table 6a). There was no effect of fumigation in the 12-24 in. depth. At harvest the average number of free-living nematodes in the 12-24 in. depth was significantly higher in the areas with low calcareous soil. No effect of treatment remained in either type of soil.

Nutritional

Pre and post fumigation soil samples were analyzed for a multitude of fertility and soil characteristics. This data is shown in three tables. Table 8 presents a comparison of the three fields. Largely, there is little difference observed between fields. Table 9 compares the high soil calcium areas to the low soil calcium areas across all three fields. There were few significant differences measured, some are unexplainable and need more examination. For example the high calcium areas had 22.4 meq/100g while the low had 8.1 meq/100g, yet these values were not significantly different. These differing levels were the reason why the locations were selected for the study, so the difference is not surprising; however the lack of significance was unexpected.

The lack of a pH response to calcium could be linked to elemental sulfur applications that occurred on the high pH areas of the field. The difference in sodium confirms selection by calcium level.

Table 10 shows treatment effect on soil characteristics. A number of interesting treatment effects were noted. Differences in ammonia (NH_4) levels in the pre plant samples are a good indication of fumigant biological impact. The higher the ammonia value and the lower the nitrate (NO3) amount measured is an indication of the fumigation effect on nitrifying microorganisms. More ammonia likely means more soil borne organisms killed by the fumigation treatment. The high ammonia level in treatment F shows up as a significant difference in cation exchange capacity (CEC) which is not realistic. In addition, there are interesting differences between pre plant and post plant samples by fumigation treatment. Soluble salts (SS) were not different pre-plant yet post-plant sampling indicated levels there are differences between 0.35 mmhos/cm to 0.57 mmhos/cm. A similar situation exists for soil pH. The differences seen in post potato crop sampling compared to pre-potato crop are most likely due to the soil not having been warm enough to create many of these differences during the winter. In other words, the full impact of fumigation was not measured until after the growing season.

Year 2 (Beginning Fall of 2009)

Soil Borne Fungi

Total colony forming units of *Pythium*, *Fusarium*, and *Verticillium dahliae* did not differ significantly between fumigation treatment plots or high and low calcareous areas prior to fumigation at both the 0-12 inch (Table 1b) and 13-24 inch (Table 2b) soil depths. As would be expected, post fumigation fungi counts were lower than pre-fumigation counts for the majority of the treatments at both soil depths. At the 0-12 inch soil depth, the combined metam sodium shanked and water run treatment was the most effective in controlling *Pythium* and *Fusarium* spp. Shanked metam sodium and shanked Telone C-17 were the least effective in controlling *Pythium* and *Fusarium* spp. at that depth. No one treatment was more effective than another in controlling *Verticillium dahliae* at either soil depth. When fumigated high and low calcareous soils were compared, post fumigation *V. dahliae* counts were significantly lower in the low calcareous soils at both soil depths.

In Plant *V. dahliae* and *Colletotrichum coccodes*

In season sampling of plant sap showed that the *V. dahliae* CFU/mL plant sap from fumigated plots with high calcareous soils were always greater than the low calcareous plots of the corresponding treatments. This difference was significant for metam sodium water run as well as one of the shanked metam sodium treatments (Table 3b). When comparing just high calcareous soil to low calcareous soil, regardless of fumigant, the plant sap from high calcareous areas had significantly higher levels of *V. dahliae* than the low calcareous sap.

Nematodes

Nematode population densities were considerably lower in the in the fields chosen for the study in 2009-10. There were no differences in levels of root-lesion nematodes between low and high calcareous soils before fumigation at either depth. However, after fumigation, population densities were higher in high calcareous soils at both depths when averaged over all treatments (Table 5b, 6b) No fumigation treatment had any effect on root-lesion densities and there was no

effect of soil Ca on the performance of any treatment. By harvest, populations in the soil had declined to low levels and no effect of treatment or soil was evident.

After fumigation, free-living nematodes in the top foot of soil were more abundant in the high calcareous plots when averaged over all treatments (Table 7b, 8b). In low calcareous soils, post treatment population densities of free-living nematodes at 0-12 in. were significantly less in the WRMS and SHMS treatments than in the untreated plots. At 12-24 in. the WRMS and Telone plus MS treatments had fewer (P = 0.0745) free-living nematodes than the control plots. No treatments were different from the control in high calcareous soil sites. No effect of treatment or soil condition was apparent at either depth by harvest

Nutritional: Main effects (Soil pH/Ca)

Some effects of soil pH and calcium were significantly different from each other, while others were not. Soil pH had no effect on the phosphorous availability in the soil including both the bicarbonate extractable P (P) and the water extractable P (WSP) (Table 13). This is surprising because high soil pH is commonly credited as being the main cause for low soil test P. This expected low available P in the high calcium and high pH environments is often credited with early death and poor performance of potato in areas where this high pH situation exists. The difference in calcium between the low and high pH areas is not surprising as this is why these locations were chosen. The high soluble salts (SS) and extractable sulfur (S) differences were expected in the high pH areas as compared to the low pH areas as elemental sulfur was applied to all treatments in the high pH areas prior to fumigation in an attempt to combat the high calcium and elevated pH. The surprising thing is how fast the sulfur was generated since fumigation and temperature should have interfered with the soil's ability to convert elemental sulfur to sulfate (extractable S). Part of the explanation for the large difference in extractable sulfur might be a remnant of past applications. Elemental S does not react very fast in soils, so previous applications, not the application the preceding fall may have been responsible for the elevated sulfur levels observed in the high pH soils. The higher soluble salts (SS) is a result of the higher sulfur in the soil. Soluble salts measures anything that is easily extracted from the soil.

The lack of difference by soil pH in metals such as zinc, copper, manganese and iron is a little surprising. This may due to the effectiveness of the acidification treatments, as post fumigation soil pH for the acid soil fields averaged 5.9 and 6.5 for the high calcium fields. Some of the high calcium areas actually had a soil pH below 5 (Table 14), particularly after sulfuric acid application, where treatment 8 dropped to 4.4 in field three as seen in the above table. Soil pH of the three fields for the low pH areas were 5.8, 5.8 and 5.9 averaged across treatments. Soil pH for the three fields for the high pH areas were 7.4, 7,4 and 4.6 averaged across the 8 treatments. The low pH of field three for the supposed high pH main effect may suggest why some of the metals and such are not significantly different, though trends indicate a pH effect. Low calcium levels (less than 5 meq/100g) in field three also suggest that this location may not have been properly chosen. The lower pH and elevated sulfur in the high pH area does suggest that the treatments were properly applied.

Figures 1 and 2 show the effect pH has on some of the measured soil parameters. This is another way of looking at the effect of soil pH on metal availability. Water soluble P (WSP) and zinc were not affected by soil pH in Figure 1. Copper on the other hand decreases with

increasing pH. Figure 2 shows how manganese and iron are influenced by soil pH. When pH decreases, solubility in the soil increases by almost 100 fold. Extractable manganese goes from less than 5 ppm when soil pH is above 7 to over 100 ppm when soil pH drops below 5.0.

Nutritional: Treatment Effects

Treatment 8 was 40 gallons of metam sodium plus the addition of sulfuric acid. This treatment should have resulted in differences between metal content. Metals such as iron, manganese and zinc should have been higher in this treatment compared to the other treatments. This, however, was not observed. Sulfuric acid reacts in soils much more quickly than elemental sulfur. The untreated treatment (1) and the treatment with sulfuric acid (8) were different from each other with the sulfuric acid treatment being higher. Soil test levels of phosphorous for both water extractable and bicarbonate was the highest for treatment 8 compared to all other treatments. This suggests the soil acidification with sulfuric acid is having an effect.

Fumigation had a significant effect on soil test properties as shown in Table 15. However, there are no consistent trends between the different analytes tested. The previous year's data showed the more rigorous the fumigation the more ammonia that was present. Treatment 7, metam plus Telone II, was higher in ammonia than the other treatments. This was not observed in this year's sampling.

Soil pH by treatment is shown in Table 16. Metam sodium water ran (2) had the lowest soil pH following fumigation. This treatment had a lower soil pH than the sulfuric acid treatment (8). Treatment 2 and 8 had the highest ammonia and the lowest calcium levels than any of the other treatments.

Yield

There were no significant yield differences between the high and low calcareous plots of each treatment (Table 4b). When both high and low calcareous plots of each treatment were combined, metam sodium water run; metam sodium water run and shanked; Telone II with metam sodium; and the metam sodium with sulfuric acid had significantly great yields of the 4-8 oz tuber size than the control. Metam sodium water run at 40 gpa had a significantly higher total yield than the control when high and low calcareous yields were combined.

Conclusions

Levels of *V. dahliae* where nearly always numerically higher in the high calcareous areas following fumigation compared to low calcareous areas, regardless of soil depth. There were no clear differences in reduction of *V. dahliae* occurring between the different fumigation treatments. Data indicate that regardless of fumigation material, reductions in *V. dahliae* were greater in the low calcareous areas compared to high calcareous locations. While beginning levels of *V. dahliae* were usually higher in the high calcareous areas when the potato crop was planted, the changes in levels of *V. dahliae* between planting and harvest were numerically greater following the potato crop in high calcareous areas compared to low calcareous locations. Levels of *V. dahliae* in year two were always numerically higher in the potato stem tissue from high calcium areas.

There was a trend for root-lesion-nematodes to be more abundant in high calcareous soils from the top foot but not from the second foot. These results were significant on all three sample dates in year one and one sample date in year two with the other two dates numerically higher. The reason for this relationship is still not understood.

There was little indication that high calcareous soils had any influence on performance of fumigants with regard to nematode control. In year one, three of the five treatments significantly reduced population densities of root-lesion nematodes in low calcareous sites and no treatments were significantly different from untreated plots in the high calcareous sites which suggests a negative effect of soil Ca on fumigant performance. However, the lack of significance is due more to variability than to a difference in effectiveness of the treatments. When percent reduction of the populations in the two sites is compared for each individual treatment the results are similar between low and high calcareous soils. Therefore, the few differences in treatments noted between the different soils in year one are more likely the result of happenstance than to any consistent effect of high calcareous soils on fumigant performance. Similarly, there was no effect of any treatment on root-lesion nematodes in year two in either type of soil so no effect of soil condition on fumigant performance could be established.

Only year one (2009) had high enough root-lesion nematode densities to evaluate treatments. There were no significant differences between treatments in the high calcareous site but looking at percent reduction, population levels from the top foot in the high calcareous site were reduced more by WR MS than by shanked MS. However best reduction with metam sodium was in the Shanked + WR MS treatment which was similar to the Telone + WRMS treatment. Population densities in the second foot were too low to meaningfully evaluate treatments.

Further analysis is needed on how soil properties in the high calcareous and low calcareous soils impact fumigant efficacy with regard to the influence of soil nutrition, soil fungi and nematode levels on yield. The dynamics of this interaction is likely to be highly variable.

Table 1a. Year one (2009) effects of soil fumigation on soil borne fungi between 0-12 inches.

Treatment	Depth (in.)[2]	Calcium Level[3]	*Pythium* spp. (CFU/g dry soil)[1]			*Fusarium* spp. (CFU/g dry soil)[1]			*Verticillium dahliae* (CFU/g dry soil)[1]		
			Pre	Post	Harvest	Pre	Post	Harvest	Pre	Post	Harvest
Control	0-12	High	9.0 [4]	24.7 a	73.3 a	2979 a	5305	3232 a	40.7 a	43.3 a	27.3 a
Control	0-12	Low	8.7 a	14.7 a	3.7 a	5434 a	2883	3083 a	2.7 a	9.3 a	4.0 a
MS WR @ 40gpa[5]	0-12	High	11.0 a	11.3 a	15.0 a	3870 a	4703	3256 a	22.7 a	30.7 a	13.3 a
MS WR @ 40gpa	0-12	Low	23.3 a	25.7 a	63.7 a	5336 a	2094	3303 a	9.3 a	14.7 a	4.7 a
MS Shanked @ 40gpa	0-12	High	23.7 a	20.7 a	30.7 a	2998 a	3230	2763 a	38.7 a	42.7 a	34.7 a
MS Shanked @ 40gpa	0-12	Low	16.3 a	31.3 a	11.0 a	4340 a	2169	2379 a	9.3 a	15.3 a	6.7 a
MS Shanked (40gpa) and WR (40gpa)	0-12	High	24.0 a	22.3 a	39.3 a	3728 a	1457	2681 a	35.3 a	57.3 a	6.0 a
MS Shanked (40gpa) and WR (40gpa)	0-12	Low	11.0 a	22.0 a	53.7 a	4542 a	5261	3441 a	8.7 a	5.3 a	4.7 a
Telone C-17 (20gpa)	0-12	High	34.0 a	13.0 a	7.7 a	4876 a	3108	2344 a	20.0 a	35.3 a	1.3 a
Telone C-17 (20gpa)	0-12	Low	7.0 a	21.7 a	89.7 a	4958 a	3332	3301 a	5.3 a	8.7 a	0.7 a
Telone @ 15g/A + MS WR @ 40g/A	0-12	High	NA[7]	11.7 a	50.0 a	NA[7]	2811	2913 a	NA[7]	20.0 a	6.0 a
Telone @ 15g/A + MS WR @ 40g/A	0-12	Low	NA[7]	0.0 a	62.3 a	NA[7]	1505	2344 a	NA[7]	12.7 a	0.7 a
Control	0-12	Both[6]	8.8 a	19.7 a	38.5 a	4207 a	3381 a	3157 a	21.7 a	26.3 a	15.7 a
MS WR @ 40gpa	0-12	Both	17.2 a	18.5 a	39.3 a	4603 a	4072 a	3280 a	16.0 a	22.7 a	9.0 a
MS Shanked @ 40gpa	0-12	Both	20.0 a	26.0 a	20.8 a	3669 a	3906 a	2571 a	24.0 a	29.0 a	20.7 a
MS Shanked (40gpa) and WR (40gpa)	0-12	Both	17.5 a	22.2 a	46.5 a	4135 a	2713 ab	3061 a	22.0 a	31.3 a	5.3 a
Telone C-17 (20gpa)	0-12	Both	20.5 a	17.3 a	48.7 a	4917 a	3021 ab	2822 a	12.7 a	22.0 a	1.0 a
Telone @ 15g/A + MS WR @ 40g/A	0-12	Both	NA[7]	5.8 a	56.2 a	NA[7]	1837 b	2629 a	NA[7]	16.3 a	3.3 a
Overall all Treatments[8]	0-12	High	20.3 a	17.3 a	36.0 a	3690 a	3397 a	2865 a	31.5 a	38.2 a	14.8 a
	0-12	Low	13.3 a	19.2 a	47.3 a	4922 a	2912 a	2975 a	7.1 b	11.0 a	3.6 a

Table 1b. Year two (2010) effects of soil fumigation on soil borne fungi between 0-12 inches.

Treatment	Depth (in.)[2]	Calcium Level[3]	*Pythium* spp. (CFU/g dry soil)[1]			*Fusarium* spp. (CFU/g dry soil)[1]			*Verticillium dahliae* (CFU/g dry soil)[1]		
			Pre	Post	Harvest	Pre	Post	Harvest	Pre	Post	Harvest
Untreated Control	0-12	High[9]	121	130 a	61	4300	2405 cde	1350 cde	32 ab	22 abcd	43 ab
Untreated Control	0-12	Low	110	39 bc	144	4060	1868 cdef	1655 bcde	19 ab	6 cd	26 ab
MS WR @ 40 gpa[5]	0-12	High	88	18 c	61	2654	2737 bcd	1363 cde	19 ab	36 a	56 a
MS WR @ 40 gpa	0-12	Low	118	6 c	165	3851	1704 def	1256 cde	18 ab	8 bcd	13 b
MS Shanked (40gpa) and WR (40gpa)	0-12	High	139	6 c	34	3285	1410 ef	2265 abcd	18 ab	25 abcd	48 ab
MS Shanked (40gpa) and WR (40gpa)	0-12	Low	115	3 c	101	5645	944 f	1297 cde	7.33 b	5 cd	13 b
MS Shanked @ 40 gpa	0-12	High	170	137 a	128	4183	3036 bc	2249 abcd	14 ab	19 abcd	64 a
MS Shanked @ 40 gpa	0-12	Low	124	44 bc	165	4893	3734 ab	2511 ab	6 b	5 cd	33 ab
Telone C-17 Shank @ 22 gpa	0-12	High	148	149 a	94	3852	3043 bc	2129 abcd	25 ab	30 abc	44 ab
Telone C-17 Shank @ 22 gpa	0-12	Low	171	94 ab	181	6839	4405 a	2871 a	24 ab	12 abcd	12 b
MS Shanked @ 40 gpa	0-12	High	137	118 a	92	3397	2879 bcd	2330 abc	30 ab	16 abcd	51 ab
MS Shanked @ 40 gpa	0-12	Low	96	44 bc	150	4932	1859 cdef	1503 bcde	21 ab	2 d	27 ab
Telone II @20 gpa+MS @ 40 gpa	0-12	High	164	19 c	71	4686	2292 cde	1597 bcde	30 ab	32 ab	55 a
Telone II @20 gpa+MS @ 40 gpa	0-12	Low	38	7 c	97	5957	1778 def	975 e	23 ab	14 abcd	29 ab
MS 40 @ gpa+ Sulfuric Acid	0-12	High	132	30 c	59	4141	1744 def	2168 abcd	46 ab	24 abcd	59 a
MS 40 @ gpa+ Sulfuric Acid	0-12	Low	47	13 c	68	4034	1695 def	1141 de	37 ab	8 bcd	35 ab
Untreated Control	0-12	Both[6]	114	75 ab	111	4156	2083 b	1533 c	24 ab	12	33
MS WR @ 40 gpa	0-12	Both	106	11 c	123	3372	2117 b	1299 c	18 b	19	30
MS Shanked (40gpa) and WR (40gpa)	0-12	Both	125	4 c	74	4701	1130 c	1684 bc	12 b	13	27
MS Shanked @ 40 gpa	0-12	Both	142	81 a	150	4868	3455 a	2406 ab	9 b	10	45
Telone C-17 Shank @ 22 gpa	0-12	Both	162	116 a	146	5644	3860 a	2574 a	24 ab	19	25
MS Shanked @ 40 gpa	0-12	Both	112	73 ab	127	4318	2267 b	1834 abc	25 ab	8	37
Telone II @20 gpa+MS @ 40 gpa	0-12	Both	89	12 c	86	5448	1983 bc	1224 c	26 ab	21	40
MS 40 @ gpa+ Sulfuric Acid	0-12	Both	81	20 bc	64	4077	1715 bc	1552 c	40 a	14	44
Overall all Treatments[8]	0-12	High	137	68	76 a	3835 a	2448	2014	26	26 a	54 a
	0-12	Low	101	30	132 b	5164 b	2302	1650	19	8 b	23 b

Table 2a. Year one (2009) effects of soil fumigation on soil borne fungi between 12-24 inches.

			Pythium spp. (CFU/g dry soil)[1]			*Fusarium* spp. (CFU/g dry soil)[1]			*Verticillium dahlia* (CFU/g dry soil)[1]		
Treatment	Depth (in)[2]	Calcium Level[3]	Pre	Post	Harvest	Pre	Post	Harvest	Pre	Post	Harvest
Control	12-24	High	9 a[4]	12 a	48 a	3921 a	2396	1386 a	15 a	13 a	17a
Control	12-24	Low	17 a	11 a	53 a	4231 a	710	1910 a	18 a	6 a	5 a
MS WR @ 40gpa[5]	12-24	High	17 a	9 a	21 a	2400 a	1108	1397.a	15 a	17 a	4 a
MS WR @ 40gpa	12-24	Low	12 a	30 a	28 a	3703 a	2109	1547 a	13 a	10 a	6 a
MS Shanked @ 40gpa	12-24	High	18 a	15 a	31 a	3769 a	2524	1183 a	14 a	26 a	5 a
MS Shanked @ 40gpa	12-24	Low	28 a	9 a	22 a	4375 a	963	1429 a	15 a	7 a	4 a
MS Shanked (40gpa) and WR (40gpa)	12-24	High	15 a	4 a	34 a	4428 a	657	949 a	9 a	8 a	5 a
MS Shanked (40gpa) and WR (40gpa)	12-24	Low	9 a	13 a	56 a	3887 a	1186	1852 a	17 a	5 a	16 a
Telone C-17 (20gpa)	12-24	High	8 a	6 a	0 a	4071 a	1141	1188 a	11 a	19 a	3 a
Telone C-17 (20gpa)	12-24	Low	18 a	4 a	56 a	2717 a	806	1383 a	17 a	5 a	3 a
Telone @ 15g/A + MS WR @ 40g/A	12-24	High	NA[7]	2 a	30 a	NA[7]	405	2563 a	NA[7]	10 a	10 a
Telone @ 15g/A + MS WR @ 40g/A	12-24	Low	NA[7]	4 a	18 a	NA[7]	510	1354 a	NA[7]	9 a	7 a
Control	12-24	Both[6]	18 a	11.3 a	51 a	4148 a	1553 a	1648 a	15 a	9 a	11 a
MS WR @ 40gpa	12-24	Both	16 a	19.8 a	24 a	4329 a	1608 a	1472 a	14 a	14 a	5 a
MS Shanked @ 40gpa	12-24	Both	13 a	12.3 a	27 a	3143 a	1743 a	1306 a	16 a	17 a	5 a
MS Shanked (40gpa) and WR (40gpa)	12-24	Both	10 a	8.3 a	45 a	3887 a	921 ab	1400 a	12 a	7 a	11 a
Telone C-17 (20gpa)	12-24	Both	18 a	4.8 a	28 a	3243 a	973 ab	1286 a	15 a	12 a	3 a
Telone @ 15g/A + MS WR @ 40g/A	12-24	Both	NA[7]	2.8 a	24 a	NA[7]	457 b	1958 a	NA[7]	10 a	8 a
Overall all Treatments[8]	12-24	High	15 a	8.0 a	27 a	3605 a	1371 a	1444 a	15 a	16 a	8 a
	12-24	Low	15 a	12 a	39 a	3895 a	1047 a	1579 a	14 a	7 a	7 a

Table 2b. Year two effects (2010) of soil fumigation on soil borne fungi between 12-24 inches.

Treatment	Depth (in.)[1]	Calcium Level[3]	*Pythium* spp. (CFU/g dry soil)[1]			*Fusarium* spp. (CFU/g dry soil)[1]			*Verticillium dahliae* (CFU/g dry soil)[1]		
			Pre	Post	Harvest	Pre	Post	Harvest	Pre	Post	Harvest
Untreated Control	12-24	High[9]	91 a	12	58	1024	1532 abc	973 a	6	20	35
Untreated Control	12-24	Low	13 cd	37	40	886	1387 abcd	299 e	20	5	53
MS WR @ 40 gpa[5]	12-24	High	11 cd	17	92	2572	1232 abcd	832 abcd	31	19	57
MS WR @ 40 gpa	12-24	Low	3 d	30	20	1391	820 bcd	298 e	14	7	20
MS Shanked (40gpa) and WR (40gpa)	12-24	High	6 cd	43	11	660	956 bcd	839 abcd	13	13	173
MS Shanked (40gpa) and WR (40gpa)	12-24	Low	0 d	51	31	1904	726 cd	444 bcde	1	11	17
MS Shanked @ 40 gpa	12-24	High	50 b	34	50	2592	943 bcd	964 ab	6	11	28
MS Shanked @ 40 gpa	12-24	Low	11 cd	32	24	1207	1223 abcd	356 de	9	7	29
Telone C-17 Shank @ 22 gpa	12-24	High	22 cd	37	40	1771	1105 bcd	652 abcde	3	12	59
Telone C-17 Shank @ 22 gpa	12-24	Low	9 cd	41	890	6892	1148 bcd	411 cde	9	0	23
MS Shanked @ 40 gpa	12-24	High	86 a	40	42	1062	2076 a	899 abc	15	14	56
MS Shanked @ 40 gpa	12-24	Low	31 bc	28	34	1960	1700 ab	449 abcde	10	5	33
Telone II @20 gpa+MS @ 40 gpa	12-24	High	6 cd	9	42	1063	780 bcd	566 abcde	24	7	57
Telone II @20 gpa+MS @ 40 gpa	12-24	Low	2 d	26	9	1264	456 d	354 de	10	1	39
MS 40 @ gpa+ Sulfuric Acid	12-24	High	14 cd	14	64	1196	659 cd	902 abc	19	15	72
MS 40 @ gpa+ Sulfuric Acid	12-24	Low	0 a	25	9	1713	927 bcd	483 abcde	15	5	25
Untreated Control	12-24	Both[6]	44 ab	27	47	941	1445 ab	569	14	11	46
MS WR @ 40 gpa	12-24	Both	6 c	25	49	1863	985 bc	512	21	12	35
MS Shanked (40gpa) and WR (40gpa)	12-24	Both	2 c	48	23	1407	818 c	602	6	12	80
MS Shanked @ 40 gpa	12-24	Both	26 abc	33	34	1761	1111 bc	599	8	8	28
Telone C-17 Shank @ 22 gpa	12-24	Both	14 bc	39	550	4843	1131 bc	507	6	5	37
MS Shanked @ 40 gpa	12-24	Both	53 a	33	37	1601	1850 a	629	12	8	42
Telone II @20 gpa+MS @ 40 gpa	12-24	Both	3 c	19	22	1184	586 c	439	16	4	46
MS 40 @ gpa+ Sulfuric Acid	12-24	Both	5 c	20	31	1506	820 c	650	17	9	44
Over all Treatments[8]	12-24	High	27	28	49	1559	1107	807 a	16 a	13 a	72 a
	12-24	Low	8	34	145	2333	1000	399 b	10 b	5 b	27 b

[1]Soil borne populations of each of these fungi were determined prior to fumigation (Pre), post fumigation (Post) and at harvest (Harvest).
[2]Depth of where soil was collected.
[3]Soils were collected from two distinct areas in each of three fields. Each plot contained all fumigation treatments; one plot was in a high calcareous area, the other from a low calcareous area.
[4] Numbers in the same column followed by a different letter are significantly different with in each of the three sub-tables ($P<0.05$). Numbers not followed by a letter or followed by the same letter are not significantly different
[5]MS=Metam Sodium; WR=Water run
[6]Both refers to the inclusion of both the low and high calcareous data for that fumigation treatment.
[7]Treatment not included in the original list but added later so initial samples were not taken.
[8] The values in this sub-table represent the average of all data from all fumigation treatments, excluding control treatments, and are separated by the high and low calcareous areas.
[9] Year two "High" averages were calculated from data collected from only two of the three selected fields. The third field was removed due to improper treatment applications.

Table 3a. Year one (2009) levels of *Verticillium dahliae* in plant sap from potato plants collected during the season[1].

Treatment	Calcium Level	*Verticillium dahliae* (CFU/ml sap)
Control	High	15190 a[2]
Control	Low	15514 a
MS Shanked 40 gpa	High	11613 a
MS Shanked 40 gpa	Low	12616 a
MS Shanked 40 gpa and WR 40 gpa	High	6132 a
MS Shanked 40 gpa and WR 40 gpa	Low	11734 a
MS WR 40 gpa	High	13386 a
MS WR 40 gpa	Low	8775 a
Telone 15 gpa + MS WR 40 gpa	High	6951 a
Telone 15 gpa + MS WR 40 gpa	Low	2787 a
Telone C-17 20 gpa	High	7105 a
Telone C-17 20 gpa	Low	8715 a

Control	Both[3]	15352 a
MS WR @ 40gpa	Both	11081 a
MS Shanked @ 40gpa	Both	12114 a
MS Shanked and WR @ 40gpa	Both	8933 a
Telone C-17	Both	7910 a
Telone @ 15gpa + MS WR @ 40gpa	Both	4869 a

Over all Treatments[4]	High	10063 a
	Low	10023 a

[1]Sap was collected from plants by squeezing stems and then plating the material on selective media. The number of propagules of *Verticillium dahliae* could then be counted.

[2]Numbers in the same column followed by a different letter are significantly different within each of the three sub-tables ($P<0.05$). Numbers not followed by a letter or followed by the same letter are not significantly different.

[3]Both refers to the inclusion of both the low and high calcareous data for that fumigation treatment.

[4]The values in this sub-table represent the average of all data from all fumigation treatments and are separated by the high and low calcareous areas.

Table 3b. Year two levels (2010) of *Verticillium dahliae* and *Colletotrichum coccodes* in plant sap from potato plants collected during the season[1].

Treatment	Calcium Level	*Verticillium dahliae* (CFU/ml plant sap)	*Colletotrichum coccodes* (CFU/ml plant sap)
Untreated Control	High[5]	2610 ab[2]	440 bc
Untreated Control	Low	857 bcde	17 c
MS WR @ 40 gpa	High	2475 abcd	985 ab
MS WR @ 40 gpa	Low	37 e	20 c
MS Shanked (40gpa) and WR (40gpa)	High	1205 bcde	1450 a
MS Shanked (40gpa) and WR (40gpa)	Low	180 cde	57 c
MS Shanked @ 40 gpa	High	1990 abcde	640 bc
MS Shanked @ 40 gpa	Low	103 de	167 bc
Telone C-17 Shank @ 22 gpa	High	1980 abcde	160 bc
Telone C-17 Shank @ 22 gpa	Low	260 bcde	80 c
MS Shanked @ 40 gpa	High	3785 a	385 bc
MS Shanked @ 40 gpa	Low	870 bcde	517 bc
Telone II @20 gpa+MS @ 40 gpa	High	260 bcde	155 bc
Telone II @20 gpa+MS @ 40 gpa	Low	67 e	57 c
MS 40 @ gpa+ Sulfuric Acid	High	2525 abc	185 bc
MS 40 @ gpa+ Sulfuric Acid	Low	620 bcde	210 bc
Untreated Control	Both[3]	1558	186
MS WR @ 40 gpa	Both	1012	406
MS Shanked (40gpa) and WR (40gpa)	Both	590	614
MS Shanked @ 40 gpa	Both	858	356
Telone C-17 Shank @ 22 gpa	Both	948	112
MS Shanked @ 40 gpa	Both	2036	464
Telone II @20 gpa+MS @ 40 gpa	Both	144	96
MS 40 @ gpa+ Sulfuric Acid	Both	1382	200
Over all Treatments[4]	Low	374 a	140 a
	High	2104 b	550 b

[1]Sap was collected from plants by squeezing stems and then plating the material on selective media.
The number of propagules of *Verticillium dahliae* could then be counted.

[2]Numbers in the same column followed by a different letter are significantly different within each of the three sub-tables ($P<0.05$). Numbers not followed by a letter or followed by the same letter are not significantly different.

[3]Both refers to the inclusion of both the low and high calcareous data for that fumigation treatment.

[4]The values in this sub-table represent the average of all data from all fumigation treatments and are separated by the high and low calcareous areas.

[5] Year two "High" averages were calculated from data collected from only two of the three selected fields. The third field was removed due to improper treatment applications.

Table 4a. Year one effects (2009) of fumigation treatments on yield and tuber count in high and low calcareous areas.

		Yield (lbs)[1]						
Treatment	Calcium Level[2]	Under 4 oz	Cull's/2's	4 to 8 oz	8 to 12 oz	Over 12 oz	Total Yield	Tuber Count
Control	High	9.0 a[3]	4.1 c	28.2 a	21.6 a	11.8 a	74.7 a	174.3 a
Control	Low	13.0 a	5.0 bc	39.6 a	22.6 a	14.7 a	94.9 a	263.7 a
MS WR @ 40gpa[4]	High	6.6 a	4.6 bc	22.8 a	13.5 a	14.5 a	61.9 a	175.3 a
MS WR @ 40gpa	Low	11.2 a	13.2 ab	38.8 a	21.6 a	13.6 a	98.3 a	255.7 a
MS Shanked @ 40gpa	High	11.4 a	6.6 bc	26.3 a	16.5 a	14.3 a	75.1 a	196.0 a
MS Shanked @ 40gpa	Low	11.6 a	8.4 bc	36.6 a	22.4 a	11.1 a	90.1 a	295.7 a
MS Shanked (40gpa) and WR (40gpa)	High	7.5 a	7.1 bc	18.2 a	15.4 a	23.3 a	71.4 a	179.3 a
MS Shanked (40gpa) and WR (40gpa)	Low	12.6 a	3.4 c	39.4 a	25.1 a	15.6 a	96.0 a	242.7 a
Telone C-17 (20gpa)	High	8.7 a	5.5 bc	25.9 a	19.8 a	14.9 a	74.9 a	224.0 a
Telone C-17 (20gpa)	Low	14.3 a	7.7 bc	36.5 a	27.1 a	11.6 a	97.2 a	249.7 a
Telone @ 15g/A + MS WR @ 40g/A	High	9.1 a	19.7 a	28.2 a	14.3 a	15.6 a	86.9 a	198.3 a
Telone @ 15g/A + MS WR @ 40g/A	Low	15.8 a	3.4 c	48.3 a	21.4 a	9.8 a	98.6 a	292.7 a
Control	Both[5]	11.0 a	4.5 a	33.9 a	22.1 a	13.2 a	84.8 a	219.0 a
MS WR @ 40gpa	Both	8.9 a	8.9 a	30.8 a	17.5 a	14.1 a	80.1 a	215.5 a
MS Shanked @ 40gpa	Both	11.5 a	7.5 a	31.4 a	19.5 a	12.7 a	82.6 a	245.8 a
MS Shanked (40gpa) and WR (40gpa)	Both	10.0 a	5.2 a	28.8 a	20.2 a	19.4 a	83.7 a	211.0 a
Telone C-17 (20gpa)	Both	11.5 a	6.6 a	31.2 a	23.5 a	13.2 a	86.1 a	236.8 a
Telone @ 15g/A + MS WR @ 40g/A	Both	12.4 a	11.6 a	38.2 a	17.9 a	12.7 a	92.8 a	245.5 a
Overall all Treatments	High[6]	8.7 a	7.9 a	24.9 a	16.8 a	15.7 a	74.2 a	191.2 a
	Low	13.1 a	6.9 a	39.9 a	23.4 a	12.7 a	95.9 a	266.7 b

[1]Average yield in pounds from the three replicated plots of each fumigation treatment. Replications were fields.
[2]Soils were collected from two distinct areas in each of three fields. Each plot contained all fumigation treatments; one plot was in a high calcareous area, the other from a low calcareous area.
[3]Numbers followed by t he same letter are not significantly different with in each of the three sub-tables ($P<0.05$).
[4]MS= metam sodium, WR=water run.
[5]Both refers to the inclusion of both the low and high calcareous data for that fumigation treatment.
[6]These values in this sub-table represent the average of all data from all fumigation treatments and are separated by the high and low calcareous areas.

Table 4b. Year two (2010) effects of fumigation treatments on yield and tuber count in high and low calcareous areas.

Treatment	Calcium Level[2]	Yield (lbs)[1]					
		Under 4 oz	Culls/2's	4 to 8 oz	8 to 12 oz	Over 12 oz	Total Yield
Untreated Control	High	12 a	1.3 a	31 a	23 a	15 a	83 ab
Untreated Control	Low	13 a	1.6 a	33 a	22 a	17 a	86 ab
MS WR @ 40 gpa[4]	High	14 a	2.9 a	40 a	29 a	16 a	103 a
MS WR @ 40 gpa	Low	15 a	1.8 a	42 a	28 a	16 a	103 a
MS Shanked (40gpa) and WR (40gpa)	High	13 a	0.9 a	38 a	31 a	11 a	94 ab
MS Shanked (40gpa) and WR (40gpa)	Low	16 a	0.6 a	44 a	25 a	10 a	96 ab
MS Shanked @ 40 gpa	High	12 a	1.4 a	32 a	19 a	8 a	73 b
MS Shanked @ 40 gpa	Low	13 a	3.0 a	32 a	21 a	20 a	89 ab
Telone C-17 Shank @ 22 gpa	High	15 a	3.4 a	40 a	24 a	18 a	100 a
Telone C-17 Shank @ 22 gpa	Low	14 a	0.8 a	37 a	30 a	12 a	93 ab
MS Shanked @ 40 gpa	High	14 a	1.3 a	41 a	23 a	7 a	87 ab
MS Shanked @ 40 gpa	Low	14 a	1.8 a	35 a	24 a	17 a	91 ab
Telone II @20 gpa+MS @ 40 gpa	High	18 a	5.0 a	42 a	28 a	10 a	103 a
Telone II @20 gpa+MS @ 40 gpa	Low	13 a	1.0 a	43 a	22 a	10 a	88 ab
MS 40 @ gpa+ Sulfuric Acid	High	15 a	3.6 a	41 a	27 a	10 a	97 ab
MS 40 @ gpa+ Sulfuric Acid	Low	14 a	2.2 a	40 a	26 a	13 a	94ab
Untreated Control	Both[5]	12.5 a	1.5 a	31.7 b	22.4 ab	16.1 a	84.1 b
MS WR @ 40 gpa	Both	14.6 a	2.4 a	41.2 a	28.9 a	15.9 a	103.0 a
MS Shanked (40gpa) and WR (40gpa)	Both	14.6 a	0.7 a	41.0 a	27.7 a	10.8 a	94.8 ab
MS Shanked @ 40 gpa	Both	12.5 a	2.2 a	32.1 b	19.9 b	14.3 a	81.0 b
Telone C-17 Shank @ 22 gpa	Both	14.4 a	2.1 a	38.7 ab	26.8 ab	14.7 a	96.7 ab
MS Shanked @ 40 gpa	Both	14.1 a	1.6 a	38.2 ab	23.5 ab	11.8 a	89.2 ab
Telone II @20 gpa+MS @ 40 gpa	Both	15.4 a	3.0 a	42.4 a	25.2 ab	9.9 a	95.9 ab
MS 40 @ gpa+ Sulfuric Acid	Both	14.3 a	2.9 a	40.6 a	26.5 ab	11.2 a	95.4 ab
Over all Treatments[6]	High	14.6 a	2.7 a	39.3 a	26.0 a	11.3 a	93.8 a
	Low	14.0 a	1.6 a	39.0 a	25.0 a	14.0 a	93.6 a

[1]Average yield in pounds from the three replicated plots of each fumigation treatment. Replications were fields.
[2]Soils were collected from two distinct areas in each of three fields. Each plot contained all fumigation treatments; one plot was in a high calcareous area, the other from a low calcareous area.
[3]Numbers followed by t he same letter are not significantly different with in each of the three sub-tables ($P<0.05$).
[4]MS= metam sodium, WR=water run.
[5]Both refers to the inclusion of both the low and high calcareous data for that fumigation treatment.
[6]These values in this sub-table represent the average of all data from all fumigation treatments and are separated by the high and low calcareous areas.

Table 5a. Year one (2009) populations of root-lesion nematodes (nematodes/250 g dry soil from 0-12 in.) in different fumigation treatments within low and high calcareous areas of potato fields.

Treatment	Prefumigation[1]	Post Fumigation[2]	Harvest[3]
		Low Calcareous Soils	
Nontreated	86	107 a[4]	11
Water-Run MS 40 gpa	108	64 ab	2
Shanked MS 40 gpa	63	12 abc	1
SH +WR MS 80 gpa	70	5 bc	4
Telone C-17	66	2 c	0
Tel 15 gpa + WRMS 30 gpa	Not Sampled	0 c	1
Pr > F	ns[4]	P = 0.0166	ns
		High Calcareous Soils	
Nontreated	174	509	76
Water-Run MS 40 gpa	315	67	9
Shanked MS 40 gpa	697	239	39
SH +WR MS 80 gpa	542	22	26
Telone C-17	309	60*[5]	7
Tel 15 gpa + WRMS 30 gpa	Not Sampled	10	1
Pr > F	ns	ns	ns
Averaged over all treatments			
Low Calcareous Soil	77	11	3
High Calcareous Soil	364*	70*	15*
Pr > F	P = 0.0007	P = 0.0119	P = 0.0144

[1]October 13, 2008. Telone 15 gpa + WRMS 30 gpa not sampled initially because this treatment was not included on the original treatment list.
[2]February 16, 2009
[3]September 18, 2009
[4]Means with the same letter are not significantly different (P<0.05), ns = no significant differences.
[5]Significantly different from corresponding treatment in low calcareous soil (P<0.05).

Table 5b. Year two (2010) populations of root-lesion nematodes (*Pratylenchus neglectus*) (nematodes/250 g dry soil from 0-12 in.) in different fumigation treatments within low and high calcareous areas of potato fields.

Treatment	Prefumigation[1]	Post Fumigation[2]	Harvest[3]
		Low Calcareous Soils	
Nontreated	69	74	30
MS WR @ 40 gpa	37	4	2
MS Shank (40 gpa) & WR(40 gpa)	69	6	3
MS Shanked @ 40 gpa	69	16	34
Telone C-17 Shanked @ 22 gpa	14	4	36
MS Shanked @ 40 gpa	73	52	48
Telone II @ 20 gpa+MS @ 40 gpa	127	2	1
MS @ 40 gpa+sulfuric acid	119	2	3
Pr > F	ns[4]	ns	ns
		High Calcareous Soils	
Nontreated	78	73	20
MS WR @ 40 gpa	25	18	2
MS Shank (40 gpa) & WR(40 gpa)	114	44	32*
MS Shanked @ 40 gpa	138	123	123
Telone C-17 Shanked @ 22 gpa	78	69	50
MS Shanked @ 40 gpa	124	97	39
Telone II @ 20 gpa+MS @ 40 gpa	110	4	3
MS @ 40 gpa+sulfuric acid	56	25	18
Pr > F	ns	ns	ns
Averaged over all treatments			
Low Calcareous Soil	61	9	10
High Calcareous Soil	80	39*[5]	21
Pr > F	ns	P=0.0141	ns

[1]October 20, 2009.
[2]March 30, 2010
[3]September 24, 2010
[4]Means with the same letter are not significantly different (P<0.05), ns = no significant differences.
[5]Significantly different from corresponding treatment in low calcareous soil (P<0.05).

Table 6a. Year one (2009) populations of root-lesion nematodes (nematodes/250 g dry soil from 12-24 in.) in different fumigation treatments within low and high calcareous areas of potato fields.

Treatment	Prefumigation[1]	Post Fumigation[2]	Harvest[3]
	Low Calcareous Soils		
Nontreated	36	9	14
Water-Run MS 40 gpa	13	6	5
Shanked MS 40 gpa	6	3	3
SH +WR MS 80 gpa	39	0	3
Telone C-17	25	2	0
Tel 15 gpa + WRMS 30 gpa	Not Sampled	0	0
Pr > F	ns[4]	ns	ns
	High Calcareous Soils		
Nontreated	63	25	4
Water-Run MS 40 gpa	33	1	2
Shanked MS 40 gpa	144	19*	6
SH +WR MS 80 gpa	109	3	2
Telone C-17	58	7	4
Tel 15 gpa + WRMS 30 gpa	Not Sampled	24	1
Pr > F	ns	ns	ns
Averaged over all treatments			
Low Calcareous Soil	20	2	3
High Calcareous Soil	72*[5]	8*	3
Pr > F	P = 0.0056	P = 0.0523	ns

[1]October 13, 2008. Telone 15 gpa + WRMS 30 gpa not sampled initially because this treatment was not included on the original treatment list.
[2]February 16, 2009
[3]September 18, 2009
[4]Means with the same letter are not significantly different (P<0.05), ns = no significant differences.
[5]Significantly different from corresponding treatment in low calcareous soil (P<0.05).

Table 6b. Year two (2010) populations of root-lesion nematodes (*Pratylenchus neglectus*) (nematodes/250 g dry soil from 12-24 in.) in different fumigation treatments within low and high calcareous areas of potato fields.

Treatment	Prefumigation[1]	Post Fumigation[2]	Harvest[3]
		Low Calcareous Soils	
Nontreated	7	11	13
MS WR @ 40 gpa	7	2	1
MS Shank (40 gpa) & WR(40 gpa)	10	10	5
MS Shanked @ 40 gpa	15	19	30
Telone C-17 Shanked @ 22 gpa	4	3	17
MS Shanked @ 40 gpa	10	5	8
Telone II @ 20 gpa+MS @ 40 gpa	14	0	0
MS @ 40 gpa+sulfuric acid	15	2	2
Pr > F	ns[4]	ns	
		High Calcareous Soils	
Nontreated	11	14	4
MS WR @ 40 gpa	69	32	7
MS Shank (40 gpa) & WR(40 gpa)	22	11	4
MS Shanked @ 40 gpa	19	33	6
Telone C-17 Shanked @ 22 gpa	4	47	0*
MS Shanked @ 40 gpa	18	15	14
Telone II @ 20 gpa+MS @ 40 gpa	18	1	5
MS @ 40 gpa+sulfuric acid	4	23	2
Pr > F	ns	ns	ns
Averaged over all treatments			
Low Calcareous Soil	9	4	6
High Calcareous Soil	14	16*[5]	4
Pr > F	ns	P=0.0074	ns

[1]October 20, 2009.
[2]March 30, 2010
[3]September 24, 2010
[4]Means with the same letter are not significantly different (P<0.05), ns = no significant differences.
[5]Significantly different from corresponding treatment in low calcareous soil (P<0.05).

Table 7a. Year one (2009) populations of free-living nematodes (nematodes/250 g dry soil from 0-12 in.) in different fumigation treatments within low and high calcareous areas of potato fields.

Treatment	Prefumigation[1]	Post Fumigation[2]	Harvest[3]
	Low Calcareous Soils		
Nontreated	1,393	2,246 a[3]	1,002
Water-Run MS 40 gpa	1,292	452 bc	1,365
Shanked MS 40 gpa	2,242	1,147 ab	2,468
SH +WR MS 80 gpa	1,775	703 abc	1,249
Telone C-17	1,127	232 c	1,617
Tel 15 gpa + WRMS 30 gpa	Not Sampled	291 bc	2,053
Pr > F	ns[4]	P = 0.0356	ns
	High Calcareous Soils		
Nontreated	1,573	1,853 a	1,334
Water-Run MS 40 gpa	1,963	344 abc	2,195
Shanked MS 40 gpa	1,285	275 bc	2,197
SH +WR MS 80 gpa	1,935	117 c*[5]	1,563
Telone C-17	1,817	1,086 ab**	1,419
Tel 15 gpa + WRMS 30 gpa	Not Sampled	129 c	1,739
Pr > F	ns	P = 0.0265	ns
Averaged over all treatments			
Low Calcareous Soil	1,518	617	1,549
High Calcareous Soil	1,694	377	1,698
Pr > F	ns	ns	ns

[1]October 13, 2008. Telone 15 gpa + WRMS 30 gpa not sampled initially because this treatment was not included on the original treatment list.
[2]February 16, 2009
[3]September 18, 2009
[4]Means with the same letter are not significantly different (P<0.05), ns = no significant differences.
[5]Significantly different from corresponding treatment in low calcareous soil (* = P<0.05, ** = P <0.10).

Table 7b. Year two (2010) populations of free-living nematodes (nematodes/250 g dry soil from 0-12 in.) in different fumigation treatments within low and high calcareous areas of potato fields.

Treatment	Prefumigation[1]	Post Fumigation[2]	Harvest[3]
		Low Calcareous Soils	
Nontreated		939 a	304
MS WR @ 40 gpa	Not Counted		310
MS Shank (40 gpa) & WR(40 gpa)		263 c	363
MS Shanked @ 40 gpa			636
Telone C-17 Shanked @ 22 gpa		401 abc	268
MS Shanked @ 40 gpa			403
Telone II @ 20 gpa+MS @ 40 gpa		351 bc	253
MS @ 40 gpa+sulfuric acid			296
		762 ab	
Pr > F		688 ab	ns
		376 abc	
		723 ab	
		P = 0.0470	
		High Calcareous Soils	
Nontreated		763*[5]	299
MS WR @ 40 gpa	Not Counted	908	456
MS Shank (40 gpa) & WR(40 gpa)		721	377
MS Shanked @ 40 gpa		460	648
Telone C-17 Shanked @ 22 gpa		801	362
MS Shanked @ 40 gpa		437	592
Telone II @ 20 gpa+MS @ 40 gpa		1,128	297
MS @ 40 gpa+sulfuric acid		1,064	645
Pr > F		ns	ns
Averaged over all treatments			
Low Calcareous Soil		512	338
High Calcareous Soil		740*	427
Pr > F		P=0.0229	ns

[1]October 20, 2009.
[2]March 30, 2010
[3]September 24, 2010
[4]Means with the same letter are not significantly different (P<0.05), ns = no significant

differences.
[5]Significantly different from corresponding treatment in low calcareous soil (P<0.05).

Table 8a. Year one (2009) populations of free-living nematodes (nematodes/250 g dry soil from 12-24 in.) in different fumigation treatments within low and high calcareous areas of potato fields.

Treatment	Prefumigation[1]	Post Fumigation[2]	Harvest[3]
	Low Calcareous Soils		
Nontreated	1,520	264	849
Water-Run MS 40 gpa	1,320	232	1,262
Shanked MS 40 gpa	1,481	119	1,329
SH +WR MS 80 gpa	1,620	82	1,435
Telone C-17	950	105	1,470
Tel 15 gpa + WRMS 30 gpa	Not Sampled	64	1,862
Pr > F	ns[4]	ns	ns
	High Calcareous Soils		
Nontreated	895	425	587
Water-Run MS 40 gpa	1,150	103	600
Shanked MS 40 gpa	1,018	312	310
SH +WR MS 80 gpa	1,908	77	610
Telone C-17	1,114	195	485
Tel 15 gpa + WRMS 30 gpa	Not Sampled	137	1,258
Pr > F	ns	ns	ns
Averaged over all treatments			
Low Calcareous Soil	1,355	126	1,318
High Calcareous Soil	1,174	175	589*[5]
Pr > F	ns	ns	P = 0.0011

[1]October 13, 2008. Telone 15 gpa + WRMS 30 gpa not sampled initially because this treatment was not included on the original treatment list.
[2]February 16, 2009
[3]September 18, 2009
[4]Means with the same letter are not significantly different (P<0.05), ns = no significant differences.
[5]Significantly different from corresponding treatment in low calcareous soil (* = P<0.05).

Table.8b Year two (2010) populations of free-living nematodes (nematodes/250 g dry soil from 12-24 in.) in different fumigation treatments within low and high calcareous areas of potato fields.

Treatment	Prefumigation[1]	Post Fumigation[2]	Harvest[3]
	Low Calcareous Soils		
Nontreated		525 a[4]	285
MS WR @ 40 gpa	Not Counted	75 c	128
MS Shank (40 gpa) & WR(40 gpa)		258 abc	126
MS Shanked @ 40 gpa		168 abc	149
Telone C-17 Shanked @ 22 gpa		284 abc	237
MS Shanked @ 40 gpa		314 ab	115
Telone II @ 20 gpa+MS @ 40 gpa		108 bc	185
MS @ 40 gpa+sulfuric acid		241 abc	87
Pr > F		P = 0.0745	ns
	High Calcareous Soils		
Nontreated		446	101
MS WR @ 40 gpa	Not Counted	293	293
MS Shank (40 gpa) & WR(40 gpa)		177	341
MS Shanked @ 40 gpa		255	122
Telone C-17 Shanked @ 22 gpa		344	100
MS Shanked @ 40 gpa		202	199
Telone II @ 20 gpa+MS @ 40 gpa		231	85
MS @ 40 gpa+sulfuric acid		200	217
Pr > F		ns	ns
Averaged over all treatments			
Low Calcareous Soil		213	152
High Calcareous Soil		250	161
Pr > F		ns	ns

[1]October 20, 2009.
[2]March 30, 2010
[3]September 24, 2010
[4]Means with the same letter are not significantly different (P<0.05), ns = no significant differences.

Table 9a. Year one (2009) effect of field location on soil characteristics, pre & post potato crop.

Pre-Fumigation

Field	no3 lb./a	NH4 lb./a	P ppm	K ppm	S ppm	Ca meq/100g	Mg meq/100g	Na meq/100g	B ppm	Zn ppm
701	39.1a[1]	18.8a	25.4a	236.3a	16.6a	12.8a	1.7a	0.10a	0.29a	3.93a
718	61.4a	19.6a	20.7a	215.2a	29.5a	16.6a	2.0a	0.13a	0.42a	3.48a
721	23.9a	18.5a	20.5a	236.3a	12.1a	7.8a	1.6a	0.10a	0.18a	3.03a

Field	Mn ppm	Cu ppm	Fe ppm	pH	SS mmhos/cm	WP ppm	WK ppm	Cl ppm	CCE %	CEC meq/100g
701	5.4a	1.4a	18.0a	7.2a	0.2a	2.5a	22.7a	11.71a	0.58a	9.18a
718	6.3a	1.5a	16.4a	7.0a	0.3a	1.5a	22.7a	20.25a	4.21a	21.33a
721	6.9a	1.1a	24.1a	6.8a	0.1a	2.3a	24.8a	7.42a	0.29a	8.47a

Post Fumigation

Field	NO3 lb./a	NH4 lb./a	P ppm	K ppm	S ppm	Ca meq/100g	Mg meq/100g	Na meq/100g	B ppm	Zn ppm
701	47.3a	6.1b	31.8a	230.0a	111.2a	15.5a	1.8b	0.14b	0.53a	2.68ab
718	56.7a	6.7ab	24.5ab	165.7a	196.6a	21.5a	2.4a	0.20a	0.66a	3.12a
721	29.8a	7.9a	22.8b	197.4a	83.6a	8.8a	1.9ab	0.12b	0.57a	1.69b

Field	Mn ppm	Cu ppm	Fe ppm	pH	SS mmhos/cm	WP ppm	WK ppm	Sand %	Silt %	Clay %
701	5.7a	1.5a	22.3a	7.2a	0.5a	4.2a	34.3a	67.58a	25.30b	7.12a
718	4.6a	1.3a	16.6a	7.2a	0.6a	2.4a	23.9a	53.00a	37.80a	9.20a
721	7.1a	1.8a	24.9a	6.6a	0.3a	3.2a	25.4a	57.88a	36.24a	5.88a

[1]Numbers followed by the same letter are not significantly different ($P<0.05$)

Table 10a. Year one (2009) effect of soil calcium level on soil characteristics, pre & post potato crop.

Pre-Fumigation

SoilCa	no3 lb./a	nh4 lb./a	P ppm	K ppm	S ppm	Ca meq/100g	Mg meq/100g	Na meq/100g	B ppm	Zn ppm
High	60.4a[1]	19.7a	22.5a	224.5a	28.7a	18.4a	2.0a	0.12a	0.41a	3.42a
Low	22.5a	18.2a	21.9a	234.0a	10.1a	6.4a	1.6a	0.10a	0.17a	3.54a

SoilCa	Mn ppm	Cu ppm	Fe ppm	pH	SS mmhos/cm	WP ppm	WK ppm	Cl ppm	CCE %	CEC meq/100g
High	5.7a	1.5a	16.0a	7.4a	0.3a	1.5b	21.2a	9.28a	0.67a	15.34a
Low	6.8a	1.2a	23.0a	6.6a	0.1a	2.7a	25.6a	16.97a	2.71a	10.63a

Post Fumigation

SoilCa	NO3 lb./a	NH4 lb./a	P ppm	K ppm	S ppm	Ca meq/100g	Mg meq/100g	Na meq/100g	B ppm	Zn ppm
High	59.3a	8.2a	29.1a	221.1a	238.7a	22.4a	2.3a	0.17a	0.67a	2.83a
Low	29.8a	5.6b	23.7a	174.3a	22.2a	8.1a	1.8a	0.13b	0.49a	2.16a

SoilCa	Mn ppm	Cu ppm	Fe ppm	pH	SS mmhos/cm	WP ppm	WK ppm	Sand %	Silt %	Clay %
High	6.7a	1.8a	21.9a	7.1a	0.7a	2.3b	35.1a	49.03b	41.28a	9.69a
Low	4.9a	1.3a	20.7a	6.9a	0.2a	4.3a	20.7a	69.94a	24.94b	5.11a

[1]Numbers followed by the same letter are not significantly different (P<0.05)

Table 12a. Continued. Year one (2009) effect of fumigation treatment on soil characteristics, pre & post potato crop.

Treatment	Mn	Cu	Fe	pH	SS	WP	WK	Sand	Silt	Clay
	ppm	ppm	ppm		mmhos/cm	ppm	ppm	%	%	%
A	4.3b[1]	1.5a	16.7bc	7.3a	0.4bc	3.8a	25.8ab	59.25ab	33.28ab	7.47ab
B	4.5b	1.6a	19.0abc	7.1ab	0.5ab	3.2a	26.8ab	58.00ab	34.43ab	7.57ab
C	4.7ab	1.6a	18.8bc	7.1abc	0.4c	3.3a	27.0ab	61.58a	31.28b	7.13ab
D	3.8b	1.4a	16.5c	7.3a	0.6a	3.4a	37.5a	54.58b	37.38a	8.03a
E	8.7a	1.5a	29.5	6.6c	0.4bc	2.9a	20.8b	60.67ab	32.03ab	7.30ab
F	8.7a	1.7a	27.2ab	6.7bc	0.5ab	3.1a	29.2ab	62.83a	30.27b	6.90b

[1]Numbers followed by the same letter are not significantly different ($P<0.05$)

Treatment Code:

A - Control
B - Metam Sodium WR @ 40gpa
C - Metam Sodium Shanked @ 40gpa
D - Metam Sodium Shanked (40gpa) and WR (40gpa)
E - Telone C-17 @20gpa
F - Telone @ 15 gpa + Metam Sodium WR @ 40gpa

Table 13. Year 2 (2010) Main effects (soil pH) for soil nutrient analysis at the 0-1 foot depth

Main effect	B Ppm		Ca Meq		Cu ppm		Fe ppm		K ppm		Mg Meq		Mn ppm	
Low pH	0.18	B	5.4	B	0.88	A	28.8	A	303	A	2.02	A	7.3	A
High pH	0.25	A	15.1	A	0.69	A	30.5	A	264	A	1.31	A	14.0	A

	NH4 Lb/a		NO3 Lb/a		Na Meq		P Ppm		S ppm		SS mmhos		WSK ppm		WSP ppm	
Low pH	16	A	174	A	0.11	A	20	A	13.4	B	0.34	B	51.0	A	2.07	A
High pH	33	A	140	A	0.10	A	27	A	163.5	A	0.69	A	59.3	A	1.96	A

Numbers followed by different letters are significantly different at p=0.10 using LSD.

Treatments:
1 - Untreated Control
2 - MS WR @ 40 gpa
3 - MS Shanked (40gpa) and WR (40gpa)
4 - MS Shanked @ 40 gpa
5 - Telone C-17 Shank @ 22 gpa
6 - MS Shanked @ 40 gpa
7 - Telone II @20 gpa+MS @ 40 gpa
8 - MS 40 @ gpa+ Sulfuric Acid

Table 14. Year 2 (2010) soil pH post fumigation by treatment for each field.

	Low pH			High pH		
	Field			Field		
Treatment	1	2	3	1	2	3
1	6.0	6.0	6.2	7.5	7.5	5.3
2	5.5	5.7	5.8	7.1	7.4	4.5
3	5.8	5.9	5.8	7.5	7.4	4.5
4	5.8	5.8	5.9	7.4	7.2	4.5
5	5.5	5.8	5.8	7.3	7.3	4.6
6	6.3	6.2	6.3	7.6	7.6	4.4
7	5.7	5.9	5.8	7.3	7.4	4.5
8	5.8	5.8	5.7	7.3	7.4	4.4
Average	5.8	5.9	5.9	7.4	7.4	4.6

Treatments:

1 - Untreated Con troll
2 - MS WR @ 40 gpa
3 - MS Shanked (40gpa) and WR (40gpa)
4 - MS Shanked @ 40 gpa
5 - Telone C-17 Shank @ 22 gpa
6 - MS Shanked @ 40 gpa
7 - Telone II @20 gpa+MS @ 40 gpa
8 - MS 40 @ gpa+ Sulfuric Acid

Table 15. Year two (2010) treatment effects were analyzed and are listed in the below table.

Treatment	B ppm		Ca Meq		Cu ppm		Fe ppm		K ppm		Mg Meq		Mn ppm	
1	0.21	AB	11.9	AB	0.73	B	21.3	B	269	BC	1.57	C	5.7	B
2	0.22	AB	9.1	C	0.78	AB	33.0	A	311	A	1.63	BC	15.0	A
3	0.20	B	12.7	A	0.81	A	29.3	AB	250	C	1.64	ABC	9.5	AB
4	0.21	AB	8.4	C	0.80	AB	29.7	AB	290	AB	1.70	AB	9.3	AB
5	0.21	AB	10.1	BC	0.78	AB	29.2	AB	295	A	1.72	AB	8.8	AB
6	0.23	A	12.2	AB	0.77	AB	29.7	AB	266	BC	1.67	AB	12.5	A
7	0.22	AB	9.4	C	0.80	AB	30.0	AB	297	A	1.73	A	10.7	AB
8	0.22	AB	8.3	C	0.77	AB	35.0	A	290	AB	1.63	BC	13.5	A

Treatment	NH4		NO3		Na		P		S		SS		WSK		WSP	
1	13	B	144	BC	0.10	A	19	D	90.2	BC	0.48	BC	43.5	B	1.62	C
2	38	A	174	AB	0.12	A	25	AB	99.7	AB	0.58	AB	68.0	A	2.22	AB
3	23	AB	132	CD	0.10	A	21	BCD	130.2	A	0.59	A	43.7	B	1.43	C
4	16	AB	195	A	0.10	A	25	AB	80.3	BC	0.52	AB	58.5	A	2.20	AB
5	16	AB	171	AB	0.10	A	24	ABC	79.7	BC	0.50	ABC	58.8	A	2.30	A
6	31	AB	108	D	0.10	A	21	CD	63.5	C	0.40	C	44.8	B	1.77	BC
7	22	AB	174	AB	0.10	A	24	ABC	88.5	BC	0.58	AB	62.0	A	2.15	AB
8	37	A	157	BC	0.12	A	28	A	75.5	BC	0.48	BC	61.5	A	2.42	A

Numbers followed by different letters are significantly different at p=0.10 using LSD.

Treatments:

1 - Untreated Control
2 - MS WR @ 40 gpa
3 - MS Shanked (40gpa) and WR (40gpa)
4 - MS Shanked @ 40 gpa
5 - Telone C-17 Shank @ 22 gpa
6 - MS Shanked @ 40 gpa
7 - Telone II @20 gpa+MS @ 40 gpa

8 - MS 40 @ gpa+ Sulfuric Acid

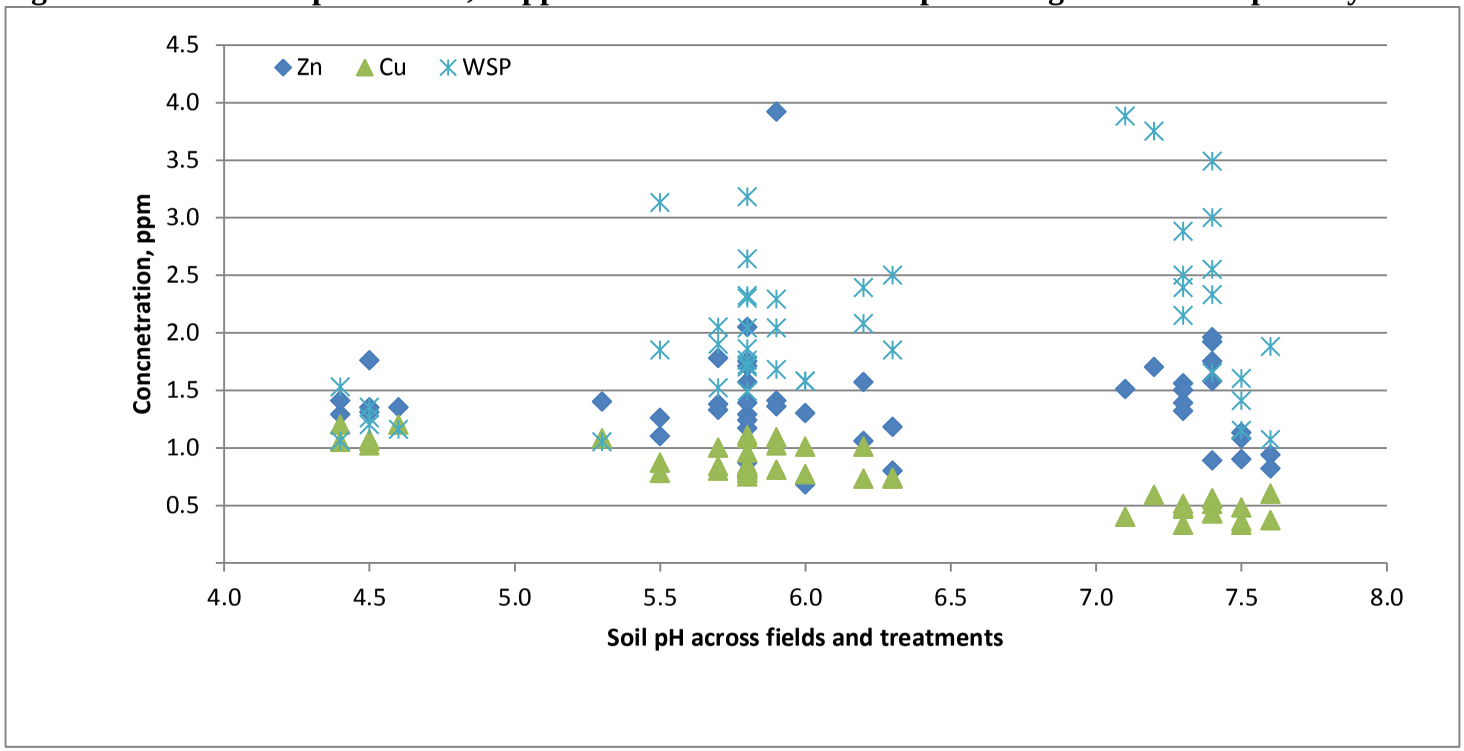
Table 16. Year two (2010) soil pH for treatments for both the high pH and low pH fields.

Treatment	Low pH	High pH
1	6.1	6.8
2	5.7	6.3
3	5.8	6.5
4	5.8	6.4
5	5.7	6.4
6	6.3	6.5
7	5.8	6.4
8	5.8	6.4

Treatments:

1 - Untreated Con troll
2 - MS WR @ 40 gpa
3 - MS Shanked (40gpa) and WR (40gpa)
4 - MS Shanked @ 40 gpa
5 - Telone C-17 Shank @ 22 gpa
6 - MS Shanked @ 40 gpa
7 - Telone II @20 gpa+MS @ 40 gpa
8 - MS 40 @ gpa+ Sulfuric Acid

Figure 1. Effect of soil pH on Zinc, Copper and water soluble P for post fumigation soil samples in year two.



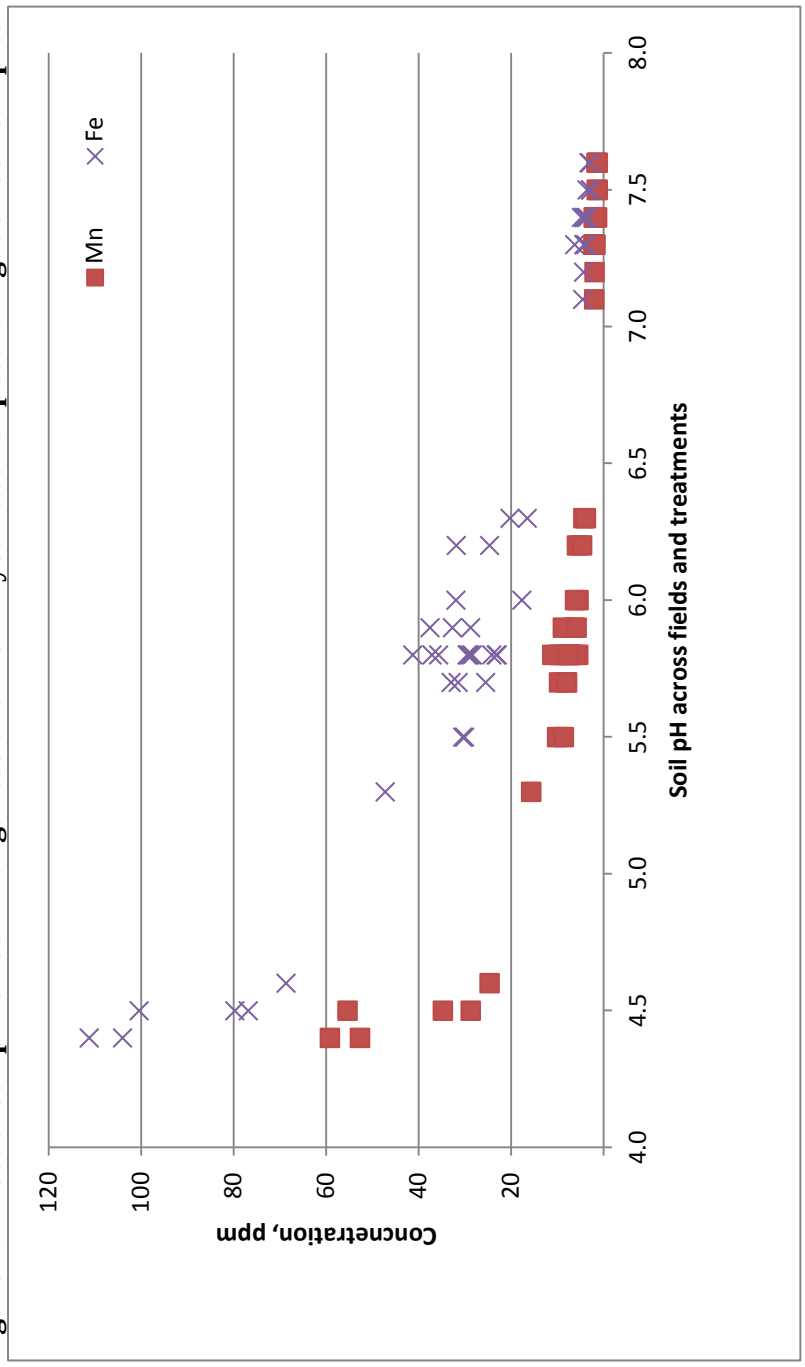


Figure 2. Effect of soil pH on soil Manganese and Iron in year two for post fumigation soil samples.

2009-2010 Metam Sodium Field-scale Shank Injection -Water Run Efficacy Demonstration

PERSONNEL:

Project Coordinator:

Vincent Hebert;	Washington State University Food and Environ Quality Lab

Project Co-Investigators:

Dennis Johnson;	Department of Plant Pathology, Washington State University
Philip Hamm ;	Dept of Botany & Plant Pathology, Hermiston Agricultural Research & Extension Center (HAREC), Oregon State University
Don Horneck;	Dept of Botany & Plant Pathology, Hermiston Agricultural Research & Extension Center (HAREC), Oregon State University

Field Cooperation:

In-kind tractor operations	Jim Ossman, Robert Oliver, Dave Barta; Crop Production Services, Pasco WA
In-kind chemigation operations	Monte Spence Wind Flow Fertilizer. Mattawa, WA
In-kind industry support**:**	Jim Owen, Kurt Volker, and Jerry Krebs Tessenderlo Kerley Inc.
In-kind grower support**:**	Ed Schneider, Schneider Farms, Pasco WA

Introduction:

Soil incorporated shank applications will allow a much greater percent of circles to be fumigated, especially in locations where residential dwellings and difficult to evacuate zones are in close proximity to the field. Upcoming EPA-OPP revised buffer specifications greatly reduce shank application buffers compared to high, medium, and low release water run fumigations. However, some growers have expressed concern that soil incorporated shank applications may not be as effective as surface water run for controlling soil-borne pathogens that can affect vine health and subsequent tuber yield/quality. To provide the grower with efficacy data, side-by-side-by side medium release-solid stream-shank efficacy demonstrations were conducted in 2009-2010 comparing Sectagon 42^{TM} effectiveness. These replicated-randomized block plot trials were also designed to compare each application method's efficacy at traditional (40 GPA), lower (20 GPA), and higher 60 GPA application rates. Pre, post fumigation and pre-harvest assays of soil-borne pathogens, in-season plant evaluations, and harvest yield/quality were collected. This efficacy assessment was conducted within a commercial potato-producing field circle in Franklin County planted in the spring 2010 season with Ranger Russets.

Methods:

A ca. 148 acre eight tower circle with corner catchment was made available in October 2009. This field demonstration was developed to compare water run to shank and to drizzle-boom when using Sectagon 42 at regional application rates of 40 GPA but also investigated product efficacy through harvest at lower (20 GPA) and higher (60 GPA) application rates. The three application rates were randomly assigned (in triplicate) among the nine ca. 12^{o} wedge sections within the test field. A tenth wedge (J) was set aside as an untreated control (see Figure 1). To

avoid edge effects, the ninety GPS positions (81 application rate-practice treatment plots (A-I) and 9 untreated control plots (J)) were equidistantly positioned between treatment tower rows and application rate sections. Because of the possibility for overlapping fumigant contamination, untreated control plot locations were not randomized within the A to I treatment sections.

Set-up, field conditioning, and applications: For the water run application, low elevation drop nozzles (ca. 5ft from ground level) were retrofitted to tower rows 1, 3, and 7. The drizzle boom assembly was positioned at tower rows 2, 4, and 5. Towers rows 6, 8, and the corner catcher (row 9) were capped off for subsequent Sectagon 42 ground application by tractor-drawn shank injection with soil compaction. During the center pivot application, line pressure was carefully monitored for sections "A" through "I" to assure even Sectagon 42 application rate coverage at 20, 40, or 60 GPA. Figure 2 shows the retrofitted center pivot water run-drizzle boom system and operations during the fumigation period (retrofitting and application performed by WindFlow Fertilzer). Shortly after completion of the field center pivot chemigation, tractor drawn shank injections (with roller compaction) were performed by Crop Production Services to a blade depth of ca. nine inches within tower rows 6, 8 and 9 (catchment area) according to the "A" to" I" plot section description in Figure 1. The drizzle boom-water run center pivot chemigation was completed one-day before conducting the shank application. Enough water was applied to bring the entire field test sections to ca. 70-80% moisture content before conducting all fumigation treatments.

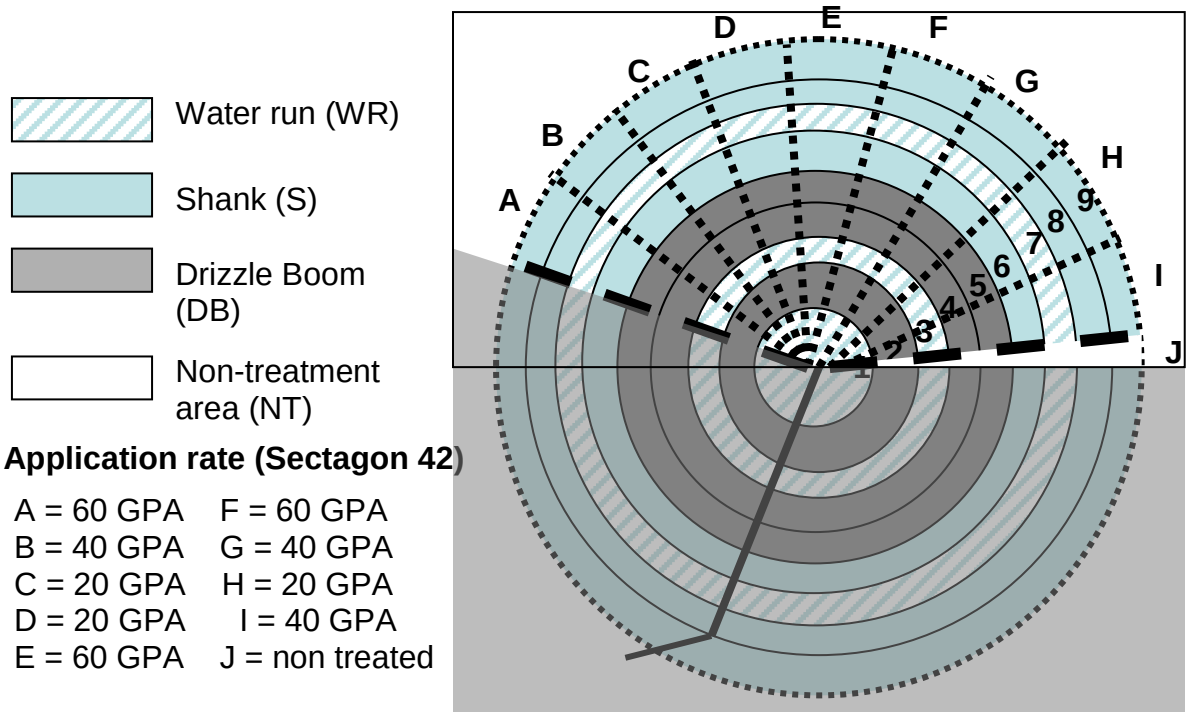


Figure 1: 2009-2010 Field Efficacy Layout (148 acre 8 tower circle with corner catchment)

Figure 2: Sectagon 42 Center Pivot Water Run-Drizzle Boom Application

Soil borne pathogen soil assays: Before the fall 2009 field fumigation and in the spring of 2010 before seeding, soil cores were taken and segregated into two soil depths (0-12 and 12-24 inches) then composited from each of the treatment plots. The 360 composited soil core samples (90 soil treatment plots x 2 depths x 2 sampling dates) were assayed by OSU HAREC for *Verticillium dahliae, Pythium* spp., and *Fusarium*.

Visual plant evaluations: Field foliage sampling was conducted by WSU-Plant Pathology on September 3rd, 2010; one week before commercial field harvesting. Stems were sampled fresh and not previously vine killed. Stems were immediately to the WSU Plant Pathology lab the day of sampling. Samples were air dried in 48°F storage, held at 90% relative humidity, and examined in November 2010 for sclerotia incidence and severity of *Verticillium dahliae*. Approximately 60 cm of combined above and below ground stem were rated for percent sclerotia on stems. Six stems (subsamples) were averaged for disease from each of three replications by rate and application method.

Yield and grade assessments: Tubers were sampled September 7th 2010 from ninety 30 foot row vine-cleared plot sections. Potatoes were removed using a single row digger (CPS) or by hand digging (OSU and WSU). The potatoes were bagged and labeled from each plot, palletized, then transported on the day of field sampling to OSU HAREC for subsequent yield and grade assessment.

Results: OSU-HAREC Soil borne pathogen soil assays: *Verticillium* CFU pre-fumigation counts were low and more variable relative to *Pythium* and *Fusarium* for all three application methods. Tables 1 and 2 show lower post fumigation *Pythium, Fusarium,* and *Verticillium* CFUs after

fumigation for all application methods-treatment rates and at both composited soil core depths. Although variable, the below tables show consistent trends in higher shank post-fumigation CFU numbers for *Fusarium* and *Pythium* when compared to the two water run and solid stream surface application method treatments at all three application rates. The observed differences in higher pre-fumigant untreated control to treatment *Pythium* and *Fusarium* CFU counts is not readily explainable but could be partially attributed to less randomization from the "J" untreated control section.

Table 1: Composited 0-12" pre and post fumigation CFUs for three application methods and at three Sectagon 42 application rates

Treatment	Pre-Fumigation Pythium (CFU/g dry soil)	Post Fumigation Pythium (CFU/g dry soil)	Pre vs. Post Pythium	Pre-Fumigation Fusarium (CFU/g dry soil)	Post Fumigation Fusarium (CFU/g dry soil)	Pre vs. Post Fusarium	Pre-Fumigation Verticillium (CFU/g dry soil)	Post Fumigation Verticillium (CFU/g dry soil)	Pre vs. Post Verticlillium
Water Run @ 60 gpa	48 b	8 c	0.0039*	4725 b	1475 bc	0.0006*	6.0 bc	0.0 a	0.0004*
Drizzle Boom @ 60 gpa	33 b	7 c	0.0402*	4937 b	1834 bc	0.002*	9.6 ab	0.4 a	0.0017*
Shank @ 60 gpa	36 b	15 bc	0.0854	4790 b	2275 bc	0.0027*	6.9 abc	0.9 a	0.0048*
Water Run @ 40 gpa	62 b	8 c	0.0013*	4978 b	1085 c	<.0001*	8.4 abc	0.9 a	0.0006*
Drizzle Boom @ 40 gpa	50 b	2 c	<.0001*	4932 b	1038 c	<.0001*	6.7 abc	0.9 a	0.0024*
Shank @ 40 gpa	53 b	22 abc	0.0495*	5213 b	1620 bc	<.0001*	5.3 bc	2.0 a	0.1555
Water Run @ 20 gpa	58 b	6 c	<.0001*	4567 b	1611 bc	<.0001*	11.1 ab	0.4 a	0.0067*
Drizzle Boom @ 20 gpa	41 b	4 c	0.0092*	5198 b	1465 bc	<.0001*	13.8 a	1.1 a	0.0007*
Shank @ 20 gpa	48 b	36 ab	0.5434	4454 b	2538 b	0.0127*	12.4 ab	0.0 a	0.0025*
Untreated Control	121 a	40 a	0.0396*	9499 a	5760 a	0.1314	1.5 c	1.3 a	0.8597
	P=0.0086	P=0.0014		P=0.0052	P<.0001		P=0.0124	P=0.4522	

Values in the same column followed by the same number are not significantly different
*Pre and post fumigation CFU values are significantly different

Table 2: Composited 12-24" pre and post fumigation CFUs for three application methods and at three Sectagon 42 application rates

Treatment	Pre-Fumigation Pythium (CFU/g dry soil)	Post Fumigation Pythium (CFU/g dry soil)	Pre vs. Post Pythium	Pre-Fumigation Fusarium (CFU/g dry soil)	Post Fumigation Fusarium (CFU/g dry soil)	Pre vs. Post Fusarium	Pre-Fumigation Verticillium (CFU/g dry soil)	Post Fumigation Verticillium (CFU/g dry soil)	Pre vs. Post Verticlillium
Water Run @ 60 gpa	30 b	1 c	0.001*	3458 b	380 c	0.009*	12.0 a	1.1 ab	0.0123*
Drizzle Boom @ 60 gpa	23 b	2 bc	0.0171*	4459 b	485 bc	0.0356*	3.8 bcd	1.1 ab	0.0037*
Shank @ 60 gpa	24 b	7 bc	0.0639	2427 b	1028 a	0.0003*	6.7 abcd	0.2 b	0.002*
Water Run @ 40 gpa	51 b	1 c	0.0003*	3542 b	334 c	0.0001*	10.2 abc	1.1 ab	0.0198*
Drizzle Boom @ 40 gpa	50 b	0 c	0.0063*	4088 b	501 bc	0.0001*	3.6 cd	1.1 ab	0.0667
Shank @ 40 gpa	62 ab	2 bc	0.0021*	3161 b	853 ab	0.0071*	6.2 abcd	1.1 ab	0.0148*
Water Run @ 20 gpa	21 b	2 bc	0.0001*	3441 b	455 bc	<.0001*	10.0 abcd	1.3 ab	0.0092*
Drizzle Boom @ 20 gpa	38 b	2 bc	0.0083*	2930 b	554 bc	0.002*	11.1 ab	0.0 b	0.0006*
Shank @ 20 gpa	32 b	15 a	0.2271	2907 b	1194 a	0.0036*	9.8 abcd	0.7 b	0.0003*
Untreated Control	94 a	9 ab	0.0071*	7499 a	989 a	0.001*	2.7 d	2.9 a	0.8914
	P=0.0079	P=0.0001		P=0.0226	P=0.0001		P=0.0286	P=0.2094	

Values in the same column followed by the same number are not significantly different
*Pre and post fumigation CFU values are significantly different

WSU-Plant Pathology *Verticillium* sclerotia assessments: There were low disease severities among all application method and application rate plots ($p < 0.5\%$). The non treated (J) plots were, however, observed to have ca. 2 % disease severity. In agreement, only 3.4% of the sub sampled stems from fumigated plots were observed with *Verticillium* sclerotia compared to 26 % of the stems from the non-fumigated (J) control plots. As was observed during the earlier 2009 plant samples, the general lack of *Verticillium* sclerotia could be influenced by the collection of stems before senescence.

Two statistical approaches were conducted: one for all the trial plots and another not using the data from the 1st two towers (center of pivot) and the last most distal tower (#9) which were typically stressed. This also aided to reduce the bias of the water run and shank treatments which were more separated (Figure 1). From the two analyses, even though there was a lack of disease and much sample variation, there was a trend among plants sampled at the higher Sectagon treatment rate plots to have fewer *Verticillium* sclerotia. The trends in the data also showed that the water run treatment method had the least *Verticillium* sclerotia compared to the shank method while the water run and the solid stream surface treatments did not appear to differ.

OSU-HAREC Yield and grade assessments: Table 3 provides yield and specific gravity for potatoes collected from the 90 test plot locations. Total yield, size, and specific gravity were not significantly different ($p < 0.05$) among treatments and non-treated controls. However, total yield numbers were consistently higher from plots treated by surface applied water run/solid stream fumigation methods compared to shank application and at most all Sectagon product rates. Among the two surface applied methods, there was no appreciably difference in yield numbers. Yield numbers among replicates were too variable to separate out differences among the incremental 20, 40, and 60 GPA application rate increases. The below data does not consistently indicate product rates above 40 GPA appreciably increase total yield.

Table 3: Yield and grade assessment

Treatment	Yield						Specific Gravity
	Under 4 oz	Culls/2's	4 to 8 oz	8 to 12 oz	Over 12 oz	Total Yield	
Water Run @ 60 gpa	15.6 c	3.4 a	66.0 a	43.0 abc	17.5 a	145.6 a	1.0896 a
Drizzle Boom @ 60 gpa	16.3 bc	3.8 a	57.9 a	44.6 ab	19.2 a	141.8 a	1.0882 ab
Shank @ 60 gpa	20.6 ab	3.5 a	56.1 a	35.0 bc	15.9 a	131.1 a	1.0842 c
Water Run @ 40 gpa	18.2 bc	4.2 a	62.3 a	49.3 a	19.1 a	153.1 a	1.0861 bc
Drizzle Boom @ 40 gpa	17.0 bc	5.3 a	62.0 a	43.3 abc	20.7 a	148.3 a	1.0856 bc
Shank @ 40 gpa	19.1 abc	3.0 a	58.5 a	42.6 abc	16.0 a	139.2 a	1.0860 bc
Water Run @ 20 gpa	17.5 bc	4.3 a	60.1 a	38.1 bc	19.3 a	139.3 a	1.0859 bc
Drizzle Boom @ 20 gpa	16.1 bc	4.8 a	61.9 a	44.4 ab	17.7 a	145.0 a	1.0861 bc
Shank @ 20 gpa	17.3 bc	1.3 a	57.2 a	40.3 abc	16.0 a	132.1 a	1.0869 abc
Untreated Control	22.6 a	2.1 a	56.1 a	33.6 c	14.7 a	129.0 a	1.0842 c
	P=0.0146	P=0.15	P=0.646	P=0.028	P=0.8703	P=0.2721	P=0.0149

Values in the same column followed by the same letter are not siginificantly different

Discussion:

This efficacy field demonstration show consistent trends towards fewer stem counts, fewer post-fumigation soil *Fusarium* and *Pythium* CFUs, and higher total yield tuber numbers at harvest when Sectagon 42 is applied at the soil surface (medium release height water run and solid stream) compared to soil incorporated shank treatments. The percent difference in total yield in shank to surface applications was ca. 7% at the 40 GPA Sectagon product rate. It is important to emphasize that the shank injection was conducted at a 9" soil depth for both soil borne pathogen control and nematode suppression.

Although there was a trend towards reduction in yield, the data sets also indicate that incremental adjustment in blade depth should enhance product efficacy while retaining reduced-emission shank buffer zone benefits to the grower. EPA-OPP made clear that buffer zones for shank applications will be substantially less restrictive when compared to all soil surface water run-solid stream application practices. As a given example during a recent February 2011 joint EPA-OPP/WSDA fumigation training session, a shank buffer (without water seal) will be ca. *60 feet* compared to a *600 foot* low release solid stream application buffer when on a 120 acre field at ca. 40 GPA Sectagon product rate. This shank buffer distance can be further reduced to *25 feet* if a water lap of 0.25 inches can be put down immediately after the shank application.

Shank and low drift solid stream application technology decisions will take on immediate importance in PNW potato-producing regions starting in 2012. Grower decisions will be especially important where field edges exist near dwellings, near or at residential/commerce interfaces, or in close proximity to "difficult to evacuate" locations and will involve considering buffer label specifications together with efficacy/economics and available shank/chemigation resources. This field-scale regional demonstration on comparative field efficacy should provide greater assurance to the grower in making prudent metam sodium fumigation decisions.

This side-by-side-by side efficacy demonstration would not have been possible funding by the Washington State Potato Commission, Oregon Potato Commissions and also without the close working associations and resources provided by crop consultants (Jim Ossman, CPS and Monte Spence, WindFlow, growers (Ed Schneider, Schneider Farms), registrants (TKI), and university WSU-OSU faculty-staff (Dennis Johnson, Tom Cummins, Phil Hamm, Don Horneck, Jordan Eggers, Jane LePage and James Cavenah).

Potential Weather Information for Management of Potatoes

Gerrit Hoogenboom
AgWeatherNet
Washington State University
Prosser, Washington 99350
Gerrit.Hoogenboom@wsu.edu
www.weather.wsu.edu

Traditionally the US Federal Government has been responsible for providing weather information to the citizens of the USA. Most people are familiar with the local weather forecasts that are issued by the National Weather Service (NWS; www.weather.gov), an agency of the National Oceanic and Atmospheric Administration (NOAA; www.noaa.gov). A second role of NWS and NOAA is to provide weather data through local monitoring stations. The more advanced and automated sites are normally located at airports of major cities to support the aviation industry, such as those located in Seattle-Tacoma, Wenatchee, Pasco and Yakima. In addition, NWS operates a network of Cooperative Observer Stations. Traditionally these sites were operated by volunteers who recorded the maximum and minimum thermometer and rainfall using traditional devices, including a liquid thermometer for temperature and a dipstick for rainfall. These volunteers were very dedicated and committed, as readings had to be taken at a fixed time each day, rain or shine and independent of holidays or weekends. There are many stations that have records that go back for at least a century. For Prosser, Washington, we have found paper records that go back as far as July, 1925. However, we found similar paper records for October, 2010. It seems that during the past 85 years not much progress had been made in recording local weather data for Prosser.

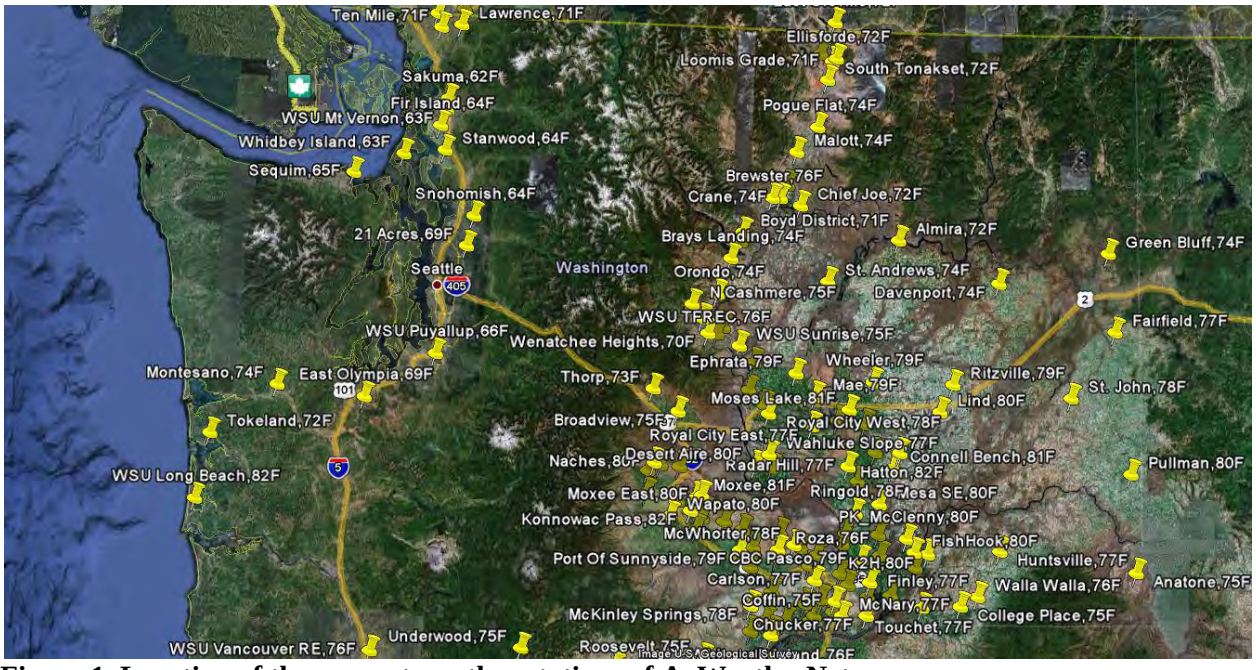


Figure 1. Location of the current weather stations of AgWeatherNet.

Many of the decisions that are made by potato growers are directly or indirectly affected by either past weather conditions, current conditions, or future conditions and forecasts. Although the NWS provides a wealth of weather information, it does not always address current agricultural issues. As a result, many Land-Grant Universities have developed automated weather station networks to specifically support local agriculture. Examples include the University of Nebraska, the University of Georgia that runs one of the largest weather networks in the southeastern USA (www.Georgiaweather.net) and Oklahoma University and Oklahoma State University, which operate one of the largest networks in the USA (www.mesonet.org). Washington State University (WSU) initiated the Public Agricultural Weather System (PAWS) in 1988. This initiative received support from many growers and producers in the Columbia Basin. Over the years the system has gone through many changes in instrumentation, communication and sensing technologies as well as management. In 2008, the network was upgraded to a state-of-the-art network and the network currently comprises 135 automated stations. The name of the network was changed from PAWS to AgWeatherNet several years ago. The location of the current weather stations can be seen in Figure 1.

Figure 2. Automated weather station at the Irrigated Agriculture Research and Extension Center (IAREC) in Prosser, Washington.

In addition to AgWeatherNet, there are many other weather monitoring networks in the Pacific Northwest. These networks are managed by various federal and state agencies as well as private companies. Installing a weather station is relatively easy, but maintaining a station that provides reliable and high quality data is a challenge. AgWeatherNet is in a position to maintain a network of automated stations that is well-maintained through direct financial support by WSU. A scheme has been developed for rotation and calibration of each sensor using the calibration facilities that are currently being developed at the Irrigated Agriculture Research and Extension Center (IAREC) in Prosser, Washington. There are also plans to hire a meteorologist who will be responsible for the daily quality assessment and quality control procedures. The goal of AgWeatherNet is to provide high quality data that are of benefit to growers, producers and others interested in local weather information.

Each weather station is a stand-alone unit that is powered by battery and solar panel. A weather station monitors air temperature, relative humidity, wind speed and wind direction, solar radiation, leaf wetness and soil temperature a depth of 8 inches continuously. The weather data

that are monitored are summarized every 15 minutes. Easy access to local weather data is as important as providing accurate data. PAWS and AgWeatherNet have moved from local radio telemetry communications to using cellular-based data telemetry and the internet for transmission of data between each weather station and local computer servers. AgWeatherNet currently has one data server located at the Tree Fruit Research and Extension Center (TFREC) in Wenatchee and one data server located at IAREC in Prosser. The data from each station are pulled every 15 minutes, sent to a local database in Prosser and pushed to a web server on the main campus of WSU in Pullman. Through the web site www.weather.wsu.edu users can retrieve current weather information, a summary of yesterday's weather data and many other customized data reports (Figure 3).

One of the strengths of AgWeatherNet is not only the dissemination of accurate weather data, but also weather-based tools and decision aids. Models for potato early and late blight have been implemented. There is also a simple tool for irrigation management. This information can not only be retrieved from the AgWeatherNet web site (www.weather.wsu.edu) using a regular personal computer, but also using a handheld or portable device (www.weather.wsu.edu/mobile). There is also an option to set an alert system that sends a text message to your cell phone based on preset threshold values for temperature and other weather variables (www.weather.wsu.edu/awn.php?favorite=show).

Communication and information technologies are rapidly developing. In parallel, scientific models and associated decision aids are also rapidly developing. Growers and producers are expected to make more timely and precise decisions in order to reduce production costs, while maintaining and improving product quality. AgWeatherNet is planning to emphasize the development and implementation of a range of models to support the local agricultural industry. Initially we are planning to develop both simple and more complex phenological models that can predict growth and development over time using local weather data from AgWeatherNet as well as crop and variety specific information. This will require using historical data bases on crop development as well as collecting detailed data where needed to help develop these models. Coupling current weather information, past weather data, weather forecasts and climate outlooks with these crop models will allow growers to have a better indication of the current status of a tree or crop and to make more informed management decisions. Ultimately the goal of AgWeatherNet is to not only provide timely and reliable data, but also to provide tools and decision aids which are relevant and can be easily accessed and applied.

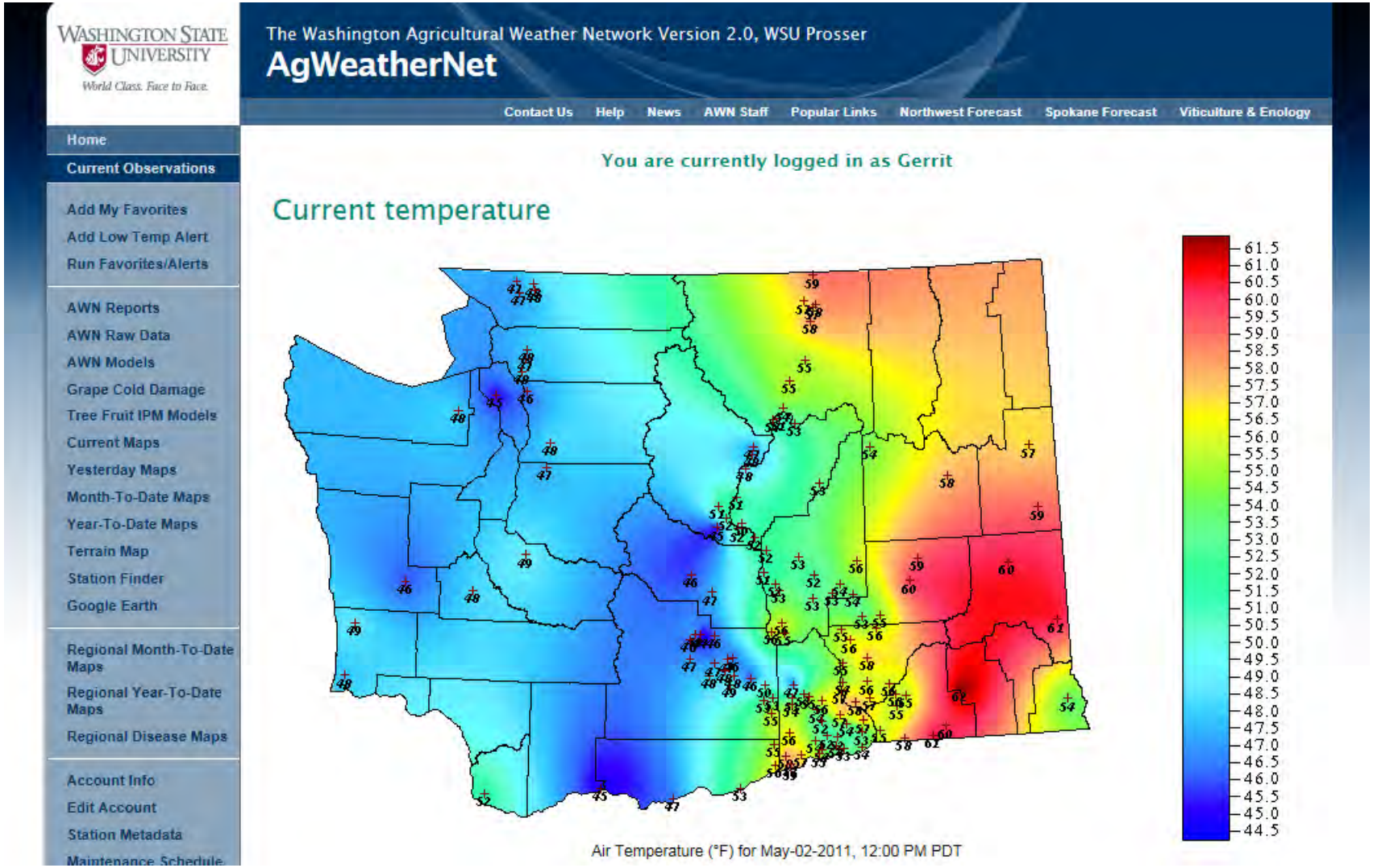


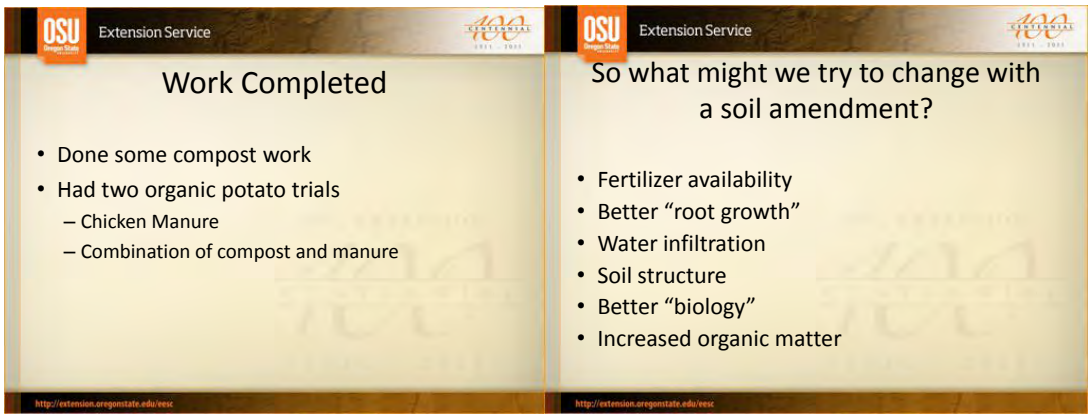
Figure 3. AgWeatherNet web site.

Soil Amendments, Manure vs. Compost

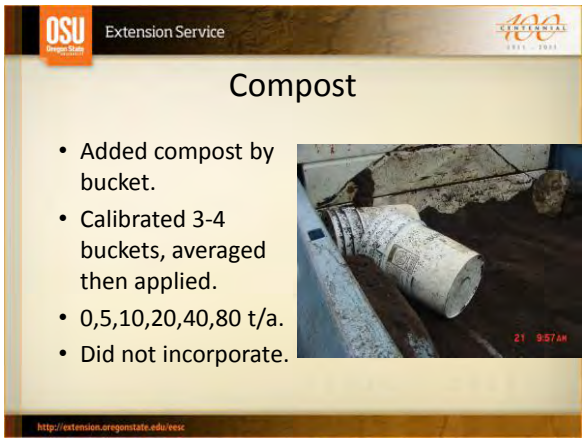
Donald Horneck, Ph.D.

OSU-Hermiston Agricultural Research and Extension Center

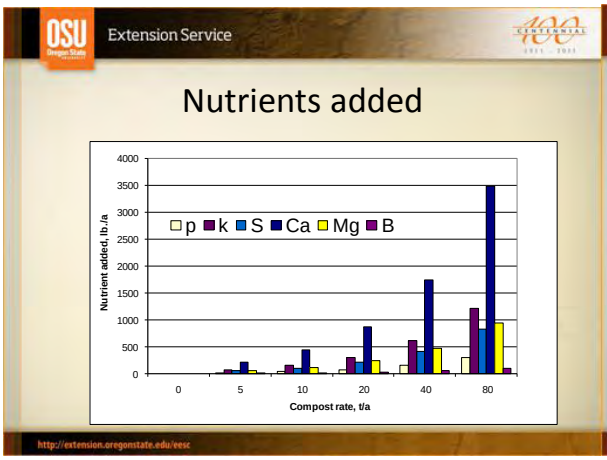
Manure is much more like fertilizer than is compost when nitrogen or sulfur is needed.

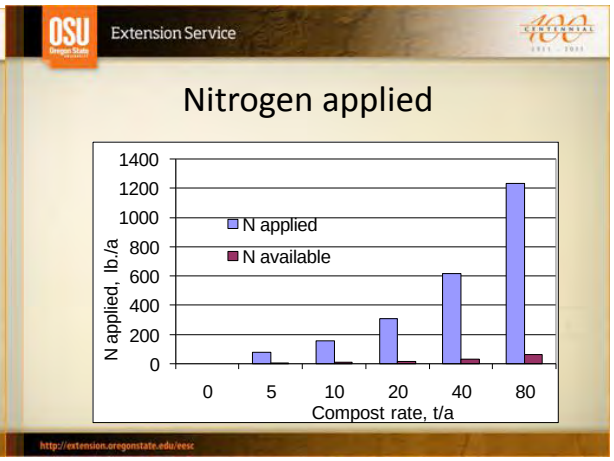


Soil amendments can have long term (15-20 years) impact on the soil.

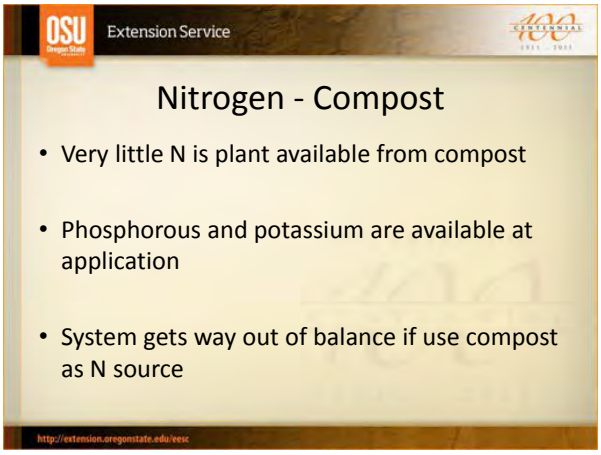


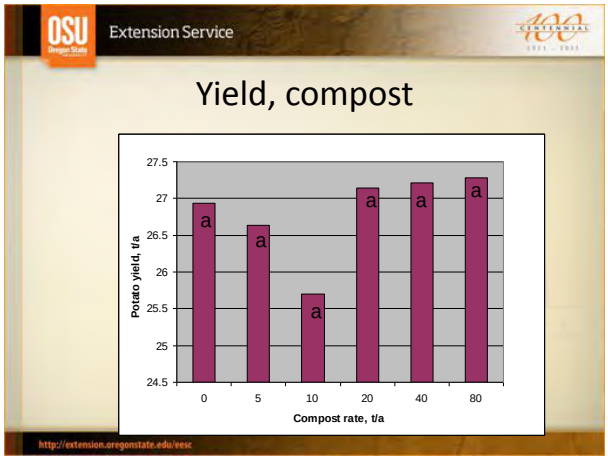
A compost trial conducted at Terra Poma Farms in Hermiston Oregon.





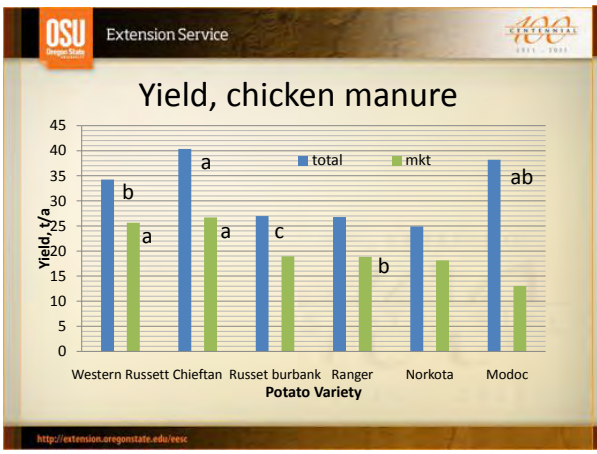
Total nutrients added vs. nutrients available. Total N added is over 1400 lb/a at the 80 t/a compost but less than 100 lb available N per acre. Sulfur would behave similar to N. Phosphorous and potassium would be available at application. To supply all nitrogen needs with compost, P and K would have to be grossly over applied.

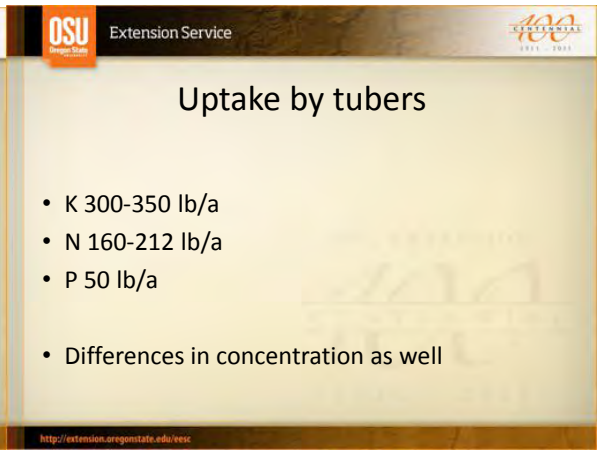




Yield for compost treatments did not significantly vary for Atlantic potato dug in June.

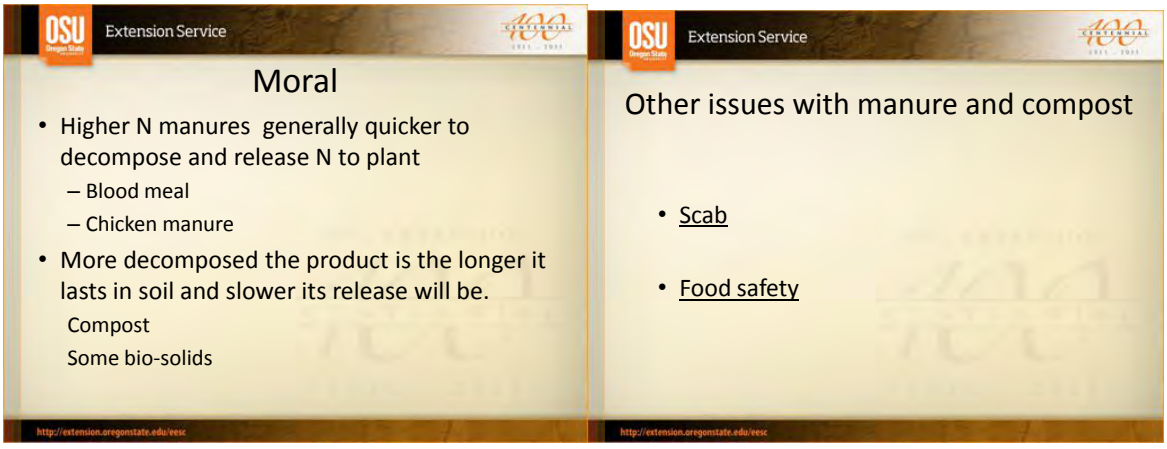
Unlike compost which is a long term soil amendment, manure nitrogen is largely available in the first year. Cow manure would have roughly 50% of the nitrogen applied in the first year. Even with 50% availability of the nitrogen in manure P and K would still be over applied.



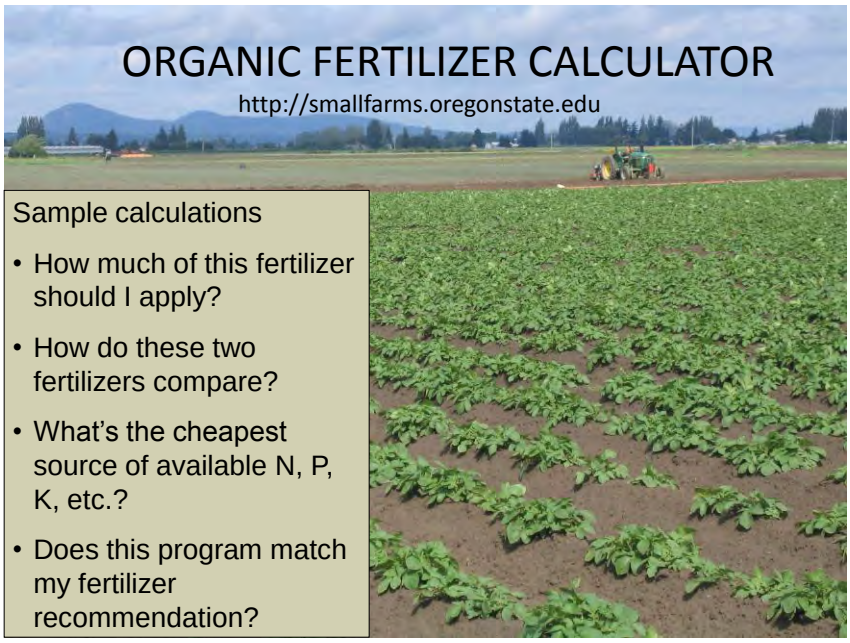


Chicken manure has 75% nitrogen availability the first year. The results from an organic nitrogen trial where 6 t/a chicken manure was applied to 6 different potato cultivars. Uptake between cultivars of K, N and P were similar.

Conventional N is soluble and available at application and does not need to be kept track of year to year because 100% is released the first year. For manure and composts N availability must take into account previous years applications. This nitrogen is not seen in a soil test and needs to be accepted based on application history.



The more N in a manure or compost the more that is generally available for potato growth in the first year and the less that will carry over into subsequent years. Other issues may drive manure and compost use such as food safety and the potential for scab.



The organic fertilizer calculator located at the above web address is an excellent tool to help you figure out the nitrogen available from a given amendment as well as the cost you are paying for a pound of nitrogen.

Aging of Seed Potatoes
Physiological Process & Consequences for Production

N.R. Knowles, Jake Blauer and L.O. Knowles
Dept. of Horticulture & Landscape Architecture
Washington State University, Pullman

Exposing seed tubers to temperatures greater than 39°F (i.e. heat-unit accumulation) increases respiration and accelerates physiological aging. Apical dominance, tuber set, tuber size distribution, and economic return can be greatly affected by differences in the physiological age of seed (Knowles and Knowles, 2006). The degree of apical dominance (number of stems per seedpiece) is a good indicator of physiological age. As seed age advances, apical dominance decreases, resulting in more stems per plant. While cultivars vary in the extent of their response to seed age, in general, tuber set per plant increases with stems, resulting in a decrease in average tuber size.

Tuber set and size distribution can be optimized for a particular market by increasing or decreasing the average number of stems per seedpiece, without affecting overall yield (Knowles and Knowles, 2006). The values of seed, fresh-market, and processing potatoes are dictated in part by the specific array of tuber size classes; therefore, manipulating tuber size profiles by varying the physiological age of seed lots can significantly affect crop value. The extent of aging induced by a given period of high temperature exposure and the target stem number for a particular size distribution are cultivar-dependent.

The relationships among stem numbers, tuber set, tuber size distributions, and crop value have been determined for many mainstream long-russet cultivars (e.g. Ranger Russet, Russet Burbank, Russet Norkotah) (see Knowles and Knowles, 2006; Knowles et al., 2008). An example of these relationships is shown for Russet Norkotah CO strain 3 in Fig. 1.

Fig. 1. Changes in tuber set and average tuber size (A), marketable yield (B), tuber size distribution (C) and economic values (fresh and seed contracts) (D) of Russent Norkotah (Colorado strain 3, CORN 3) in the Columbia Basin. Data are averaged over the 2004, 2005 and 2006 growing seasons (Knowles et al., 2008).

Development of techniques to predict, manipulate and better manage the physiological age and yield potential of seed potatoes is a core area of research in the potato postharvest program at WSU. The more we learn about the physiological process of aging, the better equipped the industry will be to understand how management practices can alter tuber physiology to affect the aging process. Recent work has suggested that tuber respiration is the 'pacemaker' of aging. Aging is an oxidative process that affects the hormonal regulation of apical dominance (Kumar and Knowles 1996a; 1996b; 1993). Preliminary studies (Knowles, unpublished) have indicated that seed tubers exposed to relatively brief periods (e.g. 10-20 days) of high temperature initially in storage, followed by holding at 39°F for the remainder of a 200-day storage interval, have a higher basal metabolic (respiration) rate at the end of storage compared with tubers stored the entire season at 39°F (Fig. 2).

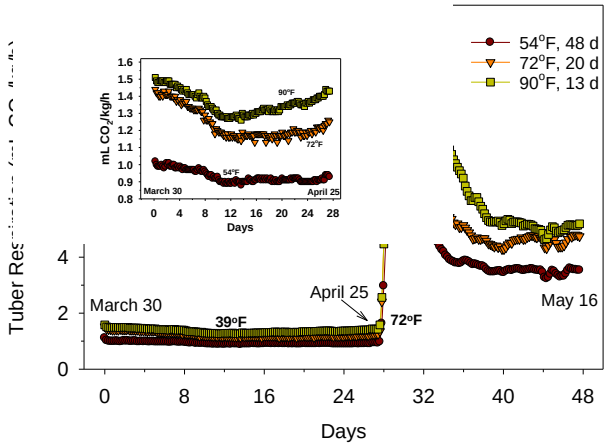
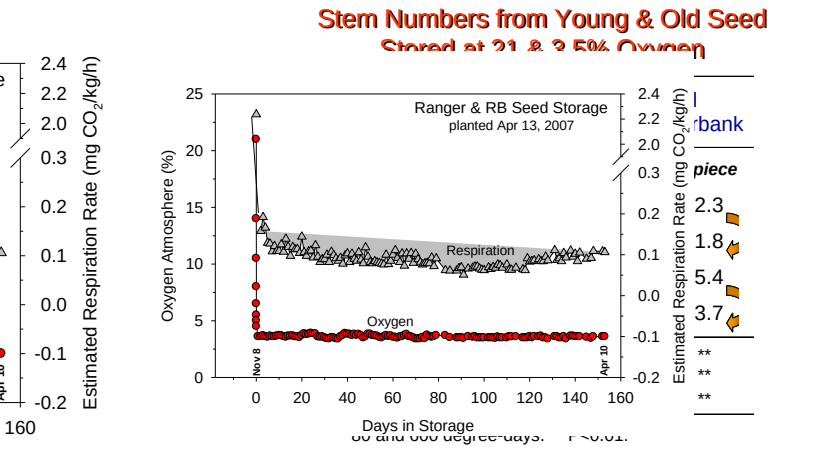


Fig. 2. Effects of high temperature aging treatments at the beginning of storage on respiration rates of Russet Burbank tubers at the end of storage. Seed-tubers accumulated 450 degree days at 54, 72 and 90°F in storage directly following harvest (late September). The tubers were then stored at 39°F until April 25. Respiration rates were compared from March 30 to April 25 at 39°F (inset). Note that tubers aged at higher temperatures at the beginning of storage had higher respiration rates at the end of storage. The storage temperature was increased to 72°F on April 25 to compare respiration rates during the early stages of sprouting. Tubers aged at 72 and 90°F had 37 and 49% higher rates of respiration than those aged at 54°F during sprouting.

ɛ brief high temperature accelerated aging
at the end of storage. An accurate but somewhat
ay therefore be the total respiratory output from
ppears to be the pacemaker that dictates the rate
t respiration may, in effect, 'set the clock speed'
ed at planting.

ling evidence of the importance of tuber
brief high-temperature (age priming) treatment
5% O_2 and 39°F until planting. The low O_2
ɛd relative to seed stored under conventional 21%
aging treatment on stem numbers, tuber set, and
3).

ıe pacemaker that controls and reflects the rate of
ıetabolic rates of tubers, even for short
'erent physiological age. Physiological age may
(e.g. from vine kill to planting). And the higher
lder the seed lot will be. Knowing this, we can
begin to design treatments that will set the respiration rate at different levels to control the aging process. The work is relevant to how seed is managed from maturation through storage to planting.



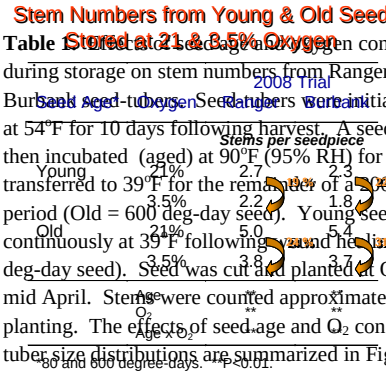


Table 1. Effects of seed age and oxygen concentrations during storage on stem numbers from Ranger and Russet Burbank seed-tubers. Seed-tubers were initially wound-healed at 54°F for 10 days following harvest. A seed sample was then incubated (aged) at 90°F (95% RH) for 21 days and then transferred to 39°F for the remainder of a 200-day storage period (Old = 600 deg-day seed). Young seed was stored continuously at 39°F following wound healing (Young = 80 deg-day seed). Seed was cut and planted at Othello, WA in mid April. Stems were counted approximately 55 days after planting. The effects of seed age and O_2 concentration on tuber size distributions are summarized in Fig. 3.

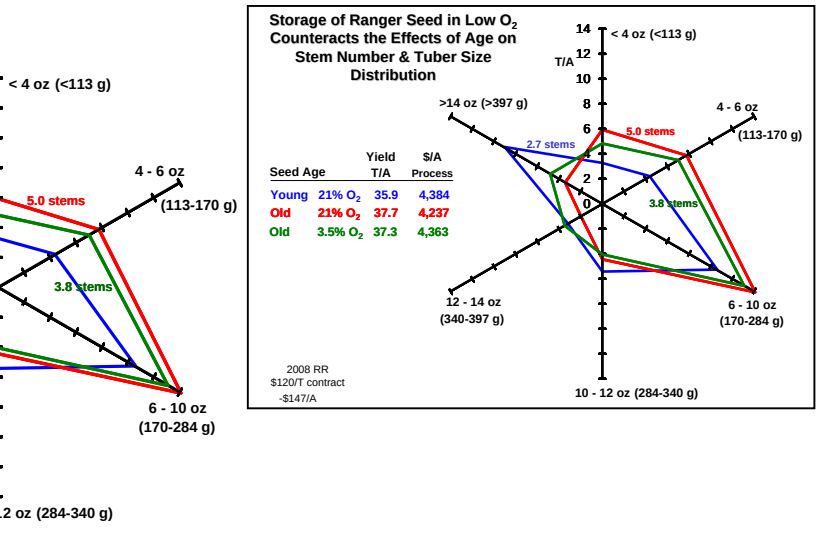


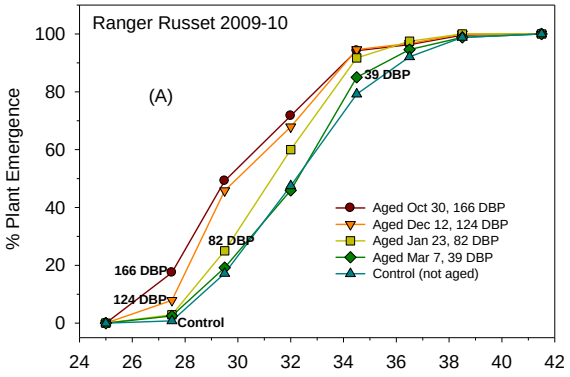
Fig. 3. Storage of Ranger Russet seed-tubers in 3.5% O_2 mitigates the effects of advanced seed age (high temperature induced) on stem numbers and shifts the tuber size distribution toward that characteristic of younger seed, which has low stem numbers.

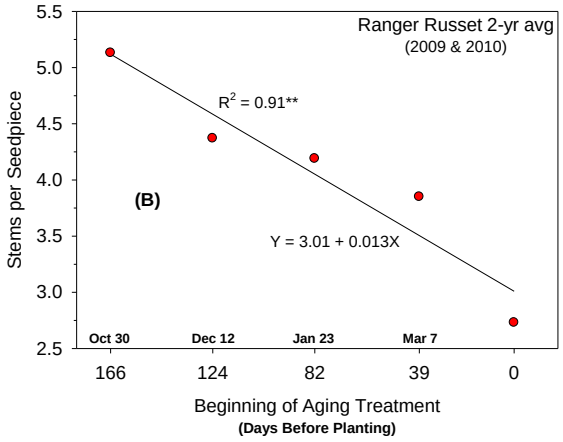
If temperature-induced accelerated aging depends on permanently elevating the basal metabolic rates of tubers, it should be possible to demonstrate progressive attenuation of the effects of an age priming treatment on respiration over a 200-day storage period, and subsequently on stem numbers, tuber set and size distribution in the resulting crop. Preliminary studies have indicated that the sensitivity of seed potatoes to high temperature-induced accelerated aging decreases from vine kill through storage to planting (Fig. 4). However, the high temperature-induced increased respiration response was the same regardless of when the age-priming treatment was given during the storage season. These results underscore the importance of time in the aging process. Exposure of seed to a high temperature age priming treatment at the beginning or end of storage elevates respiration (the pacemaker) to the same degree; however, the timing of these treatments results in vastly different physiological ages. The only difference between these treatments is the time interval from treatment to planting. The longer the respiration rate of tubers remains at an elevated level, the greater their physiological age at planting. This research is fundamental to our understanding of the aging process and has practical relevance in contributing to recommendations for end-of-season handling and storage of both seed and processing potatoes.

Summary

- Seed age affects stem numbers & tuber size distribution in a predictable manner
- Manipulating seed age & stem numbers can alter crop value
- Aging is an oxidative process involving respiration, which responds directly to temperature
- Exposure of seed-tubers to high temperature advances physiological age

- Seed tubers 'remember' exposure to high temperature, which is indicated by elevated metabolic rate; respiration is likely the pacemaker of aging.
- Sensitivity of a seed lot to aging diminishes with time in storage (need to develop treatments that can 'set the clock speed' for aging)
- Physiological age appears to be the integration of respiration over time.





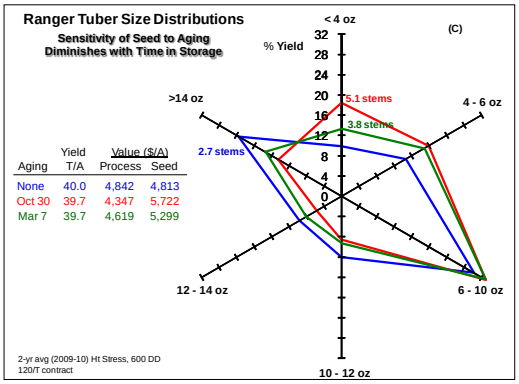


Fig. 4. Effects of seed age on plant emergence (A) stem number per seedpiece (B), and tuber size distribution (C) depend on the timing of an accelerated aging treatment (21 days at 90°F) during the storage season. Seed tubers are most sensitive to high temperature-induced accelerated aging at harvest and become progressively less receptive with time in storage. For these studies, seed-tubers were acquired at harvest and wound-healed at 54°F (95% RH) for 10 days. The seed was then stored at 39°F, except for brief (21-day) aging treatments at 90°F (95% RH) given to separate samples on Oct. 30 (166 days before planting, DBP), Dec. 12 (124 DBP), Jan 23 (82 DBP), and Mar. 7 (39 DBP). Control (non-aged) seed was stored the entire season at 39°F. The four aged seed lots had each accumulated 600 degree days (4°C base) at different times over the 200-day storage interval. Note that the greatest effect of the aging treatment on hastening plant emergence and increasing stem number occurred when given early (166 DBP). The effect of the age priming treatment diminished progressively when imposed later in the storage season. The age priming treatment sets the pacemaker of aging (tuber respiration) at a high rate and the longer the respiration is maintained at a high rate before planting, the greater the physiological age.

References Cited

Knowles, N.R. and L.O. Knowles, 2006. Manipulating stem number, tuber set, and yield relationships for northern- and southern-grown potato seed lots. Crop Sci. 46:284-296.

Knowles, N.R., Knowles, L.O., Pavek, M.J., Harris, G., and Martin, M. 2008. Effects of tuber maturity on quality of seed and processing potatoes. Washington State Potato Commission Progress Reports for 2007. pp.71-102.

Kumar, G.N.M., and N.R. Knowles. 1996a. Nature of enhanced respiration during sprouting of aged potato seed-tubers. Plysiol Plant. 97 (2): 228-236.

Kumar, G.N.M., and N.R. Knowles. 1996b. Oxidative stress results in increased sinks for metabolic energy during aging and sprouting of potato seed-tubers. Plant Physiol. 112: 1301-1313.

Kumar, G.N.M. and N.R. Knowles. 1993. Involvement of auxin in the loss of apical dominance and plant growth potential accompanying aging of potato seed-tubers. Can. J. Bot. 71:541-550.

Discovery & Development of a New Class of Potato Sprout Inhibitors

N.R. Knowles and L.O. Knowles
Dept. of Horticulture & Landscape Architecture
Washington State University, Pullman

Background

Sprout inhibition during long term storage of potatoes is required to preserve fresh weight, dry matter, processing quality, and consumer acceptability. In Washington State alone, an estimated 4.6 billion pounds of stored potato tubers are treated with sprout inhibitor annually. Currently, the most widely used and effective compound registered for this purpose is the carbamate herbicide, CIPC (isopropyl *N*-(3-chlorophenyl) carbamate). In recent years, the EPA has lowered tolerance levels for CIPC residue on potatoes and tolerance levels in many export markets are substantially lower than in the U.S., requiring more frequent applications of CIPC at lower concentrations to maintain sprout inhibition. Alternative inhibitors for prolonged sprout control are thus being investigated. Biological alternatives to CIPC, such as clove oil and 1,4-dimethylnaphthalene, are available; however, the duration of sprout control is relatively brief with these agents, requiring multiple applications to achieve season-long sprout control.

We have discovered a new chemistry (α,β-unsaturated carbonyl compounds) for the suppression of sprouting in potato tubers. Small scale studies have demonstrated that full season sprout control (7-9 months) can be effectively achieved with 2-3 applications of α,β-unsaturated carbonyl compounds having the general structure shown below (Fig. 1).

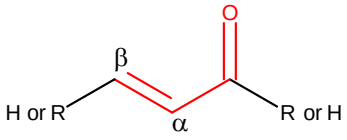


Fig. 1. General structure of an α,β-unsaturated carbonyl.

Many compounds containing this specific arrangement of functional groups are biological in origin. For example 6- to 10-carbon trans-2-aldehydes and ketones are components of the aroma and flavor of fruits, vegetables, and some mushrooms. Numerous compounds of this chemical family are approved for use as food flavoring additives in the U.S., Canada, EU, and Japan.

Efficacy

Research with the 9- and 10-carbon ketones has demonstrated that the duration of inhibition of sprouting depends on the timing of application, cultivar, and storage temperature. Maximum efficacy is achieved when applied after dormancy break when sprouts are peeping (Fig. 2). This is in contrast to CIPC, which must be applied prior to sprouting when tubers are dormant. Hence, the 'window of application' for the new inhibitors is narrower than for CIPC, demanding greater diligence to application timing for maximum efficacy. Using these compounds to control sprouting thus leverages the natural dormancy period of a particular cultivar.

The α,β-unsaturated carbonyls are volatile and can be fogged into commercial storages using conventional fogging equipment. Unlike CIPC and several other commercially available inhibitors, maintaining minimum residue levels is not important for efficacy of these compounds. Residue levels decline rapidly in tubers when ventilated with fresh air and residues are barely detectable three weeks after treatment. The precipitous decline in residue levels is due to high volatility of the compounds combined with their rapid metabolism to saturated aldehydes, ketones and ultimately alcohols.

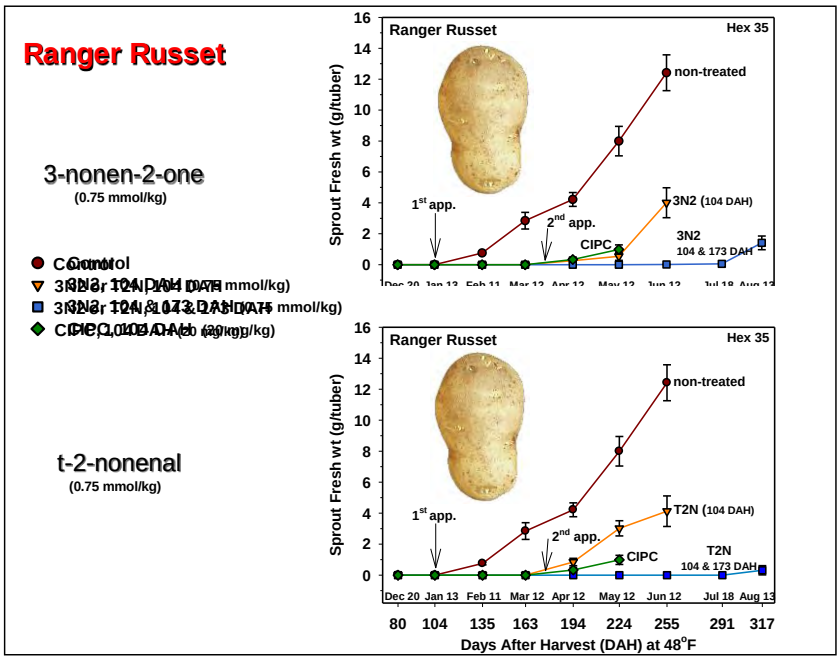


Fig. 2. Effects of single and dual applications of 3N2 (top) and T2N (bottom) on sprouting of Ranger Russet potatoes. Tubers were grown at Othello, WA and harvested October 1. Tubers were wound healed for ~10 days at 55°F and subsequently held at 48°F for the duration of storage. Timing of the first and second applications of sprout inhibitors were 104 and 173 days after harvest (DAH), respectively (arrows). CIPC was applied in a single application only. Tubers were treated for 24 h. Inset tubers show the extent of sprout development at the time of treatment.

Physiological Responses & Mode of Action

Meristematic tissues (buds) are most sensitive to being injured by the α,β-unsaturated carbonyl compounds. Sprouting tubers respond to treatment with a concentration-dependent transitory increase in respiration rate; a response that likely reflects injury to the developing sprouts. Tuber respiration rate then decreases progressively to pre-treatment levels within 7 to 10 days. Cells within sprouts experience a rapid loss of membrane integrity and increased peroxidation of membrane lipids, which results in oxidative stress. The metabolic pathways responsible for neutralizing reactive oxygen species and controlling cellular redox potential (e.g. glutathione system) are directly compromised by these compounds. The loss of membrane function, rapid water loss, and reduced ability to neutralize reactive oxygen species and modulate cellular redox potential collectively leads to unabated oxidative stress, cell death and tissue necrosis. Sprouts thus exhibit a "burnt out" appearance within 24 h of exposure to α,β-unsaturated carbonyl compounds (Fig. 3).

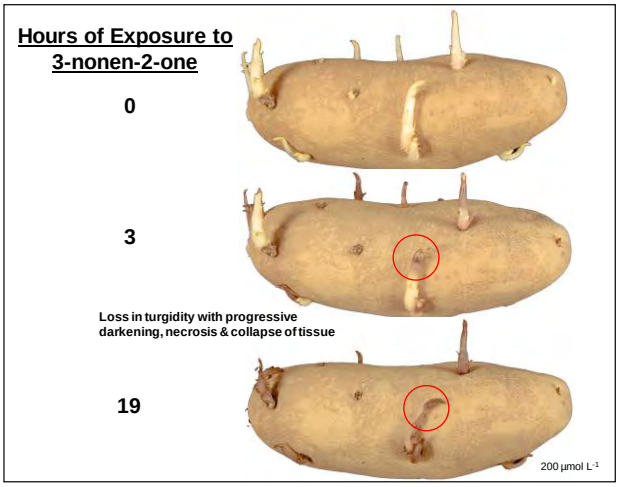


Fig. 3. Visible symptoms of the toxicity of 3-nonen-2-one (3N2) to sprouts. A sprouting tuber was exposed to 3N2 vapors for 19 h. Sprouts begin to darken within 3 h of exposure with accompanying loss of turgidity, starting at the sprout apex and moving downward. The progressive loss in turgidity results in collapse of tissue by 19 h. These symptoms are a primary consequence of reduced membrane integrity.

Current Status of Commercialization

WSU licensed the sprout inhibitor technology to AMVAC Chemical Corporation in 2005. Many compounds were screened for efficacy and ease of manufacture from 2005-07. Proof of concept studies were completed for the 10-carbon ketone (3 decen-2-one) in 2007 and a manufacturing method has been optimized. This compound, originally coded as AMV-1018, has been trademarked for commercial use as SmartBlock™. U.S. and Canadian registrations are pending. Registrations in Japan and the EU are being pursued. The following treatment strategy is based on results of trials in the U.S., France, Germany, Japan and the UK:

- Make first application as a thermal fog when potatoes show signs of breaking dormancy.
- 75% "peeping" is the preferred timing window.
- Recirculation should be for 24 hrs.
- Meristematic sprout tissue is destroyed & the initial effect lasts 2-3 months, depending on variety & temperature.
- Typically 2-3 applications will be required over a 7- to 9-month storage season.
- Sprouts up to 1 inch can be destroyed; hence, SmartBlock™ can be used to restore marketability (i.e. "rescue") sprouted tubers (Fig. 4).

Fig. 4. Sprouted Russet Burbank tubers were treated with 115 ppm SmartBlock™ for 24 h. Photo was taken 12 days after treatment. Tubers were stored at 61°F.

Making Sense of New PVMI Varieties and Their Management

MJ Pavek, NR Knowles, ZJ Holden, CD Hiles
Department of Horticulture and Landscape Architecture, Washington State University, Pullman, Washington, 99164-6414, USA

In 1874, Luther Burbank selected a white, smooth-skinned potato which was later named 'Burbank'. Decades later, a mutation of Burbank with netted skin was found in a Colorado field and eventually given the name 'Russet Burbank' or 'Netted Gem'. Since then more recently released varieties have gained market share and reduced the Russet Burbank acreage in North America. These varieties include, 'Shepody' from New Brunswick, 'Russet Norkotah' from North Dakota, and both 'Ranger Russet' and 'Umatilla Russet' from the Tri-State Research and Breeding Program.

All these successful varieties have certain qualities in common and they include good yield and storability, internal and external quality, and taste. In short, they all include the right characteristics for the market. Less obvious is the ability for growers and industry to be able to learn how to grow, manage, handle and store them; and as the industry has seen, many new varieties have fallen flat on their face because the industry was unable to make them work under "normal operating procedures".

If growers and industry are willing to learn how to handle and grow a new variety, it stands a fair chance of being successful. Ranger Russet is an example of one variety that the industry deemed worthy enough for them to accept the "new variety learning curve". When Ranger first hit the scene there were excessive issues with blackspot bruise. It was a serious issue and threatened the success of the variety. The industry responded by improving harvest and handling practices and now Ranger is grown on over 7,000 seed acres and is presently the third most widely grown commercial variety in the US.. As another example, the success of Umatilla Russet was challenged due to severe dry rot issues in the seed tubers. Seed producers responded by changing harvest and handling practices. Umatilla is now the fifth most widely produced variety in the US.

In deciphering what makes a variety successful, we examine Russet Norkotah. The obvious reasons for its success are nice shape and appearance; it has a high percent of US number ones with adequate yield and it returns profits to everyone in the distribution chain. A less obvious, but very important reason is that it is considered somewhat "bulletproof" in that it resists bruising and typically stores well without significant storage rot.

Since 2008 six named russet varieties have been released by the Tri-State Research and Breeding Program. They include Alpine Russet, Classic Russet, Clearwater Russet, Owyhee Russet and Sage Russet. Another variety currently being considered for release is A0008-1TE (anticipated name beginning in 2011: Teton Russet).

Of these new and potential releases, Classic Russet and A0008-1TE have the most promise to compete with Norkotah. Classic Russet has been increasing in seed growers

fields since 2007. It has a higher pack out rate than Russet Norkotah and an excellent taste with a brilliant white interior. It has low internal and external defects and is more resistant to PVY than Norkotah. During 2010, commercial growers expanded production quickly but several experienced post-harvest issues. In a few cases, Classic harvested directly out of the field and broke down in bags following fresh pack. Lack of proper skin set and susceptibility to shatter and soft rot are likely reasons for the break down. Skin set appears to be an issue with this variety, especially if excess nitrogen is applied prior to harvest. Management guidelines for Classic Russet can be found at www.pvmi.org to help growers produce a high quality crop. Several other harvest and handling considerations are also addressed on the website for those producing, or interested in producing, Classic. Classic typically produces a low tuber set (~ 1 less tuber/plant than R. Burbank) and has the potential for extremely large tubers. In-row spacing and nitrogen management are crucial to produce a profit maxing tuber size profile. Moreover, if Classic is planted too shallow or the hills are narrowed during cultivation, it may grow sprouts outside the hill (heat runners). As it turns out, Classic may be less "bullet proof" than Norkotah; however, it is possible to concentrate on management that avoids these issues and allows for production of a superior product. Considering Norkotah's susceptibility to PVY, its controversial flavor and internal appearance, we certainly believe Classic is worthy enough for growers to be patient and learn how to be successful with this variety.

A cross between Classic Russet and Blazer Russet has produced a new line that looks promising: A0008-1TE. It may be the first real dual purpose potato with a higher pack out and fresh market value than Russet Norkotah. It does well both early and late with a similar yield to Ranger Russet at about 110 to 120 day. It has excellent taste and high early yields with low internal and external defects. It is more resistant to PVY than Russet Norkotah and typically has higher post-harvest quality than Russet Burbank. This variety has a specific gravity similar to Russet Burbank. A0008-1TE needs to be grown similarly to Classic Russet with a few exceptions in the Columbia Basin: tubers need to be spaced at 12 inches in-row for an early (100 -130 days) harvest, and 8 – 10 inches for a harvest later than 130 days. Tubers should have fairly low hydration at harvest to prevent shatter. Interested growers should contact PVMI for up-to-date management recommendations.

Finding the right fit in the industry is crucial for several new processing varieties. Alpine Russet has excellent dormancy being slightly longer that Russet Burbank and high yields. Clearwater Russet has high specific gravity and a medium size profile. Owyhee Russet is an excellent processor with a high percentage of US number ones, a medium size profile, high specific gravity and excellent culinary qualities. Sage Russet has excellent yields both early and late and will work well as a processor.

Alpine Russet has high early yields and resists sugar ends. The extra long dormancy and processing qualities are better than Russet Burbank. Due to a low tuber set, tubers can get too large if seed is not spaced properly. The light skin may not be attractive to the fresh market. In the Columbia Basin, growers should plant 12 inches in-row for an early

harvest and 8 – 10 inches for a late harvest. Petiole N values average 2% higher than Russet Burbank in the early season.

Clearwater Russet has high protein and low internal and external defects. Its high specific gravity coupled with its resistance to sugar ends and high percent number ones make it an excellent choice. Aspects to be aware of are a tendency toward extremely high specific gravity, the possibility of a small tuber size profile (need to provide enough room between plants), susceptibility to dry rot, internal brown spot and shatter bruise. In the Columbia Basin, use an in row spacing of 10 – 12 inches for late harvest. The average petiole N values are typically 12% higher than Russet Burbank from early to mid season. As with the other varieties, allow for good skin set prior to harvest and handle with care. Some internal brown spot has been seen in the southern Columbia Basin.

Owyhee Russet has low external defects a good size profile and good specific gravity. It has excellent fry color with high process quality. A Washington State taste panel rated it high. Owyhee also resists common scab and Fusarium dry rot. The things you need to watch for are occasional vascular discoloration, late maturity and hollow heart occurring similarly to, or less than, R. Burbank. Columbia Basin management includes 10 inch in-row spacing for late season harvest. The petiole N values average 13% higher than Russet Burbank in early to mid season. Manage harvest to prevent shatter and prevent hollow heart by avoiding early lush vine growth

Lastly, Sage Russet is resistant to low temperature sweetening and late processes economic values are good. Post-harvest qualities are excellent. Sage can get too large if spaced improperly and is susceptible to blackspot bruising and shatter. This line has a short dormancy and can have a variable shape from one location to the next. In the Columbia Basin, plant at 12 inches in-row for early harvest and 8 – 10 inches for late harvest. Always harvest to minimize shatter and blackspot bruise.

In general all the new varieties have significantly superior characteristics when compared to traditional varieties. They all perform well under Russet Burbank management although many require less nitrogen. Consult www.pvmi.org for variety specifics. Most of these varieties will have higher petiole N counts than Russet Burbank and may approach Ranger Russet values. Remember, handle with care and pay attention to details. The new varieties require patience and dedication by the industry if they are to succeed.

Remember when considering a new variety, start small to minimize potential risks and losses. Do your homework, there is information regarding all the new varieties available at www.pvmi.org and at the University Extension Programs, at conferences, and workshops and from industry field consultants. With all new things there is a learning curve involved, expect hiccups and be patient.

Kansched for Potato Irrigation Scheduling

R. Troy Peters, P.E., Ph.D.

Profitable potato growing is very dependent on good irrigation management. Too little water causes poor yields and quality, while too much water encourages diseases, rinses important nutrients from the soil, and results in high water and power costs. It is important to have data-based estimates of when, and how much to irrigate. A relatively simple way to do this is to use Kansched. Kansched runs on your computer and comes in either an Excel spreadsheet (Kansched), or a compiled (Kansched2) program form and helps a grower do "checkbook" style irrigation scheduling. Reference evapotranspiration (alfalfa crop water use), and rainfall are taken from AgWeatherNet (http://weather.wsu.edu) and included in the model for that day. Irrigation amounts are also included. Kansched does a daily soil water balance (keeps track of inflows and outflows) and shows an estimate of the daily soil water content. The soil water deficit (amount of additional water the soil could hold in the root zone), and the percent of available water are given. These modeled soil water contents can be corrected with measured soil water contents as necessary.

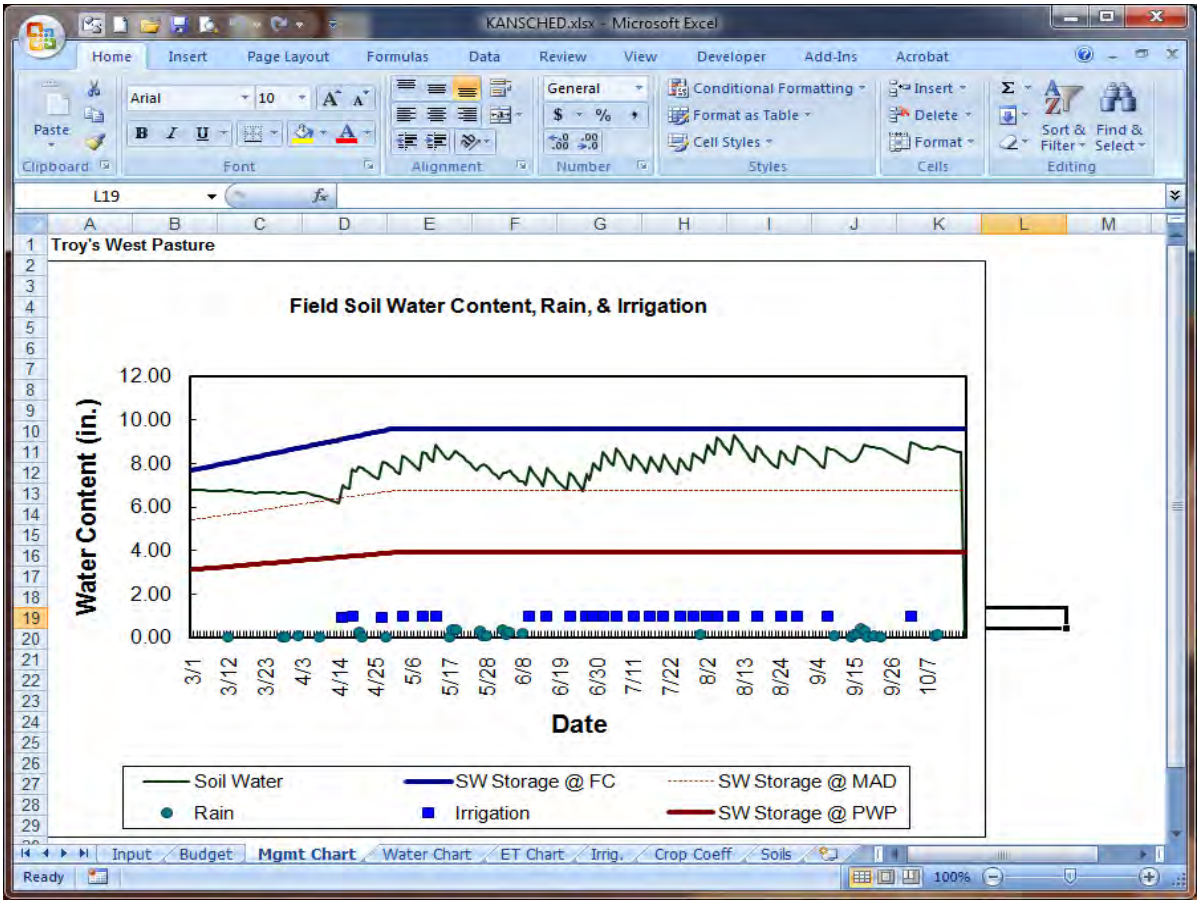
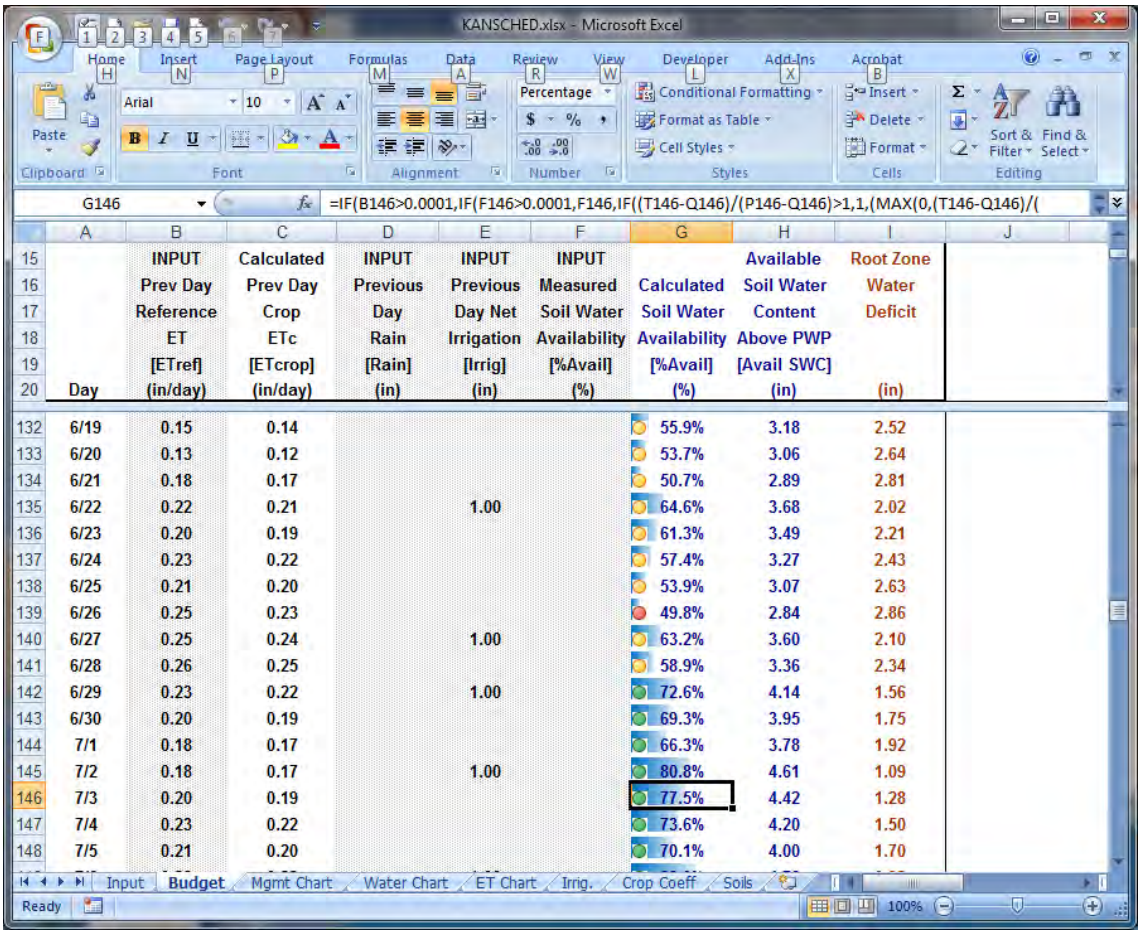


Figure 1. Soil water content chart produced automatically by Kansched (MS Excel version).



	A	B	C	D	E	F	G	H	I	J
15		INPUT	Calculated	INPUT	INPUT	INPUT		Available	Root Zone	
16		Prev Day	Prev Day	Previous	Previous	Measured	Calculated	Soil Water	Water	
17		Reference	Crop	Day	Day Net	Soil Water	Soil Water	Content	Deficit	
18		ET	ETc	Rain	Irrigation	Availability	Availability	Above PWP		
19		[ETref]	[ETcrop]	[Rain]	[Irrig]	[%Avail]	[%Avail]	[Avail SWC]		
20	Day	(in/day)	(in/day)	(in)	(in)	(%)	(%)	(in)	(in)	
132	6/19	0.15	0.14				55.9%	3.18	2.52	
133	6/20	0.13	0.12				53.7%	3.06	2.64	
134	6/21	0.18	0.17				50.7%	2.89	2.81	
135	6/22	0.22	0.21		1.00		64.6%	3.68	2.02	
136	6/23	0.20	0.19				61.3%	3.49	2.21	
137	6/24	0.23	0.22				57.4%	3.27	2.43	
138	6/25	0.21	0.20				53.9%	3.07	2.63	
139	6/26	0.25	0.23				49.8%	2.84	2.86	
140	6/27	0.25	0.24		1.00		63.2%	3.60	2.10	
141	6/28	0.26	0.25				58.9%	3.36	2.34	
142	6/29	0.23	0.22		1.00		72.6%	4.14	1.56	
143	6/30	0.20	0.19				69.3%	3.95	1.75	
144	7/1	0.18	0.17				66.3%	3.78	1.92	
145	7/2	0.18	0.17		1.00		80.8%	4.61	1.09	
146	7/3	0.20	0.19				77.5%	4.42	1.28	
147	7/4	0.23	0.22				73.6%	4.20	1.50	
148	7/5	0.21	0.20				70.1%	4.00	1.70	

Figure 2. Daily budget sheet in Kasched (MS Excel version). The grey columns are input by the grower and the white columns are calculated.

Kansched and Kansched2 were developed in Kansas and are available for free online. If entered into Google, it will be the top return. There are also user manuals available. The model needs an estimate of your soil's water holding capacity. There are defaults by soil texture available in the program, but a more accurate estimate for your particular field is available from the NRCS web soil survey (http://websoilsurvey.nrcs.usda.gov). Crop coefficients are multiplied by the daily reference alfalfa evapotranspiration (ETr) to account for the different growth stages of potatoes. Good initial estimates for the initial, maximum, and final crop coefficient are 0.4, 1.0, and 0.6 respectively. Season dates for your area will also have to be included in the model. Consult the manual for additional information. AgWeatherNet can be set up to email, or text you the daily ETr and rainfall amounts. This email or text is a good daily reminder to update this model and look at where the field is at.

Irrigation scheduling tools such as Kansched can help growers make better informed decisions on when water is required, and when soil moisture is adequate and pivots can be left off for a while. Feel free to call, or email with any questions you may have. Troy Peters, 509-786-9247, troy_peters@wsu.edu.

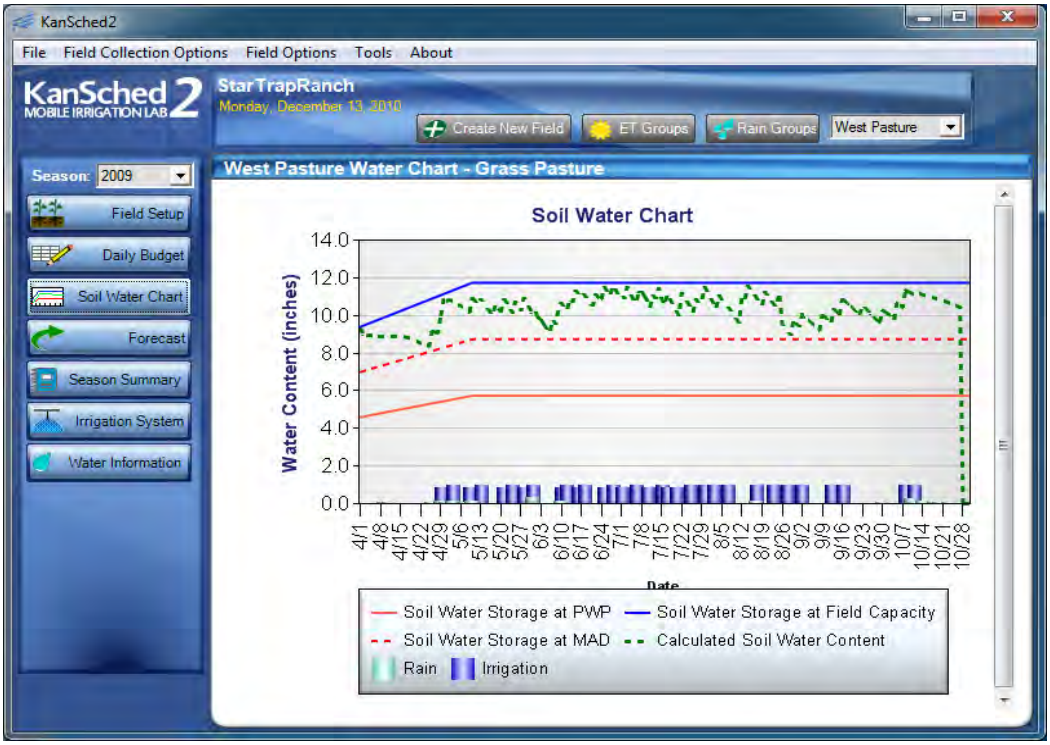
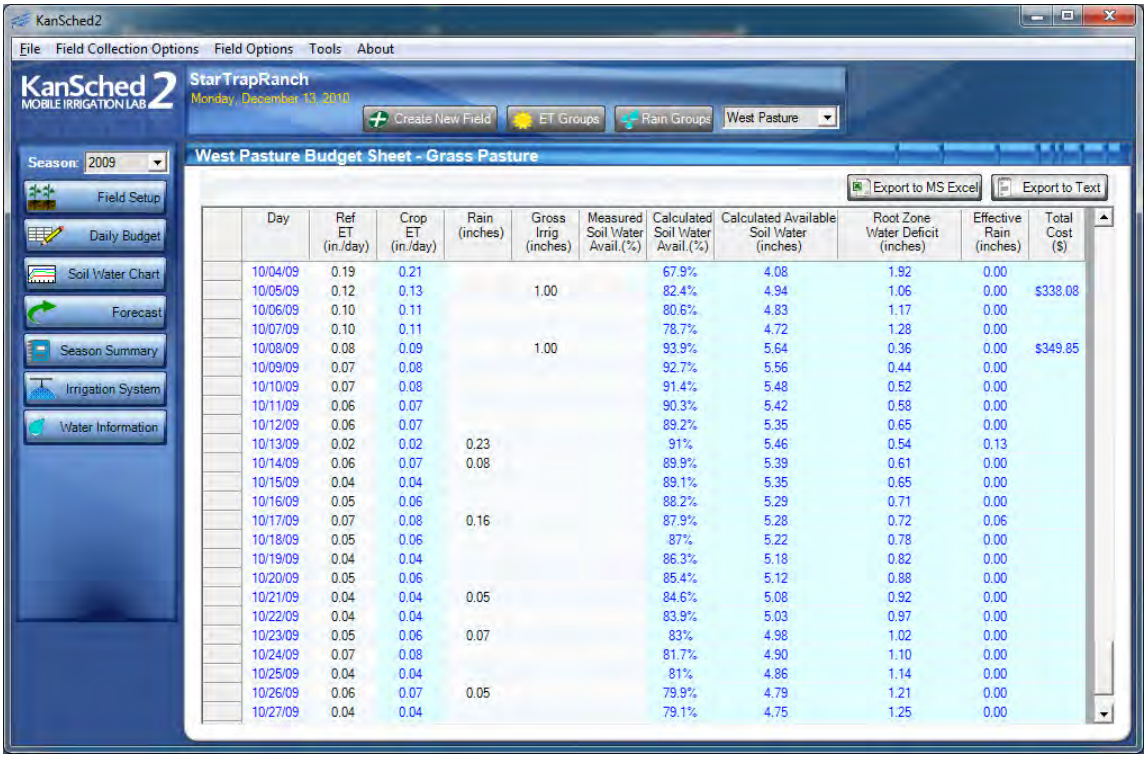


Figure 3. Soil water content chart produced automatically by Kansched2 (compiled program version).



Day	Ref ET (in./day)	Crop ET (in./day)	Rain (inches)	Gross Irrig (inches)	Measured Soil Water Avail.(%)	Calculated Soil Water Avail.(%)	Calculated Available Soil Water (inches)	Root Zone Water Deficit (inches)	Effective Rain (inches)	Total Cost ($)
10/04/09	0.19	0.21				67.9%	4.08	1.92	0.00	
10/05/09	0.12	0.13		1.00		82.4%	4.94	1.06	0.00	$338.08
10/06/09	0.10	0.11				80.6%	4.83	1.17	0.00	
10/07/09	0.10	0.11				78.7%	4.72	1.28	0.00	
10/08/09	0.08	0.09		1.00		93.9%	5.64	0.36	0.00	$349.85
10/09/09	0.07	0.08				92.7%	5.56	0.44	0.00	
10/10/09	0.07	0.08				91.4%	5.48	0.52	0.00	
10/11/09	0.06	0.07				90.3%	5.42	0.58	0.00	
10/12/09	0.06	0.07				89.2%	5.35	0.65	0.00	
10/13/09	0.02	0.02	0.23			91%	5.46	0.54	0.13	
10/14/09	0.06	0.07	0.08			89.9%	5.39	0.61	0.00	
10/15/09	0.04	0.04				89.1%	5.35	0.65	0.00	
10/16/09	0.05	0.06				88.2%	5.29	0.71	0.00	
10/17/09	0.07	0.08	0.16			87.9%	5.28	0.72	0.06	
10/18/09	0.05	0.06				87%	5.22	0.78	0.00	
10/19/09	0.04	0.04				86.3%	5.18	0.82	0.00	
10/20/09	0.05	0.06				85.4%	5.12	0.88	0.00	
10/21/09	0.04	0.04	0.05			84.6%	5.08	0.92	0.00	
10/22/09	0.04	0.04				83.9%	5.03	0.97	0.00	
10/23/09	0.05	0.06	0.07			83%	4.98	1.02	0.00	
10/24/09	0.07	0.08				81.7%	4.90	1.10	0.00	
10/25/09	0.04	0.04				81%	4.86	1.14	0.00	
10/26/09	0.06	0.07	0.05			79.9%	4.79	1.21	0.00	
10/27/09	0.04	0.04				79.1%	4.75	1.25	0.00	

Figure 4. Daily budget sheet in Kasched2 (compiled program version). The white columns are input by the grower and the light blue columns are calculated.

The architecture of basic entomology: the who, what and where of common insect pests in the 2010 season

Silvia I. Rondon, Extension Entomologist Specialist
Oregon State University, Hermiston Agricultural Research and Extension Center

The purpose of this article is to acquaint people with the incredible biological diversity represented by the largest group of living organisms: insects. We will review most of the common orders and/or insect species found in the 2010 potato growing season in relation to potato crop development. We will focus on general characteristics of potato pests, monitoring and control options.

March-April: Planting Season Begins

Planting season for potatoes in the lower Columbia Basin typically extends from about mid to late March until early June. In some instances, it may start as early as the second week of February. Insects and related pests can cause problems both at pre-planting and planting. Pre-planting general recommendations: control weed hosts, use soil-applied insecticides when necessary. At planting, use systemics properly when appropriate to target pests and to protect non-target organisms.

Wireworm

Wireworms are the larval stage of click beetles and can cause damage to potatoes in two ways: (1) feeding upon potato seed pieces and their emerging sprouts in the spring that can facilitate infection by pathogens or (2) damaging developing tubers by direct-feeding. The latter damage can result in reduction in yield and/or rejection of the entire crop. Wireworms tend to be most damaging in potatoes that follow corn or small grains and on ground just entering cultivation.

(Top) Damage caused by wireworm; (bottom) wireworm entering tuber.

Adult click beetles are slender hard-shelled insects. They range in color from tan to dark brown and from about ⅛ - ¾" long depending on species. Click beetles get their name from their ability to snap a spine on their thorax that produces a clicking sound and allows them to jump in the air when disturbed. All beetles in this family have this ability, which they use to avoid predation or to get back on their feet after falling on their backs. After mating, each female lays an average of 80 eggs singly or in small clusters in the soil. Unlike the soft-skinned immature stages of most insects, wireworms have a hardened and shiny shell and very few hairs. They have three body regions, a distinct head, a thorax with 3 pairs of legs

and a segmented abdomen with processes at the tail-end. Depending on species and age, wireworm larvae range from about 2 mm after hatching to 4 cm (1/16 - 1½") long or more at maturity. Wireworm pupae are first white, but later change to reddish-brown.


Wireworm larva. Photo by OSU-Smith

Click beetle. Photo by OSAC

Adult click beetles emerge from pupae in the soil from late spring through late summer. In the Pacific Northwest, wireworms overwinter as larvae or adults. Adults can fly, but usually they prefer to remain in areas where develope larvae. tend t laying grassy Larvae from 2-5 the soil, on species. They require several mature and can overwinter at a de 24'' or more in the soil, only to retur surface in spring to resume feedi spring when soil temperatures exc

false wireworm - adult and larva


Crane fly larva. Internet photo

80°F and above, the larvae tend to move deeper than 6 inches into the soil to escape the "heat". Be careful when you identify wireworm larva because another insect larva of the family Tenebrionidae, usually a saprophagous, resembles wireworm. Wireworm larva can also be confused with crane fly larva.

Monitoring. Wireworm presence or absence in a field should be determined before using control measures. Unfortunately, current monitoring methods are time consuming, laborious and often do not accurately reflect - field populations or this pest's damage potential. Historically, wireworms have been monitored by extracting and sifting through soil cores to locate mainly larvae. Since the distribution of wireworms in a field tends to be patchy and unpredictable, large numbers of samples are required to accurately

estimate population size. Baits have largely replaced random soil sampling, since they are less labor intensive and may detect low wireworm populations.

Control. Economic thresholds vary depending on crop susceptibility, the cost of control measures, market tolerance of pest damage and other factors. Low density but still damaging wireworm populations can be difficult to attract so we recommend trapping from April to May. Dave Horton (2006) modeled the relationship between bait trap counts and crop damage by *Limonius canus* in Wapato, WA. Damage forecast based on bait counts obtained either before or after planting of potatoes –is presented below. Remember that it is difficult to predict crop damage from trap counts so these values should be used with caution.

Wireworms per bait	Pre-planting		Post-planting				
	Predicted % of tubers suffering damage						
	20 April	26 April	3 May	10 May	17 May	24 May	22 June
0	5	2	6	7	8	7	7
0.25	14	24	15	16	16	20	50
0.5	22	40	23	24	23	32	69
1.0	37	62	36	38	35	49	83
1.5	49	74	47	49	45	61	86
2.0	59	81	56	57	52	70	86
2.5	68	85	63	63	59	75	87
3.0	75	88	68	68	65	80	87
4.0	85	90	76	75	72	84	87
5.0	93	90	81	79	77	87	86
10.0	100	91	91	85	84	89	86
15.0	100	91	92	85	85	89	86

Predicted *L. canus* damage incidence to potatoes at various population densities measured with trap counts using rolled oat baits (Horton 2006).

There are no biological control methods for wireworm. If one suspects wireworms are present in a field based on trapping, chemical control is the best management option (http://potatoes.com/Research-IPM.cfm). More information regarding wireworm control can be found at: http://extension.oregonstate.edu/catalog/pdf/pnw/pnw607.pdf

April-June: Pre-emergence, Emergence through Tuber Growth

After plant emergence, design a monitor program for insects and mites. A well designed Integrated Pest Management program combines the use of several management strategies while maintaining profitability and ecological balance. Before any control measure is taken, one needs basic information regarding the current situation of the crop, history of the crop (record of previous problems), and a register of the presence of pest (s) and natural enemies. This information will be useful in determining whether a control measure is needed or not. It is

essential to obtain at a minimum estimate of these parameters in order to establish an efficient sampling protocol that minimizes costs and time of effort. Several pests affected the potato crop in 2010 during the months of April through June. Among them were Colorado Potato Beetles, aphids, and beet leafhoppers. Few reports were received regarding loopers, cutworms, mites and thrips in the region.

Colorado Potato Beetle

The Colorado Potato Beetle (CPB) i
0.25 inch wide. They can be found with two rows of black spots on each side. Yellow egg clusters are found mainly on the undersides of leaves in the top third of the plant. This beetle can cause complete defoliation and nearly complete crop loss if allowed to reproduce unchecked. Both larvae and adults feed on potato foliage throughout the season. Pupation and overwintering occurs in the soil. Adults emerge from soil to lay eggs in the spring. In the southern Columbia Basin, – this beetle may have three generations in a season.

Colorado Potato Beetle

Eggs

Larva

Adult

Pupae

Control. Crop rotations may help in delaying or reducing CPB pressure. Adult beetles spend the winter buried 4 -10 inches in the soil and emerge in the spring just as the first volunteer potatoes appear. Recently emerged beetles either mate close to the overwintering sites or fly to new potato fields to find a mate. Colonizing beetles need to feed before starting to lay eggs, thus controlling volunteer potatoes and weeds is important. This practice will reduce the number of migrating overwintering beetles into the new field. The use of “at planting” and systemic insecticides in early potatoes will contribute to the control of early-season CPB populations. Spinosad, apply by air; ground or chemigation is a good pesticide that targets eggs and young larvae.

Green peach aphids and potato aphids

Aphids on potato are serious pests because of their ability to transmit several plant diseases such as potato leaf roll virus (PLRV) (transmitted mainly by green peach aphid) and potato virus Y (PVY) (transmitted by several species of aphids). PLRV causes necrosis while strains of PVY can cause internal brown lesions in the tubers.

Green peach aphid *Myzus persicae*) arrives on potatoes in the spring from weeds and various crops where it has overwintered as nymphs and adults, or from peaches and related trees where it overwinters as eggs. Potato aphids (*Macrosiphum euphorbiae*) also overwinter as active nymphs, adults or eggs; eggs are laid on roses and sometimes other plants. Throughout the growing season aphids produce live young, all of which are female and can be either winged or wingless. In the fall, winged males are produced which fly to overwintering hosts and mate with egg-laying females produced on that host. Aphids found in the region undergo multiple overlapping generations per year.

Potato aphid (top, wingless form; below, winged form). Photo by A. Jensen

Green peach aphid, the most serious aphid in the region. Top, wingless form, bottom, alatae. Photo by A. Jensen

Monitoring. Fields should be checked for aphids at least once a week starting after emergence. The most effective scouting method is beating sheets, trays, buckets or white paper. There are no well-established treatment thresholds for aphids in potatoes in the PNW.

Control. Weed control and elimination of secondary hosts are critical. Early aphid infestations commonly occur on a number of weeds including species of mustards and nightshade. Therefore, those weeds should be kept under control, especially in seed-growing areas where disease prevention is essential. If aphids are present, use of insecticides should occur as soon as non-winged aphids are detected.

Beet Leafhopper

The beet leafhopper (BLH) is approximately 0.125 inches long, wedge shaped, and pale green to gray or brown in color. It may have dark markings on the upper surface of the body early and late in the season (”darker form”). BLH overwinters on rangeland weeds and migrates to potatoes as early as May. Direct feeding can cause relatively minor damage; however, BLH is able to transmit BLTVA (beet leafhopper transmitted virescence agent), a very destructive and detrimental disease affecting potatoes. Among the favorite hosts of BLH, Kochia, Russian thistle, and various weedy mustard species such as tumble mustard, especially if they are young-marginal-irrigated and small.

Control. Weed control in areas surrounding the potato field can help reduce initial sources of BLTVA inoculum. Foliar insecticides can reduce BLH populations and ergo, the incidence of the disease. More information at http:///potatoes.com and http://uspest.org/pnw/insects?23POTA04.dat.

July-October: Maturation and Harvest

Potato Tuberworm

The potato tuberworm (PTW) is one of the most economically significant insect pests of cultivated potatoes. A recent study suggests that locations with higher spring, summer, or fall temperatures are associated with increased trapping rates in most seasons. Moreover, elevation and latitude appears to play a constraining role as low densities of PTW are associated with higher elevations and latitudes. It remains unclear how severe of a pest PTW will be in the Columbia Basin in the following years, but it is highly likely that the species will be with us for the near future. Although the PTW’s host range includes a wide array of Solanaceous crops such as tomatoes, peppers, eggplants, tobacco, and weeds such as nightshade, it has only been found on potatoes in the region.

PTW adults emerge as early as April in the Columbia Basin, and continue to threaten

Potato tuberworm adult (top; photo by ODA) and larva (bottom; photo by OSU L. Ketchum).

the crop through November. Populations build sharply later in the growing season (September and October) and can potentially cause tuber damage. Control efforts should be directed toward populations during this time. If PTW populations appear to be building prior to late season, additional control measures may be necessary.

Other means of control- include the elimination of cull potatoes and piles, and the control of volunteer potatoes. Daily irrigation that keeps the soil surface moist can also aid in the control of PTW. - Consider control - close to harvest, since PTW females prefer to lay eggs on potato foliage. When potato foliage starts to degrade and turn color, the risk of tuber infestation increases greatly. THE PERIOD BETWEEN DESICCATION AND HARVEST IS A TIME OF INCREASED RISK OF TUBER INFESTATION.

Occurrence, Aggressiveness and Fungicide Sensitivity of *Alternaria solani* and *Alternaria alternata* Isolates from Potato in the Columbia Basin of Washington

Lydia S. Tymon, Thomas F. Cummings, and Dennis A. Johnson
Department of Plant Pathology, Washington State University, Pullman, WA

Early blight and brown spot on potato are caused by separate species of *Alternaria.* Lesions caused by *Alternaria solani* Sorauer (Ellis), the pathogen responsible for early blight, are distinct in that large concentric rings are formed within a tan colored lesion (Stevenson et al. 2008). Initially, the lesions are small, dark, and circular, but as they enlarge, they become angular, due to the presence of the leaf veins. Lesions are typically surrounded by a chlorotic halo due to fungal metabolites (Rotem 1994). In comparison, lesions of brown spot, caused by *A. alternata*, tend to be smaller and darker in color, but can be numerous (Nolte 2008).

Both pathogens overwinter as spores or mycelium (Stevenson et al. 2008), but the source of primary inoculum is spores in debris or soil from the previous year. Three-year crop rotations are needed to reduce the initial amount of primary inoculum present. Infection occurs as spores germinate and enter into the tissue through wounds or stomata (Stevenson et al 2008). After lesions form, spores develop within the center of lesions during alternating wet and dry periods. Additional factors determining spore formation are temperature, light, and relative humidity (Stevenson et al. 2008). Multiple cycles of spore production takes place during one season. Spore dissemination is mainly by air currents (Rotem 1994), but secondary mechanisms of dispersal are splashing from rain and irrigation water (Rotem 1994). Early blight and brown spot are both regarded as diseases of senescing plant tissue, and as plants age, they are more susceptible to infection (Rotem 1994).

Fungicide resistance- Traditional management strategies include the use of broad-spectrum fungicides such as mancozeb and chlorothalonil. The benefit to these products is that resistance has not been observed in spite of frequent and prolonged use. Yet, decreased mammal toxicity and a reduction of environmental impact due to residuals on the environment (Rosenzweig et al. 2008) are two reasons for a switch from broad-spectrum to narrow-spectrum fungicides. Fungicide resistance is a regular concern when managing crops, especially when the chemical affects a single site mode of action and the development of fungicide resistance is highly likely with frequent use of these products (Hamm et al. 2008). Quinone outside inhibitor (QoI) fungicides, which include azoxystrobin, pyraclostrobin, and trifloxystrobin, inhibit cellular respiration by interfering with the electron transport chain (Rosenzweig et al. 2008). Strobilurin sensitivity has been conferred by two single point mutations in fungal genomes (Rosenzweig et al. 2008). *A. solani* has recently been reported to be insensitive to strobilurin fungicides in Idaho (Belcher et al. 2010). Currently, there are no records of *A. alternata* populations infecting potato that are resistant to strobilurin fungicides, although *A. alternata* may exhibit a natural insensitivity.

Frequency of isolates- Fungal isolations were made from lesions on leaves collected from the Columbia Basin, Bonner's Ferry, ID, and Acequia ID to determine the

prevalence of *Alternaria* species in 2009 and 2010. Of 308 isolates obtained in 2009, 107 (35%) were *A. solani*, 185 (60%) were *A. alternata*, and 16 (5%) isolates were *C. coccodes*. A total of 823 isolations were made in 2010. *A. solani* was isolated 362 (44%) times, *A. alternata* was isolated 354 (43%) times, and *C. coccodes* was isolated 91 (11%) times. Multiple fungi were isolated from the same lesion both years. The frequency of isolation of *A. solani* (19%) from lesions collected in the Columbia Basin in 2009 did not differ from the frequency of isolation of *A. alternata* (17%), even though the frequency of isolations of the two fungi did vary over time (Fig. 1). In 2010, *A. alternata* was typically isolated more frequently than *A. solani* from leaves with lesions collected in the Columbia Basin (Fig. 2). During both years, *A. solani* was isolated less frequently than *A. alternata* at the end of the potato-growing season.

Pathogenicity and Aggressiveness Assays- Pathogenicity and aggressiveness assays using 34 isolates collected in 2009 were performed on detached Norkotah Russet leaves. Leaves were collected from potted Russet Norkotah plants that were maintained in the greenhouse. Leaves were then placed into 5.5 cm deep Pyrex baking pans lined with moistened paper towels and fiberglass screen. Detached leaves were sprayed with distilled water until runoff. Ten µL of inoculum was dropped onto filter paper, which was then placed facedown onto the detached leaves. The Pyrex pans were then wrapped into large plastic bags and rubber banded closed. The filter paper was removed after 48 hours, with signs and symptoms of infection typically occurring during this time period. Lesion expansion was determined to assess aggressiveness (Berger 1997). Disease severity was measured as the proportion of leaf area covered by the lesion after 5 days using one *A. solani* isolate and one pathogenic isolate of *A. alternata*.

Pathogenicity was determined by the formation of lesions on detached leaves and aggressiveness was evaluated by lesion expansion (Fig. 3). Initial lesion formation typically occurred within 48 hours of *A. solani* inoculations and within 48 to 72 hours when leaves were inoculated with pathogenic *A. alternata* isolates. All seventeen isolates of *A. solani* (100%) resulted in lesions whereas only nine of seventeen isolates of *A. alternata* (53%) caused lesions. Expansion of lesions caused by *A. solani* occurred more rapidly than those caused by *A. alternata.* The disease severity determined was 12% for *A. solani* vs. 4% for *A. alternata.*

Frequency of Isolates from Foliage Treated with Fungicides - Fungal isolations were made from lesions on foliage treated with various fungicides in replicated plots in trials at Quincy, WA (Table 1), and Acequia, ID (Table 2). Sixteen lesions from each fungicide treatment were randomly selected and assayed on modified PDA plates. Plates were scored based upon species of fungi isolated.

In Quincy, the frequency of isolation of *A. solani* and *A. alternata* on lesions assayed from nontreated control plots was 50% and 56%, respectively. The frequency in which *A. solani* was isolated from lesions was less from lesions treated with fungicides than the nontreated control. The frequency of isolation of *A. alternata* was not significantly less than the nontreated control. A fungicide program of Quadris Top rotated with Bravo WS was the most effective at reducing the frequency of isolation of *A. alternata* (Table 1).

Three fungicide trials were done in Acequia, ID. *A. solani* occurred on all lesions assayed from nontreated plots and frequency of isolation was not significantly different among any of the fungicide programs tested. The frequency of isolation of *A. alternata*

on lesions assayed from nontreated control plots was 38%. Although the frequency of isolation of *A. alternata* increased when fungicides were applied in two of the three fungicide treatments, frequency of isolate was not significantly different from nontreated plots. Regardless of the fungicide program, *A. alternata* was isolated less frequently than *A. solani*. These results were consistent in the other two trials (Table 2).

In 2010, the frequency of isolation of *A. solani* exhibited an inverse relationship with the frequency of isolation of *A. alternata* from Quincy, WA, Acequia, ID, and Bonner's Ferry, ID. Multiple regression analysis of the proportion of *A. solani* vs. *A. alternata* from all three locations showed a significant relationship ($P<0.001$, $R^2=0.19$) (Fig. 4). Separate multiple regression analysis of *Alternaria* spp. from Quincy, WA and Acequia, ID were performed (Fig. 5). No significant relationship between the *Alternaria* spp. was observed in Quincy, WA. However, the multiple regression analysis of Acequia, ID data showed a significant relationship ($P= 0.004$, $R^2 = 0.58$).

Discussion-The strobilurin fungicides are highly desireable for managing early blight in the Columbia Basin due to their reduced impact on human health and the environment (Vincelli 2002). Due to the site specific nature of these chemicals, fungicide resistance is likely and has already been found in populations of *A. solani* in Idaho (Belcher et al. 2010). Applications of only strobilurin fungicides reduced the frequency of isolation of both *A. solani* and *A. alternata* in the fungicide trials, but not significantly when compared to nontreated plots. While these fungicide treatments appeared to be most effective at reducing frequency of isolation of *A. solani* than of *A. alternata* in most locations, Acequia, Idaho was an exception. This indicates that there may be differences in the fungicide resistance of pathogens in populations among locations. Strobilurins that were tank mixed and/or rotated with broad-spectrum fungicides consistently reduced the frequency of isolation of fungi, but as observed in the three locations, frequency of isolation in treated plots was never significantly different from nontreated plots. The unexpected observation of the high frequency of isolation of *A. solani* when treated with Bravo WS at Acequia, ID requires further investigation because fungi typically do not develop resistance to multi-site fungicides.

The fungicide trials were run with multiple tank mixes, different rotations, and at various rates, and were not intended to extract which fungicide is most responsible for controlling infection in plots. Resistance to fungicides can result in significant economic loss and is a major concern when dealing with chemicals that have a specific target. Management programs should include the use of resistant potato varieties, good sanitation practices, as well as fungicide programs with optimized application rates and rotation schedules (Hamm et al. 2008). Fungicide trials allow for the testing of these different programs to determine their effectiveness in pathogen control.

Isolates of *A. solani* were consistently pathogenic on potato and more aggressive than pathogenic *A. alternata* isolates, based on detached leaf tissue assays. Tissue that was inoculated with *A. solani* had a shorter incubation period and more rapid lesion expansion. This may be why the observed disease severity in plots was often highest when frequency of isolation of *A. solani* was approximately 50% or greater. Plots in which A. *alternata* was the primary pathogen isolated from lesions often exhibited lower disease severity. In many of the fungicide trials, treatments that were most effective in reducing *A. solani* in plots often exhibited a higher incidence of *A. alternata*. *A. alternata* has been shown to be a less aggressive pathogen on potato. High populations of *A. solani*

may inhibit *A. alternata* populations from developing, suggesting that competition may be a factor in pathogen population in potato plot.

Figure 1. Frequency of isolation of *Alternaria solani* and *A. alternata* from lesions on potato leaves collected in the Columbia Basin in 2009

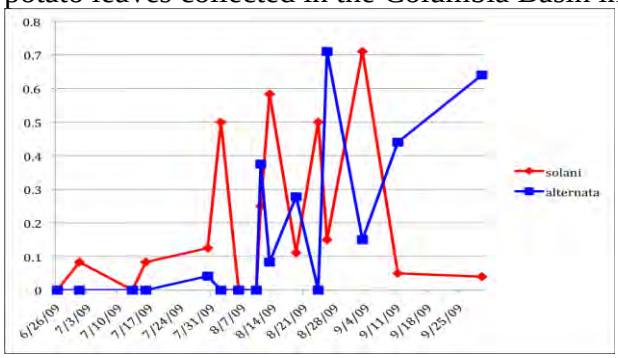


Figure 2. Frequency of isolation of *Alternaria solani* and *A. alternata* from lesions on potato leaves collected in the Columbia Basin in 2010.

Figure 3. AUDPC of *A. solani* and *A. alternata*

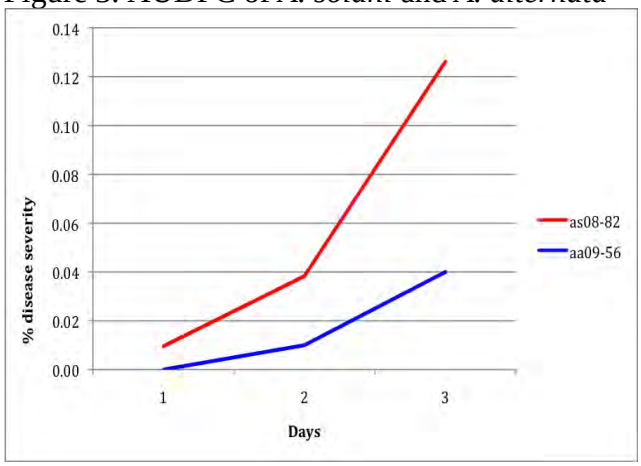


Figure 4. Proportions of assayed potato leaf *Alternaria sp*. lesions from nine fungicide trials at three locations in ID and WA, 2010

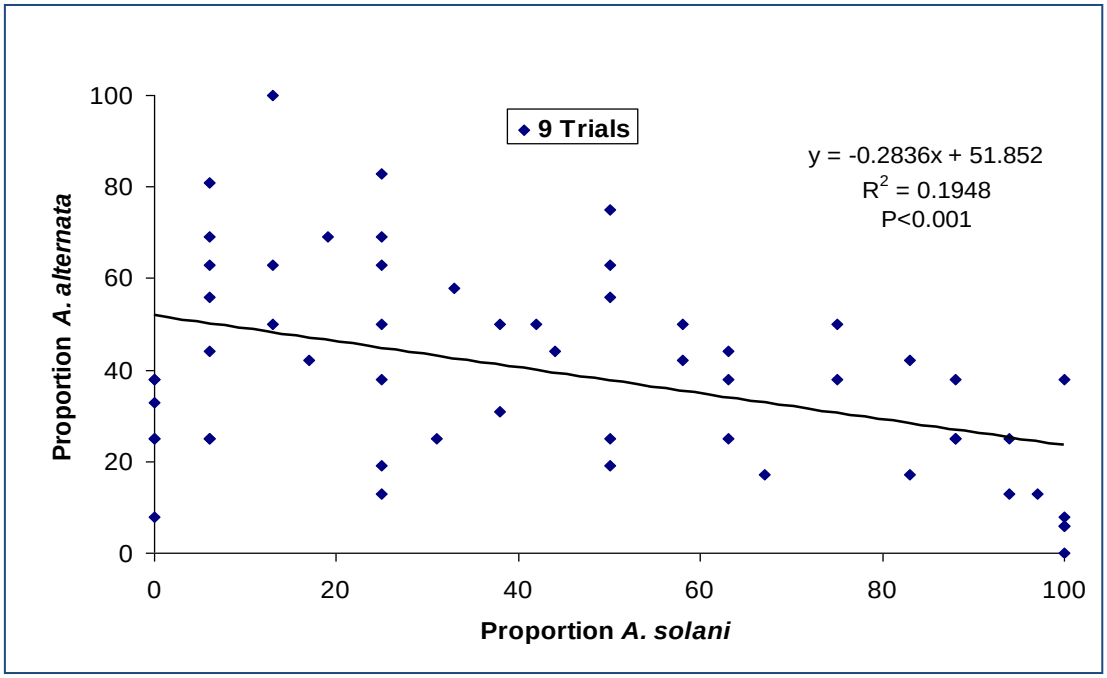


Figure 5. Proportions of assayed potato leaf *Alternaria sp*. lesions from two fungicide

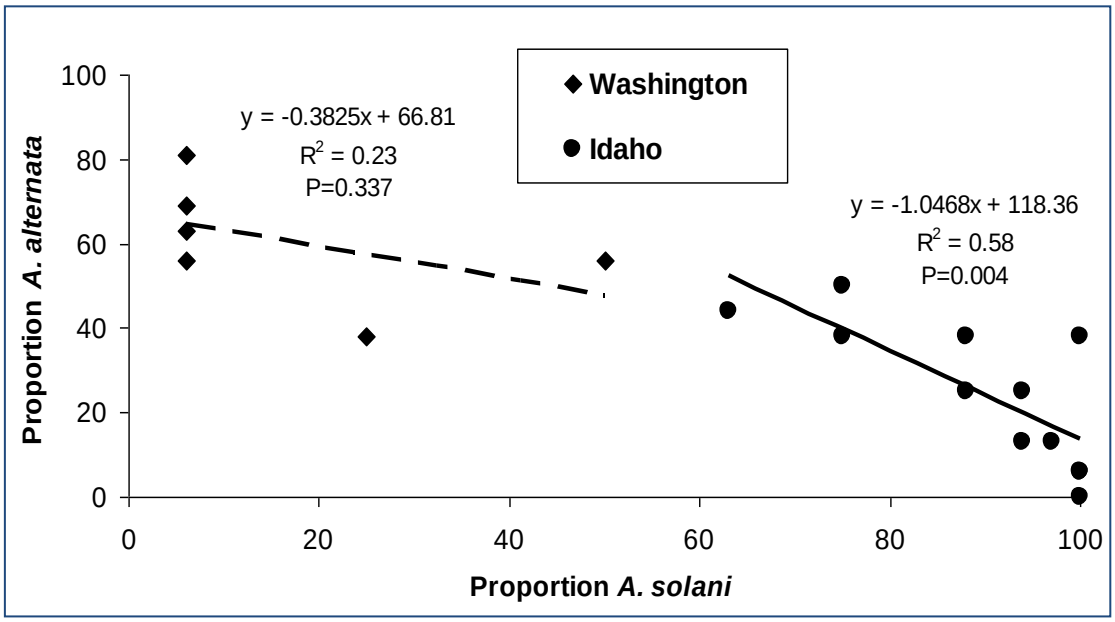


Table 1. Frequency of isolates of *Alternaria solani* and *A. alternata* from lesions on Russet Burbank potato leaves treated or not treated with various fungicides at Quincy, WA

Treatment	% lesions with *A. solani*	% lesions with *A. alternata*
Not treated	50 a	56 ab
Endura, 2.5 oz wt/a (ACE) Bravo WS, 24 fl oz/a (BDF)	6 b	56 ab
Revus Top, 7 fl oz/a (ACE) Bravo WS, 24 fl oz/a (BDF)	6 b	63 ab
Quadris Top, 8 fl oz/a (ACE) Bravo WS, 24 fl oz/a (BDF)	25 ab	38 b
Quadris Top, 8 fl oz/a (AD) Bravo WS, 24 fl oz/a (BEF) Omega, 7 fl oz/a (C) Inspire, 7 fl oz/a (C)	6 b	81 a
Quadris Top, 8 fl oz/a (AD) Bravo WS, 24 fl oz/a (BEF) Omega, 6.4 fl oz/a (C) Inspire, 6.4 fl oz/a (C)	6 b	69 ab

For most treatments, lesions from 16 leaves were sampled from each treatment. Data includes occurrences of *A. solani* and *A. alternata* on the same lesion.

Table 2. Frequency of isolates of *Alternaria solani* and *A. alternata* from lesions on Western Russet potato leaves treated or not treated with various fungicides at Acequia, ID.

Treatment	% lesions with *A. solani*	% lesions with *A. alternata*
Trial 1		
Not treated	75 ab	38 a
Endura, 2.5 oz wt/a Dithane F-45 Super Tin	94 a	13 a
Endura, 2.5 oz wt/a Dithane F-45 1.2 qt/a	63 b	44 a
Penncozeb, 2 lb/a	75 ab	50 a
Trial 2		
Not treated	100 a	6 a
Headline, 6 fl oz/a (A-D)	88 a	25 a
Endura, 2.5 oz wt/a (A-D)	97 a	13 a
Trial 3		
Not treated	100 a	6 ab
Quadris, 6 fl oz/a	94 a	25ab
Gem, 3.8 fl oz/a	100 a	38 a
Tanos, 6 oz/a	88 a	38 a
Bravo WS, 1.5 pt/a	100 a	0 b

For most treatments, lesions from 16 leaves were sampled from each treatment. Data includes occurrences of *A. solani* and *A. alternata* on the same lesion.

Literature Cited:

Belcher, A. R., Wood E., and P. S. Wharton. 2010. Sensitivity of *Alternaria solani* populations in Idaho to commonly used fungicides and its effect on potato early blight management in Idaho. *Phytopathology* 100: 6.

Berger, R. D., Filho, A. B., and L. Amorim. 1997. Lesion expansion as an epidemic component. *Phytopathology* 87: 10. pp. 1005–1013.

Hamm, P. B., Hoy, C. W., Hutchinson, P. J. S., Stevenson, W. R., Boydston, R. A., Alvarez, J. M., Alyokhin, A., Dively, G., Gudmestad, N. C., and W. W. Kirk. Managing pesticide resistance. In *Potato Health Management*, 2nd Ed; Johnson, D. A. Ed. APS Press: St. Paul, 2008. pp. 123-131.

Nolte, P. 2008. Brown spot and black pit of potato: the other early blight. *American Vegetable Grower* 56: 5. pp. 32-33.

Rosenzweig, N., Atallah, Z. K., Olaya, G., and W. R. Stevenson. 2008. Evaluation of QoI Fungicide Application Strategies for Managing Fungicide Resistance and Potato Early Blight Epidemics in Wisconsin. *Plant Disease* 92: 4. pp. 561–568.

Rosenzweig, N., Olaya G., Atallah, Z. K., Cleere, S., Stanger, C., and W. R. Stevenson. 2008. Monitoring and tracking changes in sensitivity to azoxystrobin fungicide in Alternaria solani in Wisconsin. *Plant Disease* 92: 4. pp. 555–560.

Rotem, J. 1994. *The genus Alternaria: biology, epidemiology, and pathogenicity*. Amer Phytopathological Society.

Stevenson, W. R., Kirk, W. W., and Z. K. Atallah. Managing foliar diseases: early blight, late blight, and white mold. In *Potato Health Management*, 2nd Ed; Johnson, D. A. Ed. APS Press: St. Paul, 2008. pp. 209-222.

Vincelli, P. 2002. QoI (Strobilurin) Fungicides: Benefits and Risks. *The Plant Health Instructor*. doi:10.1094/PHI-I-2002-0809-02. http://www.apsnet.org/edcenter/advanced/topics/Pages/StrobilurinFungicides.aspx.