Proceedings of the 48th Annual Washington State Potato Conference

January 26-28, 2009
Kennewick, Washington

Washington State Potato Conference Board

Mike Dodds of Basic American Foods

Dale Lathim of the Potato Growers of Washington

Karen Bonaudi of the Washington State Potato Commission

Stacy Kniveton of the Washington State Potato Commission

Ann VanDyke of Blakal Packing

Cassie Skone of Sterling Savings

Greg Jackson of Two Rivers Terminal, LLC.

Andy Jensen of the Washington State Potato Commission

Kellee Balcom of the Washington State Potato Foundation

Jim Richins of Lamb Weston

Mark Pavek of the Washington State University

Gary Hoffer of Spudnik Equipment Co.

Tim Waters of Washington State University Extension

Brian Van Pelt of Syngenta

We would like to acknowledge sponsors of this year's conference:

Diamond Sponsors ($5,000 and up):
Spudnik
Washington State Potato Commission
Columbia Basin Herald
Two Rivers Terminal

Platinum Sponsors ($3,000-$4,999):
Bayer Crop Science
JMC Ventilation Refrigeration
Syngenta Crop Protection
Basin Business Journal
Northwest Farm Credit Services
Simplot
ConAgra Foods / Lamb Weston
Wilbur Ellis-Pasco, Warden, Basin West

Gold Sponsors ($2,000-$2,999):
AgriNorthwest
Key Bank
Washington Trust Bank
WA & OR Fresh Potato Growers Co-op
Lindsay Corp / Irrigation Specialists / Zimmatic
McGregor Co. / Quincy Farm Chemicals
Basic American Foods
McCain Foods USA, Inc.

Silver Sponsors ($1,000-$1,999):
Ag World Support Systems
Washington Seed Potato Commission
Lever Advertising
Desert Graphics
Orv's Potato Service, Inc.
Gowan Company
Valent USA Corp.
Western Farm Service, Inc.

Bronze Sponsors ($500-$999):
Edmonton Potato Growers
Kuo Testing Labs, Inc
Skagit State Bank
Soiltest Farm Consultants
Dow AgroSciences
Saddle View Farms
A.J. Ochoa Corporation
McCurley Chevrolet

Associate Sponsors ($100-$499):
Ag Engineering & Development Company, Inc.
Merrill Lynch
USAg Analytical Services
Warden Welding
East High Parts – Warden Napa

2009 Trade Show Exhibitors

A & M Supply, Inc.
PO Box 1166
Hermiston, OR 97838

A&L Supply
81 E Pine
Othello, WA 98837

Ag Engineering and Dev. Co.
1515 E 7th Ave
Kennewick, WA 99336

Ag Tech Services
13184 Wheeler Road, Suite 2
Moses Lake, WA 98837

Ag World Support Systems
PO Box 1696
Moses Lake, WA 98837

AgPro Systems, Inc.
PO Box 66
Custer, MT 59024

AGRIAN
2547 W. Shaw, Suite 116
Fresno, CA 93717

ATS, LLC
9252 Goodrich Road SE
Moses Lake, WA 98837

AV Labs, Inc.
65 No. Broadway Ave
Othello, WA 99344

Bayer Crop Science
1925 S. Williams Street
Kennewick, WA 99338

BC Certified Seed Potato Growers Association
4119 40th Street
Delta, BC 0

Benshaw, Inc.
PO Box 14894
Tumwater, WA 98511

Bio Gro Inc.
681 Glade Rd
Mabton, WA 98935

Cement Mortar Lining Division of Columbia Pumping & Construction, Inc.
1005 S Maitland
Pasco, WA 99301

C-Gro, Inc.
402 W. 1st Ave.
Ritzville, WA 99169

Colorado Certified Potato Growers Association
PO Box 267
Monte Vista, CO 81144

Columbia Agricultural Conultants, Inc.
PO Box 576
Quincy, WA 98848

Columbia Basin Development League
PO Box 1235
Royal City, WA 99357

Columbia Basin Hotsy/ Hydrotek Northwest
1225 S. 10th Ave
Pasco, WA 99301

Columbia Publishing (Potato Country Magazine)
413 B. N. 20th Ave.
Yakima, WA 98902

Correll's Scale Service
PO Box 1056
Moses Lake, WA 98837

Crop Logic
Private Bag 4704
Christ Church, New Zealand

CSI Chemical - Nutri-Cal
671 Old River Road
Naches, WA 98937

Custom Chemical
320 W 1st
Warden, WA

Double L Apache River, LLC dba Double L
PO Box 597
American Falls, ID 83211

Double T Construction
1243 Reser Rd
Walla Walla, WA 99362

Drexel Chemical Co.
10751 W Wasdale Dr
Boise, ID 83709

Empire Rubber & Supply Co.
1428 West A Street
Pasco, WA 99301

Evergreen Implement
PO Box 548
Othello, WA 99344

Extreme Industrial Coatings
11319 W Willow Lane
Airway Heights, WA 99001

2009 Trade Show Exhibitors

Foremost Pump & Well Services, LLC
12 E Washington Ave
Yakima, WA 98903

G&R Ag Products
PO Box 340
Caldwell, ID 83606

Hansen & Rice
1717 E Chisholm Dr
Nampa, ID 83687

Holmes ENVIRO, LLC
2876 West Hills Road
Philomath, OR 97370

Idaho Crop Improvement Association
1680 Foote Drive
Idaho Falls, ID 83402

Industrial Ventilations, Inc.
5802 N. Industrial Way, Ste. A
Pasco, WA 99301

International Belt & Rubber Supply, Inc.
423 N Oregon Ave
Pasco, WA 99301

Irrigation Specialists Lindsey Corp
2410 N 4th
Pasco, WA 99301

IRZ Consulting, LLC
505 E Main
Hermiston, WA 97838

JMC Ventilation/Refrigeration, LLC
PO Box 6183
Kennewick, WA 99336

K & N Electric Motors, Inc.
PO Box M
Moses Lake, WA 98837

Kuo Testing Labs
337 S 1st Ave.
Othello, WA 99344

LeMaster Daniels
8131 W Grand Ridge Blvd
Kennewick, WA 99336

Logan Farm Equipment
615 E. 3rd North
Sugar City, ID 83448

Merrill Lynch
PO Box 2196
Tacoma, WA 98402

Minnesota Certified Seed Potato Growers Assoc.
312 4th Ave NE
E Grand Forks, MN 0

Montana Potato Advisory Committee
PO Box 200201
Helena, MT 59620

Monterey Agresources
PO Box 35000
Fresno, CA 93745

Mukang Labs, Inc
2526 E Saint Helens St
Pasco, WA 99301

Nachurs Alpine Solutions
421 Leader Street
Marion, OH 43302

North Pacific
PO Box 3968
Portland, OR 97208

Northwest Ag Products, Inc.
PO Box 3453
Pasco, WA 99302

Northwest Farm Credit Svcs
1700 S Assembly St
Spokane, WA 0

Oregon Seed Potato Growers Association
850 NW Dogwood
Madras, OR 97741

Perfect Blend Fertilizers
188 106th Ave. NE, Suite 401
Bellevue, WA 98004

Potato Growers Of Alberta
17507 Fort Rd
Edmnton, AB 0

Precision Fertigation Inc.
4161 Alta Campo Drive
Redding, CA 96002

PVMI - Potato Variety Management Institute
60380 Chickasaw Way
Bend, OR 0

R & H Machinery, Inc.
PO Box 1348
Caldwell, ID 83605

Rabo Agri Finance
295 Bradley Blvd, ste 201
Richland, WA 99352

2009 Trade Show Exhibitors

RDO Equipment Company
PO Box 2445
Pasco, WA 99301

Reinke Pasco, Inc.
1304 E Hillsboro
Pasco, WA 99301

Rotam North America
5201 Blue Lagoon Drive #917
Miami, FL 33126

Rotonies MFG. INC.
1050 E Puffin St
Moridian, ID 83642

Senninger Irrigation, Inc.
16220 E. Highway 50
Clermont, FL 34711

Simplot Grower Solutions
531 S. Booker Road
Othello, WA 99344

Skone Irrigation, Inc.
2051 W 1st, PO Box 160
Warden, WA 98857

Sloan-Leavitt Insurance, Inc.
PO Box 449
Othello, WA 99344

SoilTest Farm Consultants
2925 Driggs Drive
Moses Lake, WA 98837

Spudnik Equipment
5802 North Industrial Way, Ste. D
Pasco, WA 99301

Sterling Savings Bank
406 W. Broadway Ave.
Moses Lake, WA 98837

Suberizer Inc.
14222 NE 21st St
Bellevue, WA 98007

Sun Basin Operations, A Division of CHS, Inc.
13184 Wheeler Road, Suite 2
Moses Lake, WA 98837

Syngenta
7521 Exhibit Crt
Raleigh, NC 27617

Teton Seed Marketing Assoc.
PO Box 155
Tetonia, ID 83452

Teton West of WA
5802 N Industrial Way Ste A
Pasco, WA 99301

The Gellert Company
3193 Kimberly Rd
Twin Falls, ID 83301

Total Employment & Management TEAM
529 E Broadway Ste A
Moses Lake, WA 98837

Total Scale Service, Inc.
PO Box 5156
Boise, ID 0

TPC International
15803-121A Ave.
Edmnton, AB 0

Trinity Trailer Mfg., Inc.
8200 Esinman Road
Boise, ID 83716

US Potato Board
7555 E Hampden Ave #412
Denver, CO 80231

USDA AMS, Fruit & Vegetable Market News
1820 E 17th St Ste 100
Idaho Falls, ID 83404

USDA NASS
1111 Washington St. SE
Olympia, WA 98507

Valent USA
98514 Lillian Dr
Kennewick, WA 99338

Valmont Northwest Inc.
1619 E. Hillsboro
Pasco, WA 99301

Washington Seed Potato Commission
PO Box 286
Lynden, WA 98264

Westbridge Agriculture Products
1260 Avenida Chelsea
Vista, CA 92081

Western Laboratories, Inc.
PO Box 1020
Parma, ID 83660

Western Peterbilt, Inc.
12976 N Frontage Rd E
Moses Lake, WA 98837

2009 Trade Show Exhibitors

WoodPecker Truck
PO Box 1306
Pendelton, OR 97801

WorkSource Columbia Basin/
Columbia Basin College
815 N Kellog St, ste D
Kennewick, WA 99336

Zeba
8705 SW Nimbus Ave., Suite 230
Beaverton, OR 97008

Contents

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

Managing Herbicide Drift and Early Results of Simulated Glyphosate Drift to Potato Study

Rick Boydston, USDA-ARS, Prosser, WA

The off target movement of herbicides can injure sensitive crops. Off target movement of spray droplets results from displacement by wind, poor application techniques, or improper settings or operation of application equipment. Applicators should be aware of wind speed and direction, use nozzles and sprayer operating pressures that result in larger spray droplets, keep sprayer boom height to a minimum, know what is in the spray tank, and be aware of neighboring sensitive crops. Small spray droplets under 100 µm diameter are more subject to drift and result from using smaller orifice nozzles and higher operating pressures. It is wiser to anticipate and avoid problems of spray drift than to have to deal with them after the fact.

Potatoes can be sensitive to both drift and carryover (soil persistence) of certain herbicides. An Idaho extension publication, PNW498, contains pictures and descriptions of many commonly used herbicides that can injure potatoes from drift or carryover.

Herbicides that inhibit amino acid synthesis (Roundup, Raptor, Pursuit, Harmony, etc.) often reduce potato leaf size and internode length. New leaves may turn yellow and plant growth is slow. The potato crop may appear to recover, but tubers may have numerous growth cracks and folds, and tubers yields greatly reduced.

Growth regulator type herbicides (2,4-D, MCPA, Banvel, Starane, Garlon, Stinger, etc.) usually cause petiole and stem twisting, malformed leaves, and stem cracking. Leaves are often cupped, wrinkled, with a wavy appearance with twisted, epinastic growth. New leaves tend to exhibit more symptoms than older leaves.

Cell membrane disruptors (Goal, Gramoxone, Aim, Spartan, etc.) often cause spotting on leaves that were exposed at the time of the drift. New leaves are often not affected due to limited translocation of these herbicides within the plant.

Photosynthesis inhibitors (Bromoxynil, Princep, Atrazine, Karmex, etc.) cause chlorosis (yellowing) of leaves followed by necrosis (death) or slow recovery if applied at sublethal rates.

Pigment synthesis inhibitors (Zorial, Callisto, Impact, Laudis, Command, etc.) block carotenoid biosynthesis resulting in whitening (bleaching) of the leaves that may either slowly recover or become necrotic (leaf death).

Various symptoms on potato tubers can develop from herbicide drift depending on the herbicide, rate of herbicide, timing of the drift, and cultivar sensitivity. Tuber folds, cracks, knobs, and reduced tuber size can result from herbicide drift. Other causes of unusual symptoms on tubers that often mimic herbicide drift can result from nutrient shortages, diseases, water excess or drought, wind or frost damage, high temperatures, or other pesticides.

Glyphosate Simulated Drift Study to Potato.

Glyphosate is the most used herbicide in the world and new crops tolerant of glyphosate continue to be developed. As a result, glyphosate drift to sensitive crops is more likely to occur with increased use of glyphosate. In 2008, a simulated glyphosate drift study was conducted on Ranger russet potato at three locations; Ontario, OR (Dr. Joel Felix), Aberdeen, ID (Dr. Pam Hutchinson), and Paterson, WA (Dr. Rick Boydston). At the Paterson location, glyphosate was applied May 9, at 4 inch stage of potato; May 18, 6-8 inch tall potato (stolons swelling, early tuber initiation); May 27, 10 to 15 inches tall, (tuber initiation to 0.5 inch diameter tubers); and

June 13 at row closure (tuber bulking). Glyphosate was applied at 0, 0.0075, 0.048, 0.09, 0.19, and 0.375 lb ae/a in a spray volume of 20 gpa. Roundup Original Max was the glyphosate formulation used and an ammonium sulfate adjuvant (Bronc, Wilbur-Ellis) was included.

Potato foliar injury was rated at 1 and 3 weeks after treatment (WAT) and photos of injury recorded. Leaf discs from treated plants were collected and shikimic acid accumulation measured at 1 WAT by Dr. Ian Burke, WSU-Pullman. Shikimic acid is an intermediate compound that accumulates in glyphosate susceptible plants due glyphosate inhibition of an enzyme involved the synthesis of aromatic amino acids. Potato tuber yield and grade were determined in September and photos of tuber injury recorded. Tubers were held in cold storage and a 20 tuber subsample (10 symptomatic, 10 non-symptomatic) from each plot will be planted in the spring of 2009.

Potatoes treated with glyphosate exhibited chlorosis (yellowing) of the newest leaves at the higher rates of glyphosate tested and few or no symptoms at the lower rates of glyphosate tested. Foliar injury at 3 WAT was greater than at 1 WAT. Potato foliage recovered from most glyphosate applications and grew normally for the remainder of the season except for the higher rates of glyphosate tested. Injury to potato foliage was greatest from May 18 and May 27 glyphosate applications and least with May 9 applications to 4 inch potato. Glyphosate rates of 0.0075 lb ae/a caused very minor or no visual injury and had little or no effect on tuber yield or quality.

Shikimic acid levels in the leaf tissue at 1 WAT were correlated with glyphosate dose following the May 18 application. The complete data set on shikimic acid levels was not available at the time of this report.

Potato tuber yield was reduced most by glyphosate applications on May 18, whereas tuber quality was reduced most by glyphosate application on May 27. Tubers produced from potato plants treated in May had a high percentage of growth cracks, folds, and small sized tubers. Glyphosate applied at potato row closure in June tended to cause more scaly skin lesions on tubers and growth cracks on tuber ends.

Figure 1. Potato injury following glyphosate applications on May 9 (left) and May 27, 2008 (right).

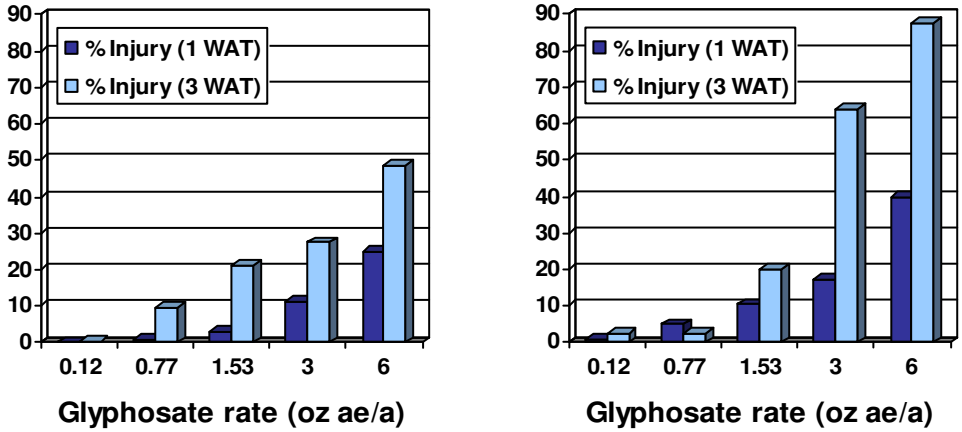


Figure 2. Potato U.S. #1 tuber yield as a function of foliar injury ratings at 3 WAT after treating with simulated drift rates of glyphosate.

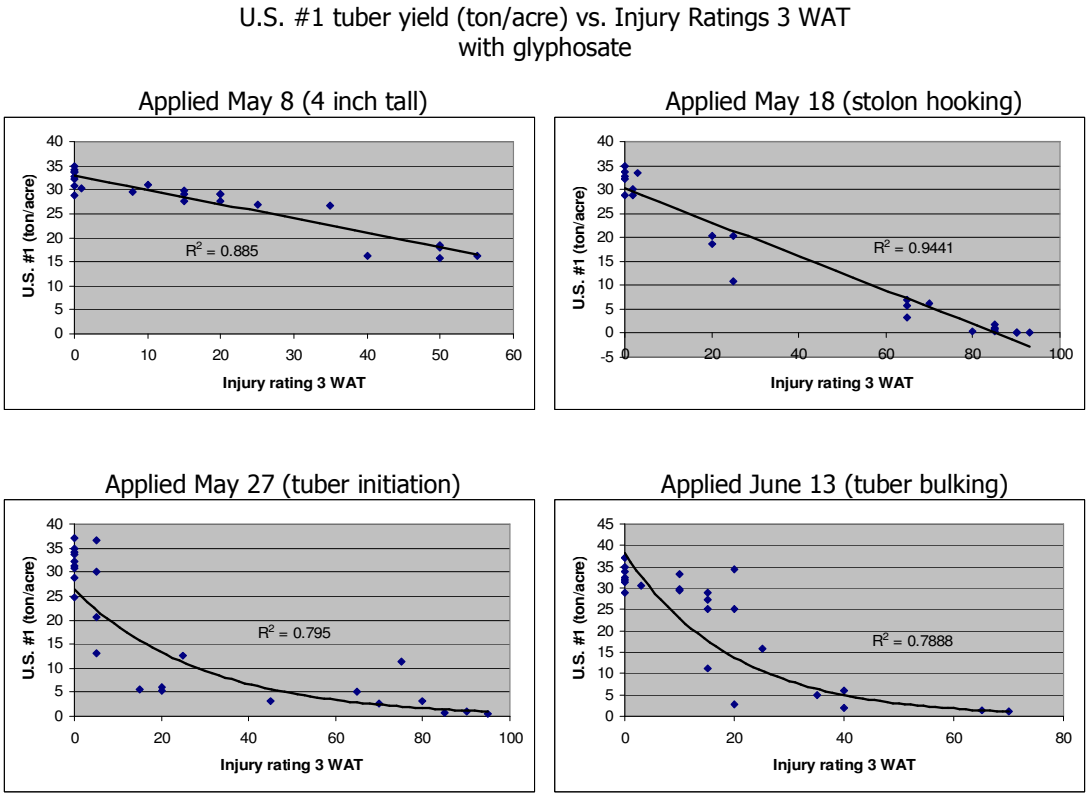


Figure 3. Potato tubers harvested from plants treated with low rates of glyphosate on May 27, 2008.

Genotypic Differences in Advanced Breeding Lines for Resistances to Black Dot and Powdery Scab

Charles R. Brown[1], Nadav Nitzan[1], Dennis Johnson[2], Jeff Miller[3], Tom Cummings[2], Dallas Batchelor[5], Chris Olsen[4], Rich Quick[1], Will Hutson[1], and Ricarda Castañeda[1].

[1/] USDA/ARS, Prosser, WA; [2/] Dept Plant Pathology, Washington State University, Pullman; [3/] Miller Research, Rupert, ID; [4/] Olsen Farms, Othello, WA; [5/] Weather or Not, Pasco, WA

Introduction

The economics of potato production require that the industry grow their crop more cheaply. From the breeding side new varieties that are improved in resistance to pests and diseases and the physical stresses that assault the crop will contribute to the solution. Powdery scab (***Spongospora subterranea***) has been steadily increasing its geographic coverage, growing from an unusual occurrence to widespread in certain areas. Russet skin varieties are not heavily damaged on the tuber, but may have substantial yield loss due to impairment of root function. Growers report an inability to use Russet Burbank and Umatilla on ground with heavy powdery scab. Total yield is reduced from historic averages and underrepresentation in the large tuber categories lowers incentive payments on contracts to unprofitable levels. Unfortunately, no fungicidal or fumigation treatments that have been tried appear to work. However, there are promising results in germplasm evaluation that indicate that resistance to root colonization may exist in breeding materials and advanced materials with commercial potential. Black dot (*Colletotrichum coccodes*) is also a relative newcomer on the scene. Little is known about it and levels of resistance are unexplored. It appears to be another profit-stealer that makes potato growing more of a challenge. Black dot varies greatly with year and location. It may appear to be an active pathogen that shortens the vegetative period with early dying type symptoms of sudden stem death. Alternatively, it may appear to come in as a saprophyte after the potato foliage has died. Easily confused with Verticillium wilt, it was recognized only within the last decade as a significant factor.

Approach

We have attempted to categorize resistance to black dot (BD) and powdery scab (PS) in field experiments. In the case of PS, plants were hand dug before the onset of senescence. The root systems were rated on a subjective scale for the degree of galling. We also measured the fresh and dry weight of the recovered root system. Fresh weight and percent dry matter of the root are presented here. In the case of BD we have harvested stems from senescing plants, excised stem disks at various intervals up the stem, and plated these out on appropriate medium to detect presence of the fungus. We also employed a technique in 2008 where we harvested the stems and allowed them to air dry. During the drying, BD sclerotia appeared on the epidermis of the stem at varying distances measured on a basal to apical axis. The total distance was measured when the stems were completely dried. We also measured the incidence of detectable BD in the basal end of the tuber. This was accomplished by excising a small piece of tissue with sterile instruments after sterilizing the surface of the tuber with dilute bleach. The excised tissue was plated onto appropriate medium.

Results

A summary of PS root galling results over five year-locations is given for germplasm entries and commercial cultivars in Table 1. The breeding lines PA98NM38-1, PA95B2-4, PA98N5-2, PO94A010-10, and PO94A09-7 were the most resistant breeding lines.

Table 1. Frequency of resistant reactions of breeding lines and cultivars in five field tests.

	Field trials screening out come [y]					
Selection [x]	04-ID	04-WA	05-WA	06-WA	07-WA	Frequency of resistance [z]
PA98NM38-1	R	R	R	R	R	5/5
PO94A009-10	R	R	R	R	S	4/5
PA95B2-4	R	R	R	S	S	3/5
PA98N5-2	R	R	R	S	S	3/5
POR00HG5-1	R	S	R	S	S	2/5
PO94A009-7	R	R	R	S	nt	3/4
PO94A012-2	S	R	R	nt	nt	2/3
Summit Russet	nt	nt	nt	R	R	2/2
Russet Burbank	S	S	S	S	S	
Russet Ranger	S	S	S	S	S	
Umatilla Russet	S	S	S	S	S	
Shepody	S	S	S	S	S	

[x] Selections with greater (P<0.05) resistance to root galling than the standard cultivars Russet Burbank, Russet Ranger, Umatilla Russet and Shepody in two or more trials.

[y] 04, 05, 06, 07 = 2004, 2005, 2006, and 2007; ID = Rexburg, Idaho; WA = Moses Lake, Washington; R= resistant; S= susceptible; nt = not tested.

[z] The number of trials the selection had a greater (P<0.05) resistance to root galling than the standard cultivars Russet Burbank, Russet Ranger, Umatilla Russet and Shepody. Excerpted from Nadav et al. 2008.

Likewise a summary of results over three years is given in Table 2 for disease severity based on culturing out the BD pathogen at different heights along stems.

Table 2. Results over three years of screening for black dot resistance. Disease Severity based on detection of *Colletotrichum coccodes* in stem disks. Shaded breeding lines demonstrate resistance. Excerpted from Nadav et al., 2009

Potato Selection or Variety	2006		2007		2008	
`	R/S	DSI (%) [a]	R/S	DSI (%)	R/S	DSI (%)
A0012-5	R	38	R	32	S	46
A00681-7	R	39	R	41	S	59
A0073-2	R	21	S	85	S	63
A95109-1	R	38	S	94	S	48
PA00N6-1	R	19	S	68	S	71
PA95B2-4	S	54	R	48	R	26
PA98N5-2	S	64	S	83	S	60
PA98NM38-1	R	25	R	46	R	38
PO94A009-7	R	19	S	55	R	19
PA99N82-4	S	42	S	49	S	52
POR00HG5-1	R	29	S	61	R	21
Russet Summit	R	21	R	42	S	75
Russet Norkotah	S	35	S	86	S	57
Shepody	S	88	S	91	S	47

The dramatic coincidence of three clones with the highest levels of resistance to both black dot and powdery scab is the most noteworthy result of these two studies (PA95B2-4, PA98NM38-1, and PA94A009-7).

Survey of components of resistance in Tri-State and Western Regional Trial Entries.

On an annual basis groups of advanced clones are planted in multiple sites for evaluation of yield, disease and pest resistance and post harvest processing and culinary quality. We took advantage of this to measure certain components of resistance in BD plus PS infested fields.

We measured the root and crown fresh weight. The results are shown in Figure 1.

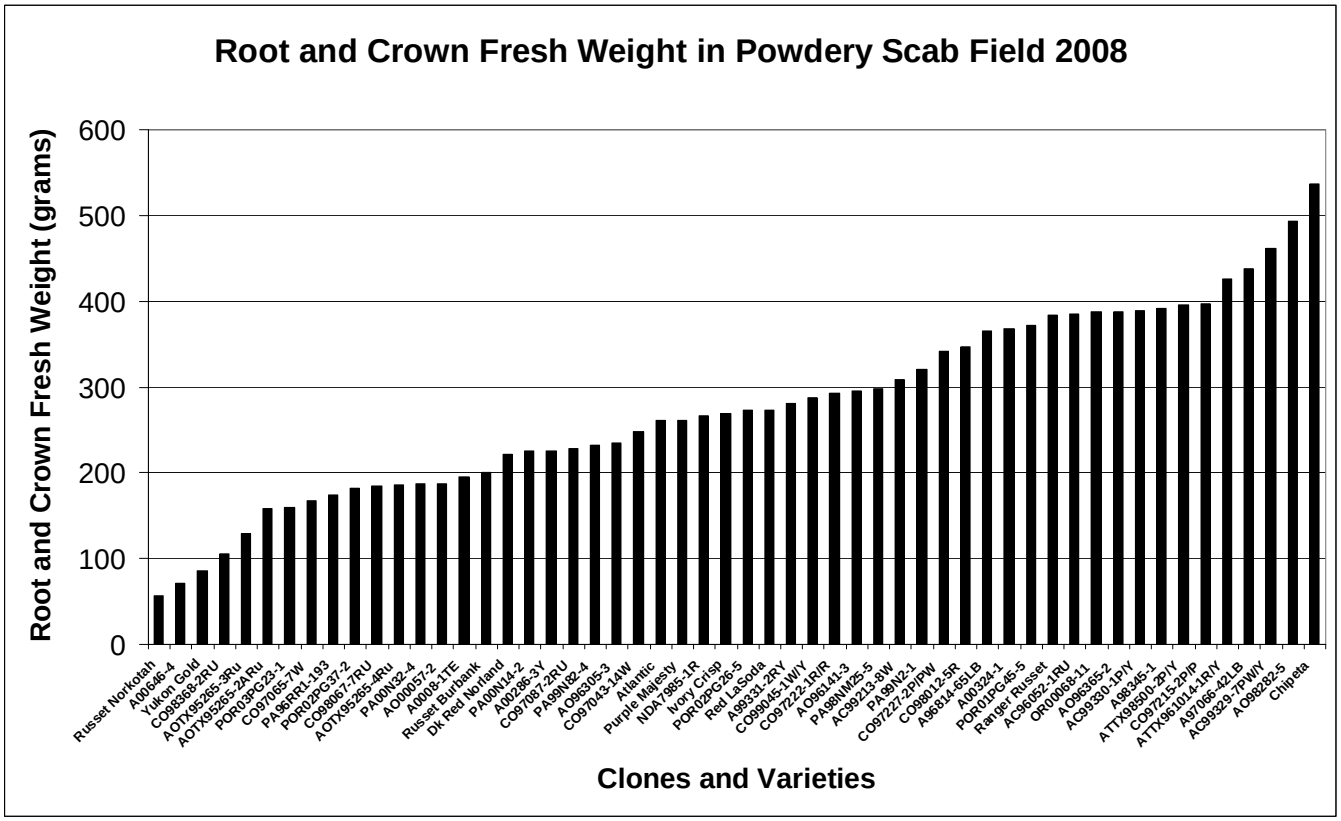


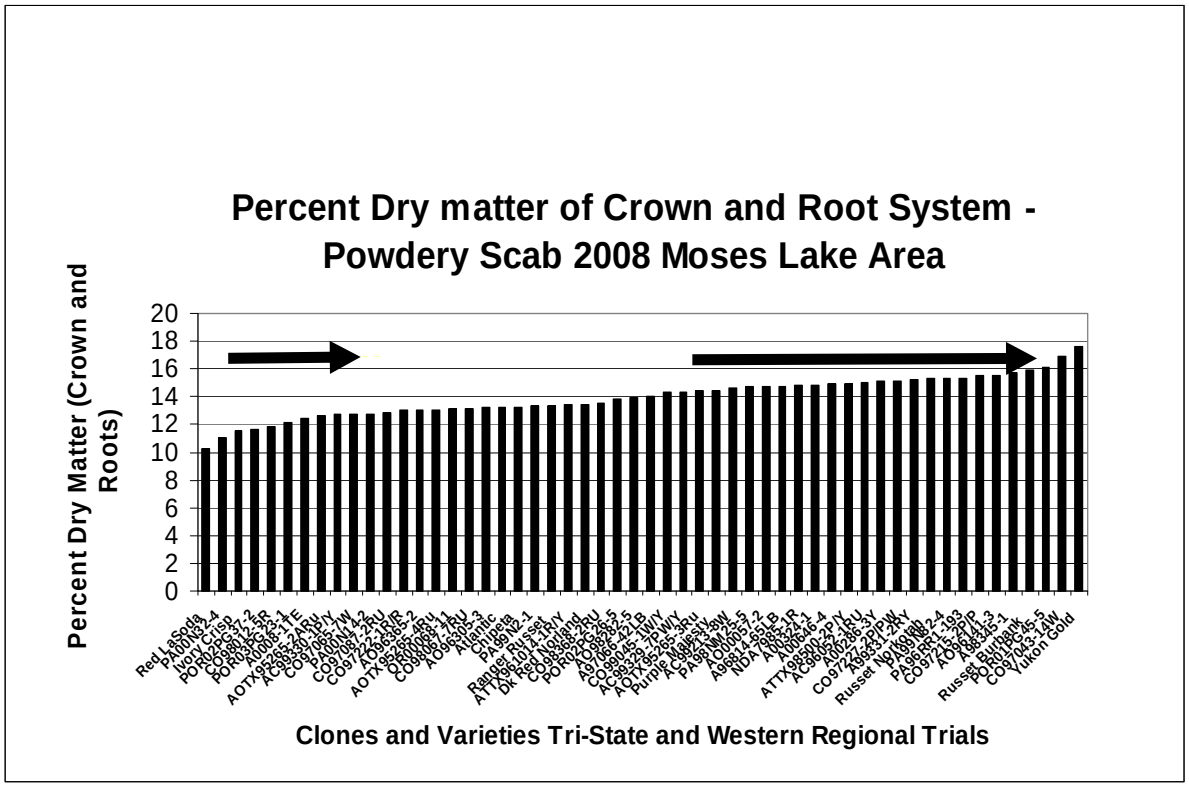
Figure 1. Fresh root and crown weight of Tri-State and Western Regional Trial entries.

Chipeta is renowned for its late maturity and large size and its huge root system comes as no surprise. It is interesting to note however that AO98282-5 and A97066-42LB are also able to maintain a large mass of roots in this infested soil.

The percent dry matter of the root systems was also determined. These results are depicted in Figure 2. This measurement has the intent of emphasizing genotypes that retain moister roots. This is a sign of a healthier root system in the face of the damaging effects of PS.

Black dot invades the stem and remains relatively inactive until the plant enters into senescence. Upon stem death, black dot sclerotia are often seen on the surface of the stem, around the crown of the plant and on the surface of shallow roots. One technique to assess resistance is to harvest senescing stems and allow them to air dry. The extension of the sclerotia up the stem is theoretically a measure of susceptibility. The expansion of BD sclerotia up stems that were harvested and allowed to air dry is shown in Figure 3.

Figure 2. Percent dry matter of Tri-State and Western Reginal Trial Entries.



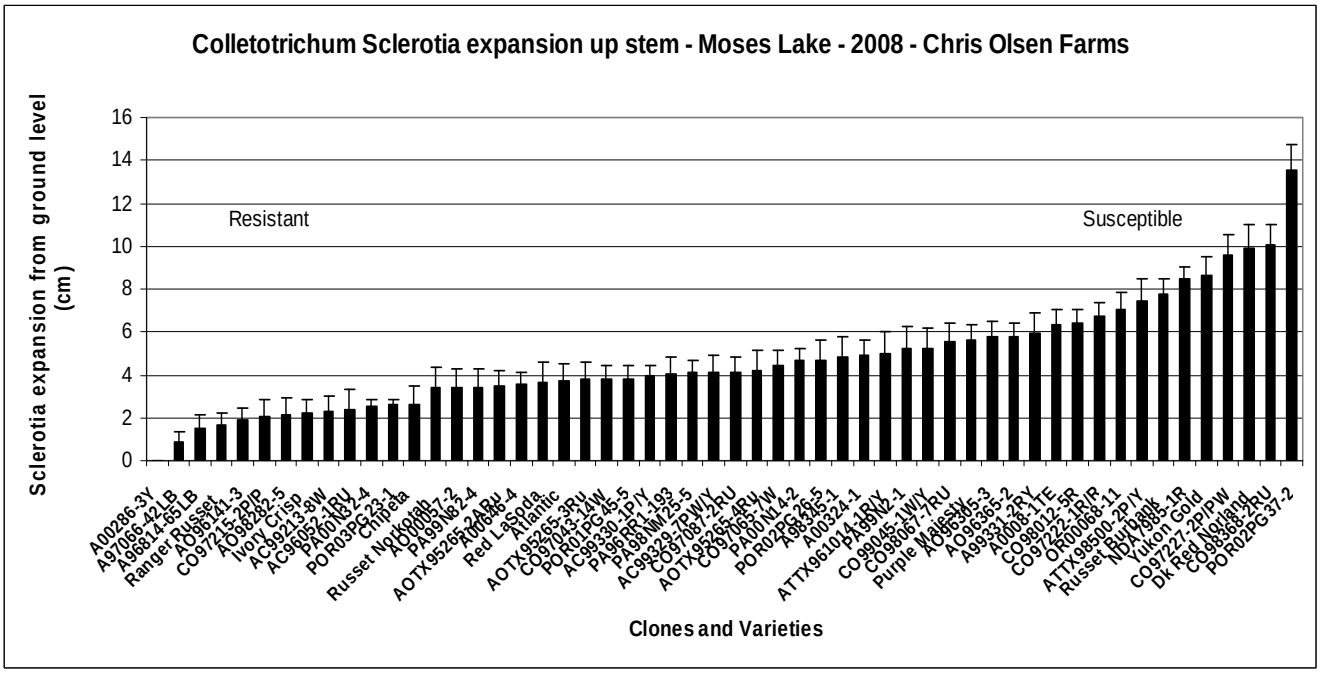


Figure 3. Expansion of sclerotia up the stems of harvested and drying stems. Tri-State and Western Regional Trials.

Interestingly, A97066-42LB and A96814-65LB, clones that have resistance to late blight, show considerable restriction of BD sclerotia expansion up the stems.

The ability of BD to invade tubers is a component of resistance. We tested for the presence of BD at the stolon end. These results are shown in Figure 4.

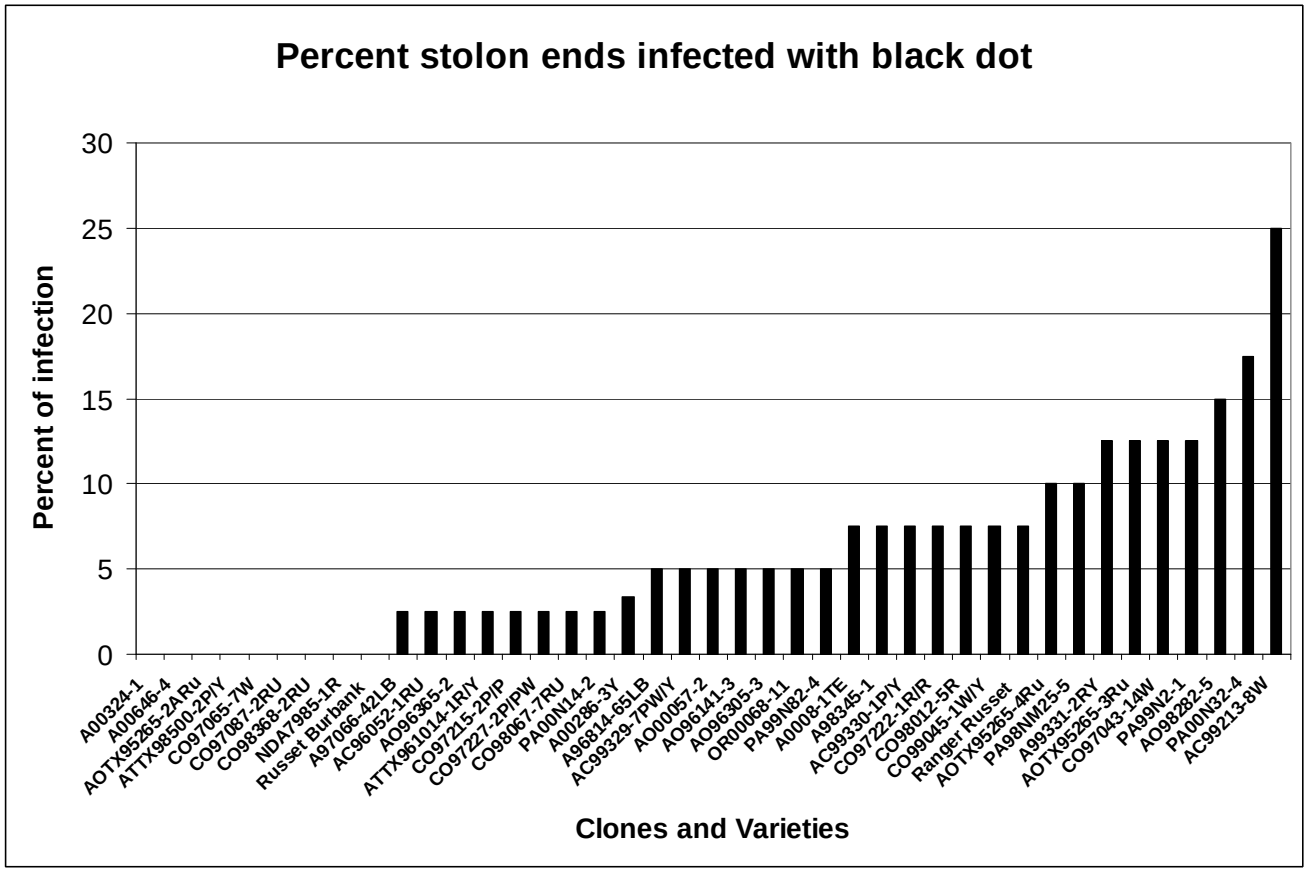


Figure 4. Incidence of infection of the stolon end of tubers by the *Colletotrichum coccodes*.

It is interesting to note that A97066-42LB occurs at the resistant end of the scale with a percent stolon end infection of 2.5.

To make sense of these measurements we included a clone for each trait on a list if its rating occurred in the top third of the range (i.e., indicating greater resistance). All the clones that had two or more attributions were placed in Table 3.

Table 3. Clones that have at least two upper third attributions for traits contributing to resistance to Black Dot and Powdery scab

Clone	Low % tuber inf	Low Sclerotia expansion	High Moist. Roots	High Root Fresh Weight
A00646-4	☺	☺		
AOTX95265-2ARu	☺	☺	☺	
A97066-42LB	☺	☺		☺
AC96052-1Ru	☺	☺		☺
CO97215-2P/P	☺	☺		☺
A00286-3Y	☺	☺		
Ivory Crisp	☺		☺	
PA00N32-4		☺	☺	
AC99330-1P/Y			☺	☺
PA00N14-2	☺		☺	
CO97087-2RU		☺	☺	
AO96365-2	☺	☺		☺
Chipeta		☺		☺
AO98282-5		☺		☺
ATTX961014-1R/Y	☺			☺
ATTX98500-2P/Y	☺			☺

A total of fourteen breeding lines and two varieties appear in this table. If we apply a stricter standard and include clones that have three or more attributions we arrive at Table 4.

Table 4. List of clones with three attributions for components of resistance to black dot and powdery scab. Pedigrees are also given.

Clone	Pistillate Parent	Pollen parent	**Low % tuber infection BD**	**Low sclerotia expansion BD**	**High Moist. Roots**	**High Root Fresh Weight**
AOTX95265-2ARu	**A89216-9**	**A86102-6**	☺	☺	☺	
A97066-42LB	**AWN86514-2**	**A86102-6**	☺	☺		☺
AC96052-1Ru	**A81386-1**	**GemStar**	☺	☺		☺
CO97215-2P/P	**CO94163-1**	**CO94183-1**	☺	☺		☺

Analyzing the ancestry of the four top clones, the parent A86102-6 appears twice and the variety GemStar Russet once. The clone AWN86514-2, which appears once, possesses a high level of resistance to late blight. These clues are helpful in trying to pin down sources of resistance and guidelines for future crossing.

Summary

Surprisingly, our initial testing for resistance to PS and BD resulted in three clones that are resistant to both pathogens at high levels in different environments. A further intriguing connection is that the three originated from a backcrossing program to incorporate resistance to Columbia root-knot nematode originating form the wild species *Solanum bulbocastanum*. However, they also had, in their geneaology, two successive backcrosses to Summit Russet. It appears that the more important clue is the Summit Russet. Our conclusion is that Summit Russet is an important contributor to both BD and PS resistance. Our work with these two diseases will continue with field tests and greenhouse measurements of root development with and without inoculation with BD and PS.

References

1. Nitzan, N, Cummings, TF, Johnson, DA, Miller, JS, Batchelor, DL, Olsen, C, Quick, RA, Brown, CR. 2008. Resistance root galling caused by the powdery scab pathogen *Spongospora subterranea* in Potato. Plant Disease 92:1643-1649.
2. Nitzan, N. Cummings, TF, Batchelor, D, Olsen, C, Brown, CR. 2009. Resistance to stem colonization by black dot pathogen *Colletotrichum coccodes* in potato. Plant Disease (Submitted)

Potato consumption on oxidative stress, inflammatory damage and immune response in humans

Boon P. Chew and Jean Soon Park
School of Food Science
Washington State University
Pullman, WA

ABSTRACT

Background: Pigmented potatoes contain high concentrations of antioxidants including phenolic acids, anthocyanins and carotenoids, which are implicated in the inhibition or prevention of cellular oxidative damage and chronic disease susceptibility.
Objective: The purpose of this study was to assess the effects of pigmented potato consumption on oxidative stress biomarkers, inflammation and immune response in healthy adult males.
Design: Free living healthy male participants (18-40 yr; *n*=12/group) were given 150 g of cooked white- (WP), yellow- (YP) or purple-flesh potatoes (PP) once a day for 6 wk in a double-blinded study. Blood was collected at baseline and wk 6 to analyze total antioxidant capacity, DNA damage (8-OHdG), protein oxidation, lipid peroxidation, C-reactive protein (CRP), inflammatory cytokines, lymphoproliferation, NK cytotoxicity and phenotypes. Potatoes were analyzed for total antioxidant capacity, phenolic acids, anthocyanins and carotenoids.
Results: Participants fed YP and PP had lower ($P < 0.08$) plasma IL-6 compared to those fed WP. A concurrent decrease ($P < 0.08$) in CRP concentration was observed in the PP group. Lower concentrations of 8-OHdG were observed in subjects fed either YP ($P < 0.03$) or PP ($P < 0.08$) compared to those fed WP. Total Tc cells were lower while B cells were higher in PP compared to the WP group ($P < 0.05$). Compared to WP, YP had high concentrations of phenolic acids ($P < 0.002$) and carotenoids ($P < 0.001$), while purple potatoes had high concentrations of phenolic acids ($P < 0.002$) and anthocyanins ($P < 0.001$).
Conclusions: Pigmented potato consumption reduced inflammation and DNA damage, and modulates immune cell phenotype in healthy adult males.

INTRODUCTION

Diets rich in antioxidants are associated with a lower incidence of chronic diseases such as cardiovascular disease and cancer. Research has demonstrated that antioxidants such as phenolic acids, anthocyanins and carotenoids have been shown to reduce LDL oxidation, reduce DNA damage, inhibit cell proliferation and decrease CRP production, while improving immune cell function. The potato is the most commonly consumed vegetable in the US. In addition to high concentrations of vitamin C and iron, some potato cultivars are rich in phenolic acids, anthocyanins and carotenoids. Phenolic acids, such as chlorogenic acid, are found in white, yellow and purple potato cultivars. Purple-flesh cultivars have 186% more antioxidants compared to white-flesh potatoes, most notably due to the presence of anthocyanins, and have 3-4 fold more phenolic acids. Yellow-flesh cultivars are rich in lutein and zeaxanthin and can provide up to 10-fold more carotenoids than their white-flesh counterparts. We studied the potential health benefits of consuming pigmented potatoes on oxidative stress markers, inflammation and immune response in healthy humans.

MATERIALS AND METHODS

Healthy male participants between 18 and 40 y old were recruited from Washington State University and the surrounding communities. Exclusion criteria included chronic diseases, infection, and the use of tobacco, anti-inflammatory drugs and antioxidant supplements. Antioxidant supplements were avoided, and pigmented potatoes were not consumed outside of the study.

Free-living participants (n=12/group) were assigned in a randomized double blind, placebo-controlled experimental design to be fed the following: 1) white-fleshed Russet (WP), 2) yellow-fleshed (YP), or 3) purple-fleshed (PP) potatoes. Randomization was based on their baseline (wk 0) BMI. Participants consumed a total of 150 g of cooked potato daily for 6 wk. In order to maximize compliance, participants consumed their potatoes at our research site between 16:00 and 18:00 h. During the intervention period, participants kept a 3 d dietary log. Height and weight measurements were taken at baseline (wk 0) and the end of the intervention period (wk 6).

The white- (Ranger Russet), yellow- (PORO3PG6-3), and purple-flesh (PORO4PG82-1) potatoes were grown locally in Washington State in 2007 (USDA-ARS, Pomeroy, WA). In order to maximize retention of bioactive compounds, whole potatoes were boiled in a steam kettle for approximately 25 min, immediately cut into quarters, frozen in sealed small plastic bags, and stored at -35 °C until use. Appropriate amounts of potatoes were thawed and cooked every day. To minimize destruction of the bioactive compounds, potato recipes utilized quick-cook methods such as soups, mash and stir-fry. Butter, milk or vegetable oil was used in potato preparation, and condiments such as ketchup or hot sauce were made available to the participants. Fasting blood was collected from all participants at baseline (wk 0) and at the end of the intervention period (wk 6).

Blood assays. Blood collected at baseline and week 6 was analyzed for the following: plasma total antioxidant capacity (TAC), C-reactive protein (CRP), DNA damage biomarker (8-hydroxydeoxyguanosine, 8-OHdG), protein carbonyl and lipid peroxidation (TBARS). Immune response measured included the inflammatory cytokines (IL1-α, IL-1β, IL-2, IL-4, IL-6, IL-8, IL-10, IFN-ɣ anḍ TNF-α), lymphocyte phenotyping by two-color flow cytometry, mitogen-induced lymphocyte proliferation response, and natural killer (NK) cell cytotoxicity,

RESULTS

Demographics of the participants are presented in Table 1. All participants (n = 36) completed the study. No significant treatment differences were observed in age or BMI. Total caloric intake based on a 3 d dietary recall was lower ($P < 0.02$) in the PP treatment compared to YP or WP. There was no significant treatment x wk interaction for BMI. Participant compliance was excellent and no adverse side effects were reported.

Estimated amounts of antioxidants consumed daily by study participants are shown in Table 2. Total phenolics in YP and PP were about 1.5-fold greater than WP. The YP group consumed between 30 and 38-fold more carotenoids than WP or PP. The WP and YP groups consumed few anthocyanins while the PP consumed at least 24-fold more. Total antioxidants, assayed by TAA, were almost 2-fold higher in PP compared to YP, and YP was 3-fold higher than WP.

C-reactive protein. Plasma CRP concentrations in PP (1.3 ng/L) were lower ($P < 0.08$) than in WP (3.4 ng/L) at wk 6 (Figure 1). Concentrations also tended to be lower in YP (1.8 ng/L) than WP.

DNA damage. Plasma 8-OHdG concentrations in YP (27.3 ng/mL, $P < 0.03$) and PP (29.4 ng/mL, $P < 0.08$) were significantly lower than in WP (37.6 ng/mL) at wk 6 (Figure 2).

Total antioxidant capacity. There was no significant treatment difference in plasma TAC after 6 wk of potato consumption however, TAC in YP and PP treatments (2.2 mM) tended ($P > 0.05$) to be higher in WP (1.9 mM) (Table 3).

Protein carbonyl. Plasma protein carbonyl content showed no significant difference between treatments at wk 6. Plasma protein carbonyl averaged 6.1 nmol/mL across all treatments (Table 3).

Lipid peroxidation. Concentrations of plasma TBARS were not significantly different among treatments at wk 6 (Table 3).

Cytokine production. Plasma cytokine concentrations are shown in Table 4. Concentrations of plasma IL-6 in YP ($P < 0.08$) and PP ($P < 0.08$) treatments were lower compared to WP (Figure 3). In contrast, no significant differences were observed in plasma IL1-α, IL-1β, IL-2, IL-4, IL-6, IL-8, IL-10, IFN-γ and TNF-α concentrations among treatments.

Lymphocyte phenotypes. The distribution of different lymphocyte subpopulations are shown in Table 5. The B cell population at wk 6 was higher ($P < 0.03$) in PP (9.3%) than in WP (6.7%) (Figure 4). Among the different T cell subsets, subjects in YP generally had higher percentages of total T cells and Th cells than in WP. The Tc cell population in PP (25.0%) but not in YP (28.5%) was lower ($P < 0.05$) than in WP (28.5%) (Figure 4). The ratio of Th:Tc was similar among treatments, averaging 1.3. Subjects in PP tended to have the highest percentage of NK cells (26.3%). These results suggest that subjects in YP had numerically lower B and NK cell subpopulations and higher T cell populations than WP. Those in PP tended to have higher B and NK cell populations but lower T cell populations.

Lymphoblastogenesis. Lymphoproliferation induced by B and T cell mitogens. No significant treatment differences were observed in lymphocyte proliferation (Table 6).
NK cell cytotoxicity. NK cell cytotoxicity showed no significant differences in NK cell killing efficiency among treatments (Table 7).

DISCUSSION

This is the first study to address the effects potato consumption on antioxidant status, oxidative stress, inflammation and immune status in humans. Consumption of pigmented

potatoes (YP and PP) decreased 8-OHdG concentrations and IL-6, while consumption of PP also decreased CRP concentrations, decreased Tc cells and increased B cells when compared to WP.

Although fasting total antioxidant capacity did not increase, it appears that YP and PP helped prevent oxidative stress associated with DNA damage. Participants in YP and PP had significantly lower concentrations of 8-OHdG, a biomarker of DNA damage. Pool-Zobel et al. (38) reported a significant decrease in DNA damage in healthy males after supplementation with fruit and vegetable juices high in β-carotene, α-carotene, lutein and lycopene. In the present study, healthy males supplemented for 6 wk with 150 g of potatoes high in carotenoids or anthocyanins had reduced DNA oxidation. Therefore, it is plausible that consumption of yellow and purple potatoes may reduce DNA damage in smokers or individuals with chronic diseases. The prevention of oxidative DNA damage by antioxidants is likely mediated by quenching ROS.

As a biomarker of inflammation, elevated CRP concentrations have recently been implicated in chronic disease development and progression. CRP is produced by the liver in response to the inflammatory cytokine IL-6; reducing circulating CRP can prevent chronic disease development or disease progression. In this study, purple potatoes, a good source of anthocyanins, significantly reduced CRP and IL-6 concentrations in healthy males; plasma IL-6 concentration was significantly lower in YP than in WP. Plasma CRP was about 2-fold lower in YP than in WP, albeit not significantly. The WP demonstrated a non-significant increase in CRP concentrations at wk 6 compared to baseline. These results imply that PP and YP consumption could potentially alleviate inflammatory symptoms associated with chronic diseases such as cardiovascular disease, rheumatoid arthritis, and inflammatory bowel diseases. Antioxidants likely decrease inflammation by down-regulating the pro-inflammatory NFκB gene, which is responsible for cytokine production in immune cells. Reduced plasma IL-6 concentrations will therefore inhibit IL-6-stimulated CRP production by the liver.

The total antioxidant status of our study participants was only marginally affected by potato supplementation. This result was surprising because a preliminary study in our laboratory indicated that plasma antioxidant status increased by 160% measured 6 h after consumption of 300 g of purple potatoes. Anthocyanins are absorbed into plasma within 15-60 min after consumption; urinary excretion is complete within 6-8 h and typically less that 1% of ingested anthocyanins are absorbed. In this study, fasting blood samples were taken at least 14 hr after potato consumption; therefore, the discrepancy in plasma antioxidant status between the two studies is likely due to the low absorption and rapid clearance of anthocyanins from the blood stream. Compliance was not considered an issue in this study, therefore decreases in oxidative damage and inflammation observed in this study may be attributed to phenolic acid, carotenoid or anthocyanin concentrations from the potatoes.

Analysis showed that all potato cultivars contain high concentrations of total phenolics. As expected, the yellow potatoes had highest concentrations of toatal carotenoids while the purple potatoes had high anthocyanin concentrations.

The beneficial effects of carotenoid antioxidants on immune function have been well documented. The Tc population in the PP was significantly lower compared to WP, whereas the B cell population was significantly higher. No other significant changes in lymphocyte subsets were observed among the potato treatments, and all lymphocyte percentages were within normal range. These results imply that anthocyanins from purple potatoes may decrease Tc cell but increase B cell subpopulations.

In conclusion, consumption of yellow and purple potatoes decreased DNA oxidative damage and inflammation associated with IL-6 production. In addition, consumption of purple

potatoes decreased concentrations of the acute phase protein, CRP. The potential physiological benefits of consuming pigmented potatoes should be explored in persons with chronic disease.

TABLE 1
Demographic characteristics of participants

	WP	YP	PP
Age (y)	21.4 ± 1.0	23.1 ± 1.4	22.4 ± 1.4
BMI (kg/m^2)			
Week 0	25.0 ± 1.1	25.8 ± 1.1	25.4 ± 1.0
Week 6	25.1 ± 1.1	25.9 ± 1.1	25.2 ± 1.1
Ethnicity (*n*)			
Caucasian	11	11	10
Asian	1	1	2
Caloric intake, kcal/d	2579 ± 141[a]	2620 ± 141[a]	2100 ± 141[b]

[a, b] Different letters represent significant treatment differences ($P < 0.05$) as analyzed by ANOVA (n =12). Values are mean ± SE.

TABLE 2
Estimated average daily intake of bioactive compounds based on 150 g potato consumed

Treatment	Total phenolics[1]	Total carotenoids[2]	Total anthocyanins[1]	Total antioxidant activity[1]
White	49.6	43.0	0.0	39.7
Yellow	72.9	1323.8	6.8	125.3
Purple	83.2	34.9	166.3	225.4

[1] mg/150 g cooked potato
[2] µg/150 g cooked potato

TABLE 3
Oxidative stress biomarkers in participants fed white (WP), yellow (YP), or purple (PP) potatoes for 6 wk[1, 2]

Treatment	TAC (mM)	Protein carbonyl (nmol/mL)	TBARS (μM)
WP	1.9 [a]	5.6 [a]	1.1 [a]
YP	2.2 [a]	6.3 [a]	1.1 [a]
PP	2.2 [a]	6.5 [a]	1.1 [a]
Overall SE	0.1	0.2	0.1

[1]Data were analyzed by ANCOVA (n =12) using wk 0 as a covariate.
[2] There were no significant treatment differences.

TABLE 4
Plasma cytokine concentrations (pg/mL) in participants fed white (WP), yellow (YP), or purple (PP) potatoes for 6 wk.[1]

Treatment	IL-1α	IL-1β	IL-2	IL-4	IL-6	IL-8	IL-10	IFN-γ	TNF-α
WP	10.6	38.8	23.8	24.4	30.2 [a]	5.2	14.6	3.6	15.4
YP	11.6	40.8	23.8	23.2	16.6[b]	3.8	13.0	3.6	15.0
PP	10.8	39.0	24.4	25.2	16.8[b]	4.4	12.8	4.0	15.0
Overall SE	0.3	0.7	0.4	0.5	3.0	0.4	0.6	0.6	0.4

[1]Data were analyzed by ANCOVA (n =12) using wk 0 as a covariate.
[a, b] Different letters denote significant difference ($P < 0.08$).

TABLE 5
The percent of lymphocyte subsets in participants fed white (WP), yellow (YP), or purple (PP) potatoes for 6 wk.[1]

Treatment	B	Total T	Th	Tc	Th:Tc ratio	NK cells
WP	6.7 [a]	64.3	30.6	28.5 [a]	1.2	24.3
YP	6.5 [a]	68.3	35.8	28.5 [a]	1.3	20.6
PP	9.3 [b]	60.4	30.0	25.0 [b]	1.3	26.3
Overall SE	0.5	1.5	1.3	0.6	0.1	1.3

[1] Data were values were analyzed by ANCOVA (n = 12) using wk 0 as a covariate.
[a, b] Different letters denote significant difference ($P < 0.05$).

TABLE 6
Mitogen-induced lymphoproliferation (cpm) in participants fed white (WP), yellow (YP), or purple (PP) potatoes for 6 wk.[1, 2]

Treatment	PHA, 100 mg/L	PHA, 20 mg/L	ConA, 100 mg/L	ConA, 20 mg/L	PWM, 50 mg/L	PWM, 10 mg/L
WP	17456	3574	14846	9483	4080	3661
YP	16199	3981	15201	10190	5094	5079
PP	15672	4740	12930	8015	3688	3413
Overall SE	1360	757	1009	838	453	475

[1]Data were analyzed by ANCOVA (n =12) using wk 0 as a covariate.
[2] No significant treatment difference ($P < 0.05$) in lymphoproliferation was observed.

TABLE 7
NK cell cytotoxicity (% killing) in participants fed white (WP), yellow (YP), or purple (PP) potatoes for 6 wk.[1, 2]

Treatment	Target : Effector cell ratio	
	(1:1)	(1:5)
WP	97.7	78.2
YP	96.7	86.3
PP	91.2	82.8
Overall SE	4.2	2.6

[1]Data were analyzed by ANCOVA (n =12) using wk 0 as a covariate.
[2] No significant treatment difference ($P < 0.05$) in NK cytotoxicity was observed.

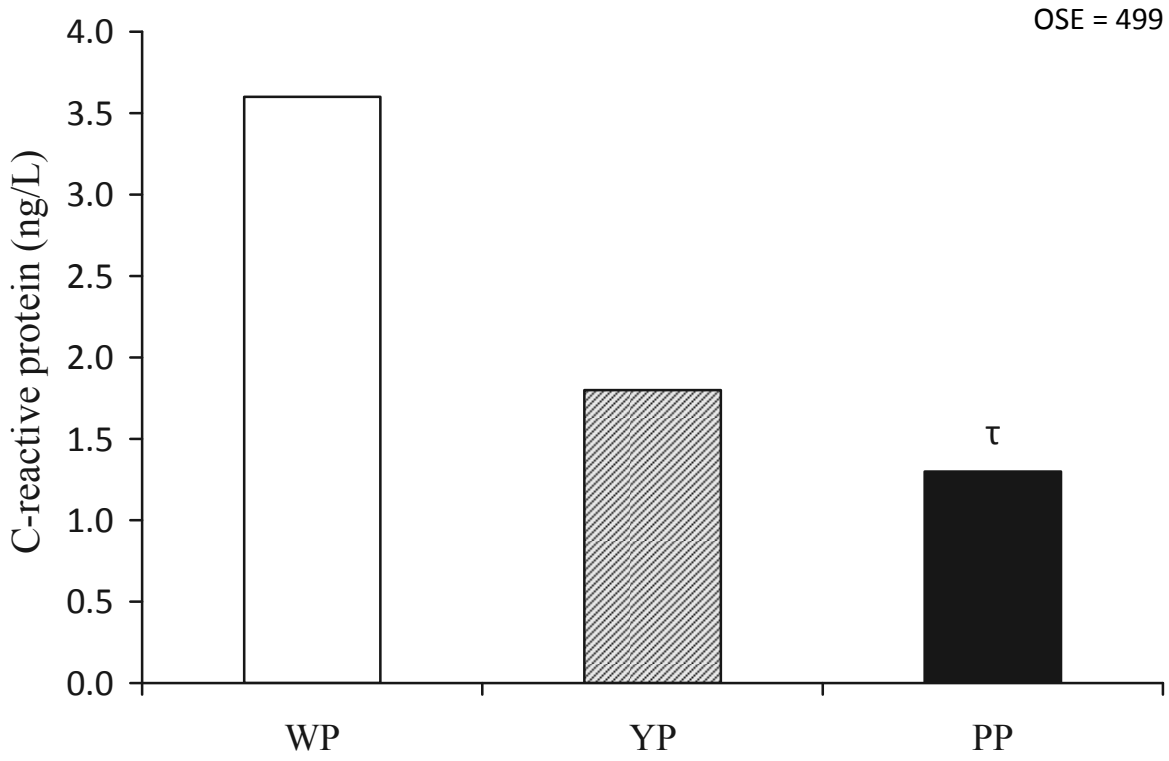


Figure 1. Plasma CRP concentrations in subjects fed white (WP), yellow (YP) or purple (PP) potatoes for 6 wk. Data were analyzed by ANCOVA using wk 0 as a covariate. Different symbols above each bar denote significant difference compared to WP ($^{\tau}P < 0.08$).

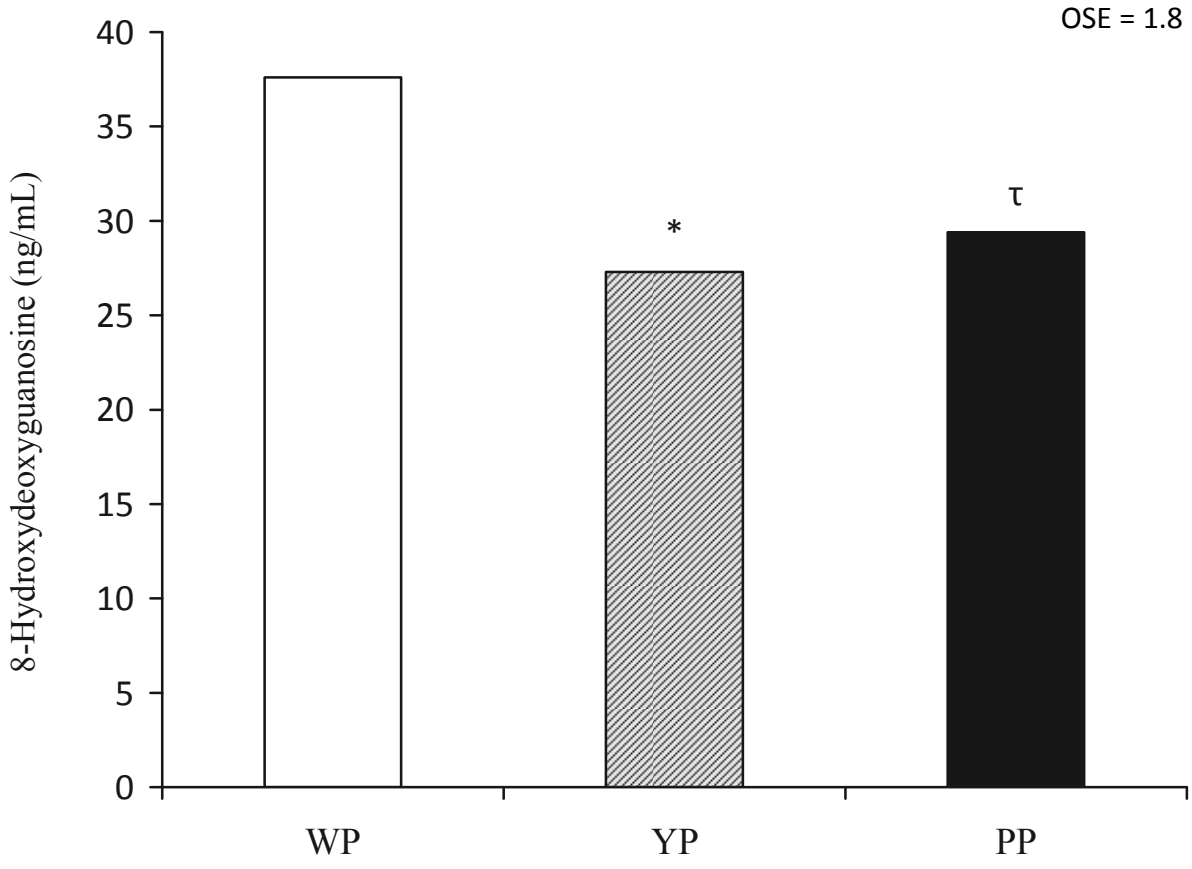


Figure 2. Plasma concentrations of 8-hydroxydeoxyguanosine in subjects fed white (WP), yellow (YP) or purple (PP) potatoes for 6 wk. Data were analyzed by ANCOVA using wk 0 as a covariate. Different symbols above each bar denote significant difference compared to WP ($^{*}P < 0.05$, $^{\tau}P < 0.08$).

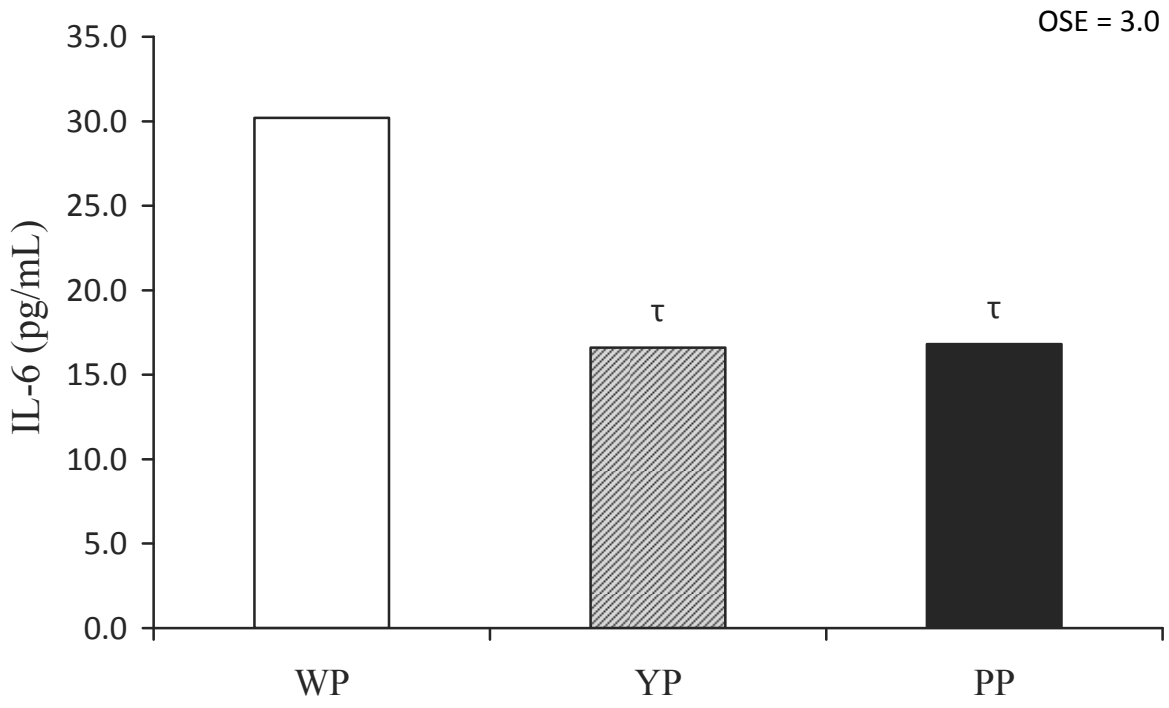


Figure 3. Plasma concentrations of IL-6 in subjects fed white (WP), yellow (YP) or purple (PP) potatoes for 6 wk. Data were analyzed by ANCOVA using wk 0 as a covariate. Different symbols above each bar denote significant difference compared to WP ($^{\tau}P < 0.08$).

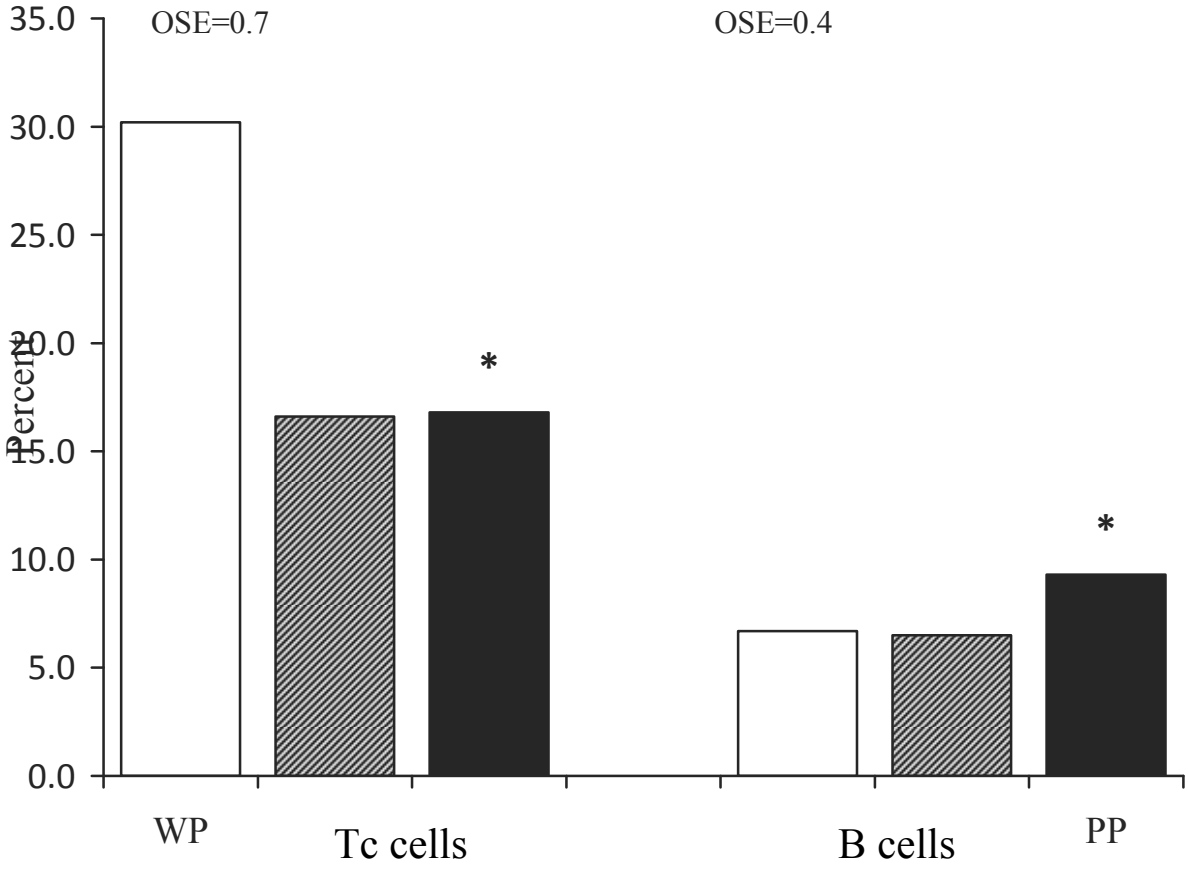


Figure 4. Percent lymphocyte Tc and B cells in subjects fed white (WP), yellow (YP) or purple (PP) potatoes for 6 wk. Data were analyzed by ANCOVA using wk 0 as a covariate. Different symbols above each bar denote significant difference compared to WP ($^{*}P < 0.05$).

Relative roles of tuber and soilborne inoculum in the development of Verticillium wilt in the potato cultivar "Russet Burbank"

Jeremiah Dung and Dennis A. Johnson

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

INTRODUCTION

Verticillium wilt of potato is a disease of major economic importance to potato growing regions in North America. The primary causal agent of Verticillium wilt in the Pacific Northwest (PNW) is *Verticillium dahliae*, a soilborne fungal pathogen with an extensive host range and widespread distribution. Although no sexual stage is known to occur, genetic diversity does exist in the form of several distinct vegetative compatibility groups (VCG). Isolates from potatoes and PNW potato fields are predominantly VCG 4A and VCG 4B, and VCG 4A isolates have been found to be more aggressive on potato than other VCGs (4, 7, 8). Symptoms of Verticillium wilt of potato include leaf epinasty, wilting and chlorosis, which progress acropetally and often occur unilaterally. Entire stems eventually become necrotic and senesce prematurely, but remain upright. Vascular discoloration in stems and tubers is often associated with VW infection, but may also result from physiological factors or other pathogens and thus is not diagnostic. Reports on the effects of Verticillium wilt on yield are variable, ranging from 12% to 30% or more, and reductions in potato yields are not necessarily correlated with above ground symptoms. Yield reductions and symptom expression are influenced by soil and environmental conditions (9) and can be more pronounced during periods of heat stress and high rates of evapotranspiration. Synergistic interactions between *Pratylenchus penetrans*, the root lesion nematode, and VCG 4A isolates of *V. dahliae* can increase disease severity, lower the disease thresholds of both pathogens and severely reduce yields.

Primary inoculum in soil consists of microsclerotia, which form during plant senescence and can persist in soil for long periods of time. Reported disease thresholds for Verticillium wilt in potato range between 5-30 cfu/cm^3 of soil for *V. dahliae* alone and 2-13 cfu/cm^3 soil when *P. penetrans* is present (9). Microsclerotia are stimulated to germinate in response to host root exudates and hyphae invade the cortex and xylem, where it produces abundant conidia which are systemically translocated through the host vascular system. Root colonization of resistant and non-hosts has also been shown to occur, however the fungus appears to be prevented from extensively colonizing the cortex or xylem (1). A short saprophytic phase occurs at host senescence, during which *V. dahliae* produces conidia and microsclerotia in colonized tissue. Conidia are short-lived and not thought to be significant in disease progress or development. Microsclerotia production is most abundant on aerial stems and colonized host debris can increase inoculum levels if incorporated into the soil. Furthermore, infested soil carried on seed tubers has been shown to contribute to Verticillium wilt symptoms (10, 11).

In addition to soilborne inoculum, intratuber inoculum of *V. dahliae* can be found in the vascular system of certified seed tubers. A 1968-1969 survey detected *Verticillium albo-atrum* and *V. dahliae* in 39% of 244 certified seed lots, with incidence in lots typically between 1-2% and rarely greater than 5% (2). A more recent study of seed lots imported from northern Europe

to Israel between 1995 and 1998 detected *V. dahliae* in 20 to 30% of seed lots at incidences < 5% and found up to 16% of seed lots with *V. dahliae* infection in >5% of seed tubers (12). Surveys of 224 seed lots intended for North American production fields in 1995 and 1996 detected *V. dahliae* in 29% of the lots and 3.6% of the seed tubers, of which 64% of isolates were VCG 4A, 33% were VCG 4B and 3% were VCG 4AB (8). The detection of *V. dahliae* in certified potato seed lots and prevalence of the more aggressive VCG 4A in both seed tubers and PNW fields (7) may have important implications in both seed and production systems as well as the epidemiology and distribution of the disease.

Despite the prevalence of *V. dahliae* in certified commercial seed lots, the contributions of intratuber inoculum in the development and epidemiology of Verticillium wilt are not fully understood. Robinson et al. (10) determined that vascular infection of seed tubers by *V. albo-atrum* did not cause symptomatic plants in several potato cultivars. A 1979 field study found no effect of intratuber infection by *V. dahliae* on plant growth, disease symptoms, yield or quality in the potato cultivar "Norgold Russet" (3), however, severity of wilt resulting from intratuber infection can vary among cultivars (10) and the effects of vascular infection by *V. dahliae* in seed tubers has not been evaluated in "Russet Burbank", the major cultivar under production in the PNW. The objectives of this study were to: (i) determine the relative roles of intratuber and soilborne inoculum in the development of Verticillium wilt symptoms in the potato cultivar "Russet Burbank"; (ii) compare plants grown from apical and basal-end seed pieces cut from infected seed tubers, since vascular infection of progeny tubers presumably occurs via underground stolons; (iii) quantify incidence of vascular host colonization, microsclerotial production on senescent stems and the incidence of infected progeny tubers to assess the potential contributions of seed tuber infection to overwintering inoculum.

MATERIALS AND METHODS

Seed tuber assays. Seventeen seed lots of potato cultivar "Russet Burbank", which is moderately susceptible to Verticillium wilt, were obtained in 2007 from Washington (WA), Idaho (ID), Montana (MT), and Alberta, Canada certified seed sources and assayed for natural *V. dahliae* infection. A total of ten WA, ID and MT certified seed lots were assayed in 2008. A random sample of thirty-five tubers from each lot were thoroughly scrubbed with a sponge under running distilled water and allowed to air dry. A ~15 mm round disk which included vascular tissue was aseptically cut from the stem-end of the tuber and plated onto either modified potato dextrose agar (5), NP-10 medium, or both. Plates were incubated at 23° C for 14 days. Positive identification of *V. dahliae* colonies was verified by sub-plating onto potato dextrose agar when necessary and eleven tubers were selected for use as naturally infected seed piece treatments. Eleven tubers were chosen as noninfected seed piece treatments based on negative results in the plate assays. Care was taken to use tubers in which other fungal pathogens (e.g. *Colletotrichum coccodes, Fusarium* spp.) were not detected.

Disease evaluation. Soil inoculum consisted of rye berries colonized with *V. dahliae* isolate 653 and was prepared. Isolate 653 was isolated from potato and identified as VCG 4A and pathogenic on potato. Berries were ground in a mill and the ground inoculum was quantified via serial dilution. Infested soil treatments were prepared by adding ground inoculum to 5.0 L of Sunshine L2 greenhouse potting mix to achieve a concentration of approximately 10 CFU/cm^3. Ground noninoculated rye was added to the noninfested soil treatments. Approximately 32 g of granular 16-16-16 N-P-K fertilizer was added to each pot prior to planting the seed pieces. The

22 tubers selected in the assays previously described were cut aseptically crosswise and then lengthwise into four equal sized pieces (approximately 60 g) with at least two eyes each. Blocks consisted of four seed pieces derived from one infected tuber and four seed pieces derived from one disease-free tuber; both seed tubers were from the same lot. Apical and basal-end seed pieces were equally divided among seed and soil treatments. Pots were arranged in the greenhouse as a randomized complete block (RCB) design with 11 replicates. The trial was performed once in 2007 and repeated in 2008.

Disease symptoms were assessed at 65 days after planting and approximately weekly thereafter until crop senescence (142 days for the first trial (2007) and 133 days for the second trial (2008)). Plants were evaluated for total percentage of chlorosis and necrosis over the entire plant as well as on a 1-6 scale where 1= no symptoms, 2 = slight chlorosis, 3 = extensive chlorosis (≥ 50% of plant), 4 = extensive chlorosis and necrosis ≥ 25% of plant, 5 = extensive chlorosis and necrosis ≥50% plant, and 6 = dead/nearly dead plant. Disease ratings and total chlorosis and necrosis over time were converted to area under disease progress curves (AUDPC), area under chlorosis progress curves (AUCPC) and area under necrosis progress curves (AUNPC).

Stem sampling and progeny tuber assays. A single aboveground stem from each plant was destructively sampled when plants appeared to be within a week of senescence (after the plant was >80% necrotic but before desiccation of the stem). A one cm section, taken 30 cm above the soil-line, was plated onto NP-10 medium and incubated for one week to detect vertical stem colonization of *V. dahliae.* The remaining stems were left to dry for 3 weeks in their containers and visually assayed for *V. dahliae* microsclerotial colonization using a dissecting microscope. Microsclerotial colonization was recorded as the percentage of stem colonization in relation to total stem length; all remaining stems were assayed and results combined to calculate the mean microsclerotial colonization per plant. A total of seven randomly selected progeny tubers from each plant were assayed for *V. dahliae* infection as described above.

RESULTS

Seed tuber assays. Assays of certified seed lots intended for Washington State production fields detected *V. dahliae* in 35% of lots with 2.0% of tubers infected in 2007 and in 70% of lots with 6.9% of tubers infected in 2008. Incidence of infected tubers within lots ranged from 0 to 11.4% in 2007 and 0 to17.1% in 2008.

Disease evaluation. Mean AUDPC and AUNPC values were significantly ($p \leq 0.05$) higher in potato plants grown in infested soil than in noninfested soil in both trials (Table 1). Significant differences in AUDPC and AUNPC were not found ($p > 0.05$) between plants grown from infected and noninfected seed tubers in noninfested soil. AUCPC was significantly higher for the infected tuber treatment compared to the control treatment in the 2007 trial and mean AUCPC was significantly higher for both infested soil treatments in the 2008 trial, however these differences were not consistent over both years. Significant interactions or additive effects were not detected between intratuber infection and soilborne inoculum in either 2007 or 2008. Analysis of disease progress curves showed that necrosis and chlorosis began earlier in plants grown in infested soil compared to those grown in noninfested soil (Figs. 1 and 2). Differences in disease development were not found in plants grown from apical and basal-end seed pieces cut from infected tubers, however mean AUNPC was significantly higher in plants grown from

basal-end seed pieces during the 2007 trial ($p < 0.03$) and a significant seed piece x soil inoculum interaction was also detected ($p < 0.04$).

A number of experimental units were lost due to bacterial soft rot during the 2008 trial. Plants which failed to emerge were included in the ANOVA as missing data points. An entire block became heavily infested with aphids approximately 100 days after planting and was not included in the analysis, bringing the total number of experimental units down from 88 to 55. Despite the reduction in degrees of freedom, ANOVA results from the 2008 trial were consistent with those from the 2007 trial with regards to AUDPC, AUNPC and re-isolation data.

Stem sampling and progeny tuber assays. Vascular infection of seed tubers by *V. dahliae* did not significantly ($p > 0.05$) contribute to aboveground vascular colonization, progeny tuber infection or microsclerotia production in senescent stems compared to noninoculated controls (Table 2). Plants grown in infested soil exhibited significantly ($p \leq 0.05$) more vascular colonization by *V. dahliae* and produced significantly more *V. dahliae*-infected progeny tubers than infected tubers grown in noninfested soil. Mean microsclerotial colonization was significantly higher in plants grown in infested soil compared to plants grown from infected seed pieces in noninfested soil. Mean microsclerotia colonization of stems originating from infected tubers ranged from 0 to7% while stems obtained from plants grown in infested soil exhibited 0 to 91% mean colonization. *V. dahliae* was not detected in or on any stems or progeny tubers from control treatments. Based on the combined stem assays, incidence of aboveground stem infection in potato plants grown from infected tubers was 21% in the 2007 trial and 13% in the 2008 trial and 100% for plants grown in infested soil in both trials.

DISCUSSION

The role of soilborne microsclerotia as primary inoculum of *V. dahliae* has long been understood, however, the pathogen can also be found in the vascular tissue of certified seed tubers. Several field experiments have demonstrated that, despite the presence of *Verticillium* spp. in certified seed lots (2, 8, 12), intratuber infection has little effect on Verticillium wilt symptoms or potato yields in various potato cultivars. These studies, however, have either used cultivars under limited current cultivation (3), artificially inoculated tubers (11) or *V. albo-atrum* (10) and focused on the effects of tuber infection on aboveground symptoms, yield, quality and vascular discoloration of progeny tubers. In addition, the potential contribution of seed tuber infection to the formation of future inoculum, i.e. microsclerotia, was not previously quantified. The results of this study show that intratuber infection exhibited a negligible effect on the development of Verticillium wilt in the commonly grown but moderately susceptible potato cultivar "Russet Burbank" and does not significantly contribute to aboveground stem infection or the formation of microsclerotia in debris.

Assays of certified seed lots detected higher levels of *V. dahliae* in 2008 compared to 2007. Incidence of *V. dahliae* among and within certified seed lots sampled in 2007 was comparable to previous survey of N. American seed lots (8). The higher incidence of the *V. dahliae* in 2008 may be due to the lack of seed sources from Canada, where the prevalent *Verticillium* species is *V. albo-atrum* (9). Assays performed in 2007 did not detect *V. dahliae* in the four seed lots obtained from Canada, however *V. dahliae* has previously been reported in Canadian-grown seed (8).

Previous studies of *V. dahliae* isolates collected from potatoes and PNW potato fields found the majority of isolates to belong to VCG 4A and VCG 4B, with VCG 4A being highly aggressiveness on potato compared to other VCGs (3, 7, 8). Although infected seed tubers used in this study were not tested for infection by the more aggressive VCG 4A, the results of this study are still of practical importance since naturally-infected tubers were used and the negligible effect of intratuber infection on necrosis and disease progression was definitive for both trials ($p > 0.73$). In addition, the density of soilborne inoculum used (10 cfu/cm^3 soil) was low, especially considering a recent study which found that 37% of PNW fields intended for potato production contained ≥ 10 cfu/g soil and 6% had inoculum densities > 30 cfu/g soil (7). Artificially inoculated tubers were not used since artificial inoculation does not simulate the natural infection process and it is difficult to obtain a sufficient number of tubers for study. Omer et al. (8) demonstrated that nearly two-thirds of infected seed tubers intended for Washington production contained isolates of the more aggressive VCG 4A and approximately one-third contained VCG 4B. It is reasonable to assume a roughly similar frequency of VCG distribution was present in seed tubers used in this study.

A second, unrepeated experiment was performed to provide additional confirmation of the results of the repeated trials. Tubers were taken from control and infested soil treatments in the 2007 trial and assayed for vascular infection as previously described. Infected tubers were taken from artificially inoculated soil and presumed to be infected with *V. dahliae* isolate 653 (VCG 4A). Plants were grown from single-drop seed and soil inoculum administered as previously described. Treatments consisted of infected tubers grown in infested soil and noninfected tubers grown in infested and noninfested soil. Plants were arranged as a RCB in the greenhouse with eight replications of each treatment. Mean AUDPC and AUNPC values, vascular and microsclerotia colonization and progeny tuber infection were consistent with results obtained from the 2007 and 2008 trials using naturally-infected seed tubers obtained from commercial seed lots (data not shown).

The development of necrosis in *V. dahliae*-infected tubers and control plants was similar in both trials, indicating that the senescence observed in infected tubers was natural (Fig. 1). AUDPCs and AUNPCs of treatments grown in infested soil were similar regardless of intratuber infection (Figs. 1 and 2). No interactive effects, either additive or synergistic, were detected between soilborne and intratuber inoculum ($p > 0.05$). Treatment comparisons of mean AUNPC and AUDPC were consistent between trials. Treatment comparisons of mean chlorosis yield different results between trials, indicating that necrosis and/or disease ratings which incorporate both necrosis and chlorosis may provide a more consistent evaluation of Verticillium wilt symptoms. Comparisons of AUNPC values indicate that premature necrosis began between 95 and 105 days after planting in plants grown in infested soil, approximately one to two weeks earlier than plants grown in noninfested soils regardless of intratuber infection.

The importance of soilborne inoculum in Verticillium wilt of potato, both for disease development and long-term survival of the pathogen, has been recognized for quite some time. Nitzan et al. (6) suggested that the distribution of soilborne *C. coccodes* inoculum in the root zone provides more potential points of infection. Although not significant, apical-end seed pieces planted in infested soil resulted in higher AUDPC and AUNPC values than basal-end seed pieces in both trials (data not shown); the likely presence of more eyes on apical-end seed pieces, which can sprout into infested soil and provide more opportunities for infection, provides one

possible explanation. In addition to their distribution in the root zone, microsclerotia in soil are capable of repeated germination and can essentially function as several CFU over time, increasing their infection potential in comparison to conidia and reducing the number of propagules required to cause disease.

Since vascular colonization is thought to be required for symptom development (1) it is not completely understood why infection of *V. dahliae* in potato seed tubers does not result in significant Verticillium wilt symptoms. Vascular colonization of aboveground stems was only detected in a few plants grown from infected tubers, indicating that the pathogen does not readily translocate from tuber vascular tissue to aboveground vascular tissue. Pathogen populations in the vascular system of the tuber may be below the threshold required to colonize growing stems and cause disease. The pathogen may also be compartmentalized in progeny tubers, either during infection, storage or growth, preventing complete colonization of the seed tuber and providing opportunities for sprouting eyes to escape infection. Prior research suggests that vascular infection of seed tubers by *V. dahliae* is often unilateral (1), indicating that if occlusion of the pathogen does occur it is likely during infection or storage. Previous studies on potato have shown varietal differences in the progression and density of vascular colonization by *V. dahliae*, with Verticillium wilt-resistant plants showing less vascular colonization than susceptible ones (1).

The results of this study indicate that intratuber infection of seed tubers of potato cultivar "Russet Burbank" does not significantly contribute to symptoms, progeny tuber infection or inoculum production in plant debris, hence management strategies should focus on soilborne inoculum. Since vascular infection of seed tubers does not appear to significantly result in vascular colonization or the production of microsclerotia in plant debris, infected seed tubers probably do not contribute to soilborne inoculum. The possibility exists that soilborne *V. dahliae* inoculum can be introduced into a field solely from infected seed pieces, which could be important if the fungus, or novel strains of the fungus, are introduced into soils not previously used to grow potatoes or where a management practice such as fumigation has been applied to reduce soilborne inoculum. Since the use of soil fumigants is both costly and subject to future restrictions, other methods of reducing *V. dahliae* propagules in field soils need to be utilized. The use of partial or completely resistant cultivars, which can restrict vascular colonization and subsequent microsclerotia formation by *V. dahliae*, have the potential to both reduce symptoms and limit the amount of inoculum in field soils. Molecular detection methods, such as quantitative polymerase chain reaction, can be utilized to help develop resistant cultivars and monitor pathogen populations in the soil (1). A combination of control methods, including resistance, pre-plant monitoring, crop rotation, green manures, proper sanitation and other cultural practices will likely be necessary to sustainably manage potato production fields affected by Verticillium wilt in the future.

LITERATURE CITED

1. Atallah, Z. K., Bae, J., Jansky, S. H., Rouse, D. I., and Stevenson, W. R. 2007. Multiplex real-time quantitative PCR to detect and quantify *Verticillium dahliae* colonization in potato lines that differ in response to Verticillium wilt. Phytopathology 97 (7):865-872.
2. Easton, G. D., Nagle, M. E., and Bailey, D. L. 1972. *Verticillium albo-atrum* carried by certified seed potatoes into Washington and control by chemicals. Amer Potato J 49 (10):397-402.
3. Hoyman, W. G. 1974. Consequence of planting Norgold Russet seed infected with *Verticillium albo-atrum*. American Potato Journal 51 (1):22-25.
4. Joaquim, T. R., and Rowe, R. C. 1991. Vegetative compatibility and virulence of strains of *Verticillium dahliae* from soil and potato plants. Phytopathology 81 (5):552-558.
5. Johnson, D. A., Rowe, R. C., and Cummings, T. F. 1997. Incidence of *Colletotrichum coccodes* in certified potato seed tubers planted in Washington State. Plant Disease 81 (10):1199-1202.
6. Nitzan, N., Cummings, T. F., and Johnson, D. A. 2008. Disease potential of soil- and tuberborne inocula of *Colletotrichum coccodes* and black dot severity on potato. Plant Disease 92 (11):1497-1502.
7. Omer, M. A., Johnson, D. A., Douhan, L. I., Hamm, P. B., and Rowe, R. C. 2008. Detection, quantification, and vegetative compatibility of *Verticillium dahliae* in potato and mint production soils in the Columbia Basin of Oregon and Washington. Plant Disease 92 (7):1127-1131.
8. Omer, M. A., Johnson, D. A., and Rowe, R. C. 2000. Recovery of *Verticillium dahliae* from North American certified seed potatoes and characterization of strains by vegetative compatibility and aggressiveness. American Journal of Potato Research 77 (5):325-331.
9. Powelson, M. L., and Rowe, R. C. 1993. Biology and management of early dying of potatoes. Annual Review of Phytopathology 31 (1):111-126.
10. Robinson, D. B., and Ayers, G. W. 1961. Verticillium wilt of potato in relation to vascular infection of the tuber. Canadian Journal of Plant Science 41:703-708.
11. Thanassoulopoulos, C. C., and Hooker, W. J. 1968. Factors influencing infection of field grown potato by *Verticillium albo-atrum*. American Journal of Potato Research 45 (6):203-216.
12. Tsror (Lahkim), L., Aharon, M., and Erlich, O. 1999. Survey of bacterial and fungal seedborne diseases in imported and domestic potato seed tubers. Phytoparasitica 27 (3):215-226.

TABLE 1. Mean AUDPC, AUCPC and AUNPC values for potato cultivar "Russet Burbank" grown from *V. dahliae*-infected and noninfected tubers in the presence and absence of soilborne inoculum.

Inoculum Source(s)		AUDPC		AUCPC		AUNPC	
Soil	Tuber	2007 Trial[a]	2008 Trial	2007 Trial	2008 Trial	2007 Trial	2008 Trial
None	None	217 a	169 a	1165 a	814 a	1749 a	1385 a
None	Infected	219 a	169 a	1544 b	832 ab	1781 a	1475 a
Infested	None	274 b	216 b	1372 b	1048 c	3022 b	1975 b
Infested	Infected	272 b	216 b	1529 b	992 bc	2905 b	1916 b

[a] Teatment means compared with Fischer's protected LSD; values with the same letter indicate no significant difference within the trial ($p > 0.05$).

TABLE 2. Differences in vascular colonization, microsclerotia production and progeny tuber infection between "Russet Burbank" potato plants grown from infected and noninfected seed tubers.

Inoculum Source(s)		Stem Colonization (% isolated at 30 cm above soil-line)		Microsclerotia Colonization (% total length)		Infected Progeny Tubers (% isolated)	
Soil	Tuber	2007 Trial[a]	2008 Trial	2007 Trial	2008 Trial	2007 Trial	2008 Trial
None	None	0.0 a	0.0 a	0.0 a	0.0 a	0.0 a	0.0 a
None	Infected	8.3 a	6.7 a	0.5 a	0.3 a	0.0 a	0.0 a
Infested	None	95.8 b	92.3 b	52.5 b	46.1 b	14.3 b	15.4 b
Infested	Infested	95.8 b	92.9 b	47.8 b	41.8 c	13.7 b	13.3 b

[a] Treatment means compared with Fischer's protected LSD; values with the same letter indicate no significant difference within the trial ($p > 0.05$).

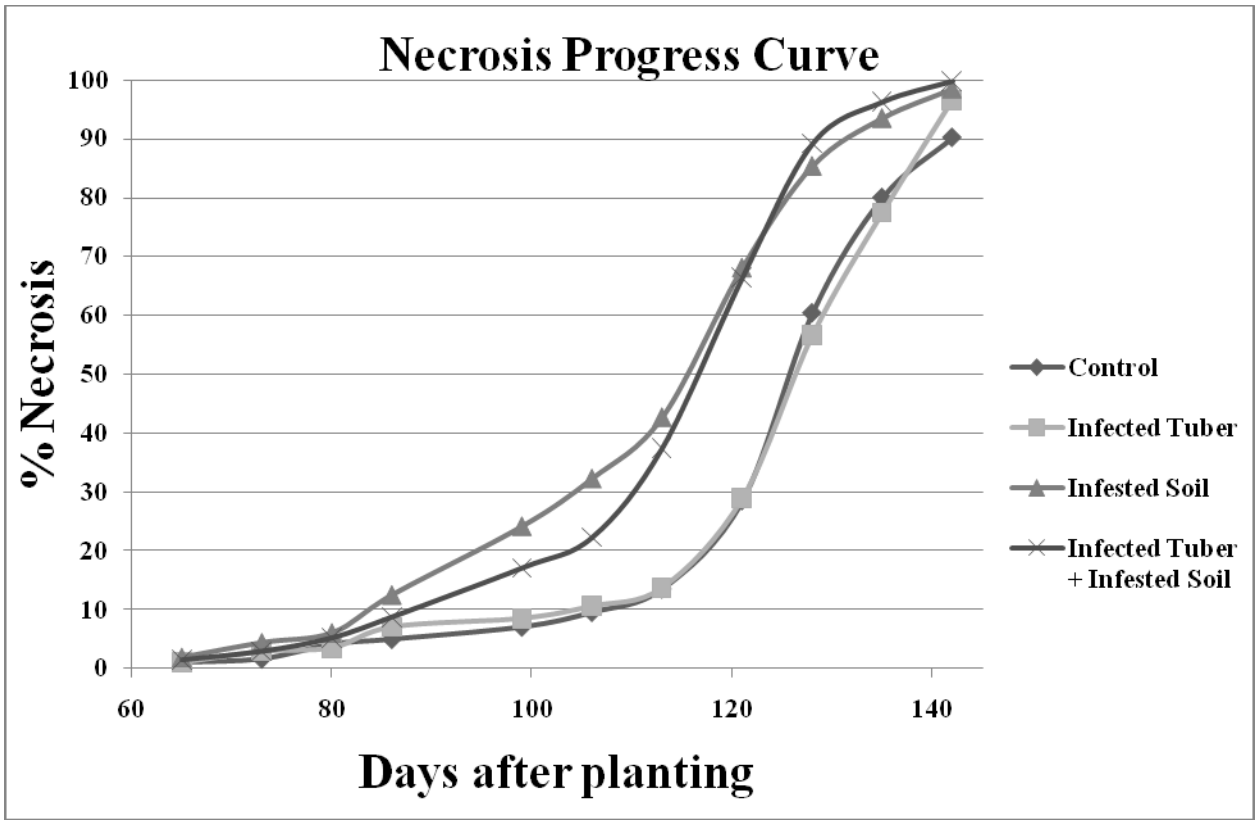


Fig 1. Necrosis progress curves for potato plants grown from *V. dahliae*-infected and noninfected tubers in infested and noninfested soil in 2007.

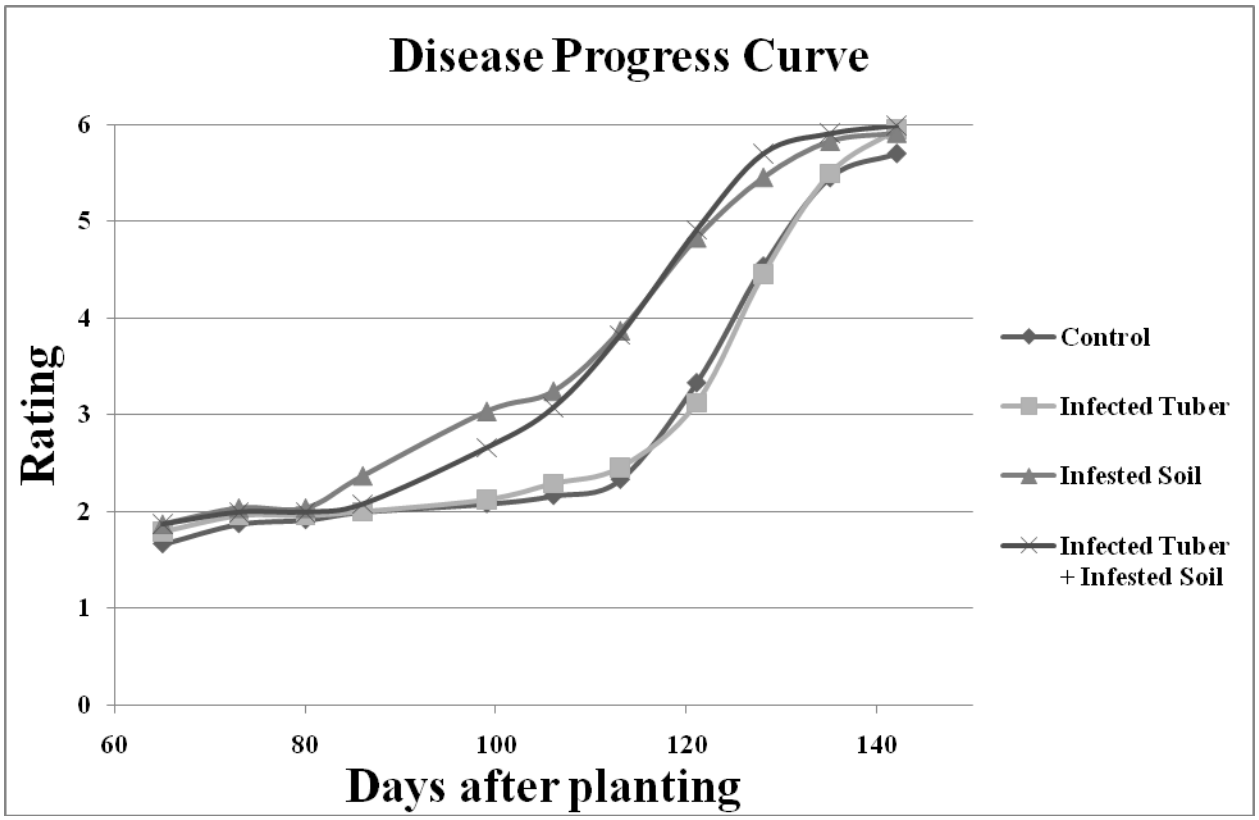


Fig 2. Disease progress curves for potato plants grown from *V. dahliae*-infected and noninfected tubers in infested and noninfested soil in 2007.

Tobacco Rattle Virus…..An Old Problem with New Symptoms

Philip B. Hamm[1] and Jim Crosslin[2]
[1]Oregon State University, Hermiston Ag Research & Extension Center, Hermiston OR and [2]USDA ARS, Prosser WA

Tobacco Rattle Virus (TRV) has been an issue in the Columbia Basin for many years. This virus, vectored by the Stubby Root Nematode ([SRN] *Paratrichodorus* species), has a wide host range as does the nematode. Fortunately the virus alone does not seem to cause damage on hosts other than potatoes and for the most part, neither does the nematode (onion is a notable exception). However, when it comes to potatoes, when TRV is transmitted to potato tubers during the feeding of the nematode, substantial damage can occur (Photo 1). This damage is known as corky ring spot (CRS) or "spraing" as it is commonly referred to in Europe. Complete fields have been lost due to this damage, rendering the tubers fit only for processing at a flake plant. Significant and widespread damage due to this disease was seen in the early 90's when Temik was removed from the market place. Apparently this product was, unknowingly, very effective in controlling the SRN. Research accomplished in the early to mid 90's proved that Telone II was very effective in controlling SRN and therefore, also controlled CRS.

The story would likely have ended there if not for the introduction of the new nematicide called Vydate. While Telone II required application prior to planting potatoes, generally in the fall, Vydate was registered for use during the cropping season. This product therefore provided an option for potato growers who decided to grow additional potatoes after the fall fumigation season had ended. They did not have to wait until soil temperatures in the spring were high enough to allow soil fumigation. Also, some growers have decided to use Vydate instead of Telone II, either because of the particular economics of that potato crop and/or because of the insects that Vydate controls. Since Vydate also controls root knot nematodes and the biology of these plant pathogens wwas already known, the recommended first use of Vydate in the season was based on when nematodes in the soil would first be attacking the newly developing tubers (around 850 degree days). Waiting until 850 degree days in fields not treated with Telone II represented a time that emerging potato plants were not protected from SRN containing TRV. That short window without protection has apparently resulted in new symptoms due to infections by TRV.

Early in the growing season in 2005 a field containing ½ Russet Norkotah and ½ Ranger Russet had very specific poor emergence issues. Close observations of the plants that had not emerged revealed thickened distorted stems, with leaves trying to form far below the soil line (Photo 2). Emerged but stunted plants adjacent to plants not yet emerged had uncharacteristic coloration of leaves similar in some ways to that caused by *Alfalfa Mosaic Virus* (Photo 3). Testing with ELISA and PCR confirmed these distorted poorly emerging plants and those with these "yellow" symptoms in the leaves were infected with TRV. Stubby root nematodes associated with these bare batches were also found to be viruliferous (containing TRV) while others found in areas where plants appeared normal were not. This field had been scheduled to receive Vydate at about row closure. Since no CRS issues at harvest were seen in either cultivar, the use of Vydate as prescribed based on the label, apparently prevented large scale losses or even tuber rejection.

Once these symptoms were recognized as potentially caused by TRV, many other situations over the last several growing seasons have been seen due to TRV, and in some cases, may have resulted in significant losses if not identified early. Damage has been seen in other Russet Norkotah fields (Photo 4), Shepody (Photo 5) and Ranger Russet (Photo 6). These problems have been found throughout the Columbia Basin potato production area. In most cases foliar symptoms have not been seen (yellowing patterns in the leaves) but delayed emergence and distorted stems are always present.

While not all the research has been done to answer all the questions these new symptoms due to TRV have raised, control can be achieved by the use of Telone II (since to our knowledge delayed emergence, distorted stems, and foliar symptoms have not been seen where Telone II has been applied). In addition, we believe that these symptoms can also be controlled with the use of Vydate with one important difference in its usage. Vydate is now recommended as an in-furrow treatment at planting. The in-furrow use has not been systematically tested in the Columbia Basin to control these newly found symptoms. However, given what we know about the SRN, timing of infection, and the result of the timing of applications of Vydate in the past at or about row closure, we believe an in-furrow application will control these issues. If Vydate is used, consult a current label of the product to ensure proper usage.

General recommendations for controlling CRS begin by remembering that any field previously found to have this disease must be considered always to have the disease and control measures should be specifically budgeted, scheduled, and correctly completed. The challenge most often is when fields are rented and the history of this problem is not always remembered or communicated with the new renter. Remember, just because a field has SRN does not mean the nematodes contain the virus. SRN by themselves do not cause any significant problems in potatoes. There are procedures that can test individual SRN to see if they are viruliferous or not. If the test shows they are, then chemical control is required. If the SRN tests are negative for TRV, this does not guarantee that no TRV is associated with SRN in the field.

If symptoms like these appear in fields this season, we would be happy to confirm whether or not TRV is responsible.

Photo 1. Typical internal symptoms due to TRV.

Photo 2. Thickened stems with abnormal production of leaves below ground due to early infection by TRV.

Photo 3. Symptoms of TRV in Russet Norkotah.

Photo 4. A "hole" in a field of Russet Norkotah caused by TRV. Notice the different rates of emergence.

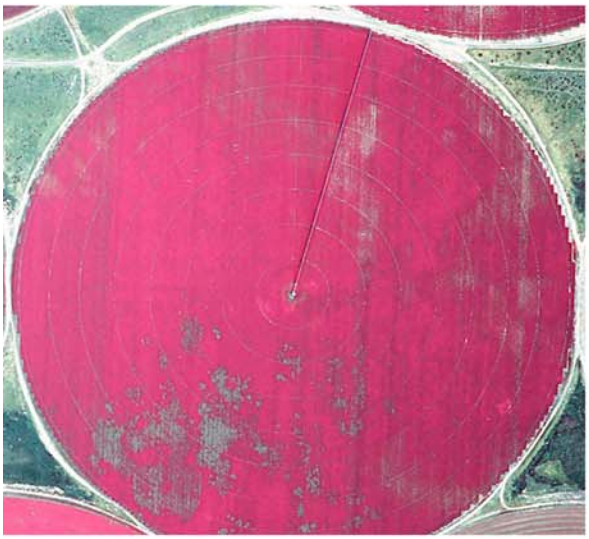


Photo 5. IR photo showing "holes" with poor emergence due to TRV.

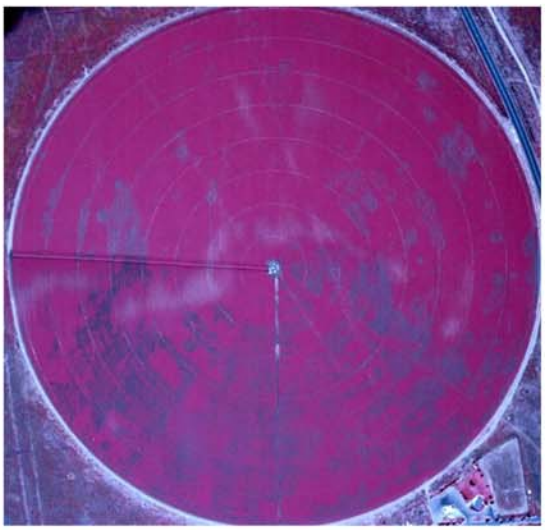


Photo 6. IR photo showing substantial wide spread emergence issues due to TRV.

Estimating Methyl Isothiocyanate Emission Rates Following Soil Incorporated Shank And Modified Center Pivot Chemigation Metam Sodium Applications

PERSONNEL:

Vincent Hebert;	WSU-Food and Environ Quality Lab, Richland WA
Monte Spence;	Wind Flow. Mattawa, WA
Jim Ossman;	Crop Production Services, Pasco WA
David Sullivan;	Sullivan Environmental Consulting, Alexandria, VA

In-kind industry support**:**	Jim Owen and Kurt Volker, TKI
In-kind grower support**:**	Ed Schneider, Schneider Farms, Pasco WA

Report Period: January – December 2008

Summary: An air sampling program was conducted in Franklin County, WA in the fall of 2008 to monitor fumigant air movement at near-field receptor locations following low drift (drizzle boom) modified center pivot chemigation and soil-incorporated shank injection applications with Sectagon 42® (42% metam sodium). This study was developed to assess emission rates and total cumulative field loss of metam sodium's gaseous by-product, methyl isothiocyanate (MITC) during and four days post-application under conditions typical for Pacific Northwest potato pre-plant fumigation. The aim of this work is to aid growers in evaluating putative reduced emission application practices particularly when deciding on application practices/timing near residential communities. We also developed this study to provide regionally specific MITC emission rate information to the United States Environmental Protection Agency Office of Pesticide Programs. As a result, this field demonstration closely adhered to Series 875 of the U.S. EPA Pesticide Assessment Guidelines: Occupational and Residential Exposure Test Guidelines. For each treatment plot, MITC concentrations (in μg m^{-3}) were generated from air collected through activated charcoal at eight receptors spaced around each test plot periphery before, during, and throughout the 4-day post application period. For each treatment plot, MITC field emission rates (μg m^{-2} sec^{-1}) together with total cumulative MITC loss were estimated using an Industrial Source Complex Short Term (ISCST3) emissions model that utilized hourly meteorological data gathered at the field study location over the study time frame. Estimated total cumulative MITC loss by drizzle boom was 47% and 12.6% by soil incorporated shank injection. Procedures for emission rate estimation acceptance followed California Department of Pesticide Regulations criteria for soundness of fit of field-measured to model-predicted near-field emission estimates.

Introduction

Starting in 2005, metam sodium along with other methyldithiocarbamate salts underwent a re-registration review overseen by EPA Office of Pesticide Programs (EPA-OPP or Agency) leading to a July 2008 re-registration eligibility decision (RED;US EPA 2008). Several field-scale monitoring studies that estimated volatilization flux density (flux) emissions of MITC were employed for buffer zone mitigation setting. Flux studies specific to the Pacific Northwest cooler fall season application conditions were not available as part of the RED assessment. Because of the absence of PNW regional flux information, the Agency relied on emission data from smaller acreage row crop summer application studies in southern California to calculate field edge buffer zones for larger acreage field crop fumigations in the PNW. These field emission data sets are limited in their utility because they provide results only for the specific conditions under which the study was conducted. Based on regional field acreage, application

rates, and chemigation practices specific to the PNW, the current RED tabulated emission data can result in appreciable field-edge buffers. Since large segments of potato growing acreage exist in close proximity to residential communities, strict adherence to the current RED buffer zone criteria could have serious economic implications throughout the PNW. The Agency has given a limited window for PNW fumigant emission flux data to be generated; however, label language changes may be forthcoming as soon as 2010 (US EPA 2008).

Methods

To help fill this needed fumigant emissions data gap, Sectagon 42 was applied to two treatment plots (1.7 acres for drizzle boom and 1.8 acres for shank injection) within a 122 acre field circle located in Franklin Co. WA to assess near-field MITC air emissions before, during, and through 4-days post application (from October 8th through the 13th). The chemigation and shank field plot locations were meteorologically positioned within this field to best minimize MITC cross-interference (Figure 1).

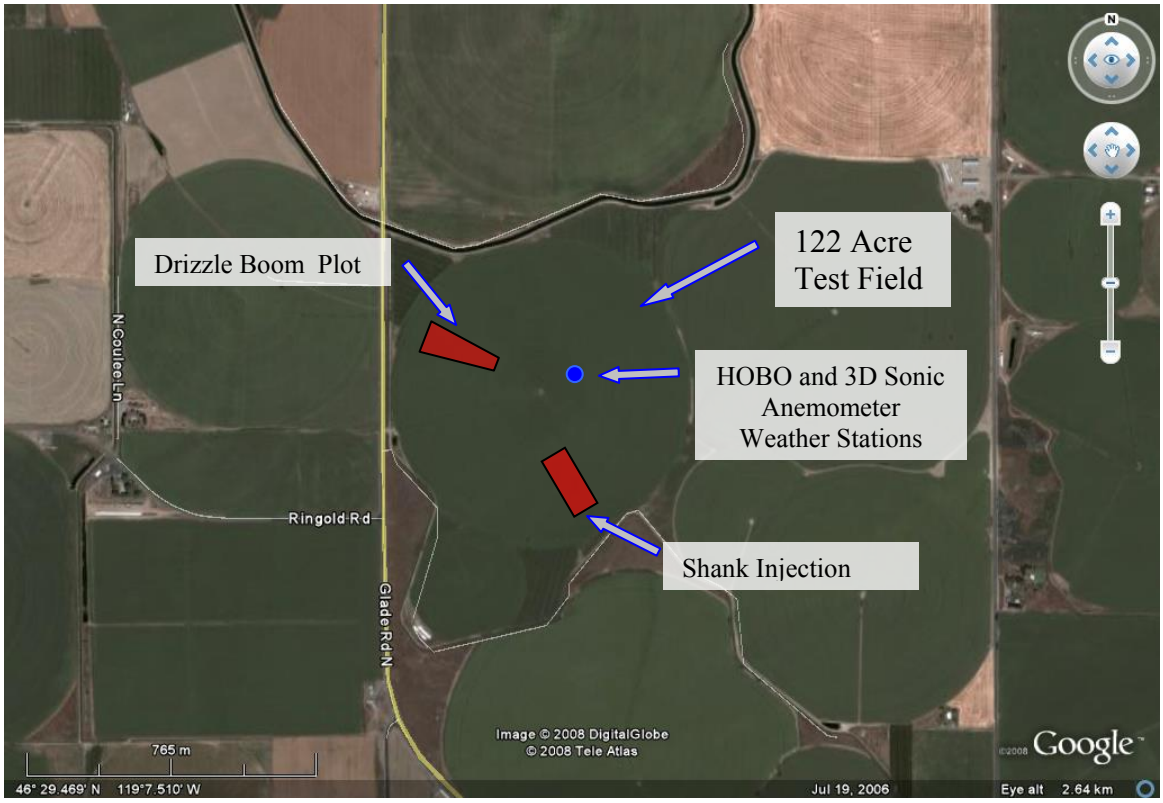


Figure 1: Field Demonstration Test Site. Franklin County, Washington State

A HOBO weather station was positioned near the center of the circle pivot to collect air/soil temperature, and soil moisture data over the study time frame and the CSAT3 3-D sonic anemometer employed to collect wind speed/direction data. The plots were positioned at these northwesterly and southeasterly locations to minimize MITC cross contamination from anticipated southwesterly prevailing winds over the study time frame.

Both fumigation applications were conducted concurrently on October 8th. To have both applications end at approximately the same time, the drizzle boom chemigation was started ca. 1-

hour earlier. For each treatment plot, MITC in air was continuously monitored by activated charcoal cartridges at eight sampling site receptor locations closely surrounding the plot periphery before, during, and throughout the 4-day post application period. The air sampling pumps were operated at ca. four-hour sampling intervals before, during, and through two-days post application. Eight-hour interval sampling was conducted on post-application days three and four. For each treatment plot, MITC concentrations (in $\mu g\ m^{-3}$) were generated from air collected through activated charcoal at eight receptors spaced around each test plot periphery before, during, and throughout the 4-day post application period. For each treatment plot, MITC field emission rates ($\mu g\ m^{-2}\ sec^{-1}$) together with total cumulative loss of MITC via the air pathway were estimated using an Industrial Source Complex Short Term (ISCST3) emissions model that utilized hourly meteorological data gathered at the field study location over the emission study time frame. The generated emission rate estimates and total cumulative losses for each treatment plot reported herein were performed by Sullivan Environmental Consulting using the CSAT data set together with measured airborne MITC concentration data supplied by the WSU-Food and Environmental Quality Laboratory. A more detailed regulatory analytical summary report (Littke et al., 2009) describing field procedures, analytical methods/quality control, and emission estimation procedures has been provided to the WSPC.

Results

Field-Measured MITC Concentrations: MITC air concentrations (i.e., the averaged MITC concentration from the eight air sampling receptors per interval sampling date) over the 4-day study time frame are summarized in Table 1. Here we observed that averaged whole field concentrations peaked during the 4-hours post application for drizzle boom modified center-pivot chemigation (417 $\mu g\ m^{-3}$ (138 ppb)) with a maximum single observation near-field concentration during this time of 963 $\mu g\ m^{-3}$ (318 ppb). Maximum whole field-averaged MITC concentrations of 78 $\mu g\ m^{-3}$ (26 ppb) were observed 16-hours post application for the shank treated field with a maximum single observation near-field concentration of 122 $\mu g\ m^{-3}$ (40 ppb) registered during this same 16-20 hour receptor period. Table 2 lists the maximum single cartridge air concentrations detected during the course of the chemigation and shank injection fumigation events.

From current regulatory inhalation exposure criteria, drizzle boom maximum downwind MITC concentrations exceeded by 4-fold the EPA OPP acute level of concern (LOC) value of 22 ppb, and were higher than the EPA no observable adverse effect level (NOAEL) of 220 ppb both during application and for the first 4 hours post application. Measured maximum downwind MITC air concentrations were lower than 22 ppb for all monitored periods for shank injection except for a 4 hour period starting 16 hours post application. Between 16 and 20 hours post-shank, the maximum observed single air monitor concentration of 40 ppb (122 $\mu g\ m^{-3}$) was observed. Measured MITC concentrations from air monitoring receptor locations positioned equidistantly between the two test plots indicate downwind emissions towards the shank plot over this interval period. Although receptors were positioned at test plots to minimize cross-contamination, it is reasonable to state that directional MITC drizzle boom source emissions contributed to the lower measured shank emission estimates, especially during the first 20 hours of this field demonstration.

Table 1
Whole Field Averaged MITC Concentrations

Approximate Hours post fumigation	Assigned Period	Drizzle Boom average[1] MITC air concentration ($\mu g/m^3$)	(ppb)[2]	Shank Injection average[1] MITC air concentration ($\mu g/m^3$)	(ppb)[2]
Pre application		0.67	0.22	0.54	0.18
Application	1	280	92.4	9.64	3.18
4	2	417	138	17.0	5.61
8	3	226	74.6	14.5	4.79
12	4	122	40.3	17.4	5.74
16	5	179	59.1	77.9	26.0
20	6	47.1	15.5	38.1	12.6
24	7	26.5	8.75	12.2	4.03
28	8	47.5	15.7	3.92	1.29
32	9	43.6	14.4	5.97	1.97
36	10	17.3	5.71	4.22	1.39
40	11	31.7	10.5	3.22	1.06
44	12	12.3	4.06	3.90	1.29
48	13	7.76	2.56	4.17	1.38
52	14	10.9	3.60	2.14	0.71
56	15	15.6	5.15	10.6	3.50
64	16	30.1	9.93	9.52	3.14
72	17	10.3	3.40	2.53	0.84
80	18	25.2	8.32	9.56	3.15
88	19	19.5	6.44	6.45	2.13
96	20	14.9	4.92	5.47	1.81

[1] Average value represent an average concentration of the eight samples, i.e. DB1-DB8, SH1-SH8

[2] MITC ppb = ($\mu g\ m^{-3}$) x $\frac{8.21 \times 10^{-2}\ \text{L-atm/mole-}^{o}\text{K}\ (298^{o}\text{K})}{(73.12\ \text{gram/mole})\ (1\ \text{atm})}$

Table 2
Maximum Measured MITC air concentrations

Receptor identification	Maximum receptor air concentration detected ($\mu g/m^3$)
Drizzle Boom Field Plot air sample DB7-R, 4-hr post application	963 (318 ppb)
Shank Injection Field Plot air sample SH5 16-hr post application	122 (40 ppb)

MITC Emission Rate Assessment: To assess the potential for bystander exposure in a manner consistent with practices employed by state and federal regulatory agencies, MITC volatilization density (flux) in units mass/surface area/time together with total cumulative loss were estimated using a steady-state Gaussian plume algorithm and California Department of Pesticide Regulations (Cal DPR) back calculation approach from the collected receptor emission and gathered meteorological data according to procedures from Ross et al. (1999) and Johnson et al. (1999). This least-squares technique regressed field-measured to model-predicted emissions over the 4-day experimental timeframe. Stability classes were determined according to Pasquill-Gifford stability methodology, using wind speed and cloud cover for each hour interval over the study time frame. California Department of Pesticide Regulations (Cal DPR, 2006) Emissions Assessment Method criteria was used to assess the best means for estimating MITC flux during each interval period for the drizzle boom and shank application test plots. Emission estimations were considered reliable if linear regression of the measured and normalized modeled data were well correlated (i.e, slope of regression line had a significance > 95th percent confidence level) and the intercept term was not significant (signifying the 95th percent confidence level included the origin). If the least squares slope was not significant, then the mean measured concentrations divided by the mean modeled concentrations was conservatively employed to calculate the emission rate for that period. Following this regulatory technical procedure for estimate fit, the estimated total cumulative MITC loss by drizzle boom was calculated to be 47% compared to 12.6% by soil incorporated shank injection. Figure 2 illustrates the relative emission rates of drizzle boom to shank over the continuous 4-day application/post application time frame.

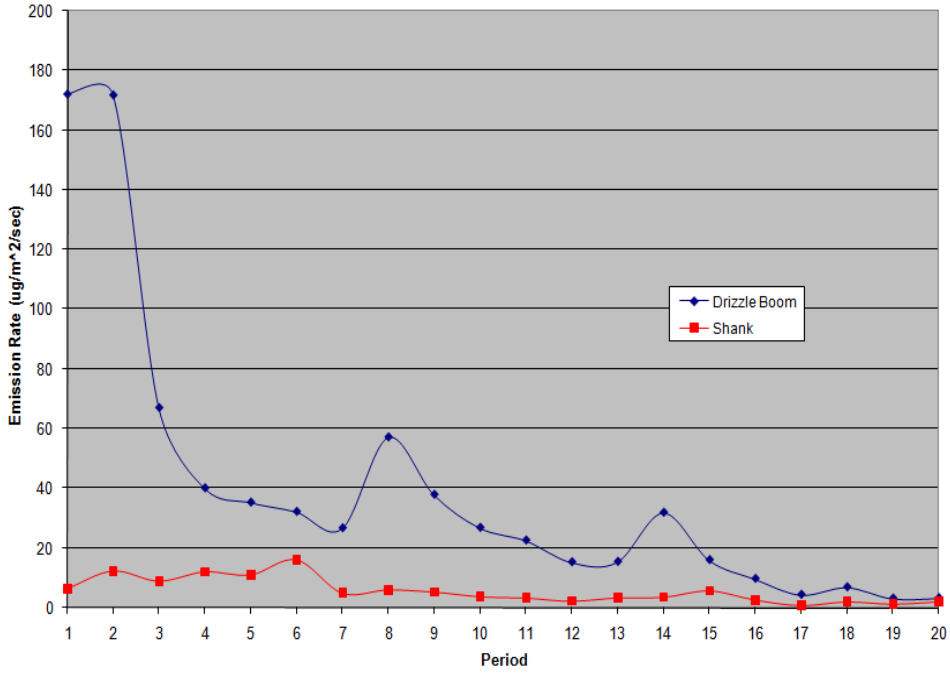


Figure 2: Comparison of Drizzle Boom and Shank Injection Emission Rates: October 8th through the 13th 2008, Franklin County, WA
(see Table 1 for interval sampling hours corresponding to each period)

Estimated low drizzle boom background MITC contributions during the early periods of this study resulted in use of the more conservative mean measured/mean flux estimation approach for the shanks test plot at application and up to the first five post-application periods. The occurrence of low MITC emissions at two off-field receptor locations approximately equidistant between the two test plots further corroborated that concentrations from the drizzle boom test plot contributed to MITC concentrations at the more northwesterly shank receptor locations. When defaulting to a more conservative approach, it is reasonable to anticipate over-estimation of actual field measured MITC emission rates. This especially would be expected at the shank plot where higher near-field source contributions can mask actual low field receptor emissions.

Acknowledgements

This proceedings represents the culmination of a proactive and collaborative research/outreach effort for providing much needed regionally specific MITC emission rate data typical of the cooler fall climatic conditions when PNW fumigations are occurring. This effort involved university research/extension specialists, experts in the area of field volatilization flux density measurements, potato growers, commodity group representatives, and pest management field advisors. Special thanks must go to many for providing their *in-kind* support leading the completion of this report. Particularly, I wish to thank Ed Schneider of Schneider Farms for donating use of his land-chemigation equipment, Monte Spence of WindFlow Fertilizer for retrofitting, center pivot drizzle boom operations/application oversight, Jim Ossman of Crop Production Services for their *in-kind* efforts in performing the concurrent shank application, Kurt Volker-Jim Owens from Tessenderlo Kerley for *in-kind* product support, and David Sullivan and his group from of Sullivan Environmental Consulting for rigorously assuring the quality of the emission rate estimations reported herein. The Food and Environmental Laboratory faculty/staff are appreciative to all who actively participated in the up-front planning, concurrent fumigant applications, field emission monitoring, and data verification that has lead to the information provided in this proceedings.

References

- Cal DPR (2006): MEMORANDUM. Dazomet flux analysis and recommendations for future study, April 26, 2006. accessed at http://www.cdpr.ca.gov. 8 pp. .
- Johnson, B., Barry, T. and P. Wofford (1999). Workbook for Gaussian Modeling Analysis of Air Concentration Measurements. Report EH99-03. State of California Department of Pesticide Regulation.
- Littke M., LePage J., Hebert V (2009). Estimating Methyl Isothiocyanate emission rates following soil incorporated shank and modified center pivot chemigation metam Sodium applications. *Analytical Summary Report*, pp 69. (Technical report FEQL-0808).
- Ross, L.J., Johnson, B., Kim, K.D., Hsu, J. (1999) Prediction of methyl bromide flux from area sources using the ISCST model. Journal of Environmental Quality 25: 885-891.
- US EPA Office of Pesticide Programs. (2008) Reregistration eligibility decision (RED) for methyldithiocarbamate salts – metam sodium/potassium and MITC. http://www.epa.gov/oppsrrd1/REDs/metamsodium-red.pdf (accessed 9/1/2008).

Defining In-Season Nitrogen Needs for Alturas and Premier Russet

C.D. Hiles, M.J. Pavek, N.R. Knowles, and Z.J. Holden

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

Proper nitrogen management is a crucial component of potato cropping systems. Insufficient N can lead to reduced growth (Harris, 1992), reduced light interception, limited yield (Chase *et al*., 1990; Laurer, 1986; Santerre *et al* .,1986) delayed tuber set (Harris, 1992), and reduced dry matter content (Yungen, *et al.,* 1958; McDole, 1972; Painter and Augustin, 1976; MacKerron and Davies, 1986; Westerman *et a,.,* 1994; Love *et al.,* 2005). Too much N may reduce tuber N uptake efficiency, can delay tuber initiation, and promote overgrowth of vines (Pavlista and Bloomenthal, 2000). Improper nitrogen management can also lead to increased incidences of disease and have adverse environmental effects such as run-off and leaching.

Traditionally N recommendations for Columbia Basin potato production have been based on requirements of the well known Russet Burbank cultivar. However different potato cultivars have unique morphological and developmental characteristics that may differ from Russet Burbank and may have unique requirements. It is no longer appropriate to make blanket N fertilizer recommendations in potato cropping systems.

The recent release of new cultivars from the Tri-State Breeding Program, such as Alturas and Premier Russet, has necessitated the development of appropriate N fertilizer recommendations tailored to each cultivar. The purpose of this study was to identify in-season N rates for Alturas and Premier that maximize grower revenue by optimizing field performance and post-harvest quality attributes with the following specific objectives: (1) to develop a cultivar specific understanding of N response as it relates to yield, quality, and economics, (2) to define specific petiole and soil critical concentrations for each cultivar for maximum economic yields, and (3) increase grower bottom lines. In addition, we wish to understand the effects of in-season N on whole plant morphology and physiology in an effort to improve our ability to make management recommendations for these and other cultivars.

MATERIALS AND METHODS

This experiment was conducted at the WSU Othello Research Station in Othello, WA, on a Shano silt loam during the 2007 and 2008 growing season. Each cultivar was planted in a randomized complete block design with five row plots, 25 ft long, with 5 ft borders and 10 inch spacing between plants. Plots were treated with five in-season N rates: 0%, 25%, 50%, 100%, and 150%. Treatments are expressed as a percentage of the current in-season N recommendations for Russet Burbank. All treatments received the same pre-plant fertilizer during a particular year. Pre-plant, in-season and total season N rates and associated in-season N expense are shown in Tables 1 and 2.

In-season N (UAN-32) was applied weekly between 50 days after planting (DAP) and 100 DAP via a custom designed fertigation simulator that delivered 0.15 in. of water (Table 3). Petioles were collected weekly from center data rows between 60 DAP and 120 DAP and soil samples were collected bi-weekly at one and two foot levels. Hand

digs were initiated at 70 DAP and performed every eighteen days. Data on stem number, tuber number, vine weight, tuber weight and tuber number were collected. At the end of the season, tubers were harvested via a two row digger and graded and sized using a custom two lane electronic sizer. An economic evaluation was performed on both cultivars via a mock processing contract modeled after contracts currently in use in the Columbia Basin.

RESULTS

Soil and petiole analysis for both cultivars across the growing season illustrated definite trends among the treatments (Figure 1).For the most part, the petiole and soil N values from each treatment were distinctly different from each other (Figure 1) demonstrating that petiole and soil analysis is sensitive enough to detect minor differences in tissue N concentrations and in-season N rates. The application timing and rate (100% treatment rates) are shown in Figure 1 with arrows and corresponding numbers. The effect of in-season N rate became increasingly visible late in the season as the canopies of the low N rate treatments started to senesce earlier than those receiving the higher rates (Figure 2). Visual ratings of vine senescence were highly correlated with in-season N rate at 141 days after planting (Figure 3).

In-season N rate had a significant effect on total yield of both Premier and Alturas (Figure 3). Premier total yield continued to increase as in-season N rates increased and the yield difference between the 0% and the 150% treatments was more than 100 CWT/A (Figure 3). Total yield peaked in Alturas between the 100% and 150% with a 140 CWT/A difference between the 0% treatment and the 150% treatment (Figure 3).

Tuber specific gravity was highly correlated with N rate for both cultivars (Figures 3). As N levels increased, specific gravity decreased significantly. The economic analysis resulted in significant non-linear trends for both cultivars (Figure 3). Premier showed inverse trends between 2007 and 2008. The 150% treatment was the most profitable in 2007. In 2008, revenue was optimized at an in-season rate close to 90% of what is typical for Russet Burbank; this was equivalent to about 200 lbs N in-season and 125-150 lbs/A N pre-plant. We believe 2008 was the more typical response from this cultivar and hope that another year of data (2009) will confirm this. A non-linear regression projected the economically optimum n-season N rate for Alturas at approximately 96% of the current in-season nitrogen recommendations for Russet Burbank, or about 220 lbs/a of in-season nitrogen and 125-150 lbs/A N pre-plant (Figure 3).

DISCUSSION

This study confirms the well known concept that maximum biological yield does not always equate into maximum economic return. The higher 150% treatment did in fact increase total and market yield (> 6oz) across both years and cultivars, but maximum economic yield was produced with rates between 90% and 100% of what is typically recommended for Russet Burbank. The exception was Premier during the 2007 season where adjusted gross income was marginally higher at the 150% rate than at the 100%. For the most part, yields from N rates greater than 100% became to expensive to achieve; the potential economic gain from the yield increase seen from the 150% treatment was offset by the cost of the extra N used to achieve the yield.

At the lower N rates, harvest index (tuber weight as a proportion of total plant weight (data not shown) and specific gravity increased as expected. The higher N rates delayed vine senescence and lead to an increase in plant longevity and vine weights. Gravities such as those found at the 0% and the 150% treatments were not within the ideal range of a typical processing contract, and both would likely result in contract penalties.

These data illustrate that careful N management can be a valuable tool for tailoring crop maturity to maximize processing incentives and profits. Based on two years of data, we recommend in-season rates of 200 to 220 lbs N for both varieties with at least 125 lbs N available prior to plant emergence. Recommended petiole ranges for the growing season are displayed in Table 4. A well maintained and carefully monitored N fertilizer regime, coupled with adequate pre-plant N and soil and tissue sampling, can maximize profits and reduce N costs.

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

Treatment as a % of standard	Preplant N + soil resid.	Fertigated in-season N	In-season N From Phos applications	Total in-season N	Total Season N	In-season N Fert expense ($0.80/lb)
%	----------lbs/A----------					
0	125	0	30	30	155	0
25	125	58	30	88	213	46
50	125	115	30	145	270	92
100	125	230	30	260	385	184
150	125	345	30	375	500	276

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

Treatment as a % of standard	Preplant N + soil resid.	Fertigated in-season N	In-season N From Phos applications	Total in-season N	Total Season N	In-season N Fert expense ($0.80/lb)
%	----------lbs/A----------					
0	150	0	9	9	155	0
25	150	58	9	67	217	46
50	150	115	9	124	274	92
100	150	230	9	239	389	184
150	150	345	9	354	504	276

Table 3. Rate scheme for five in-season N rates for 2007-2008

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

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

Table 4. Recommended petiole values at 60-, 90-, and 120-days after planting (DAP) for Alturas and Premier Russet.

Variety	End Tuber Initiation Mid June 60 DAP	Mid Bulking Early July 90 DAP	Late Bulking Late July 120 DAP
	(ppm NO3)	ppm (NO3)	(ppm NO3)
Alturas	24,000	16,000	8,000
Premier	23,000	15,000	7,400

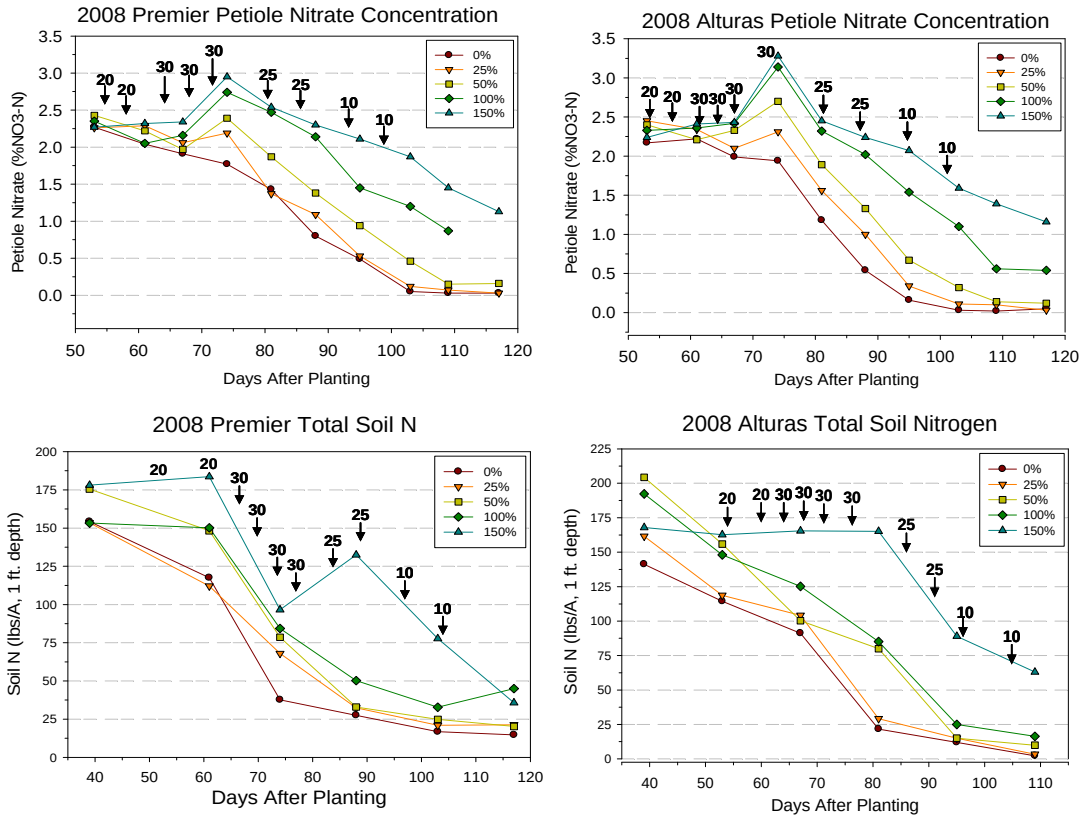


Figure 1. Petiole and soil N for Premier Russet and Alturas during 2008 for each of five in-season N rates. The 100% treatment application timing and rates (lbs/A) are shown with arrows.

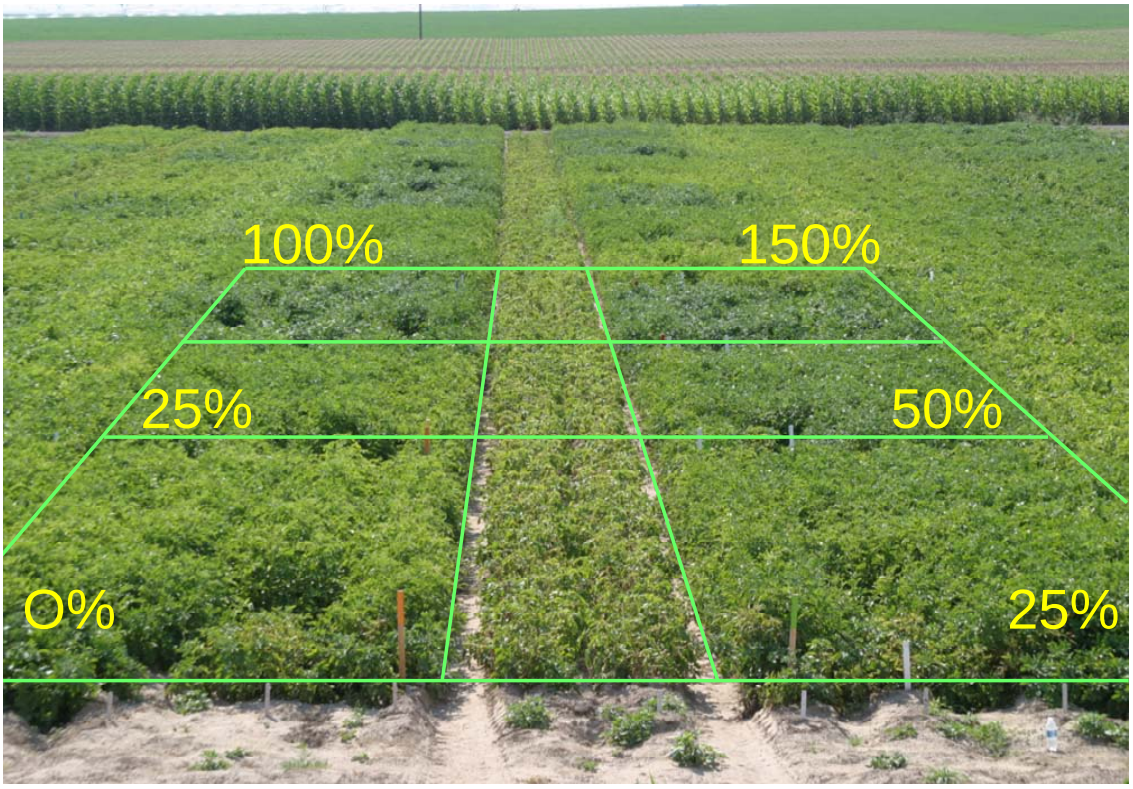


Figure 2. Alturas canopy appearance late July 2007 for each of five in-season N rates (shown as percentages).

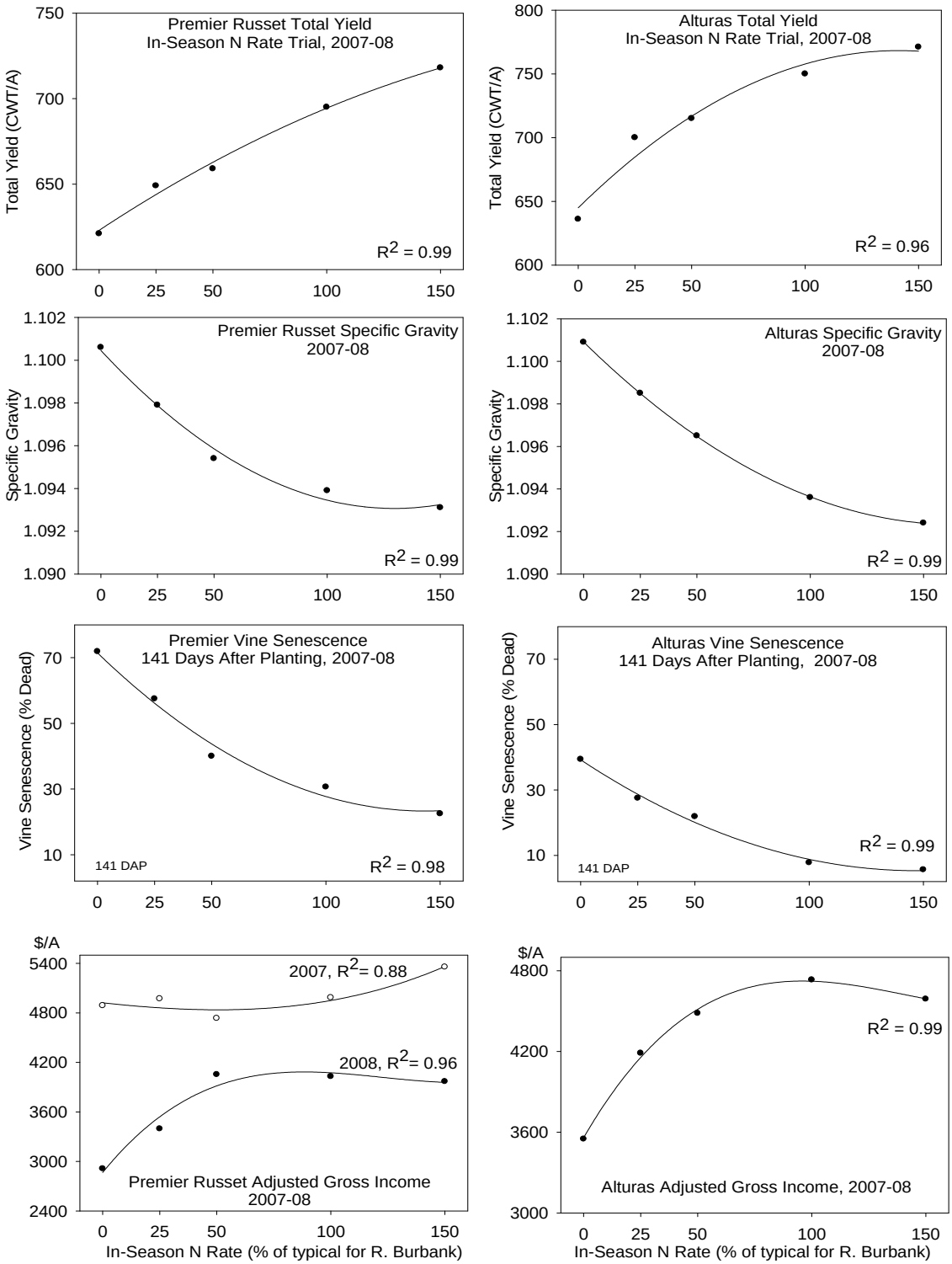


Figure 3. Total yield, specific gravity, vine senescence, and fertilizer-price-adjusted gross income for Premier Russet and Alturas during 2007-08 for each of five in-season N rates. All R^2 values were significant at the 5% level of significance.

Latent Infection of Potato Seed Tubers by the Late Blight Pathogen, *Phytophthora infestans*

Dennis A. Johnson and Thomas F. Cummings, Department of Plant Pathology,
Washington State University, Pullman, WA 99164-6430

Persistence of *Phytophthora infestans*, the cause of late blight, from year to year is a critical component of late blight epidemics. Understanding the means of pathogen survival is a major goal in developing management strategies for the disease. In the Pacific Northwest and intermountain region of North America, oospores are not currently known to be a factor in overwintering and infected tubers are considered to be the main means of overwintering for the pathogen and the source of initial inoculum. Infected tubers serving as overwintering and primary inoculum sources may be potato seed-tubers, potato tubers left in the field after harvest that produce volunteer plants, and cull potato tubers. The relative importance of the three types of infected tubers in temperate climates is unknown and may depend in part on microclimates, local conditions and the extent of infection the previous fall.

A continuum of viable host tissue is essential for survival and overwintering of *P. infestans* in potato growing regions where oospores are not an overwintering factor. Contemporary isolates, particularly the US-8 strain, are highly aggressive and rapidly rot tubers, limiting the availability of viable host tissue. However, rotting by the US-8 strain of *P. infestans* did not occur over seven weeks in inoculated tuber tissue at a storage temperature of 37ºF. Recommended holding temperatures for tubers vary depending on end use. Seed potatoes are stored between 38 to 40ºF, fresh market potatoes are stored between 38 to 50ºF, while French fry and chip processing potatoes are stored between 44 to 50ºF and 50 to 55ºF, respectively. The optimal temperature for hyphal growth of *P. infestans* in potato tubers is about 50ºF. However, the length of time infected tubers can remain intact in storage at temperatures used to store seed tubers is not known.

In the Columbia Basin of Washington and Oregon approximately 8.7×10^8 seed tubers (assuming mean seed piece weight of 60 g, mean seed tuber size of 170 g, and 5% waste) were cut and planted in 2007. *Phytophthora infestans* produces sporangia on infected tubers and the potential for multiple infections by *P. infestans* has been demonstrated when infected seed tubers are cut and handled (3). Because of the extremely large amount of seed tubers planted in a potato production region and the explosive polycyclic capabilities of *P. infestans*, a greater understanding is needed on the survival of *P. infestans* in potato seed tubers. Since infected seed tubers that survive in storage are a potential source of inoculum, the possibility of latent infection in stored seed tubers needs to be investigated. The purpose of this research was to test the hypothesis that potato tubers can be latently infected with *P. infestans* and to characterize the survival of *P. infestans* in infected potato seed tubers of susceptible and moderately resistant cultivars at temperatures (near 39°F) and time periods (6 to 7 months) used in commercial seed tuber production in the Pacific Northwest.

Methods and Materials
Four potato cultivars, Russet Burbank, Ranger Russet, Umatilla Russet, and Defender were selected for this study. Russet Burbank, Ranger Russet, and Umatilla Russet are major potato cultivars grown in the Pacific Northwest of the United States. Defender is a recently released cultivar and is not commonly grown. Tubers of Russet Burbank and Ranger Russet are susceptible to *P. infestans*. Tubers of Umatilla Russet and Defender are considered moderately resistant and resistant, respectively, to *P. infestans* when compared to Ranger Russet (5).

Four US-8 isolates of the A2 mating type, Wa02, Web04, BF05, and Wa06 of *P. infestans* were used in these studies. Isolates Wa02, Web04 and Wa06 were obtained from potato foliage collected from central Washington in 2002, 2004, and 2006 respectively. Isolate BF05 was obtained from potato foliage collected in northern Idaho in 2005. The isolates were maintained in potato tubers of cultivar Russet Burbank during winter months of October through March at 39.5°F. Isolates were then maintained and increased on excised leaflets of cultivar Russet Burbank. Sporangia were washed from excised leaflets with distilled water. Concentration of sporangia was adjusted to 10,000 per ml of distilled water using a hemacytometer. Sporangia used for inoculation were chilled for 2 h at 4°C to induce zoospore formation. Inoculation was done by applying 0.05 ml of inoculum with a micropipette to a Whatman #2 filter paper cut into 10 x 10 mm squares and then placing the saturated filter paper square to a single eye on a tuber.

Inoculated and non-inoculated tubers were placed in a humidity chamber and then allowed to dry. Tubers were then placed in one of three cold storages facilities from 30 to 209 days. Storage facility 1 was programmed at 47°F and was selected to represent storage temperature for French fry and chip processing potatoes. Storage facilities 2 and 3 were programmed at 39.5°F and 39°F, respectively, and were selected to represent temperatures used to store seed tubers.

Development of late blight in stored tubers of Russet Burbank and Umatilla –
Tubers of Russet Burbank and Umatilla Russet were inoculated in September 2006 with isolate BF05, placed in a mist chamber for 20 h at 63-73ºF, and allowed to dry for 6 h at 68-73ºF. Inoculated and non-inoculated tubers of each cultivar were then placed in storage at three storage facilities and arranged as a completely randomized design. Five inoculated and five non-inoculated tubers of each cultivar were used for each sample time and each storage facility.

In facility 1, tubers of each cultivar were destructively assessed at 34, 48, 71, 91, and 101 days. In facilities 2 and 3, tubers of each cultivar were destructively assessed at 101, 125, 146, 167, and 181 days. At each destructive sampling period, severity of late blight was visually assessed after cutting each tuber in cross section at four places of approximately equal intervals. The surface areas formed from the cuts were rated individually for the percent area of internal rot. Tubers in facilities 2 and 3 that were symptomless for late blight based on external observation on the last assessment date at 209 days were not destructively sampled, but instead were incubated at 72º to 73ºF. Tubers were inspected every two to three days for late blight symptoms over a three week period. Tubers were

considered asymptomatic if no symptoms or signs were found following a thorough examination of the periderm for discoloration and eyes for necrosis. Small peels with a knife were made to observe internal tissue under the periderm and cuts were made into the eye where the inoculation was made to observe for discoloration and necrosis.

The experiment was repeated in September 2007 using the methods as described above except as noted. The number of inoculated and non-inoculated tubers for each cultivar and time period was four. Tubers stored in facility 1 (mean 47 ºF) were destructively assessed at 30, 60 and 91 days. Tubers stored in facilities 2 and 3 (mean 39.5 º and 39 ºF, respectively) were destructively assessed for late blight at 30, 60, 91, 122, 150 and 182 days of storage.

Tuber slices from 18 asymptomatic tubers collected from the six sampling periods were incubated in humidity chambers at 59 ºF and observed with a stereo scope at 10 to 62 X magnifications for sporulation of *P. infestans* four times per week over three weeks. Each humidity chamber consisted of tuber slices 2 cm thick placed on a nylon screen over moistened filter paper in glass Petri dishes 9.5 cm dia. by 2.5 cm in height. Petri dishes were then placed in a 24 x 35 x 5 cm glass tray which was then sealed in a plastic bag. Cross sections from four symptomatic tubers with severities of 20 to 70% of each Russet Burbank and Umatilla Russet from facilities 2 and 3 at the 150 day sampling period (n = 8) were also placed in humidity chambers and incubated at 59ºF for 48 h to promote sporangia formation. The experiment was repeated (n = 8) at the 181 day sampling period. The cut surface and eyes of the tuber disks were then observed for sporangia of *P. infestans* at 21, 24, and 48 h of incubation. Time for sporangia to first be observed was recorded. Incubation period was the period in hours from initial incubation in the humidity chamber until sporangia were first observed.

Development of late blight in stored tubers inoculated with four isolates – Tubers of Russet Burbank were inoculated at a single eye in October 2006 using the filter paper technique with one of the four *P. infestans* isolates. Inoculated tubers were placed in a mist chamber for 24 h at 64° to 69°F and air dried for 6 h at 69°F. Twenty-one tubers were inoculated with WA02, 24 with Web04, 17 with BF05 and 22 with WA06.Tubers were arranged as a completely randomized design and stored in facility 2 (mean 39.5°F). Twenty tubers were not inoculated and used as controls. Tubers were destructively assessed once after 209 days of storage. Asymptomatic tubers were not cut, but were held at 72° to 73°F for three weeks. Asymptomatic tubers in which late blight symptoms later developed were then placed in a humidity chamber and incubated at 59°F for 48 h to promote sporangia formation.

The experiment was repeated with Umatilla Russet tubers in September 2007. Methods and experimental design were the same as in the first trial except the number of tubers inoculated with each of the four isolates was 15. The number of non-inoculated tubers used as the control was 15. All tubers were destructively sampled after 182 days as described previously. Tuber slices from asymptomatic tubers were incubated in humidity chambers at 59°F and observed for sporulation of *P. infestans* four times per week over three weeks.

Effect of incubation time before cold storage on development of late blight in tubers – Tubers of Russet Burbank, Ranger Russet, Umatilla Russet, and Defender were inoculated in mid September 2007 with isolate BF05. The number of tubers inoculated per cultivar was 60. Twenty tubers of each cultivar were then dried for 1, 6 or 24 h. Ten tubers for each drying time and cultivar were arranged in a completely randomized design and stored in facilities 2 and 3. The number of non-inoculated tubers used as controls for each drying time and temperature was 10. The drying time was considered the incubation period. Tubers were kept in storage for 182 days and symptomatic tubers were destructively sampled as previously described. Tubers that were asymptomatic for late blight based on external observation as previous described were not destructively sampled, but instead were incubated at 72º to 73ºF. Tubers were then monitored at a two to three day interval for late blight symptoms over a three week period. Incubation until sporulation was determined for five tubers with severities between 1 and 10% as previously described. The experiment was repeated in October 2007.

Results

Development of late blight in stored tubers of Russet Burbank and Umatilla - Severity of late blight increased during storage at 47°F in storage facility 1 (Fig. 1). Severity of late blight was significantly ($P < 0.05$) less for Umatilla Russet than for Russet Burbank at 47°F during the first (Fig. 1) and the second storage seasons (data not shown). Late blight severity did not significantly ($P > 0.05$) vary between the two cultivars and between 39.5°F and 39°F in storage facilities 2 and 3 the first (Table 1) and second (Fig. 2, data for temperatures and cultivars combined) storage seasons. For the second storage season at 39.5° and 39°F, 0 to 25% of the inoculated tubers sampled monthly up to 181 days of storage had severities less than 1% (Fig. 2). Incidence of tubers with late blight symptoms did not differ significantly ($P > 0.05$) between Umatilla Russet and Russet Burbank in each of the three storage facilities both seasons. Late blight did not develop in the non-inoculated control tubers.

For the first storage season at 39.5° and 39°F, 20% and 40% of the inoculated Umatilla Russet and Russet Burbank tubers, respectively, were asymptomatic after 209 days of storage, but later developed late blight symptoms when subsequently incubated at 73°F for three weeks. Thus, indicating a latent infection (Table 1). Some eyes on tubers produced sprouts 1.5 to 6 cm in length before blighting. Sporangia of *P. infestans* were produced on tuber eyes and slices when incubated in humidity chambers at 59°F. For the second storage season at 4.2° and 4.1°C, 6 to 44% of the inoculated tubers sampled monthly up to 181 days of storage were asymptomatic, but tuber slices later supported production of *P. infestans* sporangia when incubated in a humidity chamber at 59°F. Thus, indicating a latent infection of tubers (Fig. 2). Late blight symptoms did not develop in the non-inoculated control tubers.

Incubation period until sporulation ranged from 6 to 20 days and had a mean of 9.6 days when tuber slices from asymptomatic tubers were incubated in a humidity chamber at 59°F (Table 2). Sporangia were observed on the cut surface and eyes of 14 tuber slices from symptomatic tubers at 24h and on two tuber disks at 21h. The difference in length

of incubation period until sporulation between asymptomatic and symptomatic tubers disks was significant at $P < 0.0001$. Sporulation was light at 21h with less than 20 sporangiophores with sporangia on an eye or cut surface. The amount of sporulation increased with time of incubation.

Soft rot and dry rot symptoms occurred in some late blight symptomatic tubers sampled during the latter assessment times both storage seasons. During the first storage season at 181 and 209 days, mean incidence and severity of bacterial soft rot symptoms were each 10%. Fusarium dry rot was not evident. During the second storage season at 150 and 182 days, mean incidence and severity of Fusarium dry rot symptoms were 13% and 15%, respectively. Bacterial soft rot did not exceed 1% severity.

Development of late blight in stored tubers inoculated with four isolates– Incidence of tubers with late blight symptoms ranged from 32 to 100 % for Russet Burbank tubers inoculated with one of four isolates of *P. infestans* and stored at 39.5°F for 209 days during the first storage season. Mean severity of late blight symptoms for tubers with symptoms ranged form 68 to 89%. Severity of late blight was significantly ($P < 0.05$) greater in tubers inoculated with isolate Web04 than with isolates BF05 and Wa06 (Table 3).

Late blight symptoms developed in inoculated tubers that were asymptomatic after 209 days of storage when they were subsequently incubated at 73°F for three weeks, indicating a latent infection of tubers. Percent latent tuber infection ranged from 0 to 33% of the inoculated tubers for the four isolates (Table 2). Sprouts from tuber eyes grew 1.5 to 4 cm in length before developing late blight symptoms when latently infected tubers were incubated at 73°F. Sporangia of *P. infestans* were produced on tubers slices, tubers, and sprouting eye upon incubated in humidity chambers at 59°F. Late blight symptoms did not develop in the non-inoculated control tubers. Some symptomatic tubers for late bight also had soft rot and dry rot symptoms. Mean incidence and severity of bacterial soft rot symptoms was 33% and 10%, respectively. Mean incidence and severity of Fusarium dry rot symptoms was 18% and 5%, respectively.

During the second storage season, incidence of tubers with late blight symptoms ranged from 60 to 100 % for Umatilla Russet tubers inoculated with one of four isolates of *P. infestans* and stored at 39.5°F for 182 days. Mean severity of late blight symptoms for tubers with symptoms ranged form 47 to 77 %. Severity of late blight symptoms was significantly greater in tubers inoculated with isolates Web04 and BF05 than with isolate Wa02 (Table 3).

Twenty percent of the inoculated tubers inoculated with isolate WA02 did not exhibit late blight symptoms after 182 days of storage at 39.5°F. However, sporangia of *P. infestans* developed on tuber slices from these tubers when incubated in humidity chambers at 59°F, indicating a latent infection of tubers (Table 3). Incubation period until sporulation ranged from 7 to 15 days with a mean of 10 ($n = 3$) when tuber slices from asymptomatic tubers were incubated in humidity chamber at 59°F (Table 4). Late blight symptoms did not develop in the non-inoculated control tubers. Bacterial soft rot was not evident in

tubers. Some tubers with late blight symptoms also had Fusarium dry rot symptoms. Mean incidence and severity of Fusarium dry symptoms were both 5%.

Effect of incubation time before cold storage on development of late blight in tubers- Incidence and severity of infected tubers were each significantly ($P < 0.05$) greater for Ranger Russet than for the other three cultivars except for Russet Burbank in the first trial (Table 4). Data for the 39° and 39.5°F temperatures were combined because they were similar ($P > 0.05$). Late blight incidence and severity were similar ($P > 0.05$) among the 1, 6 and 24 h incubation periods between the end of the mist period and placement of tubers in cold storage, and thus data were combined (Table 4).

Up to 5% of the inoculated tubers had late blight severities less than 1% after 182 days of storage (Table 4). Fifteen tubers (6.3%) had severities of 5 to10% in the two trials (data not shown). Five percent of the Ranger Russet and 1.7% of both the Umatilla Russet and Defender tubers in the first trial were asymptomatic after 182 days of storage but later developed late blight symptoms when incubated at 72° to 73°F for 13 days.

Incubation period until sporulation on tubers with late blight severities of 1 to 10% ranged from 3 to 8 days (mean = 4.6 days) when tubers that eventually developed late blight symptoms were incubated in a humid chamber at 59°F. Late blight symptoms did not develop in the non-inoculated control tubers. For both trials, incidence and severity of bacterial soft rot symptoms were 2% and 30%, respectively. Incidence and severity of Fusarium dry rot symptoms were 8 and 50%, respectively.

Discussion

Phytophthora infestans is known to persist in potato tubers during storage (1), but survivability in seed tubers under extended cold storage conditions and at typical seed storage temperatures has not been known until this study. Isolates of the US 8 and other new clonal lineages of *P. infestans* are aggressive in potato tubers and quickly rot infected tubers at temperatures above 50°F. Mycelium of *P. infestans* is no longer able to survive in tubers once the host tissue is completely rotten. Tubers of Russet Burbank and Umatilla Russet infected with US 8 isolates in this study rotted within 3 months at 47°F. However, all tubers at 39.5° and 39°F did not completely rot and isolates of the US8 clonal lineage persisted in potato seed tubers during an extended storage season of 6 to 7 months at temperatures used to store seed tubers.

Variation in the severity of late blight symptoms in infected tubers stored in long term cold storage was high in this study. Tubers with late blight severities of less than 1% of were not uncommon. All tubers with low severities of symptoms are not likely to be detected and disposed during inspection, handling, cutting and planting. Such tubers are capable of supporting sporangia and perpetuating the pathogen as they continue through the process of handling to planting.

A latent infection of tubers was demonstrated in that some tubers were asymptomatic and did not exhibit late blight symptoms of discoloration or necrosis on the external or in the internal tissues at the end of a storage period. However, symptoms and sporangia of *P.*

infestans developed on asymptomatic tubers when they were placed at temperatures of 59°F and above. Eyes of tubers with low late blight severities and of tubers with latent infections were viable and sprouted after storage. Sporangia developed on sprouts from asymptomatic tubers after storage when later incubated at high humidity and 59°F. A relatively high number of tubers may be latently infected when taken out of environments typical of commercial seed tuber storage, which likely depends on the level and extent of infection the preceding fall. Various factors influence infection of tubers near harvest (4, 6). Latently infected seed tubers could be another important inoculum source of *P. infestans*.

A potential for secondary cycles of infection by *P. infestans* during seed-tuber cutting and handling has been documented (3). Sporulation of *P. infestans* occurred within 21 h at high humidity after seed tubers with late blight symptoms were removed from cold storage to a warmer environment in this study. Sporangia can be readily transmitted by direct contact from tubers or seed pieces to non-infected seed pieces (2). Sporangia can potentially become air borne and carried by air currents to cut tuber surfaces or tuber eyes within a storage and cutting facility or to plants and soil in the field, resulting in additional infections. Potato handling and cutting facilities are generally enclosed, blocking incoming solar radiation which would also increase longevity of sporangia.

The extended incubation period until sporulation of 6 to 20 days for latently infected tubers, 3 to 8 days for tubers with 1 to10% severity, and 1 to 2 days for tubers with 20 to 70% severities indicated different levels of establishment in tuber tissue by *P. infestans*. Sporulation of *P. infestans* over an extended time period on tubers taken from storage could be expected because of varying degrees of infection. This would provide a longer time period for sporangia to be present during handling and cutting of seed tubers and increase the probability for infected tubers to become exposed to environmental conditions favoring sporulation, dissemination and infection.

Severity of late blight was significantly less for Umatilla Russet than for Russet Burbank at 47°F up to 100 days of storage, but not at 39.5° and 39°F for182 to 209 days of storage. Results of the longer storage periods near 39°F differed from a previous study where Umatilla Russet was more resistant than Russet Burbank based on tuber severity. Inoculated tubers were stored for 36 days at 48°F in the previous study (5). Long storage periods at temperatures near 39°F appear to have negated the effects of the moderate resistance in Umatilla Russet in this study. Incidence of late blight also did not differ between Umatilla Russet and Russet Burbank in this study, indicating that resistance to infection does not differ between the two cultivars. Tubers of Defender and Umatilla Russet were more resistant than those of Ranger Russet for 182 days in storage at 39 to 39.5°F based on incidence and severity of infection in this study and based on severity of infection in a previous study (5**).**

Pectolytic bacteria often infect potato tubers after initial infection with *P. infestans*. Latently infected tubers that were detected were not affected by bacterial soft rot or Fusarium dry rot in this study. *Phytophthora infestans* is a poor competitor against soft rotting bacteria and dry rot *Fusaria.* Secondary infection by these organisms would

eliminate long term survival of the late blight organism in stored tubers. Wounding of tubers facilitates infection by pectolytic bacteria, and soft rot was not a major issue in this study likely because tubers were not wounded before inoculating with *P. infestans*. Also tubers surfaces were dry before placing in cold storage, eliminating possible anaerobic conditions created by a water film on tuber surfaces that favor pectolytic bacteria. Wounding tubers to inoculate with *P. infestans* may alter resistance reaction *to P. infestans*. Storage temperatures below 40°F also inhibit development of bacterial soft rot in potato tubers.

In summary, *P. infestans* is capable of surviving asymptomatically and at various levels of symptom development in potato seed tubers for extended time periods at temperatures around 39°F. Latent infection of seed tubers was demonstrated and posses a challenge for management of late blight. Visual inspection of tubers will not reveal latently infected tubers and molecular techniques and sampling procedures need to be developed to accurately detect infection levels in potato seed lots.

Literature Cited

1. Davidse, L.C., Henken, J., van Dalen, A., Jespers, A.B.K., and Mantel, B.C. 1989. Nine years of practical experience with phenylamide resistance in *Phytophthora infestans* in the Netherlands. Neth. J. Plant Pathol. 95 (Suppl. 1):197-213.
2. Dowley, L.J., and O'Sullivan. 1991. Sporulation of *Phytophthora infestans* (Mont.) De Bary on the surface of diseased potatoes and tuber to tuber spread of infection during handling. Potato Res. 34:295-296.
3. Lambert, D.H. Currier, A.I., and Olanya, M.O. 1998. Transmission of *Phytophthora infestans* in cut potato seed. Amer. J. of Potato Res. 75:257-263.
4. Porter, L.D., Dasgupta, N., and Johnson, D.A. 2005. Effects of tuber depth and soil moisture on infection of potato tubers in soil by *Phytophthora infesta*ns. Plant Dis. 89:146-152.
5. Porter, L.D., Inglis, D.A., and Johnson, D.A. 2004. Identification and characterization of resistance to *Phytophthora infestans* in leaves, stems. flowers, and tubers of potato clones in the Pacific Northwest. Plant Dis. 88:965-972.
6. Porter, L.D., and Johnson, D.A. 2006. Effects of soil-applied late blight foliar fungicides on infection of potato tubers by *Phytophthora infestans*. Plant Dis. 90:964-968.

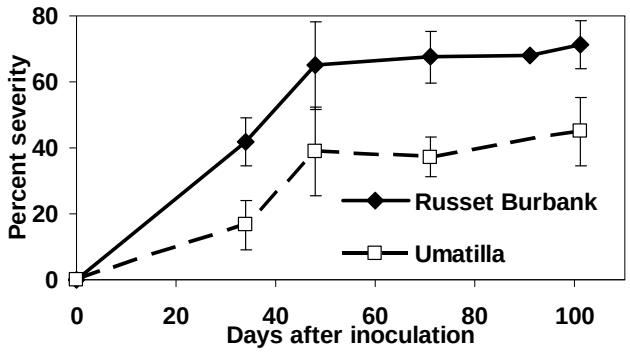


Figure 1. Severity of late blight symptoms in tubers of Russet Burbank and Umatilla Russet stored at 47°F for 100 days.

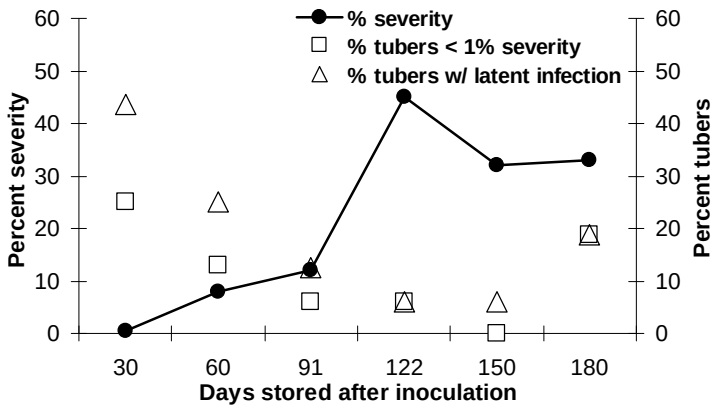


Figure 2. Severity of late blight symptoms in Russet Burbank and Umatilla Russet tubers, percentage of tubers with late blight symptom severity less than one percent severity, and percentage latent infection of tubers inoculated with *Phytophthora infestans* and stored at 39.5 and 39°F for 30 to 182 days during the 2007-2008 storage season.

Table 1. Incidence of Russet Burbank and Umatilla Russet tubers with symptoms of late blight, severity of late blight symptoms, and percentage of tubers with latent infection of tubers inoculated with *Phytophthora infestans* and stored at 39 and 39.5 F for 209 days during 2006 – 2007.

Treatment[a]	Late blight		
Temperature Cultivar	Incidence of tubers with symptoms[b] (%)	Severity of late blight symptoms (%)[b]	Percent latent tuber infection
R. Burbank	50	90	20
Umatilla R.	70	70	10

[a]Number (n) each value a mean of 10 tubers.
[b]Incidence and severity of late blight did not differ significantly between Russet Burbank and Umatilla Russet ($P > 0.05$).

Table 2. Incidence and severity of late blight symptoms and percentage latent infection of tubers of Russet Burbank inoculated with one of four isolates of *Phytophthora infestans* and stored at 39.5°F for 209 days during 2006-2007 [a].

Isolate	Total tubers (n)	Late blight		
		Incidence of tubers with symptoms (%)	Severity of tubers with symptoms (%)	Percent latent tuber infection
Wa02	21	62	81 ab	33
Web04	24	75	89 a	4
BF05	17	100	68 b	0
Wa06	22	32	69 b	9

[a] Values within a column with the same upper case letter are not significantly different at $P = 0.05$, according to Fisher's Protected LSD.

Table 3. Incidence and severity of late blight symptoms, percentage of tubers with late blight symptom severity less than one percent, and percentage latent infection of tubers of Umatilla Russet tubers inoculated with one of four isolates of *Phytophthora infestans* and stored at 39.5°F for 182 days during 2007-2008 [a].

Isolate	Late blight			
	Incidence of tubers with symptoms (%)	Severity of tubers with symptoms (%)	Percent of tubers with symptom severity < 1%	Percent latent tuber infection
Wa02	60	47 b	20	20
Web04	100	72 a	7	0
BF05	93	77 a	7	0
Wa06	87	65 ab	13	0

[a] Total inoculated tubers per isolate (n) was 15. Values within a column with the same upper case letter are not significantly different at $P = 0.05$, according to Fisher's Protected LSD.

Table 4. Incidence and severity of late blight symptoms, percentage of tubers with late blight symptoms less than one percent severity, and percentage latent infection of tubers of four potato cultivars inoculated with isolates BF05 of *Phytophthora infestans* and stored at 39° and 39.5°F for 182 days in two trials during 2007-2008 [a].

Temperature Cultivar [a]	Late blight			
	Incidence of tubers with symptoms (%)	Severity of tubers with symptoms (%) Mean ± se	Percent of tubers with symptom severity < 1%	Percent latent tuber infection
First trial				
Ranger R	60 a	85 a	5.0	5.0
R Burbank	33 ab	50 ab	0	1.7
Umatilla R	3 b	21 b	1.7	0
Defender	2 b	20 b	0	1.7
Second trial				
Ranger R	71 a	85 a	3.3	0
R Burbank	49 b	41 b	0	0
Umatilla R	0 c	-	0	0
Defender	7 c	11 c	0	0

[a] Total number of tubers per cultivar (n) at each temperature was 30. Values within a column with the same upper case letter are not significantly different at $P = 0.05$, according to Fisher's Protected LSD. Data combined for temperatures and pre-storage incubation periods.

Balancing Foliar & Tuber Growth to Optimize Yield, Quality & Storability

N.R. Knowles, M.J. Pavek, C. Hiles, L.O. Knowles, & Z. Holden
Dept. of Horticulture & Landscape Architecture
Washington State University, Pullman

Background

Premier Russet (A93157-6LS), GemStar Russet (A9014-2), Defender (A90586-11) and Alturas (A82360-7) are newly released cultivars (since 2002) from the Pacific Northwest Potato Variety Development Program. These cultivars have excellent traits for the frozen processing and long-russet fresh pack industries, produce high total and U.S. no. 1 yields, and have the potential of supplanting Russet Burbank in fresh and/or French fry processing markets. With previous funding from the WSPC (2004-07), we defined key stages of growth and development and the attainment of tuber physiological maturity for these cultivars under Columbia Basin growing conditions and determined how their processing qualities change in storage in response to conventional and non-conventional temperature regimes (Knowles *et al*., 2007; 2008). This research suggested that optimizing source/sink (foliar/tuber growth) relationships during the bulking phase of tuber development was important to maximizing yield, quality and storability. **Further research to determine how in-season N management (rate and timing) alters source/sink relationships to affect yield and quality began in 2007/08.** Herein we summarize two to four years of research to define the importance of source/sink relationships to yield, final crop maturity, and storability of Alturas and Premier Russet. Source/sink relationships were expressed as harvest index (HI), which was calculated at maximum foliar growth (see below). Collectively, these studies will contribute to recommendations for fine-tuning management to maximize yield and tuber quality (at-harvest and out-of-storage) and thus profitability for WA growers. The studies are continuing through the 2009/10 season.

$$HI = \frac{\text{Tuber Yld}}{\text{Foliar + Tuber Yld}}$$

Objectives

(1) Identify key indices of crop maturity & define their importance to yield & tuber quality.
(2) Determine how in-season N management impacts tuber maturity & postharvest quality.

Approach

Use N management to alter key milestones of crop development and evaluate effects on yield, tuber quality, and storability. Important milestones of crop development include:

- Days after planting (DAP) to emergence
- Harvest index (HI) at maximum foliar growth
- DAP to 50% HI & T/A at 50% HI (foliar biomass = tuber biomass at 50% HI)
- DAP to:
  - max. foliar fresh wt
  - max. tuber yield

    - max. sp gravity
    - min sucrose
    - min reducing sugars
    - tuber physiological maturity
  - Max. foliar biomass (T/A)
  - Max. tuber yield (T/A)
  - Specific gravity at harvest

Results

- Alturas and Premier Russet were grown with four levels of in-season N (0, 50, 100, and 150% of recommended rate). Replicated plots were planted at the Othello Research Station on April 5, 2007 and April 17, 2008. Plants and tubers were harvested at approximately 10-day intervals from about 75 to 180 days after planting (DAP) and detailed seasonal growth profiles were constructed for each cultivar.
- The early part of 2008 was much cooler than 2007 and the 5- and 10-year temperature averages (Holden and Pavek, 2008), resulting in lower cumulative degree days during the period of plant emergence from 0 to 44 DAP (Fig. 1). Consequently, plants emerged later in 2008 than in 2007.
- Various indices of foliar and tuber development were calculated for each cultivar based on polynomial models describing growth and changes in sucrose, reducing sugars, and specific gravity of tubers over time (Figs. 2 & 3, 5 & 6). These indices included: DAP and yield at 50% harvest index (HI); HI at maximum foliar development; DAP to maximum foliar development, maximum specific gravity, minimum concentrations of sucrose and reducing sugars in tubers, maximum tuber yield; and DAP to physiological maturity of tubers (Tables 1-4).
- The warmer establishment period combined with higher soil temperature in 2007 hastened plant establishment, resulting in higher rates of bulking (BR) from tuber initiation to maximum foliar development (71 to 128 DAP) for both cultivars and at all levels of in-season N when compared with 2008 (Figs. 2 & 3, 5 & 6). For Alturas, 50% harvest index (tuber biomass equals foliar biomass) was reached earlier and foliar and tuber biomass at 50% HI were higher in 2007 than in 2008 (Figs. 2 & 3). For Premier, the DAP to 50% HI was comparable across years; however, more foliar and tuber biomass were produced at 50% HI in 2007 than in 2008 (Figs. 5 & 6). Maximum foliar biomass was also greater in 2007 versus 2008.
- **The level of in-season N significantly and substantially affected key indices of crop maturity.** On average, increasing N from 0 to 150% of the recommended in-season rate, delayed the attainment (DAP) of 50% HI, increased foliar and tuber biomass (T/A) at 50% HI, shifted the attainment of maximum foliar growth later, increased the maximum amount (T/A) of foliar biomass, reduced the HI at maximum foliar growth (except for Premier in 2007), and increased final tuber yields (Tables 1 & 2, 3 & 4).
- Vine persistence (foliar duration) increased with rate of in-season N, as evident by higher foliar biomass 140 to 160 DAP (Figs. 2 & 3, 5 & 6). This effect of N was greater for Alturas than for Premier.

- **In general, vine growth (maximum T/A) was much more sensitive to increasing rate of in-season N than was tuber yield (Tables 2 & 4).** For both cultivars, tuber yield increased by approximately 0.8 T/A for every ton increase in foliar biomass at maximum foliar development ($P<0.001$) (Figs. 4 & 7). Final tuber yields declined as HI at maximum foliar biomasss (71-128 DAP) increased. For Alturas, final yields were highest when tubers accounted for 38 to 42% of total plant fresh weight at maximum foliar development (109-128 DAP) (Fig. 4 bottom). When tuber growth dominated whole plant growth at maximum foliar development (e.g. HI = 62%), final yield was reduced by about 11 T/A. Similar results were obtained for Premier (Fig. 7). **Clearly, management should be tailored to produce (favor) sufficient foliar growth during the first half of the growing season to maximize yield potential.** However, maximum yield should not be the only consideration; the economics of production and issues related to tuber maturity, postharvest use, and ability to retain processing quality should also be considered in deciding how best to manage N.
- Tuber sucrose and reducing sugar (glucose and fructose) concentrations, along with specific gravity, were profiled during development to define the attainment of physiological maturity for each cultivar, as affected by in-season N rate. Tuber physiological maturity (PM) was calculated as the average DAP to reach maximum yield, maximum specific gravity, minimum sucrose, and beginning of end-of-season increase in reducing sugars in the stem ends of tubers (Figs. 2 & 3, 5 & 6; Tables 1 & 3). PM ranged from 143 to 154 DAP (Figs. 2 & 3; 5 & 6) and occurred later with increasing level of N (Tables 1 & 3). **Hence, tubers from 100 and 150% in-season N plots were less mature (physiologically younger) at harvest than tubers from 0 and 50% N plots where the vines had senesced earlier in the season.**
- Reducing sugars in the stem ends of tubers typically increase toward the end of the season, particularly during the maturation phase under dead vines. **On average, the concentration of reducing sugars in Alturas and Premier tubers at harvest was higher when grown with lower levels of in-season N, indicating physiologically older tubers (Figs. 2 & 3, 5 & 6).**
- Days after planting to maximum specific gravity increased with N level (Tables 1 & 3), while maximum specific gravity decreased with increasing N level (Tables 2 & 4), reflecting delayed maturity. On average, specific gravity at harvest was less than the maximum achieved during the growing seasons (Figs. 2 & 3, 5 & 6). **It is clear that N management can be tailored to influence gravity for the processing industry - lower N will produce higher gravity potatoes for dehy, higher N will prevent gravities from becoming too high for frozen processing.** These effects on dry matter need to be considered in the overall economic analysis of N management.
- In-season N rate also affected the total- and protein-N content and thus the nutritional value of tubers (Table 5). Premier was the most responsive; total N increased 76% and protein N increased 48% as in-season N rate increased from 0 to 150% of recommended rate. In contrast, total- and protein-N of Alturas tubers increased 48% and 30%, respectively, in response to the two levels of in-season N. **The concentration of asparagine (Table 5) and other free amino acids in tubers also increased in response to the higher level of in-season N, which may affect acrylamide forming potential**

during processing. This possibility warrants further investigation and should also be considered in determining optimum levels of in-season N.

- Alturas and Premier tubers (8- to 12-oz) from 0, 50%, and 150% in-season N plots were harvested 172 DAP (2007), cured at 54°F, and stored at 40, 44, and 48°F for 228 days. Changes in fry color during storage were cultivar-dependent, reflecting differential sensitivities to low temperature sweetening (LTS) and associated loss of processing quality (Figs. 8 & 9). On average, Alturas produced darker fries than Premier, regardless of storage temperature.
- The effects of in-season N on out-of-storage fry color were subtle and depended on storage temperature and cultivar. Alturas sweetened rapidly during the initial 32 days at 40°F and N-induced differences in PM had no effect on this response (Fig. 8). By April 16 (191 days) however, tubers grown with 150% in-season N produced fries that were 15% and 25% lighter (=USDA 2) than tubers produced with 0% in-season N (=USDA 3). When stored at 44°F to mid April, tubers grown with all levels of in-season N produced acceptable fry color (USDA 1 or better); however, the physiologically younger tubers produced with 150% in-season N produced lighter fries (USDA 0) than the physiologically older tubers grown with 0% in-season N (USDA 1). At 48°F, tubers grown with high N processed lighter than those grown with lower in-season N through mid February. **These results were a consequence of higher levels of in-season N delaying the attainment of PM, which resulted in physiologically younger tubers at harvest, and underscore the importance of PM to storability for processing.**
- For Alturas, the delay in attainment of PM by high N (150%) produced physiologically younger tubers at harvest, as evident by a lower concentration of reducing sugars in the stem ends of tubers and a smaller difference between bud and stem end reducing sugar concentrations as compared with tubers grown under low N (Fig. 10). This translated into a longer storage life for processing. The physiologically younger tubers harvested from the high N plots retained uniform fry color (<9 reflectance units difference between stem and bud ends) through 228 days of storage at 44°F (Fig. 10). In contrast, tubers from low N plots were physiologically older at harvest, had a higher concentration of reducing sugars in the stem end, and developed unacceptable non-uniform fry color (stem to bud fry color difference ≥9 reflectance units) sooner in storage (by 131 days after harvest). **Hence, tuber physiological maturity was affected by N management, which in turn affected retention of processing quality in storage.** While the attainment of PM in Premier tubers was also delayed with increasing N, processing quality was maintained throughout the 228-day storage period, likely due to the inherent resistance of this cultivar to LTS.
- Effects of in-season N on the out-of-storage processing quality of Premier Russet were similar to Alturas. The greatest effects of N were evident when tubers were stored at 40°F (Fig. 9). Tubers produced with 150% in-season N fried 26% lighter than the 0% N tubers through mid April. The N effects on processing quality were not apparent at higher storage temperatures (44 and 48°F), reflecting the high degree of inherent resistance of Premier to sweetening over time at these temperatures.

Summary

- Rate of in-season N significantly affected key indices of foliar & tuber maturity.
- Vine growth was more sensitive to in-season N than tuber yield – tuber yield increased with N-induced increases in maximum foliar growth & decreased as HI at max foliar growth increased.
- Tuberization too early in development restricts foliar growth & limits final yield. Therefore, N should be managed to promote early foliar growth to optimize source/sink relationships & maximize yield and quality. (HI favoring foliage at max foliar dev.)
- Tubers from 100 and 150% in-season N plots were less mature (physiologically younger) at harvest than tubers from 0 and 50% N plots where the vines had senesced earlier in the season.
- Stem-end reducing sugars in tubers were higher at harvest when grown with lower levels of in-season N, indicating physiologically older tubers – this resulted in earlier loss of processing quality during storage, particularly for Alturas.
- It is clear that N management can be tailored to influence gravity for the processing industry - lower N will produce higher gravity potatoes for dehy, higher N will prevent gravities from becoming too high for frozen processing.
- In-season N rate also affected total-N, protein-N, and asparagine content and thus the nutritional value of tubers. While asparagine increased with high N, reducing sugars were lower at harvest and in storage in tubers from high N plots, which probably negates the potential for increased acrylamide formation.

References

Driskill, E.P. Jr., L.O. Knowles, and N.R. Knowles. 2007. Temperature-induced changes in potato processing quality during storage are modulated by tuber maturity. **Am. J. Pot. Res.** 84:367-383.

Holden, Z.J. and M.J.Pavek. 2008. Year of the groundhog: accumulated heat units for 2008. **Potato Progress** 8(8):1-2.

Knowles, N.R., E.P. Driskill. Jr., and L.O. Knowles. 2009. Sweetening responses of potato tubers of different maturity to conventional and non-conventional storage temperature regimes. **Postharvest Biol Tech.** 52:49-61.

Knowles, N.R., M.J. Pavek, L.O. Knowles, and Z. Holden. 2008. Developmental profiles and postharvest behavior of long-season processing cultivars. *In* Proceedings of the 47th Annual Washington State Potato Conference, Feb. 5-7, Moses Lake, WA, pp. 45-65.

Knowles, N.R., M.J. Pavek, L.O. Knowles, E.P. Driskill Jr., and Z. Holden. 2007. Growth, development and postharvest behavior of newly released cultivars in the Columbia Basin. Proceedings of the 46th Annual Washington State Potato Conf. pp. 55-64.

Knowles, N.R., E.P. Driskill Jr., L.O. Knowles, M.J. Pavek, and M.E. Martin. 2006. Physiological maturity of Ranger Russet tubers affects storability and processing quality. **Potato Progress** 6(3):1-4.

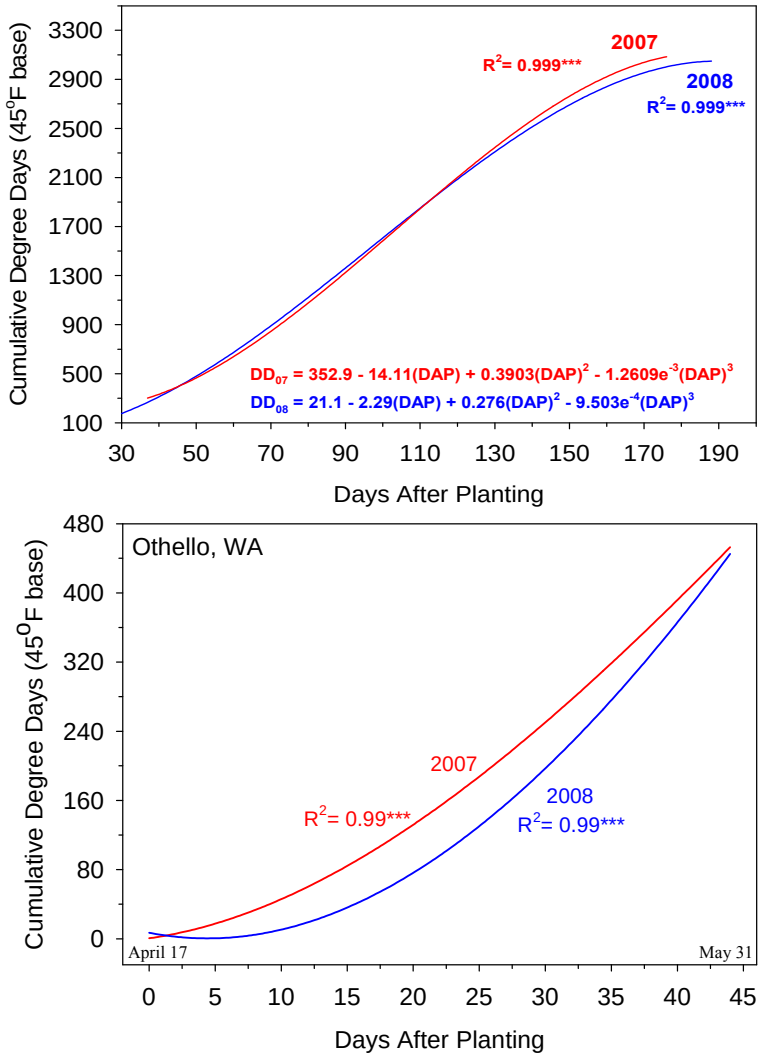


Fig. 1. Cumulative air degree days at Othello, WA during 2007 and 2008. Degree days are plotted through the entire season (top) and during plant establishment (bottom) from planting (April 17) through full emergence (44 DAP).

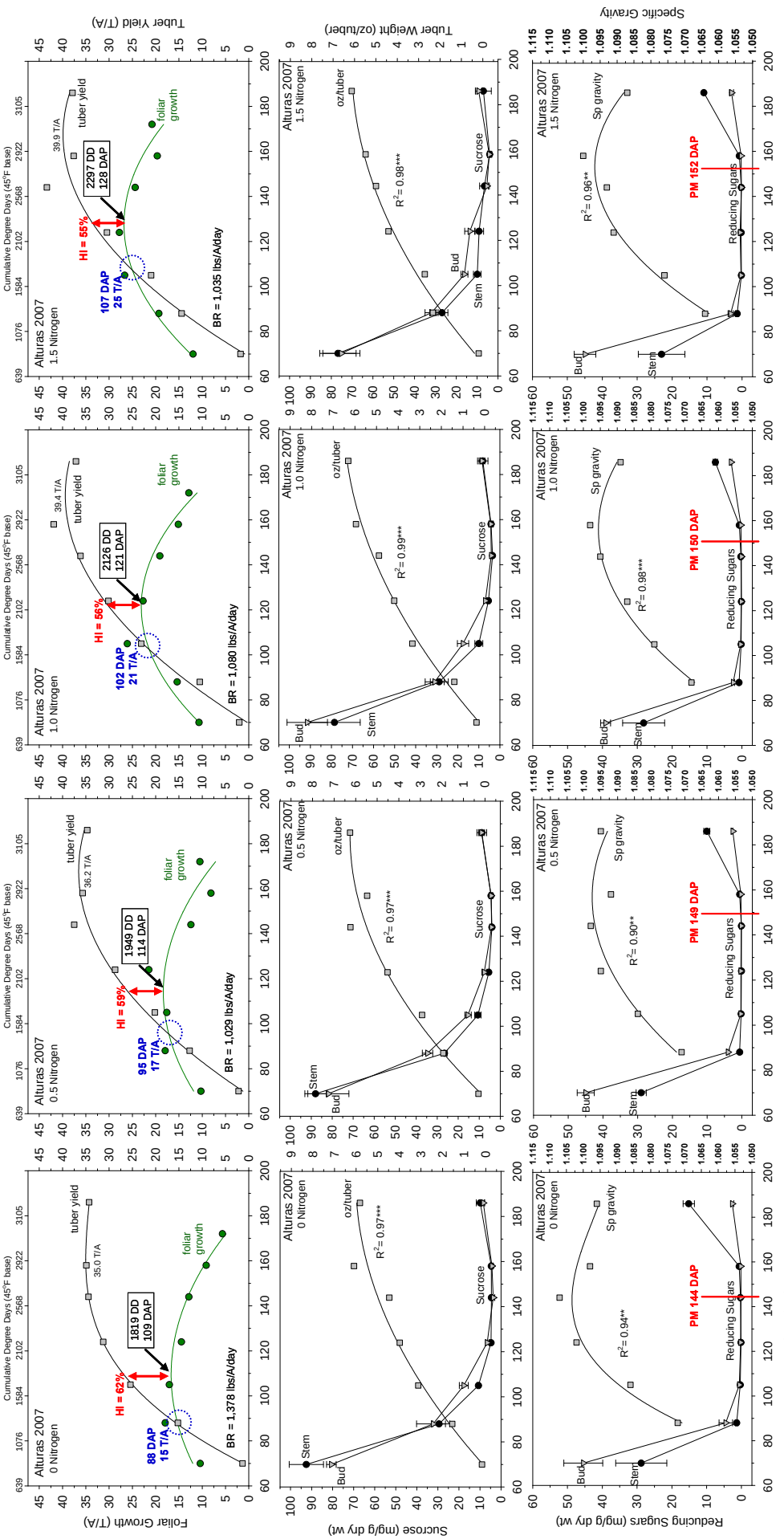


Fig. 2. Foliar and tuber growth (top row) responses of **Alturas** to four levels of in-season nitrogen (N) at Othello, WA during **2007**. Planting date was April 5. The N levels (0, 0.5, 1.0, and 1.5) are equivalent to 0, 50%, 100%, and 150% of recommended in-season rates. Plants and tubers were harvested at approximately 10-day intervals over the 186-d growing season. Changes in tuber sucrose concentrations and average tuber weights (middle row), and reducing sugars (glucose and fructose) and specific gravity (bottom row) are also shown. X- and Y-axis scales are equal to facilitate comparisons among N levels. Cumulative degree days (DD) at the corresponding days after planting (DAP) are shown (top row). BR = initial tuber bulking (growth) rate from 70 DAP to foliar maximum (top row). The days after planting (DAP), DD, and harvest indices (HI) at maximum foliar growth are shown (top row). Harvest index equals tuber fresh weight as percent of total plant (tubers + foliage) fresh weight at maximum foliar growth. The DAP to 50% HI are also indicated (where foliar and tuber growth curves intersect). Note that foliar and tuber yields are equal (shown in blue) at 50% HI. Physiological maturity (PM) was estimated at 144-, 149-, 150-, and 152-DAP as N increased from 0 to 150% of the recommended in-season rate (bottom row). Maturity indices are summarized in Tables 1 and 2.

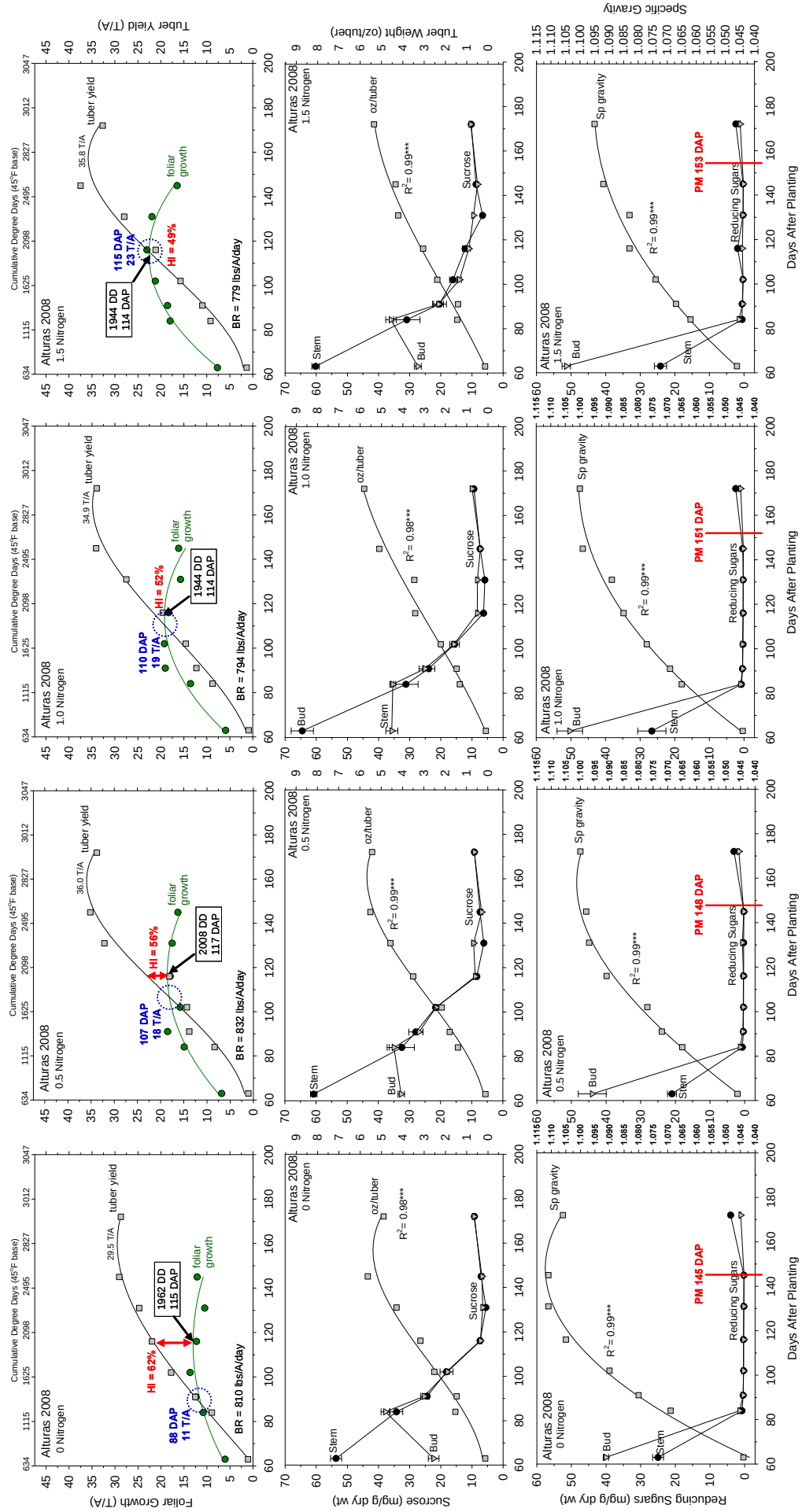


Fig. 3. Foliar and tuber growth (top row) responses of **Alturas** to four levels of in-season nitrogen (N) at Othello, WA during **2008**. Planting date was April 17. The N levels (0, 0.5, 1.0, and 1.5) are equivalent to 0, 50%, 100%, and 150% of recommended in-season rates. Plants and tubers were harvested at approximately 10-day intervals over the 172-d growing season. Changes in tuber sucrose concentrations and average tuber weights (middle row), and reducing sugars (glucose and fructose) and specific gravity (bottom row) are also shown. X- and Y-axis scales are equal to facilitate comparisons among N levels. Cumulative degree days (DD) at the corresponding days after planting (DAP) are shown (top row). BR = initial tuber bulking (growth) rate from 63 DAP to foliar maximum (top row). The days after planting (DAP), DD, and harvest indices (HI) at maximum foliar growth are shown (top row). Harvest index equals tuber fresh weight as percent of total plant (tubers + foliage) fresh weight at maximum foliar growth. The DAP to 50% HI are also indicated (where foliar and tuber growth curves intersect). Note that foliar and tuber yields are equal (shown in blue) at 50% HI. Physiological maturity (PM) was estimated at 144-, 149-, 150-, and 152-DAP as N increased from 0 to 150% of the recommended in-season rate (bottom row). Maturity indices are summarized in Tables 1 and 2.

Table 1. Effects of in-season N level on crop maturity indices of **Alturas** averaged over the 2007 and 2008 growing seasons at Othello, WA. Nitrogen levels are expressed as percent of recommended in-season rates. Planting dates were April 5, 2007 and April 17, 2008. Vines were beat 172 DAP (9/24) and final harvest was 186 DAP in 2007. Vines were beat 159 DAP (9/23) and final harvest was 172 DAP in 2008. The maturity indices were derived from regressions of foliar growth, tuber growth, and tuber carbohydrates versus DAP for each N regime (see Figs. 2 & 3).

Alt 2-yr					Days After Planting (DAP) to				
	50% HI		DAP to Maximum	HI[2]	Max	Max	Min	Min Red.	Physiological
Nitrogen[1]	*DAP*	*T/A*	Foliar F.Wt.	*%*	Yield	Gravity	Sucrose	Sugars[3]	Maturity[4]
0	88	13	112	62	160	145	145	129	145
50	101	18	116	57	164	158	148	126	148
100	106	20	118	54	168	165	147	124	151
150	111	24	121	52	162	166	151	128	153
R^2	0.99*	0.99**	0.99**	0.99*	0.81ns	0.99**	0.79ns	0.88ns	0.99**
Trend	Q	L	L	Q	Q	L	Q	Q	L

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

Table 2. Effects of in-season N level on foliar growth, tuber yield, and specific gravity of **Alturas** averaged over the 2007 and 2008 growing seasons at Othello, WA. Nitrogen levels are expressed as percent of recommended in-season rates. See Table 1 and Figs. 2 & 3.

Alt 2007				
	Max. Foliar	Final Tuber	Specific Gravity	
Nitrogen[1]	Biomass	Yield	Maximum	At harvest
	T/A	*T/A*	*SG*	*SG*
0	14.9	32.3	1.108	1.101
50	18.3	36.1	1.100	1.096
100	21.2	37.2	1.098	1.095
150	24.7	37.9	1.096	1.091
R^2	0.99**	0.99**	0.98**	0.95*
Trend	L	Q	Q	L

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

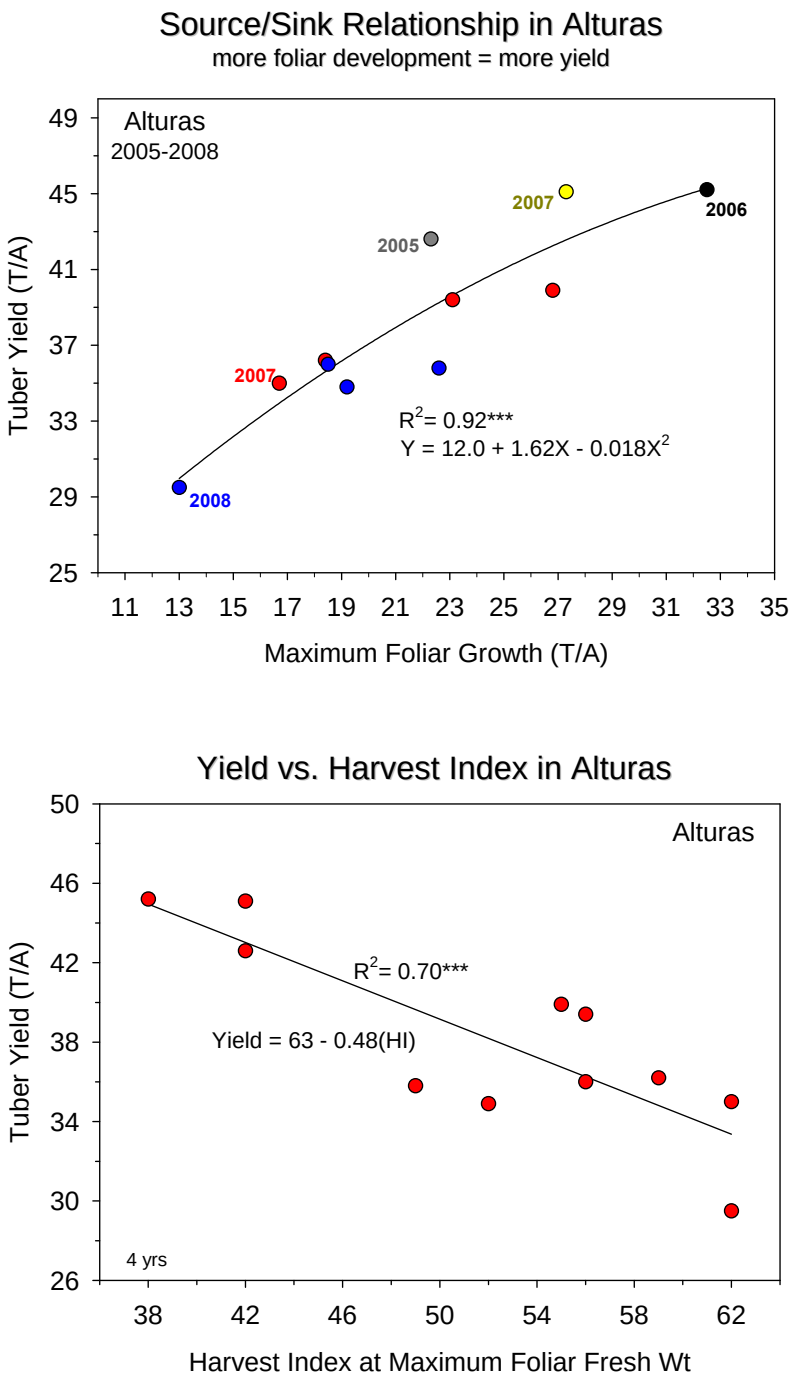


Fig. 4. Top: Dependency of tuber yield on foliar growth in Alturas. The yield (T/A) of above ground foliage at maximum foliar development was estimated from regressions of foliar fresh weight vs. Days after planting (see foliar growth curves in Figs. 2 & 3). Data from 4 years of trials (color coded) are shown. **Bottom:** Tuber yield declines with increasing harvest index (HI). HI was calculated at the point of maximum foliar development. HI is tuber fresh weight as % total plant (tubers + tops) fresh weight. Maximum yields were obtained when tubers accounted for 38 to 42% of total plant fresh weight at maximum foliar growth (109-128 DAP). A source/sink imbalance occurs if tuber growth dominates plant growth (e.g. HI = 62%) at maximum foliar development, resulting in lower yield.

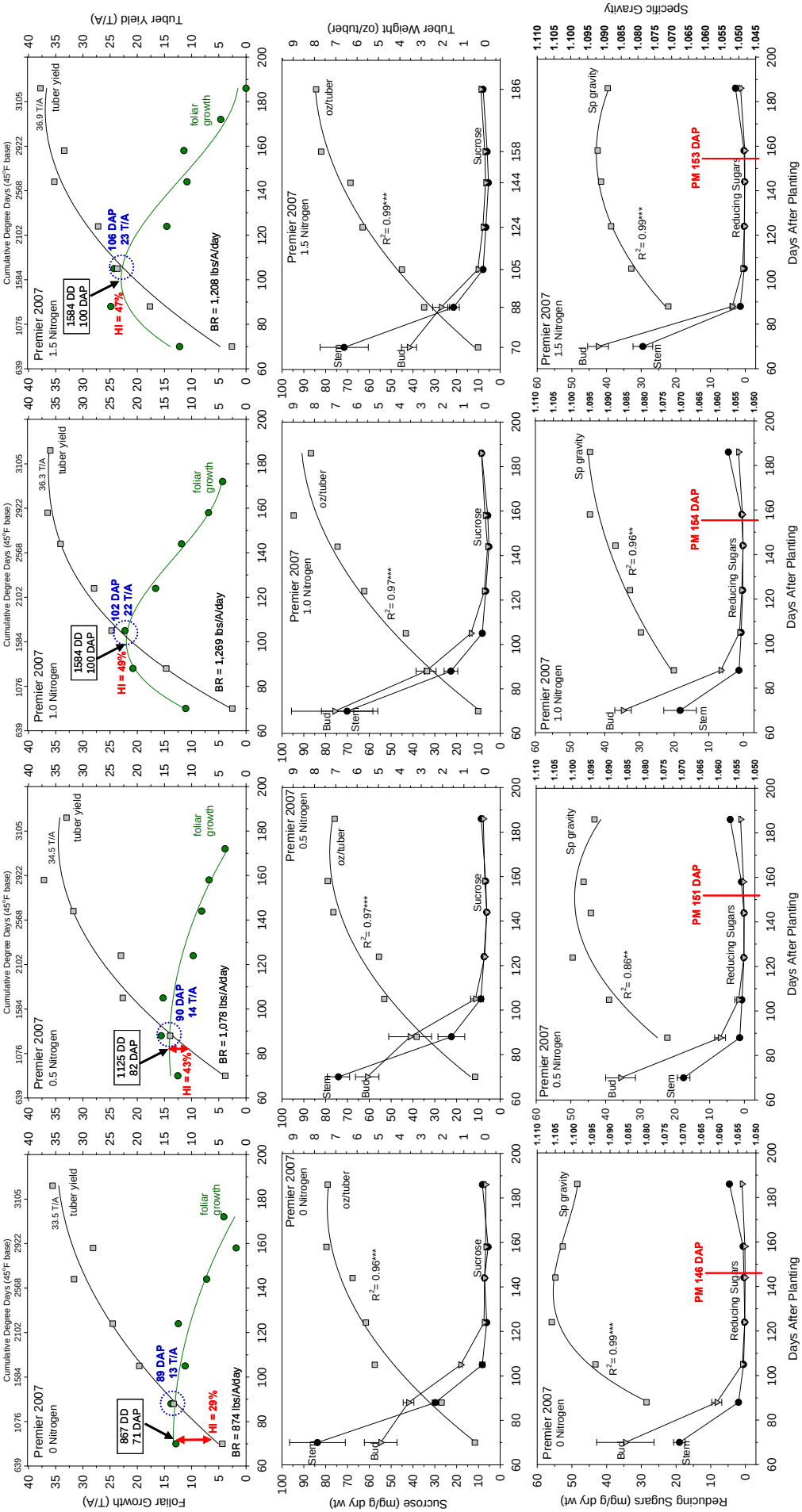


Fig. 5. Foliar and tuber growth (top row) responses of **Premier Russet** to four levels of in-season nitrogen (N) at Othello, WA during **2007**. Planting date was April 5. The N levels (0, 0.5, 1.0, and 1.5) are equivalent to 0, 50%, 100%, and 150% of recommended in-season rates. Plants and tubers were harvested at approximately 10-day intervals over the 186-d growing season. Changes in tuber sucrose concentrations and average tuber weights (middle row), and reducing sugars (glucose and fructose) and specific gravity (bottom row) are also shown. X- and Y-axis scales are equal to facilitate comparisons among N levels. Cumulative degree days (DD) at the corresponding days after planting (DAP) are shown (top row). BR = initial tuber bulking (growth) rate from 70 DAP to foliar maximum (top row). The days after planting (DAP), DD, and harvest indices (HI) at maximum foliar growth are shown (top row). Harvest index equals tuber fresh weight as percent of total plant (tubers + foliage) fresh weight at maximum foliar growth. The DAP to 50% HI are also indicated (where foliar and tuber growth curves cross). Note that foliar and tuber yields are equal (shown in blue) at 50% HI. Physiological maturity (PM) was estimated at 144-, 149-, 150-, and 152-DAP as N increased from 0 to 150% of the recommended in-season rate (bottom row). Maturity indices are summarized in Tables 3 and 4.

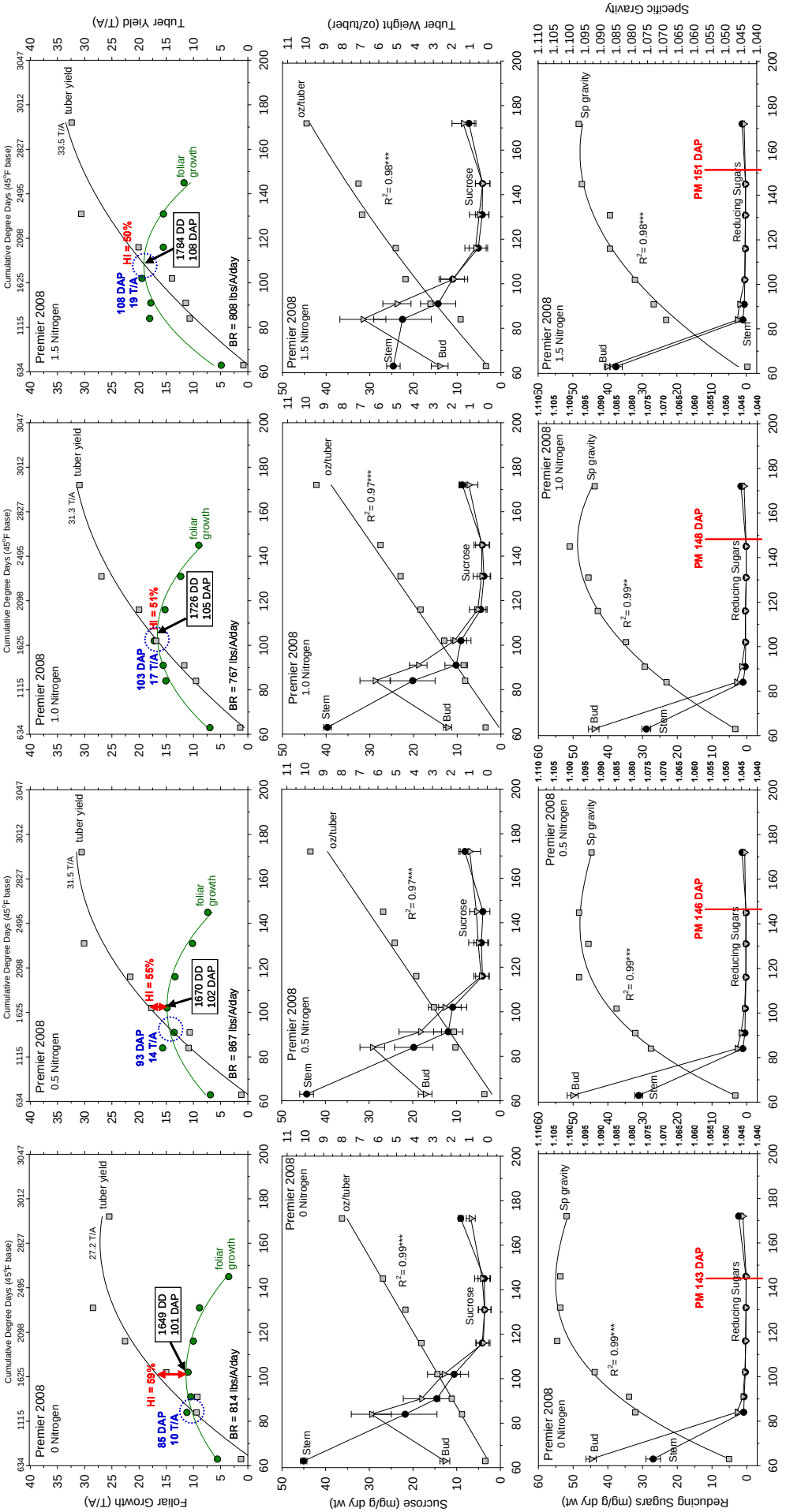


Fig. 6. Foliar and tuber growth (top row) responses of **Premier Russet** to four levels of in-season nitrogen (N) at Othello, WA during **2008**. Planting date was April 17. The N levels (0, 0.5, 1.0, and 1.5) are equivalent to 0, 50%, 100%, and 150% of recommended in-season rates. Plants and tubers were harvested at approximately 10-day intervals over the 172-d growing season. Changes in tuber sucrose concentrations and average tuber weights (middle row), and reducing sugars (glucose and fructose) and specific gravity (bottom row) are also shown. X- and Y-axis scales are equal to facilitate comparisons among N levels. Cumulative degree days (DD) at the corresponding days after planting (DAP) are shown (top row). BR = initial tuber bulking (growth) rate from 63 DAP to foliar maximum (top row). The days after planting (DAP), DD, and harvest indices (HI) at maximum foliar growth are shown (top row). Harvest index equals tuber fresh weight as percent of total plant (tubers + foliage) fresh weight at maximum foliar growth. The DAP to 50% HI are also indicated (where foliar and tuber growth curves cross). Note that foliar and tuber yields are equal (shown in blue) at 50% HI. Physiological maturity (PM) was estimated at 143-, 146-, 148-, and 151-DAP as N increased from 0 to 150% of the recommended in-season rate (bottom row). Maturity indices are summarized in Tables 3 and 4.

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

6LS 2-yr					Days After Planting (DAP) to				
	50% HI		DAP to Maximum	HI[2]	Max	Max	Min	Min Red.	Physiological
Nitrogen[1]	*DAP*	*T/A*	Foliar F.Wt.	*%*	Yield	Gravity	Sucrose	Sugars[3]	Maturity[4]
0	87	12	86	44	166	139	143	130	145
50	92	14	92	49	174	145	144	132	148
100	103	20	103	50	175	152	143	135	151
150	107	21	104	49	174	158	144	134	153
R^2	0.97**	0.96**	0.94**	0.99**	0.97*	0.99***	0.00ns	0.88ns	0.99***
Trend	L	L	L	Q	Q	L	L	Q	L

[1]In-season nitrogen as a percentage of recommended rate. [2]HI= tuber wt/tuber wt + foliar wt at maximum foliar development. [3]DAP to reach a minimum in reducing sugar concentration in the stem end of tubers. [4]Physiological maturity is the average DAP to reach maximum yield, specific gravity, minimum sucrose, and minimum reducing sugars in the stem ends of tubers. *,**,***P<0.10, 0.05, and 0.01, respectively, for linear (L) or quadratic (Q) correlation coefficients (vs. N rate).

Table 4. Effects of in-season N level on foliar growth, tuber yield, and specific gravity of **Premier Russet** averaged over the 2007 and 2008 growing seasons at Othello, WA. Nitrogen levels are expressed as percent of recommended in-season rates. See Table 3 and Figs 5 & 6.

6LS 2-yr				
	Max. Foliar	Final Tuber	Specific Gravity	
Nitrogen[1]	Biomass	Yield	Maximum	At harvest
	T/A	*T/A*	*SG*	*SG*
0	12.4	30.4	1.105	1.100
50	14.5	33.0	1.098	1.093
100	19.3	33.8	1.096	1.094
150	21.0	35.2	1.094	1.093
R^2	0.97**	0.98*	0.98*	0.59ns
Trend	L	Q	Q	L

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

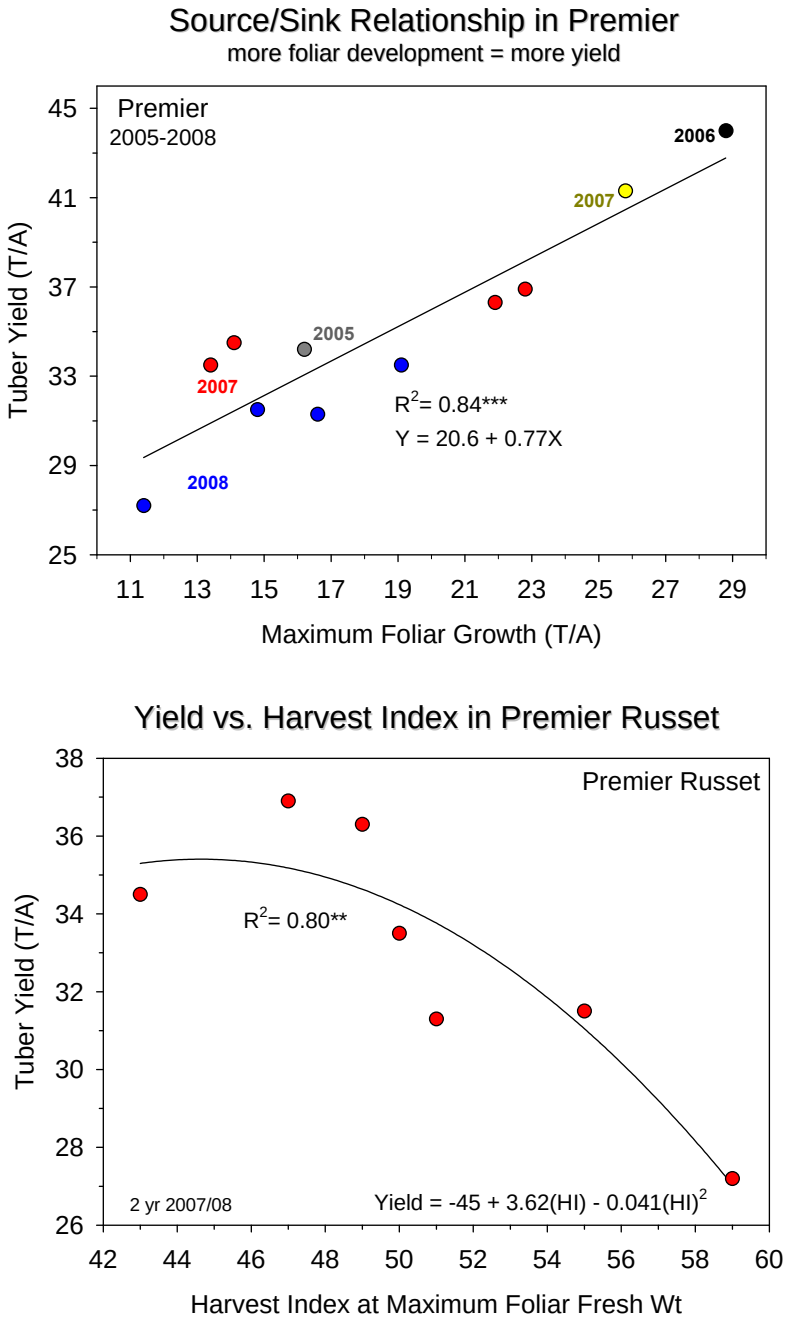


Fig. 7. Top: Dependency of tuber yield on foliar growth in Premier Russet. The yield (T/A) of above ground foliage at maximum foliar development was estimated from regressions of foliar fresh weight vs. days after planting (see foliar growth curves in Figs. 5 & 6). Data from 4 years of trials (color coded) are shown. **Bottom:** Tuber yield declines with increasing harvest index (HI). HI was calculated at the point of maximum foliar development. HI is tuber fresh weight as % total plant (tubers + tops) fresh weight. Maximum yields were obtained when tubers accounted for 43 to 46% of total plant fresh weight at maximum foliar growth (71-108 DAP). A source/sink imbalance occurs if tuber growth dominates total plant growth (e.g. = 59%) at maximum foliar development, resulting in lower yield.

Table 5. Effects of in-season N level on total-N and soluble protein-N concentrations in tubers at final harvest (186 DAP) during 2007 (Othello, WA). Nitrogen levels are expressed as percent recommended in-season rates. Tuber asparagine concentrations are also shown (avg 2007 & 08 seasons). Asparagine reacts with reducing sugars to yield acrylamide during processing.

Cultivar	In-season Nitrogen[1]	Tuber Nitrogen[2]		Asparagine
		Total-N	Protein-N	
	%	*mg/g dry wt*		*nmol/g dry wt*
Alturas	0	11.5	2.69	51.1
	150	17.0	3.49	87.2
Premier	0	11.1	2.19	57.5
	150	19.6	3.25	86.2
Cultivar (C)		ns	**	ns
In-season N		**	**	**
C x N		**	ns	*

[1]In-season nitrogen as a percentage of recommended rate. [2]Protein assessed by Bradford with BSA (16% N) as a standard. *·**P<0.05 & 0.01 (ns, not significant).

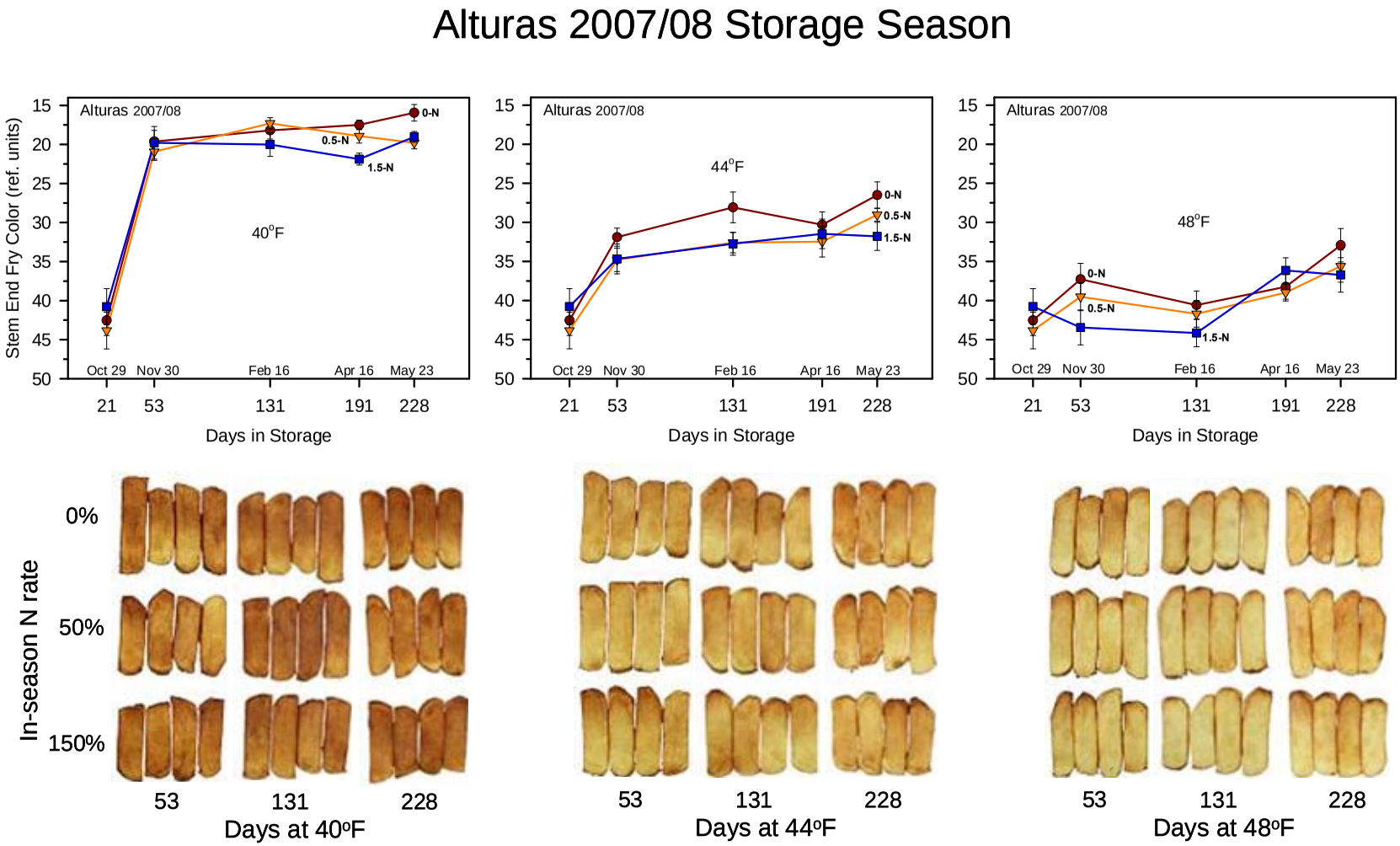


Fig. 8. Changes in fry color (Photovolt reflectance) during storage of Alturas tubers at 40, 44, and 48°F as affected by in-season nitrogen regimes. The crop was planted April 5, 2007 at Othello, WA and grown with 0, 50% and 150% of the recommended in-season rate of N. Vines were beat 172 DAP and tubers harvested 186 DAP. Tubers were wound-healed at 54°F for 21 days and then stored at the indicated temperatures. Note the inverted scale on the fry color axis. Low reflectance values indicate darker fries. Photovolt readings >31= USDA 0; 25-30= USDA 1; 20-24= USDA 2; 15-19= USDA 3; <14= USDA 4. Each point is the average of 12 tubers ±SE. Each fry plank is from a different tuber selected to represent the average fry color in a 12-tuber sample. See Fig. 2 for growth profiles.

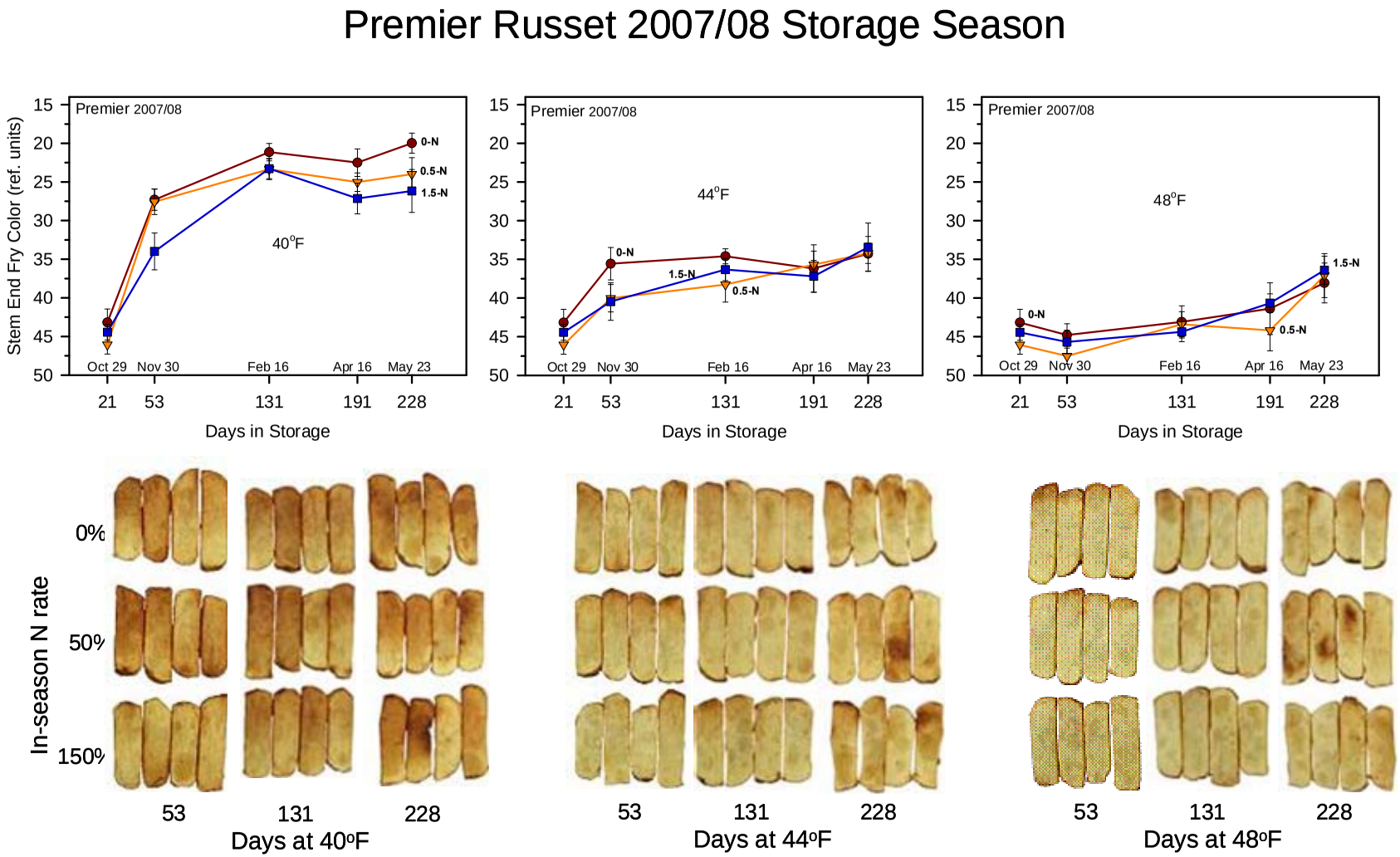


Fig. 9. Changes in fry color (Photovolt reflectance) during storage of Premier Russet tubers at 40, 44, and 48°F as affected by in-season nitrogen regimes. The crop was planted April 5, 2007 at Othello, WA and grown with 0, 50% and 150% of the recommended in-season rate of N. Vines were beat 172 DAP and tubers harvested 186 DAP. Tubers were wound-healed at 54°F for 21 days and then stored at the indicated temperatures. Note the inverted scale on the fry color axis. Low reflectance values indicate darker fries. Photovolt readings >31= USDA 0; 25-30= USDA 1; 20-24= USDA 2; 15-19= USDA 3; <14= USDA 4. Each point is the average of 12 tubers +SE. Each fry plank is from a different tuber selected to represent the average fry color in a 12-tuber sample. Note the mottling of fries at 228 DAP. See Fig. 5 for growth profiles.

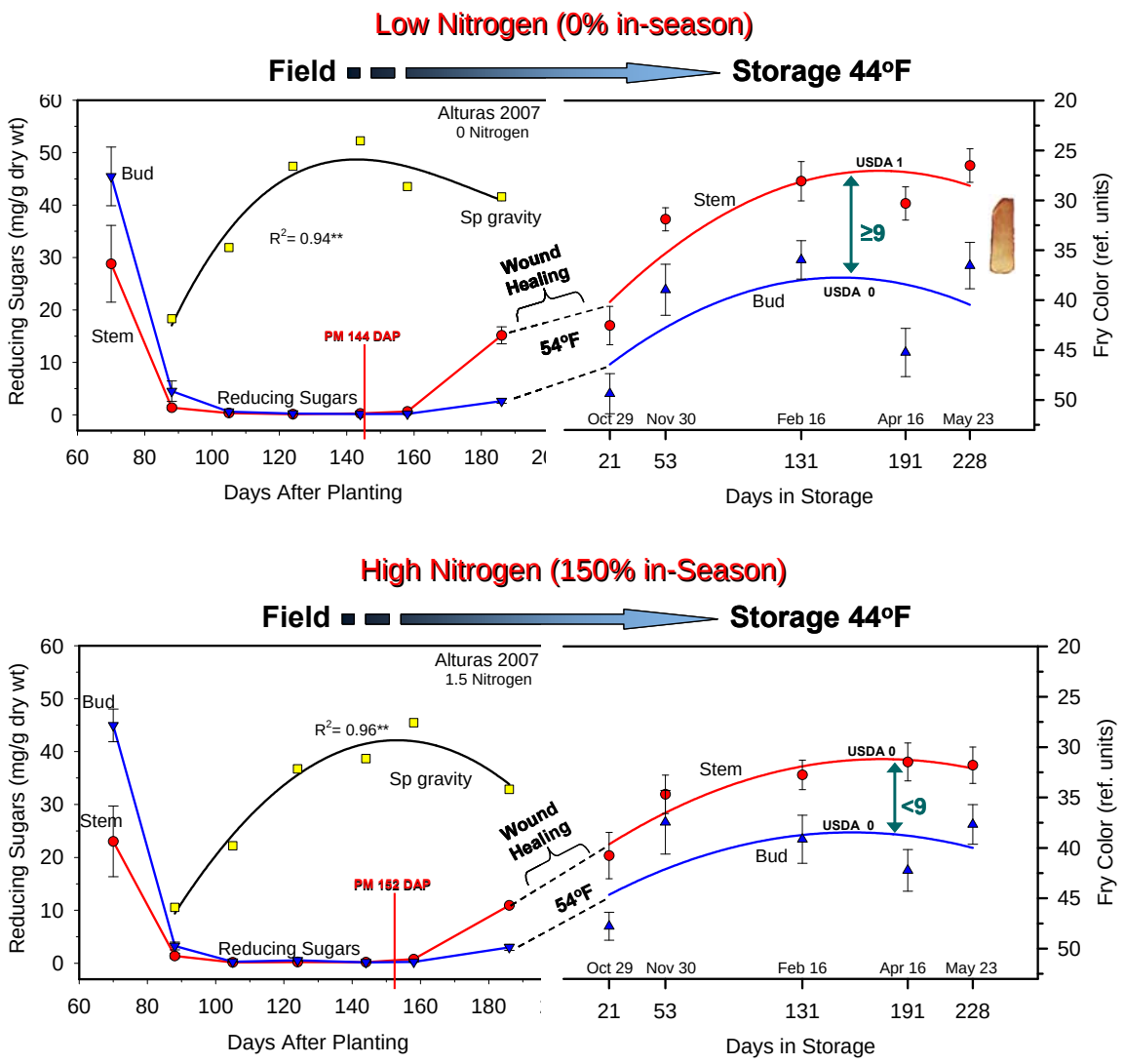


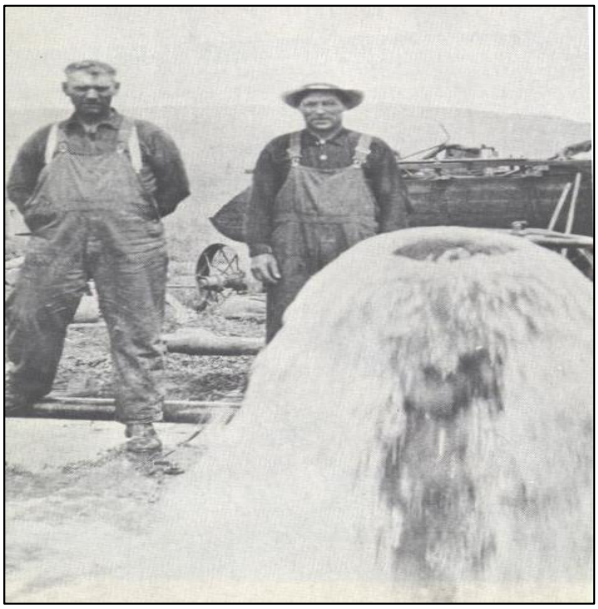
Fig. 10. Changes in reducing sugars (glucose + fructose), specific gravity and fry color of tubers during development and in storage (2007 growing season and 2007/08 storage season). The crop was planted April 5, 2007 at Othello, WA and grown with 0% (top) and 150% (bottom) of the recommended in-season rate of N. Vines were beat 172 DAP and tubers harvested 186 DAP. Physiological maturity (PM) of tubers was estimated at 144 and 152 DAP for low and high N crops, respectively. Tubers were harvested, wound-healed at 54°F for 21 days and then stored at 44°F until May 23. Changes in processing quality (fry color) of the bud and stem ends of fries were compared over the 228-day storage period. Fry color was measured as Photovolt reflectance. Note the inverted scale on the fry color axis (right). Low reflectance values indicate darker fries. Tubers grown with low N matured earlier, resulting in physiologically older tubers at harvest. The reducing sugar content of the stem ends of these tubers was very high at harvest and fry color became non-uniform by mid March (bud to stem difference in Photovolt ref units ≥9). In contrast, reducing sugar levels in the stem ends of high-N tubers were less than in low N tubers at harvest. High N tubers were physiologically younger than low N tubers at harvest and maintained uniform fry color throughout the storage period (bud to stem difference in Photovolt ref <9). Nitrogen management can thus affect tuber physiological maturity, which in turn affects retention of processing quality during storage. Photovolt readings >31= USDA 0; 25-30= USDA 1; 20-24= USDA 2; 15-19= USDA 3; <14= USDA 4. Each point is the average of 12 tubers ±SE. Each fry plank is from a different tuber selected to represent the average fry color in a 12-tuber sample. See Fig. 2 for growth profiles.

Presented by Alex McGregor
Washington State Potato Conference
January 28, 2009

Good morning, Washington State Potato industry friends!

Some thoughts on a time of where teamwork among all of us in agriculture is urgently needed, a time of opportunity with some challenges…

We've come a long ways as Northwest farm families since the first artesian irrigation well at our ranch, 1908



We have a lot of people to educate—in Washington, D.C., in Olympia and among our neighbors unfamiliar with agriculture. And we've got a great story to tell.

On my own place—where Franklin, Adams, and Whitman county borders meet, and everywhere across the Columbia Basin, a land once desolate has become a leader in producing foodstuffs for a hungry world.

The Blessing of Aridity (1899) "The land which the casual traveler, speaking out of the splendid depths of his ignorance and prejudice, condemns as 'worthless' and 'fit only to hold the earth together' is in reality rich and durable beyond the most favored districts in the humid regions."

"The miracle of irrigation"
My grandfather and three great-uncles bought a failed irrigation project, designed to use the waters of the Palouse River to irrigate 400,000 acres of the Columbia Basin. Flumes on both sides of the canyon—one day they'd wash out the railroad tracks on one side, the next day the state highway on the other.

Artesian wells provided us the first reliable water source—we irrigated 4,000 acres of apples in addition to raising dry land wheat and range sheep.

We've made great strides forward as stewards of the land….

In wise use of applied chemistry---
"The apples showed too much arsenic to be reassuring. But if the sorters wipe each one we will get by" McGregor Land & Livestock 1926
--a world of formaledehyde and lead arsenate

And, with water, far less dust than the "Dirty Thirties"
"We had dust storms that would last for three days. Dad and Mom bought a new Chevy in Nepel. On the way home they got in the dust storm and got lost out in fields for hours and hours—ruined the engine on the car before they got back. We would go out and find mice blind from the dust and sand all over the fields and chickens buried in the dust. You could walk over the fence in many places—the dust was that deep." Elmer Pfaff

Pulling Together, Farm Families Have Produced Dramatic Results….

During the lifetimes of veteran farmers, farm families have:
----increased yields 250%
----reduced waterborne soil erosion 85%
----reduced dust 600%
----reduced field burning 2200%
It's the biggest achievement of any generation of farmers in the last 10,000 years….

It's Time to Build Some Relationships and to Strengthen Others
---A 44th, the 111th, and 50 new faces…
---Some "centrists"
--- some familiar faces
----and an active environmental agenda…
I've been active speaking and working with members of Congress on behalf of farm families for thirty years now and I believe that our efforts in '09 are more critical than ever….
President Obama---
Signs are that he may be a good listener. The wheat and corn associations point out his staff has shown genuine interest in hearing the views of American farmers.
My experience: Obama's agricultural advisory committee---When I brought up issues of agricultural research, trade, rivers and transportation**,** they listened and asked attentive questions…
Kiplinger Ag Report—In Obama farmers have a good friend in D.C. He has long supported agribusiness and biofuels." Truth is, nobody knows for sure. No point in waiting or in being pessimistic.
We're starting with a clean slate with a new administration concerned about feeding the world and we'd best be getting at the business of telling our story.

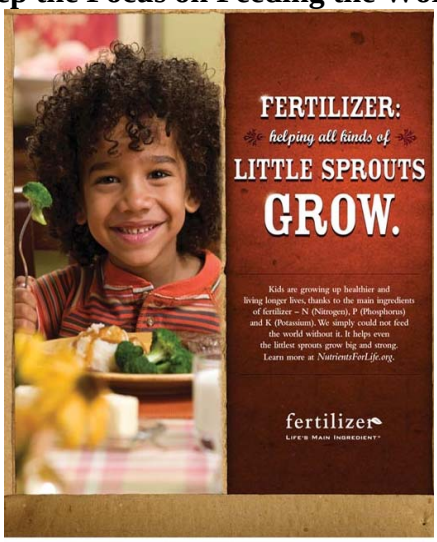
Some key people we've worked with before….
Familiar faces: Tom Harkin and Collin Peterson (agriculture)
Kent Conrad (D-N.D.) and Thad Cochran (R-Miss) (budget)
Max Baucus (D-Mt) and Chuck Grassley (R-Ia.) (finance)

Two "centrists" at Agriculture and Interior
"A big sigh of relief" Tom Vilsack (Agriculture);Ken Salazar (Interior)

Significant changes in the House of Representatives
--from moderate committee chairs to more strident ones…
Henry Waxman replaces John Dingall (energy and commerce)
Ed Markey (Mass.) pulls rank to head (air quality)

An active environmental agenda
Some aggressive leadership, with scientific credentials, on environmental issues
Lisa Jackson (EPA) and Carol Browner, ombudsman, on environment and warming

Keep the Focus on Feeding the World

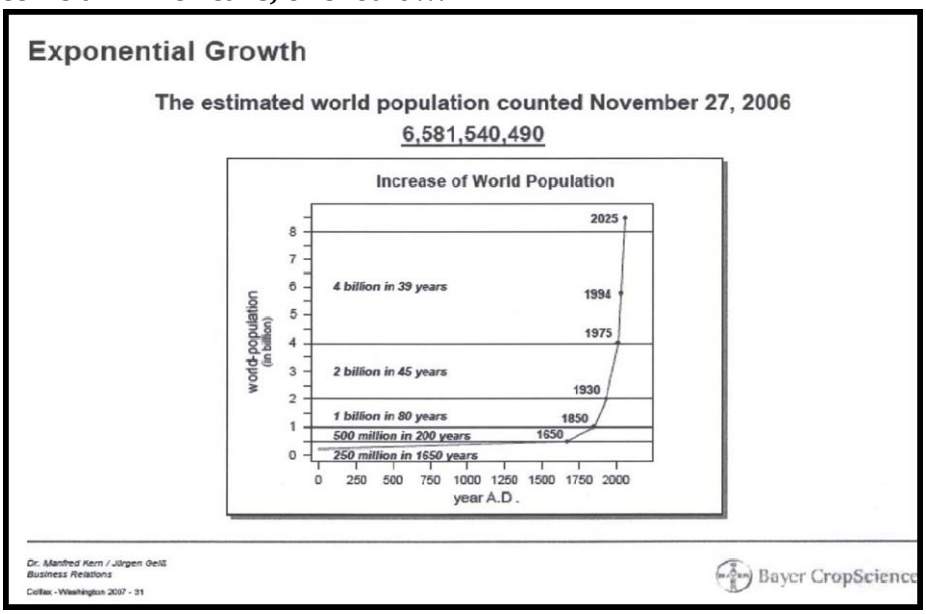


As growers, as agribusiness, as scientists….
Every second we have 3 new mouths to feed
Every 2.5 seconds we lose an acre of farm ground

Agriculture has often been taken for granted in the past—we've all had to explain why research is vital, why we must keep learning and advancing…

A new awareness is starting to reach urban America….
We must double food production worldwide during the working careers of young farmers…
We need to produce as much food between now and 2040 as we've produced in the last 10,000 years…

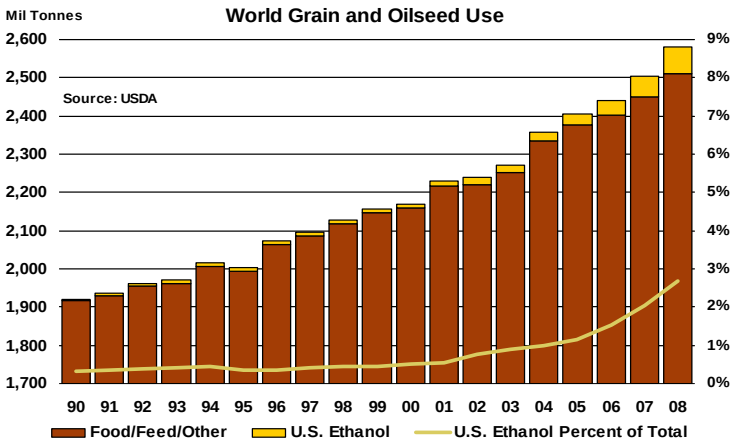
Exponential population growth—an issue that crossed the rural/ urban barrier and concerns all Americans, or should…



To critics who claimed Tom Vilsack was unfit to be Secretary of Agriculture because he had close ties with mainstream agriculture and the biofuels industry
---automatically an enemy of "sustainable" and "organic" agriculture?

Sen. George McGovern, Director of World Food Program
"The primary goal of agriculture is to feed ourselves and those around the globe who lack America's productive resources. America's farmers have become so efficient that 1 percent of the population can feed an entire country and much of the world. One of the downsides of this efficiency is that consumers have forgotten where our food comes from and what it takes to get our bounty into supermarkets. We all want a safe and inexpensive food supply. Even with the recent food price inflation Americans still spend only 10 percent of their disposable income on food, the lowest in the world. A case can be made that our entire consumer economy is fueled by cheap food. There would not be as many cell phones or other conveniences if Americans had to spend 20 percent or more of their disposable income on food. We need to get beyond ideology and depend more on science. We need to develop a new understanding of agriculture based on our larger goals if we are to craft a long-term food and farm policy that works.
Agriculture has a responsibility to help care for the environment. But let's stick to science and avoid an ideological debate about agricultural practices."

Demand for foodstuffs has soared…

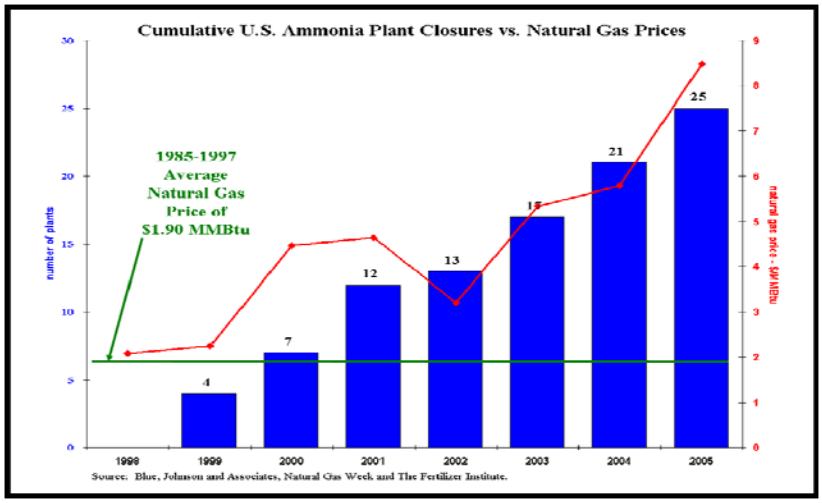


Global demand for food has doubled from a 1.3% increase every year to 2.6%
The 500 million metric ton challenge—that is the 20% increase in food production that must occur by 2020…
The '07-'08 food crop: The first time demand outstripped supply without disastrous crops somewhere in the world…
That's why there was a huge demand for fertilizers.

As demand for food escalated, so did fertilizer prices….
+ 268% between 2000 and mid-year 2008

"Fertilizer producers were clearly reacting to record commodity prices and priced their products accordingly." Farm Bureau
--runaway inflation—painful for growers and hated by those of us growers rely upon to serve them

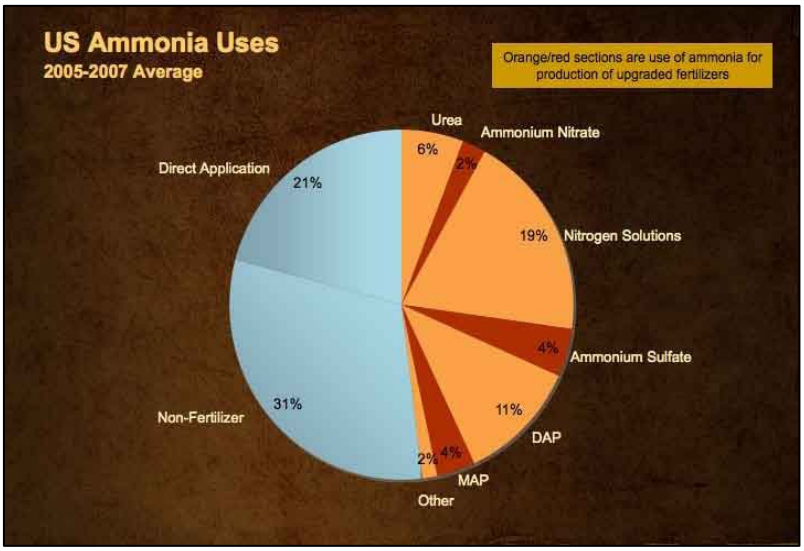
Domestic fertilizer production has been in a freefall even as demand has risen..



---escalating natural gas prices= 25 NH3 production plant closures
Domestic nitrogen production once filled 85% of U.S. needs, now 45%. Domestic phosphate production fell 30%
Leaves us vulnerable as never before

Here's why NH3 is critical

It's the feedstock to make all nitrogen solutions, urea, phosphates (to a lesser degree), industrial products also.



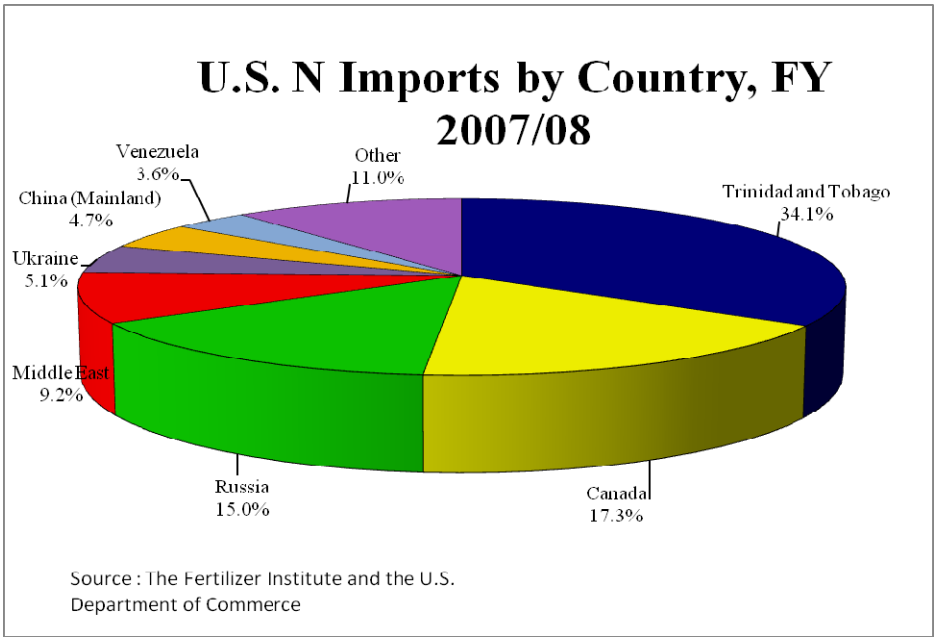
21% direct applied, 19% nitrogen solutions/ 6% for urea/ 15% MAP and DAP

We've fought to keep railroad lobby from being relieved of common carrier duties—would have meant that all NH3 would have had to have been trucked from ocean ports.

Here's where nitrogen comes from these days….

Main exporters to us: Trinidad and Tobago, Canada, Russia

China—world's largest urea exporter---in 2007 put a 135% tariff on shipments overseas of urea and phosphate.



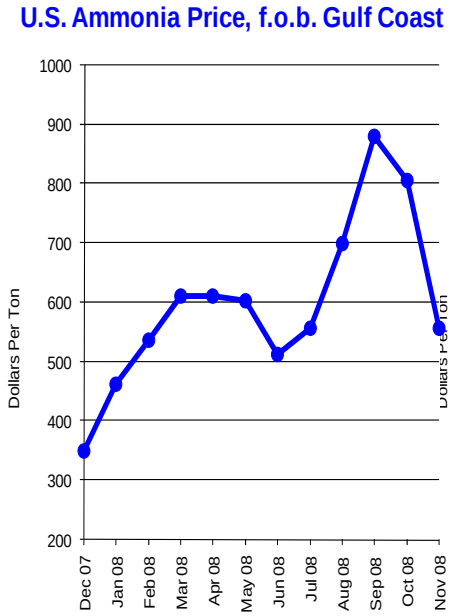
And the world of potash….

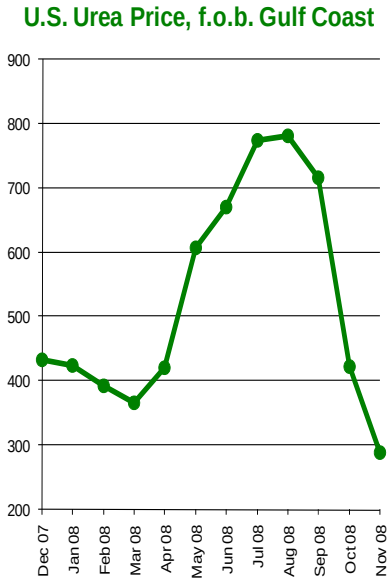
Major exporters are: Canada 39%, Russia 20%, Belarus 16%, Germany 11%, Israel 7.5%, US 0.5%

When world demand faltered, fertilizer prices fell like a stone…

Gulf Coast prices of NH3 and urea

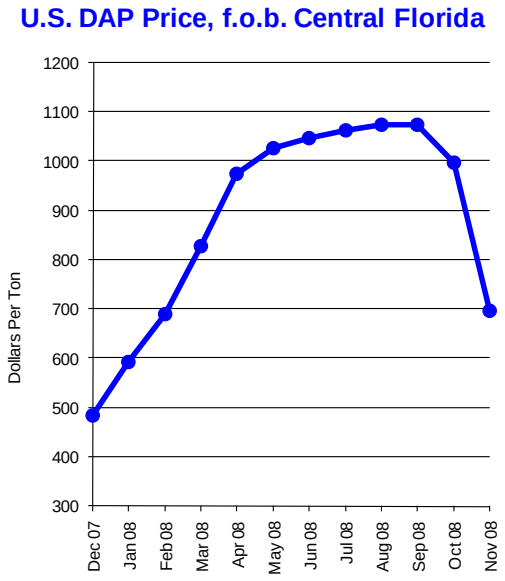
Production shut down or slowed in Trinidad, Canada, Ukraine, Italy, Romania, Estonia, Libya, Turkey, Hungary. Urea in Ukraine halted by pipeline squabble with Russia.

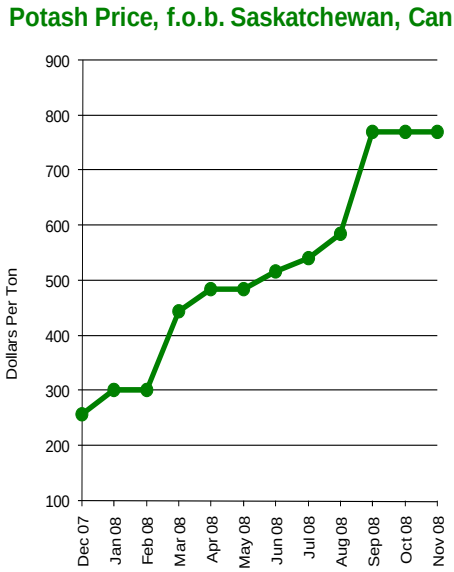




Phosphate followed, not potash.

Limited supplies. Potash from Canada, Germany, Russia.
Phosphate—Morocco, Russia, Tunisia, Lithuania, USA





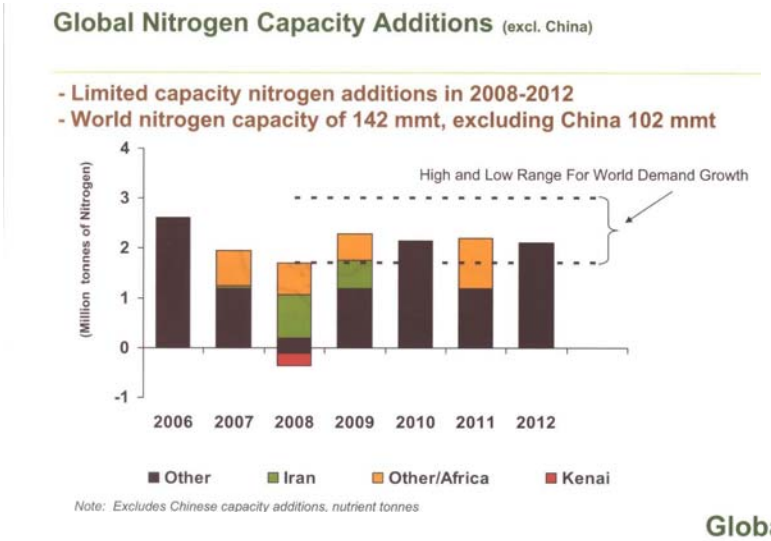
Nutrients will be more affordable this spring!

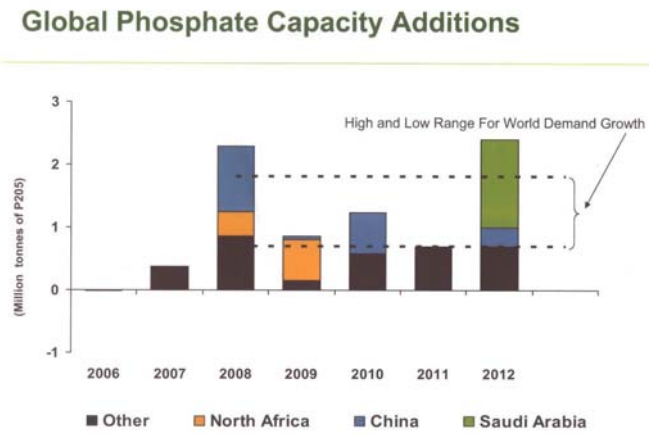
---predicting the "bottom" can be a game of very high stakes poker
even for colleagues of mine who are immersed in that world full time…

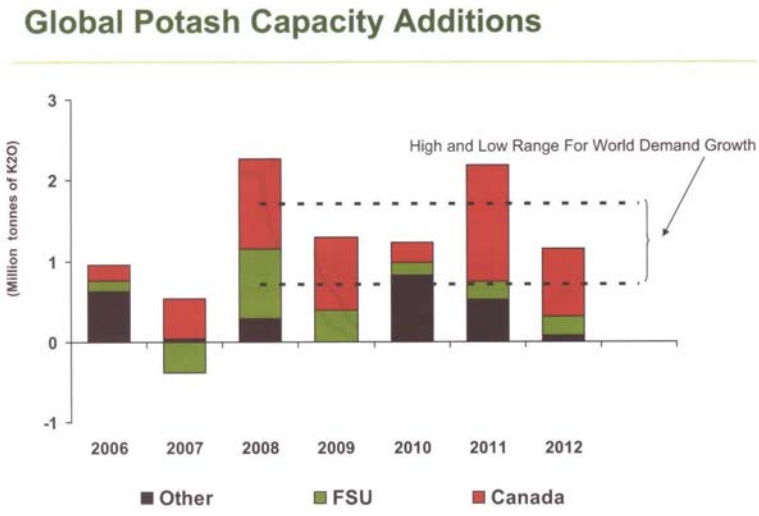
----"Global prices for fertilizer are expected to be significantly lower in '09 than in the previous year, driven by a fall in demand and the global financial crisis [Rabobank]"

----some more production will be coming on line next few years—

New production will help some….







As a business that serves potato growers out in the field….

We take advantage of our independence and our strength to buy as well as we can and pass along the savings.

We invest in growers' futures and ours, with equipment, facilities, most of all dedicated long-term people with a passion for agriculture….

We need to work together

---as growers, as crop advisers, as scientists, as suppliers of products

----To help manage risks and help farm families succeed in ever more complex times…

As a senior bank executive put it recently: *Farmers and those who serve them must be more proactive in planning and in developing 'what if' action plans and cropping ideas for this year, next year, and the years beyond. Teamwork and trusted partners are essential tools for success in a fast changing agricultural world.*

A major issue for the energy intensive potato world…

Greenhouse gases and carbon caps and trades…..

"The Western Climate Initiative" with a focus on "*the largest emitting sectors including forestry, agriculture, cement, iron, aluminum, energy and transportation."*

"Reversing the damage done by global warming is the great environmental challenge of the 21st century." Arnold Schwarzenegger.

----Greenhouse gases in your truck fleet – now a focus of the Washington Dept of Ecology.

----Do steers emit more methane when grass fed or on grain? Environmental activists unfamiliar with agriculture have claimed cattle on feed emit methane – grass fed ones don't. Untrue – pseudo-scientific baloney.

Some potential for offsets—and they will be worth fighting for. But we mustn't get all wrapped up in them—in California they were pulled off the table…

Energy Costs and Carbon Offset Consequences

Natural gas represents over 90% of the costs to produce feedstock nitrogen.

Earlier bill (Lieberman-Warner of 2008)—*would have increased costs to agriculture by 37%* **(fuel)** *and 50%* **(nitrogen).**

"Like it or not, we have a carbon based farming system. We use fuel for our tractors to make food, fuel and feed for the nation and the world." (Farm Bureau)

Help us explain—none of us uses nitrogen carelessly or casually….

We've become steadily more efficient—all across the broad spectrum of crops in our state. Soil testing, advanced agronomy, precise placement….

Please be aware of research already in place on nitrogen, minimizing CO2, and using nutrients efficiently. If you'd like copies of the international fertilizer studies, let me know—a good way to combat misconceptions….

We believe growers are the best judges of their needs in the field….

"If we are not successful in building a coalition to promote the science of nutrient use efficiency, and if the whole agricultural community does not come on board, we will surely see mandated use reduction on the farm down the road." Ford West

We need to join forces as Team Agriculture…

1). To urge Congress to consider the production of foodstuffs, including the ingredients necessary to grow them, as a top national priority

2). To show energy efficiencies we've achieved in all facets of food production…

3). To <u>avoid</u> forcing new energy producers to use natural gas so that the 3% used to produce nitrogen, and therefore bountiful crops, remains available and affordable!

We need to avoid government sanctioned "fuel switching"—driving energy producers away from coal to an energy source vital for producing food, natural gas. Could force more production to move overseas. It doesn't make sense, while striving for energy independence, to lose domestic production vital for agriculture.

The challenging world of buffers

Kudos to Potato Commission for promotion of sound research

--We as agriculture – from registrants to applicators –need to keep working with EPA providing practical information for final revisions…

---A buffer of 100' or more can cause serious economic dislocation for growers

We all need to pull together on this and many other issues – to be good stewards of important tools while minimizing farm losses…

We are happy to help fight the battles

One of the pluses of having been around agriculture for a long time is that you get to know the people we can call upon as farm families to help when the chips are down….

Let's tell of our progress as we take on many issues….

---Fine tuning and encouraging "Good Agricultural Practice" concepts
---Finding essential workers for our farms
---Research funding—we've won many battles in the past
---Transportation, dams, and many water issues
---CDL's, hazmats and regulations

We, the people of agriculture, share some values that matter
McGregor sheep herders with all the essentials—shotguns, sheep dog, Scotch, 1925

My great uncle Archie, writing from his herder's tent in 1894, described the essentials for success in agriculture—*industry, work, character, honesty and fair dealings*.
Unusual values in a more crowded and litigious society…
Hard for many to imagine making a living on the land.
----our field is the last bastion of family business--- powerful attributes that
helps make sure many an urbanite sits up and listens when farmers speak

Like our ranch harvest crew of eighty years ago….

Some with hands on hips, some with arms folded, one with a cocked straw hat and some with big smiles—*we can pitch in as a modern day crew, take on the challenges, and do pretty darned well, thank you.…*

We've conquered a lot of challenges over the years but often we get so busy we don't find the time to stop to build alliances across crops, state borders, with agribusiness, as we should.
--a good start—32 agricultural groups, from Columbia-Snake irrigators to cattle feeders to conservation districts---went to Olympia this winter with priorities they shared…

We're enthusiastic about what we can achieve pulling together.

"*Without high yield agriculture and irrigation, millions would have starved or millions of acres of pristine land would have had to be 'broken' by the plow. Dedicated farm families are part of the essential process of feeding a burgeoning world population. Have a passion about what you do and you will make a difference. Norman Borlaug*

"If we allow misconceptions, not science and good judgment, to dictate the future of agriculture we, as Americans, will be guilty of displaying a diminished gene frequency for common sense."

With a "change" agenda in D.C, and some work to do in "Olympia," too…
With many newcomers to educate…..
It is time to cast aside any pessimism or frustration
It is time for we, the people of Northwest agriculture, to pull together as never before

Please join us

The people of Northwest agriculture—potato growers, those of us who serve the potato industry, and all of us with ties to the land—in being passionate advocates for farm families and our remarkable agricultural production systems! Thanks, Friends!

Potato Cyst Nematode Research in the Pacific Northwest

Roy Navarre

Potato Cyst Nematode

Potato cyst nematode (PCN) has recently become a concern for the potato industry in the Pacific Northwest. This article will summarize PCN developments in the Northwest and provide basic details about the pest that should be of interest to producers not familiar with it.

In April 2006, the pale cyst nematode, *Globodera pallida*, was found during a routine survey of tare soil at an ISDA grader facility in eastern Idaho and subsequently traced back to a field in Bingham County, ID. Initially, this led Japan to prohibit all potato imports from the U.S.A., and several other countries including Canada, Mexico and South Korea banned potatoes from Idaho. Since these initial findings, PCN has been found in a total of 8 fields in eastern Idaho, all in close proximity to one another. Scientists are working to eradicate the PCN population in Idaho, with APHIS leading the eradication effort.

Previously in the United States, PCN had only been found in Upper State New York and Long Island. The species in New York was found in 1941 and is a different species of PCN called golden nematode, *Globodera rostochiensis*.

In addition to the discovery of PCN in eastern Idaho, two other *Globodera* discoveries have raised concerns in the Northwest. In 2008 cysts were found on a farm in central Oregon that has grown potatoes and other crops. This nematode was eventually identified as a previously unknown *Globodera* species. Very little is known about this nematode, and it is not even yet known whether potato is a host, as there are *Globodera* species that are not pests of potato.

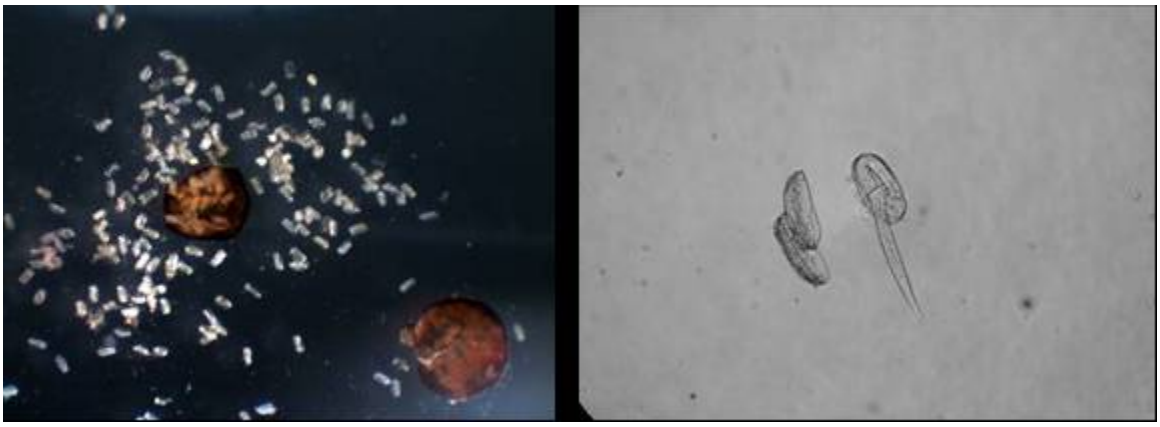
Of great concern to the Washington industry was the finding of PCN in two seed potato fields in Alberta, Canada in 2007. Each farm had a single positive sample, the first farm had one sample out of 284 test positive and the second had one out of 143. A retest was conducted using 610 soil samples from the two fields, but PCN was not detected. A more widespread Alberta survey tested 2721 samples and no PCN was detected. As of this writing, tens of thousands of samples have subsequently been tested but PCN has not been detected again. This PCN was identified as the golden nematode, so it differs from the species found in Idaho.

Estimates have been made that if PCN became more widespread in the U.S. that crop loses of $5 billion could result. The spread of PCN to new sites in the U.S. could result in trade embargoes, compromising domestic and international trade. Quarantines would affect the potato industry, but also agricultural commodities shipped from the regulated areas and carrying soil such as all nursery, turf, root, and tuber crops.

The Nematode: The PCN cysts found in Idaho are often called the white or pale cyst nematode. The cysts are typically white, almost translucent but can darken, especially if dry, and are filled with eggs (**Figure 1A**). PCN cysts typically contain 300-500 eggs, but more or less may be present. Some of the cysts from eastern Idaho contained over 700 eggs. Folded inside each egg contains a juvenile (**Figure 1B**), that

upon hatching can infest potato roots. PCN has a very narrow host range including potatoes, tomatoes, eggplant and some other solanaceous plants.

A major reason that PCN is such a problem is that the cysts can remain viable in the soil for greater than 30 years even in the absence of a host. The cyst stage of the lifecycle is somewhat resistant to many treatments, including chemical fumigation. For example, in a New York field infested with PCN in 1968, chemical treatments were followed by 7 years of non-host crops and 17 years of potato production, during which cysts were not detected. But in 1993 cysts were again detected in the field. Recommendations out of the New York PCN control program included treating all new infestations with nematicides, prohibiting host-crop production, and enforcing strict sanitation to prevent soil movement.



A. **B.**

Figure 1. A) PCN cysts that have been ruptured, allowing the eggs to spill out. Some eggs can be seen inside the cysts. B) Juvenile emerging from an egg. The juveniles are tightly coiled inside the eggs prior to hatch.

Similarly, PCN was found in British Columbia in 1965 and the field treated with nematicides. Host crop production resumed and an additional infestation was detected. In the 1970s host-crop production was prohibited, yet a 1995 soil bioassay showed the presence of viable PCN. In the absence of a host, the population will decline each year, with golden nematode thought to decline faster than the pale nematode. PCN declines more rapidly in warm soils in the absence of a host, up to 50% per year, but more slowly in colder soils such as in Scotland where decline has been estimated at 18% per year. However as the examples above illustrate, small amounts of viable cysts can persist for decades and these can quickly increase in numbers if a host crop is planted.

Detecting the cyst in a field is not easy, as a relatively small amount of soil is sampled due to labor and logistical issues. One scientist has estimated that to reach levels detectable by the typical soil assay used in the United Kingdom, that there would have to be 62 million cysts per 800 square meters. To reach this level would require 25-35 years assuming an initial population of 10 cysts and a 1 in 5 host crop rotation.

PCN Impact: If nematode concentrations are allowed to reach high enough levels in a field, they can cause severe yield loss and over 80% of the crop can be lost (**Figure 2**). One estimate is that for every 20 eggs per gram of soil, 2 tons/HA are lost. At around 100 eggs/gram of soil, yield reduction starts to exceed 50%. *G. pallida* numbers can reach 10,000 per gram of soil. Note that a single cyst will typically have more than 200 eggs. One study showed that yield losses are greater in sandy soils than in loamy soils. The nematode reduces the size of the root system and alters plant mineral uptake, which reduces growth and can lead to early senescence. Symptoms of PCN include patches of poor growth, often with yellowing, wilting, particularly at midday, delayed flowering or foliar dieback. Even with minor foliar symptoms, yields can decrease.

PCN can be effectively managed, such as with fumigation and crop rotations. So it is likely that the quarantine issues are an even bigger concern than any potential impact of PCN on yield. For example, many countries ban import of potatoes from regions known to contain PCN. PCN is a quarantine pest and is not found in many countries, which can lead to aggressive measures to keep PCN from being introduced. PCN is widespread in many parts of the world, including in Europe, with no EU country known to be PCN free. However other regions are PCN free, such as most of North America. In August of 2006, APHIS and ISDA established a regulated area near Shelley, ID of about 10,000 acres that was under a Federal Domestic Quarantine Order to restrict interstate movement of products including potatoes, nursery stock, compost, farm equipment, grass sod, soybeans, hay, ear corn and many other items at risk to spread PCN. PCN infests roots, but not tubers, but can be spread through soil adhering to tubers. PCN can also be spread through wind blown soil, contaminated farm equipment, animals, and water.

Figure 2. Potato yield from a PCN infested field (left) and non-infested field (right). Picture is from ARS Magazine.

Impact on Washington: As a result of PCN discovery, import of Alberta seed potatoes into the United States was temporarily banned. This caused difficulties for the Washington industry as about 30% of the state's seed potatoes come from Alberta and alternative sources had to be procured. There were concerns about the potential for soil clinging to Alberta seed potatoes introducing PCN into fields where they were planted. A

soil survey is currently underway in Washington. Seed potatoes from PCN infested fields are an alarming scenario for the spread of PCN. However, the very low numbers detected in Alberta is a plus and may reduce the risk of spread. Furthermore, in a strange twist *M. chitwoodi* could end up benefiting growers, because fumigation is practiced routinely by Washington growers to control the root-knot nematode. This routine fumigation along with the very low numbers found thus far in Alberta give hope that PCN has not been spread.

In May of 2008 the USDA and the Canadian Food Inspection Agency (CFIA) announced modified guidelines to allow for the continued trade of potatoes should there be future detections of potato cyst nematodes in either the United States or Canada. New export certification requirements include full grid soil sampling of all fields used to produce seed potatoes for trade between Canada and the United States. The previous soil sampling would no longer meet the requirements. All potato shipments between the two countries also must include a phytosanitary certificate with a declaration confirming that the seed potatoes originated from fields tested and found free of potato cyst nematodes.

PCN Eradication Research at Prosser: No PCN has been brought into Washington for research, but several Prosser scientists are assisting in the eradication effort and are working with colleagues at the University of Idaho, Cornell and APHIS. The Navarre group is using some of the same techniques they developed to analyze potato vitamins and phytonutrients in previous WSPC-funded work to search for compounds secreted by potato roots that stimulate PCN to hatch. Typically a cyst will not hatch until it senses environmental conditions favorable for reproduction, which include the presence of a suitable host. Roots of potato and a few other solanaceous plants, but not most other plants, produce exudates that stimulate the eggs in cysts to hatch. We have already conducted substantial metabolic profiling of diverse potato genotypes during our phytonutrient work. During this profiling we identified numerous compounds that seem unique to solanaceous crops and these are good candidates to be examined as potential hatching factors. If eggs can be tricked into hatching in the absence of a suitable host, then the nematode will die. Other ways to induce hatching, including the use of trap crops are being explored. Thus, a critical point in controlling PCN is to identify the chemicals that stimulate the eggs to hatch. We are also evaluating which plants have the potential to be used as trap crops. A successful hatch crop will secrete compounds from the roots that stimulate the eggs to hatch, but the plant will be immune to infection. Thus a trap crop will essentially be inducing a suicide hatch, as hatched juveniles will quickly die in the absence of a host. One trap crop candidate with potential is *Solanum sisymbriifolium* (**Figure 3**).

Figure 3. *Solanum sisymbriifolium* being grown in a greenhouse at Prosser, WA. Note the thorns on the stem and leaves.

The Riga group is studying the depth of kill of various nematicides and assessing the survival and parasitic potential of PCN from deep soil locations. A grower workshop will be held in the fall at Prosser. In addition the efficacy of numerous nematicides and biofumigants will be tested. Green manures will also be evaluated. For example, the bio-nematicides: DiTera, QL and NatureCur will be studied on PCN along with the impact of biofumigant green manures like mustard, arugula, the combination of mustard and arugula, and white mustard. Other crops tested will include fodder radish, ryegrass, lupin, *Phacelia*, French marigolds, persian clover, common vetch, white clover, spurry, forage rape, red clover, and sudangrass. It is well documented that brassicaceous plants contain precursors of isothiocyanates (ITCs; e.g., allyl, methyl forms), and glucosinolates which are released in the soil and have negative impact on nematodes. In addition, the green manures will be combined with the synthetic and bio-nematicides to study the combined effect on PCN.

The Boydston group, which includes Dr. Mojtahedi, is assessing whether weeds found in the Pacific Northwest can act as hosts for PCN. In temperate climates, PCN populations decline by about 30% per year in the absence of a host crop. However, if weed hosts are present in the rotation crop, one can expect multiplication of PCN on those weeds. PCN is reported to have a narrow host range that includes several weeds in the genus *Solanum* and several wild species in the genus *Lycopersicon*. Weeds are highly heterogeneous and weed biotypes from different geographic regions may not result in similar host status for Idaho PCN. Three common annual nightshade species; black nightshade, hairy nightshade, and cutleaf nightshade, exist in Idaho and other potato growing regions in the Pacific Northwest. These nightshade species and the most common weed species found in the PNW potato production region will be tested for host suitability for PCN collected from Idaho, so that local weed hosts of the nematode are identified and can be targeted for control during eradication efforts.

Hairy Nightshade Is an Alternative Host of *Spongospora subterranea*, the Potato Powdery Scab Pathogen

[1]Nadav Nitzan, [1]Rick Boydston, [2]Dallas Batchelor, [1]Jim Crosslin, [1]Launa Hamlin & [1]Chuck Brown
[1]USDA-ARS, Prosser, WA 99350; [2]Weather or Not, Pasco, WA 99301.

Introduction

Powdery scab of potato tubers is caused by *Spongospora subterranea* (Wallr.) Lagerh f. sp. *subterranea*. Potato (*Solanum tuberosum*) cultivars that are susceptible to the disease demonstrate galls on the roots and stolons and lesions on the tubers (Harrison et al. 1997). Infected potato tubers and infested soils are means of disseminating the powdery scab pathogen, which can remain viable and infectious for many years (Kole 1954), and may acquire and transmit the *Potato mop-top virus* (Jones and Harrison 1969; Qu and Christ 2006).

Spongospora subterranea is a plant pathogenic protozoan (Braselton 2001, Corliss 1994), classified in the phylum *Plasmodiophoromycota* (Alexopoulos et al. 1996). The pathogen is characterized by: 1) obligate parasitism, 2) the formation of plasmodia inside host roots and tubers, 3) bi-flagellate zoospores, 4) infectious activity at temperatures between 10 to 20°C under wet conditions, and 5) the formation of conglomerations of resting spores in sporeballs (Karling 1981; Braselton 1995). The sporeballs aggregate on the roots as galls and in the tuber lesions (Harrison et al. 1997; Merz 2008). The disease gets its name, powdery scab, from the appearance of the lesions. The life cycle of the pathogen initiates from the sporeballs that are the primary source of inoculum and may be tuber or soil-borne. In the presence of a host and favorable environmental conditions, primary zoospores emerge from the sporeballs to infect the root hairs. Following infection, a plasmodium develops within the root, and cleaves into segments that develop into zoosporangia, releasing secondary zoospores. The secondary zoospores continue to infect roots and developing tubers. Eventually, root galls and tuber lesions are produced. It has been suggested that *S. subterranea* acts as a polycyclic pathogen and secondary zoospores are released from the root galls or through the roots from zoosporangia increasing inoculum in the soil. Also, it is suggested that, during the life cycle of the pathogen, sporeballs development in root galls or tuber lesions occurs at the same time with secondary zoospore infection (Alexopoulos et al. 1996; Harrison et al. 1997; Merz 2008).

Hairy nightshade (*Solanum sarrachoides*) is an annual weed, which is wide spread in North America, and is especially abundant on irrigated lands in the western USA (Ogg and Rogers 1989). At low crop infestation densities (2-5 plants per meter row) it can produce over 45,000 seeds per plant, and at high crop infestation densities (20-50 plants per meter row) it can produce over 300,000 seeds per plant. Hairy nightshade competes with potato plants for water and nutrients (Alvarez and Hutchinson 2005, Boydston et al. 2008a, Eberlein et al. 1992) and having a physiology similar to that of potato, it is very difficult to control with herbicides in potato fields. A very important aspect of hairy nightshade in potato production is its tendency to host numerous potato nematodes, insect pests, viruses and disease causing agents (Alvarz and Sinivasan 2005, Alvarez and Hutchinson 2005, Boydston et al. 2008a, Boydston et al. 2008b). Being so, it

maintains their populations in the absence of potato, and serves as a source of inoculum in their presence.

Spongospora subterranea has been reported to have a wide host range (Jones and Harrison 1969, Harrison and Jones 1970, Jones and Harrison 1972, Ansersen et al 2002). Galls similar to those of *S. subterranea* on potato roots were observed on roots of hairy nightshade (Boydston 2006). These galls were observed annually on hairy nightshade plants grown in commercial potato fields in Washington State with history of *S. subterranea* root galls and powdery scab on tubers. When these galls were ground, sporeballs were observed (Rick Boydston-unpublished data). The present study tested the hypothesis that the root galls observed on hairy nightshade were the outcome of infection by *S. subterranea*. The objectives of the present study were to identify the causal agent of the root galls on hairy nightshade; and if it was *S. subterranea* to reinoculate potato and hairy nightshade with sporeballs from both potato and hairy nightshade to confirm cross infection.

Materials and Methods

Potato plants of the powdery scab susceptible cultivars Shepody, Umatilla Russet or Russet Burbank were propagated using stem cuttings originating from disease-free, nuclear tubers that were produced from tissue cultured plants. The stem cuttings consisting of one or two nodes were dipped in rooting hormone. The plantlets were incubated at room temperature (21-25ºC) under fluorescent light until roots developed (approximately 2 weeks), and were then moved to the greenhouse.

Hairy nightshade seed was extracted from locally collected berries and treated with 1500 ppm of gibberillic acid for 48 hrs prior to germinating at 29ºC in the dark. Seedlings in the cotyledon stage were transplanted into 4 L plastic pots containing methyl bromide fumigated (0.3 kg/m^3) loamy sand soil composed of 84% sand, 10% silt and 6% clay (Brown et. al 2006). The hairy nightshade and potato plantlets were grown to an average height of 15 cm before inoculating.

Potato inoculum was prepared from infected potato tuber lesions and root Hairy nightshade inoculum was prepared from root galls collected from hairy nightshade plants grown in a commercial potato field near Moses Lake, Washington during 2007 and 2008.

The hypothesis and objectives were tested in five independent experiments in half liter plastic pots filled with Sun-Shine potting mix and arranged in a completely randomized design with 3 to 8 replications per treatment. The treatments included potato and hairy nightshade plants inoculated or not inoculated with one of each inoculum source (potato or hairy nightshade). The trials were 2-3 months in duration, and were conducted in a growth chamber with a constant temperature of 15ºC and under continuous light. The soil was kept moist by irrigating to field capacity every 2 days.

Roots were visually assessed for presence or absence of root galls with the aid of a magnifying glass at the end of each trial, immediately after harvest. To compare between the number of sporeballs produced in root galls from potato and hairy nightshade, ten freshly harvested galls from plants grown in the growth chamber, and six dried root galls from plants collected in the field were removed at random. Since numbers of sporeballs can vary due to gall age, the root galls were removed from plants that were growing side by side in the same field, and were harvested at the same time; and from plants that were inoculated at the same time, grown in the growth chamber under the same conditions and harvested at the same time. The galls were weighed, and then macerated in 1 mL of water using a mortar and pestle, and the average number of

sporeballs was quantified with a hemacytometer per 1 g of root gall. All photographs were recorded with Canon EOS Digital Rebel XT camera. Photographs under the dissecting microscope were recorded at 60x-310x magnification.

Spongospora subterranea-specific PCR was performed to determine the presence or absence of the pathogen in: 1) root galls from field collected potato and hairy nightshade; 2) root galls from artificially inoculated potato and hairy nightshade; and 3) asymptomatic (without galls) roots of both hosts from artificially inoculated plants. Nucleic acid was extracted from root galls and root tissue using the method reported by Crosslin et al. (2006).

Statistical analysis of all data was carried out in SAS (Version 9.1, SAS Institute, Carry, NC). The relationship between the source of inoculum (potato or hairy nightshade), the type of host plant (potato or hairy nightshade) and the presence or absence of root galls was analyzed using Proc GENMOD. The association between visual assessment of root galls and PCR outcome was carried out as a correlation for dichotomous nominal-scale data using Proc FREQ. Differences in sporeballs production were analyzed as continuous data using Proc GLM, and means were separated with student's t-test LSD. All inferences were conducted at 5% significant level (Zar 1996).

Results

Root galls were recorded on potato and hairy nightshade. A statistically significant ($P<0.05$) interaction was recorded between the source of inoculum and the host in relation to the frequency of plants with root galls. More ($P<0.05$) potato plants had root galls when the inoculum originated from potato than from hairy nightshade (Table 1). The frequencies of hairy nightshade plants with root gall were similar ($P>0.05$) regardless of the inoculum source.

The visual and the PCR assessments significantly correlated ($P<0.0001$; Phi Coefficient = 0.69). The visual assessment of root galls, and the PCR assessment of the presence of *S. subterranea* corresponded in 34 of 40 samples (Table 2). Among the samples that the PCR and the visual assessments were incongruent, 5 of 40 were negative visual assessments, but positive PCR outcomes; and only 1 of 40 was a positive visual assessment, but a negative PCR outcome (Table 2).

The numbers of sporeballs produced in galls developing on potato were greater ($P<0.05$) than the numbers of sporeballs produced in galls developing on hairy nightshade (Table 3). The galls did not differ in weight (Table 3). Figures 1 and 3 represent root galls from potato and hairy nightshade plants, which were growing side by side in the same field, and were harvested at the same time (3-4 months into the growing season). Figures 2 and 4 represent galls on potato and hairy nightshade plants that were inoculated at the same time, grown in the growth chamber under the same conditions and harvested at the same time. The galls developing on potato in the field (Figure 1) or the growth chamber (Figure 2) had a milky color when freshly harvested, and had the usual *S. subterranea* gall structure (blackberry or raspberry-like structure). On the other hand, the galls developing on hairy nightshade in the field (Figure 3) were light tan in color and had a round, smooth and bulkier structure then the galls on potato. The *S. subterranea* galls developing on hairy nightshade in the growth chamber (Figure 4) were somewhat elongated, relatively smooth, and dark tan to brown (necrotic) in color when freshly harvested.

Discussion

The results of the present study supported the hypothesis that the galls observed on roots of hairy nightshade plants in commercial potato fields were the outcome of infection by *Spongospora subterranea* f.sp. *subterranea* (*S. subterranea*.). The results indicated that *S. subterranea* can infect and complete its life cycle on hairy nightshade and produce a new generation of sporeballs that are infectious on both potato and hairy nightshade.

The results of the artificial inoculations indicated that potato derived inoculum had a greater pathogenicity than hairy nightshade derived inoculum on potato, but not on hairy nightshade. However, the pathogenicity of potato derived inoculum was similar on both hosts; and also the pathogenicity of hairy nightshade inoculum was similar on both hosts. This indicated that *S. subterranea* could be transmitted to potatoes regardless of the source of inoculum. Therefore, the elimination of hairy nightshade from potato fields is highly desirable as a strategy for preventing *S. subterranea* inoculum buildup.

The limited production of sporeballs on hairy nightshade could explain the low frequencies of root galls that developed on potato plants artificially inoculated with hairy nightshade inoculum compared to potato inoculum. The limited production of sporeballs, regardless of the source of inoculum, may indicate the presence of unknown resistance factors in this host, or that the pathogen is in the process of adapting, overcoming this putative resistance. *S. subterranea* can infect a variety of plant species, other than potato, producing zoosporangia and root galls (Qu and Christ, 2006). However, knowledge of the production of root galls containing sporeballs was limited to yellow mustard (*Brassica campestris* L.), oat (*Avena sative* L.), and tomato (*Lycopersicon esculentum* Mill.) (Qu and Christ, 2006). Information is lacking regarding production of sporeballs on these three plant species under cropping systems or *in vitro*, and their ability to re-infect potato.

The *S. subterranea* specific PCR confirmed the presence of the pathogen in 34 of 40 root samples that were visually recorded with galls. Only 1 of 40 root samples was visually recorded to have galls, but was not confirmed as such by PCR. This outcome indicated that the root galls on hairy nightshade were distinct from healthy roots and could be correctly identified visually. Five of the 40 root samples testing positive for *S. subterranea* using PCR were visually asymptomatic, lacking galls. This phenomenon has been previously recorded by Qu and Christ (2006); and recently, Van de Graff et al. (2007) reported that potato plants of the cultivar Estima, which were inoculated with a range of sporeballs concentrations, were infected, but root galls did not develop.

In the present study 44% of the hairy nightshade plants that were artificially inoculated with potato or hairy nightshade derived *S. subterranea* inocula developed root galls. Additionally, 31% of the hairy nightshade plants that were artificially inoculated with hairy nightshade derived inoculum developed root galls. This is a very important agronomic observation as each of these plants had numerous galls, which contained as much as 93 sporeballs per gram (Table 3). Potato fields in the Columbia Basin of Washington State range from 32 to 81 hectares. Since hairy nightshade is a common weed, each field may contain many hairy nightshade plants producing large quantities of *S. subterranea* sporeballs. The findings of the present study indicated that hairy nightshade has the potential to sustain viable *S. subterranea* inoculum in the absence of potato, providing an inoculum source, which can be infectious and damaging to potato.

Literature Cited

Alexopoulos, C.J., Mims, C.W. Blackwell, M. 1996. Phylum *Plasmodiophoromycota*. Endoparasitic slime molds. In Introductory Mycology, 4th ed., 751-758 John Wiley & Sons, Inc.

Andersen B.A.B, Nicolaisen, M., and Nielsen, S.L. 2002. Alternative hosts for potato mop-top virus, genus Pomovirus and its vector Spongospora subterranea f.sp. subterranea. *Potato Research* 45: 37-43

Alvarez, J.M. and Sinivasan, R. 2005. Evaluation of hairy nightshade as an inoculum source for aphid-mediated transmission of potato leafroll virus. *Journal of Economic Entomology* 98:1101-1108.

Alvarez, J.M. and Hutchinson, P.J.S. 2005. Hairy nightshade management in potatoes. Managing hairy nightshade to reduce potato viruses and insect vectors. *Outlooks on Pest Management. DOI: 10.1564/16dec03*.

Brown C.R., Mojtahedi, H., James, S., Novy, R.G., and Love, S. 2006. Development and evaluation of potato breeding lines with introgressed resistance to Columbia root-knot nematode (*Meloidogyne chitwoodi*). *American Journal of Potato Research* 83:1-8.

Braselton JP (1995): Current status of the Plasmodiophorids. *Critical Reviews in Microbiology* 21(4): 263-275.

Braselton JP (2001): Plasmodiphoromycota. In The Mycota VII Part A Systematics and Evolution. DJ McLaughan, EG McLaughlin & PA Lemke. Springer-Verlag, Berlin and Heidelberg: 81-91.

Boydston, R. 2006. Potato disease, nematode, and insect problems worsened by hairy nightshade. In Proceedings of the 45th Washington State Potato Conference, 1-4. Published by the Washington State Potato Commission, www.potatoes.com.

Boydston, R.A., Hutchinson, P.J.S., Bellinder, R.R. 2008a. Managing weeds. In Potato Health Management, 2nd Ed., 223-225. The American Phytopathological Society, St. Paul, MN.

Boydston, R.A., Mojtahedi, H., Crosslin, J.M., Brown, C.R., and Anderson, T. 2008b. Effect of hairy nightshade (*Solanum sarrachoides*) presence on potato nematode, disease, and insect pests. *Weed Science* 56:151-154.

Corliss JO (1994): An interim utilitarian ("user-friendly") hierarchical classification and characterization of the Protists. *Acta Protozoologica* **33**: 1-51.

Crosslin, J.M., Vandemark, G.J., and Munyaneza, J.E. 2006. Development of a real-time, quantitative PCR for detection of the Columbia Basin potato purple top phytoplasma in plants and beet leafhoppers. *Plant Disease* 90: 663-667.

Eberlein C. V., M. J. Guttieri, and W. C. Schaffers. 1992. Hairy nightshade (*Solanum sarrachoides*) control in potatoes (*Solanum tuberosum*) with bentazon plus additives. *Weed Technol*. 6:85-90.

Harrison, B.D. and Jones, R.A.C. 1970. Host range and some properties of potato mop-top virus. *Annals of applied Biology* 65: 393-402

Harrison, J.G., Searle, R.J., and Williams, N.A. 1997. Powdery scab of potato – a review. *Plant Pathology* 46:1-25.

Jones, R.A.C., and Harrison, B.D. 1969. The behaviour of potato mop top virus in soil, and evidence for its transmission by *Spongospora subterranea* (Wallr.) Lagerh. *Annals of Applied Biology* 63:1-17.

Jones, R.A.C and Harrison, B.D. 1972. Ecological studies on potato mop-top virus in Scotland. *Annals of applied Biology* 71: 47-57

Kole, A.P. 1954. A contribution to the knowledge of *Spongospora subterranea* (Wallr.) Legerh., the cause of powdery scab of potatoes. *Tijdschr Planten* 60:1-65.
Karling JS (1981): Woronina leptolegniae n. sp., a plasmodiophorid parasite of Leptolegnia. Nova Hedwigia 37: 17-24
Merz, U. 2008. Powdery scab of potato – Occurrence, life cycle and epidemiology. *American Journal of Potato Research* 85:241-246.
Ogg, A.G. and Rogers, B.S. 1989. Taxonomy, distribution, biology, and control of black nighshade (*Solanum nigrum*) and related species in the United States and Canada. *Reviews of Weed Science* 4:25-58.
Qu, X., and Christ, B.J. 2006. The host range of *Spongospora subterranea* f.sp. *subterranea* in the United States. *American Journal of Potato Research* 83:343-347.
Van de Graaf, P., Wale, S.J., Lees, A.K. 2007. Factors affecting the incidence and severity of *Spongospora subterranea* infection and galling in potato roots. *Plant Pathology* 56:1005-1013.
Zar, Jerrold H. 1996. Biostatistical Analysis, 3rd ed. Published by Prentice Hall. NJ. U.S.A.

Table 1. Contingency table summarizing the outcomes of five growth chamber trials, which tested the relationship between numbers of potato or hairy nightshade plants with root galls and the source of *Spongospora subterranea* inoculum.

Source of inoculum	Proportion (%) of plants with galls on roots on the roots		
	Potato	Hairy nightshade	*P* [a]
Potato	83 a A	52 a A	0.08
Hairy nightshade	10 a B	31 a A	0.1
P [b]	0.0005	0.2	

Capital letters represent statistical differences within each column. Lower-case letters represent statistical differences within each row. [a] Statistical significance probabilities within row; [b] Statistical significance probabilities within column.

Table 3. Mean gall weight and number of sporeballs per root gall on potato and hairy nightshade plants that were artificially inoculated with inoculum from potato tuber lesions and grown in the growth chamber, or collected from the field [a].

Host	Mean root galls weight (g)		Number of sporeballs (sporeballs/g) [b]	
	Artificially inoculated [c]	Field collected [c]	Artificially inoculated	Field collected
Potato	0.004 a	0.003 a	1522 a	1775 a
Hairy nightshade	0.003 a	0.003 a	93 b	76 b

Different lower case letters within a column represent statistically significant differences ($P<0.05$) between potato and hairy nightshade.

Table 2. Visual and PCR assessments for the presence or absence of *Spongospora subterranea* in the roots of potato and hairy nightshade (HNS)

Sample [a]	Host [b]	Source of inoculum [c]	Visual assessment [d]	PCR assessment [e]
1	HNS	HNS	+	+
2	HNS	HNS	+	+
3	HNS	HNS	+	+
4	HNS	HNS	+	+
5	HNS	HNS	-	-
6	HNS	Potato	+	+
7	HNS	Potato	+	+
8	HNS	Potato	+	+
9	HNS	Potato	+	+
10	HNS	Potato	+	+
11	HNS	Potato	+	+
12	HNS	Potato	-	+
13	HNS	Potato	+	+
14	HNS	Potato	+	+
15	HNS	Potato	+	+
16	HNS	Potato	+	+
17	HNS	Potato	-	+
18	HNS	Potato	+	+
19	Potato	HNS	+	-
20	Potato	HNS	-	-
21	Potato	HNS	-	-
22	Potato	HNS	-	-
23	Potato	HNS	-	-
24	Potato	HNS	-	+
25	Potato	HNS	-	-
26	Potato	HNS	-	-
27	Potato	HNS	-	+
28	Potato	HNS	-	-
29	Potato	HNS	-	-
30	Potato	Potato	+	+
31	Potato	Potato	+	+
32	Potato	Potato	+	+
33	Potato	Potato	+	+
34	Potato	Potato	+	+
35	Potato	Potato	-	+
36	Potato	Field	+	+
37	HNS	Field	+	+
38	Potato	Potato	+	+
39	HNS	Healthy root	-	-
40	Potato	Healthy root	-	-

[a] Samples 1 through 35 were artificially inoculated and grown at 15ºC in a growth chamber. Sample 36 was a powdery scab lesion from an infected tuber. Sample 37 were root gall-like structures from field grown hairy nightshade (HNS) plants. Sample 38 was a powdery scab root gall used as positive control. Samples 39 and 40 were roots of disease free HNS plants grown from true seed of HNS, and of potato plants grown in tissue cultures. [b] HNS = hairy nightshade; potato = plants of the cultivars Shepody, Umatilla Russet or Russet Burbank. [c] HNS inoculum from field collected root gall-like structures. Potato inoculum from powdery scab lesions from field grown potato tubers. [d] Visual assessment: (+) and (-) indicate the presence or absence of root galls, or root gall-like structures, respectively. [e] PCR assessment: (+) and (-) indicate that the expected band was present or absent, respectively, after agarose gel electrophoresis.

Figure 1. Galls on roots of a potato plant (cultivar not recorded) grown in a commercial field where populations of *S. subterranea* were high. Photograph courtesy of Dr. Dennis Johnson, Dept. of Plant Pathology,Washington State University, Pullman.

Figure 2. Galls on roots of a potato plant (cultivar Russet Burbank) that was artificially inoculated with *Spongospora subterranea* sporeballs from potato.

Figure 3. Galls on roots of hairy nightshade grown in a commercial field where populations of *Spongospora subterranea* were high.

Figure 4. Galls on roots of a hairy nightshade plant that was artificially inoculated with *Spongospora subterranea* sporeballs from potato.

Co-Inoculations of Potato Plants with *Spongospora subterranea* (Powdery Scab), *Pratylenchus penetrans* (Root-Lesion Nematode) and *Meloidogyne chitwoodi* (Columbia Root-Knot Nematode)

Nadav Nitzan, Neusa Guera, Ekaterini Riga and Chuck Brown
First and fourth authors: USDA-ARS, Prosser, WA 99350. Second and third authors: Washington State University, IAREC, Prosser, WA 99350

Introduction

Spongospora subterranea (Wallr.) Lagerh f. sp. *subterranea* is a major concern for potato production in the Columbia Basin of central Washington and north-central Oregon (Nitzan et al. 2008). The pathogen is an obligate parasitic protozoan that causes powdery scab on potato tubers (Alexopoulos 1996, Braselton 1995, Braselton 2001), and develops galls on the roots and stolons of the plants (Harrison 1997, Fallon 1995, Fallon 1996, Merz et al 2000). The disease on the tubers causes powdery scab lesions that impair appearance and reduce tuber quality (Harrison 1997, Fallon 1995, Fallon 1996, Merz et al 2000). Infection of the roots may cause young plants to wilt and die (Lawrence & Mckenzie, 1981), and was suggested to disturb nutrient and water uptake, affecting photosynthetic translocation to the forming tubers, reducing yields in weight (Fallon 1996).

The Columbia root-knot nematode *Meloidogyne chitwoodi* Golden et al. is a serious pest of potato in the USA, and it is prevalent in the Pacific Northwest (Brodie et al 1993; MacGuidwin 2008). *Meloidogyne chitwoodi* is a sedentary endoparasite in which the female remains permanently attached to the root and tuber tissues at the feeding site once feeding is initiated. Plants infected with the nematode may demonstrate poor shoot growth, foliar chlorosis, small tubers and internal tuber browning. Roots invaded by the pest demonstrate galls at the feeding sites, and tubers demonstrate sub-epidermal swellings (bumps) and discoloration of the flesh (Brodie et al 1993; MacGuidwin 2008). The damage caused to tubers is unacceptable by the fresh market and the French-fry processing industries, resulting in price reduction penalties or rejection of harvested tubers (Brown et al. 1991).

The root lesion nematode *Pratylenchus penetrans* is a cosmopolitan plant parasitic nematode. In potatoes, lesion nematodes interact with the fungus *Verticillium dahliae* (Kleb.) causing potato early dying syndrome (Brodie et al 1993; MacGuidwin 2008). This nematode is a migratory endoparasite that inhabits the roots, but can move freely between roots and soil. Symptoms associated with this lesion nematode are mild discoloration to necrosis on the entire root system, stunting, delayed canopy closure, reduction of foliar growth and reduction in tuber yield and quality (Brodie et al 1993; MacGuidwin 2008).

The potato cultivars that are the most extensively grown in the Pacific Northwest are Russet potatoes (Schreiber 2006), which are relatively resistant to tuber infection by *S. subterranea* (Nitzan et al 2008). However, their roots can become severely infected by *S. subterranean* during the growing season demonstrating abundant root galls (Nitzan et al 2008). Potatoes grown in the Columbia Basin of Washington State in fields with a history of *S. subterranea,* had reduced numbers of large (>280 g) tubers needed for processing, resulting in the reduction of the useable potato yield. In addition, processing cultivars such as Russet Burbank are no longer commercially produced in fields where high severities of *S. subterranea* root galls occur annually (Nitzan et al. 2008). The potato industry of Washington State is concerned with damage to roots caused by *S. subterranea* and its potential to reduce yield weight

in tonnage, and affect tuber size and quality. To broaden our knowledge regarding factors that trigger *S. subterranean* damage to potato, the present study tested the hypothesis that *S. subterranea* can synergistically interact with the root-lesion nematode *Pratylenchus penetrans,* and/or the root-knot nematode *Meloidogyne chitwoodi* and reduce potato health.

Materials and Methods

The hypothesis was tested separately for each nematode species in two repeated trials. Co-inoculations with both nematodes were not carried out. The susceptible industry standard cultivar Russet Burbank was used in all trials (Nitzan et al. 2008). The experiments were arranged in a completely randomized design with five replications per treatment, which were as follows: 1) *S. subterranea* + *P. penetrans*, or *M. chitwoodi*; 2) *S. subterranea* alone; 3) *P. penetrans*, or *M. chitwoodi* alone; and 4) non-inoculated control plants. The trials were conducted in a controlled environment growth chamber with the soil kept at a temperature of 15ºC, and the plants were exposed to continuous fluorescent light. The plants were irrigated every second day and the soil was kept moist to promote *S. subterranea* infection. A soil mixture composed of 84% sand, 10% silt, and 6% clay that was previously treated with methyl bromide (0.3 kg/m^3) was used (Brown et. al 2006). This soil mix had a similar composition as the majority of the soils found in commercial potato fields in the Columbia Basin. The pots used in the trials were 0.5 liter in volume and filled with 643g of moist soil mix. Each pot received 2 grams of Osmocot® (18-6-12 N-P-K; Scotts®) at planting, and no additional fertilizer was added during the trials.

Potato plants of the cultivar Russet Burbank were propagated from disease-free nuclear tubers that were produced from tissue cultured plants. When the plants reached a height of approximately 20 cm the stems were cut into segments and were dipped in a rooting hormone. The stem cuttings were transferred into new flats in cells filled with Sun Shine potting mix #1. These stem cuttings were incubated in room temperature (21-25ºC) under fluorescent light for two weeks to allow root development, and were then moved to the greenhouse for two more weeks to harden before used.

Inoculum of *S. subterranea* was prepared from field grown infected potato tubers that were washed in warm water with soap and surface dried at room temperature. The infected epidermis was peeled and the peels were surface sterilized in 10% bleach for 20 min. and washed well in tap water. The peels were dried at room temperature and macerated into a fine powder using a coffee grinder. The inoculum was stored at 15ºC until used.

Inoculum of *P. penetrans* was prepared by extraction of nematodes from roots of mint plants maintained at the greenhouse of Washington State University, IAREC, Prosser, WA. Infested mint roots were washed well with tap water and were cut into 5 cm long sections. Then they were placed in a plastic bag, partially covered in tap water, and incubated at room temperature (21-25º) for 7 days. Following incubation, additional water was added to the plastic bag, and the bag was shaken by hand. The content was filtered through a 35 mesh screen nested over a 400 mesh screen and the nematodes were collected into flasks. Inoculum of *M. chitwoodi* (race 1) was prepared from cultures maintained on tomato (*Lycopersicum escelantum L.*) at the greenhouse of Washington State University, IAREC, Prosser, WA (Riga et al 2008). The roots were washed well and surface sterilized with 10% bleach for 10 min. Then, the roots were shaken for 10 min. in 100 ml of water to extract the eggs. The egg solution was filtered through a 35 mesh screen nested over a 400 mesh screen, and the eggs were collected in flasks. All nematodes and eggs were quantified per 1 mL of water with the aid of a StereoZoom®7

microscope (Bausch & Lomb, zoom range 1.0x – 7.0x, Boyle Instruments, P.O. Box 574, Gig Harbor, WA 98335, 206-858-8155).

Table 1 summarizes the planting, inoculations and harvesting dates of the trials. The potato plants were inoculated with 0.01 g of *S. subterranea* inoculum that was thoroughly mixed in the soil at planting. Immediately afterwards the plants were watered to field capacity and moved to the growth chamber. The nematodes were added two weeks later to the assigned replications at a concentration of 2 larvae or eggs per 1 g of soil, for *P. penetrans* and *M. chitwoodi*, respectively. The two weeks delay was carried out in order to synchronize the infection of the roots with *S. subterranea* and the nematodes. Two weeks is the typical time it takes the zoospores of *S. subterranea* to germinate from the sporosori and infect the roots under optimal conditions (Merz et al 2004). Since *S. subterranea* is an obligate parasite and can not be recovered into a pure culture, and since the source of its inoculum was from field grown potato tubers, the plants were treated during the duration of the trials with azoxystrobin (Quadris, Syngenta Crop Protection) according to the label to control certain seed-borne pathogens that could have been present on the surface of the potato tubers during the preparation of the inoculum.

Disease measurements were recorded immediately after harvest. The entire volume of the soil from each replication/pot was separated from the plants and collected in plastic bags and stored at 15ºC. The roots were washed in tap water to remove soil deposits, and were immediately blotted with a linen towel to remove excess water and weighed for fresh root weight. The severity of *S. subterranea* root galls was quantified using a semi-quantitative scale of 0 to 8, where 0 = no galls, 2 = 1 gall, 4 = 3 galls, 6 = 10 galls, 8 ≥ 10 galls (Merz et al. 2004). Root rot severity was scored using a 0 to 3 visual scale, where: 0 = no rot, 1 = low (yellow to 30% of the root with light brownish root discoloration), 2 = medium (light brown to 30% of the root with dark brown discoloration), 3 = high (more than 50% of the root with dark brown discoloration).

Immediately after scoring disease, the roots were wrapped in moist paper towel to prevent them from drying, and placed in plastic bags in 4ºC and were assessed for nematode colonization. *Pratylenchus penetrans* was extracted from roots by placing the roots in plastic bags, partially covered in tap water, and incubating at room temperature (21-25º) for 7 days. Following incubation, the bag was shaken and the content was filtered through a 35 mesh sieve onto a 400 mesh sieve on which the nematodes were collected. *P. penetrans* was extracted from soil using the sugar flotation technique (Jenkins 1964). *Meloidogyne chitwoodi* was evaluated by staining the roots with acid fuchsin using the technique described by Byrd et al. (1983). Root colonization was expressed as numbers of *P. penetrans* larvae, or *M. chitwoodi* females and 2nd stage juveniles per 1 g of fresh root weight. *Pratylenchus penetrans* in the soil was expressed as total number of larvae per pot.

Data were analyzed in SAS (SAS Institute, Carry, NC) using the general linear models procedure (Proc GLM) at a 5% significance level. The trials represented a randomized complete design and the statistical model used was response = trial + treatment + trial*treatment. Trial and treatment were analyzed as fixed effects, and the responses of interest were (i) root galls severity, (ii) root rot severity, (iii) fresh and dry root weights, and (iv) nematode colonization of root and soil. In the lack of interaction between trial and treatment the data of the trials were analyzed jointly. The severity of *S. subterranea* root galls and the severity of root rot were recorded on a category bases and were analyzed non-parametrically as ordinal data using the Kruskal-Wallis analysis of variance by ranks (Zar, 1996). Fresh and dry root weights and nematode colonization

were analyzed as continuous data, and in the lack of a normal distribution transformations were carried out with Log (response + 1). If normality was not achieved by transformation, the data was analyzed non-parametrically using the Kruskal-Wallis analysis of variance by ranks.

Results and Discussion

The majority of the potato cultivars grown in the Columbia Basin of Washington State and North-Central Oregon have russet skin (Schreiber 2006). These cultivars usually are not susceptible to tuber infection by *Spongospora subterranea*; however, their roots can become severely infected demonstrating high numbers of root galls (Nitzan et al. 2008). Therefore, this study focused on root infection. The co-inoculation with *Pratylenchus penetrans* and with *Meloidogyne chitwoodi* did not significantly (P>0.05) increase the number of *S. subterranea* galls on the roots (Tables 2 & 3). In addition, fresh and dry root weights were not reduced by the co-inoculations and did not differ (P>0.05) from the non-inoculated control plants (Tables 2 & 3). However, root rot severity was increased in the presence of *S. subterranea* regardless of the presence or absence of either nematode species (Table 4 and Fig. 1). Recording root rot due to *S. subterranea* supported the previous report by Eraslan and Turhan (1989), indicating that this pathogen can affect potato health by increasing root rot, which is usually associated with reduction of yield.

The colonization of roots or soil by *P. penetrans*, and of roots by *M. chitwoodi* was not significantly (P>0.05) increased in the presence of *S. subterranea* (Tables 2 & 3). Nevertheless, there was approximately a two-fold reduction in the numbers of *P. penetrans* larvae in the roots and the soil in the presence of *S. subterranea* (Table 2), suggesting a possible antagonistic relationship. Furthermore, in the presence of *S. subterranea* there was a two-fold increase in the numbers of 2nd stage juveniles of *M. chitwoodi* in the roots (Table 3). Synergistic interactions between plant pathogens and nematode pests causing disease complexes have been reported before in potato. For example, *Ralstonia solanacearum* bacterial wilt tends to be more severe in the presence of the southern root knot nematode *Meloidogyne incognita* than in its absence (MacGuidwin 2008). Possibly, the most well-known complex is the synergistic interaction between *V. dahliae* and *P. penetrans*, which enhances potato early dying (Martin 1982). The results of the present study suggested a possible interaction between *S. subterranea* and *M. chitwoodi*, or *P. penetrans*. However, unlike the two interactions mentioned above, the results did not point towards a disease complex that affected potato health. Yet, the trend towards a two-fold increase in the number of *M. chitwoodi* juveniles that was recorded should not be overlooked, as it could have economic importance under commercial potato production.

References

Alexopoulos, C.J., Mims, C.W., Blackwell, M. 1996. Phylum *Plasmodiophoromycota*. Endoparasitic slime molds. Chapter 26. Pp 75. In: Introductory Mycology, 4th edition, John Wieley & Sons, Inc.

Braselton JP. 1995: Current status of the Plasmodiophorids. *Critical Reviews in Microbiology* 21: 263-275.

Braselton JP. 2001. Plasmodiphoromycota. In The Mycota VII Part A Systematics and Evolution. DJ McLaughan, EG McLaughlin & PA Lemke. Springer-Verlag, Berlin and Heidelberg: 81-91.

Brown, C.R., Mojtahedi, H., and Santo, G.S. 1991. Resistance to Columbia root-knot nematode in *Solanum* ssr and in hybrids of *S. hougasii* with tetraploid cultivated potato. *American Potato Journal* 68:445-452.

Brown C.R., Mojtahedi, H., James, S., Novy, R.G., and Love, S. 2006. Development and evaluation of potato breeding lines with introgressed resistance to Columbia root-knot nematode (*Meloidogyne chitwoodi*). *American Journal of Potato Research*. 83: 1-8.

Brodie, B.B., Evans, K. and Franco, J. 1993. Nematode parasites of potato. In: Plant parasitic nematodes in temperate agriculture. Evans, K., Trudgill, D.L. and Webster, J.M. Eds. CAB International, University Press, Cambridge, UK. ISBN:0851988083.

Byrd, D.W., Jr., Kirkpatrick, T. and Barker, K.R. 1983. An improved technique for clearing and staining plant tissue for detection of nematodes. *Journal of Nematology* 15:142-143.

Eraslan, F., and Turhan, G. 1989. Studies on powdery scab of potato with special regard to the reaction of certain potato cultivars and clones. *Zeitschrift fur pflanzen-krankheiten und pflanzenschutz* 96:353-360.

Fallon, R. E., Viljanen-Rollinson, L. H., Coles, G.D., Poff, J.D. 1995. Disease severity keys for powdery and downy mildews of pea, and powdery scab of potato. *New Zealand Journal of Crop and Horticultural Science* 23: 31-37.

Fallon, R.E., Wallace, A.R., Braithwaite, M., Genet, R.A., Nott, H.M., Fletcher, J.D., Braam, W.F. 1996. Assessment of seed tuber, in-furrow, and foliar chemical treatments for control of powdery scab (*Spongospora subterranea f.sp. subterranea*) of potato. *New Zealand journal of crop and horticulture science* 24: 341-353.

Harrison, J.G., Searle, R.J., and Williams, N.A. 1997. Powdery scab of potato – a review. *Plant Pathology* 46:1-25.

Jenkins, W.R. 1964. A rapid centrifugal-flotation technique for separating nematodes from soil. *Plant Disease reporter* 48:692.

Lawrence, C.H., and McKenzie, A. R. 1981. Powdery scab. In: Hooker, W.J. ed. Compendium of potato diseases. St. Paul, Minnesota: The American Phytopathological Society.

Merz, U. 2000. Powdery scab. Research in Switzerland. In: Merz, U., Lees, A.K., edt. Proceedings of the first European Powdery Scab workshop, SAC, Aberdeen, Scotland, 20-22 July, 67-71.

Merz, U., Martinez, V. and Schw¨arzel, R. 2004. The potential for the rapid screening of potato cultivars (*Solanum tuberosum*) for resistance to powdery scab (*Spongospora*

subterranea) using a laboratory bioassay. *European Journal of Plant Pathology* 110: 71–77, 2004.

MacGuidwin, A.E. 2008. Managing diseases caused by nematodes. In: Potato Health Management. Johnson D.A. ed. Second Ed. APS Press. St. Paul, MN. ISBN:978-0-89054-353-5.

Martin, M.J., Riedel, R.M. and Rowe, R.C. 1982. *Verticillium dahliae* and *Pratylenchus penetrans*: Interactions in the early dying complex of potato in Ohio. *Phytopathology* 72:640-644.

Nitzan, N., Cummings, T. F., Johnson, D. A., Miller, J. S., Batchelor, D. L., Olsen, C., Quick, R. A., and Brown, C. R. 2008. Resistance to root galling caused by the powdery scab pathogen *Spongospora subterranea* in potato. *Plant Disease* 92:1643-1649.

Riga, E., Lacey, L.A., Guerra, N. 2008. Muscodor Albus, a potential bio-control agent against plant-parasitic nematodes of economically important vegetable crops in Washington State, USA. *Biological Control* 45: 380-385.

Schreiber, A. 2006. Potato tuber-worm: a potential new pest of potato in Washington storages. *Potato Progress* 6 (13): 3. Published by the Washington State Potato Commission. www.potatoes.com.

Zar, Jerrold H. 1996. Biostatistical Analysis, 3rd ed. Published by Prentice Hall. NJ. U.S.A.

Table 1. Planting, inoculation and harvest dates of Russet Burbank potato plants that were inoculated with *Spongospora subterranea*, and the nematodes *Pratylenchus penetrans* and/or *Meloidogyne chitwoodi* in two repeated growth chamber trials in 2008.

Trial [a]	Planting date	Inoculation with *S. subterranea*	Inoculation with *P. penetrans*	Inoculation with *M. chitwoodi*	Harvesting date
Sss x Pp – 1	July 16	July 16	July 29	--	Sept. 23
Sss x Pp – 2	Aug. 6	Aug. 6	Aug. 20	--	Oct. 14
Sss x Mc – 1	Aug. 6	Aug. 6	--	Aug. 20	Oct. 16
Sss x Mc - 2	Aug. 7	Aug. 7	--	Aug. 21	Nov. 4

[a] Sss = *Spongospora subterranea*; Pp = *Pratylenchus penetrans*; Mc = *Meloidogyne chitwoodi*; 1 = trial 1; 2 = trial 2 (repeated trial)

Table 2. Root gall and root rot severity, fresh and dry root weights and number of *Pratylenchus penetrans* nematodes in roots and soil of Russet Burbank potato plants inoculated or not inoculated with *Spongospora subterranea* and/or *P. penetrans* in two repeated growth chamber trials in 2008.

Treatment [a]	Root galls (0-8)[b]	Root rot (0-3) [c]		Fresh root Weight (g)	Dry root weight (g)	*P. penetrans* in root [d]	*P. penetrans* in soil [e]
		Trial 1	Trial 2				
Sss + / Pp +	6.5 a	0.75 a	1.6	1.1	0.03	591 a	28 a
Sss + / Pp -	5.5 a	0.56 b	2.0	1.4	0.04	0 b	0 b
Sss - / Pp +	0 b	0.5 b	1.0	1.3	0.04	965 a	65 a
Non-inoculated control plants	0 b	0 c	1.4	1.1	0.02	0 b	0 b

Different lower case letters with in a column represent significant statistical differences among the treatments at 5% significance level.
[a] Sss + = inoculated with *Spongospora subterranea*; Sss - = not inoculated with *S. subterranea*; Pp + = inoculated with *Pratylenchus penetrans*; Pp - = not inoculated with *P. penetrans*.
[b] Root galls severity was scored on 0-8 scale, where 0 = no galls, 2 = 1 gall, 4 = 3 galls, 6 = 10 galls, 8 ≥ 10 galls (Merz et al. 2004).
[c] Root rot severity was scored using a 0 to 3 visual scale, where 0 = no rot, 1 = low (yellow to 30% of the root with light brownish root discoloration), 2 = medium (light brown to 30% of the root with dark brown discoloration), 3 = high (more than 50% of the root with dark brown discoloration)
[d] Number of *P. penetrans* larvae per gram of fresh root weight.
[e] Number of *P. penetrans* larvae per pot (643g of moist soil mix).

Table 3. Root gall and root rot severity, fresh root weight and number of *Meloidogyne chitwoodi* nematodes on Russet Burbank potato plants inoculated or not inoculated with *Spongospora subterranea* and/or *M. chitwoodi* in two repeated growth chamber trials in 2008.

Treatment [a]	Galls (0-8) [b]	Root rot (0-3) [c]	Fresh root weight (g)	No. of *M. chitwoodi* females	No. of *M. chitwoodi* J2	Total nematodes
Sss + / Mc +	7.2 a	1.6 b	1.5	141 a	147 a	288 a
Sss + / Mc -	6.8 a	2.75 a	0.8	0 b	0 b	0 b
Sss - / Mc +	0.7 b	0.7 c	1.9	121 a	69 a	190 a
Non-inoculated control plants	0.9 b	1.1 c	1.5	0 b	0 b	0 b

Different lower case letters with in a column represent significant statistical differences among the treatments at 5% significance level.

[a] Sss + = inoculated with *Spongospora subterranea*; Sss - = not inoculated with *S. subterranea*; Mc + = inoculated with *Meloidogyne .chitwoodi*; Mc - = not inoculated with *M. chitwoodi*.

[b] Root galls severity was scored on 0-8 scale, where 0 = no galls, 2 = 1 gall, 4 = 3 galls, 6 = 10 galls, 8 ≥ 10 galls (Merz et al. 2004).

[c] Root rot severity was scored using a 0 to 3 visual scale, where 0 = no rot, 1 = low (yellow to 30% of the root with light brownish root discoloration), 2 = medium (light brown to 30% of the root with dark brown discoloration), 3 = high (more than 50% of the root with dark brown discoloration)

[d] Number of *M. chitwoodi* females per gram of fresh root weight.

[e] Number of *M. chitwoodi* J2 juveniles per gram of fresh root weight.

Table 4. Comparison of root rot severity on Russet Burbank potato plants inoculated with *Spongospora subterranea* or not inoculated with *S. subterranea* across all trials conducted in the growth chamber in 2008.

Treatment comparison for root rot severity (0 – 3 scale) [a]			
S. subterranea present alone without nematodes (Sss+/Pp- and Sss+/Mc-) [b]		Non-inoculated control plants	*P* [c]
2.0	vs.	0.8	0.0011
S. subterranea present with or without nematodes (Sss+/Pp+, Sss+/Pp-, Sss+/Mc+ and Sss+/Mc-)		*S. subterranea* not present (Sss-/Pp+, Sss-/Mc+ and non inoculated control plants)	
1.7	vs.	0.84	<0.0001

[a] Root rot severity was scored using a 0 to 3 visual scale, where 0 = no rot, 1 = low (yellow to 30% of the root with light brownish root discoloration), 2 = medium (light brown to 30% of the root with dark brown discoloration), 3 = high (more than 50% of the root with dark brown discoloration).

[b] Sss + = inoculated with *Spongospora subterranea*; Sss - = not inoculated with *S. subterranea*; Pp + = inoculated with *Pratylenchus penetrans*; Pp - = not inoculated with *P. penetrans*; Mc + = inoculated with *Meloidogyne .chitwoodi*; Mc - = not inoculated with *M. chitwoodi*.

[c] *P* value of ANOVA for treatment comparison.

Figure 1. Plants inoculated with *Spongospora subterranea* demonstrating root rot (1st and 2nd from the left) in comparison to non-inoculated control plants (1st and 2nd on from the right).

Fundamental and Novel Methods of Silver Scurf Control in Storage

Nora Olsen, Jeff Miller, Phil Hamm and Lynn Woodell

Although not a disease that causes the tuber to actually rot, silver scurf, caused by the fungus *Helminthosporium solani***,** causes grey to silvery blotches on the surface of the tuber. There is no internal damage with infection by the silver scurf fungus but the affected skin has a silvery sheen, appears thicker, and can be unappealing to the consumer on fresh marketed potatoes and can also cause problems on processed potatoes. This disease actually has two distinct phases. One phase occurs while the tubers are still in the field and results in infected areas that are generally on or near the stem end of the tuber called "primary lesions." Probably more important from a cosmetic standpoint are the "secondary lesions" that result from conidia from primary infections that spread through the ventilation system while the tubers are in the storage facility. Secondary lesions occur anywhere on the tuber and can be so numerous as to cover virtually the entire surface of the tuber. Secondary spread may be greater under warm and moist conditions (eg. condensation) in storage. In storage, these infected tubers lose water at a greater rate compared to healthy tubers due to the disruption made in the periderm by the pathogen. The infected skin can also produce thickened areas making it more difficult to peel for processed potatoes.

Since there are two components or phases to silver scurf infection, the field or primary infection component and the storage or secondary component, managing silver scurf requires an integrated approach combining both field and storage tactics. Additional information on this integrated method for control can be found at:

http://extension.oregonstate.edu/catalog/pdf/pnw/pnw596.pdf.

The following list includes a few suggestions to help reduce silver scurf:

1. Plant seed with a low level or preferably no incidence of silver scurf
2. Use effective seed treatments
3. Clean and disinfect storages
4. Harvest tubers as soon as skins have set; avoid delays in harvest after vine kill
5. Store at the lowest temperature possible for the end-use of your crop
6. Lower storage humidity can reduce spread but it will equate to greater shrink in storage
7. Apply an effective post-harvest product

Reliance on one method alone will not be effective and in some situations the use of all these practices may not provide adequate control, particularly in smooth skin cultivars. This article will focus on recent research related to post-harvest product applications to minimize silver scurf in storage.

Volume of post-harvest spray application

Although research has been performed looking at post-harvest products applied to the potatoes while in storage either via the humidification system or thermal applications, most of the research presented in this article was evaluated using a spray application going into storage. Our research based information recommends no more than 0.50 gallon of aqueous product/ ton of

potatoes (Figure 1). That converts to less than half a cup (3.2 ounces) of liquid per hundredweight (cwt). In order to maximize the usefulness of a post-harvest product, careful application of the rate and volume applied is necessary. Applying less than 0.5 gal/ton of potatoes may result in incomplete coverage and applying greater than 0.5 gal/ton of potatoes may add too much free moisture to the surface of the potato. Stewardship of application may take more time and effort, but the consistency of disease control will be greater.

Application of post-harvest products

The currently registered post-harvest products for control of silver scurf appear to have limited efficacy on controlling the disease in storage. Thiabendazole (Mertect 340-F) can be used for silver scurf suppression in storage but this postharvest application is no longer recommended due to fungicide resistance. Additional products are available although research has shown limited or no efficacy for the following products:

- General biocides such as ozone, hydrogen peroxide/peroxyacetic acid mixtures, and chlorine dioxide (spray application and in-storage application)
- Biological products such as *Bacillus subtillus* (Serenade) and *Pseudomonas syringae* (BioSave 10 LP)
- Clove oil (Biox C; thermally applied)

Research over the last 8 years has shown that azoxystrobin sprayed on potatoes prior to storage can be effective in reducing spread of silver scurf in storage (Table 1). Azoxystrobin is NOT CURRENTLY REGISTERED but registration is being pursued by Syngenta for the near future. Once registered this product will be a good tool to add to the silver scurf control toolbox. A resistance management plan, likely to include using a mixture of effective products including azoxystrobin will be established since this product is also utilized in controlling foliar diseases in the field.

<u>Phosphorous Acid</u>

For the past several years the potato industry has been fortunate to have access to a highly effective post-harvest material to control pink rot and late blight in storage. This material is called phosphorous acid or is also known as phosphite, phosphonate or salts of phosphorous acid. Several products are available to the potato industry that contain this active ingredient. Research results in the Pacific Northwest have been obtained using Crop-phite, Fosphite, Phostrol and Resist 57. Multiple studies over many years comparing several potato varieties have shown highly effective control of pink rot and late blight when phosphorous acid is applied at the 12.8 fl oz/ton as a post-harvest spray application prior to storage (Table 2). Tubers that have symptoms of late blight and pink rot coming out of the field can contaminate healthy tubers during the harvest operation. This post-harvest application works to help keep the healthy tubers from becoming infected.

For three years studies were conducted to evaluate the efficacy of phosphorous acid on the control of *Helminthosporium solani* (silver scurf) on naturally infected 'Russet Norkotah' tubers in storage. Tubers were treated after harvest, prior to storage, and treatments included phosphorous acid (12.8 fl. oz/ton), other potential post-harvest products, and an untreated control

that was treated with water only. All treatments were applied in a volume of 0.5gal/ton of tubers as a low pressure spray. Tubers were evaluated for disease after 3 and 6 months in storage at 95%RH and 48°F (years 1 and 2) or 42°F (year 3).

In the first year under low disease pressure, the incidence of silver scurf was significantly reduced with phosphorous acid compared to the untreated control after 6 months in storage (Table 3). Disease pressure was relatively high in the second year and phosphorous acid treated tubers had significantly lower silver scurf incidence after 3 months (5%) compared to the control (67%; data not shown). The same level of control was not achieved after 6 months (Table 3). In the third year of the study, there was no significant reduction in silver scurf by 6 months (Table 2) between the control and phosphorous acid treated tubers, although significant differences were apparent after 3 months in storage. Four additional separate research trials in the third year with two potato varieties showed similar results to the previous years' data. Significant reductions in total silver scurf incidence ranged from 17 to 42% with phosphorous acid treatments compared to the untreated control. In some years, phosphorous acid was compared to Thiabendazole (TBZ or Mertect) which is still registered for post-harvest use although there is limited use due to disease resistance issues. In comparison, phosphorous acid was consistently more effective than TBZ (Table 3). This research indicated greater consistency in phosphorous acid control of silver scurf when applied at the 12.8 fl. oz/ton rate.

Additional studies looked at the potential of phosphorous acid as a seed treatment. Seed treated with phosphorous acid showed delayed emergence and silver scurf was not controlled on the daughter tubers. The lack of disease control and the potential for crop damage indicate that at this time phosphorous acid should not be used as a seed piece treatment for silver scurf control.

These studies show that phosphorous acid use will suppress silver scurf in storage. Additional studies to evaluate application methodology and to better understand why phosphorous acid is effective against silver scurf are needed to fully maximize the potential use of the product. In addition, studies evaluating application of phosphorous acid products after potatoes are in storage are currently in development. Post storage applications may be important particularly if potatoes are to be stored for 6 months or longer given the reduced long-term control by phosphorous acid when applied following harvest but pre-storage. Phosphorous acid should not be thermally applied. Fortunately the potato industry may now have a multi-purpose post-harvest tool that is effective against late blight and pink rot and potentially silver scurf.

Clove oil

One of the newcomers to the potato sprout control sector of the industry is clove oil. The mode of action of clove oil is completely different from CIPC by physically damaging the sensitive sprouting tissue. Clove oil is distilled directly from the evergreen plant *Syzygium aromaticum* (L.). The plant is native to Indonesia but is now grown in several other countries such as Madagascar and Brazil. The active ingredient of clove oil is eugenol and other eugenol-based components in the distillate product. The products used in the potato industry are 100% naturally derived clove oil and are approved for organic use. Due to the chemistry and volatility of clove oil it can be applied with a thermal applicator and distributed throughout the storage similar to applications of CIPC. This mode of application makes it ideal to apply to potentially control silver scurf development in storage. Research has indicated that clove oil (Biox C) has some suppressive action against silver scurf when applied repeatedly in storage as a thermal fog (Table

4). The incidence of silver scurf was reduced by approximately 40% when nine applications were made throughout the storage season. The limited level of control may not warrant the use of clove oil solely for the purpose to control silver scurf in storage.

Conclusions

Managing silver scurf requires an integrated approach that uses all management tools available to a grower. Buying clean seed, treating with an effective seed treatment, cleaning and disinfecting storages and applying an effective post-harvest treatment are effective tools. Using these tools and others in an integrated manner will help growers minimize the effects of silver scurf of their stored crop.

Table 1. Effectiveness of post-harvest fungicide applications on silver scurf incidence after 3 and 6 months in storage. All products were applied in an aqueous volume of 0.5 gal/ton of potatoes. Values in the same column followed by the same letters are not significantly different from each other at p=0.05.

Treatment (rate)	*% Incidence*[1]
Untreated	26 abc
Mertect (0.42 fl. oz)	24 abc
Ozone (hooded tunnel)[2]	54 a
Oxidate (1:50 dilution)	34 b
Messenger (2 oz)	36 ab
Aluminum Chloride (0.2 M)	10 bc
Serenade WPO (0.1 lb)	9 bc
Potassium sorbate (0.2 M)	6 bc
Azoxystrobin (0.6 fl. oz)	1 c

[1] percentage of tubers with silver scurf symptoms.
[2] 500 ppm applied for 30 seconds in an enclosed tunnel.

Table 2. Effect of post harvest applications of phosphorous acid and hydrogen peroxide/peroxyacetic acid (HPPA) on percent potato tuber rot[1] after 77 days (approximately 2.5 months) in storage (48°F) in a 1-ton bin. Values in the same column followed by the same letters are not significantly different from each other at p=0.05.

Treatment	**Rate/ton tubers**	*Late blight (%)*	*Pink rot (%)*
Untreated control		90 a	61 a
HPPA	1:25 dilution	84 a	73 a
Phosphorous acid	1.6 fl oz (1:40 dilution)	26 b	32 b
Phosphorous acid	3.2 fl oz (1:20 dilution)	14 bc	10 b
Phosphorous acid	12.8 fl oz (1:5 dilution)	0 c	0 c

[1]Tubers with typical disease symptoms or showing symptoms of secondary soft rot were counted as rotted tubers.

Table 3. Efficacy of post-harvest fungicides on the incidence of silver scurf on potato cv. Russet Norkotah following 6 months in storage at Kimberly, Idaho. Values in the same column followed by the same letter are not significantly different from each other at p= 0.05.

Treatment (rate)	*Incidence (%)*		
	Year 1	Year 2	Year 3
Untreated Control	18 b	69 a	15 a
Phosphorous acid (12.8 fl oz/ ton)	0 c	37 b	5 a
TBZ (Mertect; 0.42 fl oz/ton)	38 a	47 b	NA

Table 4. Silver scurf disease severity and incidence after nine months of storage and nine Biox C applications. Values in the same column followed by the same letter are not significantly different from each other at p= 0.05.

Treatment (rate)	**Silver scurf**	
	*Severity rating***	*Incidence (%)*
Untreated Control	3.3 a	97 a
Clove oil 67 ppm	2.6 bc	77 b
Clove oil 134 ppm	2.2 cd	60 c

**Disease severity rating based on a scale of 1-4: 1=no infection, 2=slight infection, 3=moderate, 4=heavy infection

Dry tuber 0.25 gal/T 0.5 gal /T 1.0 gal/T 2.0 gal/T

Figure 1. Post-harvest spray application volumes. The desired volume of a spray application is 0.5 gal/ton of potatoes.

TO APPLY OR NOT? THE ECONOMICS BEHIND IN-SEASON NITROGEN AND POTATO PRODUCTION

M.J. Pavek, Z.J. Holden, and C.D Hiles

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

INTRODUCTION

In September 2008, the price of nitrogen (N) fertilizer was approximately three-times more expensive than two years prior. A combination of higher fuel costs and an increase in global demand for petroleum and fertilizer challenged grower profits. In 2007 Columbia Basin potato growers were spending nearly $50,000/pivot on fertilizer. This increased to approximately $88,000/pivot in 2008. Because potatoes require large quantities of N, P (Phosphorous), and K (Potassium), reducing fertilizer applications appears, at first glance, to be a reasonable approach to reducing production costs.

When reducing fertilizer applications, one will most certainly reduce input costs; however, it is also likely that potato yield and quality will be altered in some fashion. At what point does a fertilizer reduction limit profit potential due to negative effects on yield and quality? Previous research with the cultivar 'Alturas' provides insight into this question. During 2007-08, five rates of in-season N were applied to Alturas in an effort to define the rate or rates that would maximize grower revenue. By utilizing data from this research, we were able to determine the effects fertilizer and potato price changes have on grower revenue and which in-season N rates would optimize economic return following price changes.

MATERIALS AND METHODS

Potato yield and quality data from the study "Defining In-Season Nitrogen Needs for Alturas and Premier Russet" by C.D. Hiles et al. (within this proceedings book) were used in combination with constructed potato and fertilizer price changes to predict adjusted gross income and associated in-season N rates that maximize grower revenue. The in-season N study utilized rates that were below, at, or above typical rates applied to Russet Burbank in the Columbia Basin of Washington. The five rates were 0%, 25%, 50%, 100%, and 150% of what might be typical for Russet Burbank during the season (Table 1). Preplant N, P, K, and micronutrients were the same across all treatments; only the in-season N was altered. Economic results were calculated using a mock french fry processing contract for the Columbia Basin. The expense of UAN, Solution 32 between $0.20/lb N and $1.00/lb N was included in an economic analysis along with potato prices between $2.00/CWT and $10.00/CWT. More complete information on the field trial and the yield and quality data can be obtained by reading the previously mentioned Hiles et al. article within this proceedings book.

RESULTS

From the Hiles et al. study, it was determined that Alturas total yield peaked when approximately 150% of typical Russet Burbank in-season N was applied (Figure 1). This was equivalent to approximately 375 lbs N in-season and 500 lbs total season (Table 1). However, fertilizer-price-adjusted gross income peaked at rates closer to 100% of what might be typical in-season for Russet Burbank – even when considering fertilizer price changes between $0.20 and $1.00 (Figure 2). This rate was equivalent of 230 lbs N in-season and 385 lbs N total season (Table 1). The five individual curves within Figure 2 demonstrate what happens when the price of in-season N increases from $0.20/lb to

$1.00/lb between the 0% and 150% rates. At $1.00/lb, the profit-maxing N rate is around 96%. As N becomes cheaper ($0.20/lb), the profit maxing N rate moves to approximately 103% of the Russet Burbank typical. The peak income changed slightly with fertilizer price changes (Figure 2), but the peak income level at all fertilizer prices was within ±3% of the 100% level. Despite a fertilizer price increase of 500% from $0.20/lb to $1.00/lb, the fertilizer rate that optimizes income decreased by only 6%. N applications beyond 103% entered the zone of diminishing returns; the extra N needed to maximize yield was more expensive than the economic return coming from the yield increase with the >100% in-season N application. This confirms the well known concept that maximum biological yield and maximum economic yield are not always the same.

When potato prices change, the in-season N rate that provides the maximum economic yield also changes (Figure 3). In addition, as potatoes become more valuable ($10.00/CWT vs $2.00/CWT), the grower's bottom line is less affected by changes in input (N fertilizer) prices (Figure 3). When the price of potatoes is a constant $7/CWT, it is easy to visualize how the profit maxing N rate shifts as the fertilizer's price increases (Figure 4). When the price in-season N increases by 100% (from $0.40/lb to $0.80/lb), the optimum in-season N rate was reduced by 6% (Figure 4)

DISCUSSION

When input costs increase, the natural tendency is to reduce input applications as well as increase the efficiency surrounding the inputs. As the price of in-season N increases, the rate growers apply should be reduced slightly to optimize income – WITH THE EXCEPTION that the grower has already been applying the optimum rate. Herein lies the problem; how do you know the rate you were applying was the most economically feasible to start with? Even if the rate you have been applying provides profit, is the profit being maximized? Could you apply a bit more, or less, and reap a higher net return? It's possible.

To optimize revenue, growers should utilize all available crop management information coming from extension bulletins, extension personnel, consultants, professional agronomists, on-farm strip trials, updates at conferences and field days, and so on. Once growers find fertility levels that provide profit, we recommend they stick to them, regardless of fertilizer price increases. There are of course exceptions, like a $5.00/lb N price increase, or similar. For standard yearly jumps, even a 100% price increase, growers are better off bargaining with buyers for higher potato prices than playing the fertilizer version of Russian roulette.

As input costs increase, growers should do their best to optimize application and rate efficiency by using soil and petiole tests, avoiding nutrient losses via leaching and volatilization, accurately calibrating and maintaining application equipment, and reducing the use of unproven, "feel good" products commonly referred to as "Snake Oil".

TAKE HOME MESSAGES: 1) don't skimp on in-season N or other fertilizer at today's potato prices, even if the price of fertilizer doubles; 2) do your best to find the application rate that provides the best economic return; 3) seek information updates routinely; and 4) strive for efficiency in applications and in determining plants needs.

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

Treatment as a % of standard	Preplant N + soil resid.	Fertigated in-season N	In-season N From Phos applications	Total in-season N	Total Season N	In-season N Fert expense ($0.80/lb)
%	----------lbs/A----------					
0	125	0	30	30	155	0
25	125	58	30	88	213	46
50	125	115	30	145	270	92
100	125	230	30	260	385	184
150	125	345	30	375	500	276

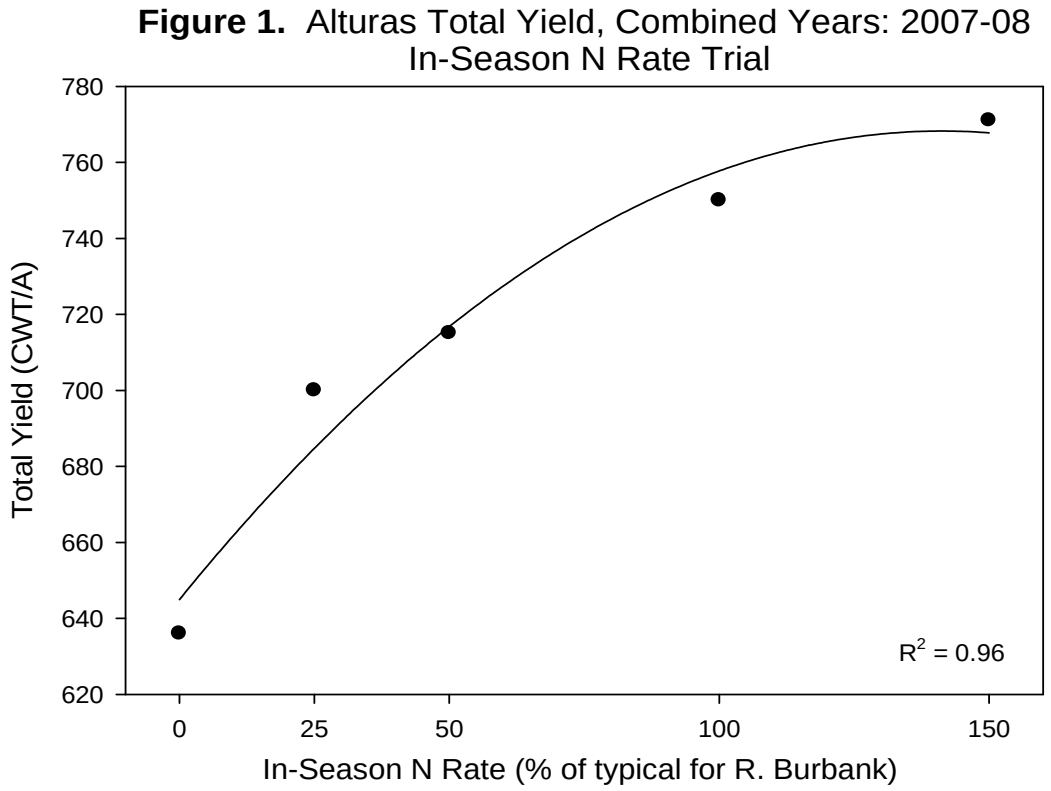


Figure 2. Alturas Adjusted Gross Income Across Different In-Season N Rates When UAN Solution 32 is priced at $0.20, $0.40, $0.60, $0.80, and $1.00/lb.

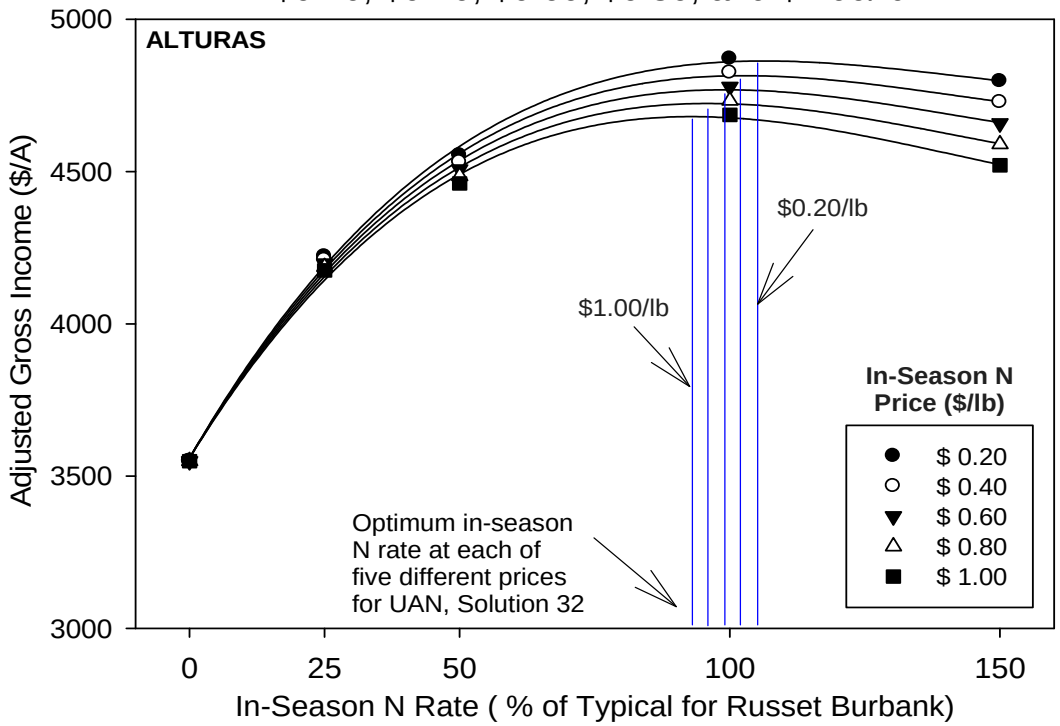


Figure 3. Profit Maxing In-Season N Rates as Fertilizer Price Increases from $0.10/lb to $1.00/lb and Potatoes Increase in value from $2/CWT to $10/CWT

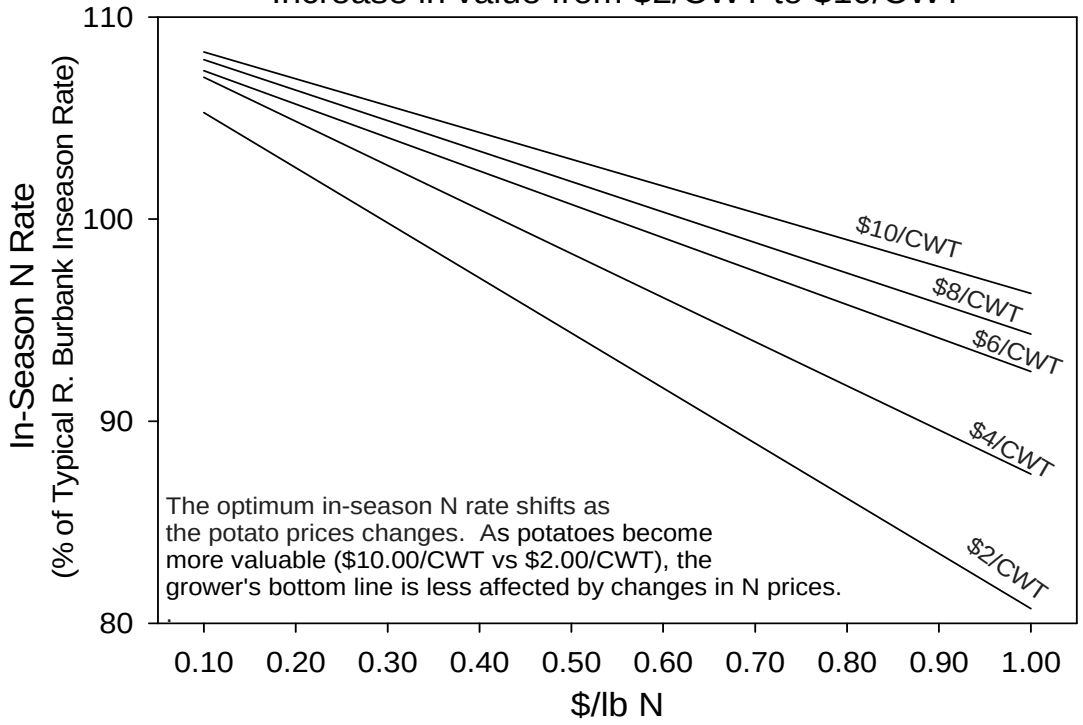
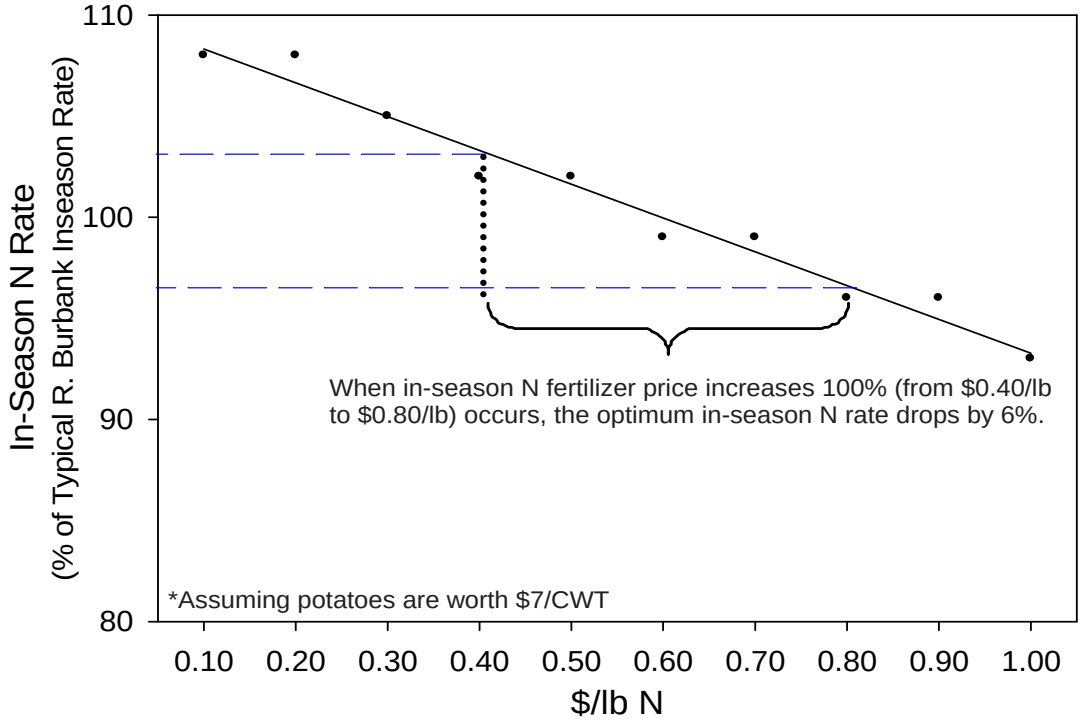


Figure 4. Alturas Profit Maxing In-Season N Rates as Nitrogen Fertilizer Prices Increase



Management of Soil and Seed Sources of *Rhizoctonia* with Fungicides

Mike Thornton, University of Idaho, Parma, ID, Dennis Atkinson, Seminis Vegetable Seeds, Payette, ID, Jeff Miller, Miller Research, Minidoka, ID, and Phil Hamm, Oregon State University, Hermiston, OR

Rhizoctonia solani is endemic to most potato production regions and can affect potato development over the entire course of the growing season. Symptoms associated with *Rhizoctonia* stem canker include reddish brown to black, sunken lesions on underground plant tissues. These lesions can girdle, or pinch-off stems, stolons and roots. The fungus may also form black sclerotia on the surface of mature tubers and is often referred to as "black scurf". Black scurf can affect the marketability of fresh pack potatoes and the quality of seed tubers if severe. It has been suggested that the most economically damaging aspect of this disease is not due to yield loss. Rather, money is lost due to a shift in the size profile, to more small tubers and fewer larger tubers, and loss of quality.

Conditions that favor extensive disease development include cool, moist soils, short potato rotations and high inoculum. Any condition that delays emergence or slows plant development will increase the chance of a severe disease outbreak. In contrast, anything that speeds up emergence or plant development, such as warm soil temperatures and shallow planting depths, will decrease the impact of *R. solani.*

Infested soil and/or infected seed tubers provide inoculum for disease development. The length of rotation between potato crops is thought to primarily determine *Rhizoctonia* levels in soil, while the amount of scelerotia on seed determines the level of seed inoculum. There is a fair amount of debate over the relative importance of inoculum sources. Seed inoculum is thought to primarily determine early sprout and stem infection levels, while soil inoculum is thought to primarily impact stolon infection and development of black scurf. Inoculum source might also impact fungicide efficacy as seed treatments would be expected to target seed inoculum more effectively compared to in-furrow treatment. Conversely, in-furrow placement would provide a broader zone of treatment for soil inoculum compared to seed treatment. This article summarizes research from 2003-2005 in ID and OR that evaluated the relative importance of inoculum source and fungicide placement on incidence of Rhizoctonia stem canker and black scurf.

Role of Inoculum Source

Seed of several potato cultivars was evaluated at low (seed with no visible sclerotia), medium (<10% black scurf), and high (>10% black scurf) inoculum levels. Prior to planting, the plots were inoculated with *R. solani* cultures at low, medium and high rates. Each level of seed inoculum was planted in each level of soil inoculum.

Seed inoculum consistently impacted disease on both stems and stolons, while soil inoculum only increased disease on stems when present at the highest levels (Figure 1). Furthermore, soil inoculum increased stem disease severity only when very clean seed was planted, while seed inoculum was always important, regardless of soil inoculum (Figure 2). This suggests that seed inoculum is more important than soil inoculum in terms of stem and stolon canker development.

Figure 1. Impact of *Rhizoctonia* inoculum source of stem and stolon disease severity.

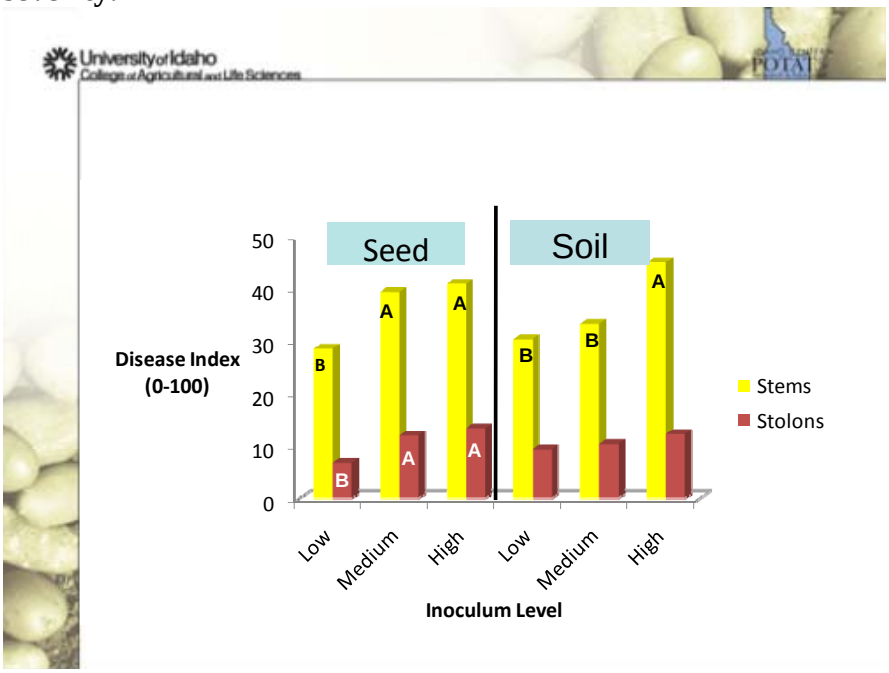
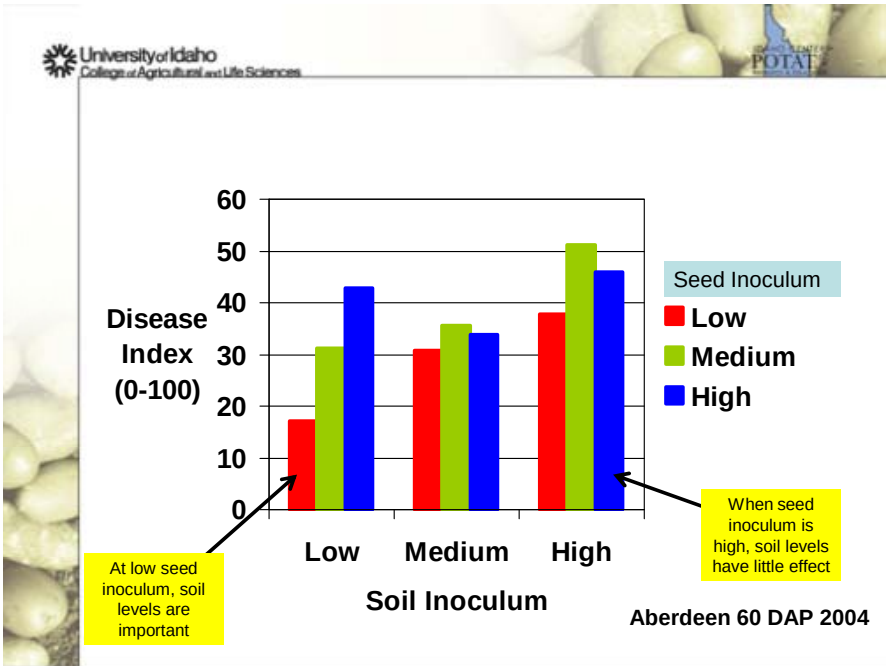
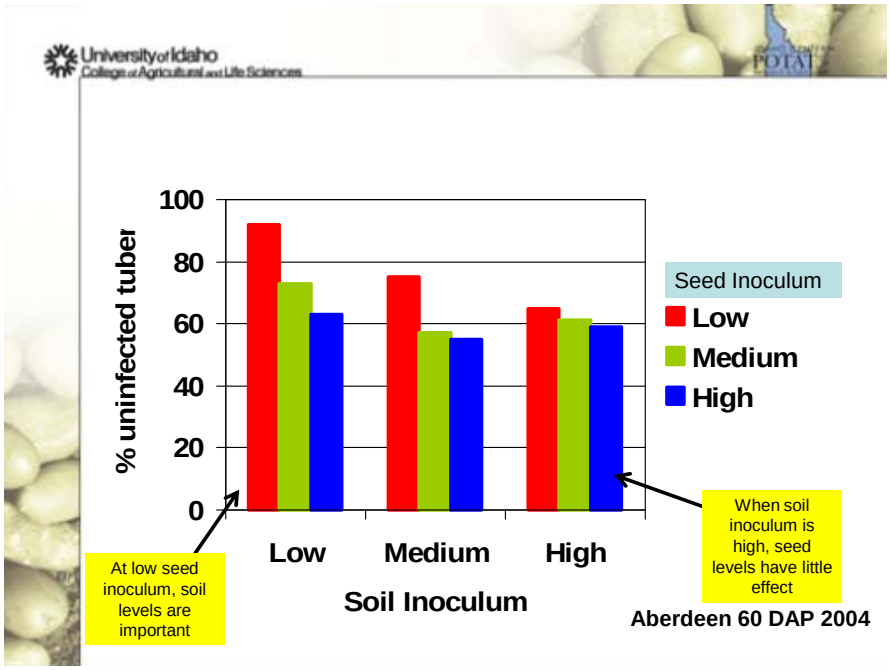


Figure 2. Relationship between seed and soil inoculum sources on development of *Rhizoctonia* stem canker.



Seed and soil inoculum were important in determining the extent of development of black scurf on daughter tubers (Figure 3). This indicates that both rotation length and seed quality impact black scurf incidence.

Figure 3. Relationship between seed and soil inoculum sources on incidence of black scurf on tubers.



Importance of Fungicide Placement

Field studies were conducted to compare the effectiveness of in-furrow fungicide treatment against seed piece treatment for the control of *Rhizoctonia* stem canker and black scurf. The effectiveness of each fungicide placement was evaluated for control of both seed-borne and soil-borne *R. solani* inoculum. Quadris was used as the in-furrow fungicide treatment and Maxim MZ was used as the seed piece treatment. A combination of seed piece treatment with an in-furrow treatment was also evaluated.

All fungicide treatments had significantly lower stem and stolon disease ratings than did the untreated control (Figure 4). Seed treatment with Maxim, and the combination of seed treatment with in-furrow treatment tended to reduce stem and stolon disease ratings more than in-furrow treatment alone. Black scurf ratings on daughter tubers were also significantly reduced by fungicide applications compared to the untreated control (Figure 5). Seed treatment and the combination treatment had lower black scurf ratings than in-furrow treatment alone. While the combination of seed treatment with in-furrow fungicide always has the lowest disease ratings, it was not significantly lower than seed treatment alone.

Figure 4. Impact of fungicide placement on *Rhizoctonia* stem and stolon disease severity.

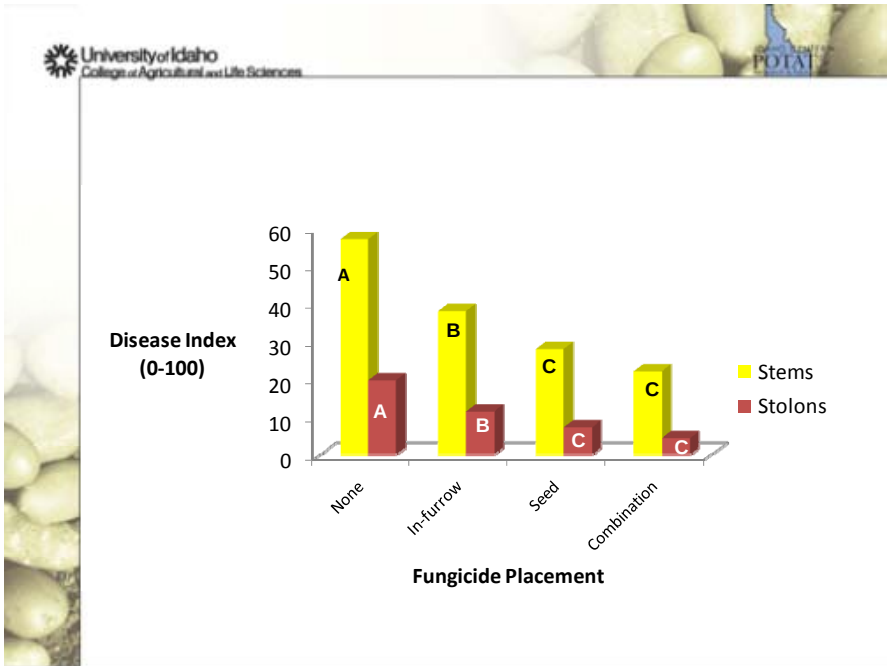
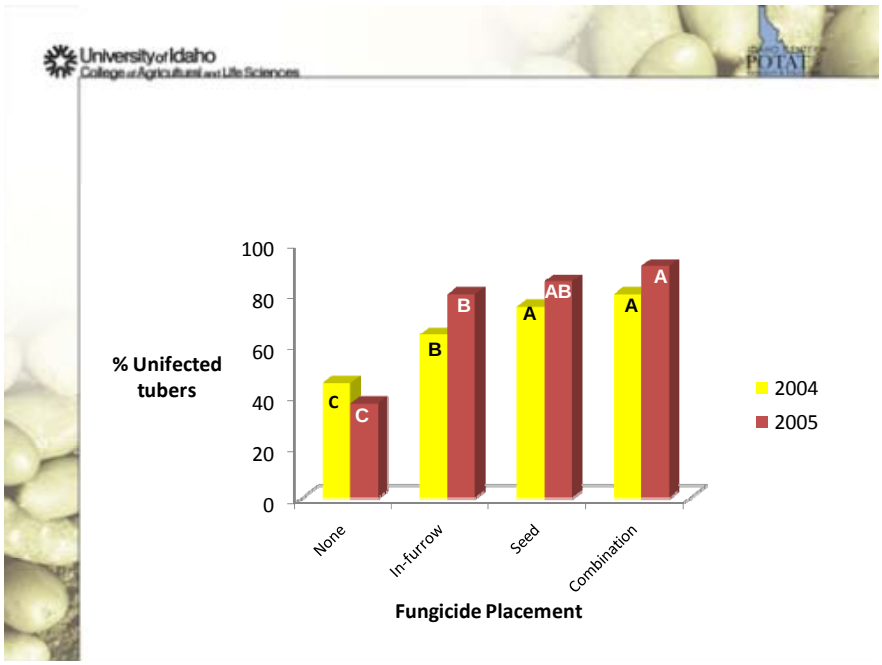
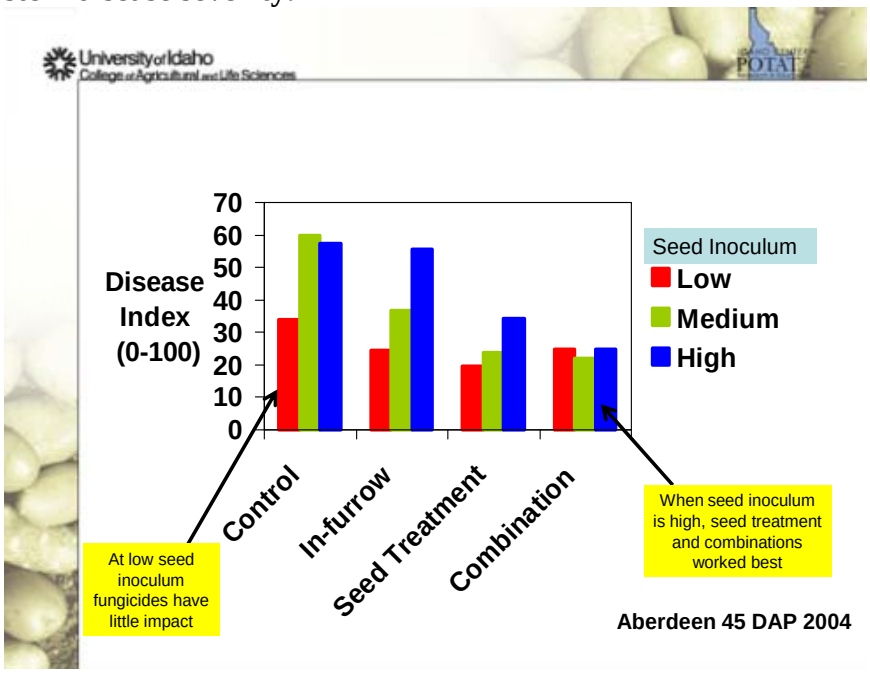


Figure 5. Impact of fungicide placement of black scurf severity.



In general, fungicide treatments caused the greatest reduction in disease levels on stems and stolons when seed inoculum was moderate to high (Figure 6). In furrow treatment was relatively more effective when inoculum was primarily from the soil (Figure 7) compared to when seed was the primary inoculum. In contrast, seed treatment and the combination tended to be effective regardless of inoculum source.

Figure 6. Impact of fungicide placement and seed inoculum level of Rhizoctonia stem disease severity.



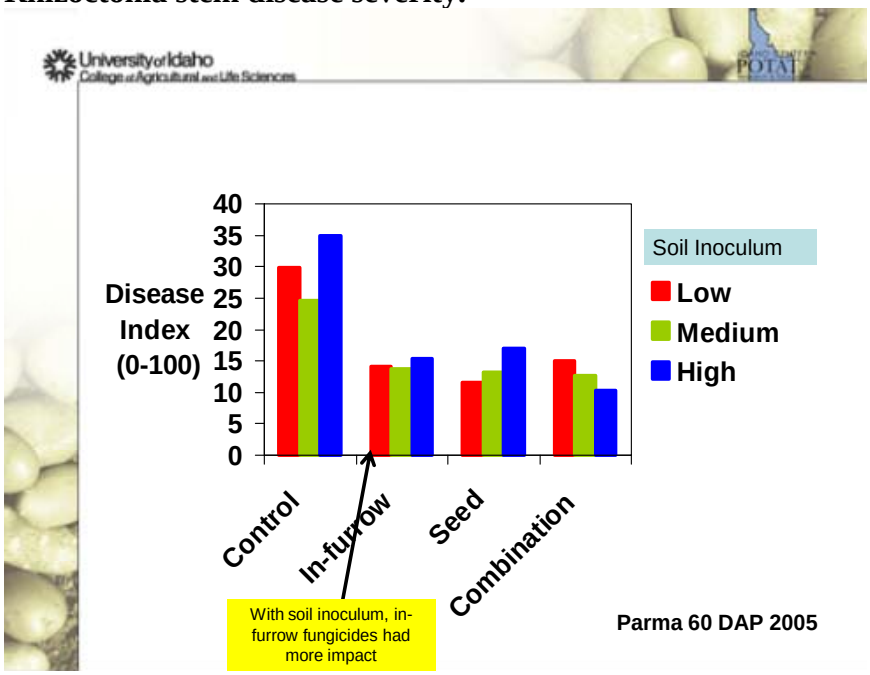
Summary

Seed inoculum was always important in determining disease severity of stems, stolons and tubers. Therefore, planting high quality seed with little or no visible black scurf is one of the best ways to reduce damage due to *Rhizoctonia*. Only the high level of soil inoculum consistently increased disease compared to fumigated soil, indicating that in areas with shorter rotations, soil inoculum may influence disease incidence. Both seed treatment and in-furrow fungicides provided disease control, regardless of inoculum source. However, seed treatment and a combination of seed treatment with in-furrow treatment provided more consistent disease control than in-furrow fungicide alone. In-furrow fungicides provided the best control of black scurf when soil inoculum was high while seed treatments provided the best control when seed inoculum was high.

ACKNOWLEDGEMENTS

Funding for this study was provided by the Idaho State Pesticide Management Commission, Idaho Potato Commission and Syngenta Crop Protection.

Figure 7. Impact of fungicide placement and soil inoculum level of Rhizoctonia stem disease severity.



Influence of soil-applied pesticides on potatoes

Mike Thornton, University of Idaho, Parma, ID, Jeff Miller, Miller Research, Minidoka, ID, Pamela Hutchinson, University of Idaho, Aberdeen, ID and Juan Manual Alvarez, University of Idaho, Aberdeen, ID

Many new pesticides have been registered for use in potatoes over the past few years. Despite the fact that interactions among systemic pesticides are well documented in crops such as soybean and corn (Hayes, et al. 1979, Waldrop and Banks, 1983), little effort has been made to evaluate these interactions in potatoes. Previous studies have shown that systemic insecticides such as Thimet® applied at planting can increase susceptibility of potatoes to damage by herbicides such as Sencor® (Cranshaw and Thornton, 1988). Temik® has been shown to reduce the populations of growth-promoting bacteria associated with potato roots (Sturz and Kimpinski, 1999), which in turn led to a reduction in plant growth and an increase in Rhizoctonia stem canker (Scholte, 1987, Sturz and Kimpinski, 1999). Insect control can also be compromised as Spartan® herbicide injury was shown to reduce the effectiveness of Admire® in controlling Colorado potato beetle (Zollinger and Fitterer, 2000).

The cause of these interactions among systemic pesticides is unknown. In an attempt to shed some light on this complicated issue studies were conducted at the University of Idaho Research and Extension Centers located in Parma and Aberdeen between 2004 and 2006 using Russet Burbank and Shepody potatoes.

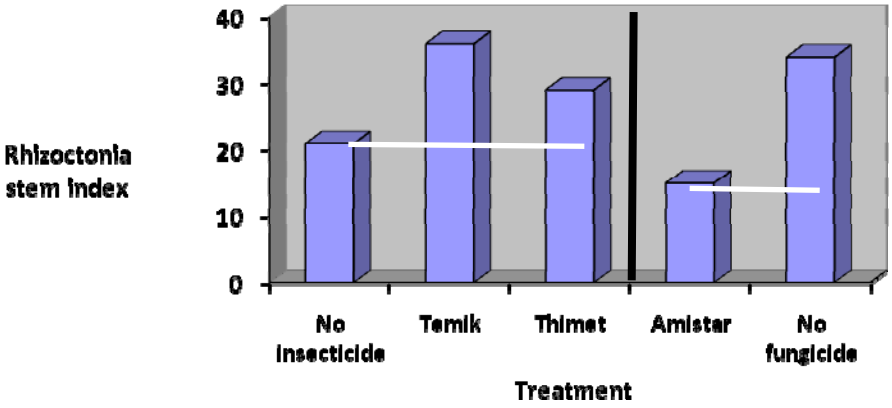
Impact of soil-applied insecticides and fungicides on disease

Commonly used insecticides/nematicides were applied at the following rates in-furrow at planting: Temik 15G® (20 lbs/acre), Vydate C-LV® (8.4 pts/acre), Admire 2F® (16 oz/acre), Platinum 2SC® (8 oz/acre), and Thimet 20G® (16.6 lbs/acre). The idea was to set up a "worst case scenario" by using maximum labeled rates and applying these products right onto or next to the fresh cut seed pieces. To evaluate the potential for an interaction between products, all insecticide treatments were applied with and without Amistar® fungicide in-furrow at planting at a rate of 3.63 oz/acre.

Both Temik and Vydate occasionally increased the level of seed decay compared to the non-treated control. However, final stands were not reduced and it appeared that the main impact was on how quickly the seed piece rotted after plants had emerged.

The most consistent impact of soil-applied insecticides was on Rhizoctonia stem canker. Averaged over the four site-years of this study, Temik increased Rhizoctonia by 69% compared to the no insecticide control, while Thimet increased Rhizoctonia by 37% (Figure 1). In contrast, Amistar fungicide applied in-furrow at planting reduced Rhizoctonia by 56% compared to the no fungicide control. These results emphasize the importance of using fungicides to control Rhizoctonia when carbamate or organophosphate insecticides are applied near the potato seed piece at planting. The neonicotinoid insecticides (Admire, Platinum) did not appear to influence Rhizoctonia severity.

Figure 1. Influence of soil-applied insecticides and fungicides on Rhizoctonia stem canker of Russet Burbank potatoes at two locations in Idaho during 2005 and 2006. Insecticide means are averaged over two fungicide treatments and fungicide means are averaged over 5 insecticide treatments.



Some of the non-target disease impacts of systemic pesticides were actually beneficial. For example, in-furrow application of Amistar reduced stem infection by the fungus *Verticillium dahlia*, one of the causes of early dying. The mechanism for the suppression of Verticillium by Amistar is not known, but has been previously reported in other regions.

Foliar early blight symptoms were also significantly reduced by in-furrow applications of Amistar. The reason for the reduction in early blight following in-furrow application of Amistar is not clear. Plants treated with Amistar had lower levels of stem infection by *Verticillium* (as reported above), and therefore may have had less senescent tissue that would be susceptible to infection by *Alternaria* spores. Conversely, Amistar may be more upwardly systemic than previously thought, and may be directly reducing infection.

None of the insecticides evaluated in this trial consistently impacted *Verticillium*, early blight, white mold or black dot. Amistar also had no impact on white mold or black dot incidence.

Impact of soil-applied insecticides and herbicides on plant injury and insect control

The same insecticide treatments outlined above were evaluated in combination with post-plant/pre-emergence applications of Spartan herbicide (4oz/acre). Dual Magnum® and Prowl® were applied to the entire trial area to keep all plots weed free.

Pre-emergence application of Spartan herbicide caused visual plant injury and stunting all locations. Spartan treated plants exhibited nine-fold higher plant injury ratings than plants treated with just Dual and Prowl (Figure 2). Plants treated with Vydate and Thimet also tended to exhibit more plant injury than the non-insecticide control. The insecticide/herbicide interaction was significant in one of the four site-years, indicating that in-furrow application of Thimet may cause plants to be more susceptible to Spartan injury. These results emphasize the role that carbamate and organophosphate insecticides can play in increasing plant susceptibility to herbicide injury. The neonicotinoid insecticides (Admire, Platinum) and Temik did not appear to influence herbicide injury (data not shown).

A detached leaf assay was used to evaluate the interaction between systemic insecticides and herbicides on survival of Colorado potato beetle (CPB) larvae and adults. Platinum and Admire tended to provide better control of CPB larvae compared to the other treatments. There was no evidence that herbicides influenced the level of insect control for early or late stage larvae. However, there was a significant insecticide by herbicide interaction for CPB adult mortality due to the fact that mortality was significantly increased for Admire, Platinum and Vydate when Spartan herbicide was applied compared to when no Spartan was applied (Figure 3).

Figure 2. Influence of soil-applied insecticides and herbicides on visual injury ratings of Russet Burbank potatoes at two locations in Idaho during 2005 and 2006. Insecticide means are averaged over two herbicide treatments and herbicide means are averaged over 5 insecticide treatments.

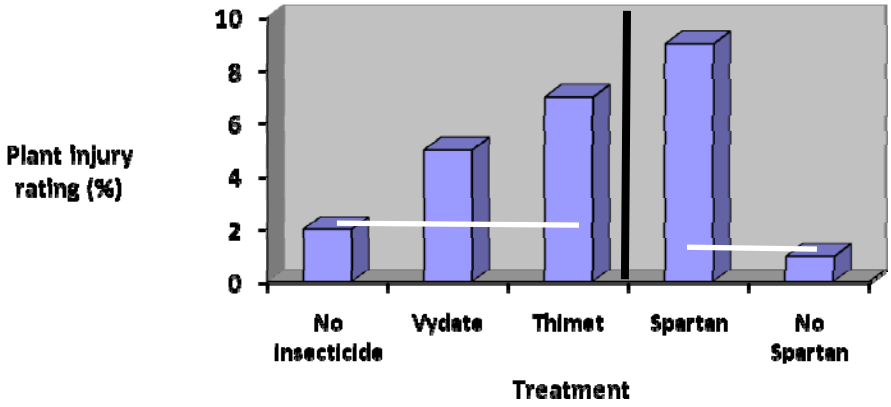
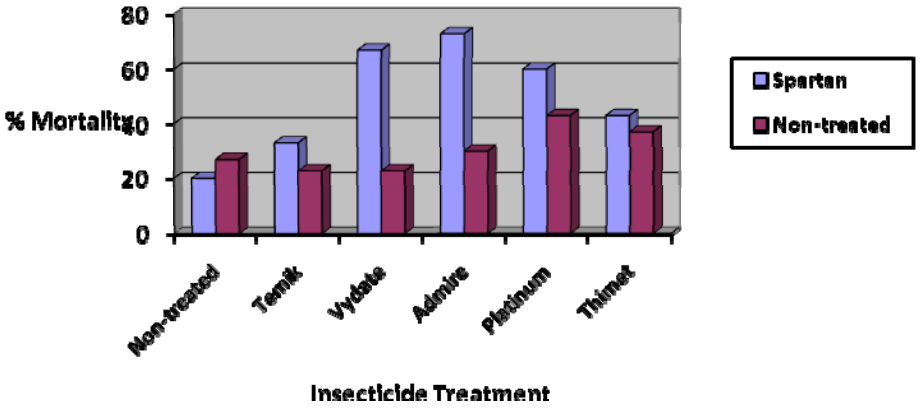


Figure 3. Interaction of insecticide with soil-applied herbicide on mortality of adult Colorado potato beetle feeding on detached leaves of Russet Burbank potatoes at Aberdeen, Idaho during 2006.



Impact of soil-applied pesticides on yield and grade

Even though systemic pesticides significantly influenced disease development and crop injury, there were relatively few differences in total tuber yield or grade (Table 1). It appeared that in most cases the benefits provided by nematode and/or insect control outweighed the impacts on disease development.

Vydate consistently decreased the percentage of US No.1 potatoes compared to the non-treated control. The rate of Vydate applied in this trial (8.4 pints/acre) is much higher than the rate most growers use for nematode control, so the grade impact may never be seen under field conditions.

Amistar significantly increased the percentage of US No.1 potatoes compared to the no-fungicide control in two of the four site-years. Rhizoctonia is known to impact tuber shape more than total yield, and this response was probably due to the effectiveness of Amistar in controlling this disease.

Despite the fact that Spartan significantly increased plant injury in all trials, it had only a slight impact on total yield (<4% compared to the non-treated control) and no impact on tuber grade. Potato plants appear to have the ability to tolerate plant injury due to herbicides, especially early in the season when plants are rapidly growing.

Table 1. Influence of in-furrow insecticides, fungicides and pre-emergence herbicides on total and marketable potato yield at two locations in Idaho during 2005 and 2006.

Treatment	Total Yield (cwt/acre)	US # 1 (%)[w]
Insecticide means [x]		
Non-treated	530	73 a
Temik	532	68 ab
Vydate	518	64 b
Admire	533	69 ab
Platinum	538	70 ab
Thimet	532	69 ab
Fungicide means [y]		
Amistar	565	73 a
Non-treated	552	67 b
Herbicide means[z]		
Spartan	495	69
Non-Spartan control	514	68

[w] Percentage by weight of tubers over 4 oz that meet US #1 grade standard.
[x] Insecticide means are averages of two fungicide treatments or two herbicide treatments over 8 trials.
[y] Fungicide means are averages of 5 insecticide treatments over 4 trials.
[z] Herbicide means are averages of 5 insecticide treatments over 4 trials.
Means followed by different letters are significantly different (P>0.05) using Fischer's protected LSD.

Impact of placement

Previous research with soybeans has shown that placement of systemic pesticides relative to the seed can influence crop injury (Waldrop and Banks, 1983). We evaluated placement of Temik and a Vydate/Moncut tank mix for two years to see if the impacts on seed decay and *Rhizoctonia* stem canker could be reduced by moving the pesticides away from direct contact with the seed. Placing these pesticides above the seed tended to reduce the incidence of both seed decay and *Rhizoctonia* compared to placement with the seed.

Summary

Carbamate and organophosphate insecticides (Temik, Thimet, and Vydate) tended to increase seed decay and Rhizoctonia. These non-target disease impacts could be reduced by using an in-furrow fungicide, or by moving the placement away from direct contact with the seed piece. Thimet and Vydate also tended to increase crop injury due to herbicides, but herbicide injury did not impact yield or insect control.

These results point out that caution should be exercised when tank mixing new pesticides, especially ones that have not previously been evaluated on your farm. It is a good idea to do a test first before applying anything to 100% of your crop.

ACKNOWLEDGEMENTS

Funding for this study was provided by the Idaho Potato Commission and the USDA Potato Research Program.

Literature Cited:

Cranshaw, W.S. and M.K. Thornton. 1988. Effects of systemic insecticides on potato growth and their interaction with metribuzin. Amer Potato J 65:535-541.

Hayes, R.M., K.V. Yeargan, W.W. Witt and H.G. Raney. 1979. Interaction of selected insecticide-herbicide combinations on Soybeans (*Glycine max*). Weed Sci 27:51-54.

Scholte, K. 1987. The effect of crop rotation and grandular nematicides on the incidence of *Rhizoctonia solani* in potato. Potato Res 30:187-199.

Sturz, A.V. and J. Kimpinski. 1999. Effects of fosthiazate and aldicarb on populations of plant-growth promoting bacteria, root-lesion nematodes and bacteria-feeding nematodes in the root zone of potatoes. Plant Pathology 48(1):26-32.

Waldrop, D.D. and P.A. Banks. 1983. Interactions of herbicides with insecticides in Soybeans (*Glycine max*). Weed Sci 31:730-734.

Zollinger, R.K. and S.A Fitterer. 2000. Weed control in potato. Western Society of Weed Science Progress Reports: 122.