2019 WSU Extension Onion Cultivar Demonstration & Field Day

Thursday, August 29th, 2019
9 a.m. to 1 p.m.
L & L Ag. Production, Connell, WA



WASHINGTON STATE UNIVERSITY EXTENSION

PACIFIC NORTHWEST VEGETABLE ASSOCIATION

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Sponsored by: WSU Extension & the Pacific Northwest Vegetable Association

Hosted by: L & L Ag. Production • Planted by: Bejo Seeds, Inc.

Organized by: Tim Waters, WSU Franklin-Benton Co., 509-545-3511, twaters@wsu.edu
Carrie Wohleb, WSU Grant-Adams Co., 509-707-3510, cwohleb@wsu.edu

BBQ luncheon following the field day is sponsored by:

American Takii, Inc. • Bejo Seeds, Inc.
Crookham Company • Enza Zaden • Gowan Seeds • Hazera Seeds
Keithly-Williams Seeds • Logan-Zenner Seeds • Nunhems USA – BASF
Sakata Seed America, Inc. • Seminis Vegetable Seeds
Columbia Basin Onion Research Committee

2019 WSU Onion Cultivar Trial - List of Entries

Seed Company	Cultivar	Plot Number			Seed Company	Cultivar	Plot Number		
American Takii	Centerstone	101	237	306	Enza Zaden	Elyse	125	244	339
American Takii	Frontier	102	203	321	Enza Zaden	Monastrell	126	222	334
American Takii	Grand Perfection	103	224	346	Nunhems	Airoso	127	213	308
American Takii	Highlander	104	216	319	Nunhems	Arcero	128	217	344
American Takii	Milestone	105	238	336	Nunhems	Granero	129	234	309
American Takii	Ridgeline	106	201	330	Nunhems	Joaquin	130	245	312
American Takii	Traverse	107	214	317	Nunhems	Marenge	131	219	314
American Takii	Trekker	108	232	323	Nunhems	Montero	132	236	322
Bejo Seeds	Bridewhite	109	246	345	Nunhems	Oloroso	133	207	315
Bejo Seeds	Crockett	110	247	343	Nunhems	Ranchero	134	212	302
Bejo Seeds	Gunnison	111	205	320	Nunhems	Vaquero	135	211	318
Bejo Seeds	Hamilton	112	220	327	Sakata Seed	Aruba	136	210	304
Bejo Seeds	Legend	113	239	307	Sakata Seed	Dulce Reina	137	208	311
Bejo Seeds	Red Mountain	114	209	328	Sakata Seed	Ovation	138	223	338
Bejo Seeds	Redwing	115	226	310	Sakata Seed	Spanish Medallion	139	240	324
Bejo Seeds	Tamara	116	229	342	Sakata Seed	Yosemite	140	221	305
Crookham Co.	Caldwell	117	230	316	Sakata Seed	Yukon	141	243	337
Crookham Co.	Caliber	118	225	335	Seminis Veg. Seeds	16000	142	241	329
Crookham Co.	Oracle	119	202	347	Seminis Veg. Seeds	Red Nugent	143	231	313
Crookham Co.	Purple Haze	120	218	333	Seminis Veg. Seeds	SV4058NV	144	242	325
Crookham Co.	Scorpion	121	204	340	Seminis Veg. Seeds	SV4643NT	145	233	331
Crookham Co.	Scout	122	227	341	Seminis Veg. Seeds	SV6672NW	146	235	332
Crookham Co.	Trident	123	206	326	Seminis Veg. Seeds	Tucannon	147	228	303
Crookham Co	White Cap	124	215	301					

2019 WSU Onion Cultivar Trial - Planting Arrangement

PLANTED: April 10, 2019

COOPERATOR: L & L Ag. Production

LOCATION: Connell, WA

IRRIGATION: Drip

ENTRIES: 47 entries, from 7 seed companies

PLOT SIZE: 34 inches x 30 feet, two double-rows per plot, 5-foot alleys between plots

REPLICATIONS: 3 in a randomized complete block design

FIELD CULTIVAR: Airoso

			347	346	345	344	343	342	341	340	339	338	337	336	335	334	333
315	316	317	318	319	320	321	322	323	324	325	326	327	328	329	330	331	332
314	313	312	311	310	309	308	307	306	305	304	303	302	301	247	246	245	244
226	227	228	229	230	231	232	233	234	235	236	237	238	239	240	241	242	243
225	224	223	222	221	220	219	218	217	216	215	214	213	212	211	210	209	208
137	138	139	140	141	142	143	144	145	146	147	201	202	203	204	205	206	207
136	135	134	133	132	131	130	129	128	127	126	125	124	123	122	121	120	119
101	102	103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118

2019 WSU Onion Cultivar Trial - Late Season Comparisons

ONION CULTIVAR	POWDERY MILDEW (0-4) Aug 16	BOLTING (#) Aug 16	TOPS DOWN (%) Aug 16	ONION CULTIVAR	POWDERY MILDEW (0-4) Aug 16	BOLTING (#) Aug 16	TOPS DOWN (%) Aug 16
Centerstone	2.0 bcd	0.0 e	10.0 g-j	Elyse	1.7 cd	0.3 de	80.0 abc
Frontier	1.7 cd	0.0 e	75.0 a-d	Monastrell	2.3 a-d	0.0 e	51.7 b-i
Grand Perfection	1.3 cd	0.3 de	5.0 j	Airoso	1.3 cd	0.0 e	21.7 f-j
Highlander	2.0 bcd	0.0 e	98.3 a	Arcero	3.0 abc	0.0 e	10.0 g-j
Milestone	2.3 a-d	0.0 e	35.0 c-j	Granero	2.3 a-d	2.0 b-e	15.0 f-j
Ridgeline	1.7 cd	0.0 e	86.7 ab	Joaquin	1.7 cd	4.7 abc	8.3 hij
Traverse	2.0 bcd	0.0 e	55.0 a-g	Marenge	2.3 a-d	0.0 e	25.0 e-j
Trekker	2.0 bcd	0.0 e	88.3 ab	Montero	1.7 cd	2.0 b-e	56.7 a-f
Bridewhite	1.3 cd	1.3 cde	6.7 ij	Oloroso	1.7 cd	0.0 e	6.7 ij
Crockett	2.0 bcd	0.0 e	8.3 hij	Ranchero	1.0 d	1.0 cde	6.7 ij
Gunnison	2.7 a-d	0.3 de	70.0 a-e	Vaquero	1.0 d	0.0 e	20.0 f-j
Hamilton		2.3 b-e	5.0 j	Aruba	1.0 d	3.3 a-e	18.3 f-j
Legend	1.3 cd	0.0 e	18.3 f-j	Dulce Reina	1.0 d	7.0 a	13.3 f-j
Red Mountain	2.0 bcd	0.0 e	6.7 ij	Ovation	2.7 a-d	0.0 e	13.3 f-j
Redwing	1.7 cd	0.0 e	5.0 j	Spanish Medallion	2.0 bcd	0.3 de	46.7 b-j
Tamara	1.3 cd	0.0 e	43.3 b-j	Yosemite	2.0 bcd	0.3 de	40.0 c-j
Caldwell	1.3 cd	1.0 cde	8.3 hij	Yukon	1.7 cd	1.0 cde	11.7 f-j
Caliber	4.0 a	0.3 de	5.0 j	16000	1.7 cd	5.3 ab	13.3 f-j
Oracle	1.3 cd	3.0 c-f	8.3 hij	Red Nugent	1.7 cd	0.0 e	43.3 b-j
Purple Haze	2.0 bcd	0.0 e	11.7 f-j	SV4058NV	1.0 d	3.0 b-e	5.0 j
Scorpion	1.3 cd	0.3 de	53.3 a-h	SV4643NT	1.3 cd	0.7 de	31.7 d-j
Scout	3.0 abc	1.0 cde	20.0 f-j	SV6672NW	1.7 cd	1.3 cde	13.3 f-j
Trident	2.0 bcd	2.3 b-e	20.0 f-j	Tucannon	3.7 ab	2.0 b-e	15.0 f-j
White Cap (W)	1.7 cd	4.0 a-d	11.7 f-j				
All results are the average from three replicate plots. Values in a row with the same letter are not significantly different according to Tukey's HSD test at p<0.01.				**MEAN**	**1.85**	**1.08**	**28.12**
				LSD P=0.01	**1.02**	**2.15**	**25.93**

2019 WSU Extension Onion Field Day

August 29, 2019

Update on Iris yellow spot virus management

Hanu R. Pappu, Professor, Department of Plant Pathology, WSU, Pullman, WA.

E-mail: hrp@wsu.edu

Thanks to the strong support from the onion stakeholders, a grant proposal submitted to USDA NIFA's Specialty Crop Research Institute was funded beginning last fall (2018). The project's goals are to develop environmentally friendly, integrated management of thrips, Iris yellow spot virus (IYSV), and white rot. Project period is for four years and the Season 1 of the four years is the current (2019) production season.

The team consisted of research and extension professionals from several universities, USDA ARS and the College of Idaho, and is led by Dr. Hanu Pappu and, from WSU, is joined by Dr. Tim Waters.

One of the ongoing efforts is to better understand the diversity of IYSV strains from different parts of the country and their evolution compared to those reported from other parts of the world. Results show that the virus exists as two distinct genotypes on a worldwide basis and the relative proportions of these two genotypes varies in different parts of the world. Information on the strain diversity of the virus would be useful in screening onions for virus resistance.

Research addressing Objectives 1 to 3 was initiated in the current production season and data collected is being analyzed. Screening for resistance to IYSV is one of the major focus areas of the SCRI-funded project. As part of this effort, several cultivars and breeding lines were evaluated in the field for their response to IYSV infection under natural conditions. Plant phenotype was recorded based on the symptoms and severity. Additionally, the relative virus levels are being determined using lab tests to better delineate the resistant/tolerant lines from those that are susceptible.

Another project funded by the WSDA Specialty Crop Block Grant Program is supporting research on understanding the onion-thrips-IYSV complex at biological, genetic, and molecular levels in order to aid in developing virus resistant onion cultivars.

WSU Onion Entomology Update 2019

Tim Waters, Jennifer Darner, Don Kinion WSU Extension
Doug Walsh and Adekunle Adesanya WSU Entomology

Funding Provided by the WSCPR and CBORC

Evaluating Insecticide Resistance in Onion Thrips:

Introduction: Onion thrips, *Thrips tabaci*, are the key insect pest of onions. Thrips feeding results in economic loss by reducing onion quality and size. Onion thrips also vector a tospovirus (IYSV) that is the causal agent of Iris Yellow Spot disease. The pest management strategy for most commercial onion farms focusses on the application of different chemistries of insecticides to reduce the infestation of onion thrips. A previous study by the Walsh lab at IAREC Prosser, documented the universal incidence of resistance to pyrethroids among onion thrips populations in Washington State. The source of resistance is through mutations in the voltage-gated sodium channel; the target site of pyrethroids such as lambda-cyhalothrin. Another class of insecticide commonly used for thrips control in onion fields is the carbamates oxamyl (Vydate ®) and methomyl (Lannate® LV). The goal of this study is to characterize the resistance status of onion thrips populations in Washington onion fields to carbamates, specifically methomyl and oxamyl. Detailed herein are our results for methomyl and oxamyl resistance status. Methomyl and oxamyl are often applied multiple times to individual onion fields over the course of the growing season and both methomyl and oxamyl have been in used on onions for over 25 years. Due to regulatory and environmental issues, the rate of development of insecticide resistance typically far outpaces the discovery and registration of new chemistries/products. Hence, following insecticide resistance management practices are essential to preserve the efficacy of the currently available insecticides.

Materials and Methods: Full dose response bioassays were performed on onion thrips larvae from five commercial onion fields (one organic and four conventional) in central Washington in 2018. The bioassays were performed in situ in the fields for a more precise resistance/susceptibility quantification using a protocol adapted from a previous study. Thrips were collected using a 2-cycle handheld blower/vac (Craftsman ®) coupled with flexible PVC pipes. Prior to field visits, 1.5 mL Eppendorf tubes were pretreated with varying doses (0, 10.8, 53.9, 107.8, 269.5, 539, 808.9, 1078 and 1617 ppm a.i.) of methomyl and (0, 12, 120, 300, 900, 1200 ppm a.i.) of oxamyl for 8 hours and allowed to dry in the fume hood for 4 hours. A tiny hole was made at the bottom of the tubes to serve as an entry point for the thrips. Sugar solution (10%) treated with a red dye (USDA red dye #4) was used as an alternative source of food for the thrips by filling the cap of the tube with the sugar solution and sealing with Parafilm. The red food colorant is added to the food to facilitate determining whether the Parafilm membrane breaks and the solution contaminates the vial. The flexible cap only serves as a container for the solution and to seal the vial. Each dose tested was replicated 3 times and the number of thrips collected in each tube ranged between twelve and twenty thrips. After collecting the thrips into the centrifuge tubes, the caps were gently closed and holes sealed with a Parafilm. The tubes were kept at 4°C for 48 hours before mortality of the thrips was assessed under a dissecting light microscope.

Results and Discussion: The thrips population from the organic onion farm was the most susceptible to oxamyl and methomyl with 100% mortality at the labeled rate of both insecticides (Tables 1 and 2). We observed significantly reduced efficacy of oxamyl and methomyl in thrips populations from conventional onion farms. The resistance ratio of the conventional onion thrips populations relative to the organic population ranges between 11-14.6 (RR50) and 3.1-8.1 fold (RR90) for oxamyl (Table 1) and between 2.7—6.3 fold (RR50) and 3.98-16.8(RR90) for methomyl (Table 2) respectively.

The field labeled Conventional 2 was the WSU Research Farm in Pasco. That farm represents relatively new onion ground as it has only had two nearby onion crops in the last 15 years. The level of control in that field by both oxamyl and methomyl was less than the organic field, but better than the other conventional fields evaluated. Conventional fields 3 and 4 were from the same farm, which has had an extended period of onion production, and extensive use of methomyl, but not much use of oxamyl. Percent mortality rates of 58% on Conventional fields 3 and 4 to methomyl indicate serious overuse of the product and resistance that needs to be addressed. Conventional field 1 also has a long history of onion production, and with only 71% control with methomyl, there is significant concern to address with relation to resistance to this insecticide. The low level of thrips control with oxamyl at Conventional field 1 is likely the result of widespread use of oxamyl on that farm. Other crops in rotation in that field would receive oxamyl applications where the crop rotation at Conventional fields 3 and 4 do not receive oxamyl applications explaining the increased sensitivity to oxamyl in those fields. These results clearly demonstrated that methomyl has been overused in conventional onion fields and that new strategies need to be developed to achieve thrips control without development of further resistance.

Table 1: Toxicity of oxamyl (Vydate) to *Thrips tabaci* populations from onion fields in Washington State

Population	N	[a]% mortality	LC_{50}(95% CI)	LC_{90} (95% CI)	Slope	χ^2(df)	RR50	RR90
Organic	330	100	55.1(19.3-102.7)	537.7(291.3-1471.8)	1.3±0.15	41.4(16)	1	1
Conventional 1	338	63.2	887.8(653.1-1178)	4117(2494-13505)	1.9±0.37	21.5(19)	16.1	7.7
Conventional 2	311	87.1	606(476.8-717.2)	1662(1271-2897)	2.9±0.58	4.2(16)	11	3.1
Conventional 3	350	86.3	624.7(454.2-838.8	4331.4(2593.4-11040)	1.5±0.25	16.2(19)	11.3	8.1
Conventional 4	397	78.6	803.7(578-1193)	1503(7180-52812)	1.1±0.13	11.4(19)	14.6	2.8

N: number of tested thrips

RR: resistance ratio i.e. $LC_{50/90}$ of conventional population/ $LC_{50/90}$ of organic population

[a]:% Mortality stands for the % mortality of thrips labelled rate of oxamyl

Table 2: Toxicity of methomyl (Lannate) to *Thrips tabaci* populations from onion fields in Washington State

Population	N	[a]% mortality	LC_{50}(95% CI)	LC_{90} (95% CI)	Slope	χ^2(df)	RR_{50}	RR_{90}
Organic	486	100	161.6(103-225)	1240(830-2285)	1.4±0.17	32.6(25)	1	1
Conventional 1	458	71.7	431.3(316-588)	4930(2907-10873)	1.2±0.12	31.4(25)	2.7	3.98
Conventional 2	428	80.2	362(242-541)	11001(4823-45352)	0.9±0.12	11.5(22)	2.2	8.9
Conventional 3	519	58.1	1025(859-1218)	3401(2485-5970)	2.5±0.39	8.6(25)	6.3	2.7
Conventional 4	466	58.2	575(402-852)	20829(9189-76022)	1.3±0.19	17.6(25)	3.6	16.8

N: number of tested thrips

RR: resistance ratio i.e. $LC_{50/90}$ of conventional population/ $LC_{50/90}$ of organic population

[a]:% Mortality stands for the % mortality of thrips labelled rate of methomyl

Thrips Insecticide Trials:

Introduction: Thrips cause crop damage by reducing bulb size and yield from feeding damage on the leaves and vectoring Iris Yellow Spot Virus (IYSV). Thrips are a common and persistent pest of dry bulb onions in the Pacific Northwest. Thrips feeding can result in a 15 to 35% decrease in bulb yield at harvest, depending on the cultivar. Onion thrips have also been identified as the primary vector for IYSV. In 2014 -2016, IYSV incidence in the Columbia Basin was greater than in previous seasons; affected bulb crops experienced a 25% reduction in yield as a result of IYSV infection. A 25% yield reduction resulted in $1,916 less profit per acre.

Materials and Methods: Thrips plots were planted April 1, 2018 in Pasco, WA. Individual plots were 2 beds by 25 feet in a randomized complete block design with four replications of each. Treatments were applied by ground application equipment at 30 gallons per acre, or overhead (pivot mimic) chemigation at 1/10 acre inch of water. Specific insecticides evaluated for conventional onions included Torac, Movento, Radiant, Lannate, Exirel, Beleaf, Warrior and Minecto Pro. A separate set of plots were established in the same methods as above to evaluate organic certified products for thrips control including Entrust, Celite, Ecotec, Venerate, and AzaDirect. Treatments were initiated when thrips were detected in the test plots and monitored weekly until the tops fell and the onions began to mature. Each insecticide was applied 6-8 times on weekly intervals. At maturity (late August), bulbs were harvested and grade and yield were determined by treatment. Foliar damage, thrips counts, and yields were evaluated for 9 conventional insecticides individually and 5 organic products.

Results and Discussion: The sum of thrips for the season did not differ for plots treated with Warrior, Torac, and Beleaf from the untreated check (Figure 3). Plots treated with Movento, Agrimek, Lannate, Radiant, Exirel and Minecto Pro all contained fewer thrips than the untreated check (Figure 3). The incidence of IYSV was reduced in plots treated with Agrimek, Lannate, Radiant, Exirel, Minecto Pro and Torac (Figure 4). Movento, Warrior, and Beleaf did not reduce IYSV incidence (Figure 4). Plant damage followed the same trend as IYSV incidence where plots treated with Agrimek, Radiant and Exirel had the least damage and plots treated with Movento, Lannate, Minecto Pro, and Torac had less damage than the untreated check, but more than the best treatments (Figure 4). Average thrips per plot by season highly correlates with the plant damage ratings, where plots with high thrips numbers also had high plant damage ratings. Plot grade and yield data is not highly significant by treatment this season even though plant damage was high (Figure 5). An early season wind storm severely impacted plant stands in the section of the field where this trial was conducted, and with the poor stands, there was a high degree of variability in the yield and grade data.

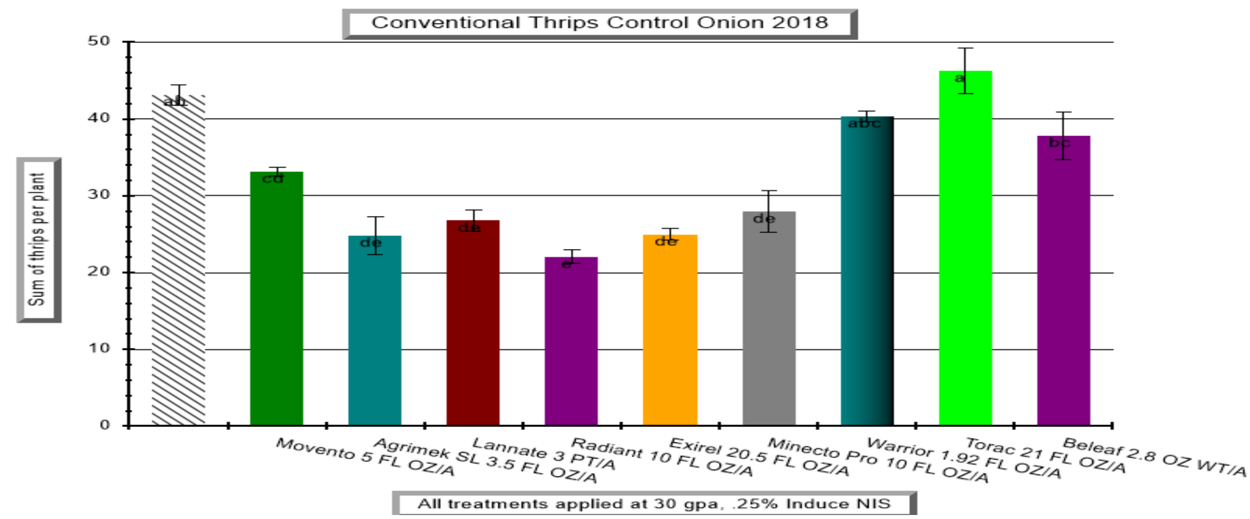


Figure 3. Sum of thrips per plant by treatment. Treatments with the same letters are not statistically different from one another (P=0.05 Student-Newman-Keuls test)

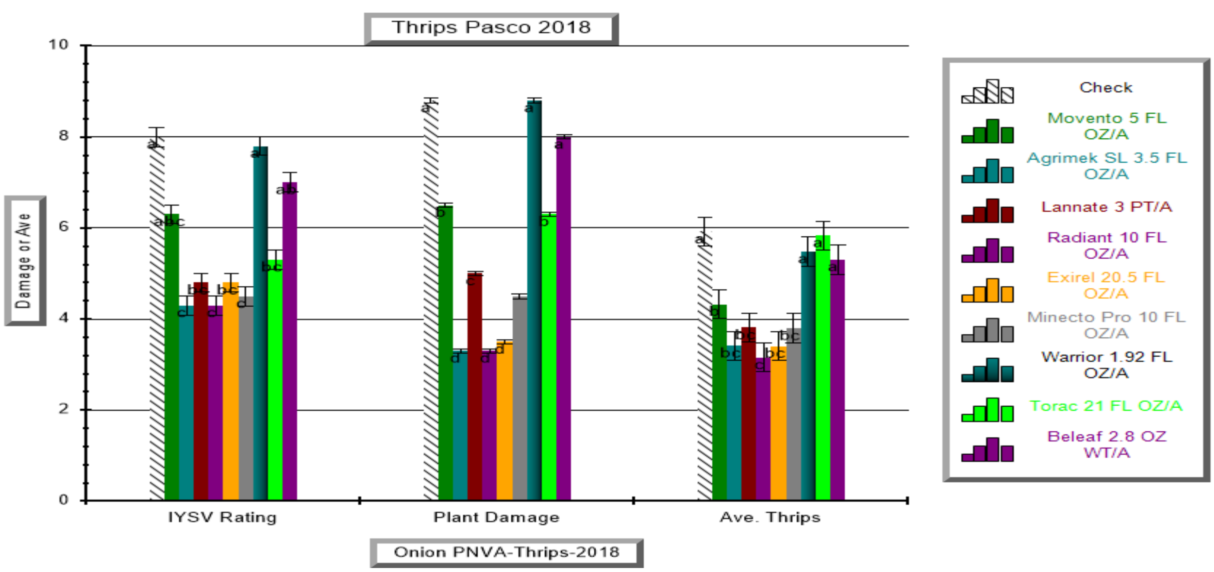


Figure 4. Iris Yellow Spot Virus, Plant Damage Ratings and Average thrips by treatment. Treatments with the same letters are not statistically different from one another (P=0.05 Student-Newman-Keuls test)

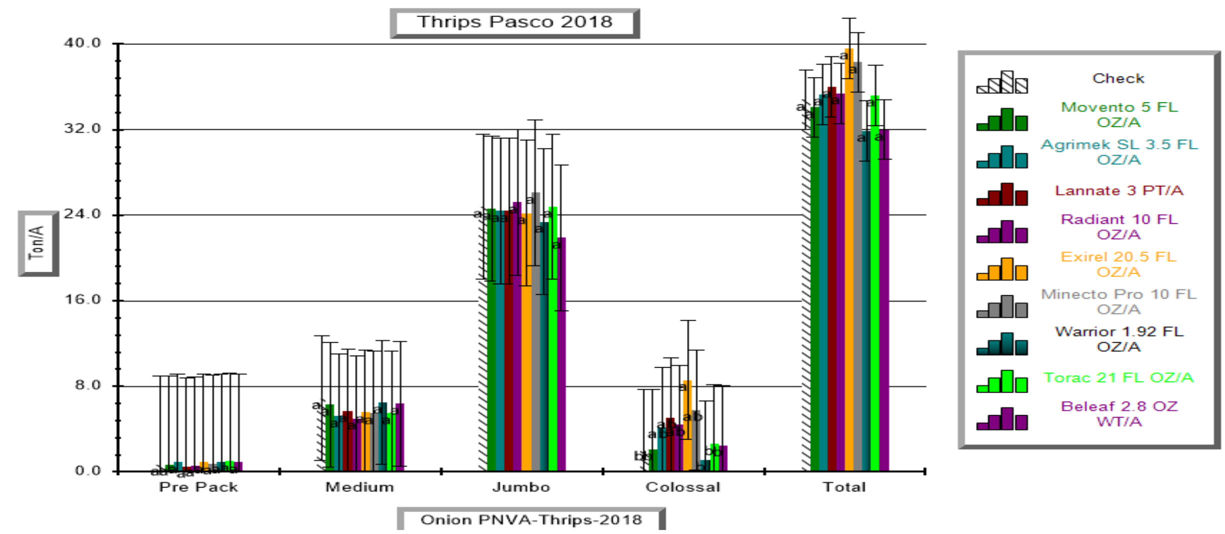


Figure 5. Grade and yield of plots by treatment. Treatments with the same letters are not statistically different from one another (P=0.05 Student-Newman-Keuls test)

For the organic insecticides evaluated, the lowest sum of thrips per plant were recorded in plots treated with Entrust +AzaDirect and Entrust + Venerate (Figure 6). Celite, Venerate, and AzaDirect treated plots did not contain fewer thrips than the untreated check (Figure 6). IYSV incidence was high and not significantly reduced with any treatments compared to the untreated check. Overall plant health was increased in the final rating in all plots treated with Entrust: Entrust alone, Entrust+Venerate and Entrust+AzaDirect. Overall yield and sizing was improved most with plots treated with Entrust + Venerate; yields were higher than plots treated with Celite and AzaDirect, but not significantly more than the untreated check plots.

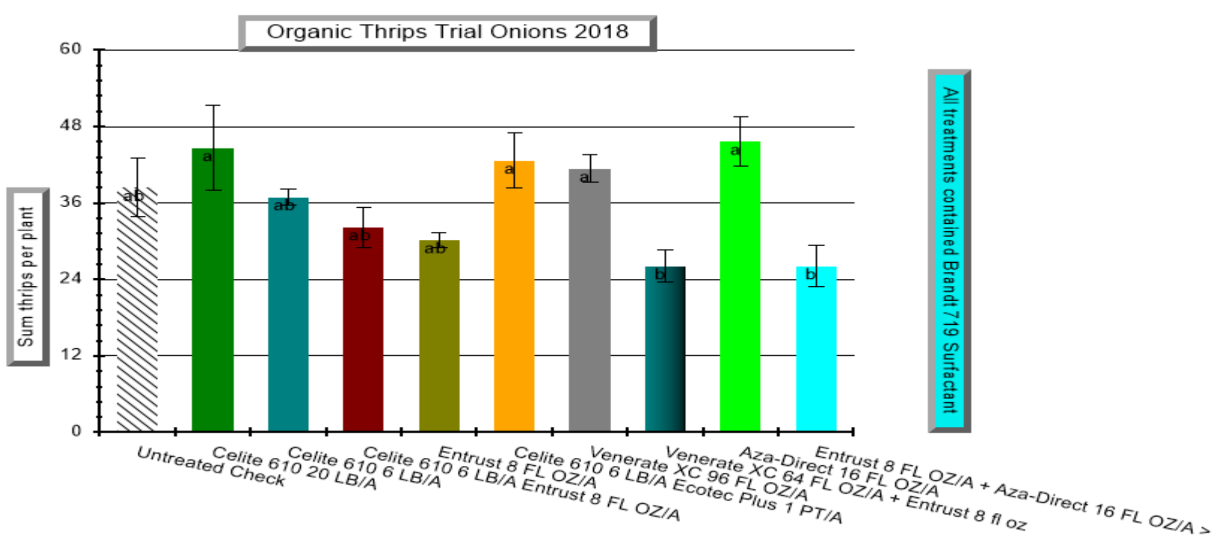


Figure 6. Sum of thrips per plant by treatment. Treatments with the same letters are not statistically different from one another (P=0.05 Student-Newman-Keuls test)

WSU Pullman Plant Pest Diagnostic Clinic

Rachel Bomberger

The Plant Pest Diagnostic Clinic, located on the WSU-Pullman campus, provides diagnostic support to the agriculture industry, green industry, urban forestry, and homeowners. The clinic works closely with both extension faculty and researchers located across the state to solve plant problems.

The clinic is able to provide disease and insect diagnostics as well as assist in abiotic and environmental problem identification. Management recommendations are included with the diagnostic service.

Frequent tests include:

- Fungi and bacteria culturing
- Virus testing (limited)
- Pest identification
- Soil tests for *Pythium, Phytophthora, Verticillium, Rhizoctonia* and *Fusarium*
- Fungicide resistance testing for Metalaxyl/Mefenoxam and Thiabendazole

To submit a sample, select plants that are symptomatic but not yet dead. Ideally, multiple plants samples showing various stages of disease, especially early symptoms. If possible also send a healthy plant. Submit whole plants whenever practical. Enclose roots and soil in a plastic bag to keep soil off of aboveground tissues. Fleshy material such as bulbs and tubers should be wrapped in dry paper towels or newspaper. If the plants are too large they can be split or cut into smaller pieces. Large trees can be submitted by selecting symptomatic branches that are 0.5 to 1 inch in diameter and 6 to 12 inches in length. Samples should be stored in a plastic bag; clean plastic trash bags work for large samples. Samples should be kept free of excess moisture and protected from extreme heat. Include the submission form, which can be found online at: **https://plantpath.wsu.edu/diagnostics/.** Mail samples as soon as possible after collecting. To avoid decay in transit samples should be sent early in the week. Samples should be packaged in sturdy container to prevent damage to sample. Specimens can also be dropped up at the WSU Pullman campus clinic.

For more information, please contact the diagnostic clinic at (509)335-3292 or visit or website at: https://plantpath.wsu.edu/diagnostics/

Send samples to:
Rachel Bomberger – Plant Pest Diagnostic Clinic
WSU Plant Pathology – Johnson Hall 345
PO Box 646430 – 100 Dairy Rd
Pullman, WA 99164-6430

WSU ONION ALERTS

Hello Onion Industry Member: *WSU Onion Alerts* is an e-newsletter that provides information about issues affecting onion crops in the Columbia Basin. Pest and disease problems that are observed or anticipated based on weather conditions or historical incidences are reported in the *WSU Onion Alerts* along with management recommendations. The alerts give onion growers early warning about impending problems so they can make informed and timely management decisions. The *WSU Onion Alerts* are produced by Carrie Wohleb and Tim Waters, WSU Extension and by Lindsey du Toit, WSU Plant Pathology.

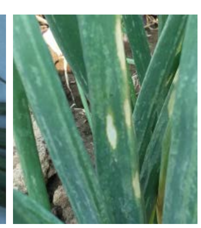
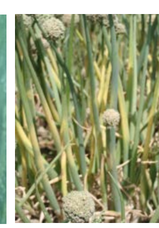
Previous issues of *WSU Onion Alerts* have covered…

- Onion thrips
- Downy mildew
- Yellow nutsedge
- Iris yellow spot
- Storm damage
- Powdery mildew
- Lightning injury
- Stemphylium leaf blight
- Botrytis neck rot
- Black mold
- Fusarium basal rot
- Onion cull disposal
- Yellow or white banding at the soil line
- Possible causes of poor stands and stunting
- Onion smut
- Nematodes
- Bolting
- Onions and air pollution
- Curing and storing onions

ACKNOWLEDGEMENTS: The *WSU Onion Alerts* e-newsletter is funded through a grant of the Columbia Basin Onion Research Committee. We appreciate the onion producers and crop consultants in the Columbia Basin who have shared information about pest and disease problems in their fields. This allows us to warn other growers to be on the alert for early signs and symptoms. The end goal is to minimize the impact of pest and disease outbreaks in the region.

WSU Onion Alerts are being sent to more than 600 subscribers via email. If you are interested in subscribing, please contact Carrie Wohleb at cwohleb@wsu.edu.




Stop the Rot:
Combating Onion Bacterial Diseases with Pathogenomic Tools & Enhanced Management Strategies

Lindsey du Toit, Washington State University, dutoit@wsu.edu or 360-848-6140

WHAT?

In July 2019, the **USDA** National Institute of Food & Agriculture (**NIFA**) Specialty Crop Research Initiative (**SCRI**) program recommended funding a 4-year proposal (# 2019-03171) led by Washington State University for **~$4 million (+ $4.2 million in matching funding)** to **mitigate the impact of bacterial diseases on onion production in the U.S.**

WHY?

Onion bulb crops are grown on ~140,000 acres/year in the U.S. at a farm-gate value of ~$925M. Bacterial pathogens cause >$60M in losses annually to this industry. Losses can be severe for stored bulbs as bacterial bulb rots typically develop in storage, after all production costs have been incurred. **Poor understanding of the diversity and epidemiology of bacterial pathogens, and the lack of systemic bactericides limit capacity to mitigate the losses.** This contrasts with what has been accomplished for many fungal diseases of onion.

WHEN? October 2019 – September 2023

HOW?

This project organizes **24 scientists from 12 states** (CA, CO, GA, ID, MI, NM, NY, OR, PA, TX, UT, WA) to research the complete system (host, pathogen, and environment) of bacterial diseases of onion in the U.S. The goal is to support profitability and sustainability of onion production using a coordinated, **national survey of bacterial pathogens affecting onion crops**, combined with a **stakeholder-focused**, systems approach to investigate how **production practices, inoculum sources, and environmental conditions can be managed** to develop effective, practical, economically-viable, and environmentally-sound strategies to limit losses to bacterial diseases.

1. Undertake a national survey of onion bacterial diseases (12 states for each of 3 seasons)
2. Develop a *National Onion Bacterial Strain Collection* (NOBSC)
3. Use this resource for genotypic characterization of onion bacterial pathogens across the U.S., and to design rapid, accurate, and robust methods for detecting and identifying these pathogens
4. Develop methods of screening onion germplasm for resistance to these bacteria
5. Integrate diagnostic and detection tools into comprehensive integrated disease management research trials based on irrigation practices, fertility practices, pesticide programs, cultural practices, post-harvest practices, and bacterial disease modeling
6. Generate predictive bacterial disease models across regions of onion production in the U.S.
7. Implement a dissemination plan to deliver results to constituents
8. A 12-person, nation-wide Stakeholder Advisory Panel (SAP) helped develop the priorities and approaches for the proposal, and will provide regular feedback/guidance over the next 4-years to ensure results are delivered to constituents and that solutions developed are viable economically and environmentally. Kerrick Bauman (L&L Farms) serves on the SAP to represent the PNW.

YOUR ROLE IN 'STOP THE ROT'?

If you would like to be involved in the 'Stop the Rot' project, e.g., the bacterial disease survey or disease management trials, or provide recommendations on the project, please contact **Lindsey du Toit**, (dutoit@wsu.edu, 360-848-6140), **Tim Waters** (twaters@wsu.edu, 509-545-3511), **Gabriel LaHue** (gabriel.lahue@wsu.edu, 360-848-6146), or **Kirti Rajagopalan** (kirtir@wsu.edu, 253-445-4626).

Efficacy of Bactericides for Control of Onion Bacterial Bulb Rots

Funding: IR-4 Minor Crops Program

Lindsey du Toit (dutoit@wsu.edu, 360-848-6140), **Tim Waters** (twaters@wsu.edu, 509-545-3511), **Jennifer Darner**, **Don Kinion**, and **Michael Derie**, Washington State University; **Beth Gugino**, Pennsylvania State University.

Objective: Evaluate the efficacy and crop safety (phytotoxicity) of diverse bactericides for control of bacterial leaf blight and bulb rots of onion.

2019 Field trials: Washington State University and Pennsylvania State University. WSU trial: Planted at WSU Extension Pasco Farm. Split plot, randomized complete block design of a factorial treatment design with 14 bactericide treatments + 1 control treatment, each applied to plants inoculated with *Burkholderia gladioli* pv. *alliicola* & *Pantoea agglomerans* and to non-inoculated plants (inoculated at night on Aug. 1st (onset of tops falling) & Aug. 15th after sprinkler irrigation of plots). Split plots are each 15 ft long x 1 bed wide.

Bactericide treatments:

1. Non-treated
2. ManKocide (mancozeb + copper hydroxide) applied 5 times at 7-day intervals at 2.25 lb/acre
3. Kocide 3000-O (copper hydroxide) applied 5 times at 7-day intervals at 1.5 lb/acre
4. Champ WG (copper hydroxide) applied 5 times at 7-day intervals at 1.5 lb/acre
5. Oxidate 2.0 (hydrogen dioxide + peroxyacetic acid) applied 7 times at 5-day intervals at 1.25 fl oz product/2 gal water
6. Kasumin 2L (kasugamycin) applied 4 times at 7-day intervals at 32 or 64 fl oz/acre
7. Non-MgO (Nano-magnesium oxide) applied 5 times at 7-day intervals at 200 and 1,000 ppm
8. GWN 10120 applied 5 times at 7-day intervals at 2 pt/acre
9. SP8010 applied 5 times at 7-day intervals at 17 fl oz/acre alone, mixed with Kocide 3000-O, or mixed with SP2700
10. Lifegard WG (*Bacillus mycoides*) applied 5 times at 7-day intervals at 4.5 oz/100 gal
11. Instill (copper sulfate pentahydrate) applied 3 times at 7-day intervals at 20 fl oz/100 gal

Treatments applied at 30-60 GPA with a tractor-mounted sprayer. Applications initiated on Jul. 24th for products applied 5 or 7 times, and Jul. 31st for products applied 3 or 4 times.

Evaluations:

1. Weekly foliar disease ratings
2. Weekly crop injury (phytotoxicity) ratings
3. Incidence of bacterial bulb rot at harvest (Sep. 2019)
4. Incidence of bacterial bulb rots after 5 months in storage (Feb. 2020)

ONION (*Allium cepa* 'Redwing', 'Tamara', and 'Legend')
Pink root; *Setophoma terrestris*
Host response; mycorrhizal colonization

Lindsey J. du Toit, Michael L. Derie, Barbara J. Holmes, C. Erin Miller, and Louisa R. Brouwer (née Winkler), Washington State University Mount Vernon NWREC, Mount Vernon, WA 98273; and Timothy D. Waters, and Jennifer Darner, Washington State University Benton/Franklin Co. Extension, Pasco, WA 99301.

Effects of the arbuscular mycorrhizal fungi inoculant Mykos Gold Granular on pink root and yield in onion bulb crops near Irrigon, OR, 2017.

Symbiotic arbuscular mycorrhizal fungi (AMF) form associations with most crop species. By enabling hosts plants to mine the soil for immobile nutrients (particularly phosphorus, P) and enhancing resistance to some biotic and abiotic stresses, AMF potentially could reduce the rate of chemical inputs needed in some production systems. Onions are particularly responsive to AMF because of the relatively unbranched root structure and scant root hairs. Trials were carried out in the semi-arid Columbia Basin of northcentral Oregon, a major region of onion production for the USA, to test the potential effects of an AMF inoculant, Mykos Gold Granular (RTI-Ag, Gilroy, CA), on onion production. The trials were planted in center-pivot-irrigated, commercial onion bulb fields near Irrigon, OR. The AMF inoculant was evaluated in four fields, each of which represented one replicate of a randomized complete block design. Each replicate rated included two adjacent, 44-in. wide beds extending the length of the field, one treated and the other not treated with Mykos Gold Granular. Each bed consisted of two double-rows of onions. Higher application rates of soluble fertilizers, especially P, can inhibit association of AMF with plant roots. Therefore, the effect of a pre-plant, banded fertilizer application on the Mykos Gold Granular treatment was tested in two of the fields (replicates), as a 2-by-2 factorial treatment combination: with and without AMF inoculant, each with and without pre-plant, banded fertilizer application. Each of the four treatment combinations was rated along the length of one bed. Mykos Gold Granular was applied in-furrow at planting at a rate of 6.6 lb/A. Details of the proprietary, pre-plant, banded fertilizer application were not provided by the grower. Two of the four fields were planted with seed of the onion cv. Redwing, one field was planted with Tamara, and the fourth field with Legend. All seed was treated with FarMore 500 (metalaxyl + fludioxonil + azoxystrobin + spinosad + thiamethoxam; Syngenta USA, Greensboro, NC). Most data were collected from five locations equally spaced along a 1,000 ft section of each plot, except stand counts which were taken at eight locations per plot. Data were averaged over subsamples in each plot. The 50- to 125-A onion crops in the four fields were planted between 14 and 27 Mar, with each field planted on a single day. Onion stands were counted from each of four 10-ft sections of bed per sampling location (1- to 3-true leaf stage). Soil was sampled from each plot on 4 May (6-in. depth) for nutrient analysis. On 15 Jun, 5 onion plants were dug from each sampling location. The roots were cut, washed, stained (Verheilig et al. 1998), and examined microscopically (5× to 20× magnification) to quantify AMF colonization for each of 40 root sections per plant based on a modified gridline intersection method (Giovannetti and Mosse 1980). For the same plants, leaf length was measured, and the bulbs and leaves dried and weighed. The dried leaves and bulbs were submitted to SoilTest Farm Consultants (Moses Lake, WA) for nutrient analysis. On 17 Aug, all the onion bulbs in a 5-ft section of the bed were dug from five sampling locations per plot. The roots were rinsed in water and rated for severity of pink root (% of roots with symptoms, averaged for all bulbs sampled in a plot). Tops were cut 2 in. above each bulb, and the bulbs weighed and graded (colossal = >4.00 in. diameter, jumbo = 3.00-4.00 in., medium = 2.25-3.00 in., prepack <2.25 in., and rejected bulbs = bulbs with split basal plates, rot, bolting, or green shoulders). Data from all four fields were evaluated for effects of Mykos Gold Granular by single-factor analyses of variance (ANOVAs), and data from fields with the 2-by-2 factorial design were evaluated for Mykos Gold Granular and fertilizer effects by two-factor ANOVAs, using R Version 3.1.1.

Results of the single-factor experiment (with and without Mykos Gold Granular) are in Table 1. In-furrow application of Mykos Gold Granular was not associated with any statistically significant changes in onion crop growth (stand count, leaf length, and dry biomass), pink root severity, or yield. Analysis of the two-factor experiment (with and without Mykos Gold Granular, and with and without a pre-plant, banded fertilizer application) identified no significant interaction between AMF and fertilizer treatments. Results organized by the two main effects are in Table 2. Leaf length, dry biomass, number and weight of jumbo bulbs, and total marketable bulb weight were all significantly greater in plots with the pre-plant, banded fertilizer application than in control plots. The growth-enhancing effects of this fertilizer treatment were expected given the relatively low soil nutrient status in these fields prior to planting (Olsen P of 26-30 ppm, and total N of 83-110 lb/A). The absence of a significant AMF effect could be due to failure of Mykos Gold Granular to induce a significant increase in AMF colonization of onion roots. Although this inoculant induced AMF root colonization in growth chamber tests in other studies (Knerr et al. 2016), root colonization rates were similar in Mykos Gold Granular-inoculated and control plots in this study, demonstrating the presence of endemic AMF in the fields. The seed treatment FarMore FI500 contains azoxystrobin in Fungicide Resistance Action Committee Group 11, which can have a negative effect on true fungi such as AMF (Diedhiou et al. 2004), potentially limiting the benefits of Mykos Gold Granular and native AMF. Root colonization by AMF was less extensive in plots that received the pre-plant, banded fertilizer application (73%) than in control plots (82%). This is consistent with results in similar field trials on other farms in the Columbia Basin (Henrichs et al. 2017; du Toit et al. 2018). This study offers no evidence of benefits from applying AMF inoculants such as Mykos Gold Granular in spring-planted, direct-seeded onion bulb crops grown using practices typical of the semi-arid Columbia Basin.

Table 1.

Crop attribute	Control	Mykos Gold Granular
Onion stand count on 18 Apr (plants/40 ft of double-row)	195 ± 4[z]	198 ± 4
Leaf length on 15 Jun (in.)[y]	24.84 ± 0.48	24.16 ± 0.44
Biomass on 15 Jun (oz dry weight)[x]	0.809 ± 0.055	0.814 ± 0.053
AMF root colonization (%)	70 ± 5	68 ± 4
Pink root severity (% per bulb)	8 ± 1	9 ± 1
Colossal bulb weight (lb)[w]	0.0 ± 0.0	0.0 ± 0.0
Jumbo bulb weight (lb)[w]	19.9 ± 1.4	20.7 ± 1.9
Medium bulb weight (lb)[w]	6.3 ± 0.7	6.2 ± 0.7
Prepack bulb weight (lb)[w]	0.2 ± 0.0	0.2 ± 0.0
Total marketable bulb weight (lb)[w]	26.4 ± 1.0	27.0 ± 1.4
Weight per bulb (lb)[w]	0.57 ± 0.02	0.57 ± 0.02
Colossal bulb number[w]	0 ± 0	0 ± 0
Jumbo bulb number[w]	30 ± 2	31 ± 2
Medium bulb number[w]	15 ± 2	15 ± 2
Prepack bulb number[w]	1 ± 0	1 ± 0
Total number of marketable bulbs[w]	46 ± 1	47 ± 2
Foliar N (%)	3.52 ± 0.17	3.46 ± 0.16
Foliar P (%)	0.46 ± 0.02	0.45 ± 0.02
Foliar K (%)	3.63 ± 0.16	3.49 ± 0.23
Foliar Ca (%)	1.57 ± 0.09	1.56 ± 0.1
Foliar Mg (%)	0.41 ± 0.03	0.40 ± 0.03
Foliar S (%)	0.48 ± 0.02	0.43 ± 0.02
Foliar Zn (%)	27 ± 2	24 ± 2
Foliar Fe (ppm)	522 ± 53	461 ± 33
Foliar Mn (ppm)	43 ± 4	41 ± 5
Foliar Cu (ppm)	13 ± 1	12 ± 1
Foliar B (ppm)	30 ± 2	28 ± 2
Foliar Na (ppm)	0.16 ± 0.05	0.14 ± 0.04

[z] Most values represent the average of four replications. The exception is AMF root colonization data collected from two of the four replicates (fields). All plots were treated with a pre-plant, banded application of fertilizer. No significant differences were detected between Mykos Gold Granular-inoculated and non-inoculated plots for any of the variables measured (p < 0.05).

y Average of five plants per sampling location per replicate (field).

[x] Dry weight of leaves from five plants per sampling site per replicate (field).

[w] Per 5 ft of bed on 17 Aug.

Table 2.

Crop attribute	AMF treatment		AMF effect[y]	Pre-plant, banded fertilizer		Fertilizer effect[y]
	Control	Mykos Gold Granular		None	Standard	
Onion stand count on 18 Apr (plants/40 ft of double-row)	204 ± 2[z]	208 ± 2	ns	205 ± 2	207 ± 2	ns
Leaf length on 15 Jun (in.)[x]	23.36 ± 0.44	23.12 ± 0.48	ns	22.32 ± 0.40	24.16 ± 0.44	***
Biomass on 15 Jun (oz dry weight)[w]	0.709 ± 0.063	0.709 ± 0.065	ns	0.620 ± 0.056	0.798 ± 0.065	*
AMF root colonization (%)	77 ± 3	79 ± 3	NA	82 ± 1	73 ± 3	NA
Pink root severity (% per bulb)	8 ± 1	8 ± 1	ns	8 ± 1	8 ± 1	ns
Colossal bulb weight (lb)[v]	0.1 ± 0.1	0.0 ± 0.0	ns	0.1 ± 0.1	0.0 ± 0.0	NA
Jumbo bulb weight (lb)[v]	15.4 ± 1.0	15.0 ± 1.1	ns	13.7 ± 1.2	16.6 ± 0.8	*
Medium bulb weight (lb)[v]	8.1 ± 0.8	9.2 ± 0.6	ns	8.8 ± 0.8	8.5 ± 0.6	ns
Prepack bulb weight (lb)[v]	0.3 ± 0.1	0.2 ± 0.1	ns	0.3 ± 0.1	0.2 ± 0.1	NA
Total marketable bulb weight (lb)[v]	23.8 ± 0.6	24.4 ± 0.8	ns	22.8 ± 0.7	25.4 ± 0.6	**
Weight per bulb (lb)	5.18 ± 0.12	4.93 ± 0.12	ns	0.50 ± 0.01	0.52 ± 0.01	ns
Colossal bulb number[v]	0 ± 0	0 ± 0	ns	0 ± 0	0 ± 0	NA
Jumbo bulb number[v]	25 ± 2	25 ± 2	ns	22 ± 2	27 ± 1	*
Medium bulb number[v]	20 ± 2	23 ± 2	ns	22 ± 2	21 ± 1	ns
Prepack bulb number[v]	2 ± 0	2 ± 0	ns	2 ± 0	2 ± 0	NA
Total number of marketable bulbs[v]	46 ± 1	49 ± 1	ns	46 ± 1	49 ± 1	ns
Foliar N (%)	3.58 ± 0.11	3.47 ± 0.12	ns	3.56 ± 0.12	3.49 ± 0.11	ns
Foliar P (%)	0.44 ± 0.01	0.42 ± 0.01	ns	0.41 ± 0.01	0.45 ± 0.01	**
Foliar K (%)	3.63 ± 0.14	3.45 ± 0.16	ns	3.52 ± 0.16	3.56 ± 0.14	ns
Foliar Ca (%)	1.53 ± 0.06	1.53 ± 0.07	ns	1.49 ± 0.06	1.56 ± 0.07	ns
Foliar Mg (%)	0.40 ± 0.02	0.40 ± 0.02	ns	0.40 ± 0.02	0.40 ± 0.02	ns
Foliar S (%)	0.48 ± 0.02	0.44 ± 0.02	*	0.47 ± 0.02	0.45 ± 0.02	ns
Foliar Zn (%)	26 ± 1	24 ± 1	ns	25 ± 1	25 ± 1	ns
Foliar Fe (ppm)[u]	517 ± 48	482 ± 34	ns	508 ± 51	491 ± 31	ns
Foliar Mn (ppm)[u]	40 ± 3	40 ± 3	ns	38 ± 3	42 ± 3	ns
Foliar Cu (ppm)	13 ± 0	13 ± 0	ns	13 ± 1	13 ± 0	ns
Foliar B (ppm)	27 ± 1	26 ± 1	ns	24 ± 1	29 ± 1	***
Foliar Na (ppm)[u]	0.15 ± 0.03	0.16 ± 0.04	ns	0.13 ± 0.03	0.15 ± 0.03	ns

[z] Most values represent averages across two fields (= replications). The exception is AMF root colonization which was measured for plant roots sampled from only one of the two fields.

[y] Variables for which a significant main effect of AMF or fertilizer were detected are highlighted in bold and identified as follows: * means 0.01 ≤ *p* ≤ 0.05, ** means 0.001 ≤ *p* <0.01, *** means *p* <0.001; ns = the treatment effect was not significant, NA = data were not analyzed owing to predominance of zero-values or, in the case of root colonization data, lack of replication among fields (only measured in one of two fields that had the 2-by-2 factorial treatment design).

[x] Average of five plants per sampling location per plot in each field.

[w] Dry weight of leaves from five plants per sampling location per plot in each field.

[v] Per 5 ft of bed at each of five sampling locations per plot in each field on 17 Aug.

[u] Square-root transformed for statistical analysis.

ONION (*Allium cepa* 'Calibra')
Host response; mycorrhizal colonization

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The influence of soil phosphorus levels on onion root colonization by arbuscular mycorrhizal fungi from commercial inoculants, 2017.

Symbiotic arbuscular mycorrhizal fungi (AMF) form associations with most plant species. AMF potentially enhance crop performance by helping host plants mine the soil for immobile nutrients, particularly phosphorus (P), and resist some biotic and abiotic stresses. AMF inoculants are proliferating in the marketplace but there is little independent data on their efficacy. This study evaluated the influence of four commercial inoculants on AMF colonization of onion roots, onion growth, and nutrient acquisition as seedlings. Since soil P concentration can influence AMF colonization of roots, the effect of soil P concentration on AMF colonization of onion roots by the four AMF inoculants was tested at a range of soil P concentrations. Soil was collected from a farm in Pasco, WA, that had 25 ppm P (Olsen test), shredded, steam-pasteurized at 65°C for 1 h, then air-dried and sieved to a particle size ≤2 mm. Superphosphate (0-45-0, Wilbur Ellis Co., Mount Vernon, WA) was added to create medium (45 ppm) and high (74 ppm) P treatments. Non-amended soil served as the low P treatment. Liquid, powder, and granular formulations of AGTIV (Premier Tech Agriculture, Rivière du Loup, Quebec) were compared to Mykos Gold Granular (Reforestation Technologies International, Gilroy, CA) and non-inoculated control soil for each soil P level. Each inoculant was added to each soil P treatment at a rate to achieve ~1,500-2,000 AMF spores per kg soil, using a twin shell blender: 20 g Mykos Gold Granular in 2,980 g soil, 30 g AGTIV Granular in 2,970 g soil, 0.354 g AGTIV Powder suspended in 360 ml water in 3,000 g soil, and 30 ml AGTIV Liquid in 2,970 g soil. Each trial was set up as a 3 x 5 factorial, randomized complete block design with five replicates. Each plot was a D40 deepot (25 cm deep × 7 cm diameter, Stuewe & Sons, Inc., Tangent, OR) with 500 g of soil of the appropriate P × AMF treatment. Ten seeds of the cv. Calibra were sown in each deepot. Deepots were watered as needed and fertilized three times weekly from 3 weeks after planting with 0.4-strength, nitrate-type Long Ashton fertilizer (without micronutrients or P). The number of onion seedlings emerged in each pot was counted weekly from one to 8 weeks after planting, and combined into an area under the emergence progress curve (AUEPC). Onion seedlings were harvested 56 days after seeding when leaf length and above-ground dry weight (leaf biomass) of all plants per deepot were measured. Dried leaves were used for foliar nutrient analysis (Soiltest Farm Consultants, Moses Lake, WA). Roots were washed, stained (Verheilig et al. 1998), and examined microscopically (5× to 20× magnification) to quantify AMF colonization in each of 40 root sections per deepot based on a modified gridline intersection method (Giovannetti and Mosse 1980). The trial was repeated with soil from the same field, at final concentrations of 21, 61, and 101 ppm P. Data were evaluated by two-way analyses of variance (ANOVAs). Dunnett's Test or the Games Howell Test (with Bonferroni correction to preserve a family-wise $\alpha = 0.05$) were used post hoc where significant AMF inoculant effects were identified, and Tukey's Test for significant fertilizer effects. Analyses were done in R version 3.1.1. The thermophilic fungus *Peziza* developed after soil steaming in 33% of the plots in Trial 2, impacting onion growth, so data from those plots were treated as missing and imputed using the R package 'mice' (van Buuren and Groothuis-Oudshoorn 2011). The trials were completed in a growth chamber set at 15 ± 1°C with a 12 h photoperiod/day. Trial 1 was planted on 6 Sep and Trial 2 on 29 Sep.

Means ± standard errors by AMF treatment are presented in Table 1. Where ANOVAs identified significant interactions between AMF and soil P treatments, results are separated by soil P treatment. In both trials, onions grown in low P soil amended with AGTIV Granular, AGTIV Powder, and Mykos Gold Granular had significantly more AMF root colonization than those in control soil (0%). Maximum root colonization (30.2%) was observed in low P soil with Mykos Gold Granular in Trial 2. Onions in this soil in Trial 1 had 27.2% root colonization. No other treatment combination in either trial yielded >10% root colonization. For all four inoculants in both trials, AMF root colonization rate decreased as soil P concentration increased, and Mykos Gold Granular yielded significantly greater colonization in low P soil than medium or high P soil. Onions in soil with AGTIV inoculants had lower overall root colonization rates with less differentiation across soil P treatments. AGTIV Liquid resulted in the least colonization. In neither trial was AMF root colonization associated with changes in onion growth (emergence, leaf length, and biomass) or nutrient acquisition. Results by soil P treatment are shown in Tables 2 (Trial 1) and 3 (Trial 2). In both trials, onion leaf length and biomass were greater in soil with medium and high P than in soil with low P. Also, maximum leaf length and biomass were observed in the medium P soil rather than the high P soil, although the differences in leaf length were only significant in Trial 2 (146 mm in high P soil vs. 165 mm in medium P soil, $p < 0.001$). Soil P concentrations covered a larger range in Trial 2, which might explain this discrepancy. For most micro- and macro-nutrients, onion foliar concentration was greater in the low P soil than the medium or high P soils, likely reflecting nutrient dilution in the greater biomass of plants in medium and high P soils. The exception was foliar P, which was significantly greater in concentration with each increase in soil P concentration. Results from this study suggest that, although granular formulations of AGTIV and Mykos Gold resulted in moderate rates of onion root colonization by AMF in the steamed soil used in this study, the increase in AMF root colonization compared to non-inoculated soil did not increase plant growth or nutrient acquisition. The most effective inoculant in this study, Mykos Gold Granular, was 76% less effective at inducing AMF colonization of onion roots in soil with 61 ppm P compared to 21 ppm P; and 64% less effective in soil with 45 ppm P compared to 25 ppm P. The results support prior evidence of higher soil P concentrations inhibiting AMF colonization of onion roots (e.g., Henrichs et al. 2017).

Table 1. Means ± standard errors by AMF treatment, Trials 1 and 2

Plant attribute	Control	AGTIV Granular	AGTIV Liquid	AGTIV Powder	Mykos Gold Granular	Transformation[z]
Trial 1						
AMF root colonization (%)						-
- Low P	0.0 ± 0.0	6.3 ± 1.2 *[y]	1.1 ± 0.2	5.7 ± 1.4 *	27.2 ± 4.8 *	√(x+1)
- Mid P	0.1 ± 0.1	4.0 ± 1.0 *	1.6 ± 0.5	3.2 ± 0.7 *	9.6 ± 1.4 *	√(x+1)
- High P	0.1 ± 0.1	1.8 ± 0.4	1.1 ± 0.3	3.1 ± 0.9 *	8.3 ± 2.1 *	√(x+1)
AUEPC[x]	346 ± 11	329 ± 9	345 ± 11	340 ± 11	358 ± 11	-
Leaf length (mm)	180 ± 7	164 ± 10	164 ± 10	171 ± 8	159 ± 10 *	-
Leaf biomass (g)	0.70 ± 0.06	0.57 ± 0.07	0.70 ± 0.08	0.65 ± 0.07	0.64 ± 0.07	-
Total foliar N (%)	3.17 ± 0.28	3.75 ± 0.36	3.12 ± 0.34	3.06 ± 0.27	3.50 ± 0.30	np
Foliar P (%)	0.38 ± 0.03	0.36 ± 0.04	0.33 ± 0.02	0.37 ± 0.03	0.33 ± 0.03	-
Foliar K (%)	5.02 ± 0.31	5.52 ± 0.47	4.60 ± 0.35	4.79 ± 0.24	4.98 ± 0.35	-
Foliar Ca (%)	0.99 ± 0.04	1.12 ± 0.08	0.99 ± 0.06	0.98 ± 0.04	1.07 ± 0.06	-
Foliar Mg (%)	0.28 ± 0.01	0.30 ± 0.02	0.27 ± 0.01	0.27 ± 0.01	0.30 ± 0.01	-
Foliar Na (%)	0.06 ± 0.01	0.07 ± 0.01	0.06 ± 0.01	0.06 ± 0.00	0.06 ± 0.01	-
Foliar S (%)	0.42 ± 0.03	0.47 ± 0.04	0.39 ± 0.04	0.37 ± 0.03	0.45 ± 0.03	-
Foliar Zn (ppm)	22.8 ± 1.5	27.3 ± 2.8	21.5 ± 2	22.1 ± 1.5	25.9 ± 2.3	-
Foliar Fe (ppm)	483 ± 31	490 ± 31	481 ± 38	550 ± 64	474 ± 51	-
Foliar Mn (ppm)	123 ± 11	148 ± 22	126 ± 19	143 ± 13	147 ± 26	-
Foliar Cu (ppm)	1.29 ± 0.19	1.12 ± 0.22	1.19 ± 0.2	0.87 ± 0.11	0.86 ± 0.13	-
Foliar B (ppm)	16.4 ± 0.5	17.6 ± 1.1	16.2 ± 0.7	15.6 ± 0.5	17.1 ± 0.8	-
Trial 2						
AMF root colonization (%)						-
- Low P	0.0 ± 0.0	6.3 ± 0.6 *	4.7 ± 1.8	5.5 ± 1.6 *	30.2 ± 1.8 *	-
- Mid P	0.0 ± 0.0	4.0 ± 0.9	2.0 ± 0.5	3.5 ± 1.4	7.3 ± 1.6 *	-
- High P	0.0 ± 0.0	2.6 ± 0.9	3.0 ± 1.4	2.7 ± 0.9	5.0 ± 0.8 *	-
AUEPC[x]	417 ± 11	412 ± 11	410 ± 11	417 ± 7	408 ± 11	√
Leaf length (mm)	149 ± 6	141 ± 5 *	142 ± 8	141 ± 7	154 ± 8	-
Leaf biomass (g)	0.56 ± 0.04	0.54 ± 0.04	0.50 ± 0.06	0.53 ± 0.04	0.51 ± 0.05	-
Total foliar N (%)	3.31 ± 0.26	3.30 ± 0.37	3.20 ± 0.32	3.52 ± 0.25	3.83 ± 0.31	√
Foliar P (%)	0.36 ± 0.03	0.34 ± 0.02	0.36 ± 0.02	0.39 ± 0.02	0.34 ± 0.02	-
Foliar K (%)	4.99 ± 0.26	4.69 ± 0.27	4.95 ± 0.26	4.78 ± 0.22	5.16 ± 0.20	-
Foliar Ca (%)	1.26 ± 0.04	1.19 ± 0.04	1.23 ± 0.05	1.32 ± 0.03	1.30 ± 0.03	-
Foliar Mg (%)	0.32 ± 0.01	0.30 ± 0.01	0.31 ± 0.01	0.33 ± 0.01	0.33 ± 0.01	-
Foliar Na (%)	0.06 ± 0.00	0.06 ± 0.00	0.06 ± 0.00	0.06 ± 0.00	0.06 ± 0.00	√
Foliar S (%)	0.45 ± 0.02	0.44 ± 0.03	0.44 ± 0.03	0.42 ± 0.02	0.51 ± 0.02	-
Foliar Zn (ppm)	23.2 ± 1.9	24.9 ± 2.7	24 ± 2.1	23.9 ± 1.9	24.9 ± 2.1	-
Foliar Fe (ppm)	575 ± 56	571 ± 50	591 ± 60	575 ± 53	493 ± 67	-
Foliar Mn (ppm) - Low P	378 ± 25	387 ± 39	374 ± 14	336 ± 24	270 ± 27 *	-
- Mid P	98 ± 8	132 ± 6 *	95 ± 5	146 ± 5 *	66 ± 3 *	-
- High P	107 ± 9	142 ± 24	185 ± 35	97 ± 14	110 ± 12	-
Foliar Cu (ppm)	2.10 ± 0.17	2.19 ± 0.19	1.84 ± 0.18	1.75 ± 0.16	2.21 ± 0.18	-
Foliar B (ppm)	17.2 ± 0.6	16.9 ± 0.6	17.1 ± 0.5	17.7 ± 0.6	17.8 ± 0.6	-

[z] If needed, data were transformed to meet assumptions for parametric analysis: square root (√) or square root of value (x) + one (√(x+1)); - = no transformation; "np" = data analyzed non-parametrically.

[y] * = The treatment differed significantly from the control plot for that variable (Dunnett's test, $0.01 \leq p \leq 0.05$).

[x] AUEPC = Area under emergence progress curve for weekly stand counts for 8 weeks after planting.

Table 2. Means ± standard errors by soil P treatment, Trial 1

Plant attribute	Low soil P (25 ppm)	Medium soil P (45 ppm)	High soil P (74 ppm)	Pr (>F)[z]	Transformation[y]
AMF root colonization (%)					-
- Control	0.0 ± 0.0	0.1 ± 0.1	0.1 ± 0.0		-
- AGTIV Granular	6.3 ± 1.2 a	4.0 ± 1.0 ab	1.8 ± 0.4 b	*	-
- AGTIV Liquid	1.1 ± 0.2	1.6 ± 0.5	1.1 ± 0.3		-
- AGTIV Powder	5.7 ± 1.4	3.2 ± 0.7	3.1 ± 0.9		-
- Mykos Gold Granular	27.2 ± 4.8 a	9.6 ± 1.4 b	8.3 ± 2.1 b	**	-
AUEPC[x]	346 ± 8	337 ± 9	349 ± 8		-
Leaf length (mm)	134 ± 4 b	188 ± 5 a	185 ± 5 a	***	-
Leaf biomass (g)	0.37 ± 0.02 b	0.82 ± 0.04 a	0.81 ± 0.03 a	***	-
Total foliar N (%)	4.55 ± 0.16 a	2.57 ± 0.11 b	2.68 ± 0.13 b	***	np
Total foliar P (%)	0.26 ± 0.01 c	0.36 ± 0.01 b	0.45 ± 0.02 a	***	√
Total foliar K (%)	6.15 ± 0.16 a	4.28 ± 0.17 b	4.34 ± 0.23 b	***	-
Foliar Ca (%)	1.24 ± 0.04 a	0.88 ± 0.02 b	0.94 ± 0.03 b	***	√
Foliar Mg (%)	0.33 ± 0.01 a	0.25 ± 0.01 b	0.27 ± 0.01 b	***	-
Foliar Na (%)	0.08 ± 0.00 a	0.05 ± 0.00 b	0.05 ± 0.00 b	***	√
Foliar S (%)	0.53 ± 0.02 a	0.35 ± 0.02 b	0.37 ± 0.02 b	***	-
Foliar Zn (ppm)	31.8 ± 1.2 a	18.9 ± 0.8 b	19.9 ± 0.9 b	***	-
Foliar Fe (ppm)	600 ± 37 a	454 ± 34 b	423 ± 20 b	***	Log
Foliar Mn (ppm)					
- Control	162 ± 13	114 ± 21	98 ± 7		-
- AGTIV Granular	229 ± 13 a	102 ± 17 b	74 ± 9 b	**	-
- AGTIV Liquid	196 ± 27 a	79 ± 11 b	85 ± 6 b	**	-
- AGTIV Powder	159 ± 7	138 ± 35	131 ± 18		-
- Mykos Gold Granular	250 ± 22 a	108 ± 35 b	67 ± 6 b	**	-
Foliar Cu (ppm)	0.93 ± 0.10	1.25 ± 0.15	1.00 ± 0.15		-
Foliar B (ppm)	18.2 ± 0.6 a	15.1 ± 0.4 b	16.1 ± 0.5 b	**	-

[z] Asterisks indicate variables for which significant differences among treatments were identified in the analysis of variance: * = 0.01 ≤ *p* ≤ 0.05, ** = 0.001 ≤ *p* <0.01, *** = *p* <0.001; values in a row with the same letter are not significantly different according to Tukey's Honestly Significant Difference test at *p* < 0.05.

[y] Where necessary, data were transformed to meet assumptions for parametric analysis: square root (√) or logarithm (Log); - = no transformation was needed; "np" = data were analyzed non-parametrically.

[x] AUEPC = Area under the emergence progress curve based on weekly stand counts for 8 weeks after planting.

Table 3. Means ± standard errors by soil P treatment, Trial 2

Plant attribute	Low soil P (21 ppm)	Medium soil P (61 ppm)	High soil P (101 ppm)	Pr (<F)[z]	Transformation[y]
AMF root colonization (%)					-
- Control	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0		-
- AGTIV Granular	6.3 ± 0.6 a	4.0 ± 0.9 ab	2.6 ± 0.9 b	*	-
- AGTIV Liquid	4.7 ± 1.8	2.0 ± 0.5	3.0 ± 1.4		-
- AGTIV Powder	5.5 ± 1.6	3.5 ± 1.4	2.2 ± 1		-
- Mykos Gold Granular	30.2 ± 1.8 a	7.3 ± 1.6 b	5.0 ± 0.8 b	***	-
AUEPC[x]	418 ± 7	408 ± 10	413 ± 6		-
Leaf length (mm)	126 ± 4 c	165 ± 4 a	146 ± 5 b	***	-
Leaf biomass (g)	0.38 ± 0.02 b	0.63 ± 0.03 a	0.57 ± 0.03 a	***	-
Total foliar N (%)	4.42 ± 0.18 a	3.10 ± 0.22 b	2.78 ± 0.17 b	***	√
Total foliar P (%)	0.26 ± 0.01 c	0.36 ± 0.01 b	0.45 ± 0.01 a	***	Log
Total foliar K (%)	5.78 ± 0.12 a	4.62 ± 0.17 b	4.35 ± 0.15 b	***	-
Foliar Ca (%)	1.29 ± 0.02	1.22 ± 0.03	1.27 ± 0.03		-
Foliar Mg (%)	0.32 ± 0.01	0.31 ± 0.01	0.33 ± 0.01		-
Foliar Na (%)	0.07 ± 0.00 a	0.05 ± 0.00 b	0.05 ± 0.00 b	***	-
Foliar S (%)	0.51 ± 0.02 a	0.44 ± 0.02 b	0.40 ± 0.01 b	***	Log
Foliar Zn (ppm)	33.5 ± 1.3 a	20.5 ± 0.8 b	18.6 ± 0.7 b	***	Log
Foliar Fe (ppm)	759 ± 38 a	419 ± 20 b	505 ± 39 b	***	-
Foliar Mn (ppm)					
- Control	378 ± 25 a	98 ± 8 b	107 ± 4 b	***	-
- AGTIV Granular	387 ± 39 a	132 ± 6 b	142 ± 24 b	***	-
- AGTIV Liquid	374 ± 14 a	95 ± 5 b	185 ± 35 b	***	-
- AGTIV Powder	336 ± 24 a	146 ± 5 b	97 ± 14 b	***	-
- Mykos Gold Granular	270 ± 27 a	66 ± 12 b	110 ± 12 b	***	-
Foliar Cu (ppm)	2.16 ± 0.14	2.03 ± 0.13	1.86 ± 0.14		-
Foliar B (ppm)	19.0 ± 0.4 a	17.0 ± 0.4 b	16.1 ± 0.4 b	***	-

[z] Asterisks indicate variables for which significant differences among treatments were identified in the analysis of variance: * = $0.01 \leq p \leq 0.05$, ** = $0.001 \leq p < 0.01$, *** = $p < 0.001$; values in a row with the same letter are not significantly different according to Tukey's Honestly Significant Difference test at $p < 0.05$.

[y] Where necessary, data were transformed to meet assumptions for parametric analysis: square root (√) or logarithm (Log); - = no transformation.

[x] AUEPC = Area under the emergence progress curve based on weekly stand counts for 8 weeks after planting.

Mycorrhizal Inoculants: Yea or Nay?

The Effects of Mycorrhizal Inoculants on Onion Crops in the Columbia Basin

By Louisa Winkler, Lindsey du Toit and Tim Waters, Washington State University

In a survey taken at the Washington State University (WSU) 2018 Onion Cultivar Demonstration and Field Day, held in central Washington state, 43 percent of farmers reported having used arbuscular mycorrhizal fungal (AMF) inoculants in onion or other crops. Of crop consultants and agronomists taking the survey, 21 percent said they had recommended AMF inoculants to clients.

Are these AMF products effective? Several years ago, seeing the increasing number of commercial AMF inoculants in the marketplace, Lindsey du Toit, WSU plant pathologist, and Tim Waters, WSU regional vegetable specialist, set out to test these products in commercial onion crops grown in the semi-arid Columbia Basin of north-central Oregon and central Washington to determine their impact on onion crop performance.

What are AMF Inoculants?

AMF are a class of fungi, usually soil-borne, that form associations with the roots of most plant species, including onion. They facilitate soil nutrient and water acquisition by crop plants and can improve tolerance of plants to some abiotic stresses such as drought and salinity, as well as some biotic stresses such as certain soil-borne pathogens.

Intensely-worked agricultural soils typically have reduced concentrations of AMF because cultivation disrupts the fungal association with plant roots. Soil fumigation also can have adverse effects on these beneficial fungi. Adding AMF back into the soil before or during seeding of a new crop could increase crop yield and quality while also reducing fertilizer requirements.

Companies such as Reforestation Technologies International (RTI-Ag), AGTIV (formerly Premier Tech Agriculture), Plant Health LLC and Mycorrhizal Applications, Inc. have launched a variety of granular, powder, liquid and other formulations of products containing propagules of certain key AMF identified as having potential benefits for plants. These AMF inoculant products have been used successfully in many perennial cropping systems (e.g. in the forestry, nursery and landscape industries) and for producing transplants. However, AMF inoculants have been evaluated far less in direct-seeded, annual cropping systems. Since more than 95 percent of onion bulb crops in the Columbia Basin are direct-seeded, du Toit and Waters led a research and extension project to help evaluate the potential benefits for onion producers in the Columbia Basin.

Mike Derie and Barbara Holmes from Washington State University rate onion roots for severity of pink root in a field trial near Paterson, Wash., in which liquid AMF products were applied to onion seed at planting.

Product	Manufacturer
AGTIV Specialty Crops Granular	AGTIV, Quebec, Canada
AGTIV Specialty Crops Liquid	AGTIV, Quebec, Canada
AGTIV Specialty Crops Powder	AGTIV, Quebec, Canada
BioTerra Plus Dry Mix	Plant Health LLC, Corvallis, Ore.
MycoApply Endo Liquid	Mycorrhizal Applications LLC, Grants Pass, Ore.
MycoApply Ultrafine Endo Powder	Mycorrhizal Applications LLC, Grants Pass, Ore.
Myconate AS	Plant Health Care, Inc./SYM-AGRO, Inc.
Myconate HB	Plant Health Care, Inc./SYM-AGRO, Inc.
Mykos Gold Granular	RTI-Ag, Gilroy, Calif.
Mykos Liquid Mycorrhizal Inoculant	RTI-Ag, Gilroy, Calif.

Table 1. Commercial arbuscular mycorrhizal fungi (AMF) products evaluated in field and growth chamber trials by Washington State University researchers.

An arbuscular mycorrhizal fungus (AMF) product is applied in March during a pre-plant, banded fertilizer application in a grower's field that was planted with an onion crop under center-pivot irrigation.

Field Trials, Growth Chamber Trials

From 2015 to 2018, 20 field trials were completed to test 10 commercial AMF inoculants (Table 1) on six commercial onion farms in the Columbia Basin. Growers used their own equipment and their standard fertilization and pest control programs. In each trial, treatments were replicated and randomized to the extent possible with large-scale growers' equipment. Products were applied according to manufacturers' recommendations, most often by banding in the seed furrow at planting. Each trial always included control plots with no AMF inoculant.

In each field trial, onion stand counts were measured about six weeks after planting. In addition, onion plants were dug carefully mid-season to measure plant height and weight, assess foliar nutrient status and rate soil-borne disease severity (pink root and/or white rot). Samples of the roots were stained and examined microscopically to calculate the extent of root colonization by AMF. Bulb yield (size and weight) was also determined for each plot from mature onion bulbs.

In addition to the field trials, AMF inoculants were evaluated under controlled conditions in growth chamber trials. Soil for these trials was sampled from an onion grower's field in the Columbia Basin. The soil was pasteurized to eliminate AMF present in the soil, so that any AMF activity detected was from the inoculants added. Onion growth and AMF root colonization were measured in these trials to compare results with the field trials.

In almost all the field trials, AMF inoculants did not cause an increase in onion root colonization rates. Of the various products tested, the most effective was Mykos Gold Granular. In the most successful field trial, this product increased root colonization rates from 48 percent in the control plots to 51 percent. When Mykos Gold Granular was applied to pasteurized soil in the growth chamber trials, root colonization levels ranged from 30 percent to 80 percent, whereas roots in control soil had 0 percent colonization. As in the field trials, Mykos Gold Granular was the most effective product tested in growth chamber tests.

Initially, many of the grower-cooperators expressed interest in treating onion seed with liquid formulations of AMF inoculants because of the ease of application (no need to modify their

Lindsey du Toit and Alex Batson from Washington State University count onion plants emerging between rows of winter wheat cover crop to assess the impacts of AMF treatments and pre-plant, banded fertilizer application rates on early-season onion stands.

The research team monitors an application of an arbuscular mycorrhizal fungus (AMF) product using gandy boxes attached to a drip tape applicator in a field that was planted with an onion crop the next day.

equipment if the product could be applied to seed). However, liquid formulations proved to be even less effective than granular formulations in growth chamber trials, even when the products were applied to seed that had not been treated with fungicides or seed that had not been pelleted for precision planting. Five trials with liquid AMF formulations in commercial fields were similarly disappointing.

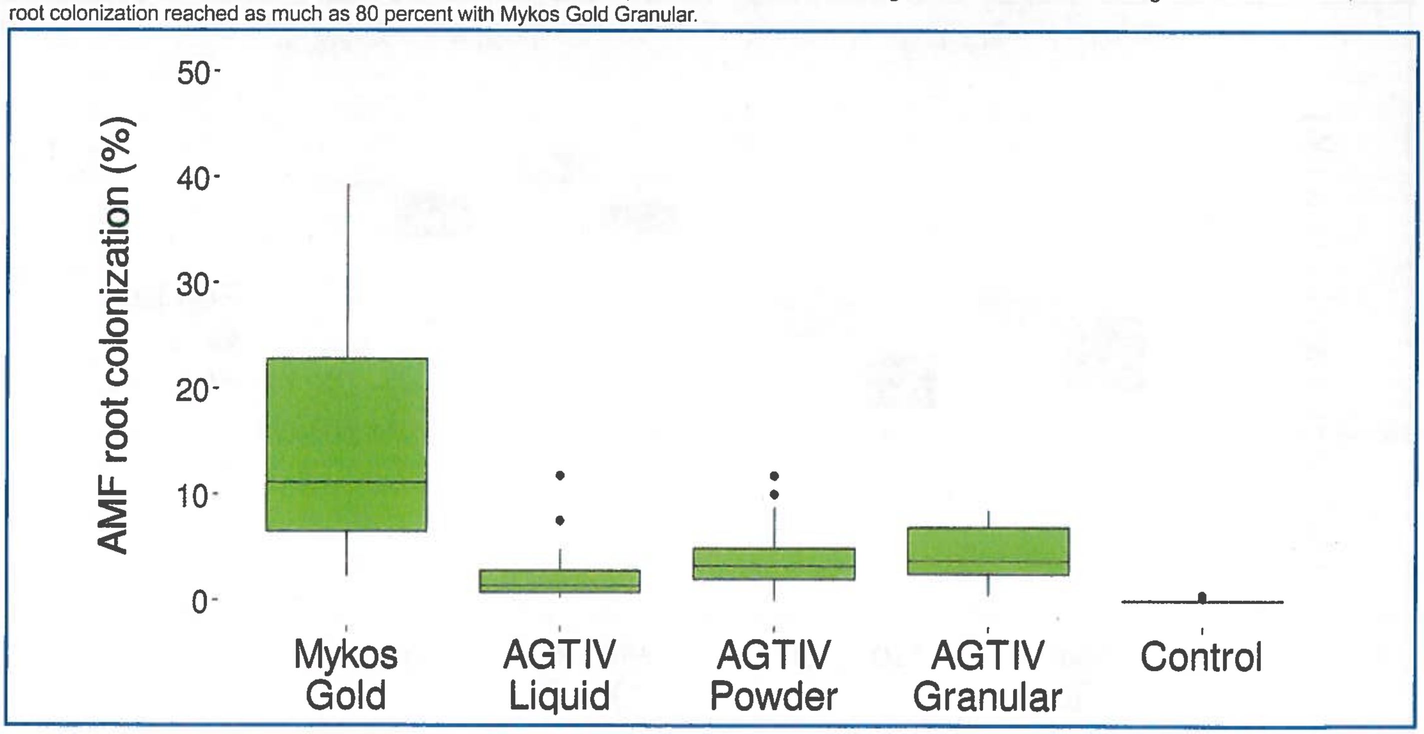
AMF in Non-Inoculated Fields

In the field trials, onion roots generally showed 40 to 50 percent colonization in non-inoculated control plots to which no AMF inoculant had been added. This indicated that root-colonizing AMF were present in the soil of these commercial production fields, even fields that had been fumigated the fall prior to planting with metam sodium applied through center pivots.

This was similar to results of two AMF surveys in onion bulb crops in 2014-2015 completed by du Toit's group with Tim Paulitz, USDA-ARS plant pathologist. For the first survey, AMF communities and root colonization rates were compared in five organic onion crops and four conventional onion crops. For the second survey, AMF were compared in eight conventional onion fields, four of which had been fumigated the autumn prior to planting with metam sodium (center-pivot chemigation) and four of which were not fumigated. AMF colonization of onion roots sampled mid-summer was greater in organic fields than conventional fields (67 versus 51 percent), and less in fumigated versus non-fumigated conventional fields (45 versus 67 percent).

Molecular analyses showed that four main AMF dominated in these soils (*Glomus, Claroideoglomus, Paraglomus* and *Diversispora*). The AMF communities were slightly more diverse

Figure 1. Onion root colonization by arbuscular mycorrhizal fungi (AMF) in a growth chamber test of the product Mykos Gold Granular and three formulations (liquid, powder and granular) of AGTIV. The trial was repeated. The data were averaged over both trials. In other growth chamber trials, AMF root colonization reached as much as 80 percent with Mykos Gold Granular.



and abundant in the organic crops than the conventional crops. However, there was no consistent effect of metam sodium on the species composition of AMF communities in onion crops in fumigated versus non-fumigated conventional fields.

In Search of Explanations

Why were AMF inoculants ineffective at increasing onion root colonization in most of the field trials? Perhaps the fungi in these inoculants were not able to compete with AMF already present in the soils. Another explanation is that AMF products delivered in the seed furrow were inhibited by fungicides in the seed coatings typically used in conventional onion crops in the Columbia Basin. FarMore FI500, for example, contains azoxystrobin and fludioxonil, fungicides that can have inhibitory effects on many true fungi such as AMF. Another possibility is that some of the commercial formulations evaluated failed to preserve the vigor of fungal propagules or limited the capacity for root colonization, as demonstrated with several liquid formulations in the growth chamber trials.

However, what was clear from this research was that less AMF root colonization occurred when soil nutrients were more concentrated, especially soil phosphorus (P). In some of the field trials, root colonization rates were compared for onions seeded with or without a pre-plant, banded fertilizer application. The results were striking: on average, AMF root colonization rates were 15 percent less in plots that received the pre-plant, banded fertilizer application than in plots that did not (Fig. 2). In companion growth chamber tests, the best inoculant, Mykos Gold Granular, was 76 percent less effective at causing AMF colonization of onion roots when soil P concentration was 74 versus 25 ppm, and 64 percent less effective at 45 versus 25 ppm. A large majority of the onion fields surveyed during these studies had soil P levels considerably greater than 40 ppm. The results suggest that AMF inoculants might be more effective in situations where available soil nutrients are in low concentration, or other stressful situations, such as where soil water is scarce. Other research has demonstrated the benefits of AMF inoculants to be most apparent when plants are under stress.

Onion Crop Performance

Across all the field trials, AMF inoculants showed no consistent effects on onion growth characteristics measured. Even in the growth chamber trials, the benefits of AMF inoculants on onion growth were not observed when plants were grown in soil with moderate or high P levels. It appears that onion plants grown with adequate levels of fertilizer can access all the nutrients needed for optimum growth, even in the absence of AMF.

AMF inoculants may be of value under nutrient-limiting conditions or in crops exposed to other stresses. Several studies demonstrated a benefit to using AMF inoculants in onion transplant production as the AMF-colonized plants displayed greater tolerance to transplant stress than non-colonized plants. However, in the context of direct-seeded onion production practices in the Columbia Basin, AMF inoculants appear to offer little to no advantage to these crops.

Requests for publications resulting from this project can be sent to du Toit at dutoit@wsu.edu.

Figure 2. Rate of onion root colonization by arbuscular mycorrhizal fungi (AMF) in two growers' field trials in which half the plots received an application of pre-plant, banded fertilizer ("+") and half the plots did not ("-"). Onions growing in plots amended with Mykos Gold Granular were compared with onions growing in control plots that were not inoculated with AMF. AMF colonization rates were greater in plots without the pre-plant fertilizer application, regardless of whether or not AMF inoculant was added. There was little difference between AMF root colonization rates in the AMF-inoculated plots compared with the control plots.