2014 BIOAG PROJECT PROGRESS OR FINAL REPORT

TITLE

Impact of Arbuscular Mycorrhizal Fungi on P Use Efficiency and Root Diseases of Onion Crops in the Columbia Basin

PRINCIPAL INVESTIGATOR(S) AND COOPERATOR(S)

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KEY WORDS

Onion, *Allium cepa*, vesicular arbuscular mycorrhizae, *Rhizoctonia solani*, *Phoma terrestris*, phosphorus use efficiency, soilborne pathogens, growth promotion, organic, conventional

ABSTRACT

Onion growers in the semi-arid, irrigated Columbia Basin produce ~27% of the US storage onions annually at a farmgate value of $4,000-$7,000/acre. Symbiotic arbuscular mycorrhizal fungi (AMF) colonize roots of many plant species and help the plants mine soils for immobile nutrients, particularly phosphorus (P). AMF can also help defend plants against some root pathogens. Onions depend significantly on AMF since the symbiotic association compensates for the relatively sparse, unbranched roots with few root hairs. However, widespread use of soil fumigation and high rates of P fertilizer applications in onion crops in the Columbia Basin may negate or reduce significantly this symbiotic association with AMF. The objectives of this proposal were to determine the prevalence and species of AMF in certified organic and conventional onion bulb crops in the Columbia Basin, and to use greenhouse trials and grower field trials to determine whether inoculation of onion plants with AMF can improve onion growth, increase P use efficiency of onion crops, and/or reduce soilborne disease pressure (particularly stunting caused by *Rhizoctonia solani*, and other prevalent soilborne onion diseases such as pink root caused by *Phoma terrestris*). A longer-term goal is to examine whether AMF can contribute to improved soil quality in the Columbia Basin by facilitating reduced reliance on soil fumigation, soil applications of fungicides, and rates of P applications in onion crops. AMF were detected in all 9 fields surveyed in 2014 (5 certified organic and 4 conventional fields) in the Columbia Basin, at incidences ranging from 42 to 90% colonization of onion roots. This suggests AMF may be more prevalent than expected in onion crops in the Basin despite the widespread use of soil fumigants (synthetic fumigants or biofumigant cover crops), although the use of AMF inoculants might help increase AMF prevalence to enhance the beneficial effects of AMF on onion production. A survey to evaluate the effects of soil fumigation on AMF in growers' fields is in progress. The commercial AMF product BioTerra Plus significantly increased onion growth, but no benefit was observed with the product MycoApply Ultrafine Endo in growth chamber trials. BioTerra Plus also suppressed stunting caused by *R. solani* in growth chamber trials. Pink root AMF trials were inconclusive because the inoculation protocol resulted in such severe pink root that no AMF effects were detected. The inoculation protocol will need to be modified to facilitate detection of any potential suppressive effect of AMF on pink root. Onion fungicide seed treatments commonly used in conventional onion crops in the Basin (Apron + Thiram, Farmore D300, and Farmore I500) all negated the beneficial effect of AMF on onion growth. However, soil application of the fungicide Quadris was either partially inhibitory or not inhibitory to AMF, and Fontelis did not inhibit AMF in either trial. These results have important ramifications for growers who routinely use fungicide seed and/or soil treatments for control of soilborne onion diseases. Attempts to evaluate AMF products in grower-cooperator trials in 2014 were complicated by incompatibility issues of the product formulations with growers' planting equipment. Although one or two AMF products were evaluated in three growers' fields, difficulties with application did not result in a reasonable evaluation of the potential value of these AMF inoculants for onion production.

Additional research is needed to address these issues in order to obtain effective, robust evaluation of the potential value and cost-benefit of onion growers using AMF products.

PROJECT DESCRIPTION

OUTPUTS

- Work Completed:

Objective 1: Determine AMF species present in conventional vs. certified organic onion crops in the Columbia Basin.

1a) AMF prevalence and species diversity: Soil samples were collected prior to onion seeding in late March-early April, and plant samples were collected mid-June from each of four conventional and five certified organic onion crops in the Columbia Basin in 2014 to determine AMF prevalence and species under these cropping systems using established microscopic and molecular methods for AMF. Soil was sampled from five GPS-referenced sites/field pre-planting, and plants were sampled from the same sites in each field in mid-June. The soil sampled from each site was subjected to nutrient analysis at Soiltest Farm Consultants, Inc. Onion seed was sown in the soil sampled from each site, in pots in a greenhouse. Onion plant height was measured, and the incidence and degree of AMF colonization determined by staining the roots as described by Vierheilig et al. (1998) ~60 days after planting. Half of the roots harvested from the onion plants were used for staining and AMF colonization calculation, and the other half were used for total DNA extraction using MoBio Powerplant DNA extraction kits. The extracted DNA was then subjected to a PCR assay for the 18S region of DNA using the primers AMV4.5NF and AMDGR (Van Geel et al. 2014). The amplified DNA will be sent to Mr. DNA in January 2015 for pyrosequencing to determine the diversity and species composition of AMF communities among fields and between conventional vs. organic fields (Stockinger et al., 2010; Van Geel et al., 2014; Yu et al., 2012). Principal component analyses, correlations and regression analyses will quantify relationships among relative AMF abundance, AMF colonization, and onion growth parameters in conventional vs. organic onion crops.

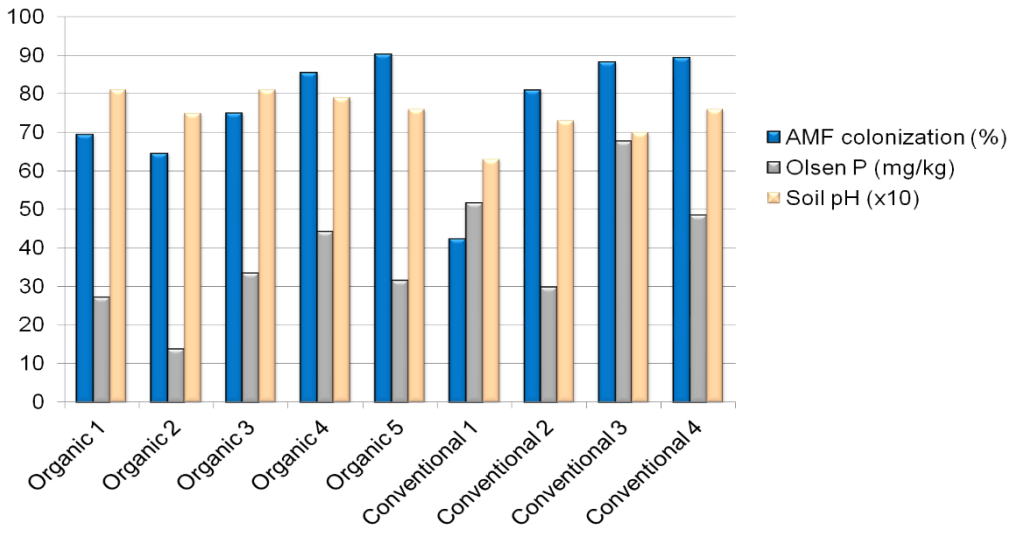

Fig. 1. Degree of colonization of onion roots by arbuscular mycorrhizal fungi (AMF) grown in soil sampled from five certified organic fields and four conventional onion fields in the Columbia Basin used to plant onion bulb crops in 2014. Soil sampled from each field was tested for phosphorus (P) level and soil pH.

Staining the roots of onion plants grown in the soil samples revealed AMF were present in all nine fields (Fig. 1). The degree of AMF colonization ranged from 42 to 90% of the roots examined. There was no difference in degree of AMF colonization between organic vs. conventional fields. This survey suggests that AMF are prevalent in onion bulb crops in the Columbia Basin despite the use of synthetic fumigants in conventional crops and planting biofumigant cover crops preceding organic crops. Soil P levels ranged

from 14 to 68 mg/kg, which was relatively low and should favor AMF establishment (Fig. 1). Soil pH ranged from 6.3 to 8.1, and was greater in the organic fields (average 7.8) vs. the conventional fields (average 7.1) (Fig. 1). Some AMF are favored by alkaline soils, hence the determination of soil pH. Only one field had a pH <7 (average 6.3 for five sites sampled in Conventional Field 1) (Fig. 1).

1b) Effect of soil fumigation on AMF: To examine potential effects of soil fumigation on AMF colonization of onion roots, soil samples were collected just prior to fumigation in fall 2014 from each of four fields in the south Columbia Basin. These fields were fumigated with metam sodium at ~38 gpa within a week of sampling. Soil was also sampled from four fields not fumigated in fall 2014 that were in close proximity to the fumigated fields. Soil from each field was placed in pots in a growth chamber and onion seed of the cultivar Tamara planted to bait AMF. The roots be stained as described above for determining AMF colonization microscopically and AMF species evaluation by pyrosequencing. Each of the eight fields will be resampled in 2015 at planting (soil) and in June 2015 (plants), the soil baited, and roots of the bait plants and the sampled plants stained as well as used for DNA extraction to determine the influence of soil fumigation on prevalence and diversity of AMF.

Objective 2: Assess the effects of AMF colonization on P use efficiency of onion roots.

2a) Effect of AMF on onion growth and P use efficiency: The effect of commercial AMF inoculants on P use efficiency and onion growth is being determined in growth chamber experiments using pasteurized soil from an organic field in the Columbia Basin. Each trial is a factorial RCBD with five replications of: 1) two commercial AMF products (BioTerra Plus, Plant Health LLC; and MycoApply Ultrafine Endo, Mycorrhizal Applications, Inc.) vs. control soil without AMF; and 2) three levels of soil P (~20, 40, and 80 ppm). Nutrient analyses of soil sampled from each field in Objective 1 was used to select a field that averaged ~20 ppm P. The soil was pasteurized to kill any AMF already present. The medium and higher P treatments were then generated by adding P fertilizer. Onion seeds were planted in soil for each treatment combination, and onion growth assessed after ~8 weeks (shoot height, root length, and shoot dry weight). Foliar nutrient analyses were completed at Soiltest Farm Consultants for each treatment combination, and nutrient analysis completed for a sample of each of the two AMF products, as well as soil samples for the three P levels (at the start and the end of the trial). The P trial is being repeated.

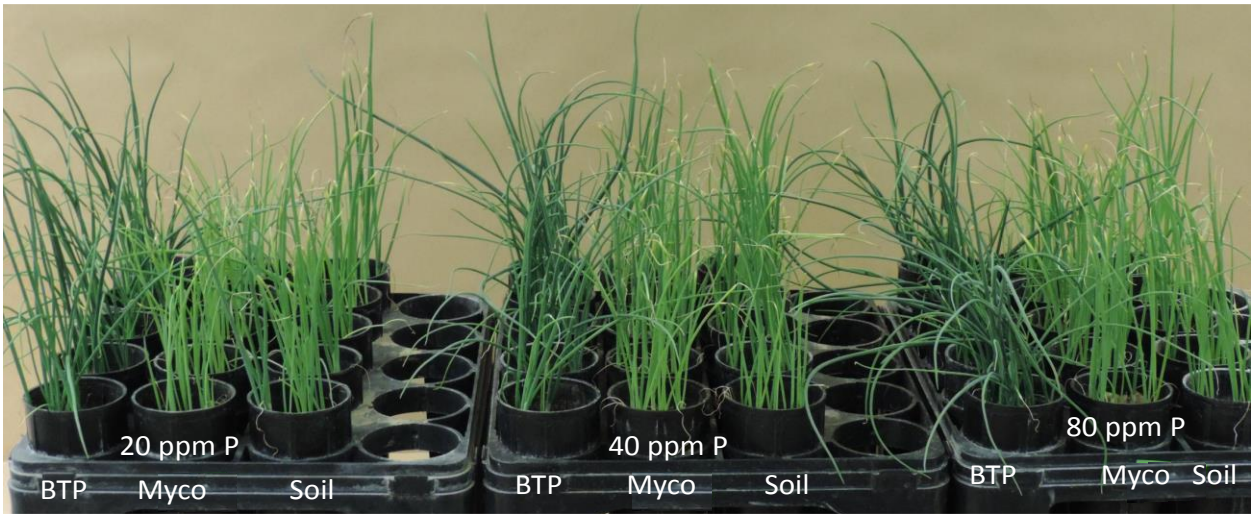

Fig. 2. Growth of onion plants in soil with an estimated 20, 40, or 80 ppm P that was not treated with AMF ('Soil') or inoculated with BioTerra Plus (BTP) or MycoApply Ultrafine Endo ('Myco') prior to planting onion seed of the cultivar Tamara. The plants were organized by treatment for taking photos just prior to assessing plant height, shoot dry weight, and staining the roots for AMF colonization, but had been arranged in a RCBD during the trial.

Analysis of variance revealed no significant effect of the three soil P levels on onion growth, a highly significant effect of AMF treatments, and no significant interaction between the two factors. Analysis of soil samples from the three soil P treatments at the start and end of the trial showed that the desired P levels (~20, 40, and 80 ppm) were not achieved as the soil analyses revealed the levels to be ~15, 30, and 40 ppm P. These low P levels may not have been adequate to assess the potential for high soil P levels to inhibit AMF colonization of onion roots.

Onion plants grown in soil amended with Bioterra Plus were significantly taller and darker green than plants in the control soil, but MycoApply Ultrafine Endo did not affect onion plant height or color (Fig. 2 and Fig. 3). Foliar nutrient analyses revealed that plants in soil with BioTerra Plus had significantly greater foliar N, K, Ca, Mg, Na, S, and Zn concentrations, and decreased foliar P, Fe, and Mn levels (Fig. 3). Plants in soil with MycoApply Ultrafine Endo did not have greater concentrations of any nutrients but had significantly reduced foliar concentrations of N, K, Na, S, Zn, Fe, and Mn (Fig. 3). Subsequent analysis of a sample of each product revealed that BioTerra Plus had far greater concentrations of N, P, K, S, B, Zn, Mn, and Fe than MycoApply Ultrafine Endo (Table 1), i.e., part of the beneficial effect of BioTerra Plus on onion growth may have been a result of the nutrient content of this product.

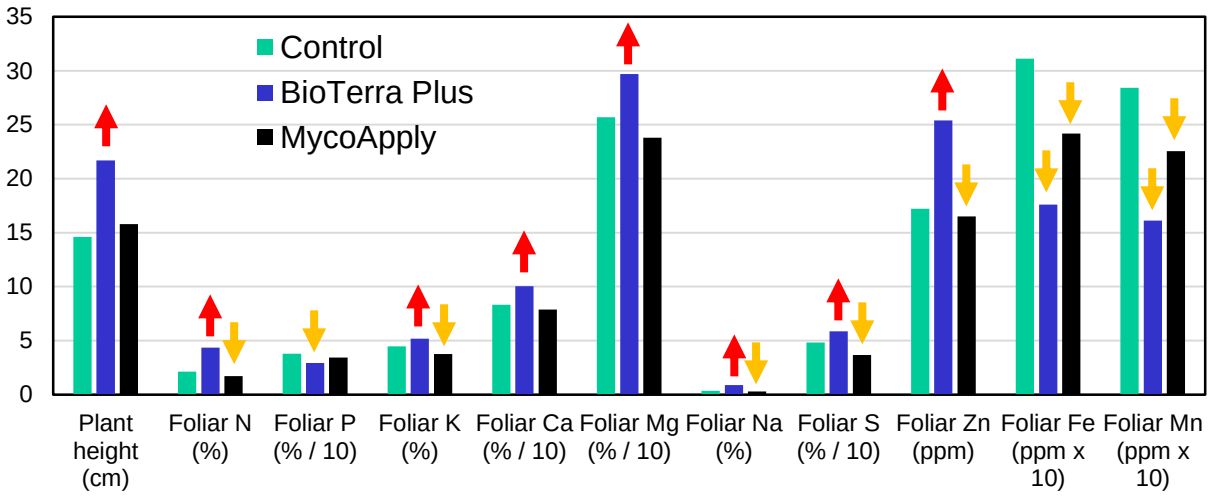

Fig. 3. Plant height and foliar nutrient analysis for onion seedlings grown in soil without AMF (control) or inoculated with one of two commercial AMF products, BioTerra Plus or MycoApply Ultrafine Endo. Red and yellow arrows indicate variables that were increased or decreased significantly in soil with the AMF product compared to plants in control soil.

Table 1. Foliar analysis of each of two commercial AMF products used in growth chamber and grower onion field trials to assess the impact of AMF on onion growth and disease suppression.

Product	N (mg/kg)	P (mg/kg)	K (mg/kg)	S (mg/kg)	B (mg/kg)	Zn (mg/kg)	Mn (mg/kg)	Fe (mg/kg)
BioTerra Plus	208	41	2,807	508	1.51	6.9	54.2	98
MycoApply Ultrafine Endo	137	20	1,139	67	0.32	1.8	4.9	34

To assess the potential confounding effect of fertilizer content vs. AMF of the two products on onion growth, the roots were stained and examined microscopically for evidence of AMF colonization. Only a single replication of stained roots had been examined for AMF quantification at the time this report was prepared, but the preliminary results revealed 0.18, 0.27, and 2.42% AMF colonization of roots in the control, MycoApply, and BioTerra treatments, respectively. The low extent of AMF colonization observed even for the BioTerra treatment suggests that at least part of the onion growth enhancement observed in

soil with this product may be from the fertility status of the product. This is being examined further as the trial is repeated and with the other growth chamber trials.

2b) Effect of AMF on two soilborne diseases of onion, stunting and pink root: Additional experiments with factorial RCBDs were set up in growth chambers to evaluate the potential role of AMF at suppressing onion stunting caused by *R. solani* and pink root caused by *P. terrestris*. Separate trials were completed for each of the two pathogens because *R. solani* infection is favored by cool soils whereas pink root is favored by warm soils so the trials were carried out in growth chambers set at different temperatures. Each trial consisted of: 1) a commercial AMF inoculant (BioTerra Plus) and control soil without AMF, and 2) inoculation of soil with the appropriate pathogen (*R. solani* AG-8 or *Phoma terrestris*) or no pathogen. Field soil from the same certified organic field sampled for the P trial was pasteurized and used for each trial. Onion seed of the cultivar Tamara was planted, and onion growth and root disease ratings completed after ~60-80 days. Roots were stained at the end of each trial, and the degree of AMF colonization will be measured microscopically as time permits because of the very time-consuming nature of this process (stained roots can be stored a long time at room temperature), and correlated with onion growth and disease rating. The experiment for each pathogen is being repeated.

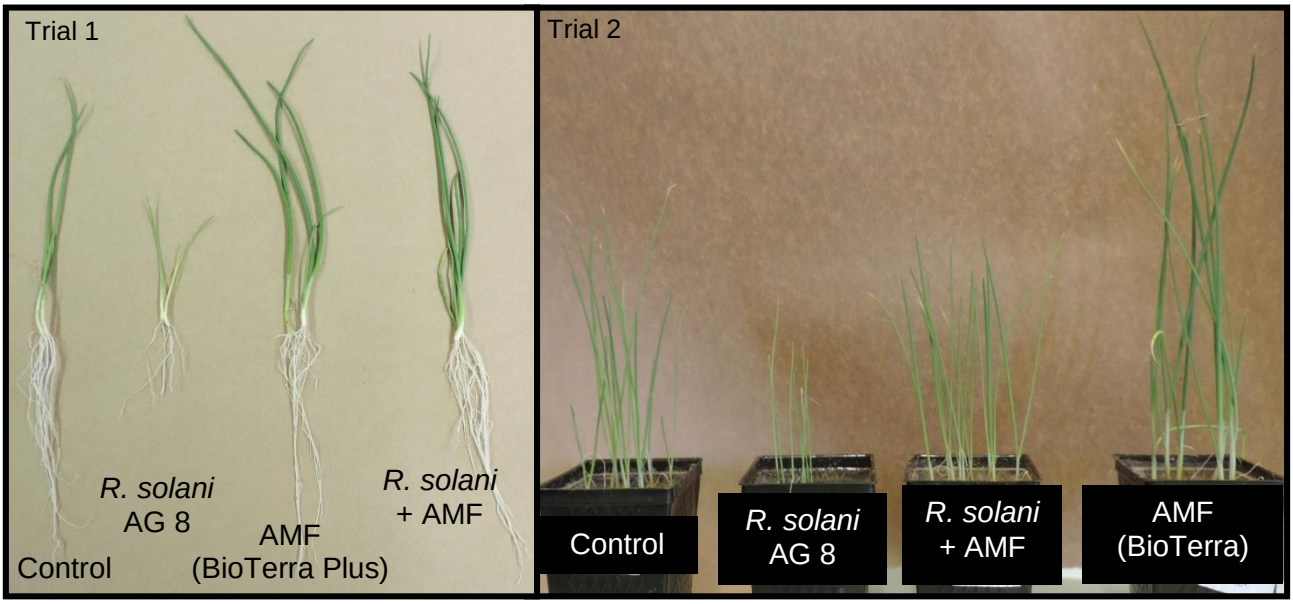

Fig. 4. Onion plants grown in soil without AMF (control) or with AMF (BioTerra Plus), in soil not inoculated or inoculated with *Rhizoctonia solani* AG 8, in each of two growth chamber trials.

In one trial, *R. solani* AG 8 reduced onion plant height by 56%, and onion shoot, root, and total dry weights by 73, 70, and 72%, respectively, compared to plants in non-inoculated soil (Fig. 4 and Fig. 5). In contrast, plants in soil with AMF were taller (average 20 cm) than plants in non-inoculated soil (16 cm). Plant height and dry weight of onion plants in soil with AMF + *R. solani* were 160 and 427% greater, respectively, than that of plants in soil with *R. solani* alone, i.e., AMF significantly reduced onion stunting. Staining of the roots of plants in soil with AMF revealed the presence of hyphae and arbuscules typical of AMF (Fig. 5), demonstrating that the BioTerra Plus product did result in AMF colonization of onion roots. Roots of plants growing in soil with *R. solani* AG 8 showed septate hyphae and sclerotial structures typical of this pathogen. Quantification of AMF colonization and *R. solani* is in progress, but preliminary results indicate the presence of AMF reduced the amount of root infection by the pathogen.

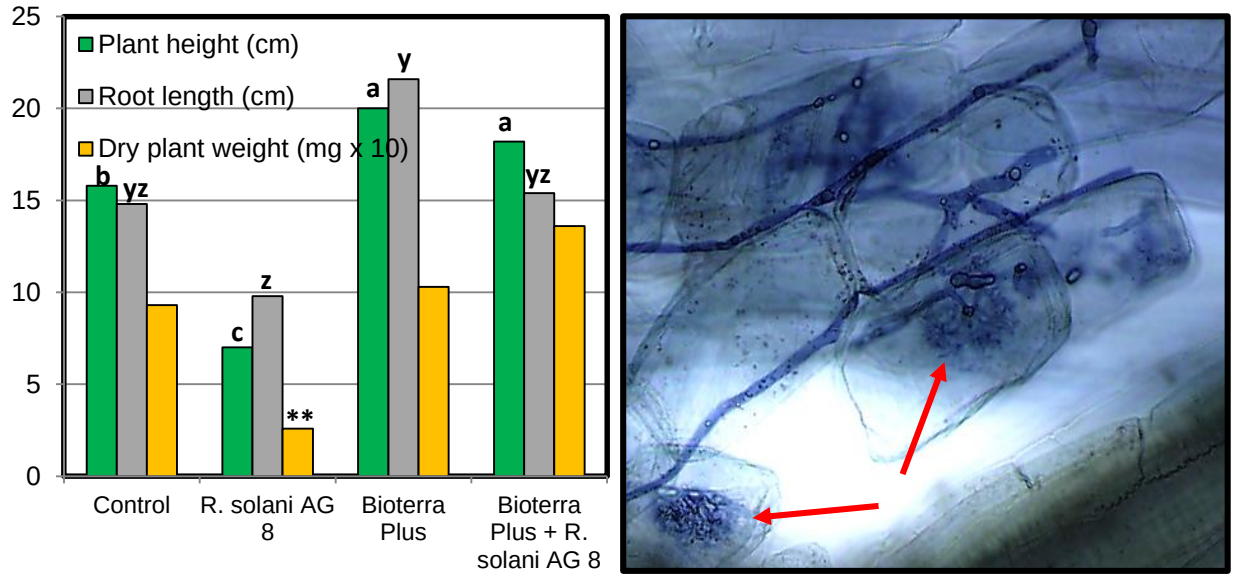

Fig. 5. Shoot height, root length, and dry weight of onion plants grown in soil without AMF (control) or with AMF (BioTerra Plus), with the soil not inoculated or inoculated with *Rhizoctonia solani* AG 8 (left); and the presence of AMF hyphae and arbuscules (red arrows) in stained onion roots grown in soil with AMF (right). For each plant growth parameter, means with the same letter(s) do not differ significantly.

The pink root trials resulted in such severe pink root that some onion plants started to die before the experiments were completed. When the roots were washed carefully to rate for severity of pink root, severe root pruning and collapse of infected, pink to red roots was evident. An alternative inoculation protocol will need to be determined that could enable quantification of any potential suppressive or antagonistic effect of AMF on *P. terrestris*, which is a far more virulent pathogen of onion than *R. solani* AG 8.

Objective 3: Evaluate the effects of seed and soil fungicide applications on AMF colonization of onion roots.

3a) Fungicide seed and soil applications: Fungicide seed treatments or soil applications that are used commonly in onion bulb crops in the Columbia Basin were tested for potential inhibitory effects on AMF colonization of onion roots. A greenhouse trial was set up with a 6 x 2 factorial RCBD with five replications of: 1) six fungicide treatments, and 2) two AMF inoculation treatments (with and without the AMF product, BioTerra Plus). Fungicide treatments included: a) Farmore D300 (metalaxyl + fludioxonil + azoxystrobin), the most common onion seed treatment for conventional bulb crops in the Columbia Basin; b) Farmore I500 (= Farmore D300 + thiamethoxam + spinosad); c) Apron + Thiram (metalaxyl + thiram), the former standard onion seed treatment; d) Quadris (azoxystrobin) incorporated into the soil to mimic the pre-plant, banded, incorporated application used by onion growers to control stunting caused by *R. solani* on very sandy soils; e) Fontelis (penthiopyrad) incorporated into the soil for the same purpose; and f) no seed or soil fungicide treatment. Fungicides were applied at typical label rates used for onion crops in Washington, and the seed treatments were applied as a film coat (slurry), not to pelleted seed. Onion seed of the cultivar Tamara was planted in soil for each treatment, and onion growth (height, root length, and biomass), and AMF root colonization measured ~60 days after planting as described previously. The experiment was repeated.

In both repeats of this trial, there was a highly significant interaction between fungicide treatments and AMF treatments in terms of onion plant height. In the absence of a fungicide treatment (seed or soil), BioTerra Plus increased onion plant height significantly in both trials by approximately 20% (Fig. 6).

However, when onion seed was treated with Apron + Thiram, FD300, or FI500, the beneficial effect of the AMF inoculum was no longer observed as there was no significant different in onion plant height in the control soil vs. soil with AMF (Fig. 6). In Trial 1, the Quadris soil application negated the beneficial effect of AMF on plant height (Fig. 6A), but the opposite occurred in Trial 2, i.e., plant height was greater in AMF vs. control that had been treated with Quadris (Fig. 6B). In both trials, Fontelis did not have an adverse effect on the AMF treatment (Fig. 6). Therefore, it appears that all three soil fungicide seed treatments have the potential to negate the benefit of AMF on onion, whereas the fungicide soil applications appear to have a less deleterious effect on the AMF product evaluated. This has important ramifications for onion growers since all conventional onion bulb crops in the Columbia Basin are planted using fungicide treated seed, and some conventional crops are also treated with pre-plant, banded, incorporated applications of Quadris or Fontelis for control of soilborne diseases like stunting and pink root.

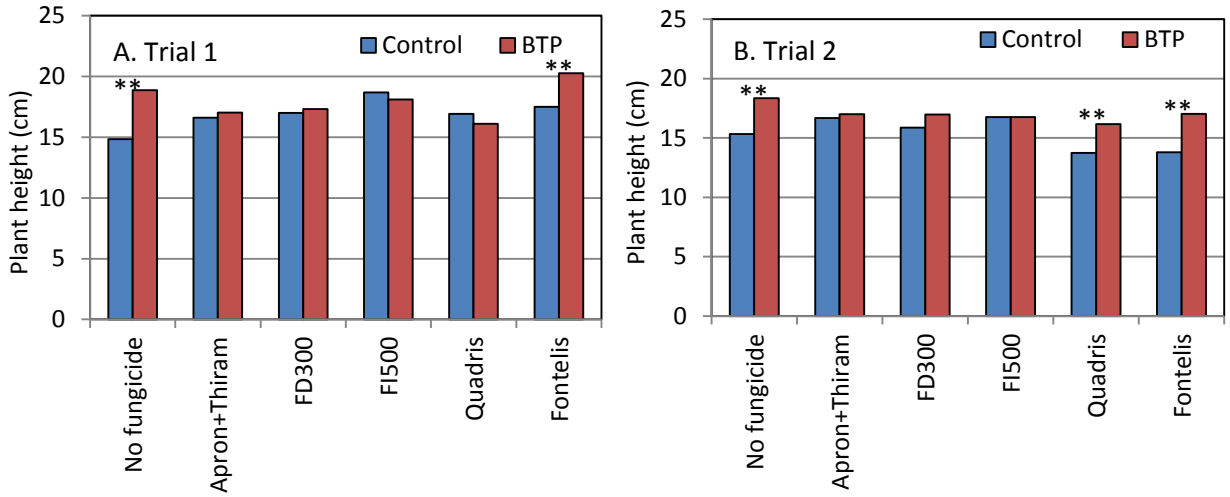

Fig. 6. Effect of onion fungicide seed treatments (Apron + Thiram, Farmore D300, and Farmore I500) and fungicide soil applications (Quadris and Fontelis) on growth of onion plants in the absence or presence of AMF (BioTerra Plus = BTP) in two growth chamber trials. The double asterisk indicates onion plant height was significantly greater in soil treated with AMF than in soil with no AMF (control) for that particular fungicide treatment.

3b) Onion grower-cooperator field trials with AMF: Attempts were made to set up three grower-cooperator field trials to evaluate AMF products for promotion of onion growth and suppression of onion diseases. Prior to planning the trials with growers, BioTerra Plus and MycoApply Ultrafine Endo were donated by the companies noted above to each of three cooperating farms. However, upon receiving the products, it became apparent that the formulations of the two products probably would not work with the planting equipment used by these growers. Grower A was able to apply MycoApply, which has a very dry, fine, powder texture, to the seed in the hopper but only at a rate of ~1/8th lb product/acre of seed planted without clogging up the planter. The supplying company had recommended ~1 lb/acre of seed planted. This product could be suspended in water, but the planting equipment used by most onion growers in the Columbia Basin is not set up to apply liquid at planting. BioTerra Plus has the consistency of a very dry, light, peat-like potting medium with highly variable particle size that was not compatible with any of the growers' planting equipment.

Grower A near Paterson, WA, set up a large RCBD trial with three treatments in a RCBD with six replications: 1) control treatment (no AMF), 2) Quadris banded and incorporated in the soil prior to planting onion seed, 3) MycoApply applied with the seed in the hopper at 1/8 lb/acre of seed planted. Each plot was 12 beds x the field diameter (~0.5 miles). The plants were monitored for differences in growth rate and incidence/severity of onion stunting (latter rated in June). Although patches of stunted

plants typical of those caused by *R. solani* AG 8 developed in the field, the low incidence of patches and the uneven distribution of the patches did not facilitate rating any of the treatments for control of this disease.

Grower B, who grows certified organic onion bulb crops, was able to apply MycoApply Ultrafine Endo and BioTerra Plus in the gandy boxes attached to the drip tape applicator, which set the drip tape ahead of planting the onion seed. A hose dribbled each product onto the soil surface immediately behind the drip tape applicator (~1-2 cm above the soil surface), and a wheel cage behind the hose then disturbed soil over the product, i.e., the products could not be applied in-furrow, as was recommended by the suppliers. Each product was applied to 4 double-rows of onions in >10 replicated strips across the diameter of the field (~0.5 miles/strip). There were problems with bridging of the products in the gandy boxes during application but, more importantly, very windy conditions on the day of application resulted in a majority of each product being blown off the soil surface. The plots were monitored through the season for any evidence of growth enhancement from the two AMF products. Severity of pink root was rated in July/August on both ends of the trial, but there were no differences in pink root severity for either of the AMF treatments compared to the replicated control plots with no AMF. Pink root severity averaged 66.6% in the north half of the field, and 41.6% in the south half of the field (which had double the rotation interval since the previous onion bulb crop compared to the north half of the field, hence lower pink root pressure).

Grower C was able to get MycoApply Ultrafine Endo applied to the seed in the hopper at planting to a single strip across the diameter of the field, but was not certain what rate of application he was able to achieve and how far across the field the treatment lasted. The 12-bed wide strip of onions planted with the AMF product were monitored for onion growth, and bulbs rated for severity of pink root in August in each of the treated strip and an adjacent non-treated section of the field. Severity of pink root averaged 34.5 ± 11.0% for the control (non-treated) bulbs vs. 22.1 ± 9.7% for bulbs in the section treated with AMF. This suggests no significant effect of the treatment on pink root, but the lack of replication and randomization of the treatment prevented statistical evaluation of the effects of the AMF treatment.

Given the problems experienced with compatibility of AMF product formulations and onion growers' planting equipment, additional AMF products available to growers are being investigated to determine which products could be evaluated in replicated, randomized trials in growers' fields in 2015. In addition to product choice, research will be needed on rates of application and methods of application. Ideally, AMF products should be placed in-furrow immediately beneath the seed so that the emerging radicle is colonized by AMF immediately at germination, even prior to emergence.

- Publications, Handouts, Other Text & Web Products:

Sharma-Poudyal, D., Paulitz, T.C., Linderman, R.G., and du Toit, L.J. 2014. Effect of arbuscular mycorrhizal fungi on onion growth and onion stunting caused by *Rhizoctonia solani*, 2013. Plant Disease Management Reports 8:V305.

Schroeder, B.K., du Toit, L.J., Waters, T., and Reitz, S. 2014. Tackling challenges facing Pacific Northwest onion growers. Onion World Dec. 2014:20-23.

See WSU Onion Field Day handout listed below under 'Outreach'.

- Outreach & Education Activities:

Conference presentation

du Toit, L.J., Knerr, A.J., Sharma-Poudyal, D., and Paulitz, T. 2014. Evaluation of arbuscular mycorrhizal fungi in onion production in the Columbia Basin of Washington and Oregon. Pp. 17-18 in: Abstracts of the 2014 National Onion Association/National Allium Research Conf., 3-5 Dec. 2014, Scottsdale, AZ.

Field day presentation and handout

du Toit, L.J., Sharma-Poudyal, D., Knerr, J., and Paulitz, T. 2014. Mycorrhizae in onion bulb production in the Columbia Basin. Pp. 7-8 in: 2014 WSU Onion Cultivar Demonstration & Field Day handouts. Washington State University, Pullman, WA. 2014 WSU Onion Field Day, Carr Farms, Pasco, WA, 28 Aug. 2014. Presented update on research projects on *Rhizoctonia* induced stunting and mycorrhizae

in onion crops. (~100 state/federal regulators, industry reps, breeders, growers, consultants, researchers, extension educators.)

Symposium poster

Knerr, J., Sharma-Poudyal, D., Paulitz, T., and du Toit, L.J. 2014. Evaluation of arbuscular mycorrhizal fungi (AMF) in conventional and organic onion production in the Columbia Basin, and the potential use of AMF to reduce the impact of soilborne pathogens of onion. WSU Center for Sustaining Agriculture & Natural Resources (CSANR) BIOAg Symposium "Saving Nature and Improving Agriculture: Where does Nature's Wisdom Lie?", 28 Oct. 2014, Pullman, WA.

Invited presentations

du Toit, L.J. Soil health for disease suppression. Building Soils for Better Crops 2014 Conf., 10 Dec. 2014, Moses Lake, WA. (~125 people)

du Toit, L.J. Onion mycorrhizae. Onion session of the Pacific Northwest Vegetable Assoc. Annual Convention & Trade Show, 12-13 Nov. 2014, Kennewick, WA. (~250 people)

du Toit, L.J. Mycorrhizae and Fusarium basal rot in onion bulb crops. Two invited presentations and discussion with onion bulb growers and consultants in the Ceres and Kouebokkeveld regions of the Western Cape Province, Ceres, South Africa, 11 Mar. 2014. (40 people)

IMPACTS

- Short-Term:

The study is revealing the prevalence and diversity of AMF in conventional and certified organic onion bulb crops in the Columbia Basin. Since onion production is an intensive, high input, high value system, the study should elucidate the potential value of AMF for enhancing P nutrition and suppressing onion root diseases. Information generated on the effects of fungicides applied as seed treatments or incorporated into soil will help growers optimize fungicide use to minimize negative impacts on AMF colonization in onion crops without compromising root disease management.

- Intermediate-Term:

Dissemination of results to consultants, extension personnel, and growers through field days, conferences, and publications will increase awareness of the potential role of AMF in soil management and crop productivity. Depending on results, the study may lead to increased adoption of AMF inoculation in onion crops and avoidance of production practices that adversely affect AMF. Since this project was initiated, more onion growers in the Columbia Basin are evaluating AMF products on their farms. This highlights the need for independent, robust trials to determine the cost-benefit of such treatments.

- Long-Term:

This research is expected to provide scientific justification for the significance of robust AMF communities in the intensely cultivated Columbia Basin, to potentially increase availability of P that should enhance onion growth and increase suppression of onion root diseases. This could reduce rates of P fertilizer application and dependency on fungicides, and possibly even soil fumigation and soil quality. This will, in turn, reduce onion production expenses. Results of this project could also be applied to other high value crops in the Columbia Basin that form mycorrhizae, e.g., potato and carrot.

ADDITIONAL FUNDING APPLIED FOR / SECURED

Additional funding was not applied for or secured in 2014 since some of the trials are still in progress. However, we plan to submit a proposal for a Washington State Department of Agriculture Specialty Crop Block Grant or a Western Region IPM grant in 2015.

GRADUATE STUDENTS FUNDED

None since the funding was only for 1 year. The postdoctoral research associate supported by this funding, Dr. Dipak Sharma-Poudyal, took a permanent position with the Oregon Department of Agriculture in July 2014. We hired temporary technical support to help finish as much of the project as possible by winter 2014-15 - Jenny Knerr worked on the project full-time from June. She was offered a

technical position at the Univ. of Idaho, starting in January 2015, but has offered to work part-time through winter/spring 2015 on the pyrosequencing work as well as some growth chamber trials and baiting of soil sampled in fall 2014 for the fumigation component of the project.

RECOMMENDATIONS FOR FUTURE RESEARCH

Additional research is needed to assess various commercial AMF products available to growers in order to determine compatibility of the formulations with growers' planting equipment. The rates and methods of product application need to be evaluated using various growers' equipment to obtain adequate efficacy data and calculate cost-effectiveness of the AMF products. The effects of biofumigant cover crops (e.g., mustards and Sudan grass) on establishment of AMF in growers' fields, remains to be investigated, given the widespread use of these crops in certified organic production in the Columbia Basin. This will help determine if organic onion growers should consider AMF inoculation treatments following the use of such biofumigant crops. This research should continue to evaluate in growers' fields as well as controlled, replicated growth chamber trials the potential value of AMF inoculation for suppressing onion diseases and enhancing onion fertilizer use efficiency, using a diversity of products available to growers. It will also be important to evaluate the compatibility of various AMF products with different fungicides, including the methods of application of fungicides used by onion growers in this region, to help maximize benefits of AMF treatments. Ideally, effective use of AMF may enable growers to reduce the number of fungicide applications or eliminate some fungicide products completely. This research could be applied to other high value crops grown in the Columbia Basin that form mycorrhizae and for which soil fumigation, soil and seed applications of fungicides, and high fertilizer application rates are used widely, e.g., carrot and potato.