Farm-Grown Microbial Soil Inoculants: Effects on Bread Wheat Yield and Quality

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Graduate Student:

Aaron Englander

Faculty Advisor:

Dr. Eric Gallandt
University of Maine

Project Information

Summary:

The use of microbial soil inoculants in agriculture is of increasing interest among growers and scientists. Research on the efficacy and application of soil inoculants, especially on-farm produced inoculants, is limited. This study aimed to determine the effects of microbial inoculants on bread wheat *(Triticum aestivum* L.*)* arbuscular mycorrhizal fungus (AMF) colonization, biomass accumulation, nutrient uptake, grain yield, and grain protein in a containerized greenhouse experiment and 2 years of field trials. We used a commercially available AMF inoculant, an on-farm produced AMF inoculant, and an on-farm produced indigenous microbial inoculant. The impact of the inoculants was compared with their relative controls, which were sterilized inoculants. In the greenhouse, both AMF inoculants enhanced AMF colonization rates as compared with their relative controls, but only the on-farm produced AMF increased aboveground biomass and phosphorus (P) uptake. In the field, the AMF inoculants vs. their respective controls showed no differences for any of the measured parameters, this may have been due to competition from the native soil microbial community and non-limiting soil P levels. When compared against all other treatments, the indigenous microbial inoculant (IMO+) increased wheat aboveground biomass, nutrient uptake and grain yield, but no increases were observed when IMO+ was contrasted against its relative control (IMO-). Therefore, wheat growth enhancements from IMO were likely due to nutrient supply from the compost-based carrier material.

Educational outreach and an assessment of inoculant production costs were also conducted. Outreach included presentations at field days, professional meetings, grower conferences, a graduate student poster competition, and a workshop on microbial inoculant production. The production cost evaluation found the on-farm

produced inoculants to be less expensive than the commercial inoculant in the greenhouse but more expensive in the field. The greenhouse costs ranged from less than $0.01 to $0.12 per gallon pot, and the field application costs were $11 to $445 per acre. The information generated from this project will help farmers and gardeners evaluate whether microbial inoculants and on-farm production of inoculants are appropriate for their farm.

Introduction:

Active microbial communities are essential to soil health needed to support crop production in sustainable agriculture systems (Birkhofer et al., 2008). Studies have demonstrated that microorganisms can benefit agricultural crops by increasing water use efficiency and drought tolerance (Al-Karaki, 1998), nutrient uptake (Zaidi et al., 2003), organic matter decomposition and nutrient availability (Higa and Wididna, 1991), resistance to plant pathogens and diseases (Linderman, 2000), grain yield (Bahrani et al., 2010), and by decreasing nutrient loss due to leaching (Verbuggen et al., 2011).

Mycorrhizal fungi are an important group of soil microorganisms for plant growth. Over 90% of Earth's plants form mycorrhizal relationships (Smith and Read, 2008), including wheat, which is associated with AMF (Hetrick and Wilson, 1992). Currently, local bread wheat production in Maine is of growing interest for farmers, bakers, millers and consumers. Nutrient management is one of the main concerns in wheat production systems.

Mycorrhizae form symbiotic relationships with plant roots in which the fungus can increase plant nutrient uptake by effectively increasing root surface area in return for photosynthates. Enhanced phosphorus (P) uptake is one proposed mechanism for the reported increased yields and biomass of AMF inoculated crops (Smith and Read, 2008). Wheat inoculated with AMF demonstrated increased P uptake and biomass compared to a sterilized control in a containerized study (Al-Karaki, 1998). A study investigating P efficiencies of old and modern wheat cultivars found significant increases in P uptake in both old and modern AMF inoculated cultivars (Zhu et al., 2001).

Common agricultural practices such as tillage, fallowing fields, and the use of inorganic chemical fertilizers and pesticides can negatively affect soil microbial diversity and abundance (Mäder et al., 2002). Soils with depleted microbial communities are often associated with poor soil quality (Doran and Parkin, 1994), and decreased organic matter, nutrient availability and water retention (Higa and Wididna, 1991). In a long-term study conducted by Oehl et al. (2004) in Switzerland, AMF diversity, colonization and spore counts were greater in organically managed than conventional plots, which was attributed to increased synthetic fertilizer inputs in the conventional management systems.

However, a Canadian study that compared diversity and abundance of AMF species in wheat fields, roadsides and natural prairie ecosystems, found that diversity alone was lower in agricultural sites, while abundance was not (Dai et al., 2013). The impact of agriculture on the soil microbial communities' abundance and diversity appears to depend upon management strategies such as organic versus conventional (Oehl et al., 2004), tillage (Schnoor et al., 2011), and crop choice (Monreal et al., 2010) and factors like climate (Dai et al., 2013) and soil type (Verbruggen et al., 2013).

The use of microbial inoculants is not new; use of rhizobial inoculants for leguminous crops was established over 100 years ago. However, today an industry is growing

based upon the production of mycorrhizal and other microbial inoculants to be used to promote plant growth in agricultural systems. There are a wide variety of commercially available microbial inoculants that farmers are using in the United States and internationally that are purported to enhance plant growth and yield. A prominent Maine organic farmer has been using MycoApply® (Mycorrhizal Applications inc., Grants Pass, OR) on bread wheat and thinks he sees positive effects on his crops but wants an objective assessment of its effectiveness. He has asked us to test the product in a controlled study at our research station.

Recent research has produced conflicting results regarding the effects of microbial inoculants on crop production. Verbruggen et al. (2011) found that AMF inoculated corn (*Zea mays*) had lower plant biomass than corn grown without AMF inoculation. The authors attributed this reduction to inoculated plants losing more photosynthate to AMF than non-inoculated plants. Conversely, Hetrick and Wilson (1992) and Al-Karaki et al. (2004) found AMF inoculation to increase wheat yields; and Bahrani et al. (2010) found that winter wheat yields and grain protein content increased with a combined inoculation of AMF and the beneficial bacteria Azobacter. Numerous studies have shown increased AMF colonization of inoculated plants grown in sterilized soil (Smith and Read, 2008), but the effects of inoculation on root colonization of plants grown in soils with an existing AMF community are less predictable (Janousková et al., 2013). Contrasting research results indicate that the efficacy of microbial inoculants remains undetermined and is dependent upon factors such as host crop, inoculant organism(s), background soil microbial community, nutrient and water availability, and the type of production system (e.g., greenhouse, nursery, field).

Should microbial inoculants be effective, farmers may opt to make them on the farm to reduce dependence on purchased inputs. Douds et al. (2005) developed one method for producing an AMF inoculant on farms that can be used for a variety of agricultural crops. This method involves culturing bahiagrass (*Paspalum notatum* Flugge) seedlings inoculated with AMF in grow bags, with a compost and vermiculite media. After one season of growth, the inoculated bahiagrass winter-kills in temperate regions and the remaining media contains AMF propagules for use as inoculum the following season as a potting or pre-plant soil amendment.

In a field trial, potatoes inoculated with the on-farm produced AMF inoculum produced 33% greater yields with conventional fertilizer and 45% greater yields with compost additions compared with their respective non-inoculated controls (Douds et al., 2007). In a separate study, strawberry (*Fragaria* x *ananassa*) plants inoculated with on-farm produced AMF yielded 17% more fruit than untreated controls (Douds et al., 2008).

A second method for on-farm production of microbial inoculants is integral to the Korean Natural Farming (KNF) technique that encourages self-sustaining, closed loop systems through minimizing external inputs. Korean Natural Farming is practiced in South Korea (Lee, 1998) and other Asian/Pacific nations, as well as Hawai'i (Zakaria, 2006; Cho, 2010; 1999; Prell, 2010). Korean Natural Farming utilizes an on-farm produced inoculant called Indigenous Micro-organism (IMO) that is intended to increase the diversity and activity of indigenous soil microbial communities. As outlined by Park and Duponte (2008), IMO production involves capturing the native microbial population found in decomposing organic matter (grass clippings, compost, leaf mulch etc.), culturing these microbes on a carbohydrate source such as wheat or rice bran, and then mixing the cultured bran with field soil before application as a potting, pre-plant or side-dress soil amendment.

Observed benefits of KNF in Malaysia included a 30% reduction of input costs and an increase in drought tolerance, disease resistance, fruit quality, soil organic matter and water retention (Zakaria, 2006). Multiple popular articles and books recommend the use of IMO (Prell, 2010; Carandang, 2011) for its agricultural and economic benefits. However, only one peer-reviewed, quantitative experiment conducted with IMO could be found (Zuraihah et al., 2012). In this trial, when compared to composted chicken manure, IMO increased soil nitrogen (N) levels, but decreased soil P and crop yields of three leafy vegetables (*Brassica alboglabra, Bassica chinensis*, and *Lactuca sativa*). The agronomic effects of the IMO inoculant remain relatively unknown in the scientific community due to a lack of quantitative evaluations in peer-reviewed literature

Project Objectives:

1) *Evaluate the effects of 2 farm-produced and 1 commercially available microbial soil inoculants on bread wheat biomass accumulation, nutrient uptake, grain yield and protein concentration in greenhouse and field trials*.

The greenhouse trial was completed in May 2012, and two years of field trials were conducted in 2012 and 2013. The microbial inoculant treatments had more of an effect on wheat growth parameters in the greenhouse trial than in the field. This may have been due to increased competition from native microbes in the field trial. See the results and discussion section for detailed results.

2) *Evaluate the costs and returns associated with producing and using the different inoculants.*

An assessment of on-farm inoculant production costs has been completed. Due to minimal inoculant treatment effects the returns were not analyzed. The commercially available MycoApply® AMF inoculant cost $0.12 per container in the greenhouse and $12/acre in the field. In the greenhouse, the on-farm AMF and IMO cost less than $0.01 per container and in the field, the on-farm AMF and the IMO cost $445 and $130 per acre, respectively. See the economic analysis section for the detailed cost assessment.

3) *Provide results to researchers and farmers through a factsheet, presentations at field days and conferences, and a hands-on workshop*.

Outreach has included oral and poster presentations to farmers, gardeners, researchers, agricultural service providers and students. Additionally, a hands-on workshop that presented methods for on-farm production of microbial inoculants was held at the University of Maine. The outreach and publications sections provides more details on the presentations and workshop, as well as upcoming outreach that has developed as a result of this NE-SARE graduate student grant.

Cooperators

- Dr. Eric Gallandt

  gallandt@maine.edu

  Professor

University of Maine

205 Roger Clapp Greenhouse
Orono, ME 04473

(207) 581-2933 (office)

- Dr. Ellen Mallory

  ellen.mallory@maine.edu

  Cooperative Extension Sustainable Agriculture Specialist and Grad Student Advisor

  University of Maine

  495 College Ave.
  Orono, ME 04473

  (207) 581-2942 (office)

Research

Materials and methods:

Inoculant Production and Source

The purchased inoculant was MycoApply® (Mycorrhizal Applications Inc., Grants Pass, O.R., http://www.mycorrhizae.com), which is a mixture of four AMF species (*Glomus aggregatum, Glomus etunicatum, Glomus intraradices,* and *Glomus mosseae*). The MycoApply® product is referred to as "MYAP."

Production of the on-farm AMF inoculant (OFAMF) was made at the University of Maine, Orono (UMaine) with the methods described in Douds et al. (2005). In this method, bahiagrass (*Paspalum notatum* Flugge) seedlings were pre-inoculated (at the USDA-ARS lab in Wyndmoor, PA) with four AMF species (*Glomus claroideum*, *Glomus etunicatum, Gigaspora gigantea,* and *Glomus mosseae*). The inoculated bahiagrass seedlings were planted into 25 L grow bags with a compost and vermiculite mixture (10:1 [v/v]). The bahiagrass grew all season and then winterkilled. The following year, the growing medium contained AMF propagules and was ready for application.

The IMO inoculant was also prepared at UMaine with the KNF method developed by Han Kyu-Cho (Cho, 2010; Park and DuPonte, 2008). The IMO production involved 4 steps. First, cooked rice was placed in a wicker basket with a cloth cover and buried in the center of a 30 L container filled with active compost (horse bedding and leaf mulch, 2:2 [v/v]). The 30 L container was kept in the greenhouse for 5 days. The active compost, 30 L container, and the greenhouse were modifications adapted for temperate climate IMO production. Then, after 5 days the inoculated rice was removed from the wicker basket and mixed with an equal volume of brown sugar to make an inoculant stock. Next, a 1:500 (v/v) solution of inoculant stock and non-chlorinated water was added to 68 kg (dry wt.) wheat bran to bring the bran to 60% moisture. The inoculated bran was covered with straw mats and cultured on the ground for 10 days at ambient outdoor temperature (average: daytime 19°C, nighttime 8°C). The bran was oxygenated by turning with a shovel when temperatures exceeded 40°C. Finally, a 2:1:1 (v/v/v) mixture of the cultured bran,

composted horse manure and field soil was brought to 60% moisture with non-chlorinated water, covered with straw mats and cultured on the ground for 10 days, and oxygenated when temperatures exceeded 40°C. Oxygenation was stopped when IMO temperatures stabilized at 25°C.

Each inoculant treatment, designated with a "+" symbol, had a relative control treatment, designated with a "-" symbol. The relative control for MYAP+ was MYAP-, which received no inoculant. The relative controls for the OFAMF+ and IMO+ treatments were sterilized versions of the inoculants to ensure equal additions of nutrients and carrier material (e.g., vermiculite, compost, wheat bran) between the treatments and their controls. Inoculants were sterilized by autoclaving for 2 cycles at 115°C for 50 minutes.

Greenhouse Growing Conditions

The experiment was conducted at the Roger Clapp greenhouse at UMaine in 2012. The greenhouse trial allowed us to test the inoculants in a controlled setting. Wheat was grown in a soil-based potting mixture of pool filter sand, unsterilized field soil, peat moss, and coarse perlite (1:2.5:6.5:6.5 [v/v/v/v]). Unsterilized field soil was used in the greenhouse container media to examine how the inoculants would perform with the presence of a background microbial community. The soil media had approximately 5500 propagules of background AMF in each container as determined by a most probable number bioassay (MPN).

Lime was added at 3.0 kg m^{-3} to correct the pH to 6.5 (Bing and Boodley, 1981). Containers (3.8 L) were then filled with 1.3 kg soil media (dry wt. equivalent). Nitrogen, P, and K were added in the form of blood meal, bone char, and langbeinite (Su-Po-Mg). In order to avoid confounding microbial inoculant effects with nutrient effects, N, P and K were balanced across treatments. Containers were seeded with hard red spring wheat (cv. Glenn) and hand watered to maintain 40% soil moisture. Wheat plants were grown with 16 hours of artificial light and the temperature was a mean of 22°C. Plants were routinely monitored for pests and diseases. Nematodes and spinosad were used for pest control of fungus gnats (*Bradysia sp.*)and western flower thrips, respectively.

Greenhouse Experimental Design

The experiment was a randomized complete block design (RCBD), with 5 blocks and two replicates per block to allow for two destructive sample dates. Each replication included the three previously described inoculants and their relative controls: MYAP+, MYAP-, OFAMF+, OFAMF-, IMO+ and IMO-. In total there were 60 containers in the experiment comprised of 6 treatments x 5 blocks x 2 sample dates. The containers were rearranged randomly within blocks once per week to increase uniformity of the growing conditions. Inoculant application rates for the greenhouse trial are detailed in Table 1.

Greenhouse Data Collection

Two destructive harvests at boot and late milk growth stages were conducted to determine AMF colonization, biomass production and nutrient uptake. Wheat was not grown to grain in the greenhouse. Wheat plants were cut at soil level and dried to determine aboveground biomass. The biomass was ground and submitted to the UMaine Analytical Lab for determination of N, P, K, Ca, Mg, Al, B, Cu, Mn, Zn, and Fe concentrations. Nutrient concentration was multiplied by wheat dry weight to determine nutrient uptake. Arbuscular mycorrhizal fungi colonization was determined at both sampling dates for the mycorrhizal inoculants and their

respective controls only. A sub-sample of roots from each pot was washed and stained with the trypan-blue dye staining process of Phillips and Hayman (1970) modified to exclude phenol and colonization was quantified via the gridline intersect method (Giovannetti and Mosse, 1980) at 40X magnification (Figure 1 and 2).

Field Site Characteristics and Management

The field experiment was conducted over 2012 and 2013 in Old Town, ME. In 2012, the trial was grown on a Suffield silt loam soil with a pH of 6.4, 6.0% organic matter, and 7.8 kg ha^{-1} soil test P and 218.4 kg ha^{-1} soil test K. In 2013, the experiment was on a Buxton silt loam soil with a pH of 6.3, 4.7% organic matter, and 6.8 kg ha^{-1} soil test P and 309.1 kg ha^{-1} soil test K. In both years, the experiment was preceded by field corn that was cut for silage in the fall. The 2012 field site was certified organic (MOFGA Certification Services, LLC), but the 2013 site was not. The bulk soils contained approximately 3 million propagules m^{-2} of naturally occurring AMF as determined by the MPN bioassay. Field plots were prepared with a chisel plow and Perfecta® II harrow. Dairy manure was spread at a target rate of 70 kg N ha^{-1}, and hard red spring wheat (cv. Glenn) was seeded at a rate of 500 seeds m^{-2} with a cone type plot seeder in May. Plots were hand weeded 4 weeks after planting.

Field Experimental Design

A RCBD was used with four replications of the three described inoculant treatments and their relative controls for a total of 24 plots. Plot size was 1.2 m by 5.0 m. Inoculant application rates for the field trial are detailed in Table 2.

Field Data Collection

Aboveground biomass at the wheat soft-dough stage (“peak biomass”) was collected to assess plant productivity and nutrient uptake. Wheat biomass was cut in two 0.1 m^2 quadrats per plot and bulked. Wheat tissue was processed and submitted for nutrient content as in the greenhouse trial. Also at peak biomass, root systems of 12 wheat plants from each plot were subsampled, washed, stained and assayed for AMF colonization as in the greenhouse trial.

For both years, wheat grain was harvested using a small plot combine. After the grain was cleaned, test weight and moisture were determined and yield was corrected to 135 g kg^{-1} grain moisture. A subsample of grain was ground and submitted to the UMaine Analytical Laboratory for determination of N concentration by combustion. Grain protein concentration was determined by multiplying the N concentration by 5.7 N (Am. Assoc. of Cereal Chem. Method 46-30) and corrected to 120 g kg^{-1} grain moisture.

Statistical Analysis

The greenhouse trial data were analyzed with a linear model (JMP, SAS Institute, Cary, NC, USA). The field trial data were analyzed with a mixed-model Analysis of Variance (ANOVA) with year and replication as random effects and treatment as a fixed effect to test the significance of year, treatment, and year X treatment interaction on experimental parameters. For both trials, pre-planned contrasts were

used to compare inoculants versus their relative controls, and IMO+/- versus all other treatments. Each contrast was chosen to evaluate a specific hypothesis, not a grouped comparison, therefore a significance level of alpha=0.05 was used for all contrasts (Quinn and Keough, 2002).

- Tables 1 and 2: Inoculant AMF and nutrient content
- Figures 1 and 2, AMF root stains

Research results and discussion:

In the greenhouse, AMF colonization in the control treatments indicated the presence of AMF in the unsterilized soil media. Despite the background AMF community, the on-farm produced and commercially available AMF inoculants increased AMF colonization by 47% and 72%, respectively, compared with their relative controls at the late milk stage (Table 3). This finding supports prior research that showed increased colonization of AMF inoculated field peas grown in pots with an unsterilized soil media (Jin et al., 2013). The field trial, however, demonstrated no enhancement of AMF colonization with inoculation (Table 4).

In the 2013 field trial, the MPN assay estimated more than 3 million propagules per m^2 in a 20 cm deep plow layer. The native AMF population likely outcompeted the added inoculant strains, even when applied directly to the seed as in the case of MycoApply®. There were no differences observed between inoculants and their relative controls in the field trial (Table 4). The absence of inoculant treatment effects on all measured parameters likely resulted from the lack of increased mycorrhizal fungus colonization. The increase in AMF colonization from inoculation seen in the greenhouse trial could be attributed to a lower concentration of background AMF species present in the containers (5500 propagules per pot).

In the greenhouse, aboveground biomass at late milk stage was 17% greater with OFAMF+ than OFAMF- (Table 3). The OFAMF+ treatment also increased P uptake by 27% compared with OFAMF- (Table 5), suggesting that the inoculant increased P availability for the plant, thereby enhancing aboveground biomass. Past studies have shown enhanced crop biomass and P-uptake promotion with AMF inoculation in wheat (Al-Karaki, 1998), marigolds (Linderman and Davis, 2004), and potatoes (Douds et al., 2007). In this study, we demonstrated that an on-farm produced AMF inoculant can be effective in boosting wheat growth in a containerized greenhouse setting.

In contrast with the on-farm produced AMF+ inoculum treatment, the commercially available inoculum (MYAP+) had no significant effects on biomass or nutrient uptake in the containerized study (Tables 3 and 5). These findings differ from prior studies (Hetrick and Wilson, 1992; Al-Karaki et al. 2004) that found commercial AMF inoculum to enhance wheat biomass. Interactions between the inoculant organism and the background AMF species in the soil media may have caused this contrary finding (Janousková et al., 2013). Further, the inoculant used in the present study contained *G. intraradices*, a “P-tolerant” AMF species (Douds and Schenck, 1990) thatcan create a carbon drain from the host plant in the absence of a P-uptake promotion, which does not typically occur if soil P levels are above 50 mg kg^{-1} (Sylvia and Schenk, 1983). The soil P level in the greenhouse trial was 69 mg kg^{-1}.

In both the greenhouse and field trials, there were no measurable differences between the biologically active IMO+ and its sterilized control IMO- for all

parameters. However, when compared with all other treatments in the greenhouse, the IMO+ and IMO- treatments enhanced wheat biomass by 31%, and increased nutrient uptake of N, Ca, K, P, Mg, Fe and Zn (Tables 3 and 5). In the field trial, IMO+/- compared with all other treatments increased biomass and grain yield by 6 and 7%, respectively (Table 4). IMO+/- also enhanced nutrient uptake of K, Mg and P when compared with the other inoculants (Table 6). Higher application rates in the containerized greenhouse trial than the field trial, likely resulted in the greater biomass increases. The lack of treatment effects between IMO+ and IMO- suggests that the wheat growth enhancements seen with the IMO+/- as compared with all the others were due to enhanced nutrient supply from the IMO inoculant media rather than microbial activity during wheat plant growth.

- Tables 3, 4, 5 and 6: Greenhouse and field trial results

Research conclusions:

Results from the field study imply that AMF inoculation of hard red spring wheat (cv. Glenn) grown in soils with healthy AMF populations and adequate nutrient and water supply does not increase AMF responsiveness. Inoculants may be most effective during drought periods or in soils that suffer from depleted nutrients and soil microbiology (Al-Karaki et al. 2004). As well, AMF inoculation of crops preceded by non-AMF host crops (e.g. brassicas) may be effective for enhancing AMF responsiveness (Monreal et al., 2011). In our field study, wheat was preceded by field corn, which is an AMF host crop. Additionally, wheat may be less susceptible to AMF colonization due to having very fine roots (Plenchette et al., 1983). Crops with coarser roots than wheat, such as onions, leeks, corn and potatos, may be more suitable to AMF inoculation. A recent study in Maine found that the on-farm produced AMF inoculant and MycoApply® increased leek yields by 12 and 30%, respectively (Wertheim et al., 2014).

Our research supports prior studies that have found mycorrhizal fungus inoculants to be effective for the greenhouse growth phase of plants transplanted to the field rather than for field inoculation (Koide et al., 1999). Results from our greenhouse study and others (Al-Karaki, 1998; Jin et al., 2013) show that AMF inoculants can enhance AMF colonization in a containerized setting. In this study, however, only the on-farm inoculant (OFAMF+) produced measurable increases in nutrient uptake and crop growth, demonstrating that on-farm produced inoculants can be effective alternatives to purchased, commercial inoculants, and may reduce the need for chemical fertilizer.

Participation Summary

Education & Outreach Activities and Participation Summary

PARTICIPATION SUMMARY:

Education/outreach description:

Over the past two years of the project several presentations were given to a variety of audiences. The following list documents these presentations

University of Maine Agriculture Field Day, Summer 2012 and 2013.

- University of Maine Rogers Research Farm, Old Town.
- Field trial demonstration for farmers, researchers and agricultural service providers. There were 29 attendees in 2012 and 40 in 2013

Graduate Student Poster Competition, Winter 2012.

- University of Maine, Orono.
- Scientific poster of the greenhouse trial presented at the UMaine graduate student poster competition open to all faculty and students.

Northeastern Branch of the Crop Science Association Annual Meeting, Summer 2013

- University of Delaware, Newark.
- Oral presentation of the greenhouse trial to 25 scientists, professionals and graduate students from the Northeast region.

Natural Farming Workshop, Spring 2013

- University of Maine, Orono
- Hands-on workshop on the production of microbial inoculants was given at UMaine to 40 farmers, gardeners, students and faculty.

Maine Grain Conference, Winter 2014

- Spectacular Events Center, Bangor, ME.
- Oral presentation of the field and greenhouse research results for 82 farmers and agricultural service providers at the 2014 growers conference.

Other Recent And Upcoming Outreach

Currently, a manuscript presenting the findings is being prepared for submission to a peer-reviewed scientific journal. Recently the principal investigator toured several Hawaiian farms implementing Korean Natural Farming (KNF) practices with Michael Duponte, a University of Hawaii extension agent. Korean Natural Farming is increasing in popularity amongst farmers and gardeners in Hawaii where off-farm inputs are typically more expensive than in the contiguous 48 states. Lastly, this spring, the PI will be offering a Northeast Organic Farming Association Massachusetts (NOFA-Mass) “advanced grower” workshop on KNF to farmers and gardeners. Interest in KNF in the Northeast was enhanced by this NE-SARE graduate student project.

Project Outcomes

Project outcomes:

MycoApply® micronized endo is available in granular and powder form. The powder is a seed treatment, both forms are lightweight and were easy to apply, perhaps 1 hour for each trial. In the greenhouse, due to the small amount of wheat seed treated for each pot, the granular form was added to the soil media at 0.3 oz/gal pot, which cost $0.12/pot (bulk price). In the field we used the powder seed treatment only at the rate of 2 lbs/acre. This was twice the suggested rate of 1 lb/acre, which costs $11/acre (bulk price). The MycoApply® was easier to apply than the on-farm produced inoculants in the field trial, which were applied in much larger quantities, broadcasted and incorporated into the soil before planting. The different costs, and application methods and rates of the three tested inoculants are shown in Table 7.

The on-farm produced AMF inoculant (OFAMF) involved 6 to 8 hours of labor to produce about 7 ft^3 (100 lbs. dry wt.). The material cost for the 100 lbs. of OFAMF was $33 (Table 8). In the greenhouse trial the OFAMF was applied at 0.35 oz/gal pot (dry wt.) and cost less than $0.01/gal pot. In the field, we broadcasted the OFAMF at the rate of 1350 lbs/acre (dry wt.), which cost approximately $445/acre. The on-farm AMF inoculant is not typically applied as a broadcast pre-plant amendment, it is more commonly applied to greenhouse soil media for transplants or in the case of potatoes applied in furrow with each potato seed. Pre-plant broadcasting of OFAMF for bread wheat production is expensive and our results suggests it was ineffective. If the on-farm AMF inoculant were to be used in a bread wheat field cropping system, the application technique would have to be refined to allow for precise application in the seed furrow only. Additionally, a lower-cost alternative to vermiculite, the main ingredient in the OFAMF medium, could reduce the production cost. However, as seen with the cost per pot in our greenhouse trial, the OFAMF is inexpensive when applied to a containerized medium.

The IMO required 12 hours to produce about 4 ft^3 (100 lbs. dry wt.) by hand. The cost of producing 100 lbs. (dry wt.) of IMO was $9.55 (Table 9). In the greenhouse IMO was applied at the rate 0.35 oz/gal pot (dry wt.) and cost less than $0.01/gal pot. In the field, we broadcasted the IMO at the rate of 1350 lbs/acre (dry wt.), which costs approximately $130/acre. IMO has a wide range of applications, it can be added to a greenhouse media, broadcast pre-plant, or side-dressed in season. Given the wide range of crops and application techniques, costs per acre vary. One way to reduce cost of the IMO for broadcast application would be to find a local carbohydrate source that is less expensive than wheat bran ($12/50lbs). A carbohydrate-rich agricultural byproduct similar in texture and dry matter to wheat bran would be ideal.

- Tables 7, 8 and 9: Economic analysis of inoculants

Farmer Adoption

Although the research found limited benefits in the field for bread wheat production, the farmer who was initially interested in the research experiment will continue to use the purchased AMF inoculant on wheat and other crops. He expressed that for a relatively low cost he has assurance that the beneficial AMF species will be present. As a sort of low-cost insurance for healthy soil microbiology, he likened the use of

AMF inoculants to rhizobium inoculants for clover, peas and other legume crops. Additionally, he will use the purchased AMF inoculant on onions this year, based on recent research that suggests AMF inoculants are effective on *Allium* crops in Maine (Wertheim et al., 2014).

Mycorrhizal inoculants have been used by some of Maine's large-scale potato growers, according to an agricultural service provider from Aroostook County, Maine, an intensive potato-growing region in Northern Maine. Soils under continual potato production can suffer from poor soil quality, therefore the use of beneficial soil microbial inoculants may have potential for increasing soil quality while maintaining crop production. Further research is needed to determine best application practices and inoculant selection for large-scale potato cropping systems.

The spring 2013 workshop on Korean Natural Farming and on-farm produced inoculants was well received at UMaine. Attendees expressed interest in adopting some of the techniques they learned in the workshop on their farms. The upcoming NOFA-Mass workshop on Korean Natural Farming in May 2014 will be another opportunity for farmers and gardeners to learn more about making inoculants on-site. This all-day workshop on KNF theory, technique and application will be held at the Heifer International Overlook Farm in Rutland, MA. The workshop manifested out of interest from local farmers in Massachusetts who learned of our SARE project on microbial inoculants at UMaine.

Assessment of Project Approach and Areas of Further Study:

Areas needing additional study

Directions for future research are to enhance our understanding of the effects of different microbial inoculants in varying agricultural scenarios, such as different soil types and textures, water and nutrient availability, crop type and variety, and production systems. The soil microbial community is incredibly diverse, therefore accurate identification of specific microbial species present in the soil can be challenging even with scientific equipment available to researchers. Development of an evaluative tool for farmers to determine existing background AMF communities may help growers predict the impact of AMF inoculants. A greater understanding of the composition of microbial species present in the soil may also help farmers determine effective types and application rates of inoculants. Also, testing the IMO inoculant with other composts that have similar nutrient contents could help determine if the IMO is different than other types of compost typically made in the Northeast.

- References

US Department of Agriculture

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