

Onion (*Allium cepa* 'B90')
Pink root; *Setophoma terrestris*
Host response; mycorrhizal colonization

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Effects of an arbuscular mycorrhizal fungus inoculant and a mycorrhizal stimulant on pink root and productivity of dehydration onion crops near Paterson, WA, 2016.

Trials were carried out in two commercial, center-pivot-irrigated, dehydration onion bulb crops near Paterson, WA during the 2016 season to test the effects of two commercial arbuscular mycorrhizal fungal (AMF) products on onion crop growth. The products were Mykos Liquid (RTI-Ag, Gilroy, CA), an AMF inoculant with propagules of *Rhizophagus intraradices*; and Myconate (Plant Health Care, Inc., Pittsburgh, PA), which contains the isoflavone formononetin that stimulates AMF in soil to form mycorrhizal associations with plants. The products were compared with a non-inoculated control treatment, in the presence and absence of a pre-plant fertilizer application. Mykos Liquid was applied at 1.50 oz/lb seed, and Myconate at 0.19 oz/lb seed. The four AMF treatments were: 1) Mykos Liquid; 2) Myconate; 3) Mykos Liquid + Myconate both applied at the full rate; and 4) non-inoculated control seed. AMF products were applied to seed of the dehydration onion cv. B-90 along with the fungicide thiram in a coating. The fertilizer treatment consisted of liquid 10-34-0 NPK at 27 gal/A + liquid humus at 1 gal/A in 100 gal water + zinc (Zn), which was banded and incorporated at bed formation. Fertilized plots received this application while non-fertilized plots did not. All other elements of the annual fertilizer program were the same across treatments (including application of fertilizer to each field in fall 2015, prior to planting onion crops in spring 2016). Fertilizer was banded onto sections of the field at planting to set up alternating fertilized and non-fertilized plots, each four beds wide and approximately 300 ft long. Seed from each AMF treatment was placed into one of four boxes on the planter and vacuum-seeded into a single bed extending the length of the field, for several passes of the planter. This resulted in an experimental layout wherein each fertilizer plot contained all four AMF treatments. Owing to planting equipment constraints, the order of the AMF treatments was not randomized. A bed contained six double-rows of onions. The trial was planted in each of the two fields with six fertilizer treatment replications in the first field and four in the second field. The first field was planted on 7 Mar, and the second on 16 Mar. Stand counts on 13 Apr were made by counting all seedlings emerged in a 10-ft section of bed in each subplot. On 22 Jun, five plants per subplot were dug and dried at 95°F. Whole dried plants were weighed, and the tops removed and submitted to Mukang Labs, Inc. (Pasco, WA) for foliar nutrient analysis. On 24 Jul, when the crop was mature, all bulbs in a 5-ft section were dug (= 30 ft of double-row) of each subplot. A sample of 50 bulbs was rated for pink root severity by estimating the percentage of symptomatic roots per plant. Top foliage was cut 2 in. above each bulb prior to size grading (bulbs >1.3 in. diameter were considered marketable; smaller bulbs and those with faults were rejected), counting, and weighing the bulbs. Bulb yield weight and number were used to calculate average bulb weights. Following harvest, total dissolved solids (Brix) were measured for 10 plants per subplot using an N-1EBX handheld refractometer (Atago USA, Inc., Bellevue, WA). Data were analyzed in R version 3.3.1 using a linear mixed effects model with fixed effects for fertilizer and AMF treatment; and random effects for field, block nested within field, and plot nested within block. An analysis of variance (ANOVA) was calculated to test the main effects of fertilizer and AMF, as well as the interaction effect between fertilizer and AMF. Dunnett's test was carried out for variables with significant AMF effects ($p < 0.05$).

Based on the ANOVAs, there was no evidence of interaction between fertilizer and AMF treatments. Foliar sulfur (S) concentration was significantly less in non-inoculated control plots (0.48%) than in plots inoculated with Mykos Liquid (0.54%, $p = 0.035$) or Mykos + Myconate plots (0.55%, $p = 0.014$). Foliar zinc (Zn) concentration was significantly greater in Mykos + Myconate plots than in control plots (19.4 vs. 16.2 ppm, $p = 0.011$). The number of marketable bulbs was significantly greater in non-inoculated control plots than in plots inoculated with Mykos Liquid (115 vs. 103, $p = 0.003$), though this result was not reflected in a significantly greater marketable weight of bulbs in control plots owing to a trend of smaller average bulb weight in control plots than in plots with other treatments. The average weight of one marketable bulb was significantly less in control plots (3.01 oz) than in plots inoculated with Mykos Liquid (3.35 oz, $p = 0.015$). The number of rejected bulbs per plot was greatest for the control treatment (8), followed by Mykos Liquid (7), Myconate (6) and Mykos + Myconate (5), though the difference was significant statistically only for the Mykos + Myconate treatment ($p = 0.008$). A trend towards greater yield of marketable bulbs in Myconate-inoculated plots compared to the control plots (21.3 vs. 20.4 lb per 30 ft of double-row) approached statistical significance ($p = 0.079$). Aboveground dry biomass was significantly greater in plots that received the pre-plant, banded and incorporated fertilizer application (1.28 vs. 1.09 oz dry weight, $p = 0.017$). Marketable bulb yield (lb per 5 ft of bed) was 5% greater in fertilized plots than non-fertilized plots (21.1 vs. 20.1, $p = 0.034$), owing to greater average bulb weight in the former (3.23 vs. 3.13 oz). Foliar nutrient concentrations and disease severity were similar across fertilizer treatments. The experimental design did not allow for causal inference to be drawn from statistical analysis alone on either the AMF or fertilizer treatment effects; therefore, all inferences made were associative, potentially confounded by any systematic variation that co-occurred with AMF and fertilizer treatment plots. Nonetheless, both fertilizer and AMF treatment effects in this study were weak. This may reflect the relatively high pre-fertilization soil nutrient status in the trial field - soil tests for a representative sample of plots that did not receive the pre-plant, banded and incorporated fertilizer application showed an average of 161 lb available nitrogen (N)/A, 68 ppm phosphorus (P), and 222 ppm potassium (K).

Table 1. AMF treatment means \pm standard errors

Crop attribute	Control	Myconate	Mykos Liquid	Myconate + Mykos Liquid	Pr (>F) ^z
Stand count, 14 Apr (plants per 30 ft of double-row)	132 \pm 5	133 \pm 4	125 \pm 5	132 \pm 4	0.092
Biomass of 5 plants (oz dry weight)	1.13 \pm 0.05	1.17 \pm 0.05	1.19 \pm 0.04	1.27 \pm 0.05	0.118
Total foliar N (%)	2.21 \pm 0.09	2.42 \pm 0.09	2.48 \pm 0.12	2.43 \pm 0.09	0.201
Foliar P (%)	0.34 \pm 0.01	0.33 \pm 0.01	0.36 \pm 0.01	0.34 \pm 0.01	0.216
Foliar K (%)	2.52 \pm 0.09	2.6 \pm 0.11	2.85 \pm 0.11	2.62 \pm 0.07	0.067
Foliar S (%)	0.48 \pm 0.01	0.53 \pm 0.02	0.54 \pm 0.02	0.55 \pm 0.01	0.022
Foliar B (ppm) ^y	24.4 \pm 1.1	25 \pm 1.3	28.8 \pm 2.2	26.1 \pm 1.7	0.226
Foliar Zn (ppm)	16.2 \pm 0.6	17.3 \pm 0.6	18.8 \pm 0.9	19.4 \pm 0.9	0.018
Foliar Mn (ppm)	29.9 \pm 3.5	27.2 \pm 2.1	30.3 \pm 3.5	29.3 \pm 3.1	0.874
Foliar Fe (ppm)	293 \pm 19	276 \pm 23	308 \pm 25	263 \pm 16	0.498
Foliar Cu (ppm) ^y	13.1 \pm 0.9	11.5 \pm 0.6	12.2 \pm 0.8	12.7 \pm 0.8	0.460
Foliar Ca (%)	1.43 \pm 0.08	1.42 \pm 0.06	1.47 \pm 0.04	1.44 \pm 0.05	0.921
Foliar Mg (%)	0.2 \pm 0.01	0.2 \pm 0	0.21 \pm 0.01	0.2 \pm 0	0.575
Total dissolved solids (Brix)	16 \pm 0.2	15.9 \pm 0.2	16.1 \pm 0.2	15.6 \pm 0.2	0.569
Pink root severity (avg % roots/bulb)	11 \pm 1	11 \pm 1	10 \pm 1	12 \pm 2	0.530
Marketable bulb yield (n)	115 \pm 3	113 \pm 2	103 \pm 3	107 \pm 2	0.004
Reject bulb yield (n)	8 \pm 1	6 \pm 1	7 \pm 1	5 \pm 0	0.014
Marketable bulb yield (lb per 30 ft of double-row)	20.4 \pm 0.3	21.3 \pm 0.4	19.9 \pm 0.4	20.8 \pm 0.3	0.079
Reject bulb yield (lb per 30 ft of double-row)	0.2 \pm 0.0	0.2 \pm 0.0	0.2 \pm 0.0	0.2 \pm 0.0	0.637
Avg. weight of one marketable bulb (oz)	3.01 \pm 0.06	3.22 \pm 0.04	3.35 \pm 0.07	3.18 \pm 0.05	0.046
Avg. weight of one reject bulb (oz) ^x	0.52 \pm 0.08	0.43 \pm 0.11	0.49 \pm 0.06	0.55 \pm 0.13	0.735
Avg. weight of one bulb overall (oz)	2.86 \pm 0.10	3.08 \pm 0.07	3.16 \pm 0.10	3.08 \pm 0.08	0.085

^z The *p* value associated with the AMF term in the analysis of variance. Treatment values significantly (*p* < 0.05) different from the control value are indicated by an asterisk and highlighted in bold font. Dunnett's test *p*-values are reported in the Results section.

^y Data were log-transformed for analysis.

^x Reject bulbs were only weighed in one of the two fields, so average bulb weight data represent that field only.

Table 2. Fertilizer treatment means \pm standard errors^z

Crop attribute	Without pre-plant fertilizer	With pre-plant fertilizer	Pr (>F) ^y
Stand count, 14 Apr (plants per 30 ft of double-row)	130 \pm 10	132 \pm 9	0.574
Biomass of 5 plants (oz dry weight)	1.09 \pm 0.08	1.28 \pm 0.10	0.017
Total foliar N (%)	2.35 \pm 0.18	2.42 \pm 0.22	0.621
Foliar P (%)	0.33 \pm 0.02	0.36 \pm 0.02	0.069
Foliar K (%)	2.69 \pm 0.16	2.60 \pm 0.23	0.564
Foliar S (%)	0.52 \pm 0.03	0.53 \pm 0.04	0.807
Foliar B (mg/kg) ^x	26.4 \pm 3.3	25.7 \pm 3.3	0.752
Foliar Zn (mg/kg)	17.1 \pm 1.5	18.7 \pm 1.7	0.123
Foliar Mn (mg/kg)	31.1 \pm 7.2	27.2 \pm 4.5	0.482
Foliar Fe (mg/kg)	282 \pm 42	288 \pm 43	0.812
Foliar Cu (mg/kg) ^x	11.8 \pm 1.6	12.9 \pm 1.4	0.382
Foliar Ca (%)	1.49 \pm 0.12	1.39 \pm 0.11	0.102
Foliar Mg (%)	0.20 \pm 0.01	0.20 \pm 0.01	0.535
Total dissolved solids (Brix)	15.9 \pm 0.4	15.9 \pm 0.4	0.954
Pink root severity (avg % roots/bulb)	10 \pm 3	12 \pm 3	0.092
Marketable bulb yield (n)	110 \pm 6	109 \pm 5	0.931
Reject bulb yield (n)	6 \pm 1	6 \pm 1	0.988
Marketable bulb yield (lb per 30 ft of double-row)	20.07 \pm 0.73	21.11 \pm 0.68	0.034
Reject bulb yield (lb per 30 ft of double-row) ^w	0.14 \pm 0.06	0.19 \pm 0.06	0.399
Avg. weight of one marketable bulb (oz)	3.13 \pm 0.12	3.26 \pm 0.1	0.263
Avg. weight of one reject bulb (oz)	0.41 \pm 0.16	0.58 \pm 0.21	0.233
Avg. weight of one bulb overall (oz)	2.99 \pm 0.19	3.10 \pm 0.17	0.404

^z “With pre-plant fertilizer” plots received an application of fertilizer banded and incorporated just prior to planting, while “Without pre-plant fertilizer” plots did not. All other components of the annual fertilizer program were the same across treatments.

^y The p value associated with the fertilizer treatment term in the analysis of variance. Treatment values significantly ($p < 0.05$) different across treatments are highlighted in bold font.

^x Data were log-transformed for analysis.

^w Reject bulbs were only weighed in one of the two fields, so average bulb weight data represent that field only.