

ONION (*Allium cepa* 'Arcero' and '16000')
Pink root; *Setophoma terrestris*
Host response; mycorrhizal colonization

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The effects of arbuscular mycorrhizal fungi inoculants on pink root and onion growth in field trials near Connell, WA, 2016.

Symbiotic arbuscular mycorrhizal fungi (AMF) colonize the roots of many plant species, help plants mine the soil for immobile nutrients (particularly phosphorus, P), and can enhance plant resistance to biotic and abiotic stresses, including diseases. Onions depend on AMF to compensate for a sparse and relatively unbranched root system. However, AMF can be impacted negatively by practices such as planting AMF-incompatible cover crops, fumigation, tillage, and excessive fertilization. In the semi-arid Columbia Basin of central Washington, there is increasing interest in using relatively inexpensive biological products such as AMF to mitigate reliance on chemical inputs without decreasing yields. A trial was planted in each of two fields near Connell, WA in 2016 to test the efficacy of two commercial AMF products for enhancing AMF colonization of onion roots and improving onion production: MYKOS Gold Liquid (Reforestation Technologies International, Gilroy, CA) at 8 fl oz/A, and MycoApply Endo Liquid (Mycorrhizal Applications, Los Angeles, CA) at 1.6 fl oz/A. Each trial was planted in Mar 2016 with 6 replications of 5 treatments set up in a complete block design. Trial 1 was in a field planted with the onion cv. 16000, with each plot 6 beds wide (20 ft) x 150 ft. Each bed was planted to 4 rows of onions, with a single drip irrigation line buried between the two middle rows. Trial 2 was in an adjacent field planted with the cv. Arcero, with each plot 6 beds wide (20 ft) x 300 ft, and the same bed configuration as Trial 1. Each AMF product was banded over the seed row at planting along with a liquid fertilizer applied at a 1.0x rate (3.3 lb N, 13.5 lb P, 6.6 lb K, and 0.27 lb Zn/A) or a 0.5x. A fifth treatment included no AMF product (control treatment) in plots with the 1.0x rate of liquid fertilizer application at planting. The grower did not include a control treatment with 0.5x liquid fertilizer rate due to planting equipment constraints. Onion stand counts were completed in each plot on 5 and 27 May (2- to 3-true leaves, and 4- to 5-true leaves, respectively) in 10 ft of each of 4 and 5 beds/plot, respectively. On 7 Jul, five plants from the center of each plot were dug carefully. The roots were then cut off, washed in tap water, and stored at 40°F in 95% ethanol. The roots were later boiled in 10% KOH and then stained by boiling in a 5% Sheaffer black ink-vinegar solution (Verheilig et al. 1998) to quantify AMF colonization by counting the number of AMF arbuscules and/or vesicles observed microscopically (5x to 20x magnification) in 40 root sections/plant using a modified gridline intersection method (Giovannetti and Mosse, 1980). Leaves and bulbs of the onion plants were dried, weighed (aboveground biomass), and subjected to foliar nutrient analyses (Mukang Labs, Inc., Pasco, WA). On 30 Aug, onion plants in 5 ft of 1 bed/plot were dug carefully and the roots rated for severity of pink root by estimating the percentage of roots on each plant with symptoms. Severity of pink root was averaged for all bulbs/plot. The necks were cut 2 in. above the bulb, and the bulbs sized into one of five categories: colossal (>4.00 in. diameter), jumbo (3.00-4.00 in.), medium (2.25-3.00 in.), prepack (<2.25 in.), and reject (split basal plates, rotten bulbs, bolted bulbs, or bulbs with green shoulders). Bulbs were counted and weighed by size category. Jumbo bulbs (n = 20) from each plot were rated for firmness on 1 Sep using a modified penetrometer. An aluminum block was pressed against the side of each bulb using an air compressor, with the pressure set using a dial and spring. The block was then pushed on the bulb at a consistent pressure, and the distance the block traveled was measured. Analyses of variance (ANOVAs) and means comparisons were computed using Fisher's protected least significant difference (LSD) at $P < 0.05$ with SAS Version 9.3 (SAS Institute Inc., Cary, NC).

In the trial with onion cv. 16000, AMF root colonization averaged <1%, regardless of AMF treatment or fertilizer application rate. In contrast, AMF root colonization in the Arcero trial ranged from 3.7 to 52.9%, with significant differences among treatments. In the control plots (no AMF inoculant) with 1.0x fertilizer application rate at planting, roots averaged 18.11% AMF colonization. MYKOS Gold did not increase AMF root colonization significantly compared to the control plots, regardless of fertilizer application rate, whereas MycoApply Endo Liquid increased AMF colonization of onion roots significantly (33.67 and 29.50% in plots fertilized at 0.5x and 1.0x rates, respectively). AMF root colonization of onion plants in plots amended with MYKOS Gold was not different from that of plots treated with MycoApply Endo Liquid or the control plots with 1.0x fertilizer application rate at planting. AMF root colonization in plots amended with either AMF product was not affected significantly by the rate of fertilizer applied at planting, although the lack of a control treatment (no AMF) in plots with the 0.5x fertilizer application rate negated thorough assessment of the impact of fertilizer rate on AMF root colonization. In the 16000 trial, the AMF-fertilizer treatment combinations did not have a significant effect on onion stand counts on 5 and 27 May, onion plant biomass on 7 Jul, bulb firmness at harvest, pink root severity, or any measure of bulb yield (total bulb weight and number, and bulb weight and number by size category). The numbers of pre-pack and reject bulbs were minimal (in both trials). Foliar nutrient analyses revealed no significant effects of AMF treatments on foliar Cu, Fe, Mg, Mn, N, P, S, and Zn levels compared with those of the control plots with the 1.0x fertilizer application rate at planting. The only significant effects of AMF treatments on foliar nutrient status were in the 0.5x fertilizer plots, in which plants in plots amended with MYKOS Gold Liquid had significantly less B and Ca (26.63 mg/kg and 1.07%, respectively) than that of plants in plots amended with MycoApply Endo Liquid (35.15 mg/kg and 1.22%, respectively); however, neither B nor Ca levels differed from those of plants in the control plots without AMF treatments and with 1.0x fertilizer application rate. In the Arcero trial, there also were no significant AMF or fertilizer application rate effects on onion stand counts on 5 or 27 May, bulb firmness at harvest, pink root severity, or any measure of bulb yield. However, onion plant biomass on 7 Jul was affected by one of the five treatments, i.e., in plots with 1.0x fertilizer application rate at planting, plant biomass was less in plots amended with MYKOS Gold Liquid (0.134 lb/5 plants) compared to control plots (0.155 lb/5 plants) or plots with MycoApply Endo Liquid (0.162 lb/5 plants). In plots with 0.5x fertilizer application rate at planting, neither MycoApply Endo Liquid nor MYKOS Gold Liquid affected onion plant biomass significantly. None of the treatments in the Arcero trial had a significant effect on onion foliar B, Cu, Fe, Mg, N, P, S, and Zn. However, foliar Mn levels were significantly less in onion plants in plots amended with MycoApply at both rates of fertilizer application (93.3 to 102.9 mg/kg), and in plots amended with MYKOS Gold Liquid and fertilized at the 0.5x rate (94.0 mg/kg), compared to that of onion plants in control plots (129.0 mg/kg) and plots amended with Mykos Gold Liquid and fertilized at 1.0x rate (147.4 mg/kg). Onion foliar concentrations of Ca were increased by one treatment, MycoApply Endo Liquid banded over the row in plots fertilized at the 0.5x rate at planting, compared to control plots or plots with any of the other AMF-fertilizer treatment combinations. Overall, the trials demonstrated no consistent effect of either of the AMF liquid inoculants on onion stand, foliar nutrient content, biomass, pink root severity, or bulb yield, regardless of the rate of liquid fertilizer applied to the onions at planting, even in plots in which the AMF treatment almost doubled the amount of onion root colonization by AMF compared to that of control plots.

Onion cv. (trial)	Variable (unit of measurement)	Treatment ^u					ANOVA P value ^x
		0.5x fertilizer at planting		1.0x fertilizer at planting			
		Myc- Apply ^v	MYKOS Gold ^w	Myc- Apply	MYKOS Gold	No AMF	
16000	AMF root colonization (%)	0.10 ^y	0.32	0.10	0.34	0.62	NA ^z
	Stand count on 5 May (plants/40 ft)	424.33	420.67	424.83	421.83	421.0	0.7684
	Stand count on 27 May (plants/50 ft)	520.00	515.17	523.83	523.83	511.83	0.2501
	Plant biomass on 7 July (lb/5 plants)	0.146	0.146	0.150	0.114	0.147	0.6596
	Total foliar N (%)	2.25	2.18	2.24	2.20	2.30	0.6985
	Foliar P (%)	3.67	2.83	2.92	2.42	3.17	0.7466 Rank ^y
	Foliar K (%)	2.81	2.80	2.82	2.78	2.80	0.9967
	Foliar S (%)	0.49	0.47	0.47	0.46	0.48	0.3247 Rank
	Foliar B (mg/kg)	35.15 a	26.63 b	35.78 a	30.27 ab	34.10 ab	0.0346 Rank
	Foliar Zn (mg/kg)	26.72	27.07	26.27	26.80	25.82	0.7355 Rank
	Foliar Mn (mg/kg)	116.63	111.72	118.90	112.82	104.87	0.6661
	Foliar Fe (mg/kg)	358.33	307.95	377.50	315.33	338.83	0.3504
	Foliar Cu (mg/kg)	58.60	35.18	39.05	47.97	32.70	0.1599
	Foliar Ca (%)	1.22 b	1.07 a	1.06 b	1.04 b	1.16 ab	0.0360 Rank
	Foliar Mg (%)	0.25	0.24	0.24	0.24	0.24	0.3824
	Bulb firmness (in. compressed)	0.288	0.290	0.294	0.293	0.283	0.3460
	Pink root severity (ave. %/bulb)	19.73	20.12	17.50	19.60	20.98	0.3532
	Colossal bulb weight (lb/5 ft bed)	18.25	16.53	18.45	15.83	16.01	0.6932
	Jumbo bulb weight (lb/5 ft bed)	30.25	29.21	30.93	30.93	14.07	0.9459
	Medium bulb weight (lb/5 ft bed)	0.53	0.68	0.37	0.71	0.66	0.8971 Rank
	Marketable bulb weight (lb/5 ft bed)	49.03	46.43	49.76	47.47	47.69	0.0975 Rank
	Total no. of bulbs (/5 ft bed)	54.17	53.33	52.67	53.84	54.83	0.5935
	No. of colossal bulbs (%)	27.17	27.18	28.98	24.15	23.32	0.5311 Log ^y
	No. of jumbo bulbs (%)	64.94	64.12	61.66	68.12	66.02	0.7164
	No. of medium bulbs (%)	3.64	4.52	2.51	3.97	3.97	0.8548
	No. of reject bulbs (%)	3.62	4.18	5.32	3.45	6.07	0.5203
Arcero	AMF root colonization (%)	33.67 a	21.65 bc	29.50 ab	21.73 bc	18.11 c	0.0293
	Stand count on 5 May (plants/40 ft)	416.0	422.3	415.5	409.3	414.8	0.2515
	Stand count on 27 May (plants/50 ft)	515.2	513.0	517.7	506.0	513.3	0.1104
	Plant biomass on 7 July (lb/5 plants)	0.165 a	0.172 a	0.162 a	0.134 b	0.155 a	0.0081
	Total foliar N (%)	2.26	2.31	2.22	2.29	2.31	0.4593
	Foliar P (%)	0.273	0.272	0.293	0.267	0.280	0.7620 Rank
	Foliar K (%)	2.35	2.38	2.30	2.54	2.54	0.1124
	Foliar S (%)	0.530	0.525	0.532	0.515	0.538	0.8834
	Foliar B (mg/kg)	27.38	25.43	25.70	26.97	26.10	0.7114
	Foliar Zn (mg/kg)	25.1	21.4	25.1	24.0	24.5	0.1058 Rank
	Foliar Mn (mg/kg)	102.9 b	93.3 b	94.0 b	147.4 a	129.0 a	0.0001
	Foliar Fe (mg/kg)	346	393	474	299	445	0.0916
	Foliar Cu (mg/kg)	60.83	53.35	58.53	61.77	53.95	0.1286 Rank
	Foliar Ca (%)	1.08 a	0.93 b	0.97 ab	0.85 b	0.898 b	0.0142
	Foliar Mg (%)	0.222	0.215	0.212	0.220	0.228	0.3759 Rank
	Bulb firmness (in. compressed)	0.256	0.265	0.263	0.259	0.262	0.2486
	Pink root severity (ave. %/bulb)	30.5	25.6	28.1	25.3	23.5	0.3254
	Colossal bulb weight (lb/5 ft bed)	13.98	11.91	14.20	10.12	13.27	0.3947
	Jumbo bulb weight (lb/5 ft bed)	33.29	33.73	33.95	34.61	32.85	0.9494
	Medium bulb weight (lb/5 ft bed)	0.64	1.28	0.28	0.53	0.50	0.4325
	Marketable bulb weight (lb/5 ft bed)	48.13	45.66	48.46	45.37	46.67	0.2437
	Total no. of bulbs (/5 ft bed)	52.0	51.2	51.8	51.2	52.0	0.9294
	No. of colossal bulbs (%)	22.78	19.64	22.77	16.33	21.89	0.4197
	No. of jumbo bulbs (%)	72.43	78.06	74.01	78.39	72.68	0.3451
	No. of medium bulbs (%)	3.18	1.62	2.34	4.31	3.49	0.5860 Rank

^u The fertilizer treatments at planting included the grower's standard (1.0x) and 0.5x rate of application of liquid fertilizer at planting.

^v MycoApply Endo Liquid (Mycorrhizal Applications, Inc., Los Angeles, CA) contains four species of mycorrhizal fungi: *Rhizophagus intraradices*, *R. mosseae*, *R. aggregatum*, and *R. etunicatum*.

^w MYKOS Gold Liquid (Reforestation Technologies International, Gilroy, CA) contains one mycorrhizal species, *R. intraradices*.

^x Within each row, numbers followed by the same letter are not significantly different based on Fisher's protected LSD.

^y Original means are shown for all variables. 'Rank' and 'Log' = means separation based on rank- or log-transformed data, respectively, because of heterogeneous variances and/or non-normal residuals, in order to meet assumptions for parametric data analysis.

^z AMF root colonization was too limited to analyze statistically, but treatment means are presented.