Mycorrhizae: a benefit to high-yield maize cropping systems?

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Abstract

It is well known that arbuscular mycorrhizal (AM) fungi improve early season vigor and yield of maize (*Zea mays* L.) when grown under nutrient and/or water stress. However, in cropping systems managed at yield potential they may function as a carbon sink that negatively impacts grain yield. We hypothesize that AM fungi are essential to meet the P demand of irrigated maize grown at yield potential, and thus benefit grain yield. Our objective was to demonstrate that carbon allocation to the AM symbiont during the reproductive stages of maize is tied to the uptake of soil P. To demonstrate this soil chambers were installed in irrigated maize fields at Lincoln and Shelton, Nebraska. Chambers were constructed to allow root and mycelial passage, or only mycelial passage, with and without additional P. Lipid biomarkers (C16:1*cis*11 and C18:1*cis*11) extracted from fungal cells colonizing the chambers were measured during the reproductive stages of maize. Our research supports carbon allocation to AM fungi during the reproductive stages of maize that coincided with a reduction in Bray P in the chambers. This increase in AM biomass was greatest in chambers where the bioavailability of P was low and roots were present, suggesting a possible role in P acquisition.

Key Words

AM fungi, fatty acid methyl esters (FAMEs), Bray P, corn (*Zea mays* L.)

Introduction

Phosphorous is an essential plant nutrient and following N, is the second most common nutrient applied in crop production. In maize, P accumulates steadily until maturity, with a higher proportion being absorbed during the reproductive period (Karlen et al. 1988) and after root biomass reaches a maximum (Plenet 1995). Radical hairs developed before and after tasseling may have a high efficiency in P uptake and may create a depletion zone around the root. Arbuscular mycorrhizal (AM) fungi form symbiotic relationships with up to 80% of land plants and also are recognized for their positive effects on plant growth and soil quality (Smith and Read 1997). It has been observed, in high production systems, that mycorrhizal biomass increases throughout the maize-growing season (Drijber 2004), and by bridging this depletion zone, may be the main mechanism for P uptake after tasseling. Management systems that enhance natural mechanisms for P acquisition will help optimize use of P fertilizer resources. AM fungi may play an important role in plant P nutrition, but factors influencing that role and temporal dynamics are poorly understood. Our objective was to demonstrate that carbon allocation to the AM symbiont during the reproductive stages of maize is tied to the uptake of soil P.

Methods

Two fields with four different levels of P availability were sampled from Shelton and Lincoln, NE, USA. Soils at Lincoln were higher in available P than those at Shelton. A shovel was used to install chambers in the furrow, 10 cm from the corn plant at tasselling. Chambers were made of PVC rings enclosed with 1 mm mesh fabric to allow (+R) or 0.04 mm mesh fabric to exclude (-R) maize roots but not AM hyphae. Soil in the rings was amended with either 0.014 M KH_2PO_4 (+P) or distilled water (-P), mixed, and packed to a bulk density of 1.2 g cm^{-3}. One chamber of each treatment was removed three, six, and nine weeks after installation. Ten soil cores were taken adjacent to the chambers and combined on each sampling date. Fatty acid methyl ester (FAME) analysis (Drijber 2004) was performed on soils collected from the field and from the chambers.

Results

The initial AM FAME concentration was lower at sites with a high availability of P. During the reproductive growth of maize, AM FAME biomarkers increased inside the chambers (Table 1) and was consistent with an increase observed in adjacent field soil. This shows that there is C allocation from the plant to the symbiont during the reproductive stages of maize. P status (+P, -P) of the chambers did not influence AM colonization of the chambers suggesting the influence of soil P availability on AM fungal development may be dependent on maize P status and its linkage to crop physiological signals.

Table 1. Concentration of C16:1*cis*11 and C18:1*cis*11 FAME biomarkers in chambers over time.

	4 August	23 August	13 September
Shelton	----------nmol g^{-1} soil----------		
C16:1*cis*11	3.81b	4.18b	5.9a
C18:1*cis*11 + R*	7.7b	8.34b	11.02a
C18:1*cis*11 - R	7.61b	7.79b	8.84b
Lincoln			
C16:1*cis*11	1.84b	2.14b	3.08a
C18:1*cis*11$^{\Psi}$	4.95b	5.04ab	5.36a

Means followed by the same letter among dates are not different ($P < 0.05$).
* significant interaction 'mesh*time' ($P = 0.02$) C18:1*cis*11 FAME biomarker; $^{\Psi}$ $P = 0.07$

Preparation of the chambers with bulk field soil disrupted the mycelial network of existing AM fungi in the field leaving only mycelial fragments and spores as inoculum for the current maize crop. Thus, the increase in AM fungal marker within chambers is evidence for hyphal penetration of the chamber (-R or +R) from adjacent field soil or successful spore germination (in terms of establishment of the plant-fungi symbiosis), and the formation of arbuscules and vesicles within the root structure in +R chambers. The smaller response of C18:1*cis*11 compared to C16:1*cis*11 was possibly related to the influence of Gram-negative bacteria (Zelles, 1999) on the concentration of this marker in the chambers.

At Shelton we observed a reduction in available P in the chambers (Table 2), while at Lincoln the results were inconsistent. Reduction in available P inside the –R chambers was likely due to hyphal-mediated P uptake and did not differ between +R and –R chambers.

Table 2. Availability of P in soil from chambers at Shelton over time.

	4 August	23 August	13 September

	----------mg kg^{-1} soil----------		
+ P chambers	38.73a	37.23a	32.3b
- P chambers	27.35a	27.53a	24.0b

Mean followed by the same letter among dates are not different ($P < 0.05$).

Conclusion

The increase in the AM biomarker concentration in field soil and in chambers during the reproductive stages of maize confirmed the allocation of C from the plant to the mycorrhizal symbiont. Since root biomass does not change from two to three weeks after tasselling to maturity, AM fungi may play an essential role in P uptake of maize later in the growing season. Chambers that allowed only passage of AM hyphae were as efficient as roots and AM hyphae in extracting P from soil within the chambers. Further work is needed to identify mechanisms controlling the temporal allocation of C from plant to AM fungus, and the mycorrhizal contribution to P uptake during the reproductive stages of maize. The dynamics of lipid accumulation and formation of specialized structures in AM fungi appears to be essential to this process.

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