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Spatio-temporal dynamics of an indigenous arbuscular mycorrhizal fungal community in an intensively managed maize agroecosystem in North China

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ABSTRACT

The temporal and spatial dynamics of arbuscular mycorrhizal fungal (AMF) spore communities and biomass were studied in an intensively managed maize agroecosystem located in the North China Plain, one of the most important regions for cereal production in China. Maize roots and soils from three depths (0–30, 30–60 and 60–90 cm) were sampled in conventional agricultural management (CAM) and recommended agricultural management (RAM) systems at V6 (six leaf collar), V12 (twelve leaf collar), R1 (silking) and R6 (physiological maturity) stage of maize. The dynamics of percent root colonization by AMF, extra-radical hyphal length density (HLD), AMF fatty acid biomarkers (C16:1w5 and C18:1w7) and spore density were analyzed. AMF spore species were identified according to their morphological characteristics. Maize roots were rapidly and heavily colonized by arbuscular mycorrhizal (AM) fungi even under intensive agricultural management. The abundance of arbuscules and hyphal coils within maize roots peaked during early reproductive growth suggesting a period of high P demand by maize. This was preceded by increased concentration of the AMF biomarker C16:1w5 in the soil at the V12 growth stage, and led to a peak in soil HLD at R1. Twenty seven AMF species belonging to five genera were isolated in total, and dominant species such as *Glomus aggregatum*, *Glomus claroideum*, *Glomus etunicatum*, *Glomus geosporum* and *Glomus mosseae* occurred widely across growth stage, soil depth and management system. Rare species occurred mainly at a particular growth stage or soil depth. The effects of growth stage, soil depth and management system on spore relative abundance differed among AMF species. The highest species richness and diversity occurred at the R1 stage and may stem from increased C supply to the fungus during peak arbuscular development within the roots. The AMF community and biomass were mainly affected by soil depth and growth stage rather than agroecosystem management. The abundance of AMF biomass and species found deep in the soil profile highlights the potential for P uptake by AMF from lower soil depths under intensive maize management.

1. Introduction

Arbuscular mycorrhizal (AM) fungi form a substantial part of the soil microbial community where they establish mutualistic symbioses with the majority of plants, including most crop plants (Smith and Read, 1997). The functions of AM fungi include absorption of mineral nutrients from the soil (Smith and Read, 1997), enhanced tolerance of or resistance to biotic (Habte et al., 1999) or abiotic (Augé, 2001; Soares and Siqueira, 2008) stresses, modification of natural plant community composition (van der Heijden et al., 1998) and improved soil quality (Miller and Jastrow, 2000). Because of their importance in terrestrial ecosystems, the abundance and diversity of AM fungi have been extensively studied both in natural and agroecosystems (Douds and Millner, 1999). A popular viewpoint is that the abundance or diversity of AM fungi in agricultural soils, especially under intensive management, is much lower compared to most natural ecosystems (Daniell et al., 2001; Helgason et al., 1998). Many studies attribute the depletion of AM fungi in agroecosystems to management practices such as the application of fertilizers, herbicides and pesticides, or disturbance resulting from tillage and irrigation (Helgason et al., 1998; Lin et al., 2003; Roldán et al., 2007). However, intensive agricultural management may not always reduce the abundance or diversity of AM fungi. Under field conditions, crops such as winter wheat (Schweiger and Jakobsen, 1999), barley and peas (Jakobsen and Nielsen, 1983) were shown to have a high percentage of the root colonized, >60, 50 and 70% respectively, by AM fungi. This was later demonstrated for sorghum and maize roots using the AMF specific biomarker C16:1w5 (García et al., 2007). Miller et al. (1995) concluded that although the application of fertilizer may markedly reduce AM colonization in the fertilized zone, the remainder of the root system would be well colonized, and have an increased ability to acquire

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phosphorus. Mathimaran et al. (2007) showed that the application of P had no significant influence on AMF community composition in fields cropped to maize and crotalaria. Furthermore, other studies have shown agricultural practices, such as tillage (Lekberg et al., 2008; Wang et al., 2008) or application of biocides (Gosling et al., 2006), may not negatively impact the abundance of the AMF community. A recent study also showed that communities of AM fungi from arable soils were not low in diversity (Hijri et al., 2006). These studies support adaptation of AMF communities to the intensive management of agroecosystems with the potential to benefit crops.

Maize is an AMF dependent crop easily colonized by AM fungi (Hamel and Smith, 1991) leading to its extensive use in trap cultures (Mathimaran et al., 2005; Moreira et al., 2007). However, under intensive maize management, rates of AMF colonization have been variable, ranging from low (Kurle and Pfleger, 1994; Wang et al., 2008) to high (Gavito and Miller, 1998; McGonigle et al., 1990). Several studies support a low diversity of AM fungi in maize cropping systems. Mathimaran et al. (2007) only found 10 AMF species from field soil based on morphological characteristics of spores, and Oehl et al. (2003) isolated only 6–8 AMF species from maize monoculture. A limitation inherent in these studies is a focus on the surface soil layer or a single sampling event which may underestimate the diversity of the AMF community within the soil profile impacted by maize during the entire growing season. AMF spore abundance and community composition change temporally and spatially (Carvalho et al., 2001; He et al., 2002; Schreiner, 2005), and the seasonality of AM fungi should be considered to better understand the drivers of AMF community dynamics in agroecosystems (Hijri et al., 2006). Linkages among AMF diversity, extra-radical hyphal biomass and nutrient acquisition under field conditions are not well established (McGonigle and Miller, 1993). Therefore spatial and temporal investigation of AMF diversity and hyphal biomass (Mathimaran et al., 2007) will provide a more complete picture of AMF function in intensively managed maize agroecosystems.

The aim of the present study was to determine the temporal and spatial dynamics of AMF spore communities and biomass in an intensively managed maize agroecosystem located in North China.

2. Materials and methods

2.1. Study area and field sites

The field study was conducted during 2008 in Quzhou County of Hebei Province located in the centre of the North China Plain (N 36°51′50.9″, E 115°00′38.0″), one of the most important regions for cereal production in China. Quzhou County has a semi-arid climate with a mean annual temperature of 12.5 °C and average annual precipitation of about 500 mm with a variation of 23% between years. Rains from July to August account for more than 60% of the annual precipitation. The total land area of Quzhou County is 67,669 ha and 75% is arable land. Soils are mainly Luvisols consisting of fluviatile deposits with a silt texture. Prior to the 1980s, soil salinity was a serious problem because of shallow saline groundwater. During the 1980s the salt problems were greatly reduced by soil reclamation and improvement (Chen et al., 2006). Quzhou County has a long history of crop cultivation, and winter wheat-summer maize rotation is a very important cropping system for this area. Summer maize is planted mid June followed by planting of winter wheat in late October following the harvest of maize.

The field experiment was a completely randomized block design with four replications. The size of each plot was 28 m × 40 m. Two intensive management systems of winter wheat-summer maize rotation were initiated in 2007: conventional agricultural management (CAM) and recommended agricultural management (RAM). The dominant management system used by local farmers in the study area (CAM) leads to degradation of the soil and pollution of the environment resulting from high input of fertilizers and poor management of resources. University recommended guidelines set forth in RAM aims to reduce inputs of nutrients and biocides without compromising yield. Prior to 2007, winter wheat-summer maize rotation had been cropped for more than 20 years in this field. Management inputs for the two systems are shown in Table 1. For both management systems, maize (Zhengdan 958) was drilled in alternating narrow and wide rows on 16 June, 2008. The average density was 65,905 plants ha^{-1}, and the average distance between the wide rows was 75 cm and 45 cm between the narrow rows. Fields were not tilled prior to planting maize, but mold board plowed to a depth of 25–30 cm followed by disking in late October prior to planting winter wheat. All nutrients except nitrogen were applied as basal fertilizers prior to planting maize. Phosphorus and potassium were applied as a compound fertilizer (15% N, 15% P and 15% K). Cattle manure was used as the manure source. Irrigation was conducted once after herbicides and pesticides were applied at V5 stage of maize. For CAM and RAM, 100 and 90 kg ha^{-1} N, in the form of a compound fertilizer (15% N, 15% P and 15% K), was applied as basal fertilizer prior to maize planting, and another 150 and 90 kg ha^{-1} N as urea was applied as topdressing on 2 August, respectively. The average maize yield for CAM and RAM was 9.01 Mg ha^{-1} and 8.09 Mg ha^{-1}, respectively, and there was no significant difference between the two yields ($P < 0.05$).

Table 1
Conventional agricultural management (CAM) and recommended agricultural management (RAM) by crop rotation.

Input type	Crop rotation	CAM	RAM
N (kg ha^{-1})	Winter wheat	250	180
	Summer maize	250	135
P_2O_5 (kg ha^{-1})	Winter wheat	150	90
	Summer maize	45	45
K_2O (kg ha^{-1})	Winter wheat	130	90
	Summer maize	45	45
$ZnSO_4 \cdot 7H_2O$ (kg ha^{-1})	Winter wheat	15	15
	Summer maize	15	0
$Na_2B_4O_7 \cdot 10H_2O$ (kg ha^{-1})	Winter wheat	15	15
	Summer maize	0	0
Manure (kg N ha^{-1})	Winter wheat	250	0
	Summer maize	0	0
Irrigation (mm)	Winter wheat	90	75
	Summer maize	70	70
Herbicide (Atrazine)	Winter wheat	Maximum recommended amount	Minimum recommended amount
	Summer maize	Maximum recommended amount	Minimum recommended amount
Pesticide (Emamectin benzoate)	Winter wheat	3–4 times than recommended amount	Recommended amount
	Summer maize	3–4 times than recommended amount	Recommended amount