Mycorrhiza (2003) 13:319–326
DOI 10.1007/s00572-003-0239-4

ORIGINAL PAPER

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Preliminary assessment of arbuscular mycorrhizal fungal diversity and community structure in an urban ecosystem

Received: 18 July 2002 / Accepted: 24 March 2003 / Published online: 14 May 2003

Abstract Arbuscular mycorrhizal fungal (AMF) species richness, composition, spore density and diversity indices were evaluated in the Phoenix metropolitan area, Arizona, USA at 20 sampling sites selected to represent the four predominant land-use types found in the greater urban area: urban-residential, urban non-residential, agriculture and desert. AMF spores were extracted and identified from soil samples and from trap cultures established using soil collected at each site. Data were analyzed according to land use, land-use history, soil chemistry and vegetation characteristics at each site. Current agricultural sites were associated with decreased spore densities and historically agricultural sites with decreased species richness. Overall species composition was similar to that previously reported for the Sonoran desert, but composition at each sampling site was influenced by the vegetation from which samples were collected. Sites with the highest degrees of similarity in AMF species composition were also similar to each other in native plants or land use. Conversely, sites with the lowest similarity in AMF composition were those from which the majority of samples were collected from non-mycorrhizal plants, predominately ectomycorrhizal plants or bare soil. Spores of *Glomus microggregatum* were most abundant in urban sites, while those of *G. eburneum* were most abundant in desert and agricultural sites. Further studies are needed to determine the functional implications of shifts in AMF communities in urban ecosystems, including effects on plant primary productivity.

Keywords Arbuscular mycorrhizal fungi · Diversity · LTER · Urban ecosystems · Sonoran Desert

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Introduction

An estimated 50% of all land has been transformed or degraded by humans (Vitoussek et al. 1997). Urban ecosystems comprise an important portion of this land change as they rapidly grow in both size and number (Ehrenfeld 1970). Urban ecosystems are recognized as spatially heterogeneous areas of land use and land cover under significant and constant human activity (Grimm et al. 2000). They are composed of anthropogenically built environments and natural or semi-natural areas containing a high proportion of non-native plant and animal species (McDonnell and Pickett 1990). These areas differ further from undeveloped surroundings in having larger areas of impervious surfaces, increased pollution and heat island effects that alter local climate (Vitoussek et al. 1997). While large-scale implications of urbanization such as air quality and climate change are extensively studied, some researchers have noted the importance of research on the "subtle effects" of urbanization (McDonnell and Pickett 1993), including effects upon soil microorganisms.

Little is known about the effects of urbanization on arbuscular mycorrhizal fungal (AMF) diversity, but the results of past research allow inference of possible effects. Urban development may entail disturbance and/or removal of topsoil, and similar disturbance resulting from agriculture or mining activities has been shown to decrease AMF species richness and infectivity (Helagson et al. 1998; Douds and Millner 1999). Non-native AMF species could enter urban ecosystems in plants and soil imported from other areas, thus altering species richness or composition compared with non-urbanized surroundings. Additionally, the introduction of non-native plant materials could impact AMF community structure (Helagson et al. 1998). After development, the new urban landscape may have increased vegetative land cover (as with turf), potentially favoring AMF communities, or a marked decrease in vegetative cover (as is the case with largely paved urban surfaces) that eliminates microbial communities in the underlying soil.

Once a new urban landscape is in place, human maintenance may produce a general stability of the landscape that increases AMF species richness. Stutz and Martin (1998) found greater AMF species richness at more established residential sites than newer residential landscapes in the Phoenix metropolitan area. Urban landscapes also may be more highly maintained than undeveloped areas, with the soil receiving more water and additional nutrients via irrigation and fertilization. Koske et al. (1997) found that these additional inputs to turf grasses resulted in higher fungal species richness and spore abundance. Common anthropogenic pollutants found in urban areas, such as nitrogen deposition, toxic metals and ozone, have been shown to decrease AMF colonization and impact community composition (Cairney and Meharg 1999; Egerton-Warburton and Allen 2000). Clearly, there are many factors that could have effects on AMF diversity in urban ecosystems.

In the United States, the fastest-growing human populations occur in the urban Southwest, where there has been substantial migration in recent decades to cities in Arizona and Nevada (Warren et al. 1996). The Central Arizona-Phoenix Long-Term Ecological Research Project (CAP-LTER) was established in Phoenix, Arizona to facilitate research on the relationships between urban development and urban ecological conditions. One focus of urban LTER is the ecological patterns and processes associated with different land uses within an urban ecosystem (Grimm et al. 2000). As part of this focus, a survey (Survey 200) of 206 sites within the Phoenix urban ecosystem was instituted in order to quantify basic ecological characters of the urban environment and to provide interdisciplinary long-term monitoring (every 5–10 years) over time and space.

Our purpose was to develop a preliminary description of the AMF community structure in the Phoenix metropolitan area, including information on AMF spore density, species richness, composition and diversity. Our specific objectives were (1) to develop methodologies for assessing diversity and AM fungal community structure in the Phoenix metropolitan area; (2) to compare AM fungal diversity and community composition between different land-use types; (3) to determine whether AM fungal species richness is influenced by vegetation factors, soil chemistry, levels of urbanization or prior land use; (4) to compare AMF diversity and species composition in the Phoenix metropolitan area to the surrounding Sonoran desert ecosystem.

Materials and methods

Sampling sites

The CAP-LTER study site encompasses an area of ~6400 km^2 including the Phoenix metropolitan area and the surrounding Sonoran Desert. The Phoenix metropolitan area is one of the fastest-growing urban areas in the United States (current population ~3.1 million), with the population projected to double within the next 25 years (Grimm et al. 2000). Development is expanding rapidly into former agricultural lands and undisturbed desert, with the urban fringe increasing at a rate of over 8 km annually (Morrison Institute for Public Policy 2000). The climate is hot and dry, with less than 200 mm rain annually, occurring in a bimodal winter-summer rainfall pattern. In developed areas, rainfall is supplemented with flood, sprinkler or drip irrigation. Natural vegetation is predominately microphyllous shrubs and leguminous trees typical of the Lower Colorado River Valley subdivision of the Sonoran Desert (Turner and Brown 1994). Many non-native plant species have been imported into developed areas for landscape use. The metropolitan area consists of a heterogeneous mosaic of residential areas, retail and industrial property, agricultural fields, and areas of remnant desert (McIntyre et al. 2001).

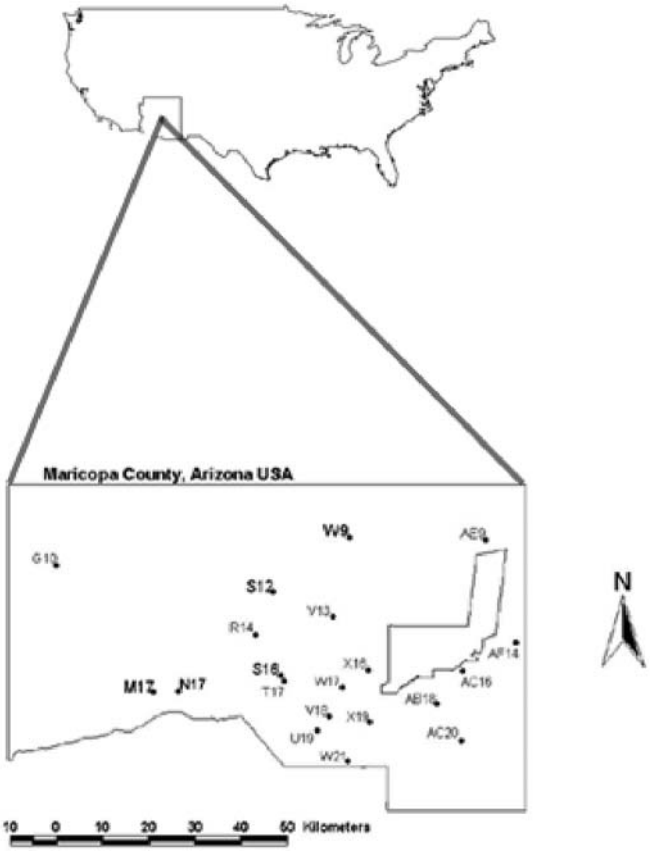

Fig. 1 Location of 20 arbuscular mycorrhizal fungi (AMF) sampling sites in the CAP-LTER study area, Maricopa County, Arizona. Site codes correspond to Table 1, Fig. 3 and Fig. 4

Samples were collected from 20 sites (Fig. 1) in the Phoenix metropolitan area and surrounding desert in May 1999 as part of a pilot study ahead of the main Survey 200 carried out in spring 2000. A probability-based approach was used to select sampling sites in order to obtain a representative and unbiased characterization of ecological resources across the entire study area. Specifically, a dual-density tessellation-stratified design was used with the entire CAP-LTER area divided into 4 × 4 km^2 grids. Within the urban core, one GPS-located survey site was centered on a randomly selected point in each of these grid squares. Outside the urban core, a random sample point was located in every third grid square. Sites were categorized by land use, and 20 of the total 206 sampling sites were chosen for this study to represent the four most common types of land use (urban-residential, urban non-residential, agriculture, and desert) (Table 1) in the Phoenix metropolitan areas (MAG 1998) and to cover a wide geographic area. Information on land-use history was obtained from aerial photographs from 1934 to the present.

Table 1 Land-use classifications (*A* agriculture, *D* desert, *R* urban-residential, *U* urban non-residential), site code, descriptions of the twenty sampling sites and arbuscular mycorrhizal fungal (AMF) spore density (mean spores per 100 cm^3 soil ± SEM) for soil samples collected in May 1999 (n=3; except site V13). Site descriptions recorded by the Survey 200 field crew at the time of sampling

Land-use	Site code	Description of site	Spore density
A	AC20	Farm yard	0
A	R14	Maize crop.	67.6 ± 8.1
A	V18	Fallow field, bare soil	8.0 ± 5.3
D	AF14	Undisturbed desert	116.6 ± 38.8
D	G10	Disturbed desert near large irrigation canal	68.4 ± 15.6
D	U19	Desert remnant park surrounded by city	101.5 ± 21.5
R	AB18	Mobile home park	18.3 ± 18.3
R	M17	Large residential lot with horse pasture	123.2 ± 35.2
R	S12	Small residential lot	21.8 ±5.9
R	S16	Residential apartment complex	29.8 ± 16.3
R	W9	Large residential lot	18.5 ± 7.9
R	X16	Residential apartment complex	72.7 ± 38.5
U	AC16	Edge of commercial gravel pit	254.4 ± 76.7
U	AE9	Golf course; adjacent disturbed desert	16.0 ± 8.0
U	N17	Vacant, bare soil lot.	0
U	T17	Street intersection; adjacent to sidewalk.	149.1 ± 20.0
U	V13	Middle school grounds; soil in planter	412
U	W17	Greyhound racing stadium entrance	56.7 ± 35.1
U	W21	Vacant, bare soil lot	0
U	X19	Car sales lot	14.1 ± 10.4

A 30-m radius circular plot was centered on each of the twenty GPS-located sampling points. In each plot, data were collected on vegetative cover, genera for all trees, shrubs, cacti and succulents vegetation, weather, soil conditions (pH, organic carbon, total carbon, total nitrogen, extractable phosphorus, electrical conductivity, and texture), arthropod and bird diversity, human activity and observable landscape practices. CAP-LTER protocols were followed for vegetation sampling and soil chemistry analyses (Zhu 2001) and the resultant data were obtained from the CAP-LTER informatics lab database.

Soil collection

Three soil samples were collected from 19 of the 20 plots (only one mycorrhizal sample was collected from site V13 due to the predominately paved surface), usually from the root zone of the three trees nearest the plot center. If there were fewer than three trees in the plot, the remaining samples were collected from shrubs or herbaceous cover. If there was no vegetation in the plot, soil samples were collected 1 m north, 1 m south and 2 m south of plot center. Surface debris (gravel, turf, etc.) was removed and soil was collected to a depth of approximately 10 cm with a metal trowel and placed into a 1-qt self-sealing plastic bag. Samples were stored at 4°C until analysis.

Spore analysis and extraction

Spores were extracted from a subsample (50–100 cm^3) of each soil sample by wet sieving and sucrose density gradient centrifugation (Daniels and Skipper 1982). Collected spores were washed into a petri dish and examined using a Leica stereomicroscope. Healthy spores (based on shape, surface condition, spore contents and no evidence of parasitism) of each distinct morphotype (as distinguished by color, shape and size) were directly counted. Spores of each morphotype were mounted on slides in polyvinyl alcohol-lactic acid-glycerol (PVLG) (Koske and Tessier 1983) and PVLG mixed 1:1 (v/v) with Melzer's reagent. Spores were examined using a Leitz research microscope and compared to voucher specimens and descriptions from the International Culture Collection of Arbuscular and Vesicular-Arbuscular Mycorrhizal Fungi (INVAM) (Morton et al. 1993). Spore density was determined as the number of healthy appearing spores per 100 cm^3 soil. Species richness was determined as the numbers of AMF species detected at each site.

Trap cultures

Trap cultures were established from all soil samples by a modification of the protocol used by Stutz and Morton (1996) in order to detect possible non-sporulating species. Sudan grass (*Sorghum sudanese* (Piper) Staph.) seeds were planted into 656-ml Deepots using a planting media of a 1:1:1 mixture (175 cm^3 each) of sample soil and steam-sterilized #20 and #12 grades silica sand and grown in a greenhouse. Plants were watered at 1- to 3-day intervals over the course of 3 months. Upon flowering, watering was stopped and the plants were allowed to dry down. Samples (100 cm^3) from 25% of the first-generation trap cultures were wet-sieved and species identified using the previously described protocols. Because few spores were detected in the first-generation trap cultures, and species identified matched those detected in the soil samples (data not shown), a second generation of trap cultures was set up using 175 cm^3 of mixture from the first-generation trap cultures. All subsequent spore analyses were made from soil and second-generation trap culture samples.

Statistical analyses

Ecological parameters including Shannon index of diversity (H'), relative diversity or evenness (J'), and Simpson's index of dominance (D) were calculated based on species richness (N) and abundance (ni) data from the soil samples (Magurran 1988). Analyses of variance (SigmaStat version 2.03) were performed to determine variations between land-use categories in spore density and diversity indices values with a Student's t-test of means where appropriate. The relative abundances of spores of AMF species in each of the four land-use categories were determined as a percentage (the number of spores of a species detected in soil in a land-use category divided by the total number of spores detected in that land-use category × 100).

Data from soil samples and second-generation trap cultures were combined to determine species richness and composition. A Sorenson's Coefficient of Similarity (Koske et al. 1997) was calculated to compare the species composition at sites and a complete linkage cluster analysis was performed using SAS software version 8.0, 1999). Linear regression analyses were performed between species richness and P, NH_4^+, percent soil moisture, soil organic matter, plant species richness per site, percent vegetation cover, biovolume, the proportion of hosts at each site from plant families that are predominately non-mycorrhizal (Brundrett 1991), and percent of area in site quadrants developed for urban use (SigmaPlot version 4.0, 1997). Analysis of variance

was used to test for differences in mean species richness between current land-use categories, and a Student's *t*-test of means was performed on mean species richness between current land-use categories and current or previous desert and agriculture land (SigmaStat version 2.03, 1992–1997). The relative frequencies of detection of AMF species in each of the four land-use categories were determined as percentages (the number of samples in which a species was detected in soil or trap cultures in a land-use category divided by the total number of samples collected in that land-use category × 100).

Results

Mean spore density per site was 65.9 ± 11.5 per 100 cm^3 soil, with the highest densities occurring at two urban non-residential sites: V13, a middle school ground, and AC16, desert land adjacent to an industrial area (Table 1). No spores were recovered from soil collected at three sites (N17, W21 and AC 20) that were bare lots with little or no vegetation. Although abundance data were not obtained from all trap culture samples, spore densities in nearly all second-generation trap culture samples were considerably higher than spore densities in the corresponding soil samples. With the exception of two samples in which no spores were detected (both from site AC20), spore density in trap cultures in this study ranged from ~600 per 100 cm^3 sample (site S12) to thousands (site W21) (data not shown).

Eighteen AMF species representing four different families were detected across the 20 sampling sites (Fig. 2). Twelve of the species were of the family Glomaceae, four species were from Acaulosporaceae, one was from Archaeosporaceae and one was from Paraglomaceae. Two of the undescribed species detected, *Glomus* AZ112 and *Glomus* AZ123, were referenced according to the INVAM accession codes of the trap cultures from which the unique spore morphotypes were first discovered. One *Acaulospora* morphotype that could only be identified to the genus level was detected at two sites. Fourteen species were detected in the soil samples and 15 species were recovered from the trap cultures. Two species, *E. infrequens* and *A. scrobiculata*, were detected in soil samples but were not recovered from trap cultures. Four species, *G. claroideum*, *G. luteum*, *A. delicata* and *Acaulospora* sp., were identified from trap cultures but not detected in soil samples.

In most cases, AMF species were detected more frequently in trap cultures than in soil samples (Fig. 2). In soil samples, only *G. eburneum* was found to predominate. This species was recovered from all four land-use categories and was detected more frequently in soil samples than any other species. A rank abundance curve showed spores of *G. eburneum* to be the most abundant spore type recovered from the soil samples (1152 spores), followed by *G. microaggregatum* (1057 spores). Abundances of the remaining species ranged from 16 to 356. However, in the analysis of the second-generation trap cultures, four species (*G. eburneum*, *G. microaggregatum*, *G. spurcum*, and *G. intraradices*) were detected at over

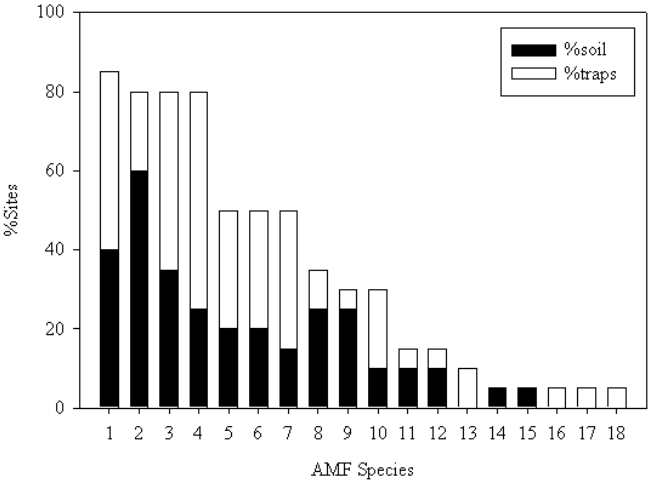

Fig. 2 The frequency of occurrence of AMF species in soil samples (shown by *black bars*) and in soil and trap cultures combined (shown in *white*). 1=*Glomus microaggregatum* Koske, Gemma & Olexia; 2=*G. eburneum* Kennedy, Morton & Stutz; 3=*G. spurcum* Pfeiffer, Walker & Bloss; 4=*G. intraradices* Schenck & Smith; 5=*G.* AZ112; 6=*G. mosseae* (Nicolson & Gerdemann) Gerdemann & Trappe; 7=*P. occultum* (Walker) Morton & Redecker; 8=*G. macrocarpum* Tulasne & Tulasne; 9=*G. etunicatum* Becker & Gerdemann; 10=*G.* AZ123; 11=*G. fasciculatum* (Thaxter) Gerdemann & Trappe emend. Walker & Koske; 12=*Archaeospora trappei* (Ames & Linderman) Morton & Redecker; 13=*Acaulospora* sp.; 14=*Acaulospora scrobiculata* Trappe; 15= *Entrophospora infrequens* (Hall) Ames & Schneider; 16=*Acaulospora delicata* Walker, Pfeiffer & Bloss; 17=*G. claroideum* Schenck & Smith; 18=*G. luteum* Kennedy, Morton & Stutz

80% of the sampling sites. Four species *(A. scrobiculata*, *E. infrequens*, *G. claroideum*, and *G. luteum*) were detected at only one sampling site and were detected in either soil samples or trap cultures, but not both.

Using only soil samples, the number of AMF species detected at each sampling site ranged from 0 to 6 (Fig. 3), with a mean of 3.2 ± 0.5. In trap cultures, the number of AM fungal species detected per sampling site ranged from 1 to 8, with a mean of 5.1 ± 0.43 per sampling site. At over half the sites, more than 50% of the species detected were only recovered from trap cultures. At sites containing little or no vegetation (AC20, N17 and W21), spores were only detected in trap cultures. At about half of the sampling sites, at least one of the AMF species detected in the soil samples was not detected in trap cultures, and at four sampling sites (G10, AB18, W9 and V13), a greater number of species was detected in soil than in trap cultures.

Analysis of the combined soil and trap culture data, showed an increase in the range of species richness per site to 2 to 9 species, with a mean of 6.4 ± 0.5 (Fig. 3). Nine species were detected at an urban non-residential site (X19), where samples were collected from *Ulmus* sp. planted in parking lot medians and at two of the desert sites, at AF14, where samples were collected from the root zone of *Parkinsonia microphylla* and *Larrea tridentata*, and at G10, where samples were associated with *Prosopis velutina.* Only two species were detected at sites

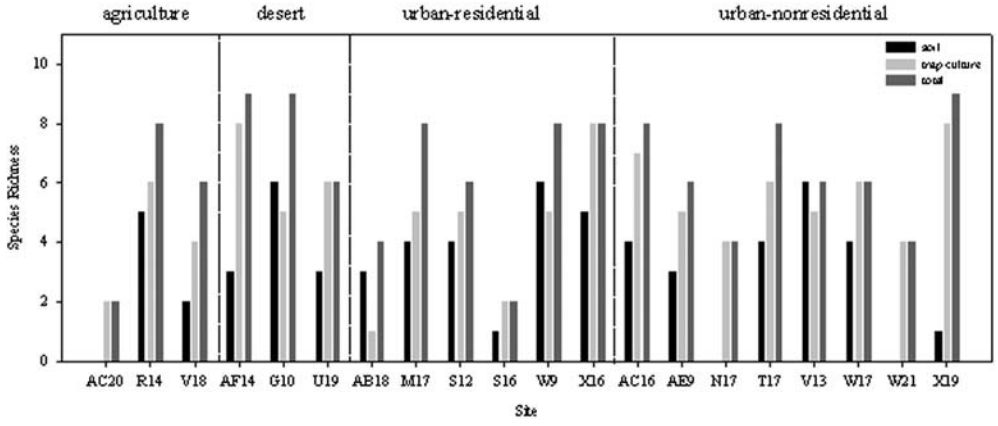

Fig. 3 AMF species richness of soil samples, trap cultures, and combined data from soil and traps from each sampling site (n=3, with the exception of site V13)

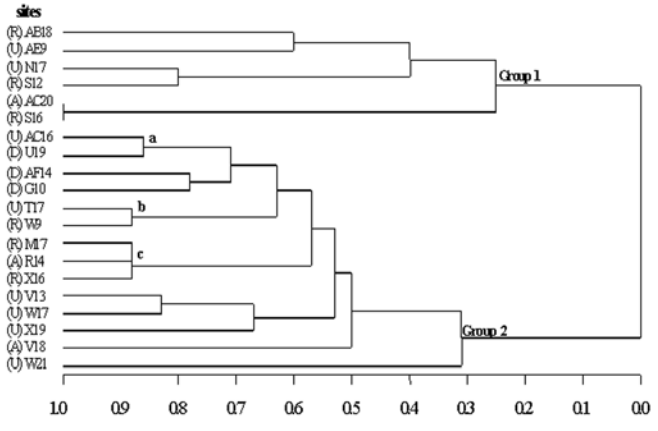

Fig. 4 Results of a complete-linkage cluster analysis based on the similarity in AMF species composition. Letters in parentheses indicate land-use groups (*R* Urban-residential; *U* urban non-residential; *A* agriculture; *D* desert). Labels *group 1* and *group 2* denote the first two clusters formed in the analysis and *a*, *b*, and *c* denote clusters of sites having the highest degrees of similarity in species composition

AC20, a farmyard with compacted soil and no vegetation, and S16, a high-density residential apartment complex where samples were collected from the root zone of *Eucalyptus* spp.

Cluster analysis based on the similarity in species composition between sites resulted in two primary groupings (Fig. 4). Group 1 contained sites with primarily urban land uses, both residential (AB18, S12, S16) and non-residential (N17, AE9), along with one further site (AC20), which was a farmyard with compacted soil and no vegetation. About 60% of the samples collected from sites in group 1 were from the root zone of non-arbuscular mycorrhizal plants or bare soil. Group 2 included sites from all four land-use categories. A high degree of similarity (greater than 0.86) was found in three clusters within this group: cluster A (AC16 and U19), which were primarily open desert land with native vegetation including *Ambrosia deltoidea* and *Larrea tridentata* (both sites) and *Parkinsonia microphylla* (U19 only), cluster B, where samples were collected from the root zone of *Parkinsonia microphylla* in urban sites, and cluster C, which included a residential horse pasture (M17), a corn field (R14), and a xeriscaped apartment complex (X16). All three sites in cluster C were currently agricultural or agricultural in nature prior to subsequent development. Two sites (AF14 and G10) that were classified in the desert land-use category were associated with cluster A (0.70 similarity). Two vacant lot sites (V18 and W21) shared little similarity with any other clusters in group 2. Samples at both sites were collected from the root zone of weed species since no perennial plants were present.

Analysis of variance indicated significant differences in spore density between the land-use categories (P<0.05). The mean spore density of desert sites was significantly higher than that of agriculture or urban-residential sites (P = 0.002 and P = 0.03, respectively) (Fig. 5). The mean spore abundance at agriculture sites was also at least 30% lower than that found in urban non-residential sites. There were no significant differences in mean spore abundance between sites in the urban non-residential and desert categories and the urban non-residential and urban-residential categories. Species richness did not differ among the four land-use categories from the soil samples, trap cultures, or from combining soil and trap culture data (P> 0.1; Fig. 5). No correlation was found between species richness and any of the edaphic or vegetation variables (plant species richness per site, percent vegetation cover and biovolume or levels of urbanization) using linear regression analysis. However, AMF species richness was higher at sites that were either currently desert or had been desert (7.3 ± 0.4) rather than agriculture (5.6 ± 0.7) prior to urban development (P = 0.07).

When data from soil samples for all sampling sites were used to calculate diversity indices, the Shannon index of diversity value (H') was 0.87, relative diversity value or evenness (J') was 0.76 and Simpson's index of dominance (D) was 0.19. Analysis of variance showed no significant differences between land-use categories in mean Shannon diversity values, evenness or dominance (P> 0.1).

Glomus microaggregatum was the most abundant spore type detected in soil samples collected from

Table 2 Relative abundance (%) in soil and relative frequency (%) in soil and trap cultures of AMF species in each of the four land-use types found in the Phoenix metropolitan area (abbreviations as in Table 1). Data presented only for those species with greater than 10% frequency or abundance

Species	Relative abundance				Relative frequency			
	A	D	R	U	A	D	R	U
G. eburneum	41.1	41.1	13.3	31.6	44.4	66.6	27.7	54.5
G. etunicatum	–	–	18.4	–	11.1	–	33.3	9.1
G. intraradices	–	–	19.4	4	66.6	44.4	33.3	59.1
G. fasiculatum	–	26.5	–	2.3	–	33.3	–	9.1
G. macrocarpum	17.9	0.5	5.2	–	22.2	11.1	16.6	9.1
G. microaggregatum	–	10.5	26.6	39.4	11.1	77.7	61.1	59.1
G. mosseae	2.7	16.8	1.1	–	55.5	77.7	27.7	9.1
G. spurcum	20.6	–	8.3	12.6	55.5	33.3	22.2	54.5
Glomus AZ112	–	2.3	0.6	3.8	11.1	33.3	16.6	22.7
Glomus AZ123	7.9	2.3	1.9	0.4	11.1	11.1	11.1	9.1
P. occultum	9.8	–	–	2.7	22.1	11.1	16.6	31.8

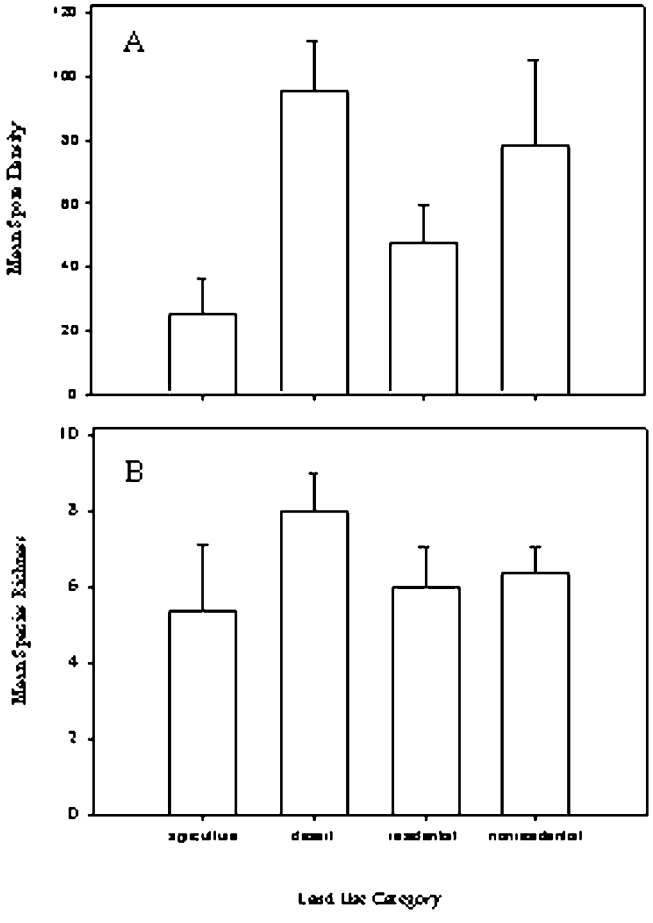

Fig. 5 A Mean AMF spore density in soil samples for each land-use type. **B** Mean AMF species richness detected in soil samples and trap cultures for each land-use type

urban-residential and urban non-residential sites (27% and 39%, respectively) (Table 2). *G. eburneum* was found to make up the largest proportion of spores detected in soil from the agriculture and desert sites (41% in each) and the second most abundant spore detected in soils from urban non-residential sites. When data from both soil and trap cultures were considered, *G. microaggregatum* was the most frequently detected species in samples from urban-residential, urban non-residential and desert sites but was infrequently detected (11%) in samples from agricultural sites. *G. mosseae* was detected in over 50% of the samples from agricultural and desert sites but less frequently in samples from urban sites. *G. intraradices* and *G. spurcum* were detected in over 50% of the samples from agricultural and urban non-residential sites, and *G. eburneum* in over 50% of the samples from the desert and urban non-residential sites.

Discussion

AMF diversity studies offer an important starting point from which to analyze AMF community structure in different anthropogenically influenced areas (Franke-Snyder et al. 2001). Our findings for an arid urban ecosystem show differences in AMF community structure to be most closely related to current land use, land-use history and vegetation type. Spore densities were lower at agricultural and residential land sites than desert sites. Species richness was also less at sites where the land was currently or previously agricultural rather than desert prior to urban development. Different AMF species appeared to predominate with different land uses, and AMF community composition was most similar at sites with similar vegetation and at desert sites.

We detected the highest number of AMF species in the Phoenix urban ecosystem when we combined results from soil samples and trap pot cultures. When soil samples alone were used to assess AMF species richness, the overall detected mean species richness was underestimated by 3.2 species per sampling site. This underestimation was most severe for desert sites and vacant urban lots, indicating that many AMF species were present in soil but not sporulating at the time of sampling. However, spores of at least one AMF species were detected in soil but not in trap pot cultures at about 50% of the sampling sites. Thus, when pot cultures alone are used to assess AMF diversity, overall detected mean species richness may be underestimated by 1.3 species per sampling site. These results illustrate some of the limitations of using spores for detecting diversity. Our findings corroborate the conclusion reached using morphological (McGee 1989; Merryweather and Fitter 1998) and molecular techniques (Clapp et al. 1995;

Kowalchuk et al. 2002) that AM fungal species can be present at a location even though spores of these species are absent from soil. Sporulation of different AM species has been demonstrated to be distinctly seasonal and to be influenced by host plant phenology (Pringle and Bever 2002). The collection of soil samples in May, the beginning of the hottest period of the year when many desert and landscape plants are actively growing, may have influenced sporulation patterns. Additional AMF species may have been detected had samples been collected during different seasons, with an increased number of samples per site or in trap cultures grown on additional host plants (Bever et al. 2001). Despite these caveats, our results give some preliminary indications of the effects of urbanization on AMF community structure.

Categorizing sites by land-use type is a common practice in urban ecology (Grimm et al. 2000; McIntyre et al. 2001) but, as seen in this study, sites in the same broad land-use category can differ substantially in vegetative characteristics and micro-habitats. However, differences were seen in spore densities and the relative abundance and frequencies of AMF species between land-use categories despite heterogeneity between sites in the same land use. In particular, spore densities were found to be lowest at agricultural sites. Conventional, chemical-based agriculture has been associated with decreases in AMF spore numbers and altered AMF communities (Kurle and Pfleger 1994; Douds and Millner 1999). Mean species richness was also lower in sites that were agricultural rather than desert prior to urban development, indicating that for AMF communities land-use history has legacy effects that can persist over long periods of time. Our results, although preliminary, also suggest that shifts in community composition may be associated with urbanization. In particular, spores of *G. eburneum* were most abundant in desert and agricultural sites, while those of *G. microaggregatum* were most abundant in urban sites. Meanwhile, certain species such as *G. mosseae* were less frequently detected at urban sites, while *G. microaggregatum* was less frequently detected at agricultural sites. It has been suggested that landscape practices such as fertilization and irrigation can select for less mutualistic fungal species (Johnson 1993; Kurle and Pfleger 1994; Stabler et al. 2001), which in turn may impact plant primary productivity. The functional implications of such alterations in community composition need further investigation.

The calculated diversity indices show that the AMF community in the Phoenix urban area is relatively even, with no significant differences in diversity, evenness or dominance between land-use types. Interpretation of diversity indices with respect to AMF should be carried out with caution because spore densities are one component of these indices. In studies such as this, where a large percentage of AMF species were not sporulating at the time of sampling, indices only give some measure of diversity, evenness and dominance of the sporulators in a mycorrhizal community (Morton et al. 1995). With this in mind, our results indicate that patterns of sporulation within the AMF community are not significantly impacted by land-use activities.

AMF species richness was not related to edaphic characteristics, plant species richness per site, percent vegetation cover and biovolume or levels of urbanization. This lack of correlation may be due to site heterogeneity or because the one-time "snapshot" sampling used did not accurately capture conditions over longer periods of time. Edaphic variables such as nutrient levels may vary considerable between seasons at desert sites and due to different landscape practices at urban sites. Soil moisture could also fluctuate over short periods, especially in urban sites, depending on irrigation frequency and timing. AMF species richness and composition were clearly affected by the plants from which samples were collected. Species richness was lowest where samples were collected from non-mycorrhizal weed species and highest at sites where samples were collected from native vegetation or elm trees. Sites with native plant species had the greatest degree of similarity in AMF species composition and differed from sites where samples were collected from non-mycorrhizal plants, predominately ectomycorrhizal plants (such as *Eucalyptus*) or from bare soil.

AMF community structure in the Phoenix metropolitan area showed many similarities with that reported for the surrounding Sonoran Desert. For example, low spore density levels (less than 50 spores per 100 cm^3 soil) previously reported for the Sonoran Desert (Rose 1981; Cui and Nobel 1992), were also found in over half of the sites in this study. Species richness was higher than that reported in other Sonoran Desert studies, where only soil samples were studied (Rose 1981; Cui and Nobel 1992), but was close to other findings in the Sonoran Desert with trap cultures (Stutz and Morton 1996; Stutz et al. 2001). The AMF species composition was also very similar to that previously reported in the Sonoran Desert (Bethenfalvay et al. 1984; Bloss 1985; Stutz and Morton 1996; Stutz et al. 2000). AMF genera were restricted to *Glomus*, *Acaulospora*, *Archaeospora*, *Entrophospora*, and *Paraglomus*, with no members of the Gigasporaceae detected, and the majority of species identified were typical of the region, such as *G. eburneum*, *G. microaggregatum*, *G. intraradices* and *G. spurcum* (Stutz et al. 2000). Meanwhile, the sites categorized as urban had the highest spore densities. Irrigation, fertilization and different host species may account for this difference to desert sites. Unlike previous studies that indicated an influx of non-native plants and animals into urban areas (McDonnell and Pickett 1990), our preliminary results show that few non-native AMF species have been successfully introduced into the Phoenix metropolitan area. Our results do not rule out the possibility that alien isolates of extant species have been introduced.

In conclusion, similarities in AMF species composition between the urban environment and surrounding desert indicate a persistence or immigration of AMF species from the surrounding desert. However, our results suggest that factors such as disturbance and introduction of non-native plants, particularly when associated with agriculture, affect AMF community structure and that these effects persist over long time periods. Analysis of data collected in the larger Survey 200 will aid in determining

whether the preliminary trends seen in this project are accurate. Future studies of the effects of factors such as urban landscape practices (e.g., irrigation, fertilization, and pruning), edaphic conditions and pollutants on AMF communities should be designed to control for differences in vegetation, land use and land-use history. Controlled experiments are also needed to determine how alterations of AMF community structure in urban ecosystems impact functional aspects of mycorrhizal associations, including effects on plant primary productivity.

Acknowledgements This material is based upon work supported by the National Science Foundation under Grant No. DEB 9714833, Central Arizona–Phoenix Long-Term Ecological Research (CAP LTER). Any opinions, findings and conclusions or recommendations expressed in this material are those of the author and do not necessarily reflect the views of the National Science Foundation. Special thanks are offered to the CAP-LTER Field Team.

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