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DIVERSTY AND ABUNDANCE OF ARBUSCULAR MYCORRHIZAL FUNGI ACROSS DIFFERENT LAND USE TYPES IN A HUMID LOW LAND AREA OF ETHIOPIA

[DIVERSIDAD Y ABUNDANCIA DE HONGOS MICORRÍCICOS ARBUSCULARES EN DIFERENTES TIPOS DE USOS DE SUELO EN ÁREAS DE TIERRAS HÚMEDAS BAJAS DE ETIOPÍA]

Zerihun Belay[1*], Mauritz Vestberg[2] and Fassil Assefa[1]

[1]Department of Microbial, Cellular and Molecular Biology, College of Natural Sciences, Addis Ababa University, Ethiopia. Email: zebelay2009@gmail.com
[2]Natural Resources Institute Finland (Luke), Laukaa, Finland, Email: mauritz.vestberg@mtt.fi
[*]Corresponding author

SUMMARY

The aim of this work was to study the effect of different land use types on arbuscular mycorrhizal (AM) fungal populations in soil and trap cultures from Showa robit, Ethiopia. Seven land use types were selected. There were low-input arable systems, either having a mixture of crops (Arable1) or monocropped with sorghum (Arable2) or maize (Arable3). Arable4 was relatively a high-input system with monocropped sorghum. A fruit cropping area (FC) managed with composts and plant residues, a natural forest (NF) and an acacia plantation (AP) were also studied. AMF spore abundance, species richness, diversity indices and mycorrhizal inoculum potential (MIP) were studied. In field soil, significantly higher spore numbers were recorded from FC, Arable1 and Arable3 (5.8-6.1 spores g^{-1} soil) than in Arable4, NF and AP (2.8-3.9 spores g^{-1} soil). In trap cultures, AP, FC, and Arable2 had the highest spore numbers (9.8-11.1 g^{-1} soil) and Arable4 and NF the lowest (2.5-3.8 g^{-1} soil). Slightly different MIP patterns also occurred with Arable1 (53.7%) and FC (52.6%), having significantly higher hyphal colonization, 53.7% and 52.6%, respectively, compared to the other land use types that fell within percentage colonization of 19.9-25.8 %. A total of 42 and 33 morphospecies of AMF were identified in field soil and trap culture soil, respectively. Trap culturing increased spore numbers but caused a loss of AMF species richness. Higher species richness was obtained in FC and Arable1 compared with the other systems. *Claroideoglomus* and *Funneliformis* were the dominant genera in all land use types in both trap culture and field soil. The results clearly imply that organic management and diversification of crops enhances AMF diversity of low-input agricultural systems.

Keywords: *Claroideoglomus; Funneliformis; Glomus;* mixed cropping; monocropping; mycorrhizal inoculum potential.

RESUMEN

El objetivo de este trabajo fue estudiar el efecto de diferentes tipos de usos de suelo sobre las poblaciones de hongos micorrícicos arbusculares (HMA) en suelo y cultivos trampa de Showa Robit, Etiopía. Siete tipos de uso de suelo fueron seleccionados. Hubo tres sistemas de cultivo de bajos insumos, teniendo una mezcla de cultivos (cultivo 1), un monocultivo de sorgo (cultivo 2), y un monocultivo de maíz (cultivo 3). El cultivo 4 fue un monocultivo de sorgo con altos insumos. También fueron estudiados un cultivo de frutales (CF) sin químicos, un bosque natural (BN) y una plantación de acacia (PA). La abundancia de esporas, la riqueza y diversidad de especies, índices de diversidad y potencial de inóculo micorrícico (PIM) fueron evaluados. Comparado con las muestras de campo, los cultivos trampa incrementaron el número de esporas pero la riqueza de especies de HMA disminuyó. La mayor riqueza de especies y el PIM fueron obtenidos en el CF y el cultivo 1 comparado con los otros usos de suelo. Se identificaron un total de 42 y 33 morfoespecies de HMA en el suelo de campo y cultivos trampa, respectivamente. *Claroideoglomus claroideum, Funneliformis mosseae,* y *Glomus* sp.2 dominaron el suelo del campo, mientras *Cl. claroideum, Cl. etunicatum, Cl. luteum, Fu. mosseae* y *Gl. aggregatum* fueron las especies dominantes en los cultivos trampa. Los resultados sugieren que los sistemas de bajos insumos combinados con policultivos pueden mantener los HMA nativos en la agricultura sostenible.

Palabras clave: *Claroideoglomus; Funneliformis; Glomus;* policultivos; monocultivos; potencial de inóculo micorrícico.

INTRODUCTION

It is a well-known fact that rapid land use change as a result of deforestation, cropland and pasture expansion, dry land degradation, urbanization, and agricultural intensification results in reduction in soil fertility (Hartemink *et al.,* 2008). The conversion of natural ecosystems to agriculture affects the above-ground plant and animal biodiversity (Wardle and Lavelle, 1997), which, in turn affects below-ground macro and microbial community structure and their functions (Bossio *et al.,* 2005).

Arbuscular Mycorrhizal Fungi (AMF) are one of the below-ground microbial groups that are severely affected by changes in vegetation cover and physical and chemical characteristics due to deforestation and land degradation (Smith and Read, 2008). These fungi are associated with more than 80 % of terrestrial plants. They enhance host growth and survival by facilitating nutrient uptake (Smith and Read, 2008) and improving tolerance to drought (Yamato *et al*., 2009) and to some root pathogens and nematodes (Azcón-Aguilar and Barea, 1997).

The influence of land use changes on AM fungal diversity and abundance has recently received considerable attention in both temperate (Oehl *et al.,* 2003; Verbruggen *et al.,* 2010) and tropical areas (Li *et al.,* 2007; Jefwa *et al.,* 2009; Stürmer and Siqueira, 2011; Jefwa *et al.,* 2012; Muchane *et al.,* 2012). It is reported that land use changes (Tchabi *et al*., 2008; Jewfa *et al.,* 2012; Muchane *et al*., 2012), ploughing, fertilizer and fungicide application (Douds *et al.,* 1993; Helgason *et al.,* 1998) land use intensity (Oehl *et al.*, 2003, 2004; Verbruggen *et al*., 2010) and tillage intensity (Jansa *et al.,* 2002) decrease AMF species richness, spore abundance and root colonization in different parts of Central Europe and tropical ecosystems in Africa.

Verbruggen *et al.* (2010) showed a decrease in mycorrhizal fungal communities in relation to land use intensity in that the average number of AMF taxa identified was highest in grasslands (8.8), intermediate in organically managed fields (6.4) and significantly lower in conventionally managed fields (3.9) in the agricultural soils of the Netherlands. It is also shown that AMF diversity and species richness in organically managed fields and natural vegetation fields was higher than that of conventionally managed fields (Oehl *et al.,* 2004; Tchabi *et al.,* 2008).

In Ethiopia, the land cover has been changed from natural forest to farmland, open grazing and fast growing plantation forests for several decades. According to FAO (2007), the country lost an average of 141,000 ha, or 1.1% per year, of its forest covers between 1990 and 2005, due to deforestation. Another study in the Central Ethiopian Rift Valley indicated that woodland cover declined from 40% to 9% at one site, while another site lost 54% of its woodland cover due to rapid deforestation (Garedew *et al.,* 2009). In all these years, deforestation has resulted in massive soil degradation with a decline in soil organic matter (SOM) and available nitrogen in the highlands of Ethiopia (Lemenih *et al.*, 2005; Girmay *et al.,* 2008). A recent study also showed drastic changes in several of the physical and chemical properties of soils from different parts of the country due to rapid land use changes (Getachew *et al.*, 2012).

The drastic change in deforestation and land use in Ethiopia decimated the large biodiversity and plant community structure of the country. This is also presumed to affect the underground microbial composition including the AMF, because several studies have showed that plant community structure affects diversity and community composition and species richness of AMF (Burrows and Pfleger, 2002; Vandenkoornhuyse *et al.,* 2002; Johnson *et al.,* 2003: Scheublin *et al.,* 2004; Sýkorová *et al.,* 2007).

It was also reported that changing the vegetation cover from tree-based intercrops to mono-cropping systems can reduce AMF fungal richness (Chifflot *et al*., 2009). Lower AMF species richness was found in arable fields, compared to different natural ecosystems and perennial communities such as tropical forests (Snoeck *et al*., 2010). It may well be that the intensive land use change in Ethiopia for several decades has brought a reduction and/or shift in abundance and diversity of AMF under monocropping and intercropping systems.

The hypothesis of this study was that AMF abundance and diversity may have been affected by land management practices such as monocropping cultivation and use of fertilizer in the agricultural systems of the country. It is also equally important that understanding the role of AMF over a broad range of land use systems is essential for land rehabilitation and effective management for sustainable production through AMF technology in the future (Estaún *et al.,* 1997; Oehl *et al.,* 2003).

The objectives of this study were; (1) to compare AM fungal diversity and community composition among different land-use systems within a single agro-

ecosystem; (2) to determine mycorrhizal inoculum potential in soil of these systems (3) and to determine whether AM fungal species richness, mycorrhizal inoculum potential (MIP) and spore abundance are influenced by land use changes.

MATERIAL AND METHODS

Study site description

The study site is located in Showa robit (10^0 06' 650" - 09^0 57'957" N, 039^0 54'37"-$039^0$56'579" E), (**Figure 1**) in north Showa Zone of Amhara Regional State, 225 km north of Addis Ababa, Ethiopia. The agro-ecology of the study site is low-land or Erteb Kola (sub-moist warm) with altitude ranging between 1120 and 1350 m a.s.l. The climate data of the study area recorded for the last ten years shows average annual maximum and minimum temperature and precipitation of 32.1 and 16.1 ^{0}C, and 968 mm, respectively (NMA, 2002-2010).

The land use of the area is mainly characterized by agroforestry practices such as agrisilvicultural (crops including and shrub/tree crops-trees) and agropastoral systems (trees+ crops+ pasture/animals) (Nair, 1993). The vegetation cover of the area is wood-land dominated by trees such as *Acacia*, *Erythrina, Cordia* and, *Ficus* species. The main grain crops of the area are sorghum, teff, finger millet and maize, whereas horticultural and commercial crops such as mango, banana, sugar cane, coffee, orange, tobacco, onion, tomato and cabbage are also grown in a mixed and/or rotation cropping system.

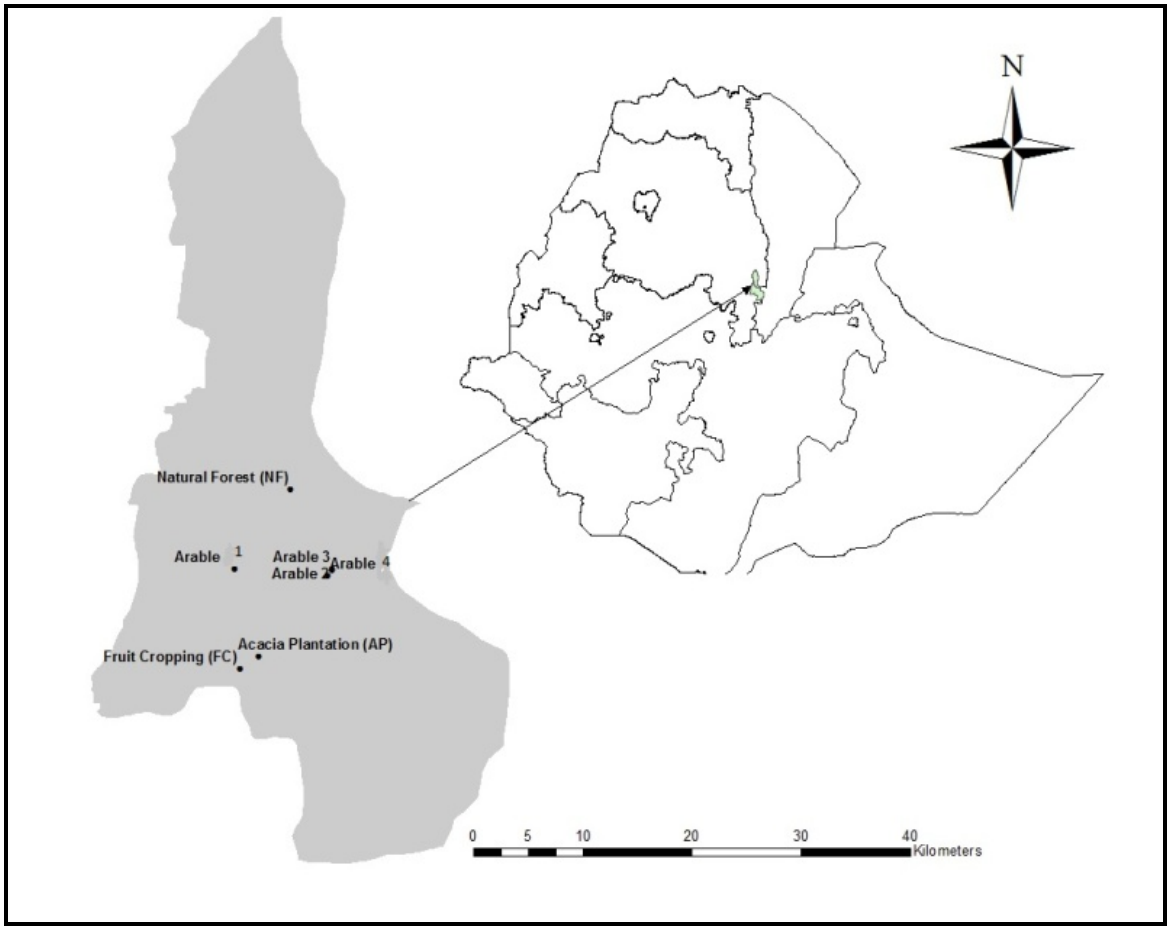

Figure 1. Map of the study site and sampling location.

Characteristics of the sampling site

The sampling area included seven different land use types and vegetation covers. There were four arable lands (Arable1-Arable4), one fruit cropping area (FC), one natural forest (NF) and one acacia plantation (AP). Arable1 was a low-input, mixed subsistence cropping (teff, sunflower and sesame). Arable2 and Arable3 were low-input sorghum and maize monocrop fields, respectively. Arable4 was relatively a high-input, conventional field cropped with sorghum. In the fruit cropping area (FC), mainly fruits, vegetables and garden cash crops were grown in an intercropping system with banana, papaya, mango, lemon, avocado, tomato and coffee. Two forest relic sites were also included. The natural forest site was dominated by acacia, fig trees and red stinkwood. The other forest relic site was an acacia plantation dominated by two acacia species (*Acacia seyal* and *A. nilotica*). A description and agricultural management practices of the study sites are given in Table 1.

Sampling was conducted during the dry season from November to December 2011. Three replicate sampling locations (approximately 100 m^2) were established for each land use type and dominant plant species. Three replicates of each dominant plant species were randomly selected.

From each sampling site, 500 g of rhizosphere soil samples were taken from a depth of 0-30 cm and subsequently pooled into one composite sample per location. A total of 54 samples, 3×3 from the three arable monocrop fields, 3×3 each from the arable mixed crop field, 3×7 from the fruit crop field, 3×3 from the natural forest and 2×3 from the acacia plantation were collected. The samples were collected in alcohol sterilized plastic containers, air dried and stored at room temperature for further analysis. Subsamples were used as inoculum for the trap culture system and for the spore extraction.

Soil physical and chemical characteristics

Soil particle size of samples from all land use types was determined using the hydrometer method (Gee and Bauder, 1986). Soil organic carbon (OC) was determined by the Walkley-Black dichromate oxidation procedure (Walkley and Black, 1934). Total nitrogen (TN) was determined by the Kjeldahl method (Hinds and Lowe, 1980). Soil available phosphorus was measured according to the method described by Olsen et al. (1954). The soil sample analyses were done at the Addis Ababa city administration environmental protection authority. Soil pH was measured at the Department of Microbial Cellular and Molecular Biology, Addis Ababa University, following 1:2.5 (v/v) soil: water suspension with a digital pH meter (HD8602) (Table 2).

Establishment of trap cultures

Trap cultures in pots were set up in triplicates for all seven land use types in a greenhouse to obtain fresh spores for identification of AM fungi and induce sporulation of species present only as hyphae in field samples. Pots with the size of 15cm were filled with 250 g of soil sub-sample containing root sections from each plot of the field and were thoroughly homogenized with sterile sand (1:1; v/v) according to Morton *et al.* (1993). Maize (*Zea mays* L.), a mycotrophic crop, was selected as an appropriate trap plant for its ability to induce high spore density, diversity and species richness (Yao *et al.,* 2010).

Seeds of maize were surface sterilized by immersing them in a 0.5% sodium hypochlorite solution for 15 minutes. After washing the seeds with sterile water they were sown at 2 cm depth in each plastic pot and covered with sterilized sand. Pots were irrigated daily as needed. No fertilizer was added during the growing period. All seedlings were grown in the greenhouse under natural ambient light and temperature conditions (about 29 °C day/18°C night).

The maize roots were checked for AMF colonization after 45 days. Pots supporting successful mycorrhization were maintained for six months. Watering was reduced during the final three weeks to maximize spore production. At the end of 6 months the plants were cut near the base, and the cultures were air-dried and checked for the presence and identification of spores.

Estimation of mychorrhizal inoculum potential (MIP)

MIP (mycorrhizal inoculum potential) of the different land use types was assessed in a greenhouse bioassay according to Sieverding (1991). A 300g soil sample from each land use type was placed in 450-ml sterile plastic pots. Five seeds of maize were sown per pot, and the seedlings were thinned down to three per pot after emergence. The pots were arranged in a completely randomized design with three replicates. After five weeks, the trap plants were harvested and their roots were cut into 1-cm sections and stained according to Brundrett *et al.* (1996). The percentage of colonized roots was quantified using the magnified intersection method (McGonigle *et al.,* 1990).

Table 1: Charactersitcs of study sites; management practices, standing crops or dominant plant species, fertilization and plant protection system. (Sources:Debere Brehan Agricultural Research Centere and Kewit Wereda Agriculture Office).

	Cropping system, land history	Fertilization (kg ha^{-1})	Plant protection	Standing crops or dominant plant species during sampling	Common name
Arable1	Crop rotation; three crops in mixture	Low-input urea (50) DAP (100)	Chemical and mechanical	*Eragrostis teff (*Zucc.) Trotter *Sesamum indicum* L. *Helianthus annuus* L.	Teff Sesame Sunflower
Arable2	Continuous sorghum monocropping field for 2 yr.	Low-input, Urea (50) DAP (50)	Chemical and mechanical	*Sorghum bicolor* L.	Sorghum
Arable3	Continuous maize monocropping field for 3 yr.	Low-input, Urea (100) DAP (100)	Chemical and mechanical	*Zea may* L.	Maize
Arable4	High-input; Sorghum monocropping field site used by DBRC	Mineral high-input ; Urea (100), DAP (150)	Chemical	*Sorghum bicolor* L.	Sorghum
Fruit cropping (FC)	Mixed fruit crops field, adjacent to river and irrigated regularly	Manure, compost and crop residues	Mechanical	*Persea americana* Mill. *Mangifera indica* L. *Coffee arabica* L. *Carica papaya* L. *Musa acuminata* Colla *Lycopersicon esculentum* Mill. *Citrus limonum* Risso.	Avocado Mango Coffee Papaya Banana Tomato Lemon
Natural forest (NF)	Mature forest (30 yr.), mixture of different trees, protected	None	None	*Acacia nilotica* (L.) Delile. *Ficus vasta* Forssk. *Prunus africana* (Hook.f.) kalkman	Acacia Fig tree Red Stinkwood
Acacia Plantation (AP)	Community managed acacia dominated forest, not protected	None	None	*Acacia seyal* Del. *Acacia nilotica* (L.) Delile.	Acacia Acacia

Table 2: Physical and chemical properties of soil samples from seven land use types at Showa robit, Ethiopia.

Land use type	pH	P (ppm)	T.N %	O.C %	Sand %	Clay %	Silt %	Texture class
Arable1	7.4	9.42	0.1	1.6	56	17	27	Sandy loam
Arable2	7.3	11.92	0.1	1.9	45	27	28	Clay loam
Arable3	7.4	5.98	0.2	1.6	52	22	26	Sandy clay loam
Arable 4	7.3	11.02	0.1	1.7	52	20	28	Loam
Fruit cropping(FC)	7.8	7.5	0.3	2.5	55	16	29	sandy loam
Natural forest (NF)	7.7	34.7	0.26	1.1	61	7	32	Sandy loam
Acacia plantation (AP)	7.9	5.4	0.1	1.3	50	25	25	Sandy loam

P: available phosphorus; T.N: Total nitrogen; O.C: organic carbon; Arable1: Low -input mixed cropping; Arable2: low-input monocropping, sorghum; Arable3: low-input monocropping, maize; Arable4: high-input monocropping, sorghum.

Staining of mycorrhizal roots

Staining of mycorrhizal roots was made according to Brundrett *et al.,* (1996). The root samples were carefully washed several times with tap water. About 0.5 g of root segments were cleared in 10 % (w/v) KOH at 90^0C in a water-bath for 2h, after which they were bleached with alkaline hydrogen peroxide at 10% for 3 minutes at room temperature. The roots were then treated with 1% HCl (v/v) for 15-20 minutes at room temperature and finally stained with 0.05% w/v trypan blue in lactoglycerol (1:1:1; lactic acid, glycerol and water) at 90^0C for 30 minutes in a water-bath**.**

With the exception of the HCl treatment, samples were drained and washed thoroughly with distilled water at the end of every step. The root samples were then left overnight in the lactoglycerol destaining solution (1:1:1; lactic acid, glycerol and water) in a dark room to remove coloration from root cells. Finally, roots were mounted in PVLG mountant on microscopic slides and covered with 40×22 mm coverslips.

Quantification of AMF root colonization

AM colonization was assessed from cleared and stained roots according to McGonigle *et al.* (1990). A total of 100 intersections were taken for each subsample to estimate percent AM root colonization under a compound microscope (OLYMPUS-BX51) at a magnification of ×200.

The presence of arbuscular colonization (AC) and vesicular colonization (VC) were calculated by dividing the count for the 'arbuscular' and 'vesicles' categories, respectively by the total number of intersections. Hyphal colonization (HC) was calculated as the proportion of non-negative intersections (McGonigle *et al.,* 1990).

Spore extraction

Soil and trap culture samples were air-dried and sieved through a 2-mm sieve to remove coarse debris before extracting, counting and identifying AM fungal spores. One hundred gram of dry soil was taken to extract the spores using the wet sieving and decanting method (Gerdemann and Nicolson, 1963), followed by centrifugation in water and in 50% sucrose solution (Brundrett *et al.,* 1996).

Each soil sample was mixed in a substantial volume of water and decanted through a series of sieves of 500, 250 and 50 µm. The contents from 250 and 50 µm sieves were mixed with water and centrifuged (Wagtech International) for 5 minutes at 2000 RPM. After having discarded the supernatant, the pellets were re-suspended in 50% sucrose solution and centrifuged for 1 minute as before. The supernatant was carefully poured through a 50 µm sieve and carefully washed with water to remove the sucrose.

Finally spores, spore clusters and sporocarps were carefully washed and transferred to a Petri dish to prepare for spore counting under the dissecting microscope (ISO 1006) at ×4. Enumeration of spore numbers per gram of dry soil was undertaken according to INVAM, *http://invam.caf.wvu.edu.*

Identification and characterization of spores

The AMF spores were morphologically identified at the Department of Microbial, Cellular and Molecular Biology, Addis Ababa University, Ethiopia and Natural Resources Institute Finland (Luke), Laukaa, Finland. About 50-70% of healthy looking spores were picked with forceps and mounted on slides in polyvinyl-lactic acid-glycerol (PVLG), (Omar *et al.,* 1979) or in PVLG mixed with Melzer's reagent (1:1 v/v) (Morton, 1991). Spores were examined under a compound microscope (OLYMPUS-BX51) at a magnification of ×400 and identified to the species level or to a specific morphotype based on (Schenck and Perez, 1990), online references of species description INVAM *http://invam.caf.wvu.edu,* West Virginia University, USA , University of Agriculture in Szczecin, Poland http://www.zor.zut.edu.pl/Glomermycota/, Schüßler and Walker (2010) and the Schüßler AMF phylogeny website http://www.lrz.de/~schuessler/amphylo/.

Determination of AMF diversity and spore density

The AMF communities on different land use types were detected and calculated based on the following parameters: Spore density (SD) was expressed as the number of AMF spores g^{-1}soil. Species richness (S) was measured as the total number of morphospecies. The Shannon–Wiener index (H′) of diversity was calculated using the formula: $H' = -\sum ((n_i/n) \ln (n_i/n))$ where: n_i = number of individuals of species i and n = number of all individuals of all species. The Simpson's dominance index (D) was calculated using the formula $D = \sum (n_i/n)^2$; Evenness (E) was calculated by dividing Shannon–Wiener diversity value by the logarithm of the species richness. These analyses were conducted using the software PAST3 (ver. 3.0).

Isolation frequency (IF) was calculated as (the number of samples in which a given species was isolated/ the total number of samples) ×100%. Relative abundance of spores (RA) was calculated as

(the number of spores in a given species / total number of spores) ×100%. The importance value (IV) was used to evaluate the dominance of AMF species based on IF and RA and was calculated as IV = (IF + RA)/2. An IV ≥ 50% indicates that a genus or species is dominant; 10% < IV < 50% applies to common genera or species; an IV ≤ 10% indicates that a genus or species is rare (Chen *et al.,* 2012).

Statistical analysis

Spore abundance data were log(x) transformed and the proportion of root colonization values were arcsine (the inverse sine of the square root of the proportion) transformed prior to analysis to meet assumptions of ANOVA such as normality and homogeneity of variance, but values were expressed as number of spores g^{-1}soil and percentage of root colonization, respectively. ANOVA and correlation analyses were carried out with the SPSS software package (version 21.0).

Significance of differences in AM fungal spore abundance and inoculum potential was tested using Fisher`s least significant difference (LSD) at $p < 0.05$ after one-way ANOVA. The relationships between AMF parameters and soil chemical properties (pH, OC, available P, and TN) were determined using Pearson's correlation analysis. The same statistical tests were applied for initial mycorrhizal root colonization and spore formation for the trap cultures inoculated soils from the different sites.

RESULTS

AMF spore abundance in the soil and in trap cultures

The AMF spore densities of the different land use types recovered directly from the soil and trap cultures is shown in (**Table 3**). Spore densities in trap cultures were up to twice as high as those recovered from soil. The data also showed differences in the spore counts between soil and trap culture. Accordingly, FC (fruit cropping) and Arable3 land use types showed the highest spore count of 6.1 spores g^{-1} soil from field soil whereas FC and AP displayed the highest spore count of more than 11 spores g^{-1} soil in trap cultures. In general, NF (2.5) and Arable4 (3.8) showed the lowest number of spores per gram of soil in trap culture.

Data are reported as averages and standard errors for the three replicates per land use type. Values followed by different letters denote significant differences between land use types according to Fisher's LSD test at the 5% level after a one-way ANOVA. N: number of replicates; Arable1: Low-input mixed cropping; Arable2: low-input monocropping, sorghum; Arable3: low-input monocropping, maize; Arable4: high-input monocropping, sorghum.

Table 3. AMF spore abundance in soil and trap cultures of the different land use types in a humid lowland sampling area at Showa robit, Ethiopia

Land use type	N	AMF spores g^{-1} of soil	
		Field soil culture	Trap
Arable1	9	5.8 ± 0.8c	7.2 ± 1.7bc
Arable2	3	5.5 ± 1.5bc	9.8± 2c
Arable3	3	6.1 ± 1.4c	6.6± 1.4bc
Arable4	3	3.9 ± 0.5ab	3.8± 0.1ab
Fruit cropping (FC)	21	6.1 ± 0.7c	11.4± 1.4c
Natural forest (NF)	9	3.5 ± 0.2ab	2.5 ± 0.2a
Acacia plantation (AP)	6	2.8 ± 0.5a	11.1± 0.7c

Spore density correlated significantly with species richness and VC%, ($r=0.84$, $P<0.05$; $r=0.94$, $P<0.01$, respectively). Species richness correlated significantly with TN% and O.C %,($r=0.79$, $P<0.05$ and $r=0.76$, $P<0.05$, respectively).

Mycorrhizal inoculum potential

The AM fungal colonization patterns within the roots of maize plants showed that there was considerable heterogeneity between the land use types (**Table 4**). Root colonization occurred with typical structures (arbuscules, vesicles and hyphae) in almost all land use types except in Arable2, where vesicles were not observed.

The highest hyphal colonization of 53.7% and 52.6% were recorded from low-input mixed cropping (Arable1) and fruit cropping systems (FC), respectively, compared with the other land use types that showed mycorrhization rate ranging from 19.9% to 25.8% ($P=0.011$).

Table 4. Percentage of mycorrhizal root colonization in maize after five weeks of growth in soil from seven land use types at Showa robit, Ethiopia.

Land use type	AM colonization (%)		
	Arbuscular Colonization	Vesicular Colonization	Hyphal Colonization
Arable1	8.6 ±3ab	4.1 ±0.6ab	53.7±10.5c
Arable2	2 ± 1.5a	0	21±7.5ab
Arable3	7.4 ±0.3ab	0.9±0.5ab	36±8abc
Arable4	3.3 ±0.1ab	1.2±0.2ab	19.9±1.2ab
Fruit crops	12.6 ± 1.8b	7.5±1.4b	52.6±5.8c
Natural forest	2.6 ± 0.8a	2.2±0.9a	25.8±7.7ab
Acacia plantation	5.5± 1.7ab	4.7±2.1ab	30.2±2.1abc

Data are reported as averages and standard errors for three replicates per land use types. Values followed by different letters denote significant differences among land use types according to Fisher's LSD test at the 5% level after a one-way ANOVA. Arable1: Low-input mixed cropping; Arable2: low-input monocropping, sorghum; Arable3: low-input monocropping, maize; Arable4: high-input monocropping, sorghum.

AMF community composition

A total of 42 and 33 AMF morphospecies, were identified from field soil and trap culture, respectively (**Fig. 2)**. Four morphospecies, from *Glomus, Acaulospora* and *Gigaspora,* from field soil samples and five morphospecies, from *Glomus*, *Acaulospora, Gigaspora* and *Ambispora* were not unidentified (data not shown). With a few exceptions of Arable 2, 3, and 4 land use types, field soil revealed more species than trap culture, and mixed cropping (Arable1), fruit cropping (FC), and natural forest (NF) and acacia plantation (AP) harbored more species than did monocrops (Arable2, Arable 3, and Arable 4).

A total of fourteen species, from *Acaulospora, Funneliformis, Glomus* and *Scutellospora* and *Claroideoglomus* and *Gigaspora* were detected in field soil samples but not from trap cultures; whereas four species from *Sclerocystis, Racocetra*, *Gigaspora* and *Ambispora* were identified from trap cultures but not detected from soil samples (data not shown).

The genera *Glomus* and *Acaulospora*, were the most diversified group represented by the highest number of morpho-species (9 species each), followed by the genera *Funneliformis* and *Gigaspora* (**Table 5).** More species from the dominant genera *Glomus, Funneliformis,* and *Acaulospora* were retrieved from field soil than from trap cultures, but the other genera showed no significant difference in their distribution between the two methods.

Isolation frequency, relative abundance and dominant AMF species

The Isolation frequency (IF) and relative abundance (RA) of AMF species varied greatly among land use types **(Table 5)**. The genera *Claroideoglomus* (all species), *Funneliformis* (*F. mossae*, and *F. geosporum*), *Paraglomus* (*P. occultum*), *Rhizophagus* (*R. diaphanus*) were distributed across all land use types. The genera *Entrophospora* and *Ambispora* were recovered only in two of the land use types. *Gigaspora* species were more limited to arable lands (Arable1, 2, 3 & 4) both in field and trap culture soils. Although the genus *Acaulospora* included a relatively large number of species, their distribution was more limited to perennial cropping systems (FC, NF, and AP).

On the basis of IV (important values), the genera *Claroideoglomus* and *Funneliformis* were categorized into the dominant genera with IV 63 and 56, respectively (Chen *et al*., 2012). However, the different species under the different AMF genera were categorized into "common" and "Rare" groups with 10<IV< 50 and IV<10), respectively.

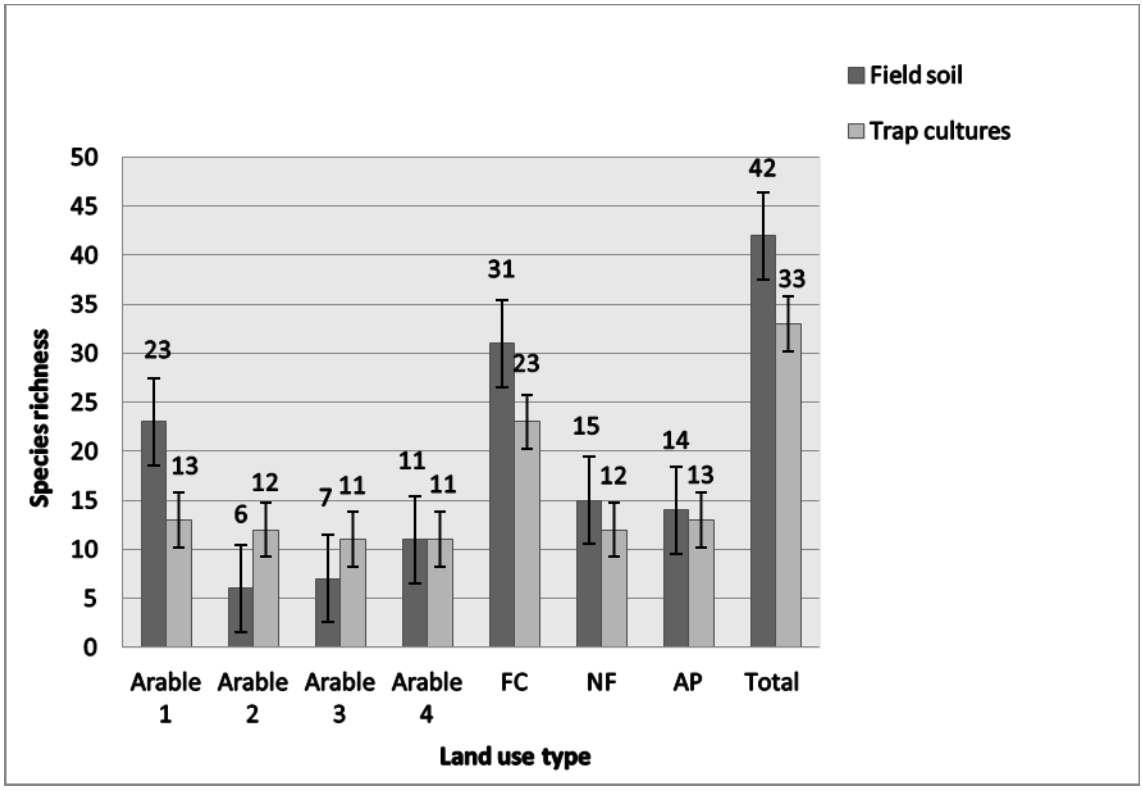

Fig. 2 AMF species richness (numbers on top of bars) in field soil and trap cultures for different land use types at Showa robit, Ethiopia. Vertical bars indicate ± standard errors of means, N= 3. Arable1: Low-input mixed cropping; Arable2: low-input monocropping, sorghum; Arable3: low-input monocropping, maize; Arable4: high-input monocropping, sorghum; FC: fruit cropping; NF: natural forest; AP: acacia plantation.

AMF species richness and diversity across land use types

AMF species richness varied among different land use types (**Fig. 2**). It ranged from 6-31 species in field soil samples and from 11-23 species in trap culture, respectively. Species richness was the highest in FC (31) followed by Arable1 (23), NF (15), AP (14) and the others (6-11) in the field soil. Likewise, the greatest species richness from trap cultures was observed in FC (23) but the others were not significantly different from one another (13-11). On average, the species richness recorded in FC, Arable1, and NF in field soil was five, four and three times greater than in the monocropped arable fields Arable2 and Arable3.

AMF diversity, expressed by the Shannon-Weaver diversity index also varied among different land use types (**Table 6**). Values for Shannon–Wiener diversity index, species dominance and species evenness were 2-2.64, 0.1-0.16 and 0.53-0.88, respectively. The highest Shannon-Wiener diversity, the lowest dominance and the lowest evenness were recorded from fruit crops, whereas the lowest diversity index, the highest dominance and the highest evenness were recorded from the monocropped fields (Arable 2, 3 & 4). In general, AMF diversity was lower in the trap cultures than in the field samples, whereas there was no significant difference in species dominance (Simpson's index) between the soil and the trap culture samples (**Table 6**).

Table 5: Community structure, isolation frequency (IF) and relative abundance (RA) and importance values (IV) of AMF species in soil and trap culture on different land use types from Showa robit, Ethiopia.

AMF genera	No of species	IF (%)	RA (%)	IV (%)	Status	AMF species	IF (%)	RA (%)	IV (%)	Status	Occurrence in land use types
Claroideoglomus	4	92.9	34.7	63.8	Dominant	*Cl. claroideum*	80.5	17.5	49	Common	All
						Cl. etunicatum	61.5	11	36.2	Common	All
						Cl. luteum	58	7.5	32.8	Common	All
Funneliformis	6	91.3	21.6	56.4	Dominant	*Funneliformis mossae*	71.5	10.5	41	Common	All
						*F. caledonium**	49	9.7	29.4	Common	All except AP
						F. geosporum	47	5.9	26.5	Common	All
Glomus	9	80.2	16.8	48.5	Common	*Glomus sp2*	42.5	7.2	24.9	Common	All except A3 &A4
						G. aggregatum	45	5.2	25.1	Common	All except A4
Paraglomus	*1*	27.3	4.06	15.7	Common	*Paraglomus occultum*	27.5	4	15.7	Common	All
Rhizophagus	*2*	34	3.8	18.9	Common	*Rhizophagus diapahanus*	30.8	3.4	17.1	Common	All
Acaulospora	*9*	21	2.8	11.6	Common	*A. scrobiculata*	6.8	0.7	3.7	Rare	A1, FC, NF, AP
Gigaspora	*5*	35	6.5	20.8	common	*Gigaspora gigantea*	25	4.8	14.9		A1, A2,A3,A4,
Diversispora	*1*	6.8	0.87	3.83	Rare	*Diversipora epigaea*	6.9	0.8	3.8	Rare	A1, FC, NF, AP
Septoglomus	*1*	16.5	3	9.7	Rare	*Septoglomus constrictum*	16.6	3	9.8	Rare	A1, FC, NF, AP
Pacispora	*1*	7.7	0.8	4.3	Rare	*Pacispora scintillans*	8	0.8	4.4	Rare	A1, FC, NF, AP
*Scutellospora**	*2*	12.7	2.8	7.75	Rare	*S. pellucida**	10.3	1.7	6	Rare	A1, NF, AP
Racocetra	*2*	8.3	1.5	4.9	Rare	*Racocetra gregaria*	3.6	0.5	2	Rare	A4, FC, NF
*Sclerocystis***	*1*	15.6	2	8.8	Rare	*Sclerocystis sinuosa***	17.2	2	9.6	Rare	A1, FC, NF
Entrophospora	*1*	8	0.6	4.4	Rare	*E. nevadensis*	8.4	0.65	4.5	Rare	A2, FC
*Ambispora **	*2*	12.9	1.4	7.15	Rare	*Ambispora fennica***	11	1.3	6.15	Rare	A3, FC

*Only in field soil; **only in trap culture

Table 6. Diversity indices of AMF community in different land use types of Showa robit, Ethiopia.

	Shannon_H			Dominance _D			Evenness_ e^H/S		
Land use type	Field soil	Trap culture	Mean	Field soil	Trap culture	Mean	Field soil	Trap culture	Mean
Arable1	2.54	2.27	2.41	0.12	0.13	0.12	0.55	0.74	0.65
Arable2	1.74	2.28	2.01	0.19	0.12	0.15	0.94	0.81	0.88
Arable3	1.8	2.19	2	0.18	0.14	0.16	0.87	0.81	0.84
Arable4	2.25	2.14	2.2	0.13	0.15	0.14	0.86	0.77	0.82
Fruit cropping	2.81	2.46	2.64	0.09	0.11	0.1	0.54	0.51	0.53
Natural forest	2.61	2.1	2.36	0.08	0.15	0.11	0.91	0.68	0.8
Acacia plantation	2.38	2.21	2.3	0.11	0.13	0.12	0.77	0.7	0.74

Arable1: low-input mixed cropping; Arable2: low-input monocropping, sorghum; Arable3: low-input monocropping, maize; Arable4: high-input monocropping, sorghum.

DISCUSSION

Spore abundance

AMF species diversity and spore abundance were studied in soil from different land use types in a low-land (sub-moist warm) agro-ecosystem, Ethiopia. The spore densities recovered through direct count from soils of all land use types varied between 2.8 spores g^{-1} and 6.1 spores g^{-1} of soil (**Table 3**). Trap cultures established from the same land use types showed higher spore numbers, 2.5-11.4 spores g^{-1} trap culture soil. The numbers of spores recovered from fruit crops and acacia plantation were 2-4 times higher in the trap cultures than when counting directly from the soil. In general, trap culturing enhanced spore abundance but decreased AMF species richness. The monocroped land use types, where the number of species recovered in the trap culture were higher or similar, were an exception from this main rule.

There was also an inverse relation between soil P content and spore density in the different land use types. The highest spore numbers in both field and trap cultures were obtained from FC associated with low P content and the lowest from natural forest and arable 4 characterized by high soil P content. Similarly, other studies in Finnish and Swedish soil showed negative relationship between spore density and P content. This indicates that certain AMF species are induced to sporulate abundantly under low P availability in the soil (Mårtensson and Carlgren, 1994; Kahiluoto *et al.,* 2001).

Mycorrhizal inoculum potential

The MIP bioassay showed that fruit cropping (FC) and mixed cropping in Arable1 were colonized by higher percentage of AMF than the relatively high-input sorghum monocroped field (Arable4), low-input sorghum monocropped field (Arable2) and natural forest (NF) (**Table 4**). In general, there was a slight, but not significant positive correlation between spore density and hyphal colonization both in the soil and trap culture. However, vesicular colonization was strongly correlated with spore density ($r=0.94$, $P<0.01$). This result is consistent with studies from southeast Spain (Azcón-Aguilar *et al.,* 2003) where it was found that the numbers of spores of AM fungal species are the propagule sources which were best correlated with the total mycorrhizal potential in the rhizosphere of the target plant species from Mediterranean shrublands.

The highest values of MIP in low-input mixed cropping and organically managed fruit cropping can be related to higher plant species diversity compared to the monocrops indicating that AMF colonized roots of different plants species are the major sources of propagules that would result in higher MIP values. Several studies also show higher levels of AMF root colonization under organic management and low input mixed cropping system than in monocropping with maize and other crops (Gosling *et al.,* 2010; Verbruggen *et al.,* 2010; Bedini *et al.,* 2013). However, contrary to this result, Purin *et al.* (2006) obtained no differences in MIP values between conventional and organic apple orchards in Brazil. A study conducted among different cropping systems and land use types in Kenya showed a significantly higher AMF inoculum potential in maize-bean intercropping systems than in maize or wheat

monocrops in both dry and wet regions (Muchane *et al.,* 2012).

AMF community composition

A total of 42 and 33 AMF morphospecies belonging to 15 genera and 8 families were identified from soil and trap cultures, respectively (**Fig. 2**). This result is quite similar to a study of different cropping systems in Sudan (Abdelhalim *et al*., 2012), in which 42 AMF species belonging to 12 genera in 8 families were discovered. The genera *Glomus, Funneliformis, Septoglomus, Claroideoglomus, Entrophospora, Acaulospora, Paraglomus, Diversispora, Pacispora,* and *Ambispora* were commonly detected in both studies. However, the genera *Gigaspora, Rhizophagus, Racocetra, Sclerocystis,* and *Scutellospora* were not identified from Sudan, and the genera *Archaeospora* and *Kuklospora*, were not detected in this study.

The AMF species diversity observed in this study was much higher than the 17 species identified in *Acaulosporaceae* (5), *Glomeraceae* (4), *Gigasporaceae* (5) and others (3) from different land use types in Kenya (Jewfa *et al*., 2009). This may be related to the diversity and the type of plants sampled from the land use types. Other studies have also showed that coexisting plant species within a habitat are associated with divergent AMF communities, showing that host preference has a strong influence on AMF community composition in soil (Vandenkoornhuyse *et al.,* 2002; Scheublin *et al.,* 2004).

Although trap culturing enhanced spore abundance it reduced AMF species richness compared with the field soil samples. Similarly, Chaturvedi *et al.* (2012) found that AMF diversity in trap cultures of one year was decreased from 50 to 21, although spore abundance was higher. Tchabi *et al.* (2008) reported that out of a total of 59 AMF species detected in soils of different ecological zones of West Africa, only seven had sporulated after 10 and 24 months of trap culturing.

Isolation frequency, relative abundance and dominant AMF species

Claroideoglomus and *Funneliformis* were dominant genera according to Chen *et al*. (2012), because they were found in all land use types. The genera *Glomus*, *Paraglomus, Rhizophagus*, *Acaulospora* and *Gigaspora* were categorized as common. It is interesting to note that more than 50% of the genera were classified as rare. Previous reports have also shown that *Glomus* was dominant in other agroecological regions of Ethiopia (Muleta *et al.,* 2008; Birhane *et al.,* 2010).

The genera *Glomus, Funneliformis,* and *Claroideoglomus* were also reported to be dominant in Cameroon (Snoeck *et al.,* 2010) and other sub-Saharan regions, in North Côte d'Ivoire (Nandjui *et al.,* 2013), in different land use types of Kenya (Jefwa *et al.,* 2009, 2012), in the Namibia desert (Stutz *et al.,* 2000), in natural and cultivated savannas of Benin, West Africa (Tchabi *et al.,* 2008), in selected crops in the White Nile State, Central Sudan (Abdelhalim *et al.,* 2013) and in temperate agroecosystems in Europe (Oehl *et al.,* 2003). The high incidence of *Glomus* and *Funneliformis* spp. has been associated with their capacity to produce more spores in a shorter time than genera such as *Gigaspora* and *Scutellospora* (Bever *et al*., 1996: Oehl *et al.,* 2009). These species could therefore, be selected for future studies as AMF inocula after testing their compatibility with different crops and checking their persistence in the field.

AMF species richness and diversity

The number of AMF morphospecies recovered from the fruit cropping system and the mixed cropping system (Arable1) was almost double that of the number of morphospecies collected from each of the other land use types from monocrop fields (Arable 2, Arable 3, and arable 4) and woody vegetation (natural forest, and acacia plantation) (**Fig. 2**). In general, lower AMF species diversity was recorded in high–input (Arable 4) and low-input monocropped fields compared to organically managed fruit crops or low-input mixed cropping (Arable1) **(Fig. 2).**

Our study also showed that the AMF species diversity (23 species) of the mixed cropping system (Arable 1) was much higher than the 12 AMF species reported from similar maize and sesbania intercrops from Southern Malawi (Jefwa *et al.,* 2006). However, the AMF diversity of monocrops (Arable 2 and Arable 3) was almost similar to the 12 AMF species collected from indigenous forest to croplands in Southern Kenya (Jefwa *et al.,* 2012) and from maize monocrops in Southern Malawi (Jefwa *et al.,* 2006). Similar pattern of AMF diversity (15-17morphospecies) was also reported from crop land, fallow land, natural forest and tree plantations in the high altitude regions of Kenya (Jefwa *et al.,* 2009) and from grassland, woodland and intensified monocropping systems in Maasai Mara ecosystems in Kenya (Muchane *et al.,* 2012).

This study showed no clear impact of soil P on the diversity of AM fungi. Accordingly, Gosling *et al.* (2013) suggested that host species is more important than soil P for determining AM diversity, except at the highest P concentration. We observed a strong positive correlation between AMF species richness and spore density ($r=0.84$, $P<0.05$). AMF species

richness also correlated strongly positively with soil organic carbon and total nitrogen both in field soil and trap cultures ($P<0.05$). Other studies have also shown that spore density and species richness are usually positively correlated with soil organic carbon contents and soil pH ($P<0.05$) (Tchabi *et al.,* 2008).

AMF diversity indices

The highest diversity index value was recorded from the FC land use type both in field soil and trap cultures. This result is similar to previous reports which show that organic systems have higher AMF community diversity indices than conventional or monocropping systems (Helgason *et al.,* 1998; Oehl *et al.,* 2003; Verbruggen *et al.,* 2010). It has been suggested that conventional farming systems may select for a small set of generalist AMF species (Helgason *et al.,* 2007; Verbruggen *et al.,* 2010), while organic farming systems are characterized by high species diversity (Mäder *et al.,* 2002).

CONCLUSION AND RECOMMENDATION

This study showed high AM fungal diversity, but also high variation in AM fungal community composition among seven land use types in the humid and semi-arid soil of Showa robit, Ethiopia. The difference in AMF community structure was most closely related to a variety of biotic and abiotic factors, including various aspects of agricultural management practice and land use. Markedly higher numbers of AMF species and higher rate of mycorrhizal infectivity potential were obtained in FC and Arable1 compared with the other land use types. This clearly implies that organic farming and diversification of crops in agriculture is a more sustainable land use system for enhancing biological soil qualities, including maintenance of AMF diversity, than highly fertilized monocropping systems.

The study also showed that *Claroideoglomus* and *Funneliformis* were the dominant genera in all land use types in both trap culture and field soil. It also showed that some AMF species could be missed when studying either soil or trap cultures implying that there is a need to use both methods for getting a full picture of the AMF species diversity in a study area. Future studies should be focused on the dominant species for further selection of AMF inocula for enhancing productivity in different cropping system.

In this study, the AM fungal diversity and community composition analyses relied on an assessment of spore morphotypes for identification. If it is complemented with molecular identification of AMF species directly from plant roots it can fully show the heterogeneity of the organisms in relation to land use types. Except the AMF genera and species that dominated all land use types and plants, the occurrence of some rare species in specific land use types should also be studied to fully realize their role in nutrient and water uptake and protection against plant pathogens and in improvement of crop productivity.

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Appendices: List, isolation frequency (IF %), relative spore abundance (RA) and important value (IV) of the AMF species identified in field soil and trap culture

Appendix A. field soil

	IF%								RA%									
AMF genera and species	A1	A2	A3	A4	FC	NF	AP	Mean	A1	A2	A3	A4	FC	NF	AP	Mean	IV	Status
Acaulospora	33.3	-	-	33	71.4	11.1	50	28.4	3	-	-	5	9.4	3.1	8.6	4.16	16	Common
A. denticulata Sieverd. & S. Toro	11.1	-	-	33	9.5	-	-	7.7	1	-	-	5	0.9	-	-	0.99	4.3	Rare
A. faveata Trappe & Janos	-	-	-	-	4.7	-	-	0.67	-	-	-	-	0.4	-	-	0.06	0.4	Rare
A. kentinesis (Wu & Liu) Kaonongbua, Morton & Bever	-	-	-	-	9.5	-	-	1.36	-	-	-	-	0.9	-	-	0.13	0.7	Rare
A. rehmii Sieverd. & S. Toro	11.1	-	-	-	4.7	11.1	-	3.84	1	-	-	-	0.4	3.1	-	0.64	2.2	Rare
A. scrobiculata Trappe	-	-	-	-	28.6	-	16.7	6.47	-	-	-	-	2.9	-	2.8	0.81	3.6	Rare
A. spinosa Walker & Trappe	-	-	-	-	19	-	-	2.71	-	-	-	-	1.9	-	-	0.27	1.5	Rare
A. splendida Sieverd, Chaverri & Rojas	11.1	-	-	-	-	-	-	1.59	1	-	-	-	-	-	-	0.14	0.9	Rare
A. tuberculata Janos & Trappe	-	-	-	-	4.7	-	33.3	5.43	-	-	-	-	0.4	-	5.7	0.87	3.2	Rare
Acaulospora sp1	-	-	-	-	9.5	-	-	1.36	--	-	-	-	0.9	-	-	0.9	1.1	Rare
Claroideoglomus	100	66.7	33.3	100	100	100	100	85.7	26.3	22.2	7.6	35	31	28.1	25.7	25.1	55	Dominant
C. claroideum (Schenck & Sm.) Walker & Schuessler	100	33.3	33.3	100	100	44.4	16.7	61.1	15.2	16.6	7.6	25	20.7	12.5	2.8	14.3	38	Common
*C. etunicatum (*Becker & Gerd.) Walker & Schuessler	22.2	-	-	67	42.8	33.3	83.3	35.5	2	-	-	10	4.4	9.3	14.3	5.7	21	Common
C. lamellosum (Dalpé, Koske & Tews) Walker & Schuessler	22.2	-	-	-	-	-	-	3.17	2	-	-	-	-	-	-	0.29	1.7	Rare
C. luteum (Kenn, Stutz & Morton) Walker & Schuessler	66.6	33.3	-	-	57.1	22.2	50	32.7	6	16.6	-	-	5.9	6.2	8.6	6.19	19	Common
Diversispora	11.1	-	-	-	28.6	22.2	-	8.84	1	-	-	-	2.9	6.2	-	1.44	5.1	Rare
D. epigaea (Daniels & Trappe) Walker & Schuessler	11.1	-	-	-	28.6	22.2	-	8.84	1	-	-	-	2.9	6.2	-	1.44	5.1	Rare
Entrophospora	-	-	-	-	47.6	-	-	6.8	-	-	-	-	4.9	-	-	0.7	3.8	Rare
E. nevadensis J. Palenzuela, N. Ferrol, Azcón-Aguilar & Oehl	-	-	-	-	47.6	-	-	6.8	-	-	-	-	4.9	-	-	0.7	3.8	Rare
Funneliformis	100	100	100	100	100	66.7	50	88.1	39.4	33.3	38.5	25	30	18.7	11.4	28	58	Dominant

F. badium (Oehl, Redecker & Sieverd.) Walker & Schuessler	-	-	-	-	4.7	-	-	0.67	-	-	-	-	0.4	-	-	0.06	0.4	Rare
*F. caledonium (*Nicolson & Gerd.) Walker & Schuessler	55.5	66.6	100	67	42.8	11.1	-	49	5	22.2	23	10	4.4	3.1	-	9.67	29	Common
F. coronatum (Giovann.) Walker & Schuessler	-	-	-	-	14.3	-	-	2.04	-	-	-	-	1.5	-	-	0.21	1.1	Rare
F. geosporum (Nicolson & Gerd.) Walker & Schuessler	88.8	-	33.3	33	80.9	22.2	50	44.1	8.1	-	7.6	5	8.4	6.2	11.4	6.67	25	Common
F. mosseae (Oehl, Redecker & Sieverd.)Walker & Schuessler	100	33.3	33.3	67	100	33.3	-	52.4	26.3	11.1	7.6	10	14.8	9.3	-	11.3	32	Common
F. verruculosusm (Błaszk.) C. Walker & Schuessler	-	-	-	-	4.7	-	-	0.67	-	-	-	-	0.4	-	-	0.06	0.4	Rare
Glomus	100	66.7	66.7	67	100	55.6	100	79.4	17.2	22.2	23	15	10.8	15.6	25.7	18.5	49	Common
Gl. aggregatum Schenck & Sm.	44.4	-	-	-	57.1	11.1	16.7	18.5	4	-	-	-	5.9	3.1	2.8	2.26	10	Common
Gl. albidum N.C. Schenck & G.S. Sm.	-	-	-	-	9.5	-	-	1.36	-	-	-	-	0.9	-	-	0.13	0.7	Rare
Gl. hoi Berch & Trappe	11.1	-	-	-	-	-	-	1.59	1	-	-	-	-	-	-	0.14	0.9	Rare
Gl. microaggregatum Koske, Gemma & Olexia	-	-	-	-	-	-	16.7	2.39	-	-	-	-	-	-	2.8	0.4	1.4	Rare
Gl. microcarpum Tul. & Tul.	-	-	-	-	19	-	-	2.71	-	-	-	-	1.9	-	-	0.27	1.5	Rare
Gl. monosporum Gerd. & Trappe	11.1	-	-	33	-	-	-	6.34	1	-	-	5	-	-	-	0.86	3.6	Rare
Gl. tortuosum N.C. Schenck & G.S. Sm.	11.1	-	-	-	-	-	-	1.59	1	-	-	-	-	-	-	0.14	0.9	Rare
Glomus sp1(#2) sporocarpic , thick wall , smooth (80-110µm)	-	-	-	-	4.7	-	100	15	-	-	-	-	0.4	-	17.1	2.5	8.8	Rare
Glomus sp2(#3) red brown geosporum like	100	66.7	66.7	67	14.3	44.4	16.7	53.6	10	22.2	23	10	1.5	12.5	2.8	11.71	33	Common
Rhizophagus	11.1	-	-	67	14.3	22.2	33.3	21.1	1	-	-	10	1.5	6.2	5.7	3.49	12	Common
R. diaphanus (Morton & Walker) Walker & Schuessler	11.1	-	-	67	4.5	22.2	33.3	19.7	1	-	-	10	0.4	6.2	5.7	3.33	12	Common
R. fasciculatus (Thaxt.) Walker & Schuessler	-	-	-	-	9.5	-	-	1.36	-	-	-	-	0.9	-	-	0.13	0.7	Rare
Septoglomus	22.2	-	-	-	46.7	11.1	50	18.6	2	-	-	-	4.9	6.2	17.1	4.31	11	Common
S. constrictum (Trappe) Sieverd., Silva& Oehl	22.2	-	-	-	46.6	11.1	50	18.6	2	-	-	-	4.9	6.2	17.1	4.31	11	Common

Racocetra	-	-	-	-	4.7	11.1	-	2.26	-	-	-	-	0.4	3.1	-	0.5	1.4	Rare
R. gregaria (Schenck & Nicolson) Oehl, Souza & Sieverd.	-	-	-	-	4.7	11.1	-	2.26	-	-	-	-	0.4	3.1	-	0.5	1.4	Rare
Gigaspora	66.7	66.7	-	67	14.3	-	-	30.6	6	22.2	-	10	1.5	-	-	5.67	18	Common
Gi. albida Schenck & Sm	22.2	-	-	-	-	-	-	3.17	2	-	-	-	-	-	-	0.29	1.7	Rare
Gi. gigantea (Nicolson & Gerd.) Gerd. & Trappe	44.4	66.7	-	33	-	-	-	20.6	4	22.2	-	5	-	-	-	4.46	13	Common
Gi. margarita Becker & Hall	-	-	-	33	4.7	-	-	5.43	-	-	-	5	0.4	-	-	0.77	3.1	Rare
Gigaspora sp.	-	-	-	-	9.5	-	-	1.36	-	-	-	-	0.9	-	-	0.13	0.7	Rare
Scutellospora	33.3	-	33.3	-	-	22.2	16.7	12.7	3	-	7.6	-	-	6.2	2.8	2.8	7.8	Rare
S. cerradensis Spain & Miranda	-	-	33.3	-	-	-	-	4.7	-	-	7.6	-	-	-	-	1.09	2.9	Rare
S. pellucida (Nicolson & Schenck) Walker & Sanders	33.3	-	-	-	-	22.2	16.7	10.3	3	-	-	-	-	6.2	2.8	1.71	6	Rare
Pacispora	11.1	-	-	-	23.8	-	-	4.99	1	-	-	-	2.5	-	-	0.5	2.7	Rare
Pacispora scintillans (Rose & Trappe) Walker, Vestberg & Schuessler	11.1	-	-	-	23.8	-	-	4.99	1	-	-	-	2.5	-	-	0.5	2.7	Rare
Paraglomus	11.1	-	66.7	-	-	22.2	16.7	16.7	1	-	23	-	-	6.2	2.8	4.71	11	Common
Paraglomus occultum (Walker) Morton & Redecker	11.1	-	66.7	-	-	22.2	16.7	16.7	1	-	23	-	-	6.2	2.8	4.71	11	Common

Appendix B. Trap culture

(A1)Arable1: low-input mixed cropping; (A2) Arable2: low-input monocropping, sorghum; (A3)Arable3: low-input monocropping, maize; (A4)Arable4: high-input monocropping, sorghum; FC: fruit cropping; NF: natural forest; AP: acacia plantation

AMF genera and species	IF%								RA%									
	A1	A2	A3	A4	FC	NF	AP	Mean	A1	A2	A3	A4	FC	NF	AP	Mean	IV	Status
Acaulospora Trappe & Gerd.	33.3	-	33.3	-	14.3	11.1	-	**13.1**	2.4	-	4.2	-	1	1.8	-	**1.343**	**7.2**	**Rare**
A. denticulata Sieverd. & S. Toro	-	-	33.3	-	-	-	-	**4.76**	-	-	4.2	-	-	-	-	**0.6**	**2.7**	**Rare**
A. rehmii Sieverd. & S. Toro	-	-	-	-	4.7	-	-	**0.67**	-	-	-	-	0.3	-	-	**0.043**	**0.4**	**Rare**
A. scrobiculata Trappe	33.3	-	-	-	4.7	11.1	-	**7.01**	2.4	-	-	-	0.3	1.8	-	**0.643**	**3.8**	**Rare**
Acaulospora sp.	-	-	-	-	4.7	-	-	**0.67**	-	-	-	-	0.3	-	-	**0.043**	**0.4**	**Rare**
Claroideoglomus	100	100	100	100	100	100	100	**100**	51.2	45.6	56.5	20.7	47.1	46.3	42.7	**44.3**	**72**	**Dominant**
C. claroideum (Schenck & Sm.) Walker & Schuessler	100	100	100	100	100	100	100	**100**	21.4	17.5	25	13.8	21.6	25.5	21.3	**20.87**	**60**	**Dominant**
*C. etunicatum (*Becker & Gerd.) Walker & Schuessler	100	100	100	66.7	100	44.4	100	**87.3**	21.4	17.5	16.7	6.9	17	12.7	17.9	**15.73**	**52**	**Dominant**
C. luteum (Kenn, Stutz & Morton) Walker & Schuessler	100	100	100	100	100	33.3	50	**83.3**	7.1	10.5	12.5	10.3	8	7.3	3.4	**8.443**	**46**	**Common**
Diversispora	-	-	-	-	-	-	33.3	**4.76**	-	-	-	-	-	-	2.2	**0.314**	**2.5**	**Rare**
D. epigaea (Daniels & Trappe) Walker & Schuessler	-	-	-	-	-	-	33.3	**4.76**	-	-	-	-	-	-	2.2	**0.314**	**2.5**	**Rare**
Entrophospora	-	33.3	-	-	33.3	-	-	**9.51**	-	1.7	-	-	2.6	-	-	**0.614**	**5.1**	**Rare**
E. nevadensis Błaszk., Madej & Tadych; J. Palenzuela, . N. Ferrol, Azcón-Aguilar & Oehl	-	33.3	-	-	33.3	-	-	**9.51**	-	1.7	-	-	2.6	-	-	**0.614**	**5.1**	**Rare**
Funneliformis	100	100	100	100	100	88.8	100	**98.4**	9.7	15.8	13	13.8	14.5	14.8	24.7	**15.19**	**57**	**Dominant**
F. badium (Oehl, Redecker & Sieverd.) Walker & Schuessler	-	-	-	-	-	11.1	-	**1.59**	-	-	-	-	-	1.8	-	**0.257**	**0.9**	**Rare**
F. geosporum (Nicolson & Gerd.) Walker & Schuessler	33.3	100	33.3	33.3	38.1	11.1	100	**49.9**	2.4	5.3	4.2	3.4	2.6	1.8	15.7	**5.057**	**27**	**Common**

F. mosseae (Oehl, Redecker & Sieverd.)Walker & Schuessler	100	100	66.7	100	100	66.6	100	**90.5**	7.1	10.5	8.3	10.3	11.7	10.9	8.9	**9.671**	**50**	**Common**
Glomus	100	100	33.3	33.3	100	100	100	**80.9**	14.6	21	4.2	3.4	19.5	27.7	14.6	**15**	**48**	**Common**
Gl. aggregatum Schenck & Sm.	100	66.6	33.3	-	100	100	100	**71.4**	7.1	3.5	4.2	-	11	21.8	8.9	**8.071**	**40**	**Common**
Gl. hoi Berch & Trappe	-	100	-	33.3	52.4	-	-	**26.5**	-	12.3	-	3.4	4.3	-	-	**2.857**	**15**	**Common**
Gl. microaggregatum Koske, Gemma & Olexia	-	-	-	-	4.7	-	-	**0.67**	-	-	-	-	0.3	-	-	**0.043**	**0.4**	**Rare**
Gl. microcarpum Tul. & Tul.	-	-	-	-	-	-	16.7	**2.39**	-	-	-	-	-	-	1.1	**0.157**	**1.3**	**Rare**
Gl. tortuosum N.C. Schenck & G.S. Sm.	66.7	-	-	-	19	-	-	**12.2**	4.8	-	-	-	1.3	-	-	**0.871**	**6.5**	**Rare**
Glomus sp1 sporocarpic , thick wall , smooth (80-110 µm)	-	-	-	-	-	-	50	**8.33**	-	-	-	-	-	-	3.4	**0.486**	**4.4**	**Rare**
Glomus sp2 red brown geosporum like	33.3	100	-	-	33.3	33.3	16.7	**30.9**	2.4	5.3	-	-	2.3	5.5	1.1	**2.371**	**17**	**Common**
Rhizophagus	-	100	100	-	28.6	-	100	**46.9**	-	5.3	13	-	2	-	8.9	**4.171**	**26**	**Common**
R. diaphanus (Morton & Walker) Walker & Schuessler	-	100	66.7	-	28.6	-	100	**42.2**	-	5.3	8.3	-	2	-	8.9	**3.5**	**23**	**Common**
R. fasciculatus (Thaxt.) Walker & Schuessler	-	-	33.3	-	-	-	-	**4.76**	-	-	4.2	-	-	-	-	**0.6**	**2.7**	**Rare**
Septoglomus	-	-	-	-	33.3	-	66.6	**14.3**	-	-	-	-	6	-	5.6	**1.657**	**8**	**Rare**
S. constrictum (Trappe) Sieverd., Silva& Oehl	-	-	-	-	33.3	-	66.6	**14.3**	-	-	-	-	6	-	5.6	**1.657**	**8**	**Rare**
Sclerocystis	100	-	-	-	9.5	-	-	**15.6**	11.9	-	-	-	0.7	1.8	-	**2.057**	**8.8**	**Rare**
S. sinuosa (Gerd. & Bakshi)	100	-	-	-	9.5	11.1	-	**17.2**	11.9	-	-	-	0.7	1.8	-	**2.057**	**9.6**	**Rare**
Racocetra	-	-	-	100	-	-	-	**14.3**	-	-	-	17.2	-	-	-	**2.457**	**8.4**	**Rare**
R. alborosea (Ferrer & Herrera) Oehl, Souza & Sieverd.	-	-	-	100	-	-	-	**14.3**	-	-	-	13.8	-	-	-	**1.971**	**8.1**	**Rare**
R. gregaria (Schenck & Nicolson) Oehl, Souza & Sieverd.	-	-	-	33.3	-	-	-	**4.76**	-	-	-	3.4	-	-	-	**0.486**	**2.6**	**Rare**
Gigaspora	100	33.3	33.3	100	9.5	-	-	**39.4**	7.3	1.7	4.2	31	0.7	-	-	**7.367**	**23**	**Rare**
Gi. albida Schenck & Sm	-	-	-	33.3	-	-	-	**4.76**	-	-	-	3.4	-	-	-	**0.486**	**2.6**	**Rare**
Gi. gigantea (Nicolson & Gerd.) Gerd. & Trappe	33.3	33.3	33.3	100	-	-	-	**28.6**	2.4	1.7	4.2	27.6	-	-	-	**5.129**	**17**	**Common**

Gi. rosa Nicolson & Schenck	66.6	-	-	-	4.7	-	-	**10.2**	4.8	-	-	-	0.3	-	-	**0.729**	**5.5**	**Rare**
Gigaspora sp (unidentified)	-	-	-	-	4.7	-	-	**0.67**	-	-	-	-	0.3	-	-	**0.043**	**0.4**	**Rare**
Ambispora	-	-	66.7	-	23.5	-	-	**12.9**	-	-	8.3	-	1.7	-	-	**1.429**	**7.2**	**Rare**
A. fennica Walker, Vestberg & Schuessler	-	-	66.7	-	9.5	-	-	**10.9**	-	-	8.3	-	0.7	-	-	**1.286**	**6.1**	**Rare**
Ambispora sp.	-	-	-	-	14.3	-	-	**2.04**	-	-	-	-	1	-	-	**0.143**	**1.1**	**Rare**
Pacispora	-	-	-	-	23.8	33.3	16.7	**10.5**	-	-	-	-	1.6	5.5	1.1	**1.171**	**5.8**	**Rare**
P. scintillans Oehl & Sieverd	-	-	-	-	23.8	33.3	16.7	**10.5**	-	-	-	-	1.6	5.5	1.1	**1.171**	**5.8**	**Rare**
Paraglomus	66.6	100	-	33.3	42.8	22.2	-	**37.8**	4.8	8.8	-	3.4	3.3	3.7	-	**3.429**	**21**	**Common**
P. occultum (Walker) Morton & Redecker	66.6	100	-	33.3	42.8	22.2	-	**37.8**	4.8	8.8	-	3.4	3.3	3.7	-	**3.429**	**21**	**Common**