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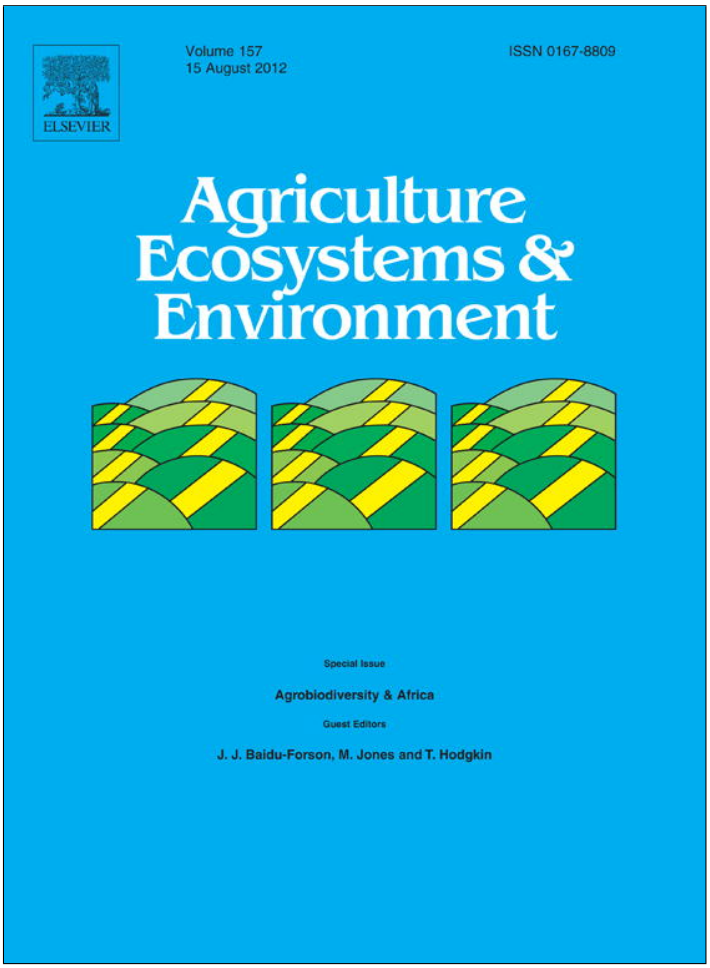

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Impact of land use types and farming practices on occurrence of arbuscular mycorrhizal fungi (AMF) Taita-Taveta district in Kenya

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ABSTRACT

A study was undertaken along land use gradients in Taita-Taveta district, southeast Kenya to evaluate the occurrence of arbuscular mycorrhizal fungi (AMF) in seven land use types (LUT). The gradient was from indigenous forest (IF) to croplands with coffee (CO), maize (MA), horticulture (HT), napier (NA) and planted forest (PF). A total of 12 AMF morphotypes comprising of 4 *Glomus*, 1 *Claroideoglomus*, 5 Acaulosporaceae, 1 *Racocetra* sp. and 1 *Gigaspora* were isolated from the study site. Occurrnace of *Acaulospora denticulata*, *Glomus ambisporum* and *Claroideoglomus etunicatum* was significantly ($p < 0.05$) affected by LUT; *A. denticulata*, *Acaulospora laevis*, *G. ambisporum*, *Glomus* sp. 1, *Glomus* sp. 2 and *Gigaspora margarita* were common in all LUT; *C. etunicatum* and *Glomus* sp. 3 were restricted and *Acaulospora scrobiculata* and two additional undescribed morpotypes were found only in trap cultures. Mean spore abundance was significantly ($p = 0.007$) different in cropped systems with CO (35), HT (36.6) and MA (41.7) recording lower mean spore abundance compared to non-cropped systems with PF (130), NA (91.3), FA (89.7) and NA (84.3). AMF species showed preference for either cropped or non-cropping systems and species diversity and richness were maintained despite dramatic changes in LUT.

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1. Introduction

The Taita Hills is situated in the Northmost part of the eastern arc mountains and coastal forest hotspots (Burgess et al., 2007). It is within the international biodiversity hotspot with high endemicity and severe degree of threat ranking first among the 25 hotspots in the number of endemic plants (Myers et al., 2000). It occupies over 1000 km^2 with over 400 plant species of which 13 are endemic recorded and nine endemic animals (Beentje, 1988). It is considered the most vulnerable hotspot likely to suffer plant and animal extinction due to loss of habitat (Myers et al., 2000). The landscape is dominated by intensive agriculture at high altitude and extensive agriculture and grazing at the foothills and plains surrounding the hills. Subsistence farming and high population pressure, with increase from 90,146 in 1962 to 300,000 persons in 2001, has caused dynamic changes in the land use patterns tending to serious degradation (Burgess et al., 2007; Maeda et al., 2010). Land use practices largely affect chemical, physical and biological properties of soils. Biological properties of soils are the least assessed of the three yet nutrient cycling processes are largely mediated by soil organisms. The mycorrhizal fungi are among organisms that play a key role in ecosystem functioning (Klironomos et al., 2000). They form mutually beneficial associations with plants and are keystone to soil processes (Van der Heijden et al., 1998a,b; Power and Mills, 1995). The arbuscular mycorrhizae fungi (AMF) in the new plylum *Glomeromycota* (Schußler et al., 2001), is the most widespread of the mycorrhizal associations. They associate with 80% of plant species, hence may greatly influence direction of ecosystem change. Arbsucular mycorrhizae link soil and the plant environment hence all factors that affect soil and plants have impacts on AMF occurrence and functions.

Mycorrhizal symbiosis is important for maintaining and promoting the productivity of croplands, rangelands and forests, and may be critical to the maintenance of biodiversity (Sanginga et al., 1992; Allen et al., 1995). Land use intensity is increasing with

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Table 1
Mean soil nutrients and pH across seven land use type.

Land use types	Soil nutrients						
	pH (H_2O)	Carbon (%)	Acidity (%)	Nitrogen (%)	Phosphorus (ppm)	Potassium (Cmol kg^{-1})	Zinc (Cmol kg^{-1})
Coffee	4.79	1.78	0.39	0.20	14.4	0.25	3.77
Fallow	4.27	1.93	0.83	0.27	13.1	0.46	1.95
Horticulture	4.78	1.57	0.33	0.20	15.2	0.31	3.42
Indigenous forest	3.72	2.55	1.19	0.42	27.8	0.23	3.40
Maize	4.59	1.68	0.31	0.20	12.5	0.38	4.50
Napier	4.93	1.89	0.34	0.28	15.2	0.76	6.16
Planted forest	3.06	2.88	2.38	0.38	5.3	0.10	0.74

expanding human populations leading to negative effects of mycorrhizal fungi in soils that have been damaged (Allen, 1988). Crops such as maize, beans, coffee bananas, cassava and other root and tuber crops which benefit from AMF associations dominate Africa's landscape (Sieverding, 1991; Jefwa et al., 2010). It is however likely that the benefits from mycorrhizal association are highly influenced by land use practices. Soil degradation has not only affected soil chemical and physical properties but biological properties as well. The occurrence of soil biota such as AMF species richness and spore abundance are low in some farming systems of Central parts of Kenya (Jefwa et al., 2009). The Taita hills is equally densely populated and forest land encroached and converted to settlement and farmlands (Newark, 1998). A study was undertaken to determine the impact of land use types on the occurrence of AMF.

2. Materials and methods

2.1. Site description

The 200 km^2 study site is located in southeast Kenya, 25 km west of Voi town in Taita-Taveta district, Coastal province of Kenya, sharing a border with Tanzania. The site is within the Taita hills which forms part of the eastern arc mountains dated over 100 million years. It lies between longitudes 38°15′ and 38°30′ East of the Greenwich and latitudes 2°15′ and 2°30′ South of the Equator. The average altitude is 1500 m with the highest peak at 2300 m a.s.l. compared to the vast surrounding semi-arid peneplain which is 500 m a.s.l. Rainfall range from 440 mm at the plains to 1900 mm. Due to the temperature and humid climate of the hills, the Taita Hills are more densely populated than the rest of the district with a population density of about 78 inhabitants per km^2 compared to the rest of the district with an average of 14 inhabitants km^{-2} (Burgess et al., 2007). Population of the district in 1962 was 90,000 persons current population is 300,000 density. It is dominated by intensive agriculture (extensive agriculture and grazing at the foothills and plains surrounding the hills with the highly fragmented forest: Ngangao (120 ha), Mbololo (220 ha) and Chawia (86 ha) forests (Rogers et al., 2008). Subsistence farming and high population pressure has caused dynamic changes in the land use patterns, leading to serious land degradation in the hills (Burgess et al., 2007).

Land use types in the study area were classified as cultivation, cultivation and grazing, grazing and forest (Muya et al., 2009). For the purposes of this study land use kinds were designated into seven broad categories that included: maize, horticulture, fallow, napier, planted forests, and indigenous forests. In this paper fallow land refers to land that was once farmland but at the time of sampling, had been abandoned or left under no cultivation. The planted forest is dominated by *Eucalyptus saligna* Sm and *Cupressus lusitanica* Mill., *Pinus patula* Schiede ex Schttdl. & Cham and *Pinus radiata* D. Don species. The soils are mainly *Humic Nitisols* (FAO-UNESCO, 1987) that are derived from basic volcanic rocks (Jaetzold and Schmidt, 1983). They are deep, well drained, weathered with a friable clay texture and moderate to high inherent fertility. The area receives a total mean annual rainfall of between 1200 and 1500 mm in two rainy seasons, 'long rains' (March to June) and 'short rains' (mid October to December). Mean monthly temperature ranges between 14 °C and 19.5 °C. Both rainfall pattern and uneven topography result in variable rainfall distribution. In addition to this, geological patterns lead to high soils variability. The combination of the biophysical factors helps to create four agro-ecological zones in the area that include: uplands, midlands, valley bottoms and lowlands. The soils are highly acidic and low in nutrients and carbon (Table 1).

2.2. Sampling procedure

Soils were sampled from 43 points in the seven designated land use categories (5 coffee (CO), 7 maize (MA), 5 horticulture (HT), 13 fallow(FA), 4 napier (NA), 3 planted forest (PF), 6 indigenous forest (IF) at depths of 0–20 and 20–40 cm using a soil auger and samples pooled together to a composite sample. The samples were collected at two radii of concentric circles surrounding a centre point monolith. The circles were located 3 and 8 m away from the centre monolith at four cores per radius according to sampling layout (Moreira et al., 2008).

A total of 12 samples were taken from each point and the sampled soils were pooled together to make a composite sample of 1 kg. Samples were collected in the dry season, a period when sporulation increase (Guadarrama and Alvarez-Sanchez, 1999). The samples were split for use in spore extraction, soil trap cultures and nutrient analysis. Only one season was sampled and some species may not be in spore form at the time of sampling. After sampling, the soil trap culture was established with *Sorghum bicolor* (L.) Moenche, Moenche *Mucuna puriens* (L.) DC, *Senna spectabilis* (DC.) Irwin & Barneby (syn. *Cassia spectabilis*) and *Gliricidia sepium* (Jacq.) in different 1 l pots to allow for sporulation and to capture higher species diversity. A sample of 250 g soil from the field was mixed with sterile sandy soil at a ratio of 2:1. At least 50 seeds of Sorghum and five each of the remaining plants were sown into the 1 l pot. The cultures were maintained under greenhouse conditions for a period of 5 months.

2.3. Spore processing and identification

Spores were extracted from 250 g soil sample at portions of 50 g per extraction by water and sucrose centrifugation method modified by using a 270 and 45 μm mesh sieves and 60 (w/v) of sucrose (Jenkins, 1964). The spores were distinguished into morphotypes under reflected light on stereomicroscope with color of spore, spore size, attachments on spore and surface appearance of spore used as the diagnostic features and the number of spores counted for each morphotype. The Edinburgh Botanic Gardens color chart for fungi was used to determine spore color. Voucher specimens were prepared for each AMF morphotype and further described under a compound microscope with spore germination characteristics,

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Table 2
Rank of total spore abundance in 50 g^{-1} air dried soil and proportions of AMF species from the study site.

AMF species	Rank	Total abundance	Proportion
Glomus ambisporum	1	825	28.1
Acaulospora laevis	2	670	21.8
Acaulospora sp. 1	3	417	13.6
Acaulospora denticulata	4	376	12.2
Glomus sp. 1	5	221	7.2
Racocetra verrucosa	6	172	5.6
Gigaspora margarita	7	140	4.6
Glomus sp. 2	8	128	4.2
Acaulospora sp. 2	9	44	1.4
Acaulospora sp. 3	10	31	1.0
Claroideoglomus etunicatum	11	6	0.2
Glomus sp. 3	12	5	0.2

Table 3
Mean spore abundance in 50 g^{-1} air dried soil of AMF species community across land use types.

AMF species	CO	FA	HT	IF	MA	NA	PF
A. laevis	9.2	19.9	7.4	20.8	13.1	11.0	22.3
A. denticulata	0.4	7.9	1.0	11.8	0.4	12.3	61.3
Ac. sp. 1	0.2	1.2	0.6	1.0	0.4	0	0.7
G.ambisporum	17.8	26.4	8.2	22.7	5.3	26.5	37.7
Glomus sp. 1	1.4	10.9	3.2	1.5	3.1	6.3	0.3
Glomus sp. 2	1.0	4.9	3.6	1.8	3.1	1.5	0.7
C. etunicatum	0	0	0	0	0.9	0	0
R. verrucosa	0	2.9	1.2	12.7	3.9	1.5	6.3
G. margarita	2.6	4.9	4.8	4.2	1.7	0.3	0.7
Ac. sp. 2	2.4	10.5	5.0	6.0	5.7	31.8	0
Ac. sp. 3	0.4	0.3	0.6	1.8	3.3	0.3	0
Glomus sp. 3	0	0	0	0	0.7	0	0

Note: CO = coffee; FA = fallow; HT = horticulture; IF = indigenous forests; MA = maize; NA = napier; PF = planted forests; Ac. sp. 1 = *Acaulospora* sp. 1; Ac. sp. 2 = *Acaulospora* sp. 2; Ac. sp. 3 = *Acaulospora* sp. 3.

spore wall characteristics, type spore wall, size and number of layers and reaction to Melzer's reagent used as diagnostic features. The spores were matched with species described by International Culture Collection of VA Mycorrhizal Fungi (INVAM) West Virginia University Morgantown, WV, USA Website and Schenck and Perez (1990). Attempts to establish spore cultures were made for final determination and confirmation of the species.

3. Statistical analysis

Analysis of variance using Genstat 14th Edition was used to compute the significant effect of land use on AMF spore abundance. Bonferroni test, a post-ANOVA test was used for comparing pairs of LUT. Extrapolating techniques using non-linear regression model such as the species accumulation curve was used to estimate the number of species that would be found in a complete survey, but may not have been encountered from the reported survey (Karl et al., 2003). The species accumulation curves, was used to estimate species richness and rank abundance of species across sites and LUTs (Colwell et al., 2004). Genetic diversity indices (hereafter meaning species richness, abundance and Shannon Index) were computed using the R statistical package called Biodiversity R (Kindt and Coe, 2005).

Species richness, species diversity (using Shannon), and the proportion of the land use type with most abundant AMF were computed by Renyi diversity profiles, H_α (H-alpha). Species richness, species diversity (using Shannon Index), and the proportion of the land use type with most abundant AMF were computed by Rènyi diversity profiles, extrapolating techniques (Tóthmérész, 1993; Pielou, 1975; Rènyi, 1961). Rényi diversity profiles are curves that also provide information on richness and evenness, as rank abundance curves do. Rényi diversity profiles have the advantage over rank-abundance curves that ordering from lowest to highest diversity is easier. For this reason, a Rényi diversity profile is one of several diversity ordering techniques (Tóthmérész, 1993).

Population estimates such as Jacknife were used to extrapolate the expected number of species in the survey area. Similarity index was used to derive dendograms that establish similarities between land use types in terms of species composition (Legendre and Gallagher, 2001).

4. Results

4.1. AMF species composition

A total of 12 species were distinguished on the basis of morphological features directly from the field (Table 2). Three additional species were observed from trap cultures. Six morphotypes were identified positively at species level based on descriptions in literature to *Acaulospora laevis* Gerd. & Trappe, *Glomus ambisporum* Smith & Schenck and *Claroideoglomus etunicatum* (Becker & Gerd.) Walker & Schussler and *Acaulospora denticulata* Sieverding & Toro. *Racocetra verrucosa* (Koske & Walker) Oehl, Souza & Sieverding and *Gigaspora margarita* Becker & Hall. The remaining morphotypes were classified as distinct morphotypes but could not be matched with known described species. Few species seemed to dominate the landscape with the four most dominant species containing 75.7% of all spores encountered (Table 2). The spores of *Glomus* spp. and *Acaulospora* spp. accounted for the 39.9% and 50%, respectively. The proportions of spores of *R. verrucosa* and *G. margarita* were the least accounting for only 16.1%. The three additional AMF morphotypes from trap cultures were *Acaulospora sccrobiculata* Trappe which occurred in all LUTs except HT and NA and two unidentified species. The spores of *G. ambisporum* were the most dominant at the study site. The upper and lower confidence limits of *Acaulospora* sp. 1, *A. denticulata* and *R. verrucosa* were too wide signifying uncertainty of the true mean for these species. This suggests that the three species are highly dispersed in distribution at the study area of 6 km^2 across seven LUTs.

4.2. AMF spore abundance

Exploratory data analysis using boxplot showed variable range of distribution of spores within LUTs (Fig. 1). Spore abundance was positively skewed particularly in LUTs with planted forests (PF) and fallow (FA), signifying non-normal distribution. The range of spore abundance was wide in LUTs with PF, IF and NA. Land use type had significant ($p = 0.006$) effect on AMF spore abundance (Fig. 2). There were marked differences in mean spore abundance between land use types PF, NA, IF and FA had the highest mean spore abundance which was more than twice the spore abundance in LUTs under cultivation (MA, HT and CO) had the least spore abundance.

Using a generalized linear model for presence and absence of species, the occurrence of AMF was confirmed to vary in each LUT with four species significantly affected (Table 3). The spore abundance of *A. denticulata* ($p = 0.009$), *G. ambisporum* (0.005), *C. etunicatum* ($p = 0.012$) and *Acaulospora* sp. 1 ($p = 0.07$) were variable across LUTs. At least six species (*A. laevis*, *A. denticulata*, *G. ambisporum*, *Glomus* sp. 1, *Glomus* sp. 2 and *G. margarita*) occurred in all LUTs, two species (*C. etunicatum* and *Glomus* sp. 3) occurred only in LUT with maize and *Acaulospora* sp. 1 and *Acaulospora* sp. 3 were low in all LUT *A. denticulata* was highest in PF, NA and IF in descending order and least in CO, HT and MA. *G. ambisporum* was also common in all LUT but highest in PF, FA, NA, IF, CO, HT and MA in descending order. *R. verrucosa* was highest in indigenous and planted forest. *A. laevis* was least in HT and CO and *G. margarita* was least in NA and PF.

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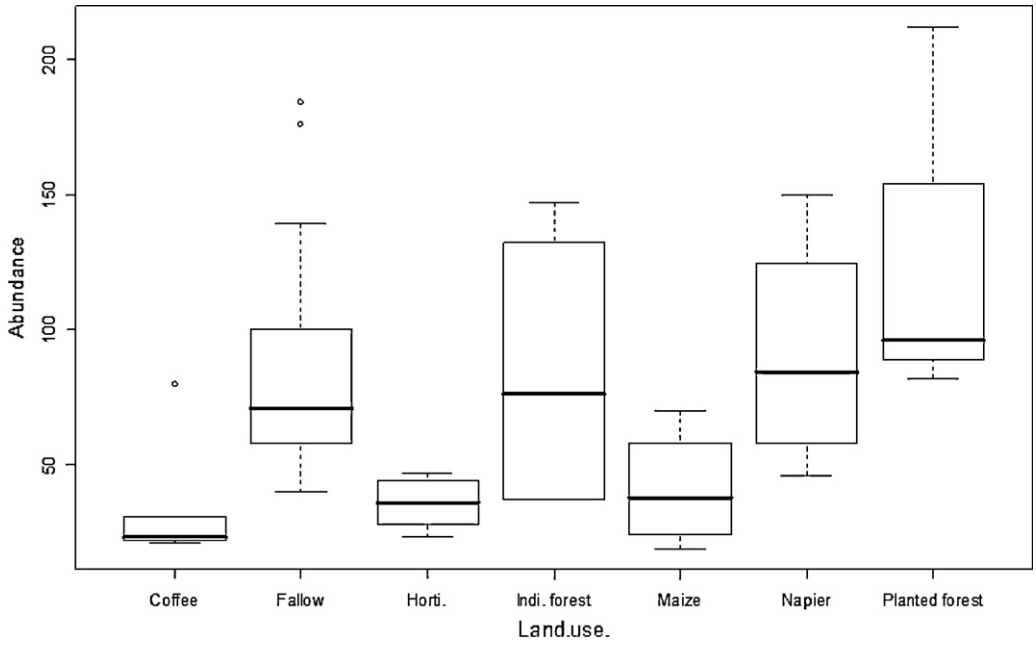

Fig. 1. Range of AMF spore abundance within a land use type.

4.3. AMF species richness and diversity

A total of 12 species were recovered from field soils in the survey and further extrapolation with jacknife also predicted species richness of 13.95 (Table 4). The species accumulation curve reached a plateau with slightly above 13 species at approximately 26 sampling points (Fig. 3). The number of LUT sampled was unequal, hence, species accumulation curves generated for individual LUT differed at the point of climax (Fig. 4). A comparison of species richness for individual LUT showed no significant different in species richness ($p = 0.9$), however, species accumulation curve reached a plateau at variable points and some never reached. Jacknife extrapolation for individual LUTs predicted more species in MA and PF than was recovered from the field. The species accumulation curve for individual LUT showed all LUTs except MA and PF to reach a plateau with the number of sampling points used during the survey.

Rènyi's diversity profile was used to provide information on species diversity (Fig. 5). The profiles indicate HT was more diverse than MA, IF, FA, NA, PF and CO in descending order. The IF and MA as well as CO and PF could not be unequivocally ordered, as the profiles cross each other at different values of the scale parameter. At the $\alpha = 0$ scale, MA runs above IF while CO runs above PF. At the scale $\alpha = 1$ (Shannon Index), species diversity in LUT is ranked HT > MA > FA > IF > NA > CO > PF. Ranking at scale $\alpha = 2$ (Simpson Index) is similar except for PF and coffee which cross at this point. Shannon Index derived from survey for all LUTs showed richness to be less than the Jacknife estimate values and the diversity of MA to precede HT (Table 4).

The land use types were grouped according to similarities (Fig. 6). Similarity in AMF abundance was significant ($p < 0.01$), by mantel = 0.73). Three groups of LUTs were distinguished: group I consisting of only FA, group II consisting of NA but diverging somewhat from IF and PF which seem to be very similar,

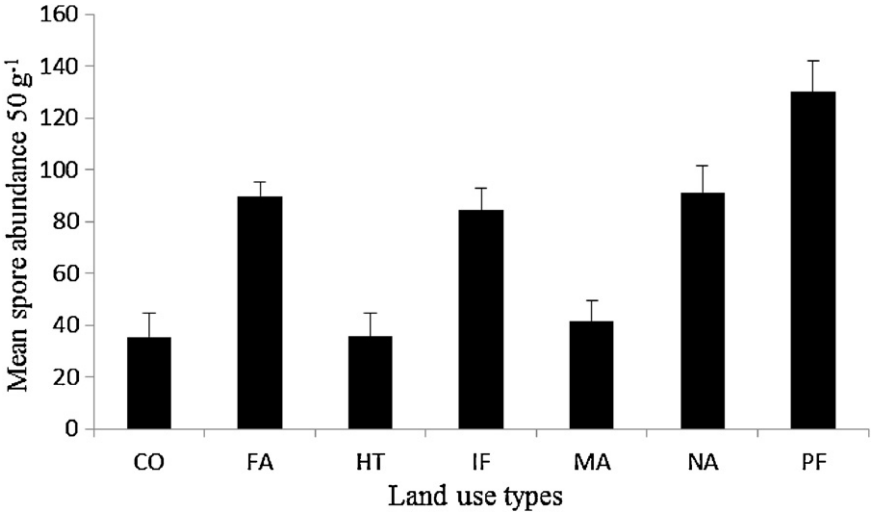

Fig. 2. Mean spore abundance of seven land use types.

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Table 4
AMF species richness and diversity in 50 g^{-1} air dried soil.

Land use type (LUT)	No. of sampling points	Total richness	Jacknife estimate	Shannon diversity	Jacknife estimate
Coffee (CO)	5	9	9.8	1.43	1.45
Fallow (FA)	13	10	10	1.92	2.00
Horticulture (HT)	5	10	10.8	2.01	2.12
Indigenous forest (IF)	6	10	10.8	1.89	2.03
Maize (MA)	7	12	14.6	2.08	2.26
Napier (NA)	4	9	10.5	1.60	1.77
Planted forest (PF)	3	8	10	1.26	1.28
Total for all LUT	43				

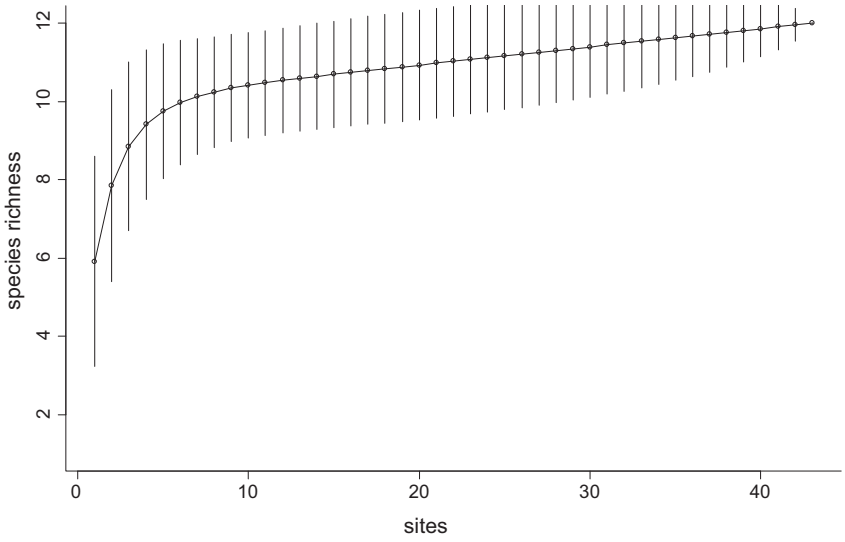

Fig. 3. Species accumulation curve for AMF species in the field.

Group III consisting of HT and MA linking with CO at higher level.

5. Discussion

5.1. AMF species composition

The number of species recovered from this site is within the range of records in parts of Kenya, Cameroon and Malawi (Jefwa et al., 2006, 2009; Mathimaran et al., 2007; Shepherd et al., 1996; Mason et al., 1992). This is comparatively less than species recorded in Brazilian Amazon, Nicaragua, Costa Rica, tropical China and Thailand (Stürmer and Siqueira, 2011; Songachan and Kayang, 2011; Cheroenpakdee et al., 2010; Zhao et al., 2003; Picone, 2003). The majority of species *Glomus* spp. and *Acaulospora* spp. were common in all LUT at variable proportions. This may be attributed to sporogenous characters of species whereby, it has been found that *Acaulospora* and *Glomus* produce more spores than *Scutellospora*

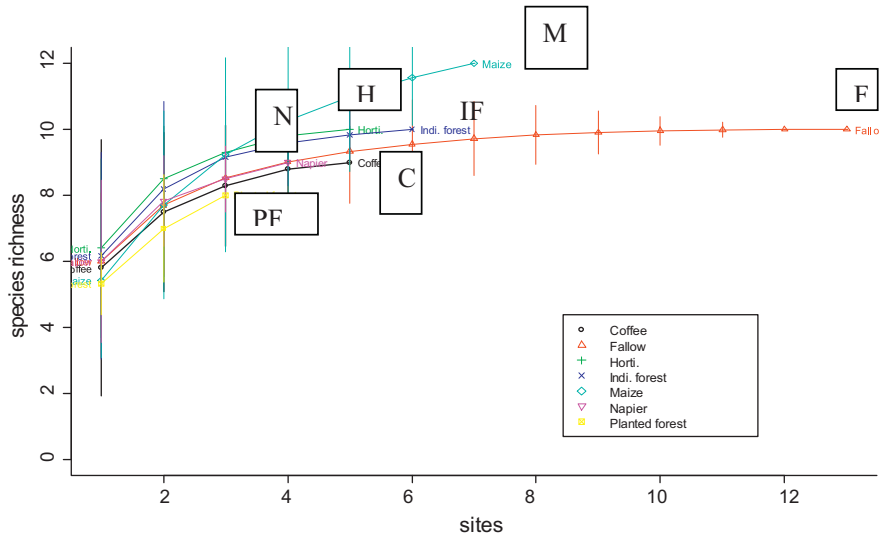

Fig. 4. Species accumulation curve with respect to individual land use type.

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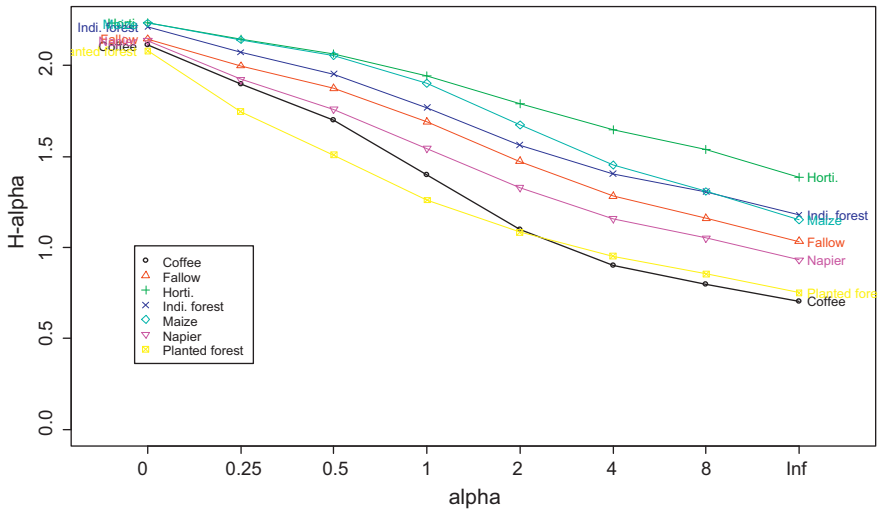

Fig. 5. Renyì diversity profile for all land use types.

and *Gigaspora* in the same environment (Bever et al., 1996). The species *A. laevis*, *A. denticulata*, *A scrobiculata*, *G. ambisporum*, *C. etunicatum*, *R. verrucosa* and *G. margarita* have all been widely reported in parts of Africa and other parts of the world (Porter et al., 1987; Schreiner et al., 2009; Sieverding and Toro, 1987; Velazquez et al., 2008; Jefwa et al., 2009; Mathimaran et al., 2007; Shepherd et al., 1996).

5.2. AMF spore abundance

There was clear evidence of response of spore abundance and not species richness and diversity following changes in land use. General observations showed LUT under cultivation (CO, MA and HT) to have lower spore abundance than non-cultivated (PF and IF) and less frequently cultivated (NA and FA) LUTs. Disturbance through cultivation of croplands may have caused the decline in AMF abundance in this site. Soil disturbance by agricultural activities has been shown to reduce the density of AMF spores (Boddington and Dodd, 2000; Jasper et al., 1989; Boerner et al., 1996; Gould et al., 1996; Wiseman and Wells, 2005). The practice in the region for most croplands is characterized by the application of inorganic fertilizer and in some of the crops (CO and HT) pesticides application. Fertilization has also been reported to decrease AMF total spore abundance and variation in species richness and diversity varying in their response (Bhadalung et al., 2005). This may also explain the differences in spore numbers for individual species in the LUTs. Both *Acaulospora* spp. and *Glomus* spp. were more abundant in the landscape with some species prevalent in specific LUT. *A. laevis*, *A. deniculata*, *G. ambisporum* and *G. margarita* plus two undescribed *Glomus* spp. were common in all LUTs. *A. laevis* and *G. ambisporum* were the most abundant species in all LUT. The spore abundance of *A. laevis* was least in HT, CO, NA and MA while *G. ambisporum* was least in MA and HT. With the exception of NA, the spore abundance of *A. laevis* and *G. ambisporum* was most likely affected by management practices. *A. laevis* in our study occurred in soils of pH range of 3.06–4.93, concurring with earlier studies which showed *A. laevis* to occur in soils of low pH (Porter et al., 1987; Dickman et al., 1984). This may explain the low spore abundance of *A. laevis* in LUTs with MA, HT, CO and NA which had slightly higher pH levels. *G. ambisporum* was reported

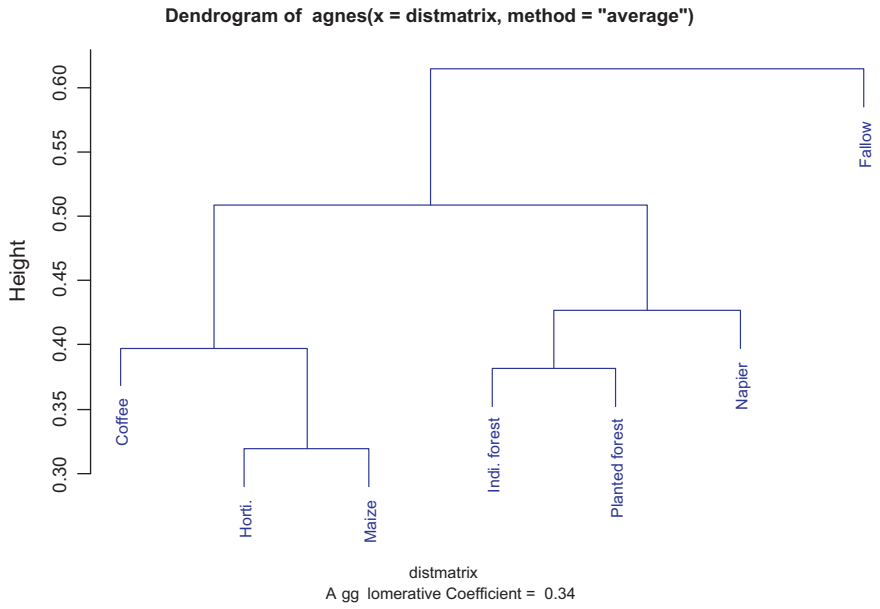

Fig. 6. Dendogram representing land use types sharing similarities in AMF spore abundance.

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by Rokin et al. (2006) and Renuka et al. (2012) to occur in wide range of conditions, a situation confirmed in this study. However, spore abundance was lower in cropping systems with MA and HT. Although *A. denticulata* was common in all LUTs, it was least in cropping systems with CO, HT and MA and highest in planted forest system. This species was reported in tropical forest, grassland and communal lands which have limited interference by man (Zao et al., 2003; Bever et al., 1996; Uhlmann et al., 2004). Similarly, *Gi margarita* was common in all LUTs although in small numbers but showed preference for croplands. This species has been reported widely in natural and cropping systems in parts of Kenya and Malawi (Jefwa et al., 2004, 2006; Mathimaran et al., 2007; Vasha and Rodrigues, 2001; Khade and Rodrigues, 2008; Pagano et al., 2010). The species *R. verrucosa* in our study was highest in non-cropped systems with less anthropogenic interference (NA, IF and PF). This is supported by studies in Venezuela and Indonesia which indicated absence of genera *Gigaspora* and *Scutellospora* upon soil disturbance imposed through practices such as agriculture with AMF communities in disturbed soils dominated by *Glomus* and *Acaulospora* (Selvam and Mahadevan, 2002; Cuenca et al., 1998; Boddington and Dodd, 2000).

In our study, *A. scrobiculata* was found only in trap cultures while *C. etunicatum* was rare and restricted to only LUTs with MA. Previous studies observed high spore density of *C. etunicatum* at the rhizosphere of maize and *A. scrobiculata* absent in disturbed sites and studies in central and western Kenya and Cameroon showed *A. scrobiculata* and *C. etunicatum* as the most widespread (Prasetyo et al., 2010; Jefwa et al., 2006, 2009; Mason et al., 1992; Wilson et al., 1992; Shepherd et al., 1996).

5.3. Species richness and diversity

The value twelve species isolated directly from field soils are close to the Jacknife extrapolated predicted value of 13.95. The species accumulation curve indicated approximately 26 sampling points as adequate to recover at least 13 species, implying 43 sampling points as over sampling at landscape level. At individual LUT level, it was noted that some LUT such as MA and PF may require extensive sampling to recover representative AMF species for these LUTs. Seven and three points were sampled for PF and MA respectively. Fewer points than MA were sampled for NA (4), HT (5), IF (6) and CO (5) but these points almost reached a plateau, indicating sufficient points sampled for these LUTs. The need for extensive sampling in MA and may emanate from heterogeneity in management practices used by farmers in the application of different farm inputs at variable rates. The planted forest was under sampled yet it is a heterogeneous LUT dominated by *E. saligna* Sm. and *C. lusitanica* Mill., *P. patula* Schiede ex Schttdl. & Cham. and *P. radiata* D. Don. species. This conforms to Cochran (1977) who suggested more sampling for highly heterogeneous samples.

The differences in species richness and diversity with changes in LUT were less evident. Violi et al. (2008) noted contrasting patterns in sporulation among AMF families across different disturbance types and maintenance of species richness and composition despite the dramatic changes in host communities. The slightly high species diversity in MA cannot be explained by the different attributes of the different LUTs, hence indicating the role of other factors. Edaphic factors, seasonality, host dependence and age were identified as factors affecting spore sensitivity, species richness and diversity (Khade and Rodrigues, 2008; Guadarrama and Alvarez-Sanchez, 1999). The studies by Galvez et al. (2001) and Jansa et al. (2002) showed community structure of AMF and spore numbers to be negatively affected by tillage treatments and high-input management. This study did not explore the effects of these factors on AMF.

6. Conclusion

AMF spore abundance grouped LUTs which shared similarity in intensity. Using similarity index and dendograms, the distribution of spores across LUT clearly distinguished land use under cultivation and non-cultivated. The LUTs with NA, IF and PF were in the same group and CO, MA and HT formed a different group, both indicating similarities management practices for LUTs in the same group. The LUTs with fallow was separate from the two groups. Similar trends were noted in boxplots with land that was not cultivated showing higher variation than cultivated land, implying heterogeneity in less managed land and homogeneity in cultivated land.

The study has shown LUTs with crops to reduce spore abundance than species richness and diversity. Spores are propagation propagules and survive in the soils longer particularly in adverse climatic conditions. It is promising to note that species diversity can still be sustained under cropping practices, however the fewer spores in these LUT points out to a likelihood of loosing species with time.

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References

Allen, E.B., Allen, M.F., Helm, D.J., Trappe, J.M., Molina, R., Rincon, E., 1995. Patterns and regulation of mycorrhizal plant and fungal diversity. Plant Soil 170, 47–62.
Allen, M.F., 1988. Re-establishment of VA mycorrhizae following severe disturbance: comparative patch dynamics of a shrub desert and subalpine volcano. Proc. R. Soc. Edinb. 94B, 63–71.
Beentje, H.J., 1988. Atlas of rare trees of Kenya. Utafiti 3, 71–123.
Bever, J.D., Morton, J.B., Antonovics, J., Schultz, P.A., 1996. Host-dependent sporulation and species diversity of arbuscular mycorrhizal fungi in a mown grassland. J. Ecol. 84, 71–82.
Bhadalung, N., Suwanarit, A., Dell, B., Napamornbodi, O., Thamchaipenet, A., Rungchuang, J., 2005. Effects of long-term NP-fertilization on abundance and diversity of arbuscular mycorrhizal fungi under maize cropping system. Plant Soil 270, 371–382.
Boddington, C.L., Dodd, J.C., 2000. The effect of agricultural practices on the development of indigenous arbuscular mycorrhizal fungi. I. Field studies in an Indonesian ultisol. Plant Soil 216, 137–144.
Boerner, R.E., De Mars, B.G., Leicht, P.N., 1996. Spatial patterns of mycorrhizal infectiveness of soils along a successional chronosequence mycorrhizae. Mycorrhiza 6, 79–90.
Burgess, N.D., Butynski, T.M., Cordeino, N.J., Doggart, N.H., Fjeldsa, J., Howell, K.M., Kilhama, F.B., Loader, S.P., Lovett, J.C., Mbilinyi, B., Menegon, M., Moyer, D.C., Nashanda, E., Perkin, A., Rovero, F., Stanley, W.T., Stuart, S.N., 2007. The biological importance of the eastern arc mountains of Tanzania and Kenya. Biol. Conserv. 134, 209–231.
Cheroenpakdee, S., Phosri, C., Dell, B., Lumyong, S., 2010. The mycorhizal status of indigenous arbuscular mycorrhizal fungi of physic nut (*Jatropha curacas*) in Thailand. Mycosphere, 167–181.
Cochran, W.G., 1977. Sampling Techniques, Third ed. John Wiley and Son, New York.
Colwell, R.K., Mao, C.X., Chang, J., 2004. Interpolating, extrapolating, and comparing incidence-based species accumulation curves. Ecology 85 (10), 2717–2727.
Cuenca, G., de Andrade, Z., Escalante, G., 1998. Diversity of glomalean spores from natural disturbed and revegetated communities growing on nutrient-poor tropical soils. Soil Biol. Biochem. 30, 711–719.
Dickman, L.A., Liberta, A.E., Anderson, R.C., 1984. Ecological interaction of little bluestem and vesicular-arbiscular mycorrhizal fungi. Can. J. Bot. 62 (11), 2272–2277.
FAO-UNESCO, 1987. In: Creutzberg, D. (Ed.), Soil Map of the World. ISRIC, Wagenigen.
Galvez, L., Douds, D.D., Drinkwater, L.E., Wagoner, P., 2001. Effect of tillage and farming system upon VAM fungus populations and mycorrhizas and nutrient uptake of maize. Plant Soil 228, 299–308.

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Gould, A.B., Hendrix, J.W., Ferris, R.S., 1996. Relationship of mycorrhizal activity to time following reclamation of surface mine land in western Kentucky. I. Propagules and spore population densities. Can. J. Bot. 74, 247–261.
Guadarrama, P., Alvarez-Sanchez, A.F.J., 1999. Abundance of Arbuscular mycorrhizal sporesin different environment in a tropical rain forest, Verracruz, Mexico. Mycorrhiza 8, 267–270.
Jansa, J., Mozfar, A., Anken, T., Ruh, R., Sanders, I.R., Frossard, E., 2002. Diversity and structure of AMF communities as affected by tillage in a temperate soil. Mycorrhiza 12, 225–234.
Jaetzold, R.H., Schmidt, H., 1983. Farm Management Handbook of Kenya, vol. II/B. Central Kenya. Ministry of Agriculture, Nairobi, Kenya.
Jasper, D.A., Abbott, L.K., Robson, A.D., 1989. Soil disturbance reduces the infectivity of external hyphae of VA mycorrhizal fungi. New Phytol. 112, 93–99.
Jefwa, J., Vanlauwe, B., Coyne, D., van Asten, P., Gaidashova, S., Rurangwa, E., Mwashasha, M., Elsen, A., 2010. Benefits and potential use of arbuscular mycorrhizal fungi (AMF). In: Dubois, T., Hauser, S., Staver, C., Coyne, D. (Eds.), Proc. IC on Banana and Plantain in Africa. Acta Hort., 479–486.
Jefwa, J.M., Mungatu, J., Okoth, P., Muya, E., Roimen, H., Njuguini, S., 2009. Influence of land use types on the occurrence of arbuscular mycorrhizal fungi in the high altitude regions of Mt. Kenya. J. Trop. Subtrop. Agroecosyst. 11, 277–290.
Jefwa, J.M., Sinclair, R., Maghembe, A.J., 2006. Diversity of glomale mycorrhizal fungi in maize/sesbania intercrops and maize monocrop systems in Southern Malawi. Agrofor. Syst. 67, 107–114.
Jefwa, J.M., Mwangi, L.M., Odee, D., Mugambi, G., 2004. Preliminary studies on mycorrhizal symbiosis in plant conservation forestry and farming systems in Kenya. J. Trop. Microbiol. 3 (1), 48–62.
Jenkins, W.R., 1964. A rapid centrifugal-floatation technique for separating nematodes from soil. Plant Dis. Rep. 48, 692.
Karl, I.U., Gray, J.S., Ellingsen, K.E., 2003. The species—accummulation curve and estimation of species richness. J. Anim. Ecol. 75 (5), 879–888.
Khade, S.W., Rodrigues, B.F., 2008. Ecology of arbuscular mycorrhizal fungi associated with *Carica papaya* L. in agro-based ecosystem of Goa, India. J. Trop. Subtrop. Agroecosyst. 8, 265–278.
Kindt, R., Coe, R., 2005. Tree Diversity Analysis. A Manual and Software for Common Statistical Methods for Ecological and Biodiversity Studies. World Agroforestry Centre (ICRAF), Nairobi.
Klironomos, J.N., McCune, J., Hart, M., Neville, J., 2000. The influence of arbuscular mycorrhizae on the relationship between plant diversity and productivity. Ecol. Lett. 3, 137–141.
Legendre, P., Gallagher, E.D., 2001. Ecologically meaningful transformations for ordination of species data. Oecologia 129, 271–280.
Maeda, E.E., Clark, P.P., Siljander, M., 2010. Modelling agricultural expansion in Kenya's eastern arc mountains biodiversity hotspot. Agric. Syst. 103 (9), 609–620.
Mason, P.A., Musoko, M.O., Last, F.T., 1992. Short term changes in vesicular arbuscular mycorrhizal spore populations in Terminalia plantations in Cameroon. In: Read, D.J., Lewis, D.H., Fitter, A.H., Alexander, I.J. (Eds.), Mycorrhizas in Ecosystems. CAB International, Wallingford, UK, pp. 261–267.
Mathimaran, Ruh, N., Jama, R., Verchont, B., Frossard, L., 2007. Impact of agricultural management on arbuscular mycorrhizal fungal communities in Kenyan ferrasol. Agric. Ecosyst. Environ. 119, 22–32.
Moreira, F.S., Huising, J.E., Bignell, D.E., 2008. A Handbook of Tropical Soil Biology: Sampling and Characterization of Below Ground Biodiversity. Earthscan, London.
Muya, E.M., Karanja, N., Okoth, P.F.Z., Roimen, H., Mungatu, J., Mutsotso, B., Thuranira, G., 2009. Comparative description of land use and characteristics of belowground biodiversity benchmark sites in Kenya. J. Trop. Subtrop. Agroecosyst. 11 (2), 263–275.
Myers, N., Mittermeier, R.A., Mittermeier, C.G., Da Fonseca, C.A.B., Kent, J., 2000. Biodiversity hotspots for conservation priorities. Nature 403, 853–858.
Newark, W.D., 1998. Forest area fragmentation, and loss in the eastern arc mountains: implications for the conservation of biological diversity. J. E. Afr. Nat. Hist. 87, 1–8.
Pagano, M.C., Cabello, M.N., Scotti, M.R., 2010. Arbuscular mycorrhizal colonization and growth of *Eremanthus incanus* Less. in a highland field. Plant Soil Environ. 56 (9), 412–418.
Picone, C., 2003. Managing mycorrhizae for a sustainable agriculture in the tropics. In: Vandermeer, J. (Ed.), Advances in Agroecology in Tropical Agroecosystems. CRC Press Inc., Boca Raton.
Pielou, E.C., 1975. Ecological Diversity. Wiley-Interscience, New York.
Porter, W.M., Robson, A.D., Abbott, L.K., 1987. Field survey of the distribution of vesicular-arbuscular mycorrhizal fungi in relation to soil pH. J. Appl. Ecol. 24, 659–662.
Power, M.E., Mills, L.S., 1995. The keystone cops meet in Hilo. Tree 10, 182–184.
Prasetyo, B., Krisnayanti, B.D., Utomo, W.H., Anderson, C.W., 2010. Rehabilitation of artisanal mining gold land in West Lombok, Indonesia. 2. Arbuscular mycorrhizal status of tailings and surrounding soils. J. Agric. Environ. Sci. 2 (2), 202–209.
Renuka, G., Rao, M.S., Ramesh, M., Kumar, P.V., Reddy, S.M., 2012. Distribution and diversity of AM fungal flora in Godvarc belt forests, Andhra Pradesh, India. Asian J. Exp. Biol. Sci. 3 (1), 228–235.
Rènyi, A., 1961. On measure of entropy and information. In: Neyman, J. (Ed.), Proceedings of the 4th Berkeley Symposium on Mathematical Statistics and Probability. Univ. California Press, Berkeley, pp. 547–561.
Rogers, P.C., O'Connell, B., Mwang'ombe, J., Madoffe, S., Hertel, G., 2008. Forest health monitoring in the Ngangao forest, Taita Hills, Kenya: a five year assessment of change. J. E. Afr. Nat. Hist. 97 (1), 3–17.
Rokin, N., Goltapeh, E.M., Alizadeh, A., 2006. Introducing one species of arbuscular mycorrhizal fungi from Khuzestan sugarcane fields in Iran. Rostaniha 7, 2.
Sanginga, N., Mulongoy, K., Swift, M.J., 1992. Contribution of soil organisms to the sustainability and productivity of cropping systems in the tropics. Agric. Ecosyst. Environ. 41, 135–152.
Schußler, A., Schwarzott, D., Walker, C., 2001. A new fungal phylum, Glomeromycota: phylogeny and evolution. Mycol. Res. 105, 1413–1421.
Schenck, N.C., Perez, Y., 1990. Manual for the Identification of VA Mycorrhizal Fungi. Synergistic Publications, Gainesville.
Schreiner, R.P., Mihara, K.L., 2009. The diversity of arbuscular mycorrhizal fungi amplified from grapevine roots (*Vitis vinifera* L.) in Oregon vineyards is seasonally stable and influenced by soil and vine age. Mycologia 10 (5), 599–611.
Selvam, A., Mahadevan, A., 2002. Distribution of mycorrhizas in an abandoned fly ash pond and mined sites of Neyveli lignite Corporation, Tamil, India. Basic Appl. Ecol. 3 (3), 277–284.
Shepherd, K.D., Jefwa, J., Wilson, J., Ndufa, J.K., Ingleby, K., Mbuthu, K.W., 1996. Infection potential of farm soils as mycorrhizal inocula for *Leucaena Leucocephala*. Biol. Fertil. Soils 22, 16–21.
Sieverding, E., 1991. Vesicular-Arbuscular Mycorrhiza Management in Tropical Agrosystems. Eschborn and Hartmut Bremer Verlag, Friedland.
Sieverding, E., Toro, S.T., 1987. *Acaulospora denticulata* sp. nov. and *Acaulospora rehmii* sp. nov. (Endogonaceae) with ornamented spore walls. Angew. Botanik 61, 217–223.
Songachan, L.S., Kayang, H., 2011. Diversity of arbuscular mycorrhizal fungi in pine forest of Meghalaya, North, East India. Mycosphere, 497–505.
Stürmer, S.L., Siqueira, J.O., 2011. Species richness and spore abundance of arbuscular mycorrhizal fungi across distinct land uses in Western Brazilian Amazon. Mycorrhiza 21, 255–267.
Tóthmérész, B., 1993. DIVORD 1.50. A program for diversity ordering. J. Veg. Sci. 6, 283–290.
Uhlmann, E., Görke, C., Peterson, A., Oberwinkler, F., 2004. Comparison of species diversity of arbuscular mycorrhizal fungi in winter-rainfall areas of South Africa and summer-rainfall areas of Namibia. J. Mycol. Prog. 3 (4), 267–274.
Van der Heijden, M.G.A., Boller, T., Wiemken, A., Sanders, I.R., 1998a. Different arbuscular mycorrhizal fungal species are potential determinants of plant community structure. Ecology 79, 2082–2091.
Van der Heijden, M.G.A., Kilronomos, J.N., Ursic, M., Moutoglis, P., Streitwolf-Engel, R., Boller, T., Wiemken, A., Sanders, I.R., 1998b. Mycorrhizal fungal diversity determines plant biodiversity, ecosystem variability and productivity. Nature 396, 69–72.
Vasha, J., Rodrigues, B.F., 2001. Occurrence and distribution of arbuscular mycorrhizal fungi in coastal sand dune vegetation of Goa. Curr. Sci. 80 (7), 826–827.
Velazquez, M.S., Cabello, M., Irrazabal, G., Godeas, A., 2008. Acaulosporaceae from El Palmar National Park, Entre Rios, Argentina. Mycotaxon 103, 171–187.
Violi, H.A., Alejandro, F., Barrientos-Priego. Wright, S.F., Escamilla-Prado, E., Morton, J.B., Menge, J.A., Lovatt, C.J., 2008. Disturbance changes arbuscular mycorrhizal fungal phenology and soil glomalin concentrations but not fungal spore composition in montane rainforests in Veracruz and Chiapas, Mexico. For. Ecol. Manage. 254, 276–290.
Wilson, J., Ingleby, K., Mason, P.A., Ibrahim, K., Lawson, G.J., 1992. Long-term changes in vesicular arbuscular mycorrhizal spore populations in Terminalia plantations in Cote d'Ivoire. In: Read, D.J., Lewis, D.H., Fitter, A.H., Alexander, I.J. (Eds.), Mycorrhizas in Ecosystems. CAB International, Wallingford, UK, pp. 268–275.
Wiseman, P.E., Wells, C., 2005. Soil inoculum potential and arbuscular mycorrhizal colonization of *Acer rubrum* in forested and developed landscapes. J. Aboricul. 3 (6), 296–301.
Zao, Z.W., Wang, G.H., Yang, L., 2003. Biodiversity of arbuscular mycorrhizal fungi in tropical rainforest of Xishuangbanna, southwest China. Fungal Divers. 13, 233–242.