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Effect of land use system on *Arbuscular Mycorrhiza* fungi in Maasai Mara ecosystem, Kenya

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*Arbuscular mycorrhiza* fungi (AMF) diversity and inoculums potential were assessed in different land use systems (protected and unprotected grassland and woodland, intensified monocropping systems and subsistence farming systems) in dry and wet region of Maasai Mara ecosystems (MME) during dry and wet season (November, 2009 and April, 2010). AMF spore were assessed in field and trap cultures (sorghum) using morphological tools. AMF inoculums potential were assessed using undisturbed soil cores planted with sorghum and cow pea. A total of 15 AMF species, dominated by species belonging to genus *Acaulospora* and *Scutellospora* were recorded across the MME. Wet region recorded high spore density and species richness in trap cultures. Human related disturbances caused by overgrazing and deforestation outside protected core altered AMF species composition in grassland, and negatively affected AMF species richness in woodland and grassland in the dry region. Similarly, intensified agriculture declined AMF diversity in dry region, but was unaffected in the wet region. Among different cropping systems, subsistence farming systems had higher AMF diversity and species numbers. This study demonstrates that human disturbances in natural ecosystems and intensified agricultural systems have adverse effects on AMF community especially in regions with semi-arid climatical conditions in Savannah ecosystems.

Key words: *Arbuscular mycorrhiza* fungi, land use, grassland, woodland, monoculture, mixed cropping.

INTRODUCTION

The Serengeti-Mara ecosystem is an area of 25,000 km² stretching across the border of Tanzania and Kenya, in East Africa, and is well known for its wildlife population in Africa. It comprises of Serengeti ecosystem in northern part of Tanzania and Maasai Mara ecosystem (MME) in the southwest of Kenya. The MME comprises approximately 6000 km², of which 25% represents Maasai Mara National Reserve (MMNR) and 75% is unprotected land which lies within pastoral and agricultural areas (Walpole et al., 2003). Over the past years, MME has undergone changes in land cover and land use, and tenure which have serious long-term implications on the future survival and conservation of wildlife (Singida, 1984; Galaty, 1992; Norton-Griffiths, 1996; Said et al., 1997). Area under agriculture (mainly wheat farming) increased from 4875 ha in 1975 to 50,000 ha in 1995 (Serneels et al., 2001). The conversion of range lands into agriculture is still going on and is expected to intensify with the increasing land subdivision into individual and corporate titles instead of communal tenure. The long-term impact of these land use changes is being attributed to decline in wildlife population especially wildebeest which are a keystone for the MME (Ottichilo et al., 2001). This calls for urgent conservations interventions aimed at promoting innovation/farming practices which sustain biological diversity without compromising food and income needs of...
the local community outside the protected core of MME (Buck et al., 2004). Choice of land use practices that are compatible with biodiversity conservation and livelihood are in return calling for studies on different aspects of biodiversity including changes in soil microbial populations.

Arbuscular mycorrhiza fungi (AMF) forms a major part of microbial community and are integral part of terrestrial plant communities, and forms symbiotic association with roots of over 80% of angiosperm plants (Trappe, 1987). These plant-fungal relationships are considered to be mutualistic, in which the fungus derives carbon from the host, and in return the plant gains several potential benefits from this association (Smith and Read, 1997). These benefits include enhanced uptake and transport of poorly mobile soil nutrients such as phosphorus (P), improved water relations, improved soil structure and reduced root pathogenic infections. The symbiosis is also of great interest because of its potential influence on ecosystem processes such as determining plant diversity in natural communities. AMF individual species or isolates have been shown to vary in their potential to promote plant growth and adaptation to biotic and abiotic factors (Beever, 2002). The composition and dynamics of populations of AMF as a result have a marked impact on the structure and diversity of the associated plant communities, both in natural and agricultural ecosystems (Grime et al., 1987; Gange et al., 1990; van der Heijden et al., 1999).

The sustainability of mycorrhizae in soil is thus, important to maintain and promote productivity of croplands, rangelands and forests, and may be critical to maintenance of biodiversity (Allen et al., 1995), and as a result, loss or perturbation of this relationship can have serious consequences in terms of plant community degradation, health or productivity. Loss of AMF propagules will result in a decrease in the capacity of plants to take up nutrients, thus threaten the stability of a given ecosystem. Agricultural management factors such as the intensity of cultivation, the quality and quantity of fertilizers applied and the plant protection strategies used in modern agriculture have severely affected AMF community structure and plant interactions (Sievendng, 1989; Douds and Millner, 1999; Oehl et al., 2003). On the other hand, disturbance of vegetation, soils and associate microflora depletes AMF population and alters AMF composition (Allen, 1988). AMF diversity may respond more rapidly to changes induced by management activities and land use changes, and consequently may be an early and sensitive indicator of change (Bosatta and A’gren, 1993).

An understanding of AMF communities is thus, an important tool which can be used to understand how key ecological processes in natural ecosystems and agro-ecosystems respond to anthropogenic disturbances, management changes or land use changes. Additional identification of innovative technologies in any ecosystems should take into consideration AMF communities. Describing the diversity of AMF at a given site is an important step in determining the effects of management and the eventual development of management regimes for these fungi.

The objective of this study was to examine the effects of: (1) human disturbances in natural ecosystems (comparing natural woodland and grassland inside and outside the park) and (2) agriculture practices with different levels of intensification (intensified maize and wheat mono cropping and subsistence farming with maize-bean intercrop) on AMF diversity and inoculums potential.

**RESEARCH METHODOLOGY**

**Study site**

The study was conducted in MME, bounded by international boundary of Kenya and Tanzania in the south, the Siria escarpment (Esol Oloololo) to the west, agriculture and forest to the north, Loita hills to the east and Siana plains to the southeast (Figure 1). The protected core of MME comprises of MMNR which is surrounded by range land. The range lands surrounding the MMNR can be divided into two range units, based on climate. These units comprises of semi-arid range lands in the east which falls under agro-climatic zone V with a mean average annual rainfall of 450 to 900 mm and a mean maximum temperature of 22 to 39°C and a mean minimum temperature of 10 to 18°C (Pratt and Gwynne, 1977). This area is generally dry and in this study, it is referred as dry region. In the west, we have semi-humid zone falling under agro-climatic zone IV with a mean average rainfall of 600 to 1100 mm, and has a mean maximum temperature of 22 to 26°C and a mean minimum temperature of 10 to 14°C (Figure 1). The area is generally wet and it is referred in this study as the wet region.

The annual distribution of the rainfall across the study area is bimodal, characterized by two rainy seasons as well as two dry seasons. The long rains are from March to May and short rains occur in between November and December. The main dry period is from June to October with lesser dry spell in January and February. The land use system in this region comprises of natural woodland and grassland inside and outside the park. Natural woodland and grassland inside the park are characterized by minimal human disturbances while woodland and grassland outside the park are characterized by heavy human disturbances associated with overgrazing by the cattle and wild animals and other human related activities such as charcoal burning, cutting of trees for timber, fire wood, harvesting of non-timber products etc. Agricultural systems outside the protected core of MME comprises of small-scale subsistence varieties grown with heavy applications of external inorganic fertilizer inputs, pesticides and irrigation.

**Experimental design**

A 1-year survey was conducted during the short rain of September to November, 2009 and long rains of March to June, 2010 in the two regions of MME (dry and wet) in pre-established land use/habitat categories containing uniform land use differing according to major land use types viz: indigenous woodland, grasslands and cropland. Soil samples were collected from seven land uses systems in each region; four land use categories in natural ecosystems namely; (1) grassland inside the park, (2) grassland outside the park, (3) woodland inside the park and (4) woodland outside the park and three land use categories within the
Figure 1. Study area (MME) showing respective study plots.

agricultural matrix (a) maize mono-cropping, (b) wheat mono-cropping, (c) small maize-bean intercropping in dry region; and (i) maize monocropping, (ii) large-scale maize-bean intercropping and (iii) small-scale maize-bean intercropping in the wet region. The study plots in wet region comprised of (1) Kichwa Tembo in woodland outside the park (KMWWO1), (2) Mpata in grassland outside park (KMGWO1), (3) Serena in woodland inside the park (KMWWO1), (4) Olono gate in grassland inside the park (KMGW1), (5) Isokon maize monocropping (KMCPWO1-1), (6) Isokon large-scale maize-beans intercrop (KMCPWO1-2) and (7) Isokon small-scale maize-beans intercrop (KMCPWO1-3) (Table 1). In the dry region, the study plots comprised of (1) Olonannet in woodland outside the park (KMWDO1), (2) Koiyaki in grassland outside the park (KMGDO1), (3) Nkama in woodland outside the park (KMWDO1).
Table 1. Overview of characteristics of different land uses systems in the dry and wet region of the MME.

<table>
<thead>
<tr>
<th>Location</th>
<th>Plot name</th>
<th>Land use</th>
<th>Plot code</th>
<th>Dominant trees species</th>
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<tr>
<td>Inside park</td>
<td>Posse plains</td>
<td>Grassland</td>
<td>KMGDI1</td>
<td>Grass mainly <em>Themeda triandra</em> and <em>Pennisetum</em> sp.</td>
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<td></td>
<td>Nkama</td>
<td>Woodland</td>
<td>KMWDI1</td>
<td><em>Tarconanthus camphorates</em>, <em>Teclea nobilis</em>, <em>Rhus natalencies</em>, <em>Acacia drepanolobium</em>, <em>Combretum molle</em>, <em>Croton Dichogamus</em> <em>Tarconanthus camphorates</em>. Average vegetation cover was 0.44%.</td>
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<tr>
<td>Outside park</td>
<td>Koyiaki</td>
<td>Grassland</td>
<td>KMGDO1</td>
<td>Grass mainly <em>Themeda triandra</em> and <em>Pennisetum</em> sp.</td>
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<td></td>
<td>Olnananet</td>
<td>Woodland</td>
<td>KMWDO1</td>
<td><em>Acacia drepanolobium</em>, <em>Acacia gerradii</em>, <em>Croton Dichogamus</em>, <em>Commiphora Africana</em>, <em>Rhus natalencies</em>, <em>Balanties aegyptiaca</em>. Average vegetation cover was 0.09%.</td>
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<td>Agriculture</td>
<td>Hugo farm</td>
<td>Maize</td>
<td>KMCPDO1</td>
<td>Maize monocropping with high fertilization (annual average of 100 kg N and P/ha, 50 kg K/ha), pesticides applications and irrigation</td>
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<tr>
<td></td>
<td>Olnananet</td>
<td>Wheat</td>
<td>KMCPDO2</td>
<td>Wheat monocropping with high fertilization (annual average of 100 kg N and P/ha, 50 kg K/ha), pesticides applications and irrigation</td>
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<td></td>
<td>Soka farm</td>
<td>M-B(S)</td>
<td>KMCPDO3</td>
<td>Maize intercropped with beans with only manure inputs</td>
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<tr>
<td>Inside park</td>
<td>Ofolo gate</td>
<td>Grassland</td>
<td>KMGW11</td>
<td>Grass mainly <em>Themeda triandra</em> and <em>Pennisetum</em> sp.</td>
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<td></td>
<td>Serena</td>
<td>Woodland</td>
<td>KMWW11</td>
<td><em>Euclea divinorum</em>, <em>Tannea graviolencies</em>, <em>solanum incanum</em>, <em>Acacia drepanolobium</em>, <em>Ocimum suave</em>, <em>Croton Dichogamus</em>. Average vegetation cover was 0.12%.</td>
</tr>
<tr>
<td>Outside park</td>
<td>Kichwa Tembo</td>
<td>Grassland</td>
<td>KMGWO1</td>
<td>Grass mainly <em>Themeda triandra</em> and <em>Pennisetum</em> sp.</td>
</tr>
<tr>
<td></td>
<td>Mpata</td>
<td>Woodland</td>
<td>KMWWO1</td>
<td><em>Rhus natalencies</em>, <em>Tarconanthus camphorates</em>, <em>Acacia Kirkii</em>, <em>Acacia gerradii</em>, <em>Acacia drepanolobium</em>, <em>Combretum molle</em>. Average vegetation cover was 0.12%.</td>
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<td>Agriculture</td>
<td>Isokon</td>
<td>Maize</td>
<td>KMCPD01-1</td>
<td>Maize monocropping with high fertilization (50 kg P and 100 kg N/ha) and irrigation</td>
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<td></td>
<td>Isokon</td>
<td>M-B(L)</td>
<td>KMCPD01-2</td>
<td>Maize-bean intercrop with manure and fertilization (30 kg P and N/ha) combined with farm yard manure.</td>
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<tr>
<td></td>
<td>Isokon</td>
<td>M-B(S)</td>
<td>KMCPD01-3</td>
<td>Maize-beans intercrop with no or sometimes with or without farm yard manure inputs.</td>
</tr>
</tbody>
</table>

(KMWDI1), (4) Posse plains in grassland inside park (KMGDI1), (5) Hugo farm maize mono-cropping (KMCPDO1), (6) Hugo farm wheat mono-cropping (KMCPDO2) and (7) Soka farm maize-beans intercropping (KMCPDO3) (Table 1). In each of study plot, three transects each measuring 1 x 0.05 km were laid out, 1 km away from each other and 500 m away from the road. In each transect, three sampling plots of 10 m by 10 m were demarcated 300 m away from each other along the transects. Soil samples were taken randomly in 10 different points at a depth of 0 to 30 cm in each 10 x 10 m sampling plots. The soil samples from these 10 points were pooled and mixed to obtain a representative samples per plot. In total, 9 samples were taken per given land use systems.

Characteristics of land use systems used in the study

Summary of characteristics and dominant tree species found in different land uses systems in MME are shown in Table 1. Percentage vegetation cover in woodlands inside the park was 0.44% while outside the park was 0.09% in the dry region. In the wet region, percentage vegetation cover was 0.12% in woodland inside and outside the park. In cultivated soil, maize and wheat monocropping were characterized by high inorganic fertilization (annual average of 100 kg N and P/ha, 50 kg K/ha), pesticides applications and irrigation while maize-bean intercropping system was characterized by low inputs of farm yard manure in the dry region. In the wet region, maize monocropping was cultivated using high inputs of inorganic fertilizer (estimates of 50 kg P/ha and 100 kg N/ha). Large-scale maize intercropping had low inorganic inputs (an estimate of 30 kg P and N/ha) combined with farm yard manure while in small-scale maize-bean intercrop cultivation was done with or without farmyard manure cultivation.

Sampling method and setting of trap cultures

Soils were sampled with a soil auger from various sampling depths (0 to 30 cm). Samples were loosely closed immediately in sterile polyethylene bags and stored in a cool box, before being transported for analysis. Trap cultures were initiated according to the recommendation of Morton, (1993). Briefly, a pot culture with each pot representing a single transect was set up at National...
Museums of Kenya. Sorghum was used as trap due to the fact that 1000 AMF isolates of 98 species in all 6 genera have been able to grow and sporulate in all pots with Sorghum sudanense (Piper) (Morton, 1993). The aim of trap cultures was to dilute the parasitic pressure on the AMF propagules in the soil and induce sporulations to recover spores from AMF species present in the soil, including some which may not have sporulated at the time of sampling in order to get spores of similar developmental ages. A sub-sample of 150 g from each transect soil inoculum was diluted with 200 g of autoclaved medium sized sand and mixed before being poured into 0.5 l pot. Sand was chosen as a diluting subtracted at it and is inert and does not affect inoculum pH. Sorghum was later sown as host plant at a density of 25 plants per pot. Each pot was then covered with autoclaved sand to prevent unintentional dispersal of AMF. After seedling emergency, the pots were watered daily with tap water. The pot cultures were allowed to grow for 4 months. During the last week, the moisture was successively lowered to stop growth of plants and enhance sporulation of existing AMF species.

Soil analysis

Sub-samples of collected soil samples were analyzed for total nitrogen, carbon, available P and pH at Kenya Agricultural Research Institute (KARI) soil laboratory following standard methods for tropical soils (Anderson and Ingram, 1993). Phosphorus was extracted with 0.5 M NaHCO₃ + 0.01 M ethylenediaminetetraacetic acid (EDTA) (pH 8.5, modified Olsen) using a 1:10 soil/solution ratio. Available P was estimated colorimetrically (molybdenum blue). Organic C (SOC) was determined colorimetrically after H₂SO₄ - dichromate oxidation at 150°C for 30 min. Total N was determined by Kjeldahl digestion with sulphuric acid and selenium as a catalyst and was estimated colorimetrically. Soil pH was measured in aqueous suspension (1:2.5 w:v).

AMF inoculum potential

Alongside soil samples, undisturbed soil cores were also taken in each sampling plots (two undisturbed cores) to assess the AMF inoculum potential. The AMF bioassay were established using two fast growing host plants (Sorghum and cow pea), which were allowed to grow for 4 weeks, after which the plants roots were harvested. The roots were rinsed, cut into 1 cm root pieces, mixed, cleared and stained for AMF structure (Kormnik and McGraw, 1982), and assessed for AMF colonization according to Trouvelot et al. (1986).

AMF taxonomy

AM assessment was done from both field collected soil samples as well as from trap cultures (sorghum). 50 g of soil was taken for AMF spore extraction which was done by centrifugation in sucrose gradients (Gerdemann and Nicolson, 1963). Intact spore were counted and the spore morphotype were separated and transferred to object glasses, and identified by investigating the range of mean, spore and saccule size, colour and distances between spores and saccule. To further examine the organization and histochemistry of spore subcellular structure, the spore were mounted on slides with 1 to 30 spores with polyvinyl alcohol-lactic acid-glycerol (PVLG) media and Melzer reagent according to Schenck and Perez (1990). The international collection of arbuscular and vesicular-arbuscular mycorrhizal fungi (INVAM) isolates and voucher specimen were used as taxonomic references. Some spores were identified to species but this proved difficult, to numbered morphospecies. Voucher specimens are being held at the NMK, Nairobi.

Data analysis

Data on percentage of AMF colonization were transformed by arcsine and spore densities were transformed by log(x+1) to fulfill the assumption of normality and homogeneity of variances before analysis of variance. Species richness was calculated as a number of species recorded in each sample and Shannon (H) diversity index was calculated for each field sample/trap pot. Transformed data were subjected to one-way analysis of variance (ANOVA) to test the differences in AM colonization, spore density, species richness and diversity within and between different land use types. Mean separation was done by Fisher’s least significant difference (LSD) at the 0.05 level of probability. The relationship between AMF parameters and soil chemical properties (pH, C, P, N, and exchangeable cations) was determined by Pearson’s correlation analysis. The analysis was carried out using SPSS Version 15. Further, effects of different land use systems on AMF spore community composition were assessed by multivariate redundancy analysis (RDA) in CANOCO (Version 4.5).

RESULTS

Soil chemical characteristics across land use systems

Some of the soil chemical properties (pH, available P, total N and C) differed significantly across different land use systems in MME (Table 2). Human related disturbance in natural grassland and woodland outside the protected core of MME had no effect on levels of soil P, N, C and available P in the drier region of MME (p<0.05 in all cases; Table 2). However, human disturbances declined levels of soil C and increased soil pH only in grassland in the wet region (p<0.05 in both cases; Table 2). On the other hand, agricultural systems especially intensively managed systems (maize and wheat monocropping) declined soil pH compared to natural grassland and woodland (p<0.05 in all cases; Table 2), but subsistence agriculture (small-scale maize-bean intercropping) had no effect on soil pH in both wet and dry region of MME. Levels of N and C were high in small-scale maize-bean intercropping systems and wheat monocropping than in natural grassland and woodland in the dry region of MME. In the wet region, level N were significantly higher in both large- and small-scale mixed cropping systems than in natural grassland while levels of C was significantly high in agricultural systems than in natural woodland (p<0.05 in all cases). Available P was significantly higher in wheat and maize monocropping than natural grassland in the drier region. In the wet region, available P was significantly lower in maize monocropping and large-scale mixed cropping systems than in natural grassland (p<0.05 in all cases). Intensively managed agriculture (maize and wheat monocropping systems) had lower soil pH, N and C and higher levels of available P than maize-bean intercropping systems in the drier region of MME (p<0.05 in all cases). However, in wetter region of MME, intensively managed agricultural systems had lower levels of soil pH and available P than small-scale mixed cropping but no significant differences.
were noted on levels of N and C (p<0.05 in all cases).

**AMF species**

From both the field and trap cultures, 15 AMF species were recorded belonging to four AMF genera namely; *Glomus, Gigaspora, Scutellospora* and *Acaulospora*. The AMF species across land use systems included *Acaulospora denticulata, Acaulospora scrobilata, Acaulospora* species 1 to 3, *Glomus* species 1 to 4, *Scutellospora persica, Scutellospora pellucida, Scutellospora* species 1 to 3 and *Gigaspora* sp.1 (Table 3). Thirteen (13) species were recovered in the field collected soils while 11 species were recovered in sorghum trap cultures. *A. scrobilata* and *Acaulospora* sp.2 were not found in field collected soils while *Acaulospora* sp.3, *Glomus* sp. 2 and 3 and *Scutellospora* sp.3 were not recovered in trap cultures (Figure 2).

**AMF composition**

The AMF communities in the field soil was dominated by *Glomus* and *Scutellospora* species while in the trap pots AMF community was dominated by *Acaulospora* species and *Scutellospora* species. The composition of AMF community in the field soil was not affected by different land use systems in both dry and wet side of MME (p>0.05 in all cases). However, the composition of AMF community in the trap cultures was significantly affected by human disturbances in the grassland outside the protected core in the dry region (RDA, F = 10.74, p = 0.01, explained 36% of total variation in data set), and by both large- and small-scale maize-bean intercrop systems in the wet region (RDA, F = 8.10 and 4.58, p = 0.02, explained 30 and 14% of total variation in data set, respectively). The abundance of *Glomus* sp.1 was high in grassland outside protected core in the drier region as well as in large- and small-scale maize-bean intercropping systems in the wetter region (p<0.05 in both cases; Figure 3). Similarly, abundance of *A. denticulata* was significantly high in both large- and small-scale maize-bean intercropping systems in the wetter region (p<0.05 in both cases; Figure 2).

**Spore density, species richness and diversity**

AMF spore densities, species richness and species diversity in MME were generally high in the trap cultures (71.45±14.71 spore per 100 g) than in the field collected soils.
In the natural ecosystems, land uses comprised of woodland and grassland inside and outside protected core. In agricultural land, land uses comprised of maize and wheat monocropping (abbreviated as maize and wheat) and subsistence cropping system with maize—bean intercropping (abbreviated as M/B-S small-scale system with or without inputs and M/B-L for large-scale systems with both inorganic and organic inputs). +/− indicates presence/absence of a species.

soils (13.59±6.19 spores per 100 g; p<0.05). The total AMF densities and species richness were significantly affected by season (p≤0.001 in both cases), but species diversity (Shannon H index) was unaffected (p=0.08). The AMF species richness was significantly high during the dry season (3.10±0.56 species) than wet season (2.60±0.28 species) while AMF spore densities were high during wet season (15.07±9.40 spores in 100 g) than in the dry season (12.10±3.00 spores in 100 g). Human related disturbances caused by overgrazing and deforestation in the natural grasslands outside protected core of MME increased AMF density and species diversity, but decreased species richness in the drier side of MME (p<0.05 in all cases; Figure 4). In the wet region, the human related disturbances in natural grasslands increased species richness and diversity (p<0.05 in both cases), but had no effect on spore density (p>0.05; Figure 4). In the natural woodland, human related disturbances decreased species richness and diversity, but had no effect on spore density in the dry region of MME. In the wetter region of MME, human disturbances in woodland decreased AMF spore density (p=0.02), but had no effect on species richness and diversity (p>0.05 in both cases; Figure 4). On the other hand, agricultural systems in MME declined in spore density, species richness and diversity compared to natural woodland and grassland in the dry region of MME (Figure 5). However, in the wetter region of MME, agricultural systems increased in spore density, species richness and diversity (Figure 6). In the drier side of MME, maize and wheat monocropping significantly declined spore density, species richness and diversity (p<0.05 in both cases), but maize—bean intercropping systems had no effect on spore density, species richness and diversity (p>0.05 in both cases; Figure 5). Both large- and small-scale maize—bean intercrops recorded high spore density, species richness and diversity than grassland, but only small-scale maize monocropping recorded significantly high spore density, species richness and diversity than woodland (p<0.05 in all cases; Figure 6). Maize monocropping had no effect on spore density, species richness and diversity when compared to natural grassland and woodland (p<0.05 in all cases). Maize—bean intercropping systems in both drier and wetter side of MME recorded

<table>
<thead>
<tr>
<th>Location</th>
<th>Plot</th>
<th>Land use</th>
<th>A. denticulata</th>
<th>A. scrobiculata</th>
<th>Acaulospora sp.1</th>
<th>Acaulospora sp.2</th>
<th>Acaulospora sp.3</th>
<th>Glomus sp.1</th>
<th>Glomus sp.2</th>
<th>Glomus sp.3</th>
<th>Glomus sp.4</th>
<th>S. persica</th>
<th>S. pellucida</th>
<th>Scutellospora sp.1</th>
<th>Scutellospora sp.2</th>
<th>Scutellospora sp.3</th>
<th>Gigaspora sp.1</th>
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AMF inoculums potential

Mycorrhiza inoculums potential (MIP) was significantly increased by different land use systems in both dry and wet side of MME (Table 2). Human disturbances in natural woodland and grassland had no effect on MIP in the dry region of MME (p>0.05 in all cases; Table 2). However, in the wetter region of MME, human disturbances in the woodland increased MIP (p<0.001 in both cases), but MIP was unaffected by human disturbances in the grassland (p>0.05; Table 2). Maize-bean cropping system recorded significantly higher MIP than natural grassland and woodland in dry and wet region of MME (p<0.05 in all cases; Table 2). In dry region, wheat monocropping recorded significantly higher MIP than natural grassland and woodland (p<0.05 in both cases), but MIP in maize monocropping though slightly higher was not significantly different (p>0.05 in all cases) in the dry region of MME. Among the different cropping systems, AMF inoculums potential was significantly high in maize-bean intercropping systems than maize or wheat monocropping systems in both dry and wet region of MME (p<0.05 in all cases).

Relationship between soil properties and AMF variables

The AMF species richness and species diversity (Shannon H index) were significantly negatively correlated with total N (species richness; r = -0.33; diversity; r = -0.48), soil C (diversity; r = -0.36) and available P levels (Species richness: r = -0.36) in the field collected soil. In the trap cultures, the AMF spore density, species richness and species diversity species diversity were positively correlated with soil pH (Species richness: r = 0.43; species diversity; r = 0.41), N (density; r = 0.34) and soil carbon (density; r = 0.33).

DISCUSSION

In this study, 15 AMF species all belonging to four genera (Glomus, Scutellospora, Gigaspora and Acaulospora) were observed across different land use system in MME. The number is within the range of what has been observed in some of agro-ecosystems in Kenya (Mathimaran et al., 2007; Jefwa et al., 2009). Interestingly, some of the AMF species found in the field collected soil could not be found in the trap culture. S. sudanense (Piper) was chosen as a trap culture in this study due to earlier reports that it can associate with most genera of AMF (Morton, 1993). However, in this study, Sorghum was not able to propagate some slow-growing and non-sporulating AMF species in MME, suggesting that AMF species in this region could be host specific. Studies with several successive trap cultures using some dominant trees and grass species within the study region may be desirable to propagate slow and also non-sporulating fungi.

Scutellospora and Acaulospora species (5 species each) dominated in all the land use systems in MME, followed by Glomus species (4 species), while Gigaspora species (1 species) had the least representation. This result is in accordance with Mathimaran et al. (2007), who reported dominance of Acaulospora and Scutellospora species in Western Kenya. Genus Acaulospora has been shown to sporulates more in acid environments.
Figure 3. Abundances of spores of two AMF species in the trap cultures as affected by land use systems in the dry and wet region of MME. The land uses comprised of woodland and grassland inside and outside protected core. In agricultural land (agric.), the land uses comprised of maize and wheat monocropping (abbreviated as maize and wheat) and subsistence cropping system with maize-bean intercropping (abbreviated as M/B-S small-scale system with or without inputs and M/B-L for large-scale systems with both inorganic and organic inputs). Bars followed by the same letter are not significantly different at $p<0.05$. Error bars represent the standard error of the differences (SED).

Figure 4. Effect of human related disturbances in natural grassland and woodland on AMF spore densities (number of individuals per 100 g of soil), species richness and species diversity (Shannon H index) in the dry and wet region of MME. The land uses comprised of woodland and grassland inside (In) and outside protected core. Bars followed by the same letter are not significantly different at $p<0.05$. Error bars represent the standard error of the differences (SED).

Figure 5. Effect of farming systems on AMF spore densities (number of individuals per 100 g of soil), species richness and species diversity (Shannon H index) in the drier region of MME. The land uses comprised of woodland (wood) and grassland (grass) inside protected core, maize and wheat monocropping (abbreviated as maize and wheat) and subsistence cropping system with maize-bean intercropping (abbreviated as M-B-S small-scale system with or without inputs. Bars followed by the same letter are not significantly different at $p<0.05$. Error bars represent the standard error of the differences (SED).
soils (Gai and Liu, 2003) and a narrow range of soil pH (acidic to neutral; 5.51 to 6.77) in this region could have stimulated dominance of genus *Acaulospora*. Genus *Scutellospora* on the other hand, sporulates more in undisturbed and moderately disturbed soils (Jansa et al., 2002). The level of soil disturbances in this region was minimal especially in natural ecosystems and in mixed cropping systems, hence, favoring sporulation of *Scutellospora* species. Only 1 species belonging to *Gigaspora* was reported in our study site. Various studies have reported low density of *Gigaspora* species (Schalamuk et al., 2006; Jefwa et al., 2009) suggesting low level occurrence of this species in many ecosystems compared to other species. However, more studies especially on the AMF diversity in the root systems of the plants may be desirable to ascertain the occurrences of these species since spore extraction alone may miss species which may have not sporulated, and species that may not have associated with the trap cultures used in this study.

This study has also reported seasonal effects in AMF spore densities and species richness. Low spore densities were observed during dry season than in wet season, but high species numbers were observed during dry season than in wet season. Seasonal patterns have been reported with low spores densities and diversity being observed during the growing season and high densities recorded towards the end of growing season (An and Hendrix, 1993; Douds and Millner, 1999). Low AMF densities observed during dry season were caused by effects of climate change which resulted to unexpected rains towards end of growing season (dry season). The rains may have caused germination of some of these species due to prompted plant growth. On the other hand, wet season (coinciding with growing period) was accompanied with unexpected dry spells which may have caused sporulation of AMF due to stress up of plants which resulted in wilting of the vegetation and lowering the carbon allocation to AMF (Dodd et al., 1990). Low species richness during wet season indicates that not all AMF species detected during the dry season sampling had sporulated.

The wet side of MME (Trans-Mara region) supported high spore densities in the trap cultures, but in the field collected soil the drier side (Maasai Mara region) supported high species richness, diversity and spore densities. The two region of MME differs largely in climatic conditions as well as plants species composition and diversity (Ngoru et al., 2010). The dry side of MME is characterized by irregular and scarce rainfall as well as long, dry and hot dry spells while the wet region of MME is characterized by regular rainfall patterns and relatively cooler dry seasons. Under such dry conditions, the drier region would be expected to have low soil organic matter content and low nutrients and water availability, which would consequently result to decline soil productivity, low levels of microbially populations, and limited plant growth due to water deficit which cannot sustain the vegetation cover of natural soils (Alguacil et al., 2009). In fact, we have shown in our soil data (Table 2) lower levels of carbon and nitrogen in the drier region than in the wetter region. The long-term result of all these effects is changes in AMF species composition as well as decline in AMF species richness. Additionally, the wet region of MME supported high plant species richness and diversity than in dry region (Ngoru et al., 2010). Positive correlations have been reported between plant species richness and mycorrhizal community (Johnson et al., 1991; Sieverding, 1990), indicating high mycorrhizal species richness in areas with high plant diversity. In this study, we however, provided little evidences of these scenarios in the trap culture but not in field collected soil. AMF communities in field collected soil could not have provided a good scenario for comparisons since it was
raining during the two sampling periods and most of the species could have germinated.

Human related disturbances caused by overgrazing and deforestation outside protected core of MME in this study altered AMF species composition in grassland and negatively affected AMF species richness in woodland and grassland in the dry region of MME. However, an increase in Shannon H index and spore density was observed in disturbed grassland in the dry region. In the region, human disturbances positively improved AMF diversity (Shannon H index and species richness) in grassland and woodland as well as inoculums potential in woodland. Shift of AMF species composition and decline of AMF diversity following disturbance in this study is in accordance to several other studies (Eom et al., 2001) and deforestation (Waltert et al., 2002; Allen et al., 2003). These changes are attributed to continual removal of nutrient within the ecosystem which decreases photosynthetic source for mycorrhizal fungi and associated microbes (Gehring and Whitham, 1994; Eom et al., 2001; Gange et al., 2002). In addition, grazing and deforestation may alter plant community structure and in return cause a shift AMF species composition (O’Connor et al., 2002). Changes in soil chemical properties found in this study (low C in disturbed grassland) could have also caused shift in AMF composition.

Unlike in dry region, positive effects of human disturbances on AMF diversity were observed in wet region. This suggests improved mycorrhizal symbiosis in disturbed environments especially when environmental conditions are favorable. Environmental conditions such as moisture and nutrient have been shown to play a significant role in determining mycorrhizal responses to human disturbances (Gehring and Whitham, 1995, 2002; Dandan and Zhiwei, 2007). Defoliation was shown to decline AMF colonization when water and nutrient were deficient but had no effect to colonization when water and nutrient was unlimited (Gehring and Whitham, 1995). Since defoliated plant may be in high demand for nutrient, host plant may respond to this demand by increasing AMF symbiosis (Kula et al., 2005), thus, increasing the AMF diversity.

Our result indicate human disturbance in natural grassland and woodland under favorable climatic condition may not negatively affect AMF community. However, under adverse climatic conditions (high temperature, low relative humidity and frequent occurrence of droughts) human disturbance may negatively impact on AMF community either through limited natural regeneration potential of plant species or sterilization of soil by high temperatures. Our results are in agreement with earlier finding that environmental factors in semi-arid areas influences AMF community structure more (Dandan and Zhiwei, 2007), demonstrating the need for proper management of unprotected natural grassland and woodland, and need for alternative measure to reduce the level of human disturbances in semi-arid region of MME.

Our data in agricultural farms indicate a marked decrease in AMF species numbers and diversity upon intensification of agricultural management in dry region of MME. However, in wet region, agriculture practices increased AMF species number and diversity with significant increases found in subsistence farming systems. Among the different cropping systems, the subsistence farming systems had significantly higher species number and diversity index than sites with intensive agriculture with high input, and continuous maize and wheat monocropping in the two region of MME. Our findings are consistent with previous reports in which the AMF community was found to be impoverished in species composition upon agricultural intensification (An et al., 1993; Munyanziza et al., 1997; Mader et al., 2000; Oehl et al., 2003; Mathimaran et al., 2007). This may be due to degrading soil chemical qualities in the intensified cropping systems evidenced by high soil acidity, low levels of carbon and high levels of available P (Table 1).

Correlation analyses between soil chemical properties and some diversity aspects of AMF have shown positive relationship between soil pH and AMF diversity, and negative relationship between levels of available P and AMF diversity parameter suggesting that declining soil acidity resulted in declining AMF diversity. Similarly, several studies have reported negative effects of P on AMF spore density, diversity and species numbers following increases of available soil P levels (Kahiluoto et al., 2001; Allison and Goldberg, 2002). This implies increased soil acidity, which may translate to low nutrient use efficiency and subsequent low crop productivity in the long-term (Muchane et al., 2010). High AMF diversity in subsistence cropping systems in both drier and wet region of MME supports previous studies showing high AMF diversity in multiple cropping systems (Hart and Klironomos, 2002). The result of this study implies that mixed cropping is a more sustainable land use system in enhancing both biological soil qualities (evidenced by high AMF density) than highly fertilized monocropping systems in drier side of MME.

Unlike in the drier region, agriculture maintained AMF species numbers, diversity and density in the wet region, although, subsistence farming systems (mixed cropping systems) altered the AMF species composition. We attribute this result to high diversity of weed, which may have mimicked the structure and function of natural systems. In addition, agriculture in this area was less than 10 years old after the conversion from natural woodland suggesting minimal impacts of agriculture, which may not have had negative impacts on the AMF community. However, changes in species composition in subsistence cropping systems in this region suggest impact of agriculture on AMF species composition, increasing some while reducing the other. These changes are associated with different amounts and qualities of SOC inputs to the soil (either root exudates or
litter), as well as soil temperatures and moisture dynamics in the differently cropped soil (Mathimaran et al., 2007). Our result demonstrates that under certain conditions (agriculture with high plant diversity) agriculture may not have negative impact on AMF diversity, but may cause shifts in AMF species composition. This implies functional changes of AMF community, since different AMF species have been shown to exhibit different functional traits (Bever, 2002). Future researches that focus on function of dominant AMF species in different agro-ecosystems may be desirable for proper management of AMF symbiosis.

Conclusion

The results of the current work showed that AMF are a common component in the Savannah ecosystems. The AMF community is however, adversely affected by human disturbances especially in regions with semi-arid climatic conditions, necessitating alternative measures to reduce the levels of human disturbance. Afforestation programmes in disturbed areas to replace some dominant plant species in the region may be desirable. In addition, our result shows that modern agricultural practices with high levels of fertilizer and monocultures have adverse effects on the diversity of AMF in Savannah ecosystems while subsistence farming with mixed cropping (cereals and legumes) was more resilient in maintaining AMF diversity. With expected increases in agriculture intensification to address the demand of increasing human population, management of AMF may require use of both intensive and extensive agro-systems alongside each other to provide both basic food requirements and supply an increasing market for sustainably-produced crops in this region. Promotion of organic farming and diversification of crops may enhance soil biological and chemical properties and in return improve crop production. Incorporation of drought resistance crops such as cassava and pigeon pea in cropping systems and agro-forestry tree species may be necessary to ensure continued productivity. Additionally, development of biotechnological tools, which entail selection of efficient native AMF ecotypes and their incorporation into bio-fertilizers, may facilitate restoration of AMF community in this region.

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