Abundance and diversity of AM fungi across a gradient of land use intensity and their seasonal variations in Western Ghats, Karnataka

R. Lakshmipathy, A.N. Balakrishna and Bagyaraj, D.J.
Department of Agricultural Microbiology,
University of Agricultural Sciences, GKVK, Bangalore-560 065

Abstract

The impact of land use intensity on the abundance and diversity of arbuscular mycorrhifungi (AMF) was investigated at six land use types *viz*., natural forest, grassland, acacia plantations, cardamom plantations, coffee plantations and paddy fields in the Western Ghats near Koothy village of Somavarpet taluk of Coorg district, Karnataka. Though, mycorrhizal activity as assessed by root colonization was not significant in roots collected from different land use types during pre-monsoon but was significantly higher in natural forests and grasslands as compared to all other land use types during post-monsoon season. The AMF spore density and infective propagules were significantly higher in grasslands and acacia plantations compared to all other land use types during both the seasons. Excepting for paddy fields, the spore density and infective propagules were higher in post-monsoon season compared to pre-monsoon season in other land use types. 56 and 67 species of AM fungi were identified during pre- and post-monsoon seasons respectively suggesting seasonal variations in diversity. During both the seasons *Glomus fasciculatum* was recorded in maximum number of sampling points across the land scape followed by *G. geosporum* during pre-monsoon while it was *G. mosseae* during post-monsoon season. The species diversity was higher in natural forests and grasslands as compared to other land use types in both the seasons. The species richness index for AM fungi was higher in natural forests and least in paddy fields during both the seasons. The sand, bulk density, total N, organic C, alkaline and acid phosphatases positively correlated with AMF activity while clay, silt, K, total P and available P were negatively correlated.

Introduction

The main components of the soil micobiota in most agro-ecosystems are the arbuscular mycorrhizal fungi (AMF). AMF exist in two different phases, inside the root and in the soil. The intraradical mycelium consists of hyphae and other fungal structures, such as arbuscules and vesicles; the extraradical mycelium forms spores, explores soil and new areas for colonization and absorbs nutrients (Tommerup and Sivasithamparam, 1990).

These fungi come under the phylum Glomeromycota formerly Glomales within the Zygomycota (Schussler *et al*. 2001). The order Glomales is divided into 2 sub-orders Glomineae and Gigasporineae. The sub-order Glomineae has four families namely Glomaceae,

Acaulosporaceae, Paraglomaceae and Archeosporaceae (Pirozynski and Dalphe, 1989). Further, Glomaceae has a genus *Glomus*, Acaulosporacaeae is having two genera *viz*. *Acaulospora* and *Entrophospora*, Archaeosporaceae is having a genus *Archaeospora* and Paraglomaceae is having a genus *Paraglomus*. The suborder Gigasporineae is having only one family Gigasporaceae. Gigasporaceae includes the genera *Gigaspora* and *Scutellospora.*

Taxonomic groupings of Glomalean fungi are mainly based on stable and discrete morphological characters of fungal mycelium and spores (Morton and Benny, 1990). Further, variations in morphological characters are known to be a reflection of either developmental constraints within the organism or selective constraints imposed by the external environment (Morton, 1990).

Since these fungi are obligate symbionts, their population and diversity are determined by the plant species present in the given ecosystem. Apart from plant species, human activities also affect these fungi and play an important role in carbon allocation, nutrient cycling and maintenance of diversified ecosystem (Doss and Bagyaraj, 2001). The presence of these fungi and their genetic and functional diversities are important for both plant community and ecosystem productivity. Improved plant growth due to inoculation of plants with AM fungi has been demonstrated especially under P deficient condition. The growth improvement is mainly because of enhanced P uptake. AM fungi can also enhance tolerance or resistance to root pathogens and abiotic stresses such as drought and metal toxicity (Bagyaraj and Varma, 1995).

There is no clear indication that only certain AM fungi exist in the tropical regions of the Indian Sub-continent. Information on the distribution and frequency of occurrence of specific AM fungi in the Western Ghat area is very scarce. A few studies made so far have recorded the occurrence of *Glomus* species in the root zone soils of different tree species (Muthukumar and Manian, 1993; Vasanthakrishna *et al.,* 1994). Similarly, Lakshmipathy *et al.* (2004) recorded *Glomus etunicatum* in the root zone soil of cashew. The mycorrhizal activity in terms of root colonization was examined in 59 different forest tree species and the intensity of colonization was found to be high in four species, moderate in 23 species and low in 32 species (Byra Reddy *et al.,* 1994). Santhaguru *et al*. (1995) observed mycorrhizal root colonization in twenty species of tree legumes in the Eastern Ghats and found altogether 21 species of AMF belonging to six genera *viz. Acaulospora, Entrophospora, Gigaspora, Glomus, Sclerocystis* and *Scutellospora.* Therefore, it appears that occurrence of AM fungi in different forest tree species defines ecological niches to that particular tree species, thus determining plant community composition.

In tropical soils, application of organic matter stimulated the proliferation of AM fungi This was attributed to the low organic matter content in tropical soils (Harinikumar and Bagyaraj, 1989). The addition of organic amendments such as paddy straw, maize straw and pongamia leaf increased the mycorrhizal activity. Of the three amendments used, addition of pongamia leaf encouraged AM fungi to the maximum, followed by maize straw (Harinikumar and Bagyaraj, 1988). High P availability is reported to have negatively correlated with AM fungal activity (Krishna and Bagyaraj, 1982). Balakrishna *et al*. (2001) reported that application of inorganic fertilizers affected native AM fungal spore density, infective propagules and per cent root colonization in a finger millet- maize-fallow crop rotation system. Further, studies conducted on the effect of mono and mixed cropping systems on AMF population in soil has revealed that mixed cropping of soybean and maize stimulated the proliferation of AM fungi compared to mono-cropping of maize or soybean (Harinikumar *et al.*, 1990).

The seasonal fluctuation also seems to have a considerable impact on the AM fungal development in the soil. Harinikumar and Bagyaraj (1988) and Mallesh and Bagyaraj (1991) showed that AM fungi sporulate during winter in the tropics. The optimum temperature for sporulation by mycorrhizal fungi appears to be around 25^0 C.

The AMF abundance and diversity occurring over a broad land use types and in different seasons under tropical conditions has, to our knowledge, not yet been investigated. Thus, the study was undertaken in Western Ghats of Karnataka.

Materials and methods

Study area: The benchmark area, Koothy village of Somwarpet taluk is located in the Kodagu district of Karnataka. A wide range of land use types with a diversified species composition is found in the region. This benchmark area is situated very close to the Nilgiri Biosphere Reserve at the northern region and lies between $12^040^1\ 03^{11}$ N–$12^0\ 42^1\ 19^{11}$ N and $75^0\ 47^1\ 10^{11}$ E–$75^0\ 79^1\ 14^{11}$ E. The annul rainfall of the area ranges from 2000 mm to 3500 mm. Most of the rainfall is drawn from southwest monsoon during June-August period. Four seasons could be clearly distinguished; summer from March to May, monsoon from June to September, post-monsoon during October and November, and clear bright weather (winter) during December to February. The temperature begins to increase from March to April, with a mean daily maximum of 28.6^{o}C and mean daily minimum of 17.8^{o}C and reaching as high as 32 to 35^o C during April or May. The daily lowest temperature of around 9^{o}C is recorded during January. Coffee and cardamom

plantations cover major part of the study area. The natural forests at the periphery of the plantations, which are evergreen with varying levels of degradation. A few patches of *Acacia auriculiformis* plantations (monoculture) and grassy blanks are found adjacent to the forests. Rain-fed agriculture is practiced in the valleys with one paddy crop every year during the rainy season. Additionally, crops like chilly and short duration grain legumes are also grown in the summer season utilizing the residual moisture and sparse rainfall of northeast monsoon

Land use pattern: The satellite data (IRS -1D- LISS III data of the year 2000, path 98 and row 64) was interpreted to prepare land use/land cover map of the study area at 1:50,000 scales. Using hybrid classification approach a mask was created for almost non-overlapping classes (*viz*, agriculture areas and vegetated areas) obtained from unsupervised classification. The vegetated areas were further classified into forests, grasslands, coffee/cardamom plantations and forest tree plantations by supervised classification. The outputs obtained from unsupervised and supervised methods were merged to get the hybrid output. The classified output was draped over the Digital Elevation Model (DEM) (Plate 1), misclassified patches identified and necessary corrections were incorporated. A 200 m grid was overlaid on the map and 60 intersection points were sampled for aboveground/belowground biodiversity studies. The sampling points identified on the map were reached in the field using hand held *Garmin 12* Geographical Positioning System. The 60 sampling points were distributed in two windows of the size 6.4 sq km (4 x 1.6 km) and 0.8 sq km (0.4 x 2 km) so as to cover all the above said land cover types. Fifty-three sampling points were distributed in the first large window and seven points in the second small window. The stratified sampling technique was adapted and two windows were selected, as the first large window that was selected did not have enough natural forests, grasslands and *Acacia* plantations. Therefore, an additional window in the study area was selected to cover the required number of land use types.

The sampling points were laid in the intersection point of the windows and were located in the ground using hand held *Garmin 12* GPS. The intersection points at which sampling could not be done due to some natural obstructions (presence of a tree, stone/water body etc.) were kipped and the next sampling was done in the next intersection point. Six land use – land cover types could be distinguished in the study area. A brief description of these land use types is presented in tables 1 and 2.

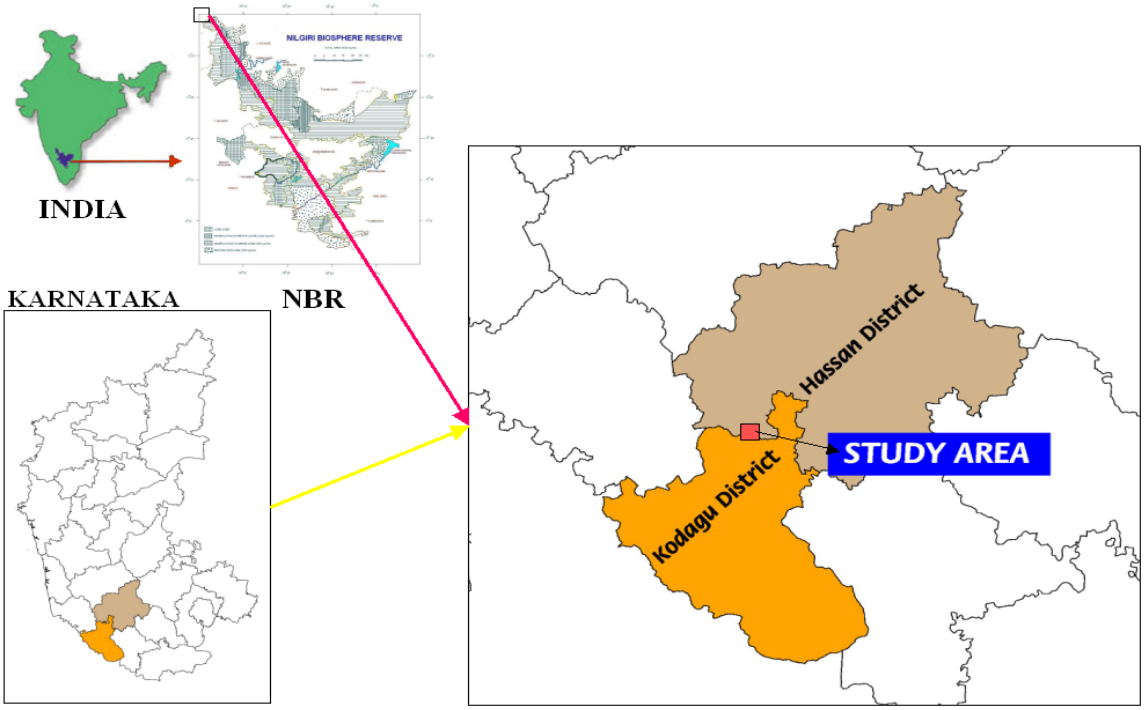

Figure 1: Location map of the study area – koothy, Somwarpet taluk, Kodagu, Karnataka.

The soil samples were collected in pre-monsoon season (February) and post-monsoon season (October) for analysis of soil physical, chemical, biochemical and microbiological properties.

Table 1. Chemical soil parameters of the different land use types differing in land use intensity

Land use types	pH		Organic C ($g\ kg^{-1}$)	Total N (mg/kg)	Total K (mg/kg)	Total P (mg/kg)	Avail.-P (mg/kg)
	H_2O	KCl					
Natural forests	6.20	5.24	15.5	46.90	232.0	1.9	0.63
Grasslands	5.57	4.37	11.8	40.88	175.5	2.47	0.80
Acacia plantations	5.51	4.43	13.8	42.35	240.0	1.74	1.04
Cardamom plantation	6.16	5.20	10.4	95.80	261.0	3.58	1.38
Coffee plantations	6.16	5.03	11.5	47.90	283.5	3.46	1.23
Paddy fields	5.30	4.21	7.7	37.24	189.0	3.86	1.48

Table2. Dominant vegetation types and management practices of the different land use types in the study area

Land use type	Major vegetation	Fertilization (Kg ha^{-1})	Plant protection	Cultivation intensity
Natural forest	These forests are little disturbed and adjacent to coffee and cardamom plantations. There are as many as 153 species of plants. Dominated by *Caryota urens*, *Olea dioica, Canthium dicoccum, Artocarpus heterophyllus* and *Dimoacarpus longan* trees, shrubs like *Leea indica, Dichapetalum gelonioides, Flacourtia indica, Nilgirianthus heyneanus* etc. and herbs like *Brachiaria milliformis, Justisia trinervia, Blumea barabata, Alysicarpus vagnailis, Archidendron monodelphum, Derris indica, Derris scandens, Pongamia pinnata* were the dominant on the forest floor.	None	None	None
Grasslands	These are the open patches found in slightly elevated regions of the Ghats and adjoining agricultural fields. Dominated by grasses like *Panicum repens, Sporobolus diander* and herbs like *Stachytarpheta indica, , Borreria articularis, Oldenalnadia corymbosa, Derris seandens, Desmodium triquetrum, Mimosa pudica, Zornia gibbosa* etc.	None	None	None
Acacia plantations	These are the monoculture plantations of *Acacia auriculiformis* of 15-25 years old raised in the open and disturbed areas. The ground flora is mainly dominated by species like *Stachytarpheta indica, Brachiaria milliformis, Centella asiatica* and shrubs like *Lantana camara, Maesa indica, Randia dumatorum.*.	None	None	None
Coffee plantations	About 106 species of plants belonging to trees, shrubs and herbs were recorded in addition to coffee plantations. The most dominant tree species are *Grevillea robusta, Caryota urens, Artocarpus heterophyllus, Acrocarpus fraxinifolius and Derris scanden, Mucuna prurienss*. Most of the plantations have naturally occurring species maintained as shade trees and in a few plantations *Grevilia robusta* is planted as shade trees. The *Brachiaria molliformis* grass is the most dominant ground flora.	Mineral and farmyard manure As per the University recommendation	Chemical	Very low
Cardamom plantations	One hundred and thirty four species of plants belonging to trees, shrubs and herbs were recorded. The plant species like *Olea dioica, Litsea flrobunda*, *Caryota urens*, C*innamomum zeylanicum, Acacia concinna*, *Acrocarpus fraxinifolius, Albizia lebbeck, Albizia odoratissima, Dalbergia latifolia, Derris scandens and Mucuna pruriens were* the most dominant flora with *Brachiaria molliformis* grass as the dominant ground flora.	Mineral and farmyard manure as per the University recommendation	Chemical	Very low
Paddy fields	The agricultural crop grown in that region is mainly rain fed rice. The ground flora varies with the season and as many as 47 species of herbs are recorded. The dominant herbaceous weeds present in the area are *Panicum repens*, *Grangea maderaspatana, Centella asiatica, Blumea barbata*,	Mineral and farmyard manure	Chemical	Very low

Soil sampling:

A triangle of 50 x 50 x 50 m was laid at each sampling point. From the center of the triangle at a distance of three and six meters two concentric circles were drawn as shown in the figure. At equidistance from each other three soil cores were collected on the circumference of each of the circle as shown in the figure (Fig.1) avoiding the litter above the ground. The six soil samples thus collected were mixed together and a composite soil sample was drawn using quaternary technique. The soil sample thus collected was divided in to two parts. One part was air dried and used for chemical analysis and the other part was stored at 5^{o} C in a refrigerator. The soil samples were collected at nine sampling points from natural forests, eight from grass lands, six from acacia plantation, thirteen from cardamom plantation, sixteen from coffee plantations and eight from paddy fields.

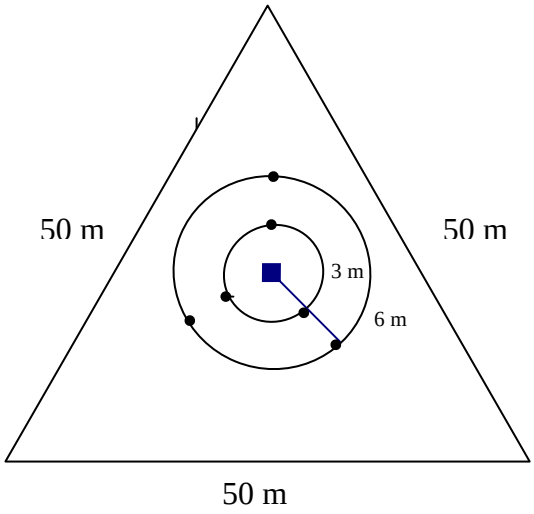

Fig. 1. Soil sampling procedure for studying soil properties and AM fungi

Soil physical, chemical and biological properties: The clay, silt and sand were quantified by mechanical analysis as outlined in the 'TSBF Hand Book of Methods' by Anderson and Ingram, 1989. The organic carbon was determined by the modified Walkley-Black method as per the procedure outlined by Anderson and Ingram (1989). The total nitrogen in the soil samples was analyzed by semi microkjeldhal method as per the procedure outlined by Jackson (1973) using Gerhardt auto analyzer. The total phosphorus content of the soil samples was determined by vanado-molybdo phosphoric yellow colour method in nitric acid system as per the procedure given by Jackson, 1973. The soil samples used in this study were acidic and hence Bray's extracting solution containing 0.03 N NH_4F in 0.025 N HCl was used as per the

procedure outlined by Jackson, 1973. The available potassium was determined by following ammonium acetate method as described by Merwin and Peach (1951). The Bulk density was determined as per the procedure outlined by Anderson and Ingram (1989). The acid and alkaline phosphatase activities were estimated as per the procedure given by Eivazi and Tabatabai (1977).

Assessment of mycorrhizal activity: The assessment of mycorrhizal activity was measured through mycorrhizal root colonization, spore density and infective propagule numbers. The mycorrhzal spore density in the root zone soil was determined by wet sieving and decantation procedure as outlined by Gerdemann and Nicolson, 1963. The Staining of root segments was carried out as per the procedure proposed by Philips and Hayman (1970). The determination of mycorrhizal root colonization was determined following the gridline intersect method proposed by Giovannetti and Mosse (1980) and the most probable number method for estimating the infective propagules was determined the method outlined by Porter (1979).

Identification of the diversity of AM fungi using trap plants: Although, spores extracted direct from soil can de used for identification, better identification of AMF is after "host baiting technique" or "trap pot culturing", because not all AMF species sporulate at the time of sampling or the spore number can be very low in soil. Further, spores from baits are in a better state (*e.g.* more percentage viable) to be analyzed.

The composite samples obtained from the sampling points were brought to the laboratory. The test soil sample was mixed with sterile sand soil (1:1) mix [50 % test soil sample + 50 % sterile sand soil mix] and planted with suitable trap crops like a mixture of sorghum and cowpea. After 3-4 months, the potting mix was wet sieved and the spores were observed under a compound microscope. Morphologically similar spores were picked up and the population of each spore type was enumerated. The spores of each type were brought into pot culture by funnel technique after surface sterilization of the spores (Nicolson, 1967) with an aqueous solution containing 200-ppm streptomycin sulphate and 2% chloramine T. The spores were mounted on a glass slide in lacto- glycerol. They were later identified with the help of "Manual for identification of VA mycorrhizal fungi" by Schenck and Perez (1990) and the INVAM website by Joe Morton. http://invam.caf.wvu.edu

Statistical analysis: The data collected from the field experiments were subjected to statistical analysis following the statistical package Excel and SYSTAT version 10.2. Arcsin transformations were done as per the procedure given by Snedecor and Cochran (1968) wherever

necessary. The treatment means were separated by the Dunkan's Multiple Range Test and by Probability matrix.

The Shanon-Weaver diversity index, Jakknife's species richness index, Sorenson similarity index for AMF between different land use types was calculated as out lined by Krebs (1989).

Results

Population of arbuscular mycorrizal fungi (AMF) in different land use types

Mycorrhizal root colonization: Significant differences in root colonization across a gradient of land use types only in the post-monsoon season. The colonization was significantly high in roots collected from natural forests (72.10%) and grass lands (68.22%) compared to acacia plantations (64.25%), coffee plantations (56.58%), cardamom plantations (49.09%) and was least in paddy fields (33.32%). There were no seasonal variations in mycorrhizal root colonization across the land scape. But, root colonization was significantly higher in post-monsoon season compared to pre-monsoon in natural forests, grasslands and acacia plantations while it was more during pre-monsoon season in coffee plantations, cardamom plantations and paddy fields (Table-3).

Table 3. AM fungal root colonization pattern in different land use types during pre-monsoon and post monsoon seasons

Land use types	AMF colonization (%)		CD at 0.05%
	Pre-monsoon	Post-monsoon	
Natural forests	59.27	72.10[a]	6.37 (183.99)
Grass lands	63.65	68.22[ab]	7.31 (214.04)
Acacia plantations	57.38	64.25[b]	5.82 (101.81)
Cardamom plantations	64.41	49.09[d]	5.82 (101.81)
Coffee plantations	65.82	56.58[cd]	4.90 (192.71)
Paddy fields	47.22	33.32[e]	9.99 (392.28)
F test at 0.05%	NS	*	-
Seasons mean	59.72	57.26	4.50

Note: Values in parenthesis represents Error Mean Sum * Significant

Mean values followed by the same superscript in each column do not differ significantly at P=0.05 level by DMRT

Spore density and infective propagules: The spore density in soils collected from acacia plantations (767.0 spores 50^{-1}g soil) was significantly higher as compared to all other land use types except for grasslands (641.0 spores 50^{-1}g soil) which was on par with each other in pre-monsoon season. The least spore density was recorded in the paddy fields (184.0 spores 50^{-1}g soil). In post-monsoon season, the spore density in soils collected from grasslands (653.8 spores 50^{-1}g soil) and acacia plantations (615.8 spores 50^{-1}g soil) were significantly higher as compared to the other land use types. The paddy fields recorded the least (200.6 spores 50^{-1}g soil).

The average spore density of all the land use types at two different seasons was higher during post-monsoon season (405.0 spores 50^{-1}g soil) compared to pre-monsoon season (371.0 spores 50^{-1}g soil). In soils collected from natural forests, cardamom and coffee plantations the spore density was significantly higher during post-monsoon season (373.8 spores 50^{-1}g soil, 315.6 spores 50^{-1}g soil and 275.3 spores 50^{-1}g soil respectively) as compared to pre-monsoon season (201.0 spores 50^{-1}g soil, 258.0 spores 50^{-1}g soil and 176.0 spores 50^{-1}g soil respectively) (Table-).

Table 4. AM fungal spore density in different land use types during pre- and post-monsoon seasons

Land use types	Spore density (No. g^{-1} soil)		CD at 0.05%
	Pre-monsoon	Post-monsoon	
Natural forests	201.00^{cd}	373.77^{c}	116 (60721.44)
Grass lands	641.00^{ab}	653.75^{a}	135 (73351.96)
Acacia plantations	767.00^{a}	615.83^{ab}	180.22 (97442.02)
Cardamom plantations	176.00^{cdef}	275.30^{d}	60.54 (23825.63)
Coffee plantations	258.00^{d}	315.63^{d}	63.59 (32357.23)
Paddy fields	184.00^{cde}	200.62^{e}	41.85 (7006.53)
F test at 0.05%	*	*	-
Seasons mean	371.00	405.00	131.44 (51830.59)

Note: Values in parenthesis represents Error Mean Sum ***:** Significant
Mean values followed by the same superscript in each column do not differ significantly at P=0.05 level by DMRT

The infective propagules in soils collected from acacia plantations (775.0 I.P. g^{-1} soil) and grasslands (690.0 I.P. g^{-1} soil) were on par with each other and significantly higher as compared to the other land use types in the pre-monsoon season. The paddy fields recorded the least (215.0 I.P. g^{-1} soil). A similar trend was also observed in the post-monsoon season.

The mean infective propagules in soils collected from all the land use types were more during post-monsoon season (527.92 IP g^{-1} soil) compared to pre-monsoon season (403.66 IP g^{-1} soil). Further, AMF infective propagules were statistically higher in natural forests (558.80 IP g^{-1} soil) and cardamom plantations (407.07 IP g^{-1} soil) during post-monsoon season compared to pre-monsoon season, while such significant differences were not observed in other land use types between seasons (Table-4).

Table 5. AM fungal infective propagules in different land use types during during pre- and post-monsoon seasons

Land use types	Infective propagules (No. g^{-1} soil)		CD at 0.05%
	Pre-monsoon	Post-monsoon	
Natural forests	305.00^{c}	558.8^{c}	128.40 (74192.44)
Grass lands	690.00^{ab}	838.75^{a}	176.60 (124763.41)
Acacia plantations	775.00^{a}	736.66^{ab}	142.46 (60888.33)
Cardamom plantations	177.00^{cd}	407.07^{d}	95.77 (59623.02)
Coffee plantations	260.00^{cd}	442.50^{d}	68.76 (37823.95)
Paddy fields	215.00^{cd}	183.75^{e}	59.93 (14370.96)
F test at 0.05%	*	*	
Seasons mean	403.66	527.92	130.05 (50745.28)

Note: Values in parenthesis represents Error Mean Sum
* Significant
Mean values followed by the same superscript in each column do not differ significantly at P=0.05 level by DMRT

Effect of soil properties on AM fungi: The influence of soil physical, chemical and bio-chemical properties on different mycorrhizal components was studied. Among the soil physical properties, sand and bulk density had a positive influence on root colonization, spore density and

infective propogules, while the clay was negatively correlated to root colonization, spore density and infective propagules. The chemical properties of the soils such as organic-C had a significant positive influence on the formation of AMF in soil while the total P and available P had a negative influence on AMF formation. The bio-chemical properties of soil like the acid and alkaline phosphatase activities were positively correlated with mycorrhizal activity.

Table 6. Correlation matrix between soil properties and components of AM fungi in different land uses types

Soil properties	Root colonization (%)	Spore load 50g $^{-1}$soil	Infective propagules (I.P. g^{-1} soil)
Clay	-0.039	-0.067	-0.086
Silt	-0.203	-0.237	-0.142
Sand	0.122	0.151	0.091
Bulk density	0.068	0.302*	0.446*
Alkaline phosphatase	0.647**	0.456*	0.400*
Acid phosphatase	0.836**	0.486*	0.465*
Org. carbon	0.796**	0.379*	0.465*
Nitrogen	0.115	0.058	0.103
Potassium	0.065	-0.073	-0.079
Total phosphorus	-0.279*	-0.308*	-0.232
Available phosphorus	-0.441*	-0.366*	-0.224

* Significant ** Highly significant

Species abundance and diversity of AM fungi in different land use types: AMF spores were isolated from field soil using “host baiting technique” The test soil sample was mixed with sterile sand soil (1:1) mix [50 % test soil sample + 50 % sterile sand soil mix] and planted with suitable trap crops like a mixture of sorghum and cowpea. After three months based on morphological characters they were identified up to species level. Altogether, a total of 67 species of AM fungi were isolated from all the six different land use types across the sampling site, out of which 56 and 67 species were recorded in pre- and post-monsoon seasons respectively. Most of the species belonged to the genus *Glomus* and 12 belonged to *Acaulospora,* three species each to *Gigaspora* and *Scutellospora* and one to *Entrophosphora.* Some of them appeared to be generalists, since most of them were found virtually in all land use types. These included *G. mosseae, A. lacunose,*

G. fasciculatum, A. bireticulata and *G. geosporum.* They were found either in the pre- or post monsoon seasons in all the land use types. Some species like *G. geosporum, G. citricolum, G. heterosporum, G. halonatum* were common to natural forests, grasslands, acacia plantations and coffee plantations and were found to be present in both the seasons while some of them were either found in pre-monsoon or in post monsoon seasons. Much of the species diversity was found in natural forests especially in the post monsoon season. This clearly suggests that seasonal variations also influence species composition. Majority of the species that were found in natural forests were not found in most of the land use types except that only a few of them were found in acacia plantations. Further, seven species that were not recorded in the pre-monsoon were found in the post monsoon season. One particular species namely, G. *fulvum* was associated with only cardamom plantations in both the seasons while it was found in natural forests only in the pre-monsoon season. It was absent in all the other land use types. The species *A. trappei* was recorded only in the grasslands. Some others like *G. australe, G. intraradices, A. mellea, G. hoi, A. spinosa, G. magnicaulis, A. morrowe,* were recorded both in the pre- and post monsoons. The species, *G. phansihalos, Gi. albida, G. pachycaulis, G. scintillans* were recorded in the pre-monsoon while others like *G. reticulatum, G. caledonium, A. delicata, E. schenckeii, G. diaphanum G. pustulatumin* were recorded in post-monsoon season and almost confined to grasslands. A few species like *G. diaphanum, G. segmentatus, S. persica, G. gerdemannii, G. macrocarpum, G. radiatum* and *G. lacteum* were confined only to acacia plantations. Only a few species *viz., G. radiatum, G. lacteum, A.dilatata, G. invermaium* and *G. constrictum* were confined to cardamom plantations. But, quite a few species like *G. constrictum, G. clavispora, G. tenebrosum, G. deserticola, S. heterogama, Gi. margarita* and *G. tortuosum* were recorded in coffee plantations in addition to those species recorded in cardamom plantations. Very few species *viz., G. tortuous, Gi. rosea* and *G. clarum* were confined only to paddy fields. However, the others found in paddy fields, were also associated with one or the other land use types.

The abundance of spores of different AMF species in different land use types in different seasons indicates that seasonal variations also influence species diversity (Table- 4). Those species that were common to all the land use types *viz., G. mosseae, A. lacunose, G. fasciculatum, A. bireticulata* and G. *geosporum* recorded very high number of spores in the post-monsoon season as compared to pre-monsoon season.

Table 7. Disrribution of AMF species in different land use types in pre- and post-monsoon seasons

Sl. No	AMF species	Natural forest		Grasslands		Acacia plantations		Cardamom plantations		Coffee plantations		Paddy fields	
		PRM	POM	PRM	POM	PRM	POM	PRM	POM	PRM	POM	PRM	POM
1	*Glomus mosseae*	15	526	69	366	44	620	84	319	527	854	38	215
2	*Acaulospora lacunosa*	36	132	306	491	138	203		55	178	198	91	27
3	*G. fasciculatum*	219	776	401	1013	696	897	278	881	573	795	50	
4	*A. bireticulata*	65	180	502	749	383	293		72	166	384	24	
5	G. geosporum	82	297	230	407	67	102	251	612	379	612	114	
6	*G. citricolum*	78	403	9	119	90	209		52	2	128		
7	*G. heterosporum*	29	117	419	273					42	77		
8	*G. halonatum*	67	101	202	456					121	181		
9	*A. scrobiculata*	18	88					53	241	210	523		24
10	*G. aggregatum*	3	150				114			151	845	48	544
11	*G. globiferum*	8	44			34	73						
12	*G. maculosum*	92	155	149	157	154	402	197	152			78	182
13	*G. multicaulis*	26	187			96	293	128	329	21	410		
14	*A. nicolsoni*	41	133			276	67						
15	*G. manihotis*	59	141			85	81					23	75
16	*G. albidum*	101	161	342	368	272	288						
17	*G. etunicatum*	39	286	51	93		151	171	199				
18	*G. monosporum*	124	192					30	30	80	68		
19	*G. canadense*	67	71						46				
20	*G. delhiense*	25	366										
21	*G. boreale*	100	180										
22	*G. multisbstensum*	27	58										
23	*G. dimorphicum*	17	42										
24	*G. versiforme*	27	146										
25	*S. calospora*	12	105										
26	*G. verrucosa*	23	129										
27	*G. fulvum*	19						228	259				
28	*G. australe*		96	454	178								
29	*G. intraradices*		120	88	459						137		
30	*A .appendicula*		55	115								28	34
31	*A. laevis*		87		78				33		58		
32	*G. claroideum*		97									47	41
33	*G. leptotichum*		24										
34	*G. ambisporum*		80				377						
35	*A. mellea*			225	217		118	319	590				
36	*G. hoi*			121	225	77	145	334	123	14	98	7	
37	*A. spinosa*			60	124	459	311	3	43				
38	*G. magnicaulis*			116	102					213	160		
39	*A. morrowe*			188	231								
40	*A. trappei*			475	160								
41	*G. phansihalos*			99		85	137	36	81				
42	*G gaspora albida*			58		272							
43	*G. pachycaulis*			218				28	103				
44	*G. scintillans*			58									
45	*G. pustulatum*			17	109								
46	*G. reticulatum*				554								
47	*G. caledonium*				78				504				
48	*A. delicata*				44			244	39				
49	*Entrophospora schenckeii*				40								
50	G. diaphanum				56	51	96			96	50	7	66
51	*G. segmentatus*					90	98						
52	*S. persica*					138	258					21	
53	*G. gerdemannii*					45	61						
54	*G. macrocarpum*					99	380						
55	G. radiatum					138	138		41	113	386		
56	*G. lacteum*					230	128	75	234	28	42	69	194
57	*A. dilatata*							16	131	234	263		
58	*G. invermaium*							34	159	252	153		
59	G. constrictum								21	375	325		
60	*G. clavispora*									13	58		
61	*G. tenebrosum*									209			
62	*G. deserticola*									73			
63	*Scutellospora heterogama*										52		
64	*Gi .margarita*										48	144	69
65	*G. tortuosum*											41	51
66	*Gi .rosea*												39
67	*G. clarum*				97								

Distributon and species abundance across the land scape over two different seasons: The **i**frequency of distribution of AMF species in sixty sampling points across six different land use followed by *G. geosporum* (19), *G. mosseae* (11), *Acaulospora bireticulata* and *G. maculosum* in ten each, *A. dilalata* and *G. hoi* in eight each, *A. mellea, A. scrobiculata* and *G. multicaulis* in six each, *G. halonatum* and *G. macrocarpum* in five each, A. *dilatata, G. citricolum, G. constrictum, G. etunicatum, G. heterosporum, G. magnicaulis, G. manihotis, G. monosporum* and *G. pansihalos* in four each, *A. nicolsoni, A. spinosa* and *G. diaphanum* in three types in the land scape has revealed that during pre-monsoon season, of the 58 AM fungal species identified, *Glomus fasciculatum* was distributed in most of the sampling points (24), each. *Gigaspora albida, Glomous albidum, G. australe, G. borreale, G. delhiens, G. fulvum, G. globiferum, G. intraradices, G. invermaium, G. macrocarpum, G. tenebrosum* and *S. persica* in two each and the remaining species were present in only one sampling point each. During the post-monsoon season, out of 67 different AMF species identified, *Glomus fasciculatum* was present in most of the sampling points (28) followed by *G. mosseae* (19), *G. geosporum* (17), *G. aggregatum* (15), *Acaulospora scrobiculata* (13), *A. lacunosa* (10), *G. diaphanum* and *G. hoi* in nine each; *G. maculosum* and *G. multicaulis* in eight each, *A. mellea* in seven; *G. citricolum* and *G. lacteum* in six each; *G. constrictum, G. etunicatum, G. halonatum, G. intraradices* & *G. radiatum* in five each; *Acaulospora dilatata, A. nicolsoni, G. caledonium, G. heterosporum, G. manihotis, G. monosporum* and *G. ambisporum* in four each; *A. spinosa, G. magnicaulis* and *G. pansihalos* in three each. *A. appendicula, A. delicata, G. albidum, G. australe, G. borreale, G. claroidem, G. delhiense, G. fulvum, G. globiferum, G. invermaium, G. macrocarpum* and *Gigspora margarita* in two each. The remaining species were present in only one sampling point each.

Most of the AM fungi were present in most of the of sampling points during post-monsoon than during the pre-monsoon season, while a few species *viz. G. geosporum, G. maculosum, G. pansihalos, Gi. albida* and *S. persica* were present in most of sampling points during pre-monsoon than in the post-monsoon season. Certain species like, *A. spinosa, A. trappei, G. albidum, G. australe, G. boreale, G. delhiens, G. fulvum, G. globiferm, G. halonatum, G. heterosporum, G. invermaius, G. macrocarpum, G. monosporum, G. manihotis, G. multisubstensum, G. pachycaulis, G. pustulatum, G. segmetatum, G. tortuosum, G. verrucosa,*

G. versiforme, S. calospora were distributed in equal number of sampling points during both the seasons (Table).

The abundance of different AMF species over different land use types has indicated that, it was higher during post-monsoon season than in pre-monsoon season. During post-monsoon season, majority of the species produced chlamaydospores abundantly in soil compared to pre-monsoon season. A few species such as *A. delicata, A. morrowae, G. albidum, G. fulvum, G. magnicaulis* produced more chlamaydospores during pre-monsoon than in post-monsoon season. Chlamaydospores of *A. laevis*, *Entrophospora schenckii*, *G. caledonium, G. clarum, G. leptotichum, G. reticulatum, G. ambisporum, Gi. rosea, S. heterogama* were not at all noticed during pre-monsoon season while in post-monsoon season chlamaydospores of *G. deserticola* and *G. tenebrosum* were not observed (Table).

Diversity of AM fungi in different land use types: Shannon-Wiener diversity index during pre-monsoon season was higher in natural forests (4.41) compared to grasslands (4.20), acacia plantations (3.99), coffee plantations (3.80), cardamom plantations (3.57) and paddy fields (3.26). A similar trend also existed in the post-monsoon season and was significantly high in natural forests (4.59) compared to acacia plantations (4.26), cardamom plantations (4.08), coffee plantations (4.04) and paddy fields (3.01). There was a significant seasonal diversity in species composition across the landscape. It was significantly higher in post monsoon (4.07) as compared to pre-monsoon season (3.87). Even within land use types, the diversity index was significantly higher in post-monsoon as compared to pre-monsoon season excepting in paddy fields.

Jacknife's species richness index for AMF in different land use types during pre-monsoon season was higher in natural forests (43.00) followed by acacia plantations (38.67), grasslands (37.13), coffee plantations (30.44), and paddy fields (25.63) with least in cardamom plantations. In post-monsoon season AMF species richness index was more in natural forests (51.67) followed by grasslands (48.50), acacia plantations (41.83), cardamom plantations (37.08), coffee plantations (34.37) with least in paddy fields (20.87). Seasonal variation in species richness index was higher during post-monsoon as compared to pre-monsoon season in all the land use types except in paddy fields where the species richness index was higher in pre-monsoon season (25.63) than in post-monsoon season (20.87) (Table 10).

Table 8. Abundance of spores of different species of AM fungi across sampling site during pre- and post-monsoon seasons

		Spore abundance (No. 50g^{-1} soil)					
		Pre-monsoon			Post monsoon		
1	G.macculosum	670	±	65	1048	±	127
2	*A.lacunosa*	749	±	110	1106	±	167
3	*G.fasciculatum*	2217	±	238	4362	±	366
4	*A.bireticulata*	1140	±	216	1678	±	269
5	*G.geosporum*	1123	±	121	2030	±	256
6	*G.citricolum*	179	±	42	911	±	142
7	*G.heterosporum*	490	±	166	467	±	108
8	*G.halonatum*	390	±	83	738	±	179
9	*A.scrobiculata*	28	±	83	852	±	206
10	*G.globiferum*	42	±	14	117	±	32
11	*A.nicolsoni*	317	±	111	200	±	56
12	*G.albidum*	515	±	137	817	±	151
13	*G.etinicatum*	261	±	66	729	±	113
14	*G.delhiens*	25	±	10	366	±	149
15	*G.canedense*	113	±	27	71	±	31
16	*G.borreals*	100	±	41	180	±	73
17	*G.dimorphicum*	17	±	7	42	±	17
18	*G.fulvum*	247	±	92	259	±	106
19	*G.aggregatum*	202	±	61	1653	±	343
20	*G.mosseae*	777	±	251	2900	±	233
21	*G.intraradices*	88	±	32	716	±	178
22	*G.australe*	454	±	63	274	±	82
23	*G.manihotene*	167	±	36	297	±	59
24	*G.diaphanum*	154	±	40	268	±	38
25	*G.claroideum*	47	±	19	138	±	40
26	*A.appendicula*	143	±	27	89	±	24
27	*A.laevis*	ND	±	ND	256	±	38
28	*G.multicaulis*	27	±	46	1219	±	141
29	*G.monosporum*	234	±	52	290	±	75
30	*G.leptotichum*	ND	±	ND	24	±	10
31	*G.multisubstensum*	27	±	11	58	±	24
32	*G.versiforme*	27	±	11	146	±	60
33	*S.calospora*	15	±	5	105	±	43
34	*G.verrucosa*	23	±	9	129	±	53
35	*G. ambisporum*	457	±	63	ND	±	ND
36	*A. meellea*	544	±	143	854	±	231
37	*A.marrowe*	188	±	77	231	±	94
38	*A.trappei*	475	±	64	160	±	64
39	*G.magnicaulis*	329	±	90	262	±	70
40	*G.hoi*	553	±	127	591	±	87
41	*A.spinosa*	522	±	109	478	±	115
42	*G.phansihalos*	220	±	59	218	±	57
43	*Gi.albida*	715	±	109	817	±	115
44	*G.pachycaulis*	317	±	11	103	±	42
45	*G.pustulatum*	17	±	7	109	±	44
46	*G.reticulatum*	554	±	143	ND	±	ND
47	*G.scintillans*	58	±	24	ND	±	20
48	*G. caledonium*	ND	±	ND	502	±	202
49	*A.delicata*	244	±	100	83	±	28
50	*E.schenckeii*	ND	±	ND	40	±	16
51	*G.segmentatus*	90	±	37	98	±	40
52	*S.persica*	158	±	55	258	±	105
53	*G.gerdimanii*	45	±	18	61	±	25
54	*G.radiatum*	251	±	65	565	±	153
55	*G.lacteum*	179	±	86	588	±	99
56	*G.macrocarpum*	99	±	203	380	±	155
57	*A.dilatata*	250	±	94	394	±	110
58	*G.invermaians*	402	±	101	598	±	82
59	*G.constrictum*	375	±	153	346	±	131
60	*G.clavispora*	13	±	5	58	±	24
61	*G.tenebrosum*	209	±	85	ND	±	ND
62	*G.deserticola*	73	±	30	ND	±	ND
63	*S.heterogama*	ND	±	ND	52	±	21
64	*G. clarum*	ND	±	ND	97	±	40
65	*Gi.margarita*	144	±	59	117	±	31
66	*G.tortuosum*	117	±	17	51	±	88
67	*Gi.rosea*	ND	±	ND	39	±	16

Note: ND – Not Detected

Table 9. AM fungal species diversity in different land use types during pre and post-monsoon seasons

Land use types	No. of AMF species		Shanon-weaver Diversity index		CD at 0.0 5% for comparing season
	Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon	
Natural Forests	27	33	4.41[a]	4.59[a]	0.000037 (0.648)
Grasslands	24	27	4.20[ab]	4.45[ab]	0.000032 (0.435)
Acacia Plantations	22	26	3.99[b]	4.26[b]	0.000045 (0.631)
Cardamom Plantations	19	26	3.57[cd]	4.08[bc]	0.000028 (0.545)
Coffee Plantations	23	25	3.80[c]	4.04[bc]	0.000024 (0.475)
Paddy Fields	16	13	3.26[d]	3.01[d]	0.00015 (0.618)
F test at 0.05%	-	-	*	*	-
Season mean			3.87	4.07	0.000028 (0.245)

Note: Values in parenthesis represents Error Mean Sum
* Significant
Mean values followed by the same superscript in each column do not differ significantly at P=0.05 level by DMRT

Table 10. Jakknife's species richness index for AM fungi in different land use types during pre and post-monsoon seasons

Land use types	No. of sampling points		Unique species		Species richness index	
	Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon
Natural Forest	9	9	18	21	43.00	51.67
Grasslands	8	8	15	20	37.13	48.50
Acacia plantations	6	6	20	19	38.67	41.83
Cardamom plantations	13	13	8	12	24.38	37.08
Coffee plantations	16	16	9	10	30.44	34.37
Paddy fields	8	8	11	9	25.63	20.87

Discussion

Modern intensive farming practices are evidently a threat for AM fungi. Their abundance and effectiveness with respect to root colonization and plant growth promotion are declining upon agricultural intensification. However, little is known about the effect of management practices on the species diversity of these fungi. Oehl *et al*. (2003) observed a decrease in species richness of AM fungi with increased land use intensity in Central Europe. But, studies concerning land use intensity on AMF abundance and diversity are little known. The present investigation has thrown some light on the impact of land use intensity in Western Ghats, Karnataka.

Population of AM fungi in different land use types

AMF root Colonization: Though, there were no significant differences in mycorrhizal root colonization in pre-monsoon season, significant differences were observed during post-monsoon season. Significantly higher root colonization was observed in natural forests and grasslands that are more or less not subjected to too much disturbance compared to the other land use types. The P contents in soil play an important role in mycorrhizal colonization and spore production. Several studies have indicted that high P-content (>9 ppm) reduced mycorrhizal colonization and spore production (Koide, 1991; Lakshmipathy *et al.,* 2002 and 2003). The available-P in soils of theses land use types (Table-1) is lower compared to other and land uses. This could be one of the reasons for variations in mycorrhizal root colonization in different land use types in this study. Pande and Tarafdar (2004) suggested increased rainfall and relative humidity in the atmosphere increased AMF colonization. With the onset of rains in the post-monsoon season significant moisture prevailed in the soil that favoured better root growth of plant species and enhanced AMF root colonization.AMF spore density and infective propagules**:** The spore density and infective propagules were significantly more in soils of grasslands and acacia plantations compared to natural forests, cardamom and coffee plantations with least in paddy fields in both the seasons. It has been observed that the root densities in the upper five centimeters of tropical species favour better mycorrization in soils (Janos and Read, 1992). Several others have also recorded higher sporulation by AM fungi in pastures compared to forests (Picone, 2000; Fischer *et al.,* 1994). The root system in grasslands is fibrous with much of the roots spreading at the top 20-30 cm depth. This could have favoured better mycorrhization and in turn resulted in more sporulation and infective propagules. Whereas, in natural forests, cardamom and coffee plantations, even though, a high diversity of plant species is present, dicotyledonous plants without much graminacious dominate them. Therefore, much of the active roots are concentrated beyond 20-30 cm depth. This could be one of the reasons for spore densities and infective propagules being less in these land use types. A general tendency is that a combination of graminaceous and leguminous crops generally increase mycorrhizal populations. The root infection and sporulation in cassava increased by intercropping with legumes (Sieverding and Leihnar, 1984). The floor of acacia plantations in the study area is also covered with patches of graminaceous species and acacia itself being a leguminous plant, could be the cause for higher spore density and infective propagules. The mycorrhizal population is also affected by several agricultural practices like application of fertilizers, pesticides and herbicides reduced the mycorrhizal spores and infective propagules (Boddington and Dodd, 2000; Balakrishna *et al.*,

2001). These factors must have influenced for the lower number of spores and infective propagules in paddy fields, cardamom and coffee plantations in this study

Seasonal variations may also influence spore density and species diversity. Several workers have reported earlier that the spore density and infective propagules were higher in winter than in summer (Mallesh and Bagyaraj, 1991; Picone, 2000) suggesting that the mycorrhizal activity is favoured during winter season. In this study, however, by and large such variations were observed between land use types but was not significant across the landscape..

Influence of soil properties: Soil physical, chemical and biochemical properties also influenced AM fungal root colonization, spore density and infective propagules. Sand and bulk density had a positive influence, while clay and silt content had a negative influence on AM fungi. In sandy soils, plant roots proliferated better because of good aeration; there by enhanced the spore production. Similar observations have also been reported earlier (Pande and Tarafdar, 2004). Soil org.-C is known to favour higher mycorrhizal activity (Johnson and Wedin, 1997; Pande and Tarafdar, 2004). The organic-C and N content of the soils in the study area showed a positive influence on AM fungi. Therefore, it suggests that, the status of organic matter content in soils is important in mycorrhizal activity. The P contents in soil play an important role in mycorrhizal colonization and spore production. Several studies have indicted that high P-content (>9 ppm) reduced mycorrhizal colonization and spore production (Koide, 1991; Lakshmipathy *et al.,* 2002 and 2003). The total P and available P contents in soils in the study area seems to have a significant negative influence on AMF activity.

Isolation and characterization of AM fungi in different land use types: In the present investigation, 58 AMF species were identified during pre-monsoon season and in addition to this, seven species were detected in the post-monsoon season from all the six land use types studied. During pre-monsoon, soil moisture was less and atmospheric temperature was high while in the post-monsoon season it was *vice-versa*. Therefore, variation in AMF species during different seasons could be attributed to changes in moisture regimes in soil and other climatic conditions. Lovelock *et al.*, 2003 and Husband *et al.*, 2002 also recorded more number of species in rainy season as compared to summer season. There was a strong shift in mycorrhizal communities and their numbers over time. They suggested that, during wet season a large number of newly germinated seedlings prevail, hence there were more number of species present. It appears therefore, that a few species, which may appear the moment seeds of some plant species regenerate, may also vanish along with the plant species. In other words there could be some AMF species, which have a close association with some plant species. The variations

in species composition in different seasons are quite obvious in this study owing to the reasons already explained.

During both the seasons, a number of AMF species were recorded in natural forests, grasslands and acacia plantations than in the cardamom and coffee plantations and paddy fields. Oehl *et al.* (2003) while studying the impact of land use types have also reported, that the AMF species composition was highest in grasslands, lower in the low and moderate input arable lands and lowest in the lands with intensive continuous maize mono-cropping. Certain other studies have also indicated that the number of species was more in undisturbed areas than the disturbed areas. Picone (2000) reported while studying the AMF species composition in Nicaragua and Costa-Rican forests and pastures, found similar species composition in both forests and pastures, while Mendez *et al.* (2001) noticed higher AMF species composition in pasture soils than in cultivated soils. The results in the present study follow a similar pattern as the natural forests and grasslands and to some extent acacia plantations are more or less undisturbed, because these plantations are almost 10 years old and have not been subjected to disturbance from then. Whereas, in coffee plantations and paddy fields the species composition was less because of intensification of agricultural practices.

AMF species spore abundance over landscape

AMF species spore abundance was more during post-monsoon than during pre-monsoon season. Majority of the species produced more number of chlamydospores during post-monsoon than during pre-monsoon season. A few species like *A. delicata, A. morreae, G. albidum, G. fulvum* and *G. magnicaulis* produced more chlamydospores during pre-monsoon compared to post-monsoon season. Chlamydospores of *A. laevis, E. schenckii, G. caledaneum, G. clarum, G. leptotichum, G. reticulata, G. ambisporum, Gi. rosea, G. heterogama* were not at all detected in pre-monsoon season, but present only during post-monsoon season, while *G. deserticola* and *G. tenebrosum* were present only during pre-monsoon season but not in post-monsoon season. This kind of variation in AM fungal species composition over different seasons could be attributed to adoption of specific AMF species to a particular climatic condition and soil moisture regimes. Sampling of soils over seasons has revealed that some AM fungal species sporulated better during wet season while some species sporulated during dry season. Lovelock (2003) also observed that the relative abundance of spores of *Acaulospora* was lower than that of *Glomus*, during wet season and found that *Glomus* produced relatively more spores at highest seasonal rainfall. Further, he also suggested that during wet season a number of plant species

with profuse rooting favoured the sporulation of AMF species. Sanders and Fitter (1992) opined that the composition of plant community might also affect mycorrhizal fungi causing differential reproduction and survival, which will definitely act as a selective force on the composition of AM fungi.

These seasonal variations could be attributed to changes in climatic conditions, soil moisture regimes and change in plant species during two different seasons. In fact, Schenck and Kinloch (1980) also noticed incidence of AMF species over different periods of time over the years; the spores of *Gi. margarita* increased while the spores of *Gi.gregaria* and *Gi.gigantia* decreased and spores of *G. macrocarpum* and *G. fasciculatum* observed during one season disappeared in the next season.

Difficulties in predicting the levels of indigenous AMF populations in different soils arise from the large number of factors that can affect their contribution, activity and survival. These include soil fertility, soil moisture, pH, plant susceptibility, light intensity, altitude, soil organic matter, depth and soil disturbance; physical movement by water, earthworms and the soil microfauna. The wide range of AM fungi in many natural habitats suggest a degree of ecological equivalence between species (Hayman, 1978; Molina *et al.* 1978). Likewise, similar agricultural soils growing the same crop may contain different species. Furthermore, chemicals added to agricultural soils can change the species composition as well as the total size of the mycorrhizal population and the indigenous mycorrhizal populations of natural soils are often very sensitive to soil amendments.

Further, it is quite evident that AMF generic distribution pattern varies with the soil type, vegetation, season and change in land use types. In the present study, at landscape level *Glomus* and *Acaulospora* were present in all the land use types whereas the genus *Gigaspora* was present in grasslands, acacia and coffee plantations and paddy fields while *Scutellospora* was present in natural forests, acacia, cardomom and coffee plantations and paddy fields. The genus *Entrophospora* was present only in grasslands. Of the sixty sampling points *Glomus* was present in all the sampling points during both the seasons while *Acaulospora* was present in only 50-60% of the sampling points. On the other hand, *Gigaspora*, *Scutellospora* and *Entrophospora* were present in very few sampling points. Several workers have also reported the preponderance of species of *Glomus* and *Acaulospora* in Western Ghat soils under tropical conditions. (Vasanthakrishna *et al*., 1994; Muthukumar and Udaiyan, 2000; Mohan, 2003). Soil pH may play a crucial role in the distribution of these fungi. Porter *et al*. (1987) have reported that

Glomus spp. was of rare occurrence in Western Australia due to high pH. This suggests, that the wide distribution of *Glomus* and *Acaulospora* could be pH dependent and this could be one of the reasons, why these genera are predominant in the present study where the soils are acidic in nature.

Diversity of AM fungi in different land use types: Mycorrhizal fungi are likely to be affected by plant community composition (Janos, 1980; Kormanik *et al.,* 1980). Baylis (1962) observed that soil from the rooting zone of a tree, which bore abundant mycorrhiza readily, infected seedlings, although soil from beneath a species that is rarely infected did not. The arbuscular mycorrhizal populations may readily respond to the proportion of mycotrophic plants in a community because the fungi cannot live without hosts. In the present study, variation in Shannon-Wiener diversity index of AM fungal species in different land use types was noticed. The diversity index of AMF was significantly more in natural forests and grasslands than in acacia, cardamom and coffee plantations and paddy fields in both the seasons but diversity index of AMF was on par with each other in grasslands, acacia, cardamom and coffee plantations. In paddy fields, diversity index was significantly lower compared to all other land use types. The diversity index of AMF during the post-monsoon season was significantly higher as compared to the diversity index during pre-monsoon season. This kind of variation in the diversity of AMF in different land use types and during different seasons was noticed even in earlier studies. Picone (2000) reported that the AMF diversity indices for forest and pastures were similar. Even in this study, the diversity index of AMF in natural forests and grasslands was on par with each other. This suggests that, AMF diversity in undisturbed systems as that of forests and grasslands is less affected. But, the diversity index was quite different in less undisturbed grasslands and more disturbed paddy fields were considered. Oehl *et al.* (2003) in their study also recorded highest mycorrhizal diversity index in grasslands compared to moderate and low input arable lands and intensive continuous maize mono cropping. Carpenter *et al*. (2001) in their study on spore density and diversity of AM fungi in different land uses found that diversity of AM fungi changed due to change in land use types, a similar observation as that of ours who have found AMF diversity between different land use types.

It is a very well established fact, that the plant species differ in their degree to which they support AM fungi (Bagyaraj and Manjunath, 1980). There is a clear indication from this study that natural forests, grasslands and acacia plantations supported the highest number of spores and infective propagules and in turn the diversity of AM fungi. This could be attributed to the fact

that the natural forests also have a good diversity of plant species (Table 2), which in turn could contribute to the higher diversity index for AM fungi. However, it is also quite possible that due to low fertility status of the soils of natural forests in this study, there could have been an increased dependence of plants on mycorrhizae for growth and survival which lead to the development of a diverse species of AM fungi.

In the present study, it was observed that there were differences in AMF species richness between different land use types as well as between different seasons. In both the seasons, AMF species richness index was more in natural forests followed by acacia plantations, grasslands, coffee and cardamom plantations and least in paddy fields. The lower species richness index for paddy fields could be due to intensive agricultural practices. Many other studies have also shown that application of fertilizers, pesticides, tillage and other soil disturbances have shown to decrease mycorrhizal population and diversity (Kruckelman, 1975; Hayman, 1980). The species richness index was higher during post-monsoon than during pre-monsoon season. Since, sporulation of AMF is seasonal (Gemma, 1988), the sampling period determines the species richness index as it has been observed in this study. In natural forests due to plant species richness and their diversity, supported large number of mycorrhizal species. Further, low fertility status of the soils in natural forests, acacia plantations and grasslands in our studies probably required an increased dependence of plants on mycorrhizae for growth and survival, which facilitated the growth of a diverse species of AM fungi. Blaszkowski (1994) also made similar observations with species richness for different plants grown in different places of Hel peninsula of Poland wherein the average species richness was recorded in soils sampled under Cupressaceae followed by Rosaceae, Graminae.

References

Anderson, J. M. and Ingram, J. S. I. 1993. Tropical Soil Biology and Fertility: a Handbook of Methods. 2nd edition. CAB International, Wallingford.

Bagyaraj, D..J. and Manjunath, A., 1980. Selection of suitable host for mass productin of VA mycorrhizal inoculation. *Plant Soil*, 55: 495-498.

Balakrishna, A.N., Lakshmipathy, R., Sudhir, K., and Bagyaraj, D.J., 2001. Effect of long Term application of inorganic fertilizers on native VA mycorrhizal fungi and soil microbial biomass in a Finger Millet-Maize-Fallow Rotation. *J.Soil Biol.Ecol*,21:1-6.

Bayaraj, D. J. and Varma A. , 1995. Interactions between arbuscular mycorrhizal fungi and plants: their importance in sustainable agriculture in arid and semiarid tropics, *Adv Microbiol Ecol*, 14 : 119.

Baylis, G.J.S., 1962. *Rhizophagus*, the catholic symbiont, *Aust. J. Sci.*, 25: 195-209.

Bhardwaj, S., Dudeja, S.S.and Khurana, A.L., 1997. Distribution of vesicular-arbuscular mycorrhizal fungi in the natural ecosystem. *Folia-Microbiol*., 42: 6, 589-594.

Blaszkowski, J. 1994. Comparative studies on the occurrence of arbuscular fungi and mycorrhizae (Glomales) in cultivated and uncultivated soils of Poland. *Acta Mycol.*, 28: 93-140.

Boddington, C.L. and Dodd, J.C., 2000. The effect of agricultural practices on the development of indigenous arbuscular Mycorrhizal fungi, II. Studies in experimental microcosms, *Plant Soil*, 218: 145-157.

Byra Reddy, M.S, Krishna Naik,L., Bhaskar,V. and Bagyaraj,D.J., 1994. Status of Mycorrhizal association in some tropical tree species. *J. Soil Biol. Ecol*., 14:51-54.

Carpenter, F.L., Palacios, M.S., Gonzalez, Q.E. and Schroeder, M., 2001. Land use and erosion of a Costa Rican ultisol affect soil chemistry, mycorrhizal fungi and early regeneration. *For. Ecol. Manage.*, 144:1-17.

Doss, D. D. and Bagyaraj, D. J., 2001. Ecosystem dynamics of mycorrhizae. In: *Innovative Approaches in Microbiology*. (Eds.) D.K. Maheswari and R.C. Dubey, Bishen Singh Mahendra Pal Singh Pub:, Dehra Dun, India. pp.115-129

Eivazi, F. and Tabatabai, M.A., 1977. Phosphatases in soils. *Soil. Biol. Biochem*., **9:** 167-172.

Fischer, C.R., Janos, D.P., Perry, D.A. Linderman, R.G. and Sollins, P., 1994. Mycorrhiza inoculum potentials in tropical secondary sucession. *Biotropica*, 26: 369-377.

Gemma, J.N., Koske, R.E., 1988. Seasonal variation in spore abundance and dormancy of *Gigaspora gigantea* and in mycorrhizal inoculum potential of a dune soil. *Mycologia*, 80:211-216.

Gerdemann, J.W. and Nicolson, T.H., 1963. Spores of mycorrhizal Endogone species extracted from the soil by wet sieving and decanting. *Trans. Br. Mycol. Soc*., 46 : 235-244.

Giovannetti, M. and Mosse, B., 1980. An evaluation of techniques to measure vesicular arbuscular infection in roots. *New Phytol*., 84 : 489-500.

Harinikumar, K.M. and Bagyaraj, D.J. 1988. The effect of season on VA mycorrhiza of leucaena and mango in semi-arid tropic. *Arid Soil Res. Rehabil.*, 7: 139-143.

Harinikumar, K.M. and Bagyaraj, D.J. and Mallesha B.C., 1990. Effect of intercropping and organic soil amendments on native VA mycorrhiza in semi-arid tropics. *Arid Soil Res. Rehabil*., 4: 193-197.

Harinikumar, K.M. and Bagyaraj, D.J., 1989. Effect of cropping sequences, fertilizers and farm yard manure on VA mycorrhizal fungi. *Biol. Fert. Soils*, 7: 173-175.

Hayman, D.S., 1978. Mycorrhizal population of sown pastures and native vegetation in Otago. NewZealand. *N.Z. J. Agric. Res.*, 21: 271-276.

Hayman, D.S., 1980. VA mycorrhiza and crop production. *Nature*, 287:487-488.

Husband, R., Herre, E.A., Turner, S.L. Gallery, R. and Young, J.P.W., 2002. Molecular Diversity of arbuscular mycorrhizal fungi and pattern of host association over time and space in a tropical forest. *Molecular Ecol.*, 11: 2669-2678.

Jackson, M.L., 1973. *Soil chemical Analysis.* Prentice Hall Pvt. Ltd., New Delhi, India.

Janos, D.P. and Read, D.J., 1992. Heterogenity and scale in tropical vesicular-arbuscular mycorrhiza formation. In: *Mycorrhiza in Ecosystems* (Eds.) A.H. Fitter and I.J. Alexander, I.J., CAB international US, London, pp. 276-282.

Janos, D.P., 1980. Mycorrhizae influence tropical sucession. *Biotropica*, 12: 56-64.

Johnson, N.C. Wedin, D.A., 1997. Soil carbon, nutrients, and mycorrhizae during conversion of dry tropical forest to grassland. *Ecol. Applications*. 7 : 171-182.

Koide, R.T., 1991, Nutrient supply, nutrient demand and plant response to mycorrhizal infection. *New Phytol*., 117: 365-386.

Kormanik, P.P., Bryan, W.C. and Schultz, R.C., 1980. increasing endomycorrhizal fungus inoculum in forest nursery soil with cover crops. South. *J.Appl. For*., 4: 151-153.

Krebs, C.J., 1989, *Ecological Methodology.* Harper Collins Publishers.

Krishna, K.R. and Bagyaraj, D.J., 1982. Effect of vesicular-arbuscular mycorrhiza and soluble phosphate on *Abelmoscus esculentus* (L.) Moench.*Plant Soil*. 64: 209-213.

Kruckelman, H.W. 1975. Effects of fertilizers, soils, soil tillage and plant species on the frequency of *Endogone* chlamadospores and mycorrhizal infection in arable soils. In: *Endomycorrhizas*. (Ed.) F.E.Sanders, B.Mosse, and P.B.Tinker. Academic press, London. pp.511-525.

Lakshmipathy, R., Sumana, D.A., Balakrishna, A.N., Bagyaraj, D.J. and Kumar, D.P., 2004. Evaluation, grafting success and field establishment of cashew rootstock as influenced by VAM fungi. *I.J. Expt. Biol*., 42:1132-1135

Lakshmipathy.R., Balakrishna Gowda, and Bagyaraj,D.J., 2003. VA Mycorhizal colonization pattern in RET medicinal plants(*Mammea suriga, Saraca asoca, Garcinia spp., and Embelia ribes and Calamus sp*.) in different parts of Karnataka. *Asian J. Microbiol. Biotech. Env. Sci*., 5:505-508.

Lakshmipathy.R., Balakrishna Gowda, Chandrika,K., and Bagyaraj,D.J., 2002. VA mycorrhizal colonization pattern in *Hemidesmus indicus* and *Dioscorea bulbifera* in different parts of Karnataka. *Giobios*, 29:209-212.

Lovelock, C.E., Andersen, K. and Morton, J.B., 2003. Arbuscular mycorrhizal communities in tropical forests are affected by host tree species and environment. *Oceologia*, 132: 268-279.

Mallesha, B.C. and Bagyaraj, D.J., 1991. Season favouring sporulation of VA mycorrhizal fungi in cardamom plantations. *Soil Boil. Ecol*. 11: 75-78.

Mendez, A.B., Scervine, J.M. and Fodeas, AM., 2001. Arbuscular mycorrhizal population associated with natural and cultivated vegetation on a site of Buenos Aires Province, Argentina. *Biol. Fertil. Soils*, **33:** 373-381.

Mervin and Peech, 1951. Soil Science Society of America. Proc., 15:125.

Mohan, C., 2003. Mycorrhizae in forest plantations: association, diversity and exploitation in planting stock improvement. KFRI Research Report- 252. Peechi.

Molina, R.J., Trappe, J.M. and Strickler, G.S., 1978. Mycorrhizal fungi associated with *Festuca* in the western United States and Canada. *Can. J. Bot.*, 56: 1691-1695.

Morton, J.B. and Benny, G.L., 1990. Revised classification of arbuscular mycorrhizal fungi (Zygomycetes) : A new order, Glomales, two new families, *Acaulosporaceae* and *Gigasporaceae* with an emendation of *Glomaceae*. *Mycotaxon*, 37 : 471-491.

Morton, J.B.,1990. Species and clones of arbuscular mycorrhizal fungi (Glomales Zygomycetes): their role in macro and micro – evolutionary process. *Mycotaxon*, **37:** 493 – 515.

Muthukumar, T. and Udayan, K., 2000. Arbuscular mycorrhizas of plants growing in the Western Ghats region, Southern India. *Mycorrhiza*, 9: 297-313.

Muthukumar, T.K.V. and Manian, S., 1993. Vesicular arbuscular mycorrhizal fungi in western Ghats. *Ind. Bot*., 10:79-83.

Oehl, F., Sieverding, E., Ineichen, L., Mader, P., Boller, T. and Wienmken, A., 2003. Impact of land use intensity on the species diversity of arbuscular myocrrhial fungi in agroecosystems of central Europe. *Appl. Env. Microbiol*., 69: 2816-2824.

Pande, M. and Tarafdar, J.C., 2004. Arbuscular mycorrhizal fungal diversity in neem based Agroforestry systems in Rajasthan. *App. Soil Ecol.*, 26:233-241.

Phillips, J.M. and Hayman, D.S., 1970. Improved procedures for clearing and staining parasites and vesicular arbuscular mycorrhizal fungi for rapid assessment of infection. *Trans. Br. Mycol. Soc*., 55 : 158-161.

Picone, C.M., 2000. Diversity and abundance of arbuscular mycorrhizal fungus spores in tropical forest and pasture, *Biotropica*, 32: 734-750.

Pirozynski, K.A. and Y. Dalphe., 1989. Geological history of the Glomaceae with particular reference to mycorrhizal symbiosis. *Symbiosis* 7:1 – 36.

Porter, W.M. 1979. The most probable number method for enumerating infective propagules of vesicular arbuscular mycorrhizal fungi in soil. *Aus. J. Soil Res*., 17:515-519.

Porter, W.M., Robson, A.D. and Abbott, L.K., 1987. Field survey of the distribuation of vesicular-arbuscular mycorrhizal fungi in relation to soil. pH. *J. App. Ecol.* 24: 659-662.

Sanders, I.R. and Fitter, A.H., 1992. Evidence for differential responses between host-fungus combinations of vesicular-arbuscular mycorrhizas from a grassland. *Mycol. Res*., 96: 415-419.

Santhaguru, K., Ponmalar, S.B.G.and Karunakaran, R. 1995. Vesicular-arbuscular mycorrhizae in tree-legumes and its rhizospheric soils in Alagar hills. *Ind.For*., 121: 9, 817-823.

Schenck, N. C., and Kinloch, R.A., 1980. Incidence of mycorrhizal fungi on six field crops in monoculture on a newly cleared woodland site. *Mycologia,* 72 : 229-443.

Schenk, N.C., Perez, Y., 1990. *Manual for Identification of VA Mycorrhizal Fungi.* 3rd Edition, Synergistic Publications., Gainesville, Florida, USA.

Schussler, A., Schwarzott, D. and Walker, C., 2001. A new fungal phylum, the Glomeromycota; Phylogeny and evolution. *Mycol. Res.* 105: 1413-1421.

Sieverding, E., and Leihner, D., 1984. Effect of herbicides on population dynamics of VA mycorrhiza with cassava. *Angew Botanic*, 58: 283-294.

Snedecor, S.W. and Cochram, W.G., 1968. Statistical Methods, Oxford and IBH Publication, New Delhi.

Tommerup, I.C. and Sivasithamparam, K., 1990. Zygospores and asexual spores of *Gigaspora decipiens*, an arbuscular mycorrhizal fungus. *Mycol. Res*., 94:897-900.

Vasanthakrishna, M., Muthanna, M.B.and Bagyaraj, D.J. 1994. Succession of vesicular arbuscular mycorrhizal fungi associated with *Casuarina equisetifolia L. Annals-of-Forestry*, 2: 2, 123-126.