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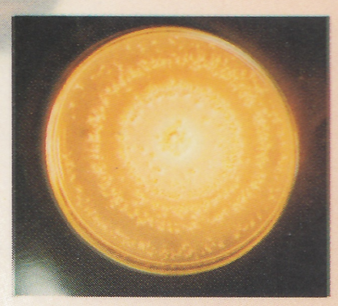
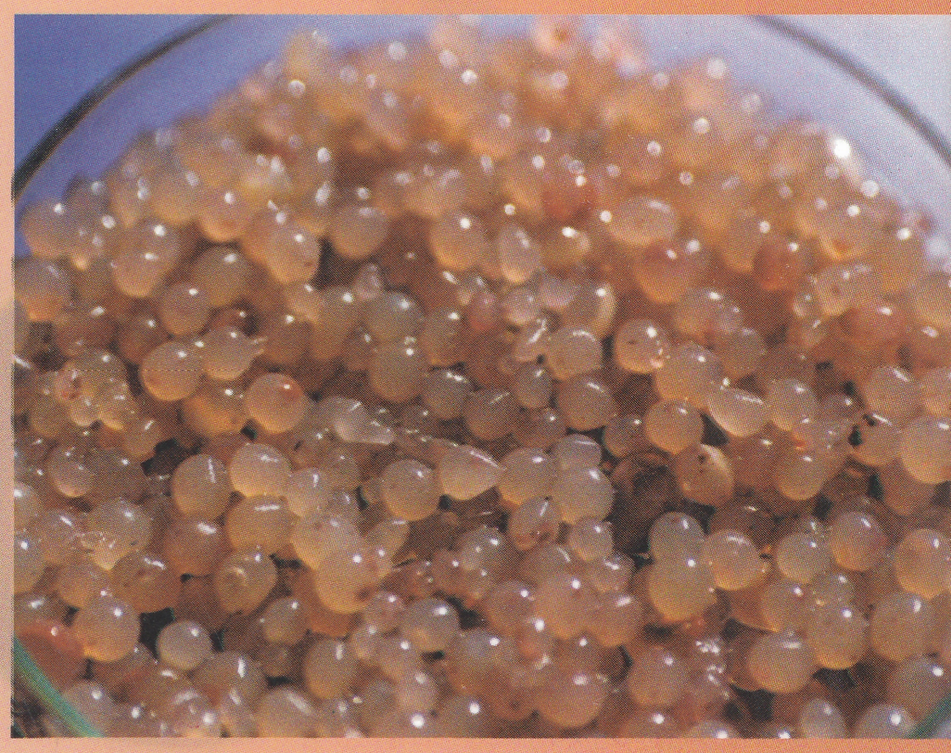
Mycorrhizae in Forest Plantations: Association, Diversity and Exploitation in Planting Stock Improvement

C. Mohanan
Division of Pathology





Kerala Forest Research Institute
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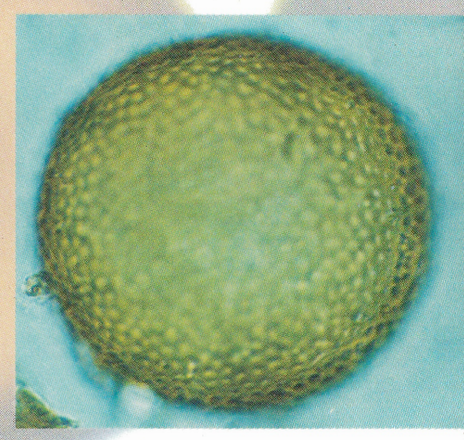
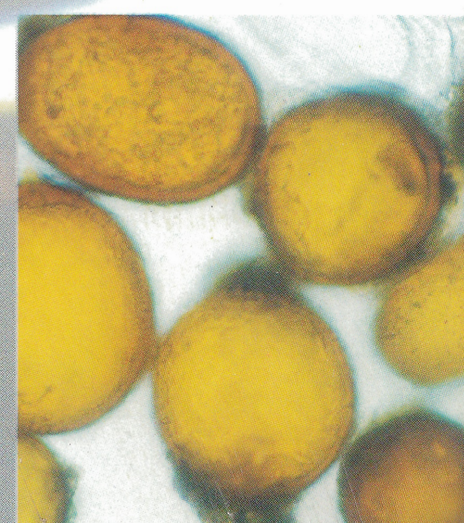
July 2003





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MYCORRHIZAE IN FOREST PLANTATIONS: ASSOCIATION, DIVERSITY AND EXPLOITATION IN PLANTING STOCK IMPROVEMENT

(Final Report of the Research Project KFRI 310/ 98)

C. MOHANAN

Division of Pathology

Kerala Forest Research Institute
Peechi- 680 653, Kerala, India

July 2003

ABSTRACT OF THE PROJECT PROPOSAL

1. Project No. : KFRI 310/ 98
2. Project Title : Mycorrhiza in forest plantations : Association, diversity and exploitation in planting stock improvement
3. Objectives :
   i. To study the mycorrhizal association in forest plantation species viz., *Tectona grandis, Eucalyptus* spp., *Acacia* spp., *Gmelina arborea, Dalbergia latifolia, Ailanthus triphysa, Bombax ceiba, Santalum album, Albizia falcataria, Pterocarpus* sp., *Swietenia macrophylla* and *Terminalia* sp.
   ii. To study the mycorrhizal fungal diversity in forest plantations in the State.
   iii. To select potential candidate mycorrhizal fungus for each forest plantation species for improving the planting stock.
4. Date of commencement :September 1998
5. Scheduled date of completion : August 2001 (extended up to December 2002)
6. Project Team:
   Principal Investigator : Dr. C. Mohanan (Division of Pathology)
   Research Fellow : Smt. K.K. Sheeba (December 1998 to August 2001)
7. Funding Agency : Kerala Forest Department (Development)

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ABSTRACT

A survey on mycorrhizal association in forestry species viz., *Tectona grandis, Eucalyptus camaldulensis, E. deglupta, E. globulus, E. grandis, E. pellita, E. regnans, E. tereticornis, E. tessellaris, E. urophylla, Dalbergia latifolia, Santalum album, Gmelina arborea, Acacia auriculiformis, A. aulacocarpa, A. crassicarpa, A. mangium, A. mearnsii, Paraserianthes falcataria, Bombax ceiba, Swietenia macrophylla, Ailanthus triphysa, Pterocarpus santalinus,* and *Terminalia paniculata* raised in plantations/plots and natural stands in different parts of the State was made and their mycorrhizal status and mycorrhizal dependency were studied. Biodiversity of mycorrhizal fungi in rhizosphere soils from representative sample plots of these 23-plantation tree species was also studied.

All the forestry species studied exhibited arbuscular mycorrhizal (AM) association. All typical arbuscular mycorrhizal features like arbuscules, vesicles, intra-cellular hyphal coils, extra and intra-radical hyphae, etc. were observed in root samples of most of the tree species studied. However, percent root infection as well as characteristics of arbuscules and vesicles varied among the host species. Teak exhibited a high level of AM fungal association in most of the 70 plantations surveyed with a mean AM fungal root infection of 32.4 per cent irrespective of differences in age, elevation and edaphic conditions. The highest infection (>86%) was recorded in teak plantations belonging to 11-20 years old; both young (<10-year-old) and old (>40-year-old) teak trees showed comparatively low AM fungal root infection. *Swietenia macrophylla* recorded the least (2.5%) symbiotic association with AM fungi, while all the other forestry species like *D. latifolia, S. album, G. arborea, P. falcataria*, etc. exhibited moderate to high AM fungal root infection. All the five *Acacia* species studied showed 88 to 96 per cent AM fungal root infection. Among the eucalypts, *E. tereticornis, E.grandis* and *E. camaldulensis* recorded comparatively high AM fungal root infection than the others.

Rhizosphere soils of all the forestry species exhibited a remarkable diversity of AM fungi and the population in each host species comprised of 11 to 85 fungal species belonging to six genera viz., *Glomus, Sclerocystis, Acaulospora, Scutellospora, Entrophospora* and *Gigaspora*. Among these, *Glomus* and *Acaulospora* were the most predominant genera encountered with large number of species as well as high spore density. *Glomus* was represented by 7 to 44 species, while *Acaulospora* represented 2 to 15 species in most rhizosphere soil samples. AM fungal root infection as well as AM fungal spatial distribution, species diversity and composition were highly influenced by host as well

available phosphorus and nitrogen. Among these, soil pH accounted for around 35 per cent of the total variability in AM fungal root infection in teak. However, exchangeable cations (Ca) was found to be the most influential variable affecting the AM root infection in eucalypts. Biodiversity indices of AM fungi in each host plantations were worked out separately; relative abundance of AM fungi was measured using Shannon-Wiener and Simpson's indices and gamma and beta diversity were also estimated for each plantation species.

Ectomycorrhizal (ECM) fungal association was recorded in eucalypts, acacias, teak, *D. latifolia* and *G. arborea*. However, it was predominant in *Eucalyptus grandis, E. tereticornis,* and *Acacia auriculiformis* as evidenced and characterized by various forms of heterorhizy as well as different ECM fungal partners. More than 37 ectomycorrhizal fungi belonging to Sclerodermatales, Lycoperdales, Aphyllophorales and Agaricales were found associated with different hosts and of these, *Pisolithus tinctorius*, *Scleroderma verrucosum, S. citrinum*, *Laccaria* spp. were the most predominant ones. Ectomycorrhizal synthesis was carried out employing eucalypt seedlings and pure cultures of *P.tinctorius*, *S. verrucosum* and *L. laccata*.

Laboratory and nursery trials were carried out to improve the planting stock of selected tree species viz., *Tectona grandis, Santalum album* and *Dalbergia latifolia* using arbuscular mycorrhizal fungi viz., *Glomus fasciculatum, G. mosseae* and *Acaulospora appendicula*. Attempts were also made to exploit the ectomycorrhizal fungi, *Pisolithus tinctorius* and *Scleroderma verrucosum* to improve the seedlings of *Eucalyptus grandis, E. tereticornis* and *Acacia mangium*.

Preliminary trials on improvement of planting stock using AM fungi viz., *Glomus fasciculatum, G. mosseae* and *Acaulospora appendicula* yielded promising results for teak, rosewood and sandal seedlings. In teak, seedling height as well as total biomass increased in AM fungal treated seedlings. *Acaulospora appendicula* treated seedlings recorded the maximum (>60%) mycorrhizal inoculation effect (MIE) followed by *Glomus fasciculatum* treated seedlings (38%). In *Santalum album*, treatment with a combination of *G. fasciculatum* and *A. appendicula* gave the maximum (>48%) MIE. In *D. latifolia* seedlings, inoculation with a mixture of *G. fasciculatum* and *A. appendicula* gave the maximum mycorrhizal inoculation effect of 39.58%.

Ectomycorrhization of *Eucalyptus grandis, E. tereticornis* and *Acacia mangium* seedlings by application of different forms of *P. tinctorius* inoculum was also found promising. The ECM fungal inoculation has significant effect on seedling height increment, number of leaf pairs and also in

seedling biomass production. Among various forms of inoculum tried, PT- spore-sand mixture was found most efficient and gave maximum mycorrhizal inoculation effect (MIE) in *E. tereticornis* (>90%), *E. grandis* (>50%) and *Acacia mangium* (>123%). The PT- spore slurry and PT- mycelial beads were also proved to be efficient inocula, which gave maximum (>65%) MIE in *E. tereticornis* and *A. mangium*. However, more in-depth studies are warranted for selecting appropriate fungal partners for forest tree species as well as mycorrhization of their planting stock.

1. INTRODUCTION

Mycorrhizae are highly evolved, symbiotic associations between soil fungi and plant roots. The partners in this association are members of the Fungus Kingdom, Basidiomycetes, Ascomycetes and Zygomycetes and most vascular plants (Harley and Smith, 1983; Kendrick, 1992; Brundrett, 1991). The term 'mycorrhiza' was first coined a century back (1885) by a German Botanist, Albert Bernard Frank, which literally means 'fungus root'. The term 'symbiotic association' is often used to describe the highly interdependent mutualistic relationships, where the host plant receives mineral nutrients, while the fungus obtains photosynthetically derived carbon compounds (Harley, 1989; Smith, 1995). Mycorrhizal fungi have ancient origin as fungal structures have been recorded in fossil studies dates back to about 300 million years (Butler, 1939). So far, at least seven different types of mycorrhizal associations have been recognized, involving different groups of fungi and host plants and with distinct morphological patterns. However, mycorrhizae are broadly grouped into ectotrophic (ectomycorrhiza) and endotrophic (endomycorrhiza).

In the ectomycorrhizal type of symbiosis, fungus grows as a thick mantle known as 'Hartig net' on the root surface. The fungus mantle shields the feeder roots from pathogens, absorb mineral nutrients and is capable of converting complex organic molecules into simple available forms. The ectomycorrhizal (ECM) fungi belong to mainly three classes of Eumycota viz., Basidiomycotina, Ascomycotina and Zygomycotina.

Endomycorrhizae are classified into three types namely – Ericoid, Orchid, and Vesicular-arbuscular mycorrhizae (VAM). Ericoid mycorrhizae are association where fungi produce hyphal coils in outer cells of the narrow 'hair roots' of plants in the plant order Ericales. In the case of Orchid mycorrhizae, fungi produce coils of hyphae within roots (or stems) of orchidaceous plants. Vesicular-arbuscular mycorrhizae (=arbuscular mycorrhizae, VAM, AM), are associations where Zygomycetes fungi (Glomalean) produce arbuscules, hyphae, vesicles, etc. within the roots. The arbuscular mycorrhizal (AM) fungal spores are formed in soil or in roots. The AM fungi (Glomalean fungi) are ubiquitous soil microorganisms and are found in roots of most angiosperms, gymnosperms, pteridophytes, and thallophytes (Mosse *et al.*, 1981). AM fungi have great potential to enhance plant growth by increasing nutrient uptake (Bagyaraj, 1992) and the association formed by these fungi act as a potential factors in determining diversity in ecosystem (Geovannetti and Gianinazzi-Pearson, 1993).

Arbuscular mycorrhizal fungi have bimodal pattern of differentiation as they survive in two distinct habitats, the interior of a root and the surrounding soil matrix. The vegetative phase of these fungi consists of intraradical appressoria, intra- and extraradical coenocytic hyphae and dichotomously branched intraradical arbuscules. The reproductive phase of the fungi consists mainly of asexual spores formed on the hyphae, inside or outside the root. Formation of sexual spores has also been reported recently only in one fungus, *Gigaspora decipiens* Hall & Abbot (Tommerup and Sivasithamparam, 1990). The AM fungi establish a compatible interaction with host cell and develop a biotrophic nutritional relationship of long duration with host plant, which normally results in increased growth of the host plant. Significant morphological and physiological differences between species exist in vegetative and reproductive structures, which have been used to differentiate taxa in AM fungi.

As far as forestry is concerned, the potential for manipulating mycorrhizal associations to increase productivity in plantation forestry is the focus of major research activities. There is also much interest in their potential utilization in agriculture and horticulture. However, our knowledge is very limited with regard to the association of mycorrhizal fungi with forest plantation species and their diversity in different forest ecosystems in the State. Knowledge of mycorrhizal associations and diversity is important because of their functional roles in natural and managed ecosystems. The benefits to plants through mycorrhizal association include: plant nutrient supply through mycorrhizal roots, antagonism against parasitic organisms, non-nutritional benefits due to water relations, nutrient cycling and conservation by soil mycelia, improving soil structure, carbon transport from plant roots to other soil organisms, etc. Some of the benefits to people include: valuable food resources (ectomycorrhizal fruit bodies), medicinal uses, aesthetic values and fungal diversity as a bio-indicator of environmental quality. Since, different fungal taxa vary in their capacity to utilize resources, withstand adverse conditions, etc. mycorrhizal fungal diversity must contribute to the resilience of forest ecosystems.

The functional diversity of mycorrhizal fungi includes variations between individual species in the following capacities: mobilizing of limiting soil nutrients viz., inorganic forms of phosphorus, nitrogen, trace elements, etc., amelioration of adverse soil conditions due to toxic concentration of metal ions, extremes in soil pH, high conductivity (salinity), nutrient imbalance such as high Mg : Ca ratios, responses to severe climatic conditions such as limited or excessive water supply, temperature extremes, etc., compatibility with different hosts, tolerance of adverse soil conditions such as disturbance, microbial competition, etc.

Productivity of forest plantations in the State is at an alarmingly diminishing phase. Even though, many factors such as sivicultural management measures, host's genetic makeup, pests and diseases, etc. are partly responsible for this, edaphic factors are the most critical ones. In general, soils under forest plantation crops, especially teak and eucalypts in the State are reported to be problematic and nitrogen (N) and phosphorus (P) are the major limiting factors. Improving the soil nutrient status and their mobility by mycorrhizal manipulation is a long-term strategy as well as self-sustainable. Sustainability of soil-plant system requires a well-balanced functional mycorrhizal association. The functional diversity of mycorrhizal fungi provides opportunities to select fungi adapted to specific combinations of host/environment/soil conditions in plantations. The selected efficient mycorrhizal fungal candidates can be employed as effective biological tool for improving the planting stock as well as increasing the stand productivity in a most environment friendly way by avoiding chemical fertilizers and pesticides inputs. However, our knowledge of the mycorrhizal status of the forest plantation species, biodiversity of mycorrhizal fungi, as well as mycorrhizal dependency of forest plantation species in the State is very meagre. The present study has been undertaken with the following objectives:

i. To study the mycorrhizal association in forest plantation species viz., *Tectona grandis*, *Eucalyptus* spp., *Gmelina arborea*, *Dalbergia latifolia*, *Ailanthus triphysa*, *Bombax ceiba*, *Santalum album*, *Paraserianthes falcataria*, *Pterocarpus* sp., *Swietenia macrophylla*, and *Terminalia* sp.

ii. To study the mycorrhizal fungal diversity in forest plantations in the State.

iii. To select potential candidate mycorrhizal fungus for each forest plantation species for improving the planting stock.

2. MATERIALS AND METHODS

2.1. Selection of sample plots and sampling method

A reconnaissance survey was made in teak (*Tectona grandis* L.), eucalypts (*Eucalyptus camaldulensis* Dehnh., *E. deglupta* Bl., *E. globulus* Labill, *E. grandis* Hills ex Maiden, *E. pellita* F. Muell., *E. regnanas* F. Muell., *E. tereticornis* Sm., *E. tessellaris* F. Muell., *E. urophylla* S.T. Blake), acacias (*Acacia auriculiformis* Cunn ex Benth., *A. aulacocarpa* Cunn. ex Benth., *A. crassicarpa* Cunn. ex Benth,, *A. mangium* Willd, *A. mearnsii* Willd.), *Paraserianthes falcataria* (L.) Fosberg., mahogany (*Swietenia macrophylla* King), *Ailanthus triphysa* (Dennst.) Alston, *Bombax ceiba* L., *Pterocarpus santalinus* Roxb., *Gmelina arborea* L., *Dalbergia latifolia* Roxb., *Terminalia paniculata* Roth and *Santalum album* L. plantations/plots/ natural stands in the State and sample plots were selected for the study (Figures 1-3; Tables 1-8). In the case of teak, plantations falling under different age groups (1-10 yr, 11-20 yr, 21- 40 yr, > 40 yr) were selected for the study. Line transect method was followed for sampling in teak and eucalypts plantations, whereas random sampling method was followed for the other forestry species. In line transect sampling, a distance of 50 m was given between each sample tree and three to five sample trees were selected and paint-marked in each plantation. In the case of other forestry species mentioned above, three to five sample trees were selected in each plantation/plot/ stands and paint-marked. Information on age of the plantation, cultural and management practices adopted including fertilizer application, fire incidence, etc. was collected from the concerned Forest Range Office/Forest Stations. The selected plantations/plots were visited during 1998-2001 and rhizosphere soil and root samples were collected from the selected host plants. Details on elevation of the area, girth at breast height (gbh) and approximate height of the sample trees, etc. were also recorded.

2.2. Collection and processing of rhizosphere soil and roots

About three kilogram of rhizosphere soil along with young feeder roots from 10 to 20 cm depth was collected from each host tree from different plantations/plots. Care was taken to ensure that fine feeder roots were well represented in samples and to exclude the entangled roots of other plant species. The soil and root samples collected were kept in polythene bags and transported to the laboratory. Young feeder roots were separated using sieve (1 mm) and processed. The moisture content (%MC) of the soil was determined by oven dry method and soil pH was measured. The soil samples were kept in polythene bags and stored at 5^0C until they were further processed.

Table 1: Details on sample plots of teak selected for the study

Sample plot No.	Locality	Forest Range	Altitude (m .a.s.l.)	Age (yr)	Mean gbh (cm)	Mean ht (m)
T1	Kaimaram	Tholpetty	810	38	97.2	15.8
T2	Camp road	Tholpetty	820	23	93.8	12.4
T3	Naikkatty	Tholpetty	800	46	111	14.8
T4	Panavally	Tholpetty	760	18	78	10.2
T5	Begur	Begur	800	8	38.2	5.5
T6	Chembuvalli	Begur	810	22	106	11.2
T7	Bavali	Begur	800	36	96.2	15.8
T8	Irumbupalam	Vazhachal	505	20	42.6	7.2
T9	Irumbupalam	Vazhachal	505	17	33.8	6.8
T10	Vazhachal	Vazhachal	290	37	107	11.8
T11	Vazhachal	Vazhachal	270	9	36.2	5.7
T12	Kariummurium	Nilambur	110	23	85.1	9.1
T13	Kariammurium kunnu	Nilambur	160	19	82.7	7
T14	Thannikkadavu	Vazhikkadavu	120	27	84.7	11.4
T15	Cherupuzha	Karulai	40	4	28.7	7.6
T16	Cherupuzha	Karulai	80	26	89.6	19.8
T17	Nedumkayam	Karulai	80	90	239	22.2
T18	Pulimunda	Karulai	90	41	110	16.2
T19	Poolakkappara	Karulai	70	50	114	18.8
T20	Poolakkappara	Karulai	80	30	102	22.6
T21	Nellikkuthu	Karulai	90	67	175	26.8
T22	Nellikkuthu	Karulai	100	13	21.8	6.8
T23	Valluvassery	Nilambur	90	9	28.7	6.3
T24-	Valluvassery	Nilambur	90	7	31.5	7.9
T25	Mailady	Nilambur	30	12	44.5	11
T26	Chaliarmukku	Nilambur	40	45	89.4	17.8
T27	Akampadam	Nilambur	50	45	102	19.8
T28	Edakkode	Edavanna	80	23	67.2	16.2
T29	Mulamkuzhy	Kalady	75	45	83.2	12.6
T30	Mulamkuzhy	Kalady	80	20	80.2	14.8
T31	Mallana	Kodanad	90	2	18.6	5.7
T32	Perumthode	Kodanad	88	37	96	17.3
T33	Perumthode	Kodanad	90	23	83.4	13.9
T34	Perumthode	Kodanad	90	2	13.8	4
T35	Karimpani	Thundathil	90	5	38.6	8.5
T36	Karimpani	Thundathil	90	19	76.8	16.3
T37	Thundamthodu	Thundathil	95	27	71.4	117
T38	Irumbupalam	Pattikkad	80	44	79.2	20.8
T39	Chakkolatharisu	Pattikkad	90	45	105	20.2
T40	Vallikkayam	Peechi	110	41	94	16.4
T41	Dhoni	Olavakkod	150	1	11.4	2.38
T42	Dhoni	Olavakkod	160	65	187	20.2
T43	Banglamkunnu	Olavakkod	150	3	30.6	6.2
T44	Dhoni-Quarters	Olavakkod	160	43	153	25
T45	Vattappara	Walayar	210	23	74.4	17
T46	Walayar	Walayar	260	41	112	19.8
T47	Kottappara	Kodanad	50	16	80.4	19.2

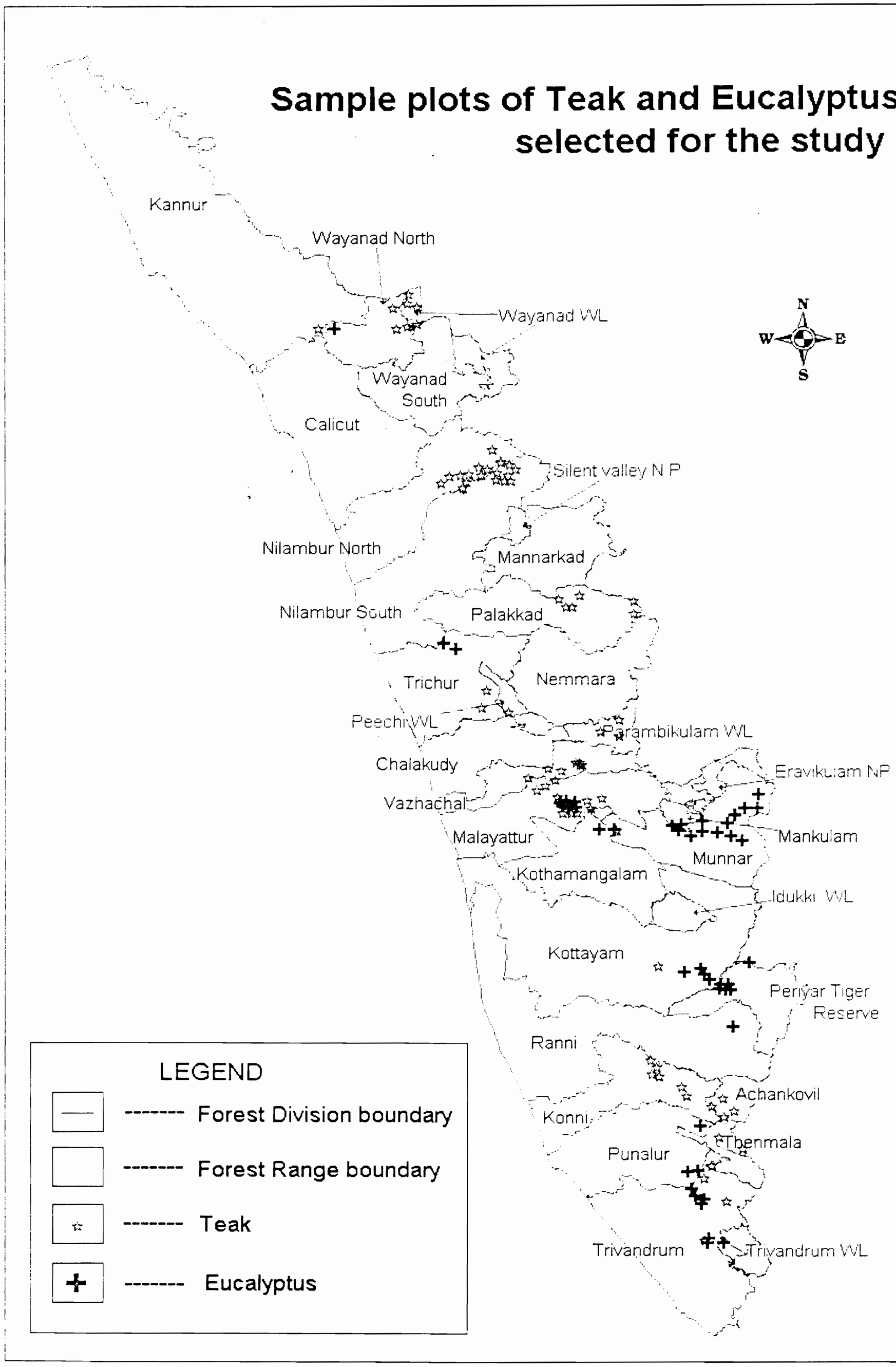


Figure 1. Locations of sample plots of teak and eucalypts selected for the study

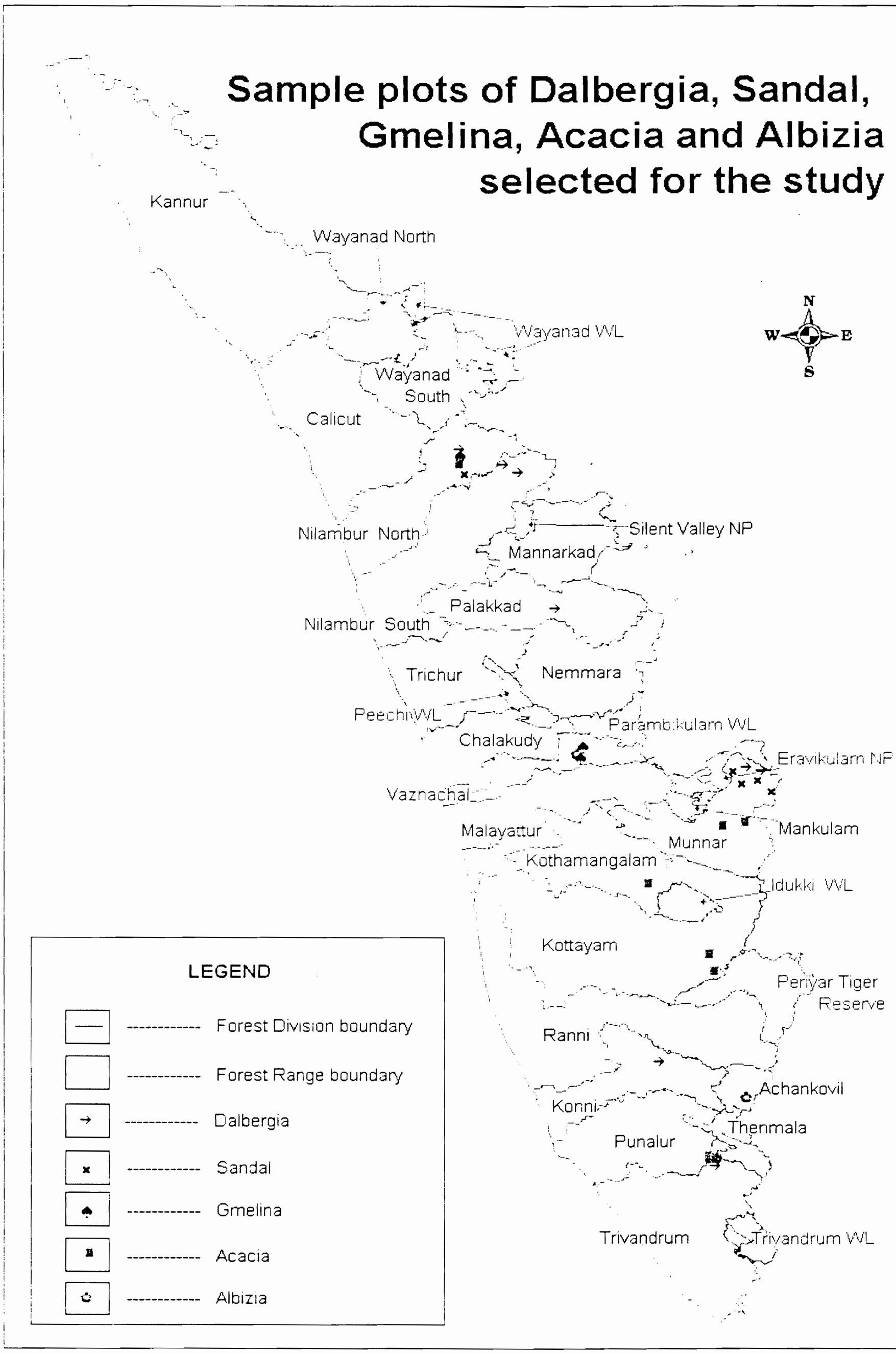


Figure 2. Locations of sample plots of rosewood, sandal, acacia and albizia selected for the study

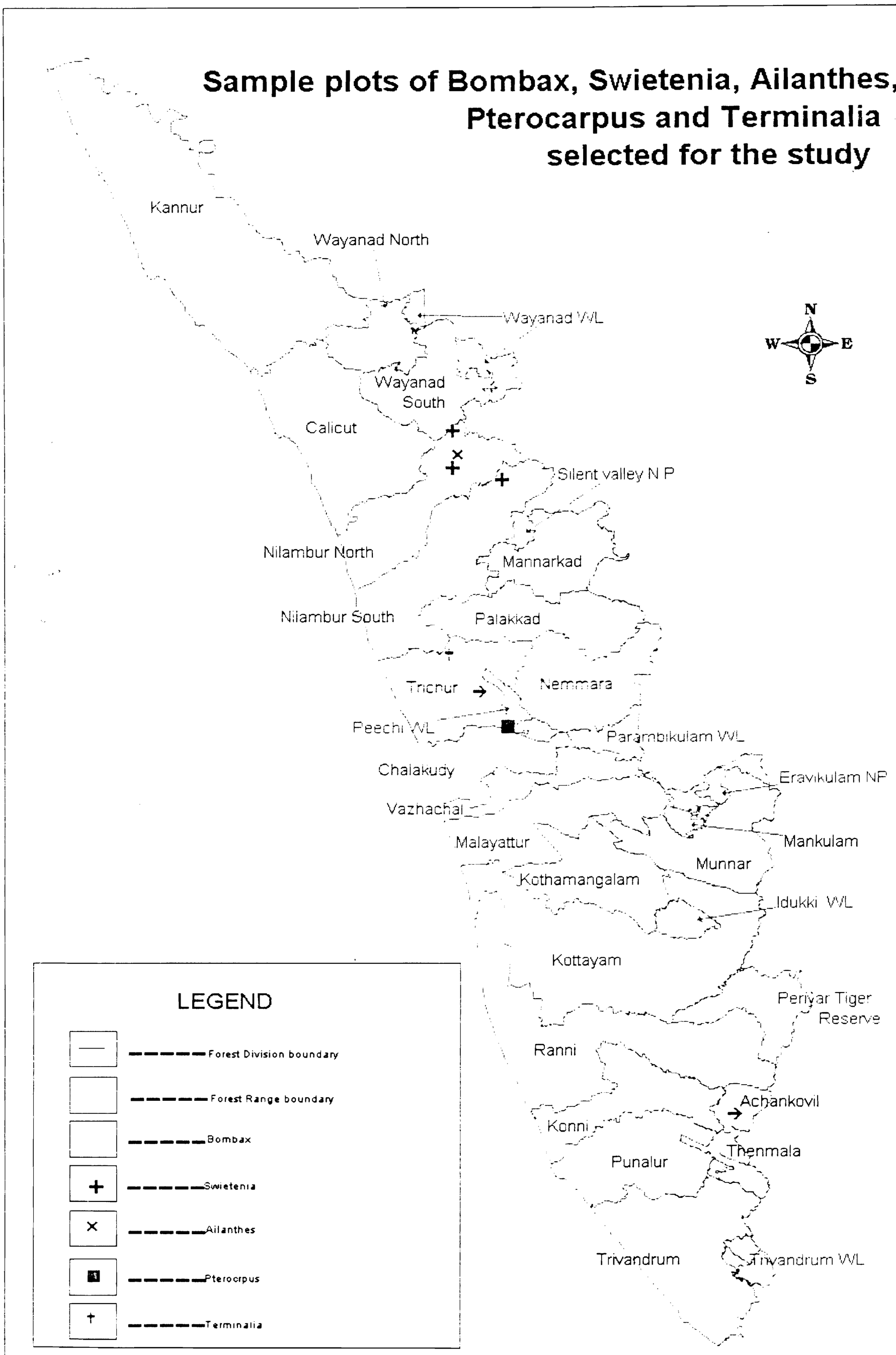


Figure 3. Locations of sample plots of *Bombax*, *Swietenia*, *Ailanthus*, *Pterocarpus* and *Terminalia* selected

T48	Kulathupuzha	Kulathupuzha	90	37	97.4	16.5
T49	Decentmukku	Kulathupuzha	90	39	90	15.6
T50	Kattilappara	Thenmala	95	41	88.4	15.2
T51	Nadavanoorkadavu	Kulathupuzha	90	37	76.2	15.6
T52	Valara	Neriamangalam	310	35	82.8	12.7
T53	Vithura	Paruthipally	110	42	114	15.6
T54	Nhaloor	Konni	25	51	146	17.8
T55	Kumaramperoor	Konni	30	3	18	9.16
T56	Cheruvalam	Erumely	80	16	84	12.6
T57	Aryamkavu	Aryankavu	200	9	51.2	11.2
T58	Palaruvi	Aryankavu	210	33	133	22.3
T59	Kumbharukadavu	Achankovil	160	4	52.8	13.4
T60	Kuttippara	Kallar	80	44	108	21
T61	Kodamala	Achankovil	150	9	51.8	10
T62	Valayam	Mannarappara	140	40	63.4	17.2
T63	Achankovil	Achankovil	80	44	139	18.6
T64	Konni	Konni	100	55	153	25.5
T65	Perumthammoozhy	Naduvathoomuzhy	100	38	173	23.6
T66	Elimullumplackal	Konni	100	3	28	8.8
T67	Kannavam	Kannoth	20	43	125	18.3
T68	Parambikulam	Parambikulam	550	38	162	24.3
T69	Orukomban	Orukomban	540	36	155	24
T70	Sungam	Sungam	520	38	126	27

Table 2: Details on sample plots of *Eucalyptus* selected for the study

Sample plot No.	Species	Locality	Forest Range	Altitude (m a.s.l.)	Age (yr)	Mean gbh (cm)	Mean ht (m)
E1	*E. tereticornis*	Perumkunnu	Wadakkanchery	90	2	17.4	3.71
E2	*E. camaldulensis*	Kottappara	Kodanad	60	5	63.2	20.7
E3	*E. pellita*	Kottappara	Kodanad	60	5	75.4	22.2
E4	*E. urophylla*	Kottappara	Kodanad	60	5	93.5	23.5
E5	*E. tereticornis*	Kottappara	Kodanad	60	5	91.2	25.7
E6	*E. grandis*	Kottappara	Kodanad	60	9	57	17
E7	*E. deglupta*	Kottappara	Kodanad	60	9	44	13
E8	*E. tessellaris*	Kottappara	Kodanad	60	9	35	8.75
E9	*E. tereticornis*	Arippa	Kulathupuzha	80	2	16.8	9.5
E10	*E. tereticornis*	Kulathupuzha	Kulathupuzha	90	4	15.8	5.2
E11	*E. tereticornis*	Kattilappara	Kulathupuzha	90	5	33.4	9.9
E12	*E. grandis*	Suryanelli	Devikulam	1100	7	23	8.4
E13	*E. grandis*	Suryanelli	Devikulam	1100	4	26.8	7.2
E14	*E.grandis*	Suryanelli	Devikulam	1400	4	43.6	7.5
E15	*E.grandis*	Pappathisholay	Devikulam	1400	4	22.4	16.7
E16	*E.grandis*	Chinnakkal	Munnar	1250	2	35.6	6.4
E17	*E.grandis*	Devikulam	Devikulam	1350	4	35.6	11.1
E18	*E.grandis*	Mattupetty	Devikulam	1480	3	32.4	14.4
E19	*E.grandis*	Palar	Devikulam	1420	7	41.8	21.6

E20	*E.grandis*	Vattavada	Devikulam	1520	4	26.8	7
E21	*E.grandis*	Vattavada	Devikulam	1520	7	41	17
E22	*E.globulus*	Mannavanshola	Marayoor	1890	32	74.6	20
E23	*E.grandis*	Aanachal	Adimaly	930	2	18.3	4.2
E24	*E.grandis*	Shenkulam	Adimaly	850	7	59.8	22.4
E25	*E.grandis*	Kathippara	Adimaly	700	7	72.4	21.4
E26	*E.tereticornis*	Kozhikkunnu	Wadakkenchery	120	3	5.9	3
E27	*E.grandis*	Peerumedu	Peerumedu	1020	8	56.8	25
E28	*E. regnans*	Pambanar	Peermedu	1120	8	33	11.8
E29	*E.grandis*	Vallakkadavu	Vallakkadavu	900	5	45.8	16.4
E30	*E.grandis*	Vallakkadavu	Vallakkadavu	880	4	47.8	12.8
E31	*E.grandis*	Uppupara	Vallakkadavu	1210	4	43.6	11.6
E32	*E.grandis*	Pamba	Vallakkadavu	980	7	46	16.6
E33	*E.grandis*	Kakki	Vallakkadavu	1050	7	60.6	18.6
E34	*E.grandis*	Paramavu	Nagarampara	710	21	145.3	22
E35	*E.grandis*	Meenmutty	Nagarampara	860	11	100.5	14.8
E36	*E.grandis*	Mankode	Paruthipally	150	7	28.6	19.6
E37	*E. tereticornis*	Vithura	Paruthipally	150	6	39.33	15.8
E38	*E. camaldulensis*	Kodakkamon	Pathanapuram	130	2	19.4	5.1
E39	*E. tereticornis*	Onthupacha	Anchal	150	2	16.8	3.9
E40	*E. tereticornis*	Peringamala	Palode	150	6	25.8	18.6
E41	*E. grandis*	Periya	Periya	750	7	51.33	28.33

Table 3: Details on sample plots of *Dalbergia latifolia* selected for the study

Sample Plot No.	Locality	Forest Range	Altitude (m a.s.l)	Mean gbh (cm)	Mean ht (m)
D1	Pulimunda	Karulai	100	92	15.9
D2	Nellikuthu	Karulai	110	130	23.66
D3	Mulepadam	Nilambur	40	131	25.4
D4	Dhoni	Olavakkode	150	101	22.2
D5	Naduvannoorkadavu	Kulathupuzha	100	86	19.25
D6	Kovilpady	Marayoor	920	95	15
D7	Elimullumplackal	Konni	110	122	23.66

Table 4 : Details on sample plots of *Santalum album* selected for the study

Sample plot No.	Locality	Forest Range	Altitude (m a.s.l)	Mean gbh (cm)	Mean ht (m)
SA1	Nilambur	Nilambur	90	20.3	18.33
SA2	Marayoor	Marayoor	850	70	5.75
SA3	Nachuvayal	Marayoor	850	45.6	11
SA4	Manjapatty	Marayoor	950	34.2	10.6
SA5	Koolikadavu	Marayoor	900	66.7	13.66

Table 5: Details on sample plots of *Gmelina arborea* selected for the study

Sample plot No.	Locality	Forest Range	Altitude (m a.s.l)	Mean gbh (cm)	Mean ht (m)
G1	Arnadampadam	Nilambur	110	79.7	10.5
G2	Panjamamkuthu	Vazhachal	430	106.80	14.5
G3	Vachumaram	Kollathirumede	350	168	16

Table 6: Details on *Acacia* plantations selected for the study

Sample plot No.	Species	Locality	Forest Range	Altitude (m a.s.l)	Mean gbh (cm)	Mean ht (m)
A1	*Acacia auriculiformis*	Chandakunnu	Nilambur	90	79.6	19.6
A2	*A. mangium*	Decentmukku	Kulathupuzha	50	29.8	8.4
A3	*A. aulacocarpa*	Decentmukku	Kulathupuzha	50	23.8	6.3
A4	*A.crassicarpa*	Decentmukku	Kulathupuzha	50	33.2	7.6
A5	*A. mearnsii*	Sooryanelli	Devikulam	1200	30	7.8
A6	*A. mearnsii*	Vattavada	Devikulam	1600	31.4	5.8
A7	*A. mearnsii*	Kanthalloor	Marayoor	1750	46.8	19.8
A8	*A.auriculiformis*	Paramavu	Nagarampara	710	80	13
A9	*A.mangium*	Kodachuritty	Thodupuzha	800	14	1.68
A10	*A.auriculiformis*	Kulamavu	Nagarampara	760	30.3	7.6

Table 7: Details on *Paraserianthes falcataria* sample plots selected for the study

Sample plot No.	Locality	Forest Range	Age (yr)	Alt (m a.s.l)	Mean gbh (cm)	Mean ht (m)
Alb1	Anamukku	Kollathirumedu	11	430	108.2	17.6
Alb2	Arippa	Kulathupuzha	15	150	66.33	23.5
Alb3	Manalar	Achenkoil	9	110	93.6	23.6
Alb4	Idinjar	Peringamala	5	120	45.3	11

Table 8: Details on sample plots of *Bombax,Swietenia,Ailanthes,Pterocarpus* and *Terminalia* species

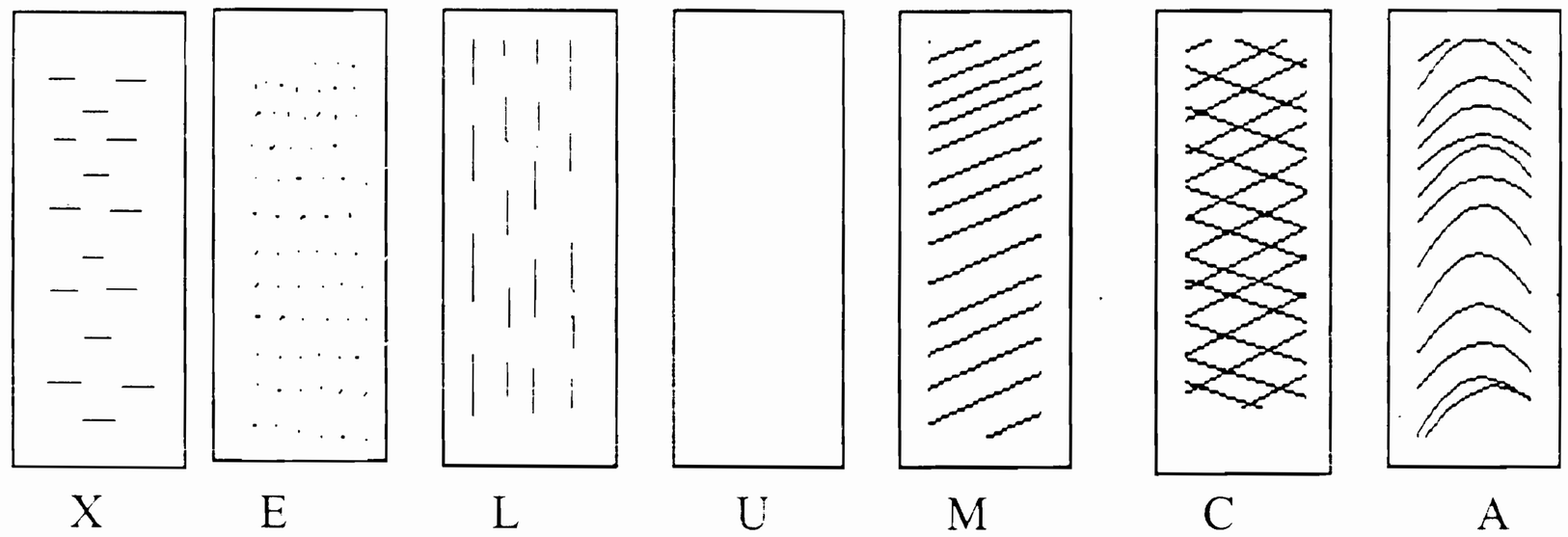
Sample plot No.	Species	Locality	Forest Range	Altitude (m a.s.l)	Mean gbh (cm)	Mean ht (m)
B1	*B. ceiba*	Irumpupalam	Pattikkad	90	97.5	19
B2	*B. ceiba*	Kumbarakadavu	Achenkoil	100	107	21.8
Sw1	*S. macrophylla*	Nellikuthu	Karulai	110	149.2	21.2
Sw2	*S. macrophylla*	Chaliarmukku	Nilambur	40	278	27.4
Sw3	*S. macrophylla*	Panayamkode	Nilambur	30	127.8	23.8
At1	*A. triphysa*	Velianthode	Nilambur	40	39.9	9.5
Ps1	*P. santalinus*	Palappilly	Palappilly	120	38.50	14.60
Tp1	*T. paniculata*	Mundathikode	Wadakkanchery	40	46.32	18.00

2.3. Separating arbuscular mycorrhizal fungal spores from soil

The rhizosphere soil samples were air-dried and wet sieving-decanting method (Gerdemann and Nicolson, 1963) with modification and wet sieving-centrifuging method were employed for retrieving the arbuscular mycorrhizal (AM) fungal spores from soil samples. Ten gram of air-dried soil sample was taken in a beaker (1000 ml), stirred thoroughly with tap water and kept for sometime to settle down heavier particles. The supernatant was decanted through a series of test sieves ranging from 45µm to 750µm mesh. This process was repeated for four to five times until the soil solution becomes clear. The sievings from the three sieves viz., 45µm, 100 µm, and 250 µm were collected into a conical flask using a wash bottle, mixed thoroughly and kept for sometime. The supernatant was filtered through a filter paper (120 mm dia) and observed under a Stereo-binocular microscope. In the case of wet sieving and centrifugation method, the sievings collected on 45µm, 100 µm, and 250 µm sieves were suspended in 50% sucrose solution in centrifuge tubes separately and centrifuged for one minute at 2000 rpm. Immediately after the centrifugation, the spores in sucrose supernatant were poured onto a sieve (45µm mesh) and carefully washed with tap water to remove sucrose. After rinsing the spores, washed them onto a pre-wetted filter paper in a Buchner funnel before vacuum filtration. AM fungal spores from the filter paper surface were selected and transferred to a drop of polyvinyl-lacto-glycerol (PVLGA) or polyvinyl alcohol (PVA) mountant on microscope slide using a sharpened wooden dowel. AM fungal spore preparations with and without Melzer's reagent were made to reveal details on spore inner-wall layers and other spore characteristics of taxonomic importance.

2.4. Identification of arbuscular mycorrhizal fungal spores

Identification of the AM fungal taxa was made by following the taxonomic descriptions of Schenck and Perez (1990) and Morton (1993). Spore characteristics such as spore color, shape, spore wall structure, subtending hypha, presence or absence of germination shield, suspensor, spore ornamentation, etc. were taken for identification. Measurements on spores, spore wall layers, suspensor, subtending hypha, details on spore inclusion, etc. were also recorded. The eight types of spore wall layers described so far include: Evanescent (E), Unit (U), Laminated (L), Membranous (M), Coriaceous (C), Amorphous (A), Expanding (X) and Germinal (G) (Figure 4). Details on spore wall layer characteristics were utilized for stylized graphic representation of wall layers (murograph), and abbreviation of the wall terminology (muronym) was used to summarize spore wall characteristics.



*X: Expanding, E:Evanescent, L:Laminated,U: Unit, M: Membranous, C:Coriaceous, A:Amorphous.

Figur 4: Graphic representation of AM fungal spore wall layers

2.5. Processing of mycorrhizal root samples and detection of AM fungal infection

Roots were separated from the rhizosphere soil and washed thoroughly with tap water over a 1-2 mm screen. After washing, the roots were kept moist in polythene bags and refrigerated at 5^0C. A working sample of the roots was drawn by chopping the selected fine roots ca. 1 cm in length and mixing them thoroughly. Then random sub-samples were drawn and kept in Petri dishes at 5^0C.

Clearing of mycorrhizal roots was required as structures produced by AM fungi were not visible when fresh roots were observed, as they were often obscured by the natural pigments and cell contents within roots. The root bits (1cm in length) were immersed in KOH 40% w/v solution in beakers and autoclaved for 45 min at 15 p.s.i. However, the treatment time varied with the types of roots. For the normal non-pigmented roots like that of teak, albizia and acacia, a clearing period of 45 min was given. For moderately pigmented roots (*Eucalyptus* spp., *Ailanthes triphysa*, *Bombax ceiba*) and highly pigmented roots (*Swietenia macrophylla, Santalum album, Dalbergia latifolia*), clearing time ranged from 60 to 90 min.

After clearing the roots, KOH was drained off and the roots were thoroughly washed with tap water for three to four times. Bleaching was done for moderately and highly pigmented roots by using alkaline H_2O_2. The bleaching time was also varied depending on the type of roots used. For normal pigmented roots, 20 to 30 min of bleaching time was given. For moderately pigmented roots, the bleaching period ranged from 2 to 3 hrs, while for highly pigmented roots of *Swietenia macrophylla, Santalum album* and *Dalbergia latifolia*, the samples were kept overnight in bleaching solution. After bleaching, the roots were captured on fine sieve and rinsed thoroughly with tap water for three to four times. The roots were then neutralized with 1N HCl for 1-3 min and then stained with Trypan blue (Phillips and Hayman, 1970; Kormanik and

McGraw, 1982). A washing step after the neutralization is not required as the acidic pH was found to increase the binding of the Trypan blue stain to the roots. The roots were immersed in 0.06% Trypan blue and kept it for overnight. After staining, the roots were separated from staining solution and immersed in Lacto-glycerol, if necessary. The root bits were then observed under a light microscope for the presence of AM fungal structures, viz., arbuscules, vesicles, internal hyphae, spores, etc. From each sub-samples, 100 root bits were observed and the percentage root colonization (%RC) was calculated (Giovannetti and Mosse, 1980) by using the formula:

$$\%RC = \frac{\text{No. of root bits with vesicles and arbuscules}}{\text{Total number of root bits observed}} \times 100$$

2.6. Collection and processing of ecto-mycorrhizal fungi

After establishing the mycorrhizal association with the host plants, the ectomycorrhizal fungi produce their reproductive structures, sporocarps, around the host plant. The sporocarps of ectomycorrhizal fungi are usually produced intermittently in response to seasonal changes in environmental factors, such as precipitation and temperature. Hence, survey on ectomycorrhizal fungi in sample plots was carried out during pre-monsoon showers (May-June) and post-monsoon period (September-October). Morphological characteristics of the sporocarps such as shape, texture, colour, etc. were recorded when the fungi were in fresh condition. To provide a clear visual record of the main characteristics of the fungal sporocarps, photographs were taken in the field itself. As far as possible, detection of hyphal connection between sporocarps and mycorrhizal roots was made. Ectomycorrhizal roots were collected and their pattern of heterorhizy, pigmentation, mycelial covering, rhizomorphs, hyphal strands, etc. were recorded. Fungal fruit bodies at their different stages and mycorrhizal roots were collected and kept in paper bags/ cotton cloth bags and transported to the laboratory. Spore prints were prepared and both macroscopic and microscopic details on the fungi were recorded and identification of the fungi up to species level made. Fungal specimens were air-dried and preserved. For describing the colour of the sporocarps *Methuen Handbook of Colour* (Kornerup & Wanscher, 1978) was used.

2.7. Ectomycorrhizal fungal isolation and culture preparation

Young fructifications of ectomycorrhizal fungi viz., *Pisolithus tinctorius* (Pers.) Coker & Couch, *Scleroderma verrucosum* (Bull.) Pers., *S. citrinum* Pers., *Laccaria laccata* (Scop.:Fr.) Cooke were thoroughly washed in tap water and soil debris was removed. The sporocarps were then surface sterilized with 0.02 % $HgCl_2$ solution followed by serial washing with sterile water. Small pieces of

tissues (approximately $2mm^3$) from the sporocarps were removed with fine sterile forceps and transferred to sterile culture media. Modified Melin Norkrans medium (MMN) (Marx, 1969) and Potato Dextrose Agar medium (PDA), were used for isolating the ectomycorrhizal fungi. The inoculated plates were incubated for 10 to15 days in dark at room temperature 24 ± 2^0C. Cultural characteristics were studied and pure isolates were maintained in slants (MMN, PDA) and liquid cultures.

2.8. Ectomycorrhizal synthesis in sterile cultures

The axenic-culture synthesis technique described below was developed to test the compatibility of host plants and mycorrhizal fungi. Fifteen-day-old cultures of ECM fungi, viz., *Pisolithus tinctorius, Laccaria laccata* and *Scleroderma verrucosum* in MMN agar plates were used. Discs (2 mm dia) cut from the periphery of the fungal colony were transferred to Petri plates (90 mm dia) containing 15 ml of Mineral salt nutrient agar (agar content 0.8%) supplemented with 0.01% glucose (to support fungal growth). Discs were placed in the center of agar plates approximately 1.5 cm apart in two rows (4 to 5 discs per row). The edges of the Petri plates were sealed with Parafilm and incubated at 22 ± 2^0C in the dark for two weeks. Seeds of *Eucalyptus tereticornis* were surface sterilized with 0.02% H_2O_2 for 3 min. washed in sterile distilled water and plated on moistened sterile blotter paper kept in Petri plates. Three-day-old seedlings of *E. tereticornis* with short emerging radicle were placed in a row 1-3 cm above the level of outermost growing hyphae in the Petri plates with fungi. The plates were then resealed and incubated on a slant (approximately 20^0 from the vertical), so that the seedlings roots grow towards the fungus, while excess water drains away from the roots. The Petri plates were incubated at 22 ± 2^0C with a cycle of 12 hr light and dark period for two weeks. The treated seedlings were removed from the plates and observed the roots for ECM fungal association.

2.9. Ectomycorrhizal fungal inoculum production

The most predominant ectomycorrhizal fungi viz., *Pisolithus tinctorius, Scleroderma verrucosum* and *S. citrinum* were selected for the study. Mycelium and spore-based inocula were prepared for screening their efficacy in improving the growth of the host seedlings. Spore-based inoculum was prepared by using the freshly collected mature sporocarps. The mature sporocarps were cleaned and placed in large polythene bags and crushed manually to release the spores. The released spores were collected and stored as such or mixed with sterilized fine sand (1: 80 w/w ratio) and stored at 5^0C.

The viability of the stored spores was checked periodically by recording the spore germination ability in different dilutions of saline solution (0.5, 1, 1.5, 2%) at different temperatures (20^0C, 25^0C, 30^0C).

Spore slurry of ectomycorrhizal fungi was prepared by using the dry spores collected from the respective sporocarps. The dry spores were sieved through 250 µm sieve to make the spores of uniform size. The spore slurry was prepared by suspending dry spores in sterile water and Tween-20 (0.1 ml/l) was used as surfactant. Spore concentration was adjusted to 2 x10^8 /ml using a Haemocytometer. The inoculum was used immediately after the preparation. Spore-sand mixture was prepared by mixing sterile fine sand (particles size < 750µ) as carrier material with dry spores of ECM fungi (1: 80 w/w ratio). Spore encapsulation was carried out as in the case of fungal mycelial bits. ECM fungal spore suspension (2 x 10^8 spore / ml) was prepared in sterile distilled water. The spore suspension was mixed with sodium alginate (4% w/v in sterilized distilled water) and then using a 10 ml syringe the suspension was extruded from a height of 10 cm to $CaCl_2$ (0.7 M) solution and converted into beads which were stabilized within 10-15 min. Viability of the spore beads was checked by inoculating the beads in MMN agar periodically.

Mycelium-based inoculum was made by using pure cultures of ECM fungi viz., *P. tinctorius*, *S. verrucosum* and *S. citrinum* raised in MMN agar. Fifteen-day-old cultures of ECM fungi were transferred to 150 ml MMN liquid media, in a 250 ml Erlenmeyer conical flasks. Periodical shaking was done by placing them in a rotary shaker at an interval of 2 to 3 days. After incubation for a period of 25 to 30 days at room temperature (22 ± 2 ^{0}C), the liquid cultures were filtered through sterile filter paper. The fungal mycelium was homogenized and mixed with sodium alginate solution (2% w/v in sterilized distilled water) and then solidified into beads by adding drops of 0.7M calcium chloride solution (Mauperin *et al.*, 1987). This results in the encapsulation of hyphal fragments within the beads of alginate gel. The homogenized fungal mycelial bits mixed with sterile water at a concentration of 2 x 10^8 cfu/ml were also used as inoculum

2.10. Arbuscular mycorrhizal fungal inoculum production

Arbuscular mycorrhizal fungi were selected for the planting stock improvement trial mainly on the basis of their predominance in the rhizosphere soils of the respective host plants. Pot cultures were established from single spore of different species of Glomalean fungi, viz. *Glomus fasciculatum* (Thaxt.) Gerd. & Trappe, *G. mosseae* (Nicol. & Gerd.) Gerd. & Trappe, *Acaulospora appendicula* Spain, Sieverding & Schenck, and *Gigaspora gigantea* (Nicol. & Gerd.) Gerd. & Trappe employing

funnel technique. The pot cultures were grown in non-draining buckets (20 cm height and 12 cm dia) and maintained in glasshouse. Maize (*Zea mays*) and Rhodes grass (*Chloris gayana* Kunth) were used as host plants. After six months of growth in pots, the maize and rhodes grass plants were cut at collar region and left for two weeks. Resilient propagules of AM fungi include spores, mycorrhizal root pieces, and organic matter containing hyphae. AM fungal inoculum was prepared by chopping the roots and mixing them with the rhizosphere soil.

Trap pot cultures were also prepared by using soil samples from the field. Rhizosphere soil samples collected from different hosts (teak, eucalypts, acacia, rosewood, sandal, albizia) were used for pot culturing. Five hundred gram of rhizosphere soil along with root bits was layered over sterile sand-soil mixture (1:1) half filled in plastic pots (non-draining, 200 cc). A thin layer of sterile soil-sand mixture was put over this. Germinated maize (*Zea mays*) and Rhodes grass seeds were aseptically transferred and planted in the pots containing soil-sand mixture and inoculum. The set ups were maintained in the glasshouse. Hoaglands micronutrient solutions was applied to the seedlings periodically. After six months of growth, plants were cut at the ground level. The soil was subjected to drying for two weeks. A portion of soil sample was taken out and total spore count was made by retrieving the spores by wet sieving and decanting method. AM fungal inoculum was prepared by chopping the roots and then mixing them with the rhizosphere soil. The inoculum, consisting of the substrate and the roots chopped into small bits, was air-dried and kept in polythene bags and stored at 10^0 C until used.

2.11. Mycorrhization of planting stock

Seedlings of *Eucalyptus tereticornis*, *E. grandis*, *Dalbergia latifolia*, *Acacia mangium*, and *Santalum album* were raised in rootrainers filled with soil-sand (1:1 ratio). Surface sterilized (with 30 % H_2O_2) seeds were sown on polyurethane foam sheet kept immersed in water in an Aluminium tray (30 x 30 x 5 cm). Fifteen-day-old seedlings were transferred to rootrainers and watered regularly. After 15 days growth in rootrainers, the seedlings of different host species were inoculated with different formulations (inoculum forms) of AM and ECM fungal propagules separately. Inoculum of AM fungus was applied at the rate of 10 g per rootrainer cell. The ECM fungal inoculum viz., spore-sand mixture, encapsulated ECM fungal spores, encapsulated ECM fungal mycelia, ECM fungal mycelial slurry and ECM spore slurry were applied separately. ECM spore–sand mixture inoculum was applied at rate of 10 g per seedling and the alginate beads containing spores/mycelia at the rate of five beads per seedling. ECM spore slurry (spore concentration adjusted to $2x10^8$ spore /ml) was applied at the rate of 10 ml per root trainer cell. The inoculated and control sets of seedlings were kept in

glasshouse. Observations on various parameters like seedling height, leaf pairs, etc. were recorded at regular intervals (20, 40, 60, 80, 100 days). The seedling biomass of AM and ECM fungal inoculum treated and control seedlings (wet and dry weight) was recorded by destructive sampling method and mycorrhizal inoculation effect (MIE) evaluated using the following formula:

$$\% \text{ MIE} = \frac{\text{Dry wt. of inoculated plant} - \text{Dry wt. of uninoculated plant}}{\text{Dry wt. of inoculated plant}} \times 100$$

2.12. Evaluation of physical and chemical properties of rhizosphere soils

Rhizosphere soil samples collected from different hosts were brought to the laboratory and analyzed for their physical and chemical characteristics (Keeney, 1980; Hefferman, 1985; Rayment and Higginson, 1992). Soil moisture content was determined by oven dry method and soil pH was measured using digital pH meter.

2.12.1. Exchangeable cations in soil

The following procedures and materials were used. Ammonium chloride solution 1M was prepared by dissolving 213.96 g of NH_4Cl in about 3.5 l of distilled water and the pH was adjusted to 8.2 by adding NH_4OH(28-30% NH_3 w/w) and made up to a volume of 4 l. Air dried soil (0.5 g) was weighed, sieved through < 0.2 mm screen and taken in 50 ml plastic vials and a few milliliter of NH_4Cl solution was added. Swirled to remove any air inside and made sure that soil was saturated with the solution. The standard soil and blanks were also prepared. The mixture was transferred to 250 ml conical flasks (calibrated to 150 ml) through a 65 cm dia funnel lined with Whatman No.42 filter paper. The vials were rinsed with NH_4Cl solution and allowed the solution to drain completely before starting leaching. The addition was made in small quantity and frequently without letting the soil dry in such a way that leaching has taken between 2 to 3 hours. When the final volume has been reached, mixed thoroughly and transferred to the vial for analysis. Analyzed for Ca, Na, K, Mg on AA Spectrophotometer. Standards were prepared by following the same matrix with sample. Results are expressed in milli equivalent /100 g.

Na (meq/ 100g) = (ppm in solution- blank) 0.652/ wt. of the sample (g)

K (meq/ 100g) = (ppm in solution- blank) 0.3846/ wt. of the sample (g)

Mg (meq/ 100g) = (ppm in solution- blank) 0.1.25/ wt. of the sample (g)

Ca (meq/ 100g) = (ppm in solution- blank) 0.75/ wt. of the sample (g)

2.12.2. Total Nitrogen (N) and Phosphorus (P) in the soil

Soil sample (0.5 g) was weighed and ground to less than 0.2 mm into the digest tube. Standard reference soil and blank were also prepared. Added 1 ml of Cu solution and 0.02 g of Salicylic acid and kept for overnight. Added 2.5 ml of acid digestion mixture (dissolved 30 g of K_2SO_4 in 100ml of H_2SO_4 and heated if necessary. Cu catalyst : dissolved 18 g of $CuSO_4$ in 100 ml of distilled water) and placed on digestion chamber. Heated to 360^0 C for 30 min, removed and cooled. Added 2 ml of H_2SO_2 and digested at 360° C for one hour. This step was repeated again until the digest was clear. Removed, cooled and then added 47.5 ml of distilled water, mixed thoroughly and filtered through Whatman No. 42 filter paper. Analyzed the solution for N and P using a TECHNICON Autoanalyzer and standards were made in similar matrix to digest the soil. Calculation was made as follows: Total N or P (%) = (ppm in solution – blank) x 0. 005/wt. of the sample (g).

2.12.3. Organic carbon in soil

Soil sample (0.5 g) was weighed and ground to <0.5 mm and dried in a Kjeldal's flask. Added 12 ml of 8% $K_2Cr_2O_7$, shaken well for about 30 sec and added 20 ml of conc. H_2SO_4 slowly from a dispenser and swirled well for about 90 sec. Allowed to cool and added 65 ml of distilled water and shaken cautiously and allowed to settle overnight. Placed the sampling tube to a depth of 10 cm of solution (without disturbing the residue). The carbon oxidation was measured by using Spectrophotometer UNICAM 5625 at 625 nm. Standard and blank were read in the same way. Organic carbon (OC)% was calculated as follows: OC % = ppm in solution /wt. of soil sample taken x 100.

2.13. Statistical analysis

The relation between mycorrhizal root infection percentage and the set of extraneous variables like age of the plantation and soil variables was investigated through multiple linear regression. Stepwise regression was employed to identify the most influential set of variables affecting the mycorrhizal root infection percentage. The root infection percentage was transformed to angular scale before the regression analysis.

Biodiversity indices were worked out for each sample plot. Relative abundance was measured using Shannon-Wiener index and Simpson's index. Shannon-Wiener index was calculated as:

$$H' = -\sum p_i \ln p_i$$

where quantity p_i is the proportion of individuals found in the ith species and ln indicates natural logarithm. The value of H' can range from 0 to ln S, the value of the Shannon index is usually found to fall between 1.5 and 3.5 and only rarely surpasses 4.5. Simpson's index assumes that the proportion of individuals in an area adequately weighs their importance to diversity. The equation for this index used is :

$$D = 1 / \sum p_i^2$$

where D is the diversity and p_i is the proportion of the ith species in the total sample. This index goes from zero to the total number of species. An index of one indicates that all of the individuals in the area belong to a single species, and when $D = S$, then every individual belongs to a different species. The levels of diversity viz., Gamma diversity and Beta diversity of AM fungal species in selected forest plantations were estimated. Beta diversity was estimated using the following equation:

$$\beta_w = (S / \bar{S}) - 1$$

where S = Total number of species recorded in the system; $\bar{S}$ = Average sample diversity where each sample is of standard size and diversity is measured as species richness.

3. RESULTS AND DISCUSSION

3.1. Teak

3.1.1. Arbuscular mycorrhizal association in teak

A total of 70 teak plantations located in different Forest Ranges in the State (Table 1) were sampled for arbuscular mycorrhizal (AM) association. The teak plantations were arbitrarily grouped into four, viz., 1 to 10-year-old (Group1), 11 to 20-year-old (Group2), 21 to 40-year-old (Group3), and >40-year-old (Group4). The arbuscular mycorrhizal (AM) fungal infection in young feeder roots assessed by following the method of Giovannetti and Mosse (1980) showed that all the sampled teak plants in different Forest Ranges throughout the State, irrespective of their difference in age, altitude and edaphic factors, exhibited AM fungal association. However, the per cent root infection as well as the AM fungal species association varied with age of the plants and soil physical and chemical properties. All the teak plants sampled from the different localities had arbuscular mycorrhizal structures within their feeder roots. All typical AM features, such as arbuscules, vesicles, intra-cellular hyphal coils, extra and intraradical hyphae, were observed in the root samples (Plate 1). Arbuscules were present in all the samples studied, providing unequivocal evidence of AM fungal association with the teak roots. Presence of arbuscules is a *sine qua none* for identification of AM fungal infection in roots (Bonfante-Fasolo, 1984), as these structures are formed by all AM fungi, whereas vesicles are not always formed (Gerdemann and Trappe, 1974). Vesicles were also observed within roots, where they were intra or extra-cellular and on extramatrical hyphae. Intracellular hyphae, which varied in diameter, also formed coils or loops inside the cortical cells. Arbuscules showed either fine or coarse branching. The morphological diversity of the different fungal structures observed within the same root samples indicates that teak roots were colonized by several different AM fungal species. The overall extent of root colonization varied from 2.00 to 86.1 per cent with a mean of 32.42 per cent. The highest values were registered in root samples collected during the month of April, which is the driest period, however, since samples from the same plants were not collected in different seasons, a conclusion cannot be drawn on this. It is well known that root infection by AM fungi varies from season to season depending on the soil physical and chemical characteristics as well as host's response.

Of the 15 teak plantations belonging to the Group1 (1- to 10-year-old), AM fungal root infection was observed in all the sampled trees and infection ranged from 3.6 to 83.9 per cent. However, the average root infection was 27.18 per cent. The highest mycorrhizal root infection of 83.9 per cent in

this Group was recorded in a nine-year-old plantation at Vazhachal, Vazhachal Forest Range (Table 9), and lowest root infection in a one-year-old plantation at Dhoni, Olavakkode Forest Range. The young teak plantations located at different altitudes (30 to 800 m a.s.l.) did not show any marked difference on AM fungal root colonization. However, there is a possible relationship between root infection and soil characteristics. Rhizosphere soil samples from most teak plantations were moderately to strongly acidic, except plantation soils at Olavakkode, Kodanad, and Thundathil Forest Ranges, which were near neutral to basic. The lowest root infection was observed in a very young plantation (1-year-old), where the soil pH was comparatively high (pH 7.3) and with a low soil moisture content (3.6%). Whereas the highest root infection in this group was recorded in plantation with a soil pH of 4.81 and soil moisture content of 10.01 per cent. In general, plantation soils with comparatively high soil pH (6.8 to 7.3) and low soil moisture content (0.56 – 4.31%) showed low AM fungal root infection.

Table 9: AM fungal root infection in teak plantations (1 to 10 years-old) in different parts of the State

Sl. No.	Sample Plot No.	Locality	Forest Range	Altitude (m)	Age (yr)	Root infection %	AMF spore count	Soil pH	Soil MC%
1.	T5	Begur	Begur	800	8	30.3	289	5.53	2.16
2	T11	Vazhachal	Vazhachal	270	9	83.9	164	4.81	10.01
3	T15	Cherupuzha	Karulai	40	4	43.6	100	5.32	10.01
4	T23	Valluvassery	Nilambur	90	9	26.4	421	4.99	6.09
5	T24	Valluvassery	Nilambur	90	7	22.3	139	4.85	4.89
6	T31	Mallana	Kodanade	90	2	13.1	358	6.76	0.56
7	T34	Perumthode	Kodanade	90	2	8.1	182	6.8	2.02
8	T35	Karimpani	Thundathil	90	5	12.8	364	6.83	4.31
9	T41	Dhoni	Olavakkode	150	1	3.6	690	7.3	3.16
10	T43	Banglamkunnu	Olavakkode	150	3	23.6	216	7.46	4.05
11	T55	Kumaramperoor	Konni	30	3	17	181	4.76	20.3
12	T57	Aryankavu	Aryankavu	200	9	18	187	4.93	16.02
13	T59	Kumbharukadavu	Achankovil	160	4	35	108	5.46	9.34
14	T61	Kodamala	Achankovil	50	9	15	117	5.71	10.86
15	T66	Elimullumplackal	Konni	100	3	55	89	4.76	17.81

Among the ten teak plantations belonging to the age group of 11 to 20-year-old (Group II), AM root infection ranged from 22.9 to 82.1 per cent. The average mycorrhizal infection was 38.55 per cent. From all the teak plantations, except one 19-year-old plantation at Karimpani, Thundathil Forest Range, more than 25 per cent of AM root infection was recorded (Table 10). In this Group also, high per cent AM fungal root infections (73.6%, 82.1%) were recorded in plantations with low soil pH (Table 10).

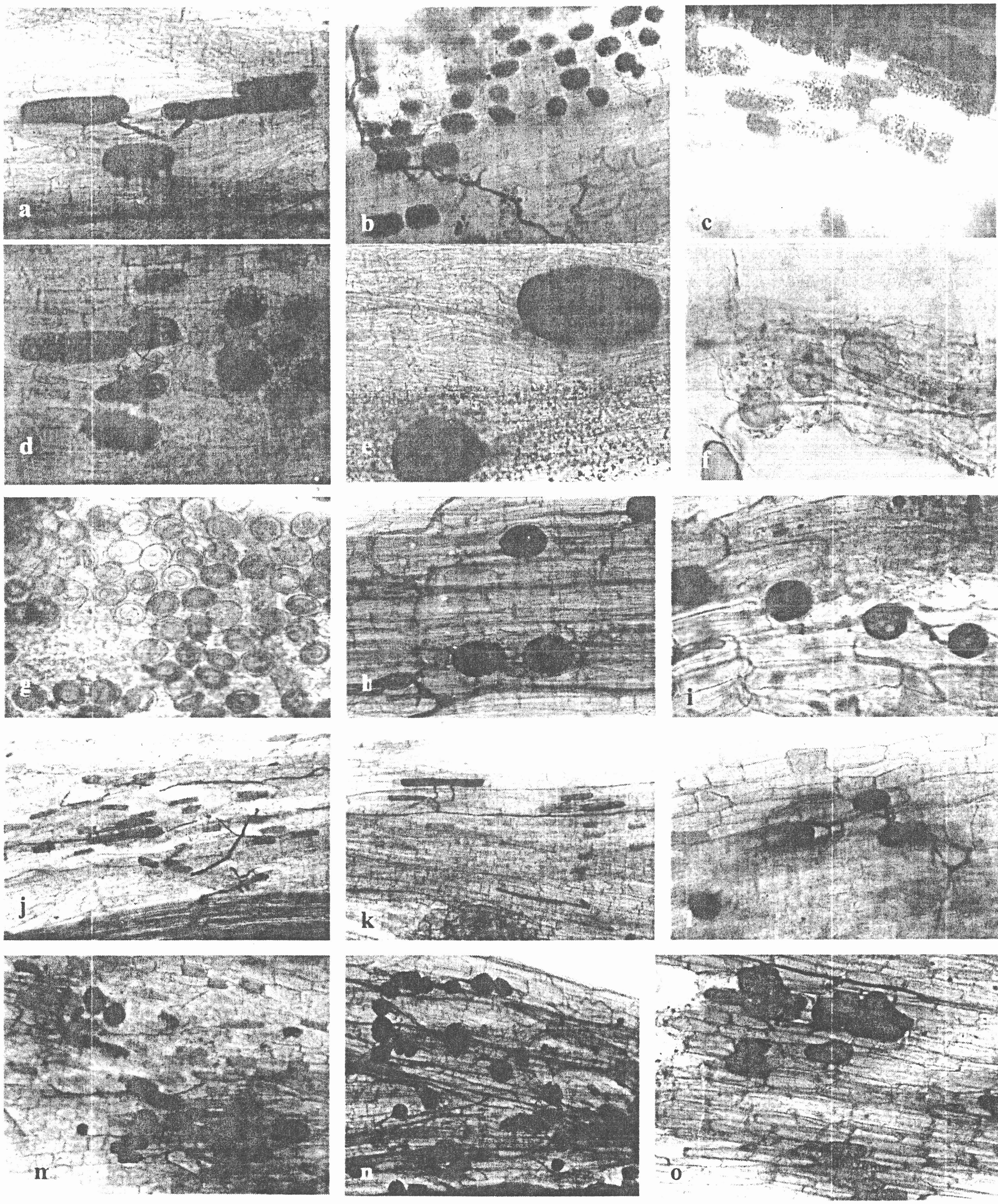


Plate 1: AM fungal root infection: a-e: vesicles and arbuscules in infected teak roots, f, g: spores of *Glomus intraradices* inside the infected teak root, h: vesicles in *Acacia auriculiformis*, i: vesicles in *Gmelina arborea*, j: vesicles and arbuscules in root of *D. latifolia*, k: vesicles and arbuscules in root of *E. tereticornis*, l: vesicles and arbuscules in root of *E. grandis*, m: vesicles and arbuscules in teak roots, n, o: vesicles, arbuscules and hyphae in *Paraserianthes falcataria* roots.

Table 10: AM fungal root infection in teak plantations (11 to 20- year-old) in different parts of the State

Sl. No.	Sample Plot No.	Locality	Forest Range	Altitude (m)	Age (yr)	Root infection %	AM F spore count	Soil pH	Soil MC%
1	T4	Panavally	Tholpetty	760	18	38.2	631	5.35	8.16
2	T8	Irumbupalam	Vazhachal	505	20	73.6	810	5.13	12.34
3	T9	Irumbupalam	Vazhachal	505	17	82.1	357	5.04	13.32
4	T13	Kariammurium	Nilambur	160	19	33.5	98	5.49	9.34
5	T22	Nellikkuthu	Karulai	100	13	25.6	401	5.23	10.03
6	T25	Mailady	Nilambur	30	12	28	65	4.87	19.01
7	T30	Mulamkuzhy	Kalady	80	20	27.5	239	6.92	0.31
8	T36	Karimpani	Thundathil	90	19	22.9	295	6.59	5.63
9	T47	Kottappara	Kodanad	50	16	27.1	168	5.73	7.86
10	T56	Cheruvalam	Erumely	80	16	27	244	5.53	19.33

Table 11 : AM fungal root infection in teak plantations (21-40- year-old) in different parts of the State

Sl. No.	Sample Plot No.	Locality	Forest Range	Altitude (m a.s.l.)	Age (yr)	Root infection %	AMF spore count	Soil pH	Soil MC%
1	T1	Kaimaram	Tholpetty	810	38	53	621	5.79	9.82
2	T2	Camp road	Tholpetty	820	23	58	357	6.02	8.43
3	T6	Chembuvalli	Begur	810	22	31.6	174	5.76	2.74
4	T7	Bavali	Begur	800	36	23.1	231	6.01	2.69
5	T10	Vazhachal	Vazhachal	290	37	86.1	461	5.51	15.61
6	T12	Kariummurium	Nilambur	110	23	38	168	5.24	8.68
7	T14	Thannikkadavu	Vazhikkadavu	120	27	36.1	93	5.09	9.34
8	T16	Cherupuzha	Karulai	80	26	30.8	156	5.23	10.03
9	T20	Poolakkappara	Karulai	80	30	32	101	5.22	10.39
10	T28	Edakkode	Edavanna	80	23	43.2	67	5.08	6.11
11	T32	Perumthode	Kodanade	88	37	6.8	238	7.01	1.8
12	T33	Perumthode	Kodanade	90	23	9.8	151	6.81	3.01
13	T37	Thundamthodu	Thundathil	95	27	11	196	6.81	3.61
14	T45	Vattappara	Walayar	210	23	16.6	171	7.45	1.25
15	T48	Kulathupuzha	Kulathupuzha	90	37	32.8	103	6.7	3.12
16	T49	Decentmukku	Kulathupuzha	90	39	65.2	120	5.6	2.9
17	T51	Nadavanoorkadavu	Kulathupuzha	80	37	35.7	78	5.3	4.15
18	T52	Valara	Neriamangalam	310	35	8	160	4.8	6.8
19	T58	Palaruvi	Aryankavu	210	33	39	169	5.36	11.03
20	T62	Valayam	Mannarppara	40	40	14	169	5.75	9.69
21	T65	Perumthammoozhy	Naduvathoomuzhy	110	38	53	153	6.18	16.97
22	T68	Parambikulam	Parambikulam	550	38	31	209	6.56	11.24
23	T69	Orukomban	Orukomban	540	36	46	88	6.5	14.56
24	T70	Sungam	Sungam	520	38	29.5	237	6.26	16.16

All the 24 teak plantations belonging to the age group of 21 to 40-year-old (Group III) in different parts of the State studied showed AM root infection which ranged from 6.8 to 86.1 per cent. The average mycorrhizal infection was 34.59 per cent. The highest percentage of AM root infection was recorded in a 37-year-old teak plantation at Vazhachal, Vazhachal Forest Range (Table 11). In this category of plantations also low AM root infection was recorded in plantation soils with high soil pH. Teak plantations at Vattappara (Walayar Forest Range), Perunthode (Kodanad Forest Range), Thundamthodu (Thundathil Forest Range), where the soils were near neutral to basic (pH ranged from 6.81 to 7.45), exhibited comparatively a low AM root infection than the other plantations with low soil pH. Twenty one teak plantations falling under the group of >40 –year-old (Group IV) showed AM root infection which ranged from 2 to 56.9 per cent. The average AM fungal root infection was 27.22 per cent. Age of the teak plantation varied from 41 to 90 years. The 90-year-old teak plantation at Nedumkayam (Karulai Forest Range) showed 31.23 per cent AM root infection, while a 45-year-old teak plantation at Chakkolatharisu (Pattikkad Forest Range) showed the highest per cent AM root infection of 56.9. However, teak plantations at Olavakkode and Walayar Forest Ranges, where the soils were basic (soil pH ranged from 7.83-7.96), exhibited a very low per cent AM root infection. The lowest per cent AM root infection (2%) was observed in a 65-year-old teak plantation at Dhoni (Olavakkode Forest Range). The teak plantations with comparatively high soil pH (7.48 to 7.96) and low soil moisture content (0.76 to 3.89%) showed low AM root infection. However, highest value for AM root infection in teak plantations belonging to this Group was observed in plantation with soil pH 6.78 and soil moisture content of 5.98% (Table 12).

3.1.2. Factors influencing AM association in teak plantations

Arbuscular mycorrhizal infection in plants is usually influenced by the prevailing edaphic and environmental factors. Physical and chemical properties of the rhizosphere soil samples from the teak plantations showed a wide range of differences. Soil pH ranged from 4.03 to 7.96; most of the plantation soils were moderately acidic to highly acidic. Only soil samples from plantations in Olavakkode, Kodanad, Thundathil, Kalady and Walayar Forest Ranges were near neutral to basic. Soil moisture content in the teak plantations also ranged from 0.31 to 19.33 per cent with a mean of 6.63 per cent. Organic carbon in the soil samples ranged from 0.99 to 5.88 with a mean of 2.45 per cent. In most of the plantation soils, the ratio of OC % to N% was found about 10:1 ratio indicating the nutrient richness of the soils. Exchangeable cations viz., Na, Ca, Mg, and K also showed high variation. Sodium (Na) ranged from 0.052 to 0.109 (meq/100g), calcium (Ca) ranged from 0.166 to 3.804 (meq/100g), and magnesium (Mg) ranged from 0.041 to 0.541 meq/100g. Total nitrogen (N) and phosphorus (P) percentage varied from 0.09 to 0.515 and 0.01 to 0.31 respectively (Table 13-16).

Table 12: AM fungal root infection in teak plantations (>40 year-old) in different parts of the State

Sl. No.	Sample Plot No.	Locality	Forest Range	Altitude (m.a.s.l.)	Age (yr)	Root infection %	AMF spore count	Soil pH	Soil MC%
1	T3	Naikkatty	Tholpetty	800	46	43.6	619	5.95	8.03
2	T17	Nedumkayam	Karulai	80	90	31.2	83	5.24	9.69
3	T18	Pulimunda	Karulai	90	41	31.23	86	5.02	10.02
4	T19	Poolakkappara	Karulai	70	50	38	68	5.33	10.11
5	T21	Nellikkuthu	Karulai	90	67	39.4	164	5.36	9.81
6	T26	Chliarmukku	Nilambur	20	45	31.8	29	4.03	19.08
7	T27	Akampadam	Nilambur	50	45	46	64	5.17	8.31
8	T29	Mulamkuzhy	Kalady	75	45	26.5	282	6.48	0.08
9	T38	Irumbupalam	Pattikkad	80	44	23	136	6.65	5.35
10	T39	Chakkolatharisu	Pattikkad	90	45	56.9	110	6.78	5.98
11	T40	Vallikkayam	Peechi	110	41	10	190	6.92	3.78
12	T42	Dhoni	Olavakkode	160	65	2	129	7.83	3.89
13	T44	Dhoni-Quarters	Olavakkode	160	43	8.2	138	7.48	2.42
14	T46	Walayar	Walayar	260	41	14	146	7.96	0.76
15	T50	Kattilappara	Thenmala	90	41	15.8	141	5.4	4.16
16	T53	Vithura	Paruthipally	110	42	43	88	4.49	14.91
17	T54	Nhaloor	Konni	25	51	12	206	4.05	17.59
18	T60	Kuttippara	Kallar	80	44	26	167	5.76	10.19
19	T63	Acahankovil	Achankovil	80	44	22	194	5.97	10.46
20	T64	Konni	Konni	100	55	10	388	5.69	14.77
21	T67	Kannavam	Kanneth	80	43	41	164	5.72	19.02

Table 13: Chemical and physical properties of soil and AM root infection and spore density in teak plantations (1 to 10-year-old)

Sample No.	Locality	Root infection %	AM F spore count	Soil pH	MC %	OC %	Na meq/ 100g	K meq/ 100 g	Ca meq/ 100 g	Mg meq/ 100 g	N (%)	P (%)
T5	Begur	30.3	289	5.53	2.16	3.56	0.07	0.055	3.09	0.452	0.32	0.31
T11	Vazhachal	83.9	164	4.81	10.01	1.87	0.06	0.049	0.83	0.104	0.19	0.08
T15	Cherupuzha	43.6	100	5.32	10.01	0.99	0.06	0.038	0.78	0.124	0.09	0.13
T23	Valluvassery	26.4	421	4.99	6.09	1.5	0.08	0.051	0.78	0.125	0.17	0.05
T24	Valluvassery	22.3	139	4.85	4.89	1.49	0.08	0.032	1.4	0.163	0.15	0.05
T31	Mallana	13.1	358	6.76	0.56	4.4	0.08	0.057	0.45	0.054	0.49	0.18
T34	Perumthode	8.1	182	6.8	2.02	2.65	0.07	0.057	0.39	0.046	0.04	0.12
T35	Karimpani	12.8	364	6.83	4.31	3.14	0.07	0.063	0.34	0.065	0.34	0.12
T41	Dhoni	3.6	690	7.3	3.16	2.91	0.09	0.177	1.56	0.197	0.37	0.11
T43	Banglamkunnu	23.6	216	7.46	4.05	2.66	0.07	0.06	1.41	0.156	0.33	0.13
T55	Kumaramperoor	17	181	4.76	20.3	3.5	-	-	-	-	-	-
T57	Aryankavu	18	187	4.93	16.02	1.47	-	-	-	-	-	-
T59	Kumbharukadavu	35	108	5.46	9.34	2.39	-	-	-	-	-	-
T61	Kodamala	15	117	5.71	10.86	1.63	-	-	-	-	-	-
T66	Elimullumplackal	55	89	4.76	17.81	2.96	-	-	-	-	-	-

- samples not analysed

Table 14: Chemical and physical properties of soil and AM fungal root infection and spore density in teak plantations (11 to 20-year-old) in different parts of the State

Sample Plot No.	Locality	Root infection %	AMF spore	Soil pH	MC %	OC %	Na meq/ 100 g	K meq/ 100 g	Ca meq/ 100 g	Mg meq/ 100 g	N (%)	P (%)
T4	Panavally	38.2	631	5.35	8.16	2.314	0.109	0.054	2.107	0.22	0.227	0.088
T8	Irumbupalam	73.6	810	5.13	12.34	2.992	0.057	0.072	0.672	0.11	0.34	0.16
T9	Irumbupalam	82.1	357	5.04	13.32	2.176	0.065	0.115	0.861	0.12	0.245	0.096
T13	Kariammurium	33.5	98	5.49	9.34	2.67	0.062	0.063	1.942	0.179	0.21	0.068
T22	Nellikkuthu	25.6	401	5.23	10.03	1.925	0.059	0.023	0.819	0.162	0.213	0.052
T25	Mailady	28	65	4.87	19.01	1.979	0.063	0.048	0.642	0.103	0.232	0.049
T30	Mulamkuzhy	27.5	239	6.92	0.31	5.882	0.056	0.056	0.722	0.111	0.515	0.111
T36	Karimpani	22.9	295	6.59	5.63	2.99	0.074	0.063	0.416	0.09	0.328	0.117
T47	Kottappara	27.1	168	5.73	7.86	2.662	0.068	0.055	0.236	0.048	0.282	0.132
T56	Cheruvalam	27.0	244	5.53	19.33	3.8	-	-	-	-	-	-

- samples not analysed

In general, rhizosphere soil samples (5-20 cm depth) from teak plantations throughout the State showed high organic carbon (OC) and available nitrogen (N) percentage. In most of the soils, 10:1 ratio for OC% to N% was observed which indicates the high nutrient status of the teak rhizosphere soils. The available phosphorus was also found in good percentage in most of the teak plantations. However, as most of the soils were moderate to highly acidic, the nutrient availability as well as mobility depend on interrelationships among the various chemical and physical factors of the soils.

Under natural conditions it is believed that AM fungi play a major role in plant nutrient uptake and also stress tolerance mechanism. Arbuscular mycorrhizal fungi increase the volume of soil exploited by plants (Bolan, 1991) by their network of hyphae. Root colonization by AM fungi often results in enhanced uptake of relatively immobile micro-nutrients (Faber *et al.*, 1990; Kothari *et al.*, 1990; Li *et al.*, 1991).

Among soil nutrients, phosphorus availability in particular has been shown to play a major role in plant/mycorrhizal relations (Mosse, 1973; Hayman, 1983). Low phosphorus availability has been repeatedly shown to encourage AM fungal colonization, which in turn improves plant phosphorus nutrition (Daft and Nicolson, 1969; Hayman and Mosse, 1971). The AM fungal root infection in teak plants was found in the range of 2 to 86.1 per cent with a mean of 32.42 per cent and highest per cent infection was recorded in teak plantations belonging to 11 to 20-year-old. In general, young (1 to 10-year-old) as well as old (> 40-year-old) plantations showed comparatively low per cent AM fungal root infection (Figure 5).

Table 15: Chemical and physical properties of soil and AM fungal root infection and spore density in teak plantations (21 to 40- year-old) in different parts of the State

Plot No.	Locality	Root infection %	AMF spore count	Soil pH	MC%	OC%	Na meq/ 100 g	K meq/ 100 g	Ca meq/ 100g	Mg meq/ 100 g	N(%)	P(%)
T6	Chembuvalli	31.6	174	5.76	2.74	3.196	0.071	0.073	3.804	0.258	0.22	0.057
T7	Bavali	23.1	231	6.01	2.69	1.936	0.06	0.058	0.846	0.541	0.142	0.054
T10	Vazhachal	86.1	461	5.51	15.61	2.547	0.052	0.058	0.809	0.1	0.262	0.15
T12	Kariummurium	38	168	5.24	8.68	1.216	0.069	0.157	0.521	0.09	0.103	0.042
T14	Thannikkadavu	36.1	93	5.09	9.34	1.574	0.059	0.027	0.775	0.207	0.178	0.039
T16	Cherupuzha	30.8	156	5.23	10.03	1.46	0.063	0.07	1.354	0.207	0.177	0.099
T20	Poolakkappara	32	101	5.22	10.39	1.592	0.064	0.036	0.865	0.111	0.196	0.088
T28	Edakkode	43.2	67	5.08	6.11	3.278	0.061	0.043	0.836	0.127	0.274	0.038
T32	Perumthode	6.8	238	7.01	1.8	2.137	0.068	0.067	0.558	0.106	0.298	0.114
T33	Perumthode	9.8	151	6.81	3.01	3.16	0.077	0.057	0.606	0.097	0.301	0.12
T37	Thundamthodu	11	196	6.81	3.61	2.395	0.062	0.044	0.286	0.041	0.285	0.153
T45	Vattappara	16.6	171	7.45	1.25	1.522	0.067	0.071	1.993	0.126	0.195	0.105
T48	Kulathupuzha	32.8	103	6.7	3.12	1.683	0.09	0.06	0.369	0.135	0.179	0.073
T49	Decentmukku	65.2	120	5.6	2.9	2.591	0.058	0.07	0.936	0.204	0.375	0.056
T51	Nadavanoorkadavu	35.7	78	5.3	4.15	2.81	0.086	0.108	0.166	0.075	0.373	0.079
T52	Valara	8	160	4.8	6.8	2.79	-	-	-	-	-	-
T58	Palaruvi	39	169	5.36	11.03	1.6	-	-	-	-	-	-
T62	Valayam	14	169	5.75	9.69	2.32	-	-	-	-	-	-
T65	Perumthammoozhy	53	153	6.18	16.97	2.41	-	-	-	-	-	-
T68	Parambikulam	31	209	6.56	11.24	2.68	-	-	-	-	-	-
T69	Orukomban	46	88	6.5	14.56	3.12	-	-	-	-	-	-
T70	Sungam	29.5	237	6.26	16.16	3.67	-	-	-	-	-	-

- Samples not analysed

Table 16 : Chemical and physical properties of soil and AM fungal root infection and spore density in teak plantations (>40-year-old)

Sample Plot No.	Lovality	Rootin fection %	AM F spore	Soil pH	MC %	OC %	Na meq/ 100 g	K meq/ 100 g	Ca meq /100 g	Mg meq/ 100 g	N (%)	P (%)
T3	Naikkatty	43.6	619	5.95	8.03	3.562	0.07	0.047	1.823	0.259	0.183	0.051
T17	Nedumkayam	31.2	83	5.24	9.69	2.218	0.053	0.029	2.161	0.28	0.22	0.068
T18	Pulimunda	31.23	86	5.02	10.02	1.839	0.065	0.031	1.426	0.195	0.203	0.051
T19	Poolakkappara	38	68	5.33	10.11	1.217	0.061	0.057	0.94	0.199	0.169	0.01
T21	Nellikkuthu	39.4	164	5.36	9.81	1.288	0.062	0.038	1.026	0.137	0.136	0.066
T26	Chliarmukku	31.8	29	4.03	19.08	1.895	0.079	0.058	1.441	0.223	0.238	0.053
T27	Akampadam	46	64	5.17	8.31	2.688	0.06	0.076	1.182	0.117	0.274	0.049
T29	Mulamkuzhy	26.5	282	6.48	0.08	3.33	0.057	0.04	0.188	0.042	0.355	0.099
T38	Irumbupalam	23	136	6.65	5.35	2.55	0.067	0.067	0.661	0.114	0.292	0.124
T39	Chakkolatharisu	56.9	110	6.78	5.98	2.349	0.082	0.093	1.637	0.262	0.339	0.145
T40	Vallikkayam	10	190	6.92	3.78	3.365	0.073	0.097	1.705	0.248	0.307	0.089
T42	Dhoni	2	129	7.83	3.89	2.46	0.083	0.095	2.096	0.232	0.295	0.101
T44	Dhoni-Quarters	8.2	138	7.48	2.42	2.783	0.069	0.073	1.938	0.155	0.33	0.131

T46	Walayar	14	146	7.96	0.76	2.045	0.073	0.117	2.689	0.199	0.232	0.106
T50	Kattilappara	15.8	141	5.4	4.16	3.447	0.059	0.172	1.437	0.429	0.419	0.071
T53	Vithura	43	88	4.49	14.91	2.58	-	-	-	-	-	-
T54	Nhaloor	12	206	4.05	17.59	2.53	-	-	-	-	-	-
T60	Kuttippara	26	167	5.76	10.19	1.89	-	-	-	-	-	-
T63	Achankovil	22	194	5.97	10.46	1.49	-	-	-	-	-	-
T64	Konni	10	388	5.69	14.77	2.32	-	-	-	-	-	-
T67	Kannavam	41	164	5.72	19.02		-	-	-	-	-	-

- samples not analysed

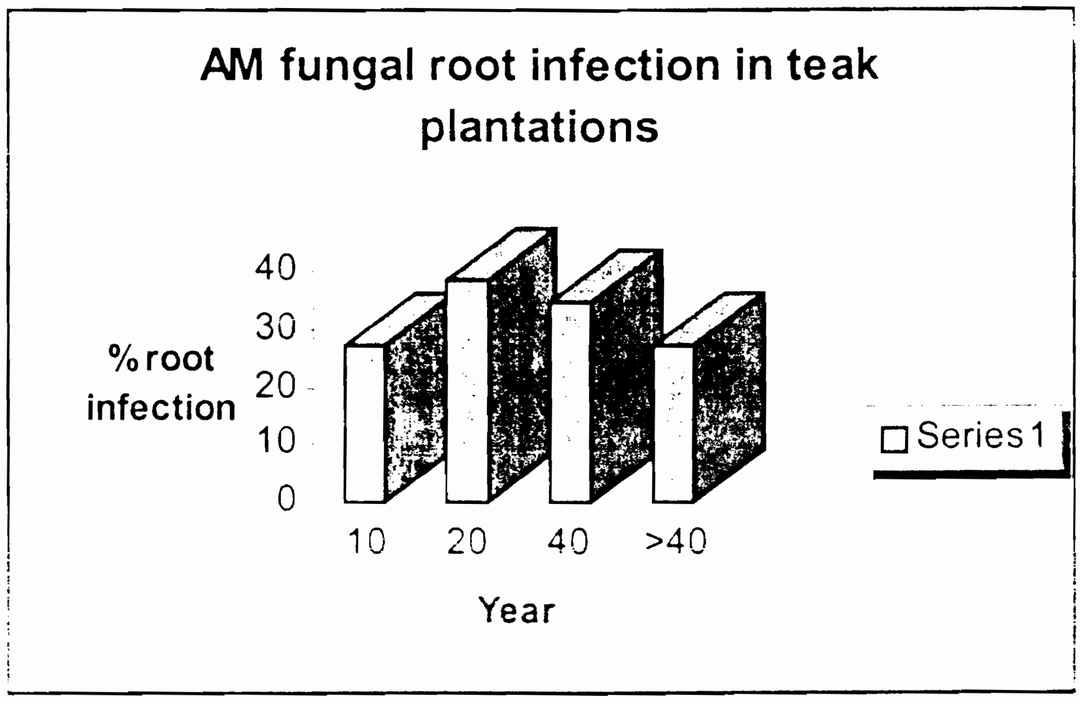


Figure 5: AM fungal root infection in teak plantations of different age

The relation between AM fungal root infection percentage and the set of extraneous variables like altitude, age of the plantation and the soil variables like soil pH, soil moisture content (MC%), organic carbon (OC%), total nitrogen (N) and phosphorus (P) percentage, exchangeable cations (Na, Ca, Mg) were analysed through multiple linear regression. Stepwise regression employed to identify the most influential set of variables affecting the root infection percentage showed that soil pH, altitude, soil magnesium (Mg) and sodium (Na) levels influenced the root infection.

However, of these, soil pH accounted for around 35 per cent of the total variability in AM root infection percentage followed by altitude, magnesium and sodium levels. Effects of all the above variables were significant at 0.05 level, while that of the variables like soil moisture content (MC%), organic carbon (OC%), total available nitrogen (N) and phosphorus (P) and cation (Ca), etc. were found insignificant in the model used (Tables 17-18)

Table 17a: Analysis of variance of data on AM root infection percentage, altitude and soil physical and chemical characteristics

Source	Degree of freedom	Sum of squares	Mean square	*F* value	*P* > *F*
Model	4	4908.55560	1227.13890	14.16	<.0001
Error	46	3985.46546	86. 64055		
Corrected Total	50	8894.02106			

*Significant at P = 0.05

Table 17b: Parameter estimates of regression model relating AM fungal root infection percentage, altitude and soil physical and chemical characteristics

Variables	Parameter Estimate	Standard Error	Type II SS	*F* value	*P* >*F*
Intercept	101.50613	11.13848	7195.42570	83.05	<.0001
Altitude	0.02619	0.00625	1519.71229	17.54	0.0001
Soil pH	-7.70467	1.46454	2397.86919	27.68	<.0001
Na	-296.07794	129.42053	453.44745	5.23	0.0268
Mg	-43.03769	15.23967	690.98420	7.98	0.0070

* Significant at P= 0.05

Table 18: Summary of stepwise selection

Step	Variables entered	Partial R^2	Model R^2	C (p)	*F* value	*P* >*F*
1	Soil pH	0.3537	0.3537	23.0251	26.82	<.0001
2	Altitude	0.0786	0.4324	16.5040	6.65	0.0130
3	Mg	0.0685	0.5009	11.0781	6.45	0.0144
4	Na	0.0510	0.5519	7.3539	5.23	0.0268

* Significant at P = 0.05

3.1.3. AM root infection and AM fungal spores in rhizosphere soils

For retrieving the AM fungal spores from the soil samples, wet sieving-decanting as well as wet sieving-centrifugation methods were employed. Both the techniques yielded almost similar results as far as total AM spore count is concerned. However, AM fungal spores retrieved by wet sieving-centrifugation method often lose hyphal attachments to the spores which are more crucial for taxonomic investigations.

The AM spores retrieved from different soil samples ranged from 29 to 810 with a mean value of 216 per 10 g of soil. The AM fungi produce the reproductive structures viz., spores and sporocarps in soil or in infected root tissues. Production of the asexual spores depends on the intrinsic

characteristics of the AM fungal species, and influenced by the physical and chemical characteristics of the soil and also the host plants. Most AM fungi produce spores in large numbers, while a few species produce a limited number of spores in the substratum. Also the available technology employed to assess the spores in soil samples may be inefficient to record all the available spores. Hence, there is limitation in assessing the spore density of AM fungi in soils and requires periodic assessment to get a clear picture about the AM fungal population dynamics. However, total spore density and species-wise frequency were taken into consideration to assign the most predominant AM fungal species in the population. The relation between AM fungal spore density in rhizosphere soil and AM fungal root infection in teak showed a weak linear relation; the correlation coefficient was found non-significant (Figure 6).

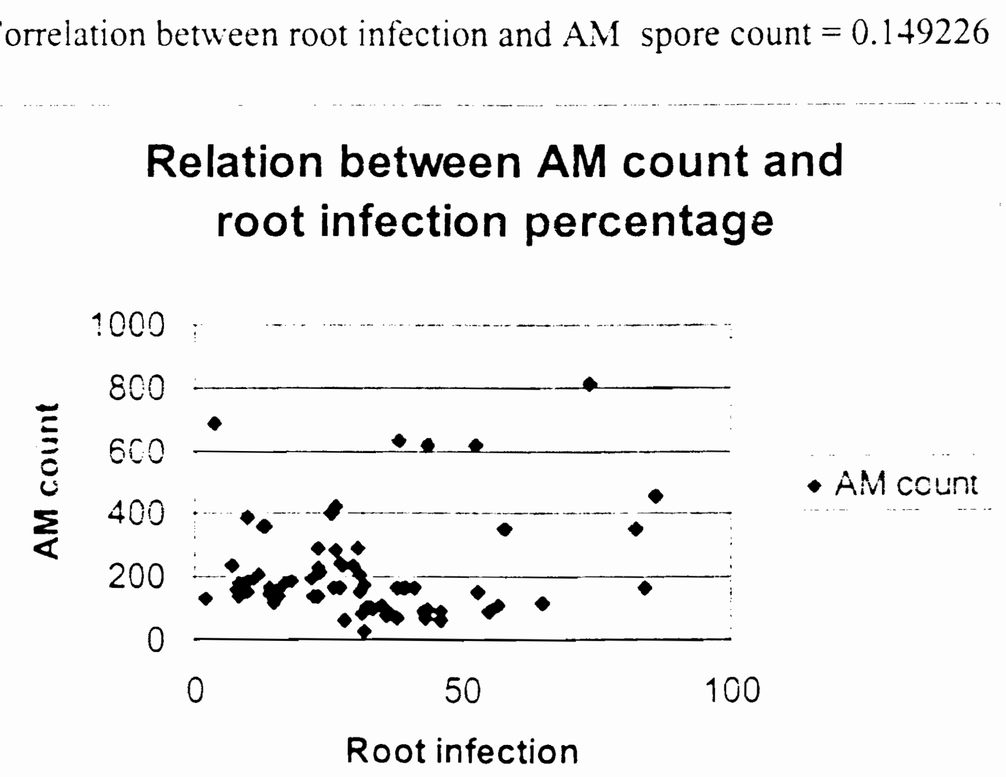


Figure 6: Relation between AM fungal spore density and AM fungal root infection

3.1.4. AM fungal diversity in teak plantations

Teak exhibited varying degree of mycorrhizal root infection under different edaphic and environmental conditions. The AM fungi associated with it also showed diversity in their temporal and spatial distribution. Altogether, 85 species of Glomalean fungi belonging to six genera viz., *Glomus*, *Acaulospora*, *Gigaspora*, *Entrophospora*, *Scutellospora* and *Sclerocystis* were recorded from the rhizosphere soils from 70 teak plantations (Plates 2-3). The AM fungal community in soils under teak consisted of 12 to 39 species belonging to different genera with a mean spore density of 211.85 per sample plot (Figure 7; Table 19).

Table 19: Distribution of AM fungi in soils under teak plantations in the State

Sl. No.	AM fungi	No. of AM fungal species	Mean No. of AMF spores per plantation	Total No. of AM fungal spores
1	*Glomus*	43	119.44	8361
2	*Sclerocystis*	7	44.52	3117
3	*Scutellospora*	13	8.98	629
4	*Acaulospora*	13	20.35	1425
5	*Entrophospora*	2	1.0	70
6	*Gigaspora*	7	7.2	504
7	Unidentified	-	10.34	724
	Total	85	211.85	14830

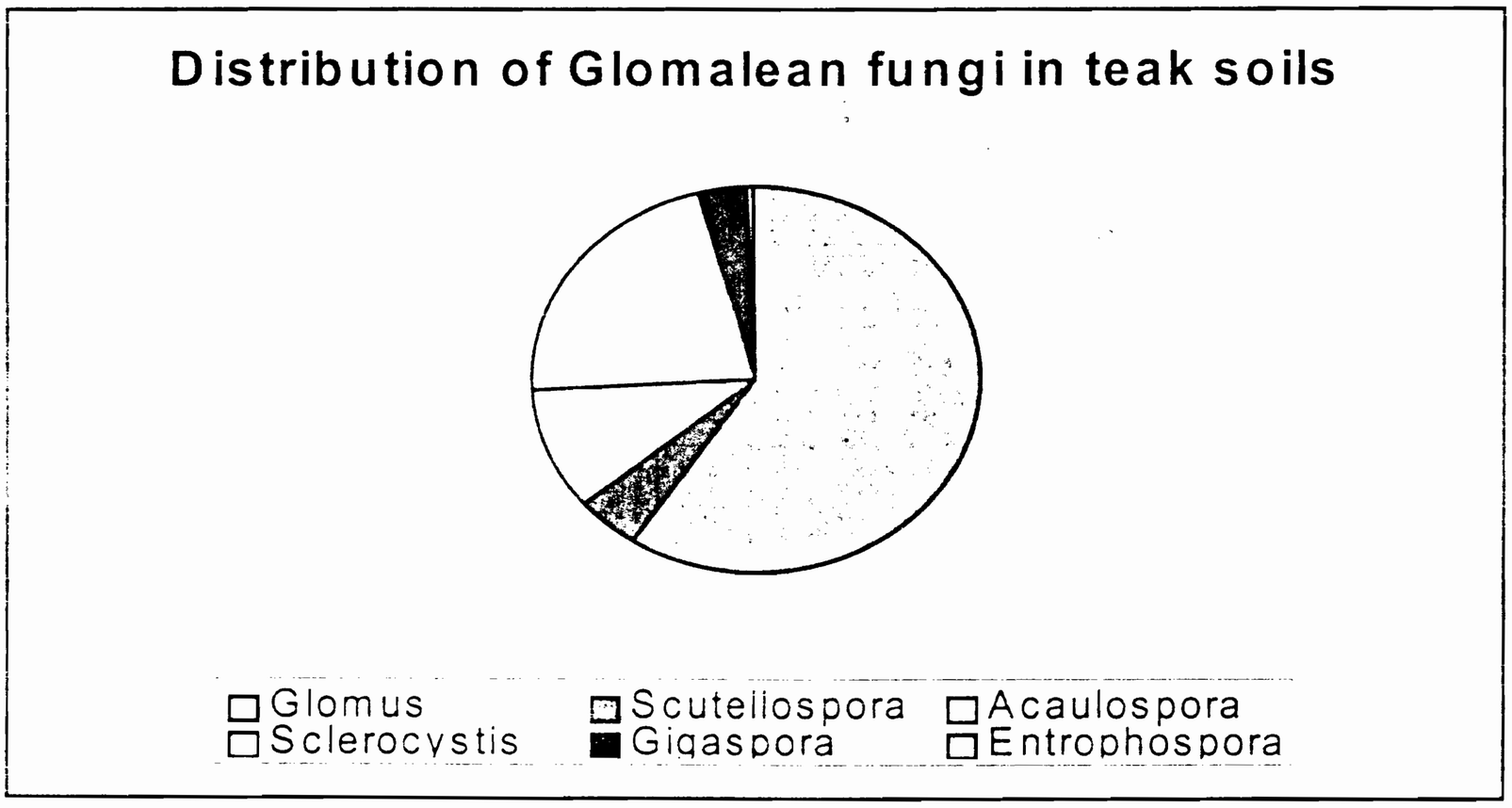


Figure 7: Distribution of Glomalean fungi in soils under teak plantations

Among the Glomalean fungi, *Glomus* was the most predominant genus in all the rhizosphere soils samples collected from teak plantations in the State. A total of 44 species belonging to *Glomus* were identified. Of these, 24 species were found widespread in teak soils throughout the State and their mean spore density ranged from 0.76 – 30.61 per sample plot. Among these, *Glomus australe* (Berk.) Berch, *G. botryoides* Rothwell & Victor, *G. deserticola* Trappe, Bloss & Menge, *G. fasciculatum, G. geosporum* (Nicol. & Gerd.) Walker, *G. macrocarpum* Tul. & Tul, *G. mosseae, G. multicaule* Gerd & Bakshi are the most frequently encountered species (Plates 2,3) and their spore density ranged from 3.65 – 30.61 (Figure 8). Another 16 *Glomus* species were found sparsely distributed in soils under teak in the State with a mean spore density of 0.028 – 0.385 per plot.

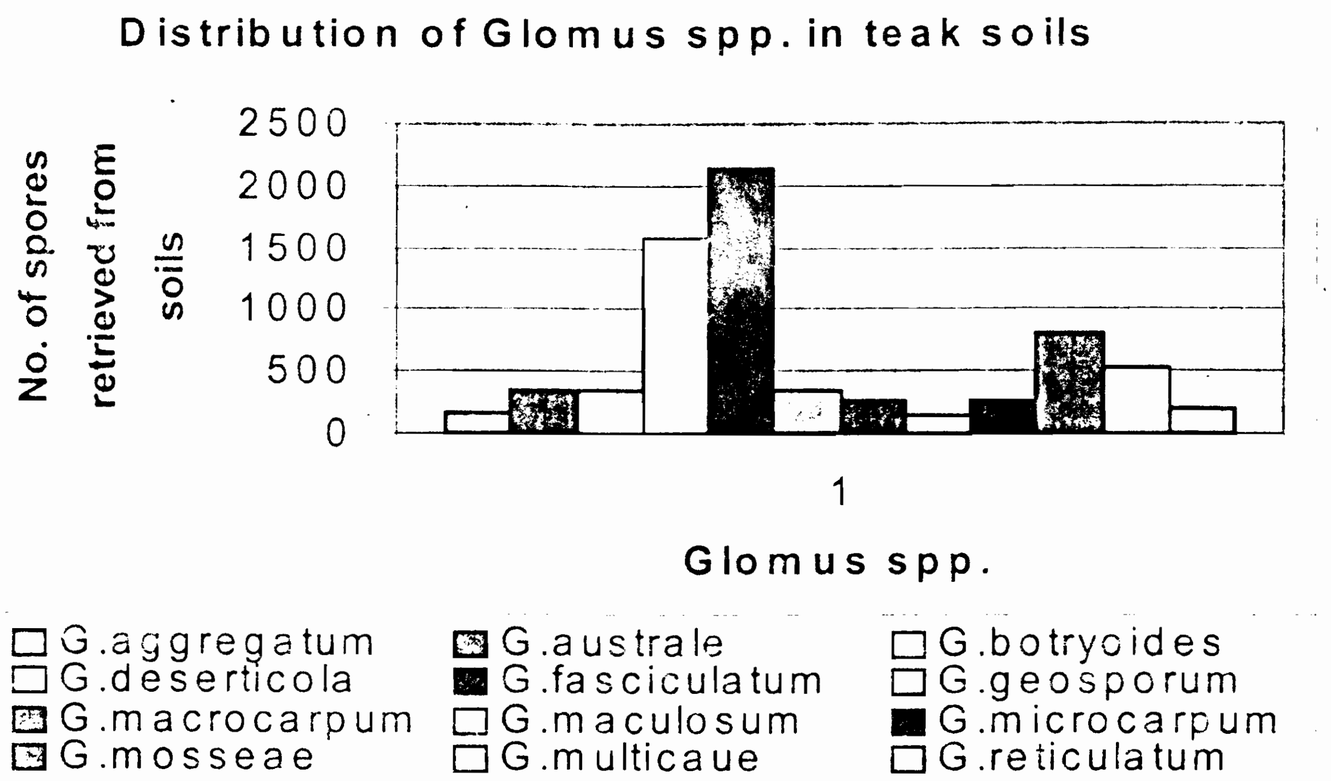


Figure 8: Distribution of *Glomus* spp. in soils under teak plantations

Thirteen species of *Scutellospora* were recorded from the teak rhizosphere soils (Plate 9). Among these, *Scutellospora erythropa* (Koske & Walker) Walker & Sanders, *Scut. heterogama* (Nicol. & Gerd.) Walker & Sanders, *Scut. nigra* ((Redhead) Walker & Sanders, and *Scut. persica* (Koske & Walker) Walker & Sanders were the most widely distributed species (Figure 9). Many spores belonging to *Scutellospora* could not be identified up to species level due to insufficient murographic data.

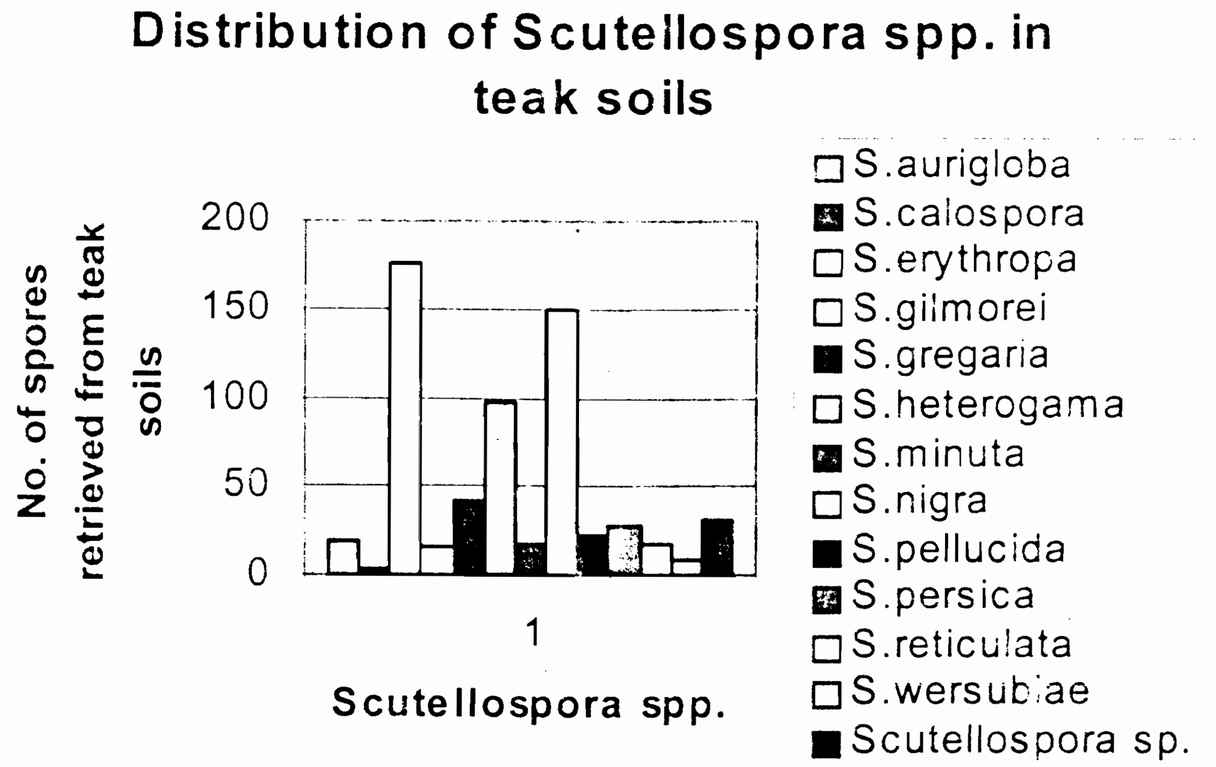


Figure 9: Distribution of *Scutellospora* spp. in soils under teak plantations

A total of 15 *Acaulospora* species were recorded from the teak rhizosphere soils from the State. The spore density of individual species varied from 1.14 – 8.08 and the mean spore density of of sample plot recorded was 20.35. *Acaulospora appendicula*, *A. scorbiculata* Trappe, *A. rehmii* Sieverding & Toro, *A. spinosa* Walker & Trappe were the most frequently encountered species in teak soils (Plates 6,7). Even though, the spore density recorded was comparatively less than the above species, *A. bireticulata* Rothwell & Trappe, *A. foveata* Trappe & Janos and *A. delicata* Walker, Pfeiffer & Bloss were also represented in most of the teak soils (Figure 10). A large number of spores (> 40) of *Acaulospora* could not fit into descriptions of known species. Even though, the present study indicates a predominance of *Glomus* over other AM fungal genera, the genus *Acaulospora* represented all the soil samples from teak plantations and is one of the important component of the AM fungal community.

The genera *Acaulospora* and *Scutellospora* are diverse in the tropics (Walker, 1992; Allen *et al.*, 1995) and are often associated with acidic soils (Morton, 1986; Abbott and Robson, 1991). Similar observations have also been made in the tropical soils by Raghupathy and Mahadevan (1993), Thapar and Khan (1985) and Muthukumar and Udaiyan (2000). In the present study also *Acaulospora* and *Scutellospora* species recorded a moderately high frequency of occurrence in most of the soil samples. The soil samples from teak plantations except in Olavakkod, Walayar and Kodanad Forest Ranges were moderately to highly acidic. However, no difference could be recorded on their distributional pattern in near neutral or basic soils.

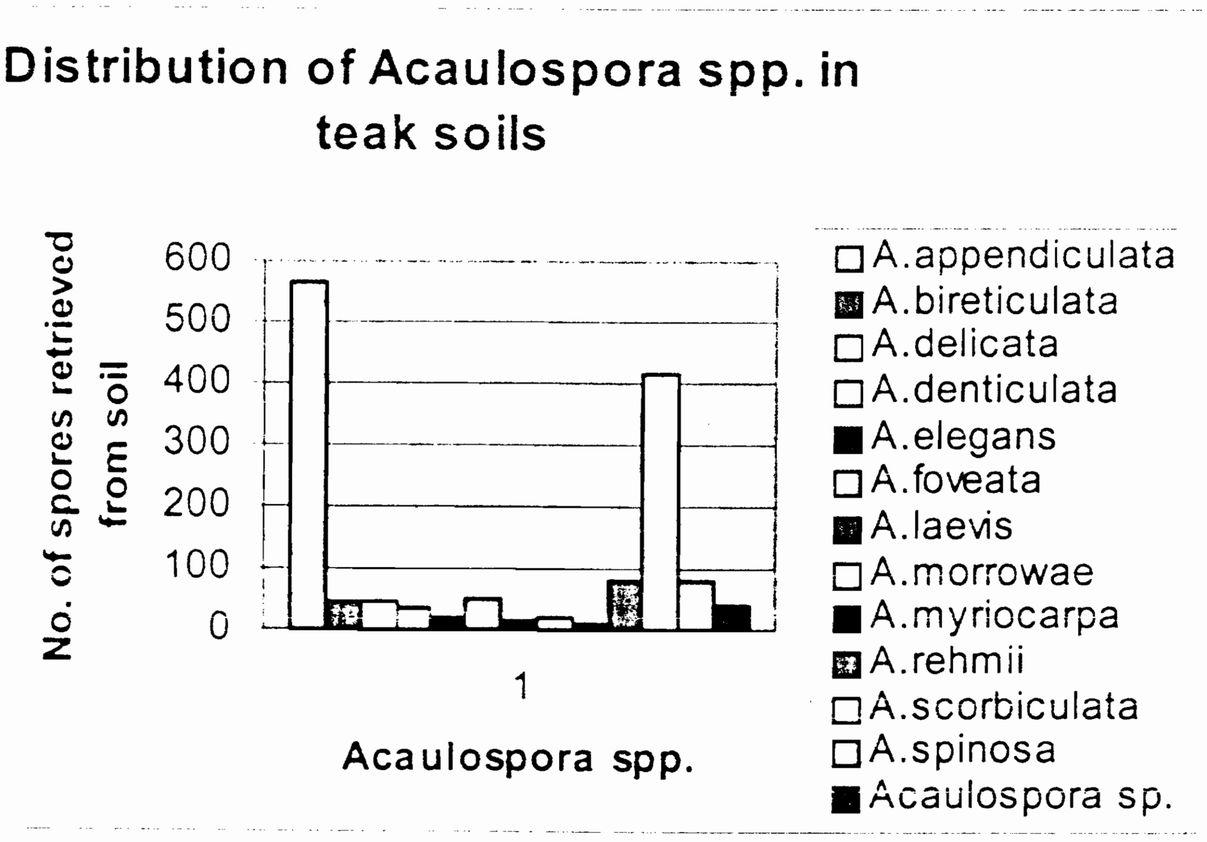


Figure 10: Distribution of *Acaulospora* spp. in soils under teak plantations

Seven species of *Gigaspora* were recorded from the rhizosphere soils collected from different teak plantations with a mean spore density of 7.2 per sample plot. Among these *Gigaspora albida* Schenck & Smith, *Gi. decipiens* Hall & Abbott and *Gi. gigantea* (Nicol. & Gerd.) Gerd. & Trappe (Plate 8) were the most frequently observed and widely distributed species in teak plantations (Figure 11). Many spores (> 39) belonging to the genus *Gigaspora* could not be identified up to species level due to want of more murographic information. Usually *Gigaspora* and *Scutellospora* were observed more frequently in sandy soils. *Gigaspora* species have been reported to predominate in soils with a high sand content (Lee and Koske, 1994).

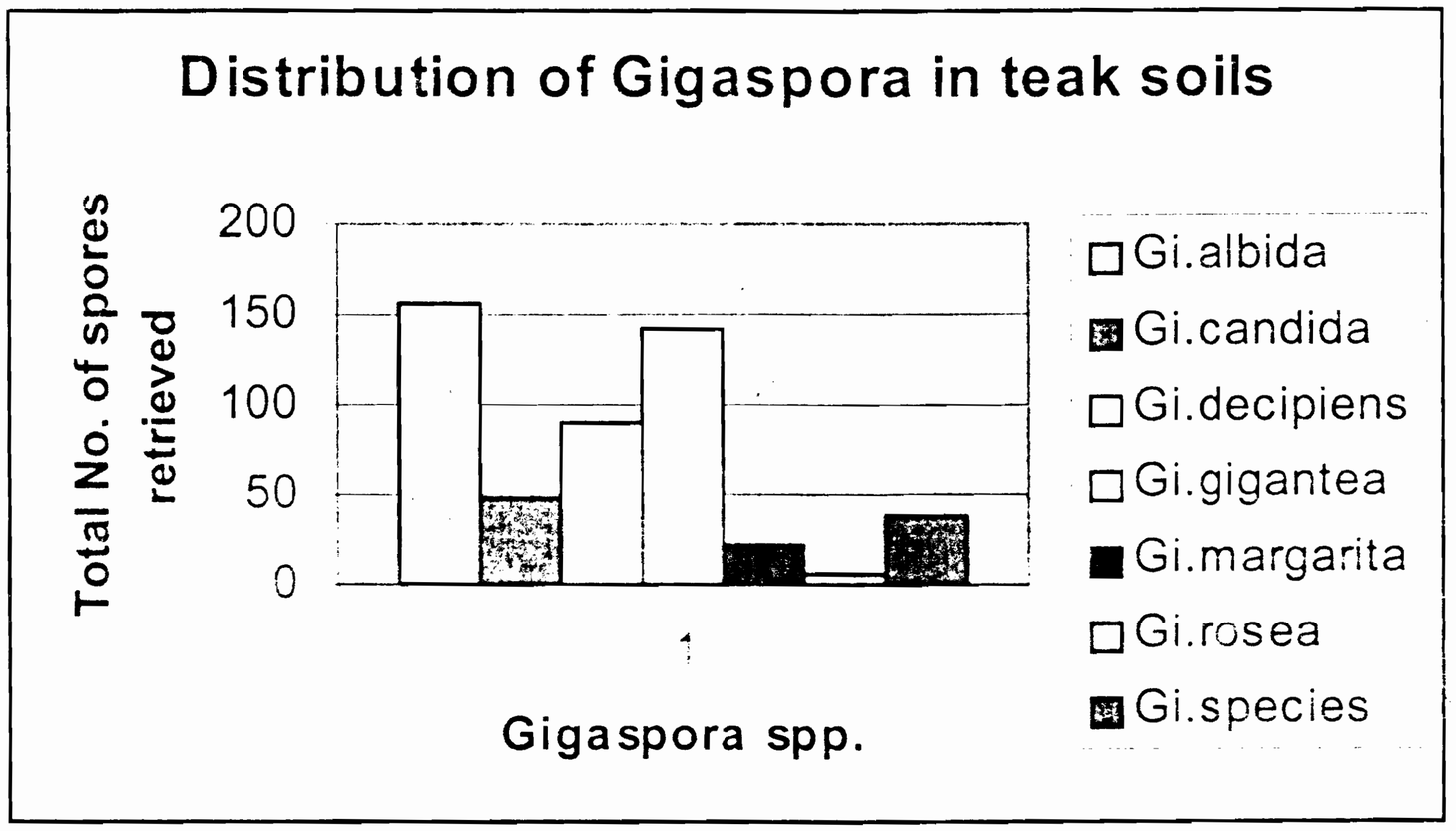


Figure 11: Distribution of *Gigaspora* spp. in soils under teak plantations

Seven species of *Sclerocystis*, viz., *S.clavispora* Trappe, *S. coremeoides* Berk. & Broome , *S. dussii* (Pat.) von Hohn., *S. microcarpus* Iqbal & Bushra, *S. pachycaulis* Wu & Chen, *S. rubiformis* Gerd. & Trappe, and *S. sinuosa* Gerd. & Bakshi were recorded in soils from teak plantations (Plate 5), suggesting the common and diverse occurrence of this genus in tropical plantation soils. Among these, *Sclerocystis microcarpus* and *S. clavispora* are the most widely distributed species (Figure 12). *Sclerocystis dussii* and *S. rubiformis* were recorded from 36-year-old and 20-year-old teak plantations respectively at Baveli (Begur Forest Range) and Irumpupalam (Vazhachal Forest Range). *Sclerocystis coremeoides* was recorded from 40-year-old teak plantation at Mannarappara and *S. sinuosa* was recorded from 46-year-old teak plantation at Naikatty (Tholpetty Forest Range), 37year-old teak plantation at Perumthode (Kodanad Forest Range), and 50-year-old plantation at Kottappara

(Kodanad Forest Range). The mean spore density was 44.52 spore per sample plot. Species of *Sclerocystis* produce spores in sporocarps and usually by wet seiving and decanting method, intact sporocarps are obtained apart from freed single spores. However, individual spores have been taken as propagule unit for the spore density studies and hence the comparatively high spore density per sample plot. Frequency of distribution of *Sclerocystis* species was found comparatively low when compared with other Glomalean fungi.

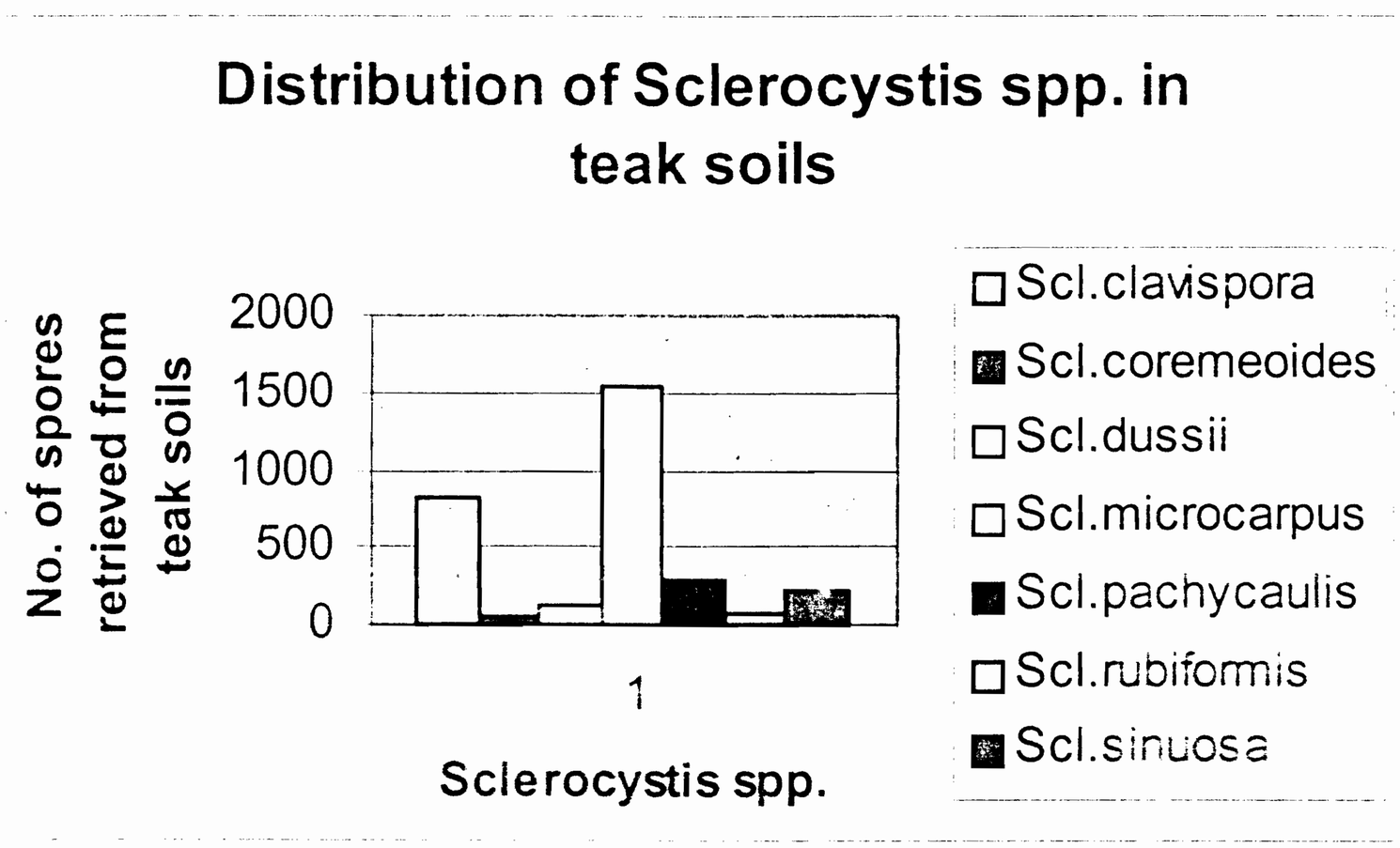


Figure 12: Distribution of *Sclerocystis* spp. in soils under teak plantations

Almedia and Schenck (1990) transferred most of the *Sclerocystis* species to *Glomus* but retained *S. coremeioides* Berk. & Br. based on four unique characters such as: spore formation individually on an unbranched sporophore, arrangement of spores in hemispherical layer, delimitation of spores by a well-defined septum and distal or lateral formation of sporocarps from older sporocarps appear fused in a column or branch. They applied Medeline's (1979) mode of sympodial conidial formation to distinguish the spore ontogeny of *Glomus* from *Sclerocystis*. Furthermore, Almedia and Schenck (1990) indicated similarities in spore ontogeny in several *Sclerocystis* and *Glomus* species. However, recent studies on spore ontogeny and sporocarp formation in several *Sclerocystis* species by Wu (1993) indicated the affinity of *S. coremeoides* to other *Sclerocystis* species and retained all the transferred species under *Sclerocystis*. The arrangement of spores in sporocarps in *Glomus* is random compared with the orderly arrangement in *Sclerocystis*. Hence the dimorphic species of *Glomus*

probably represents a transitional taxa linking *Glomus* and *Sclerocystis*. *Sclerocystis* spp. have been reported in soils under permanent vegetation and were absent in cultivated soils (Sieverding, 1989).

Among the Glomalean fungi, *Entrophospora* represented only two species, viz., *Entrophospora columbiana* Spain & Schenck and *E. infrequens* (Hall) Ames & Schneider in rhizosphere soils of teak plantations in the State. The distribution of the genus was found very limited and many of the spores (>58) belonging to *Entrophospora* could not be identified up to species level due to lack of characteristic features. In general, *Entrophospora* showed a poor representation in the Glomalean fungal community in the teak rhizosphere soils.

Table 20: AM fungi in teak plantations and their relative abundance (Teak sample plot No.T1 to T18)

Sl. No.	AMFungi	Number of AM fungal spores in teak rhizosphere soil samples																	
		T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12	T13	T14	T15	T16	T17	T18
1	*G.aggregatum*		18				9									4	6		8
2	*G. albidum*		12										2						
3	*G. ambisporum*			8	4														
4	*G. australe*	52	28		25	14			31				6	5		2			2
5	*G. boreale*					9	4	3	6	17									
6	*G. botryoides*			28	8		7		26		17		14			6	8	4	7
7	*G. canadense*	4					4			6		2			2	2	7		1
8	*G. claroideum*						3												
9	*G. constrictum*			5												1	2		
10	*G. convolutum*			11		6													1
11	*G. delhiense*								13								6		
12	*G. deserticola*	78	56	62	48	23	29	19	66	5	149	13	4		6	4	16	6	5
13	*G. fasciculatum*	116	72	26	65	58	27	44	192	32	104	29	16	23	18	16		12	13
14	*G. geosporum*	12	8	12	21		9	11	26	15	6	6	4	4	3	2	5	8	3
15	*G. globiferum*									7	2	1		2	2		2	2	2
16	*G. glomerulatum*		12																
17	*G. hoi*							2	2										
18	*G. intraradices*		6	4	12	9			5	6					2				
19	*G. lacteum*	3												3			2		
20	*G. macrocarpum*		12	3	6	12										6	6	4	3
21	*G. maculosum*					14	2	5	21	8	2					2	1		
22	*G. magnicaule*																2		3
23	*G. melanosporum*	18														7	2		
24	*G. microcarpum*		12	9	12	15	2	10	14	11	9	7	4	6	6				
25	*G. monosporum*			3	3														
26	*G. mosseae*	22	14	32	48		5		44	18	13	8	16	5	7		6		6
27	*G. multicaule*		12	34	56	36			86	50	77	6	9	7	4			4	5
28	*G. multisubtensum*																2		
29	*G. pallidum*						6				11		2						
30	*G. pulvinatum*													3					

31	*G. reticulatum*	12					4	8	24	9	5	2	2			5	4	3	3
32	*G.tenebrosum*	60							8	4									
33	*G. tenue*						9										6	8	
34	*G. tortuosum*									2	11		6						
35	*Glomus* sp.	4	6	6	5	8			29	9	6	6	6	5	8	3	3	2	
36	*Sclero. clavispora*									10		20	12						
37	*S. dussii*							22	62										
38	*S. microcarpus*	140		260	180								36				32		
39	*S. pachycaulis*									60									
40	*S. rubiformis*							44	36										
41	*S. sinuosa*			80															
42	*Scut. auriglobа*			2	2					2									
43	*S. erythropa*	12	6		6					2		3	2	2	3	3	1	2	2
44	*S. gregaria*								7					1					
45	*S. heterogama*	10	4																
46	*S. nigra*																2	2	
47	*S. pellucida*						1												
48	*S. persica*						2									2			
49	*S. reticulata*									1									
50	*Scutellospora* sp.		4	4		6			8										
51	*A.appendicula*	24	32	4	12	9	6	7	18	18	5	8	3	4	6	6	4	4	2
52	*A. biretticulata*								6	6		3	3	1					
53	*A. delicata*								7	4		6							2
54	*A. denticulata*								16	2	1			1					
55	*A. elegans*	4	8																
56	*A. foveata*										6	3	4		2	3		1	
57	*A. laevis*									1						1			
58	*A. morrowae*																2		
59	*A. rehmii*									4	2	2	5	2	3	2	4	2	
60	*A. rugosa*																		2
61	*A. scorbiculata*	20	22	7	21	12	7	4	11	13	4	9		6	6	4	6	4	3
62	*A. spinosa*										1								
63	*Acaulospora* sp.				8	9	1	2	6	6									
64	*E. colombiana*										3								
65	*Entrophospora* sp.												2					1	
66	*Gigaspora albida*	8	2				1		6	3	1	2		3	1		2		2
67	*G. candida*									11								1	
68	*G. decipiens*									7	2	4	1	2	1		3		1
69	*G. gigantea*						5			2	1	2	3	1	2	3		1	
70	*G. margarita*																		
71	*Gigaspora* sp.					3										1	2		
72	Unidentified	22	11	13	89	22	31	50	76	6	12	22	9	9	11	15	12	10	8
	Total No. of species	19	21	21	20	17	22	14	28	33	24	22	24	21	19	23	28	20	23
	Shannon index	2.3935	2.6621	2.1455	2.3689	2.6605	2.6226	2.1875	2.8187	3.0032	2.1751	2.7160	2.7990	2.7302	2.6613	2.8348	2.9666	2.7778	2.8886
	Simpson index	7.9736	10.408	4.6578	7.3080	11.084	9.8748	7.0129	10.7269	13.551	5.2959	11.396	11.3715	10.6711	11.2764	12.9199	12.9035	13.121	14.445

Table 21: AM fungi in teak plantations and their relative abundance (Sample plots No. T19 to T36)

Sl. No.	AMFungi	Number of AM fungal spores in teak rhizosphere soil samples (T19-T36)																	
		T 19	T 20	T 21	T 22	T 23	T 24	T 25	T 26	T 27	T 28	T 29	T 30	T 31	T 32	T 33	T 34	T 35	T 36
1	*G.aggregatum*						8			4	4		2			4			
2	*G. albidum*									1	2			2	1			3	2
3	*G. australe*	3		6			2		2		3		8	11	3	8	14	16	9
4	*G. boreale*																	2	
5	*G. botryoides*	5					7	5	3	3	4		5	2	3	9	3	28	6
6	*G. caledonium*																		
7	*G. canadense*	2	3	2			2	2	1	2			2			2		2	2
8	*G. claroideum*																		4
9	*G. constrictum*	1																	
10	*G. convolutum*				5	7							1		5			8	
11	*G. delhiense*												2						
12	*G. deserticola*	5	5		113	120	5	5		8	6		53	58	24	33	28	71	102
13	*G. diaphnum*																		1
14	*G. fasciculatum*	16	14	32	72	68	32	16	9	17	15	2	19	50	23	16	43	101	24
15	*G. fulvum*	1	1								2		1						
16	*G. geosporum*		4	12					2				9	10	6	6	5	6	
17	*G. globiferum*		2				1						2	3	4	7	2	25	
18	*G. glomerulatum*				10	8				1	1					3	1		
19	*G. intraradices*	4			2	2		2					1				3	2	7
20	*G. lacteum*	2	1	2			2	1					2		1				1
21	*G. macrocarpum*	6		18			4	6	4				5	3	3	3	2		
22	*G. maculosum*		3		13	16	3	3		2	1		1	1			2	3	3
23	*G. magnicaule*				6	4													4
24	*G. melanosporum*				2					1						4			9
25	*G. microcarpum*		6				9	8						6		8		7	2
26	*G. mosseae*		8	14		44	12	4			6		14	46	7	8	12	14	24
27	*G. multicaule*	3	4			2		2			2		9	27	4	8	9	15	14
28	*G. multisubtensum*				5	5										2			
29	*G. pallidum*			2															4
30	*G. pansihalos*							1											2
31	*G. pulvinatum*												2						
32	*G. pustulatum*							1											
33	*G. reticulatum*	2	2	9	2		2	1	1	2	1		2	1	2	2	2	3	3
34	*G.tenebrosum*										2			3					
35	*G. tenue*			6						5									4
36	*G. tortuosum*													1	4	3	2		10
37	*G. tubeforme*														8				3
38	*Glomus sp.*		3	5			2							3	5				
39	*Scle. clavispora*											68							
40	*S. microcarpus*				110	120	24						24	60					
41	*S. pachycaulis*		18																
42	*S. sinuosa*														75				
43	*Scut. aurigloba*			2															
44	*S. calospora*						1						1						
45	*S. erythropa*	1	2	6			2			2	2	2	9	1	2				2

46	*S. gregaria*			4							1			3	2	4	1	2	3
47	*S. heterogama*	2										1		2	3		2	5	2
48	*S. minuta*													1	4			3	
49	*S. nigra*			4				2	2			3	2		5		3	2	4
50	*S. pellucida*																		1
51	*S. persica*						1			1						2			
52	*S. reticulata*			2			2												
53	*Scutellospora* sp.														2				
54	*A. appendicula*	4	5	7	3	3	3	2	1	3	4	13	25	15	7	4	11	4	9
55	*A. biretticulata*						2							2					
56	*A. delicata*									2	2		1		1	1		1	
57	*A. denticulata*											2							
58	*A. foveata*		2	2	2			2		1		3	3						
59	*A. laevis*		1																
60	*A. morrowae*			3			2							3					2
61	*A. rehmii*		5			4			1	1	2	6	3		2		2		1
62	*A. rugosa*																		
63	*A. scorbiculata*	2	2	4	7	7	3	2	2	2	2	9	21	19	7	2	4	8	9
64	*A. spinosa*														2		9		
65	*Acaulospora* sp.														2				
66	*E. colombiana*																	2	1
67	*E. infrequens*															2		3	1
68	*Entrophospora* sp.						1					1		4	8	1	3		2
69	*Gigaspora albida*	2	4	8					1				3	7	1			9	3
70	*G. candida*			2														3	
71	*G. decipiens*						3			3	3	4	2		1	1			2
72	*G. gigantea*		2									2		3	2		9		4
73	*G. margarita*											1						1	
74	*G. rosea*	1												3					
75	*Gigaspora* sp.			3													2		3
76	Unidentified	6	4	9	4	11	4	-	-	3	2	7	5	6	9	8	6	12	9
	No. of species	19	23	24	15	15	26	18	12	20	21	15	31	30	34	26	25	29	39
	Shannon index	2.6319	2.8242	2.7271	1.9536	1.9043	2.6911	2.5377	2.1893	2.5980	2.7446	1.7004	2.7716	2.6259	2.7519	2.8487	2.6902	2.5546	2.7387
	Simpson index	10.1404	12.5474	12.2813	5.0189	4.9271	9.3293	9.1253	6.6220	8.9043	11.1390	3.0508	10.4636	9.5917	7.7235	11.6988	9.4966	7.4037	6.9481

Table 22: AM fungi in teak plantations and their relative abundance (Sample plot No. T37 to T54)

Sl. No.	AMFungi	Number of AM fungal spores in teak rhizosphere soil samples (T37-T54)																	
		T37	T38	T39	T40	T41	T42	T43	T44	T45	T46	T47	T48	T49	T50	T51	T52	T53	T54
1	*G.aggregatum*		12		6	8	8					4					8		9
2	*G. albidum*	1		2	2		2		2		1	1				2	2	2	
3	*G. ambisporum*																		
4	*G. australe*	2	4	4	6	8	6	7	2			3					4	3	3
5	*G. boreale*																		2

6	*G. botryoides*	5	6	8	9		5			16	3						6		6
7	*G. caledonium*																	1	
8	*G. canadense*	3		1	1	1			3				4			3		2	
9	*G. claroideum*					3													
10	*G. convolutum*			2	2	6		4					2	3	3	4			
11	*G. deserticola*	51	11	11	3	22	19	22	6	23	6	13	11	9	9	.		.4	
12	*G. diaphnum*	7							2										
13	*G. fasciculatum*	25	23	21	22	17	16	27	11	13	16	22	21	18	26	18	19	16	37
14	*G. fulvum*		2	1														1	2
15	*G. geosporum*		9	12		3	2	8	1	3	5	7		6	6		4	2	
16	*G. globiferum*			2				3		1			7						
17	*G. glomerulatum*																	6	
18	*G. intraradices*	1			1	5	1	2											
19	*G. invermaium*																1		
20	*G. lacteum*	2	2	3		3		3	7		3				2	4	2		
21	*G. macrocarpum*	5	8	8				2	6	8	1		13	3	6	8	8	4	8
22	*G. maculosum*	6	2	5	2		2		2				2					2	2
23	*G. melanosporum*		5			14					7	6				4			
24	*G. microcarpum*					16	8	3											
25	*G. mosseae*	23	5	5	19	18	10	27	5			13	16	8	12	9	7	3	5
26	*G. multicaule*	2		3	2	9		7	11			21		4		3	2	2	
27	*G. multisubtensum*					5													
28	*G. occultum*									2									
29	*G. pallidum*				2														
30	*G. pansihalos*											2							
31	*G. radiatum*					26													
32	*G. reticulatum*	1		3	2	8	2		6	7	7		2	2			2	2	2
33	*G.tenebrosum*											1			3	3			
34	*G. tenue*											14						12	14
35	*G. tortuosum*	4	2	2	3	2								3		3	1		
36	*Glomus* sp.											1							
37	*Sclerocystis clavispora*														42				72
38	*S. microcarpus*					400								40					
39	*S. pachycaulis*				46												70		
40	*S. sinuosa*											30							
41	*S. aurigloba*											3			2	3		2	
42	*S. calospora*	1																	
43	*S. erythropa*	3	2	1		9	5	5	12	8	5		2		4		2	3	
44	*S. gilmorei*																		2
45	*S. gregaria*	4				2	3	1	2										2
46	*S. heterogama*	2	4	2		9	2	2	2	4	8		3			2	1		
47	*S. minuta*					6								2					
48	*S. nigra*	4	3	4	6	7	9	5	3	8	9	2	4	3	6			4	3
49	*S. pellucida*								6	3									
50	*S. persica*		1		3									1			2	1	1
51	*S. reticulata*								1		6						1		
52	*S.wersubiae*	2							4		3								
53	*Scutellospora* sp.					4		4											
54	*A. appendicula*	11	7	8	9	21	5	17	21	13	15	4	2	3	7	4	3	4	5
55	*A. biretticulata*		1			2	2	5						1				1	1

56	*A. delicata*					3		4									1		
57	*A. denticulata*	3	2			3													1
58	*A. elegans*												3					3	
59	*A. foveata*		2	2										1	1				
60	*A. laevis*				1		2	1				1							2
61	*A. morrowae*				2							3							
62	*A. myriocarpa*						4		5										
63	*A. rehmii*		2	2								2		1	2		1		
64	*A. scorbiculata*	6	6	3	8	26		31											3
65	*A. spinosa*					3	3	4	2	11	5	5	4	5	6	2	3	1	
66	*A. trappei*										1		1						
67	*Acaulospora* sp.										4								
68	*Entrophospora* sp.	3			1	1				5	5						1	1	
69	*Gigaspora albida*	1	2	2	2	5	3	3	4	14	5		2	2		2	2		2
70	*G. candida*	3		1	1	2	2				2							1	1
71	*G. decipiens*		1		3	9				2	3	2	1	3		1	1	1	4
72	*G. gigantea*	2	3	2	4	3	2	2	3	9	6	4					3	1	3
73	*G. margarita*	3				1		2											
74	*G. rosea*			1															
75	*Gigaspora* sp.	3	1		2	2					3								
	Unidentified	7	8	3	6	6		15	9	21	16	4	3	2	4	3	3	3	5
	No. of species	31	28	29	28	38	24	26	26	19	25	24	19	21	17	18	25	28	26
	Shannon index	2.7661	2.9808	2.9280	2.8172	2.0869	2.9224	2.8219	2.9730	2.7049	2.9954	2.6975	2.5214	2.4070	2.3264	2.6139	2.2942	2.9626	2.4461
	Simpson's index	9.0689	14.6329	13.1808	10.1064	2.9673	14.4328	12.3559	15.3581	12.8758	16.6012	10.9395	9.0908	6.4865	6.8062	10.0728	4.5895	13.3058	5.9451

Table 23: AM fungi in teak plantations and their relative abundance (Sample plots No. T55 to T70)

Sl. No.	AMFungi	Number of AM fungal spores in teak rhizosphere soil samples (T56-T70)															
		T 55	T 56	T 57	T 58	T 59	T 60	T 61	T 62	T 63	T 64	T 65	T 66	T 67	T 68	T 69	T 70
1	*G.aggregatum*				6	8		4		8						6	
2	*G. albidum*			2	2		2	1	2							2	
3	*G. australe*		4	6		2	6		5	3	3		1		4		5
4	*G. boreale*		1		12								2				
5	*G. botryoides*	7	3	4			6	6	7	5	7	3		5	7	5	11
6	*G. caledonium*										1						
7	*G. canadense*	2	2	2	3		3	1		2		3	4	1	2		2
8	*G. convolutum*	1		1		2		2	1		2					2	2
9	*G. delhiense*								2								
10	*G. deserticola*	5	7	12	9	9	8			7	18	13	6	8	8	4	9
11	*G. fasciculatum*	19	12	28	28	17	23	14	17	19	76	17	12	17	14	18	16
12	*G. fulvum*								2								2
13	*G. geosporum*	3		3	5	2	5	2	3	3	16				4	2	4
14	*G. globiferum*	2				1	1		2	2	7	2		3	3		
15	*G. glomerulatum*					2					2			1	4	1	

16	*G. hoi*	2															
17	*G. intraradices*	1		2	1		2		2	2				2	2		
18	*G. invermaium*											5			2		
19	*G. lacteum*	2	2	3	3	4	3	1			3			3			
20	*G. macrocarpum*		6			8	4	4	5	6	12		5	6	4	3	3
21	*G. maculosum*			1		2	2			2	3						5
22	*G. magnicaule*								1				1				
23	*G. melanosporum*		4							7	5			16	12	4	12
24	*G. microcarpum*	6			7	6			12		14		4	2	2	2	16
25	*G. mosseae*	12	6	6	12		9	7	9	13	28	8	9	11	8	5	9
26	*G. multicaule*							2			12						2
27	*G. multisubtensum*								1								
28	*G. occultum*												2				
29	*G. pallidum*					1											
30	*G. pansihalos*							1		2					2		
31	*G. pustulatum*									1							
32	*G. reticulatum*	2	1		2	2		2	3	3	6			6	6	1	
33	*G. tenue*																16
34	*G. tortuosum*	3	2	2	2		2		2	3		2		3	3	3	4
35	*G. vessiculiferum*	1				1		1			1				2		
36	*Scl. clavispora*	80	166		40		44				112				60		60
37	*S. coremioides*								48								
38	*S. dussii*							32									
39	*S. microcarpus*			70						62							
40	*S. pachycaulis*											84					
41	*S. sinuosa*														16	12	
42	*Scutellospora alborosea*											3					
43	*S. aurigloba*		1														
44	*S. calospora*	2										1		42			
45	*S. erythropa*	3	2	2	3	3	3	2	2	3	4		6			2	4
46	*S. gilmorei*				1					1	1	2		2	2	1	3
47	*S. heterogama*		2	1	2		3	1	2	3				4	4		4
48	*S. minuta*							2									
49	*S. nigra*	3		5		5			6		2		9		2		6
50	*S. pellucida*													5	5	2	
51	*S. persica*					2	1		2	2							3
52	*S. reticulata*				3		2										
53	*A. appendicula*	5	7	6	6	5	8	6	5	5	16		17	5	7	2	12
54	*A. biretticulata*					2	1		1	2	2			2	1		
55	*A. delicata*	1	1		1				1			2					2
56	*A. denticulata*			2							2						
57	*A. elegans*								2	1							
58	*A. foveata*		1	3										1	2		3
59	*A. laevis*				1						3	3					
60	*A. longula*												3				
61	*A. morrowae*					1	2										
62	*A. rehmii*		4		2	2	1			2	4			1	1		
63	*A. scrobiculata*	2	4	7		4	5	2	3	3	4			6	4	2	4
64	*A. spinosa*	1		2		1		2	2	1		2	3				
65	*Entrophospora* sp.	1		1	4	2	1		1	2	1			1	2		2

66	*Gigasp[illegible] albida*	1	2	1	2		2	2	3	3	5		4	4	4	2	2
67	*G. can[illegible]a*			2		2				4	7						3
68	*G. decipiens*	4				1	3	2		2		3	1	1	2		
69	*G. gigantea*	4	1	5	4	5	9	3	5		4			2	5	1	5
70	*G. margarita*		2		1						2					3	6
71	*G. rosea*								1	1							
	Unidentified	6	4	7	7	6	6	5	7	9					3	3	
	No. of species	28	25	27	27	29	29	25	33	34	33	16	17	27	33	24	31
	Shannon index	2.3	1.55	2.43	2.70	3.04	2.77	2.74	2.86	2.78	2.59	1.75	2.54	2.76	2.911	2.82	2.920
	Simpson index	4.5	2.12	5.67	9.37	15.8	9.36	9.09	9.08	7.78	7.23	3.05	10.3	9.68	9.307	11.6	10.72

3.1.5. Biodiversity indices

Relative abundance of AM fungi in teak plantation soils measured using Shannon-Wiener index and Simpson's index are given for each sample plots separately (Tables 20-23). Shannon-Wiener index ranged from 1.5532 to 3.0032, whereas Simpson's index ranged from 3.0508 to 16.6012.

Gamma diversity, and beta diversity of AM fungal species in teak plantation soils were worked out separately. Gamma diversity is the number of fungal species that occur in a heterogeneous region. Within this region, the fungi are adapted for the general conditions, but within different habitats they may have specialized for exploiting different resources. The actual species may be different in the habitats, so the species turnover is important. Beta diversity, the species turnover in a heterogeneous habitat was estimated by dividing gamma diversity by alpha diversity. Gamma and beta diversity of AM fungi estimated in teak plantation were 98 and 69 respectively.

3.2. Eucalypts

3.2.1. Arbuscular mycorrhizal association in eucalypts

A total of 41 eucalypts plantations belonging to nine different species (Table 2) located in different Forest Ranges in the State were sampled for studying the arbuscular mycorrhizal (AM) fungal association. Arbuscular mycorrhizal fungal infection in young feeder roots showed a great variation depending on the eucalypts species, soil chemical and physical factors, etc. All the *Eucalyptus* species sampled from different localities in the State showed arbuscular mycorrhizal structures in their feeder roots. Arbuscules, vesicles, intra-cellular hyphal coils, and intraradical hyphae were observed in the root samples. Arbuscules showed either fine or coarse branching. Variation in morphological characteristics of fungal structures observed within the same root samples indicated the colonization by different AM fungal species (Plate 1). The overall extent of root colonization varied from 2.00 to 58.00 per cent. The highest percent AM fungal root infection (58%) was registered in root samples collected from *Eucalyptus grandis* plantation at Pamba, Vallakkadavu and the lowest per cent root infection was also recorded in root samples from *E. grandis* at Vattavada, Devikulam. *Eucalyptus tereticornis* and *E. camaldulensis* showed a mean root infection of 30 per cent. *E.grandis* recorded a mean root infection of 24.86 per cent. While *E. pellita*, *E. deglupta*, *E globulus* and *E. tessellaris* showed 13, 23.8, 24 and 18 per cent root infections respectively. In both *E. urophylla* and *E. regnans* root samples, 11 per cent root infection was recorded (Tables 24, 25).

Physical and chemical properties of the rhizosphere soils from the eucalypt plantations differed at a wide range. Most soils were moderately to highly acidic and soil pH ranged from 3.9 to 5.7. Soil moisture content in the eucalypts plantations ranged from 1.73 to 29.8 %. Organic carbon percentage varied from 1.747 to 4.754 with a mean value of 3.07 per cent. Most of the soil samples showed high organic carbon and exhibited more than 10:1 ratio with total nitrogen (N) per cent which indicates the high nutrient status of the rhizosphere soils under eucalypts. Soil chemical characteristics such as exchangeable cations and total nitrogen (N) and phosphorus (P) in the soil were studied for 11 out of 41 soil samples from eucalypts plantations. Exchangeable cations varied largely from sample to sample. Sodium (Na) ranged from 0.048 to 0.084 with a mean value of 0.055 and potassium (K) ranged from 0.032 to 0.185 with a mean value of 0.0647; calcium (Ca) ranged from 0.094 to 0.505 with a mean value of 0.2887 and magnesium (Mg) ranged from 0.027 to 0.095 with a mean value of 0.0614. Available nitrogen (N) ranged from 0.321 to 0.628 per cent and available phosphorus (P) ranged from 0.0602 to 0.1425 per cent (Table 24).

Table 24: AM root infection in different *Eucalyptus* spp. and physical and chemical properties of rhizosphere soils

Sample plot No.	Species	AM root infection %	AM spore count	MC%	Soil pH	OC (%)	K meq/ 100g	Na meq/ 100g	Ca meq/ 100g	Mg meq/ 100g	N (%)	P (%)
E1	*E.tereticornis*	24.2	383	1.7	5.1	1.747	0.061	0.084	0.154	0.08	0.337	0.1326
E2	*E.camaldulensis*	19	156	1.73	6.4	3.654	0.185	0.053	0.367	0.044	0.476	0.1312
E3	*E.pellita*	13	118	4.99	3.9	2.700	0.132	0.056	0.316	0.055	0.381	0.1302
E4	*E.urophylla*	11.1	229	3.6	5.6	3.105	0.039	0.051	0.45	0.095	0.503	0.1234
E5	*E.tereticornis*	16	140	3.41	6.3	3.613	0.049	0.058	0.505	0.057	0.628	0.1244
E6	*E.grandis*	24	170	3.95	5.7	2.513	0.038	0.048	0.143	0.027	0.354	0.1425
E7	*E.deglupta*	23.8	141	5.6	5.4	2.679	0.032	0.051	0.094	0.074	0.35	0.1394
E9	*E.tereticornis*	26	203	5.95	4.7	4.754	0.048	0.051	0.349	0.045	0.46	0.0715
E10	*E.tereticornis*	21	144	2.8	5.1	3.455	0.043	0.051	0.186	0.044	0.412	0.0602
E11	*E.tereticornis*	25.1	333	3.03	4.7	3.047	0.043	0.051	0.281	0.068	0.404	0.0718
E22	*E.globulus*	24	76	31.1	4.85	9.93	-	-	-	-	-	-
E26	*E.tereticornis*	55	129	6.75	4.27	1.62	-	-	-	-	-	-
E28	*E.regnans*	11	83	24.8	4.58	4.58	-	-	-	-	-	-
E37	*E.tereticornis*	29	79	8.90	3.61	4.69	-	-	-	-	-	-
E38	*E.camaldulensis*	41	93	5.1	3.63	2.49	-	-	-	-	-	-
E39	*E.tereticornis*	45	140	14.97	4.72	2.17	-	-	-	-	-	-
E40	*E.tereticornis*	50	74	9.15	4.85	1.80	-	-	-	-	-	-

- samples not analysed

All the eight *Eucalyptus* species studied showed almost similar trend in AM fungal root infection. *E. grandis* plantations at Vattavada (Devikulam Forest Range), Vallakkadavu and Uppupara (Vallakkadavu Forest Range) showed very low per cent AM fungal root infection (2 to 7%), however, maximum per cent root infection of 58 per cent was also recorded from 7-year-old *E. grandis* plantation at Pamba, Vallakkadavu Forest Range (Table 25). *Eucalyptus* species is well known for their ectomycorrhizal association and in older plantations ectomycorrhizal dependency is more pronounced than the arbuscular mycorrhizal dependency. The nature and type of mycorrhizal association largely depends on the host as well as the edaphic and environmental factors.

Stepwise regression analyses were carried out utilizing 11 data points to determine the most influencing factor(s) for the AM fungal root infection in eucalypts. Of the variables analyzed (soil pH, soil MC%, OC%, total AMF spore count, N%.P%, cations, etc.), only calcium (Ca) was found to be the influential variable affecting the root infection with a R^2 of around 60% (Tables 26,27). However, correlation could not be made on AM fungal root infection percentage and AM fungal spores present in the soils. The correlation coefficient was non-significant, although a weak linear relation is indicated (Figure 13).

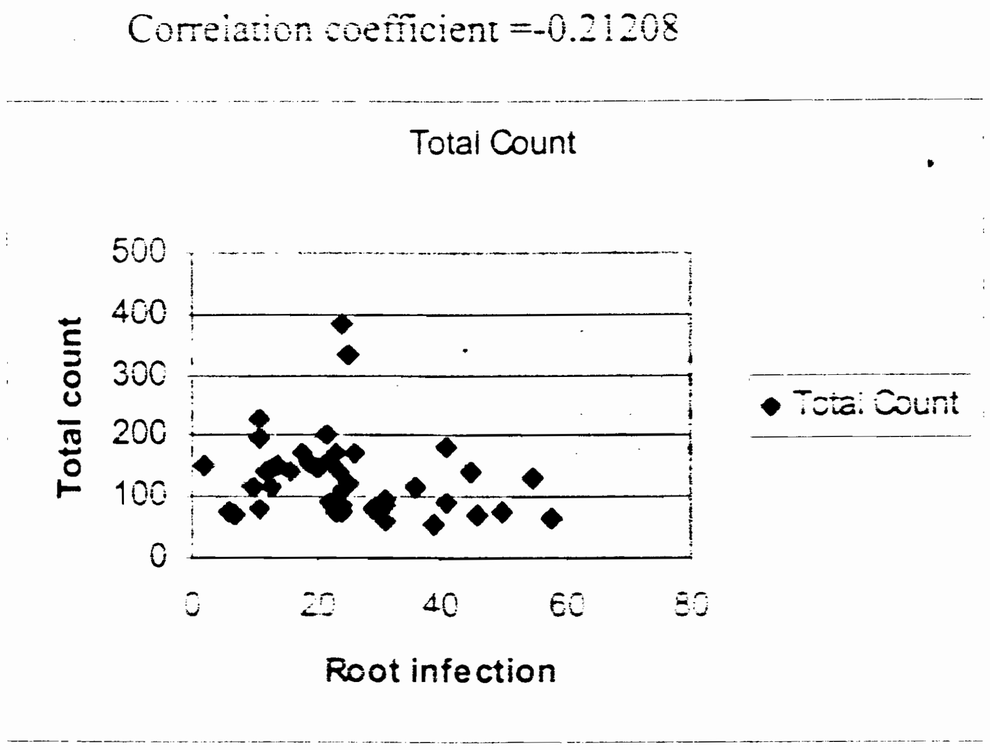


Figure 13: Relation between AM fungal spore density and AM fungal root infection

Table 25: AM root infection in *Eucalyptus grandis* plantations at different localities in the State

Sample plot No.	Species	AMF root infection%	Total AMF spore count	MC%	OC (%)	Soil pH
E6	*E. grandis*	24	170	3.95	2.513	5.7
E12	*E. grandis*	22	92	21.8	4.38	4.6
E13	*E. grandis*	31	96	17.3	5.83	5.2
E14	*E. grandis*	28	173	26.8	5.69	4.7
E15	*E. grandis*	12	148	18.9	4.88	5
E16	*E. grandis*	22	162	19.5	4.51	5.10
E17	*E. grandis*	31	63	28.6	10.69	5.00
E18	*E. grandis*	14	154	29.8	11.25	5.08
E19	*E. grandis*	25	119	20.9	2.57	5.03
E20	*E. grandis*	16	141	23.3	4.93	4.62
E21	*E. grandis*	2	154	21.5	3.11	4.33
E23	*E. grandis*	36	116	20.4	4.87	4.29
E24	*E. grandis*	24	109	17	4.92	4.34
E25	*E. grandis*	41	184	16.6	4.56	5.02
E27	*E. grandis*	23	77	22	3.52	4.71
E29	*E. grandis*	6	74	21.9	3.82	5.10
E30	*E. grandis*	39	58	18	3.85	3.68
E31	*E. grandis*	-	69	25	4.99	3.83
E32	*E. grandis*	58	64	22.3	4.59	3.96
E33	*E. grandis*	46	72	10.9	2.19	4.11
E34	*E. grandis*	10	116	13	3.22	3.82
E35	*E. grandis*	24	84	15.9	2.92	3.98
E41	*E. grandis*	31	85	8.01	3.92	2.81
E36	*E. grandis*	11	196	12.79	4.78	4.70

Table 26: Analysis of variance of data on AM root infection, soil physical and chemical characteristics

Source	Degree of freedom	Sum of squares	Mean square	*F* value	*P* > *F*
Model	1	91.73901	91.73901	13.82	0.0048
Error	9	59.74086	6.63787		
Corrected Total	10	151.47987			

* Significant at P =.05

Table 27: Parameter estimate of regression model relating AM root infection, soil physical and chemical properties

Variables	Parameter estimate	Standard error	Type II SS	*F* value	*P* >*F*
Intercept	32.40742	1.94992	1833.51974	276.22	<.0001
Ca	-23.02840	6.19443	91.73901	13.82	0.0048

* Significant at P =.05

3.2. 2. Biodiversity of AM fungi in eucalypt plantations

A total of 80 Glomalean fungi were identified from the eucalypts rhizosphere soils collected from different localities in the State (Plates 2-9). Glomalean fungal community comprised of 12 – 35 species with a mean number of 21.87 species per sample. Lowest number of species (12) was recorded in *E. grandis* plantation soils at Devikulam, while highest number (35) was recorded from *E. tereticornis* plantation at Kattilepara, Kulathupuzha. Soils from *Eucalyptus tereticornis* plantation at Wadakkanchery also recorded comparatively less number of Glomalean species, but a very high ectomycorrhizal association (*Pisolithus tinctorius*) was recorded. All the six reported genera of AM fungi viz., *Glomus*, *Acaulospora*, *Gigaspora*, *Scutellospora*, *Sclerocystis* and *Entrophospora* were recorded from the eucalypts rhizosphere soils from the State. Among these *Glomus* was the most predominant and widely distributed genus in all the eucalypts plantations, irrespective of the soil physical and chemical characteristics as well as the altitudinal differences. A total of 41 species belonging to *Glomus* were retrieved and identified from the soil samples. Of these about 15 species were found widespread in eucalypts soils throughout the State and their total spore density ranged from 35 to 856 with a mean 131 spores per soil sample (Table 28). Among these, *Glomus australe* (Berk.) Berch, *G. botryoides*, *G. deserticola*, *G. fasciculatum*, *G. geosporum*, *G. intraradices* Schenck & Smith, *G. macrocarpum* Tul. & Tul., *G. mosseae*, *G. multicaule* Gerd. & Bakshi (Plates 2,3) were the most frequently encountered species. Other *Glomus* species were found sparsely distributed in soils under eucalypts and their total spore count ranged from 3-31 (Figure 14).

Table 28: Distribution of AM fungi in soils under different *Eucalyptus* plantations

Sl. No.	AM fungi	No. of AM fungal species	Mean No. of AMF spores per plantation	Total No. of AM fungal spores
1	*Glomus*	41	80.1463	3286
2	*Sclerocystis*	4	24.7317	1014
3	*Scutellospora*	13	6.1951	254
4	*Acaulospora*	13	11.7317	481
5	*Entrophospora*	2	0.9512	39
6	*Gigaspora*	7	4.7560	195
7	Unidentified	-	1.6829	69
	Total	80	131.4146	5388

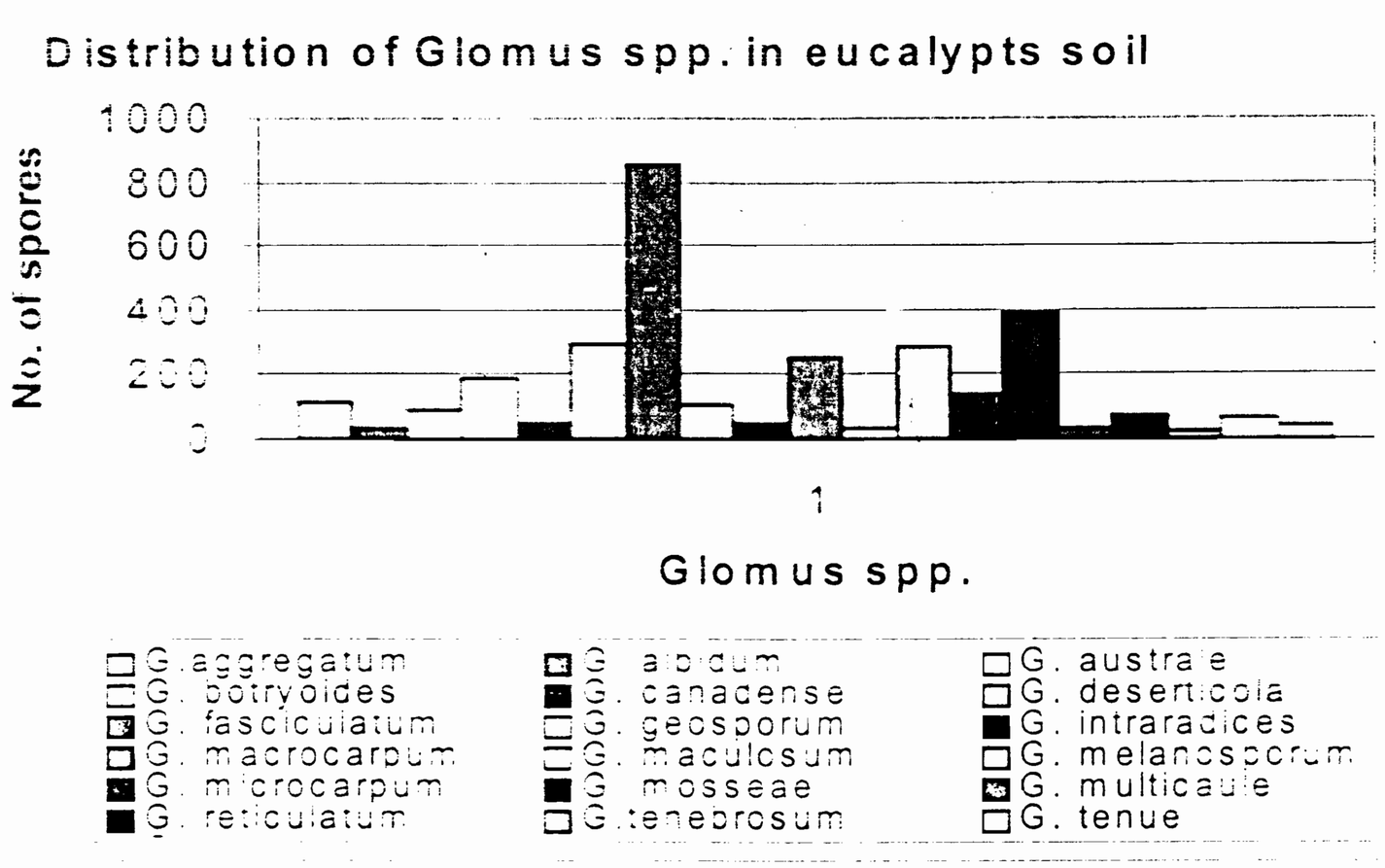


Figure 14: Distribution of *Glomus* spp. in soils under eucalypts plantations

Thirteen species of *Scutellospora* were recorded from the eucalypts rhizosphere soils (Plate 9). Among these, *Scutellospora erythropa*, *S. heterogama*, *S. nigra*, and *S. persica* were the most widely distributed species (Figure 15). *Scutellospora pellucida*, *S. dipappillosa*, *S. gilmorei*, *S. reticulata*, etc. were recorded only from a few plantations. Total number of spores of *Scutellospora* species retrieved from the soil samples from different locations is 254 with a mean distribution of 6.19 spores per plantation (Table 28). Many spores belonging to *Scutellospora* could not be identified up to species level due to lack of murographic evidents.

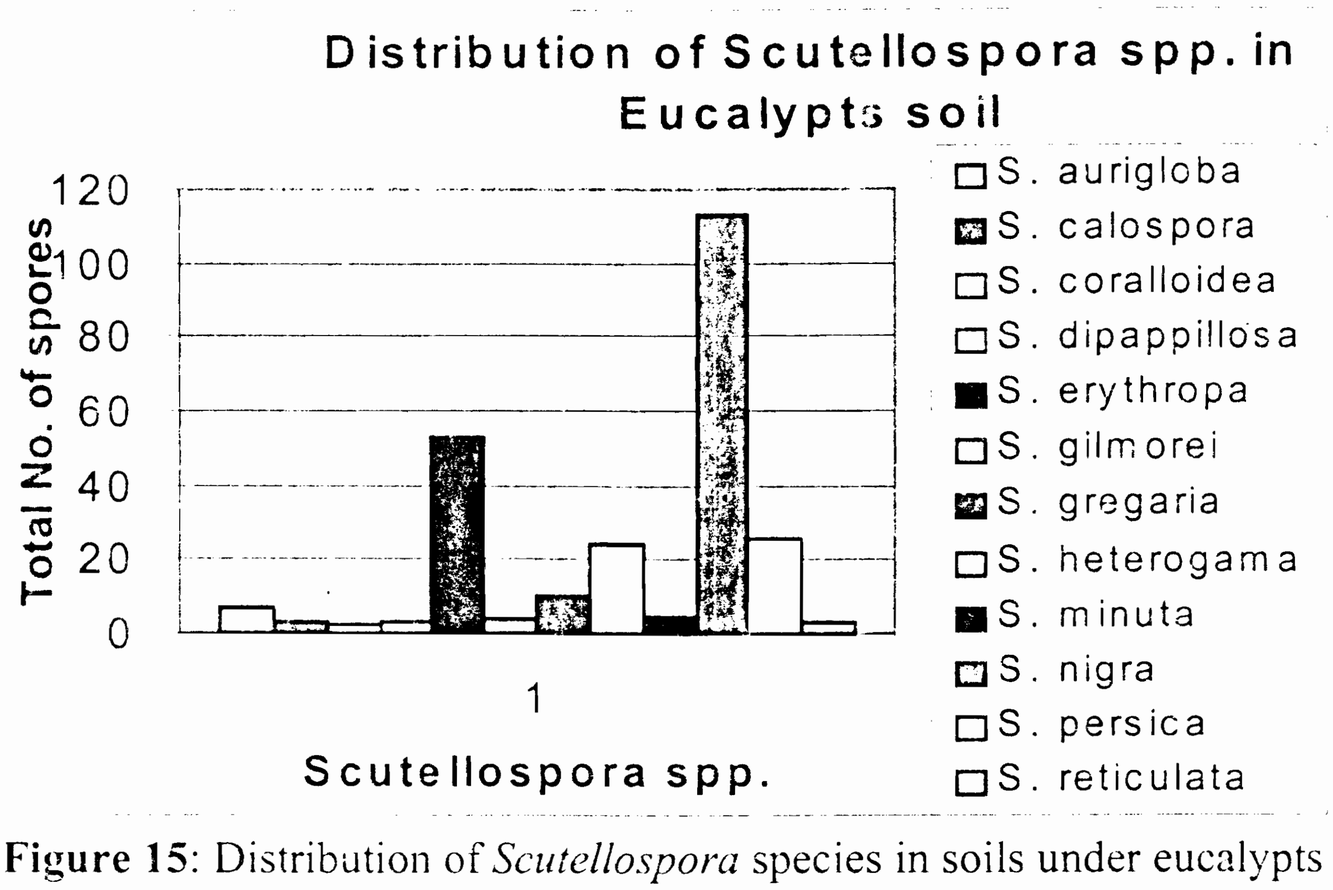


Figure 15: Distribution of *Scutellospora* species in soils under eucalypts

Thirteen *Acaulospora* species were recorded from the eucalypts rhizosphere soils (Plates 6,7) and their spore density varied from 2 to 255. *Acaulospora appendicula, A. scorbiculata,* and *A. rehmii* were the most frequently recorded species. *A. foveata, A. bireticulata, A. rugosa* Morton and *A. delicata* Walker, Pfeiffer & Bloss were also represented in most of the eucalypts soils with a low density (Figure 16). Though, the present study indicates a predominance of *Glomus* in the soils under different species of eucalypts, *Acaulospora* was encountered in almost all the soil samples with a moderately high frequency of occurrence. Thus, the genus *Acaulospora* forms one of the important component of the Glomalean fungal community in the rhizosphere soils of eucalypts.

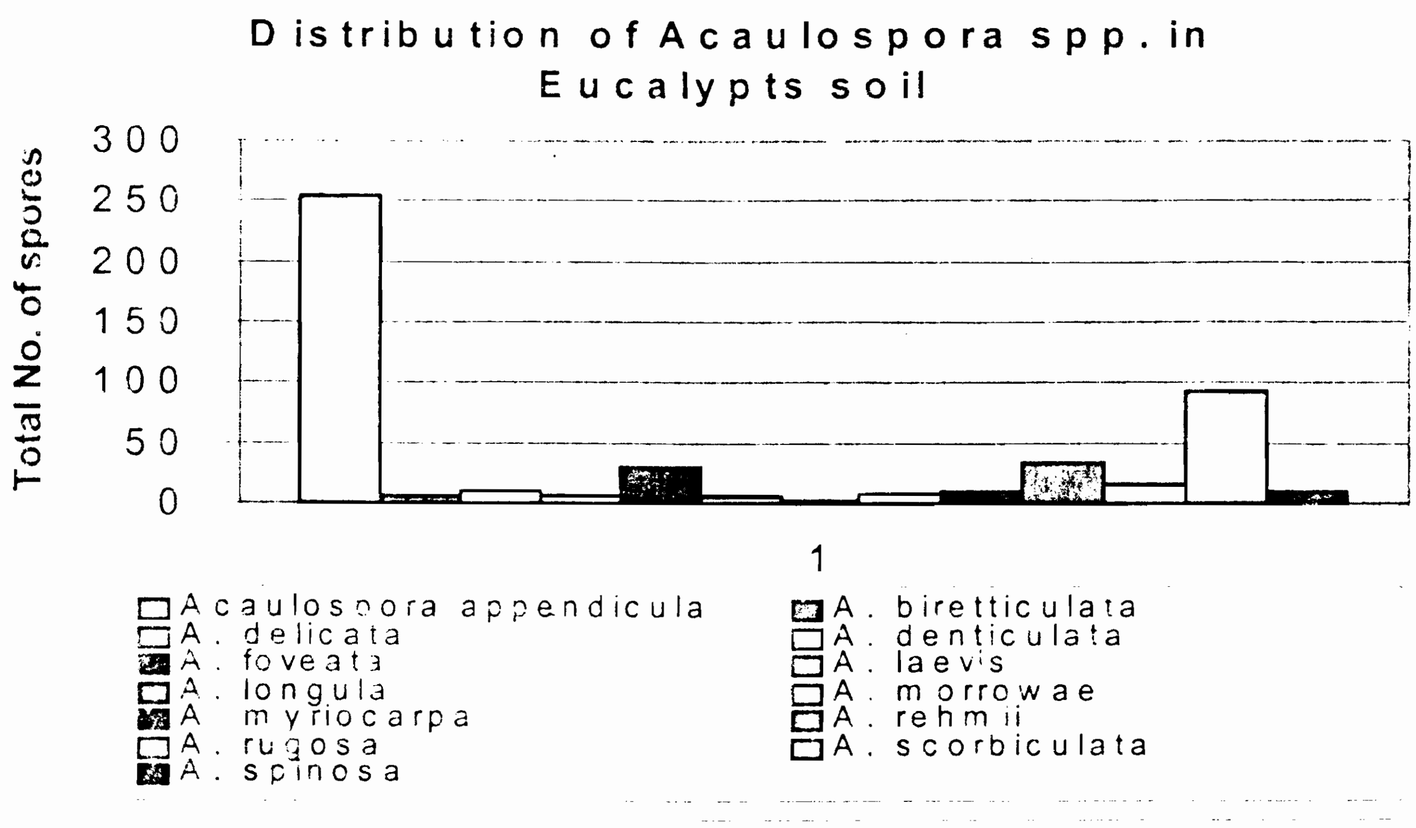


Figure 16: Distribution of *Acaulospora* species in soils under eucalypts

Seven species of *Gigaspora* were recorded from the eucalypts soils with a mean spore density of 4.75 per sample. *Gigaspora albida* Schenck & Smith, *G. decipiens* Hall & Abbott and *G. gigantea* (Nicol. & Gerd.) Gerd. & Trappe (Plate 8) were the most frequently observed and widely distributed species in eucalypts plantations (Figure 17). Many spores (> 19) of *Gigaspora* could not be assigned to a particular species for want of more murographic information.

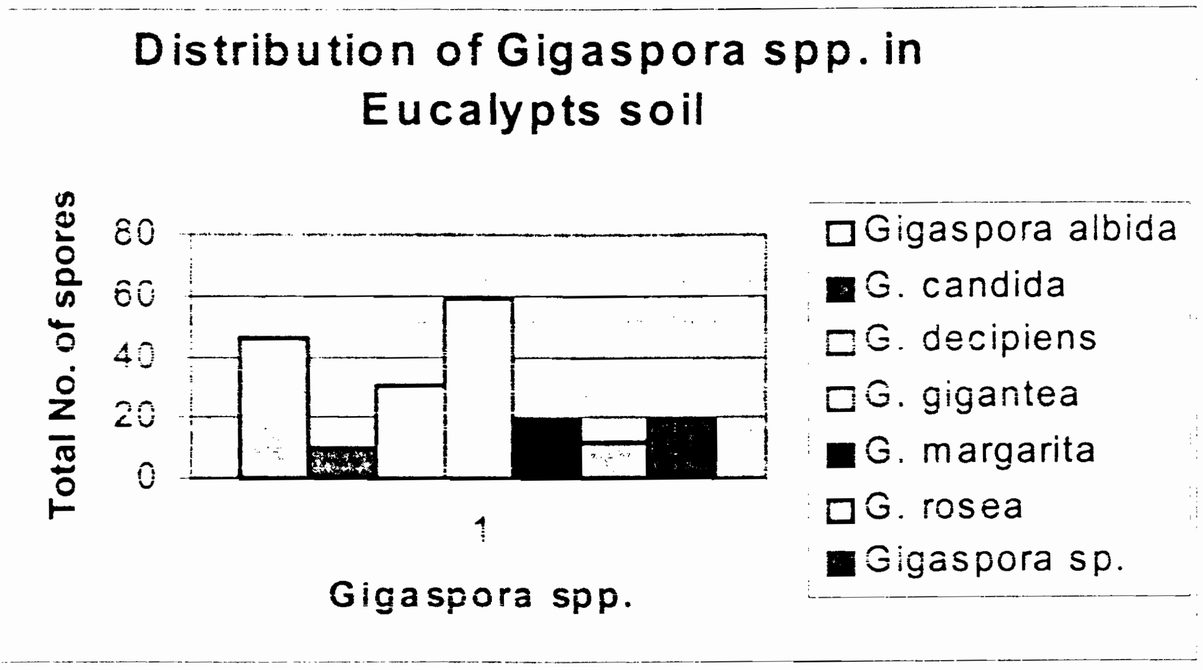


Figure 17: Distribution of *Gigaspora* species in soils under eucalypts

Four species of *Sclerocystis*, viz., *S. clavispora*, *S. dussii*, *S. microcarpus* and *S. pachycaulis* were recorded in soils from eucalypts plantations, suggesting the common and diverse occurrence of this genus under soils of exotic plantation species (Figure 18). Among these, *Sclerocystis microcarpus* and *S. clavispora* (Plate 5) were the most widely distributed species. *Sclerocystis dussii* was recorded from soils under 3-year-old *E. grandis* plantation at Mattupetty, Devikulam, and *S. pachycaulis* recorded from 4-year-old *E. grandis* plantation at Vattavada, Devikulam Forest Range.

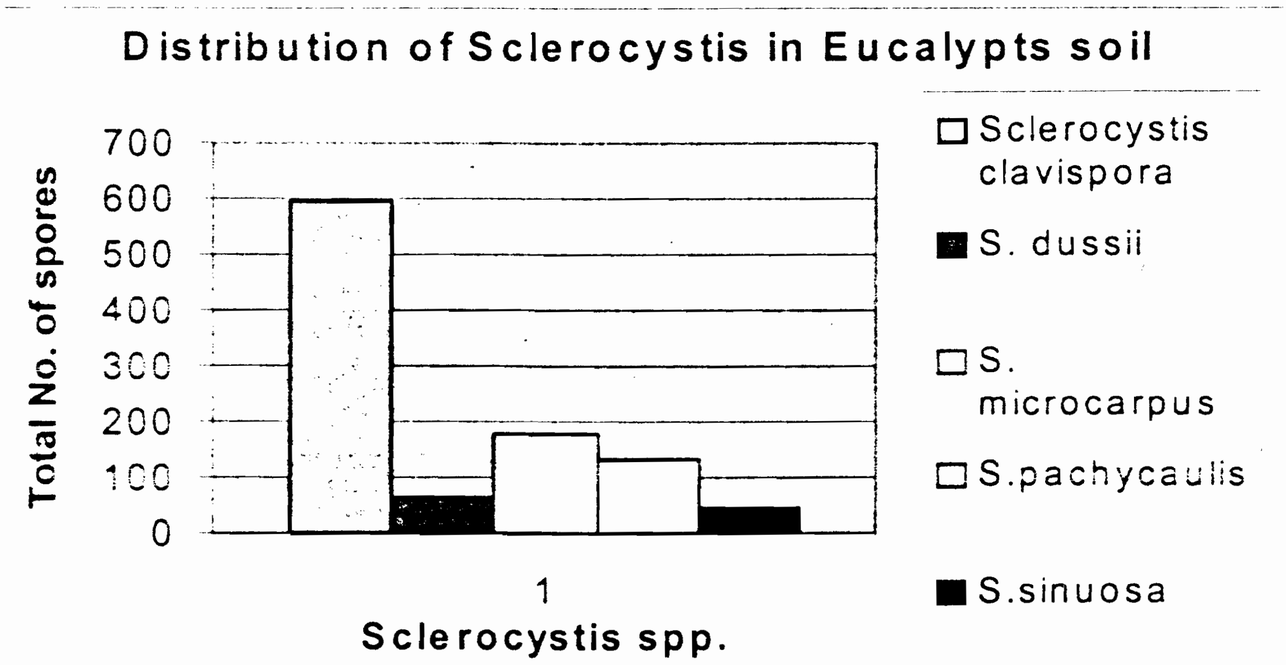


Figure 18: Distribution of *Sclerocystis* species in soils under eucalypts

Entrophospora columbiana was retrieved from soil samples under *E. pellita* at Kottappara, Kodanad Forest Range. So far, no AM fungi have been reported from eucalypts in the State. All the AM fungi recorded from different eucalypt species herein are new record from the State.

3.2.3. Biodiversity indices

Relative abundance of AM fungi in eucalypts plantation soils measured using Shannon-Wiener and Simpson's indices are given for each sample plots separately (Tables 29-31). Shannon-Wiener index ranged from 1.9245 to 2.9253, whereas Simpson's index ranged from 3.9218 to 13.7619. Gamma and beta diversities of AM fungi were estimated separately. Gamma diversity of AM fungi was 84, whereas beta diversity was 40.

Table 29: Diversity of AM fungi in soils under *Eucalyptus* species (Sample plots No. 1-15)

Sl. No.	AMFungi	Number of AM fungal spores in rhizosphere soils of eucalypts sample plots														
		E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	E11	E12	E13	E14	E15
1	*G.aggregatum*						8		12	6	12				6	12
2	*G. albidum*						2		3		2	2	3	1		2
3	*G. ambisporum*								2							
4	*G. australe*		1	2			3	6		3	3	4	6	3	2	
5	*G. boreale*															
6	*G. botryoides*						9	7	8	16	16	6			9	9
7	*G. caledonium*				2				2		2					
8	*G. canadense*			1			2	3		2		1			2	2
9	*G. citricolum*								1		1					
10	*G. claroideum*		14		1											
11	*G. convolutum*			1		2	1	2				1				2
12	*G. deserticola*	12	17	6	45	12		12	7	12	14	6	14	14	12	14
13	*G. diaphnum*							1								1
14	*G. fasciculatum*	48	32	31	54	20	34	17	28	23	21	19	23	18	22	13
15	*G. fulvum*								1	1	2					
16	*G. geosporum*	8	6		1		5	3	3	4		7		5	1	6
17	*G. globiferum*									2		3			2	
18	*G. glomerulatum*	1										1				
19	*G. hoi*			2			1							2		1
20	*G. intraradices*							2			3				3	
21	*G. lacteum*					5	2			2						2
22	*G. macrocarpum*	32	26	14	12				9		8	16			8	15
23	*G. maculosum*				3				3		1	7				
24	*G. melanosporum*						9	9	12	14	6	14		7	15	7
25	*G. microcarpum*		3	6	5	6		4				18	7	9		13
26	*G. mosseae*	17	5	10		31	14	16	5	20	15	11	9	11	11	22
27	*G. multicaule*					2	3	2		6	1	2	1	4	2	2
28	*G. occultum*							2								
29	*G. pallidum*										1		2			
30	*G. pulvinatum*						2					1				

33	*G.tenebrosum*		2	3	2				2				2	2		
34	*G. tenue*				14	1		16				14				
35	*G. tortuosum*		1	1		5			3		2	2	1	1	2	1
36	*Glomus* sp.				3							3		3		
37	*G. vesiculiferum*				1					2						
38	*Scl. clavispora*	160					40		44			162				
39	*Scl. microcarpus*									62						
40	*Scut. aurigloba*												2			2
41	*S. calospora*														48	
42	*S. coralloidea*			2												
43	*S. dipappillosa*													3		
44	*S. erythropa*			4	2		1		3	5	4	3	3		3	2
45	*S. gilmorei*								2			1				
46	*S. gregaria*														2	
47	*S. heterogama*					4				2	1	3		1		1
48	*S. minuta*	4	1													
49	*S. nigra*	6		5	7	3	3	2	1		2		4	4		
50	*S. pellucida*									1						
51	*S. persica*		1					5				2			1	3
52	*S. reticulata*						2									
53	*A. appendicula*	21	21	10	21	16	6	9	4	3	9	6	6	5	6	3
54	*A. bireticulata*					1					1				1	
55	*A. delicata*						1			1						
56	*A. denticulata*												1			
57	*A. foveata*	3						1			1	3	2	2	1	
58	*A. longula*			2												
59	*A. morrowae*										1					2
60	*A. myriocarpa*			2		3			1						1	
61	*A. rehmii*		2	2	9		2			1	1	1		1		2
62	*A. rugosa*					2				1						
63	*A. scorbiculata*	12	8	4	11	6	4	3	2	2		4	5			
64	*A. spinosa*					2			1							
65	*Acaulospora* sp.					1										
66	*Entrophospora colombiana*			2												
67	*Entrophospora* sp.		2			4	2		2	3	1	1	1		1	
68	*Gigaspora albida*			1	1	2			4		2				5	1
69	*G. candida*	2						1		1		1			1	
70	*G. decipiens*				1							1				
71	*G. gigantea*	2			2			4	2	3	5	4				5
72	*G. margarita*	3	1													
73	*G. rosea*				6						1					
74	*Gigaspora* sp.					4		2	1						2	
75	Unidentified	6	6		4	7	8	6	5	3	4	3				
	No. of species	17	19	22	23	23	25	25	29	28	31	35	18	19	27	27
	Shannon index	1.9245	2.4400	2.5692	2.4863	2.6422	2.5952	2.9253	2.7091	2.5530	2.9081	2.3022	2.4599	2.5854	2.6190	2.8707
	Simpson index	3.9218	8.5751	8.5110	8.0765	9.6934	8.4651	14.6507	8.8995	7.4104	13.3436	4.0484	8.4135	10.2857	8.3391	13.3398

Table 30: Diversity of AM fungi in soils under *Eucalyptus* species (Sample plots No. 16-30)

Sl. No.	AMFungi	Number of AM fungal spores in rhizosphere soils of eucalypts sample plots														
		E16	E17	E18	E19	E20	E21	E22	E23	E24	E25	E26	E27	E28	E29	E30
1	*G.aggregatum*			9		2		6	6		18			4		
2	*G. albidum*	1		2		3				2			2			2
3	*G. ambisporum*					1										
4	*G. australe*	3			4	4	2	5	3	6	2		3	4		
5	*G. boreale*					6		1								
6	*G. botryoides*	8	5	4	6	7	5	3	7	16			6		3	
7	*G. caledonium*													2		1
8	*G. canadense*			1	1				3	3			1	3	2	
9	*G. claroideum*										1	6				
10	*G. convolutum*							1	1							
11	*G. deserticola*	16	7		7				8		7			7		
12	*G. diaphnum*															2
13	*G. fasciculatum*	11	13	11	12	37	35	17	27	17	62	25	16	16	12	11
14	*G. geosporum*	2	4	6	2	3	1	3	4	2			4	2	4	3
15	*G. globiferum*												1			
16	*G. glomerulatum*				1				2	1					1	
17	*G. hoi*			1							1					
18	*G. intraradices*		6	2		3	2	2		3			2	3		4
19	*G. lacteum*			1		1		1		2		2				
20	*G. macrocarpum*	8		6	4	6	3	4	4			3	9		4	
21	*G. maculosum*			1				2	2	1				4	2	
22	*G. magnicaule*													1		
23	*G. melanosporum*	12	8	7	7		16	9	9	12	9		6		9	18
24	*G. microcarpum*									8	12	6		8	8	
25	*G. mosseae*	9	7	14	8		17	3	4		36	7	7	7	4	
26	*G. multicaule*								2							
27	*G. occultum*				2											2
28	*G. panshihalos*						2									
29	*G. reticulatum*	2		2			2	2			2		2		7	
30	*G.tenebrosum*									1				3		3
31	*G. tortuosum*				1			1	2	3				1		
32	*G. vesiculiferum*			2			1									1
33	*Sclerocystis clavispora*				46		42					52				
34	*S.dussii*			64												
35	*S. microcarpus*	68														
36	*Scut. calospora*					3										
37	*S. erythropa*	1		3			4						3			
38	*S. gilmorei*															1
39	*S. gregaria*					2						5		1		
40	*S. heterogama*			1	2	2					1				2	
41	*S. nigra*	4	2	2	3	1		3	2	5	4	5	4	4	4	2
42	*S. persica*	2	1				3	1	1	1	2		2	1		
43	*A. appendicula*	4	7	4	3	2	7	2	3	2	17	8	3	3	3	
44	*A. buretticulata*													1		
45	*A. elegans*	1				2			2							
46	*A. foveata*	1		2	1		3				3	2	2			3

47	*A. laevis*		1					1		1				2		
48	*A. morrowae*						1								2	
49	*A. rehmii*	1		1	1							2				
50	*A. rugosa*						1	1	1	1						
51	*A. scorbiculata*	2	2	2	2	1			12		2					
52	*A. spinosa*					46		1		1			1			
53	*Entrophospora* sp.	2			1	1	1	2		2					2	
54	*Gigaspora albida*	1		1	1	1	2	1	3	1	4	22				
55	*G. candida*												1			2
56	*G. decipiens*			2				1		1		4	2	4	1	
57	*G. gigantea*	3		3		3	3	2		2	1				2	3
58	*G. margarita*				4			1	2	1						
59	*G. rosea*													2		
60	*Gigaspora* sp.					4									1	
	No. of species	22	12	26	22	23	21	26	23	25	18	14	20	22	19	15
	Shannon index	2.2163	2.2708	2.3541	2.3477	2.2584	2.2890	2.8336	2.7720	2.7331	2.1267	2.0057	2.6743	2.7960	2.6722	2.2662
	Simpson index	4.8331	8.4989	5.0417	5.5599	5.3602	6.4271	11.1506	10.7305	11.6139	5.5611	4.6161	10.8789	12.4126	11.8017	6.4692

Table 31 : Diversity of AM fungi in soils under *Eucalyptus* species (Sample plots No. 31-41)

Sl.No.	AMFungi	Number of AM fungal spores in rhizosphere soils of eucalypts sample plots										
		E31	E32	E33	E34	E35	E36	E37	E38	E39	E40	E41
1	*G.aggregatum*					12		6				
2	*G. albidum*					2				2		
3	*G. australe*		3		3					6		6
4	*G. botryoides*	6	5		2		9	8		4		7
5	*G. caledonium*			4							1	
6	*G. canadense*		2	2	1	3		2	3		3	2
7	*G. citricolum*		1									
8	*G. claroideum*						2		2		2	
9	*G. convolutum*	2						1	1			
10	*G. deserticola*			5			14	12	4	4		3
11	*G.etunicatum*								1			
12	*G. fasciculatum*	9	9	9	6	14	27	23	18	14	13	9
13	*G. fulvum*					1						
14	*G. geosporum*			3		3	3	2		3	6	
15	*G. globiferum*	3					2	1			2	
16	*G. intraradices*						4			3		4
17	*G. lacteum*		1			2		1				2
18	*G. macrocarpum*	6	5			11	7	3	6	6	3	12
19	*G. maculosum*	2		2		2			2		1	
20	*G. magnicaule*								2			
21	*G. melanosporum*	18	9	12	11				9	7		
22	*G. microaggregatum*					9						
23	*G. microcarpum*		6	3						9	8	
24	*G. mosseae*	3	11	5			11		6	3	9	

25	*G. multicaule*						2	4	2			
26	*G. multisubtensum*	1										2
27	*G. panshinalos*									2		
28	*G. pulvinatum*					1						
29	*G. reticulatum*	2							3	3	2	3
30	*G.tenebrosum*		2	1								2
31	*G. tenue*				12				12			
32	*G. tortuosum*			2	3		5	2		1		
33	*Glomus* sp.				3							
34	*G. vessiculiferum*				2	2	2		1	2		
35	*Scl. microcarpus*				43							
36	*Scl. pachycaulis*						86			46		
37	*Scut. aurigloba*											3
38	*S. erythropa*				3		3	2				4
39	*S. heterogama*		2	2								
40	*S. nigra*	6	5	5	6				5	4		
41	*S. persica*	2				3	3	3			3	
42	*S. reticulata*										1	
43	*A. appendicula*		3	7	6	3	5	3		2	3	9
44	*A. biretticulata*										2	
45	*A. delicata*	1				2						4
46	*A. denticulata*					1			2		2	
47	*A. foveata*	1		1			2	2		3		
48	*A. morrowae*								1			
49	*A. myriocarpa*		2									
50	*A. rehmii*			3			1			2		2
51	*A. rugosa*				1				2		5	
52	*A. scorbiculata*			2	2		3	1		1		
53	*A. spinosa*					2			1			
54	*Entrophospora* sp.				2	2				2	1	2
55	*Gigaspora albida*				2		3	2	3	3		
56	*G. candida*								1			
57	*G. decipiens*					5	2				3	3
58	*G. gigantea*		1	3				1		5		
59	*G. margarita*	4							2		1	
60	*G. rosea*	2										1
61	*Gigaspora* sp.	2	2	1								
	Unidentified				3	4			4	3	3	
	No. of species	17	17	20	18	20	21	19	24	25	21	19
	Shannon index	2.449	2.577	2.707	2.1874	2.6952	2.1392	2.4318	2.7923	2.627	2.746	2.7965
	Simpson index	8.338	10.94	12.22	4.9038	11.607	4.4116	7.3858	11.703	7.324	12.06	13.761

3.3. Rosewood

3.3.1. Arbuscular mycorrhizal association in *Dalbergia latifolia*

Dalbergia latifolia (Rosewood) trees in natural stands at seven localities in different parts of the State were selected for the study (Table 3). All the sampled *D. latifolia* trees showed AM fungal association (Table 32). However, per cent root infection as well as AM fungal species association varied among the samples. The AM fungal root infection varied from 10 to 60.5 per cent among the sampled plots. Of the seven plots of *D. latifolia* studied, AM fungal root infection was low to moderate (10 to 27 %), in all the plots, except at Naduvannoorkadavu, Kulathupuzha Forest Range, where 60.5 per cent root infection was recorded. The feeder roots of *D. latifolia* showed all typical arbuscular mycorrhizal features like vesicles, arbuscules, intracellular hyphal coils, extra and intra-radical hyphae (Plate 1).

Rhizosphere soils in all the *D. latifolia* sample plots were strongly acidic, except the soil samples from Dhoni, Olavakkode Forest Range which was near neutral (pH 6.87). Soil moisture content ranged from 2.84 to 22.9 per cent. In general, rhizosphere soils were rich in organic carbon which ranged from 2.115 to 3.92 per cent. Organic carbon percentage showed a 10:1 ratio with the total nitrogen (N) which indicated the high nutrient status of the soil. Available nitrogen (N%) and phosphorus (P%) were also high and ranged from 0.311 to 0.448% and 0.043 to 0.3334% respectively. Exchangeable cations were also high (Table 32). Usually, soils rich in organic carbon and minerals exhibit comparatively low AM spore density than in nutrients deficient soils. AM spore density was low in all the plots, except at Mulepadam, Nilambur Forest Range which ranged from 88 to 115. Rhizosphere soils of *D. latifolia* at Mulepadam yielded highest AM spore density of 242. However, no correlation could be drawn on the influence of various soil chemical and physical factors on the root infection as well as AM spore density.

Table 32: AM fungal root infection in *D. latifolia*, AM fungal spore density and chemical and physical characteristics of the rhizosphere soils

Sample No.	AMF root infection %	AMF spore count	Soil MC%	Soil pH	OC %	K meq/ 100g	Na meq/ 100g	Ca meq/ 100g	Mg meq/ 100g	N %	P %
D1	11	112	3.21	4.94	3.125	0.044	0.098	1.679	0.365	0.311	0.043
D2	17	90	2.84	5.35	3.735	0.045	0.069	0.933	0.136	0.381	0.3334
D3	18	242	13.61	4.91	2.115	0.061	0.057	1.204	0.096	0.321	0.0528
D4	24	113	2.92	6.87	2.315	0.066	0.055	0.584	0.268	0.333	0.2577
D5	60.5	68	3.41	4.49	3.425	0.077	0.065	0.707	0.301	0.448	0.017
D6	27	115	11.02	5.28	3.920	-	-	-	-	-	-
D7	10	88	22.9	4.49	3.432	-	-	-	-	-	-

- samples not analysed

3.3.2. Biodiversity of AM fungi in *Dalbergia latifolia* stands

Altogether 45 Glomalean fungal species were encountered in rhizosphere soils of *D. latifolia* collected from different parts of the State. All the six reported genera of AM fungi were recorded from the soils and among these, *Glomus* was the most predominant and widely distributed genus which represented 22 species (Table 33).

Table 33: Distribution of AM fungal genera in *D. latifolia* stands

Sl.No.	AM Fungal genus	No. of species	Mean No. of AMF spores	Total AM spore count
1	*Glomus*	22	87.5714	613
2	*Sclerocystis*	1	6.00	42
3	*Scutellospora*	7	6.8571	48
4	*Acaulospora*	8	11.2857	79
5	*Entrophospora*	1	0.4285	3
6	*Gigaspora*	6	6.1428	43
	Total	45	118.2857	828

The Glomalean fungal community in rhizosphere soils of *D. latifolia* comprised of 14 to 22 species with a low spore density. Lowest number of Glomalean species was recorded in soil samples from Naduvannurkadavu, Kulathupuzha. Among the *Glomus* species, *G. deserticola,G. fasciculatum,G. geosporum* and *G. mosseae* were widespread in soils under *D. latifolia*. G. *fasciculatum* showed highest mean spore density of 25 per sample. Other *Glomus* species were found sparsely distributed in the soils with a very low spore density (Figure 19; Table 34).

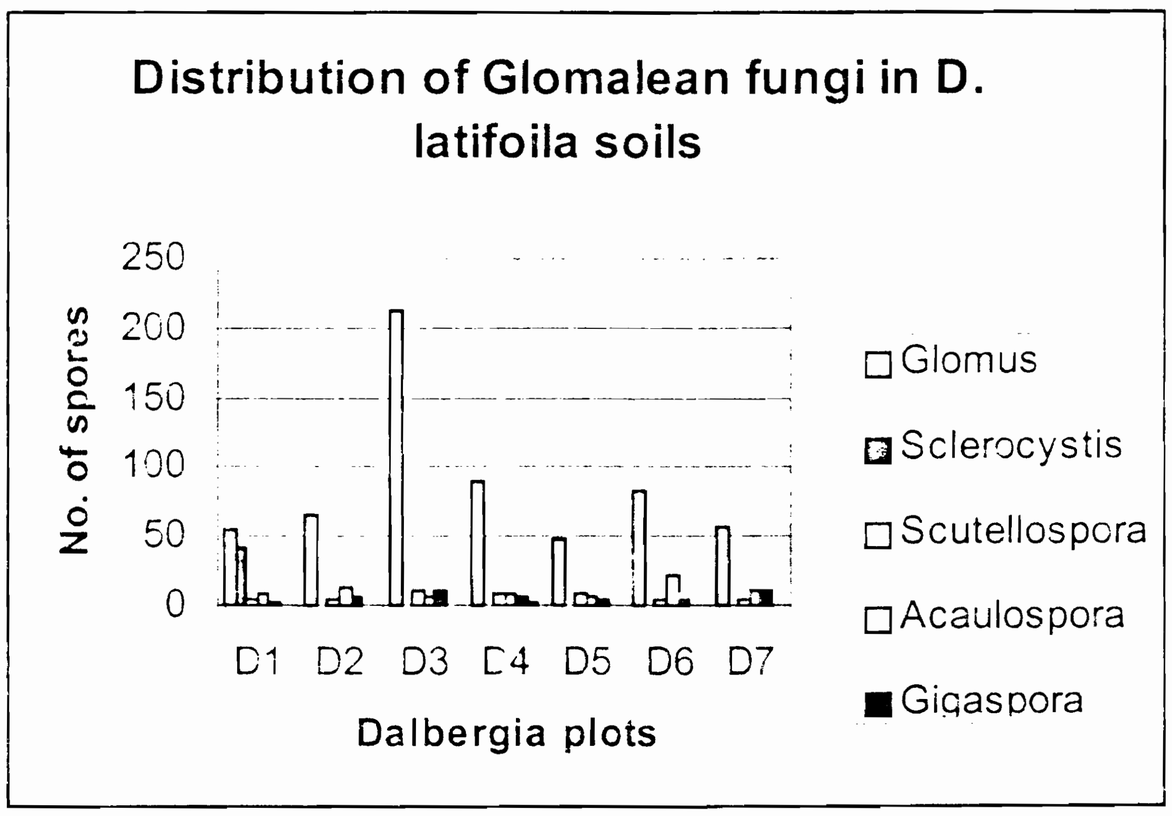


Figure 19: Distribution of AM fungi in *D. latifoila* plots

Table 34: AM fungal diversity in *D. latifoila* stands

Sl.No.	AMFungi	Number of AM fungal spores in soils under *Dalbergia latifolia* plots						
		D1	D2	D3	D4	D5	D6	D7
1	*Glomus aggregatum*	6			6			8
2	*G. albidum*			1	4		2	1
3	*G. ambisporum*	6						
4	*G. australe*			12	6	2	8	3
5	*G. botryoides*		8	2	14			7
6	*G. caledonium*	2						
7	*G. canadense*							2
8	*G. convolutum*					2	2	
9	*G. deserticola*		7	64	9	4	8	4
10	*G. fasciculatum*	17	16	59	31	16	17	19
11	*G. geosporum*	4	3	4	3	6	14	2
12	*G. intraradices*		2	3				2
13	*G. lacteum*		2	1	1			
14	*G. macrocarpum*		8		6		3	
15	*G. melanosporum*		7				3	3
16	*G. microaggregatum*					5		
17	*G. microcarpum*	4		12		11	9	
18	*G. mosseae*	6		51	6		10	5
19	*G. multicaule*	3	4					
20	*G. occultum*						3	
21	*G. reticulatum*	6	6	4	2	2	3	
22	*G. tortuosum*		2		1		1	2
23	*Sclerocystis clavispora*	42						
24	*Scutellospora erythropa*	1	2	7		6		3
25	*S. gregaria*						3	
26	*S. heterogama*				2			
27	*S. nigra*	2	3	2	6	3	2	2
28	*S. persica*	2						
29	*S. reticulata*							1
30	*S. trycalypta*			1				
31	*Acaulospora appendicula*	4	6	3	4	6	14	6
32	*A. biretticulata*				1			1
33	*A. delicata*	1	2	2				
34	*A. foveata*		2					
35	*A. laevis*			1		1		
36	*A. rehmii*				1			1
37	*A. scorbiculata*	3	4	1	3		3	4
38	*A. tuberculata*						5	
39	*Entrophospora sp.*				2	1		
40	*Gigaspora albida*	3	1	2			5	3
41	*G. candida*				2			
42	*G. decipiens*		3					
43	*G. gigantea*		2	3	3	3		5
44	*G. margarita*							3
45	*G. rosea*			5				
	Shannon index	2.2289	2.7547	2.1150	2.5730	2.3470	2.6740	2.8007
	Simpson index	5.4873	12.6168	5.5124	8.5297	8.2867	11.9467	11.6979

Altogether seven species of *Scutellospora* were recorded from rhizosphere soils of *D. latifolia*. Among these, *Scutellospora nigra* and *Scut. erythropa* (Plate 9) were the most widely distributed species (Table 34). *Scutellospora nigra* showed a mean spore density of 2.8 per sample.

Nine *Acaulospora* species were recorded from the soil samples and *A. appendicula* and *A. scorbiculata* were the widespread ones. *A. appendicula* was encountered in all the seven soil samples with a mean spore density of 6.14 per plot. Other six species of *Acaulospora* were distributed very sparsely and with a very low spore density.

Five species of *Gigaspora* were recorded from *D. latifolia* rhizosphere soils with a mean spore density of 6.14 per sample. All the six species were sparsely distributed and of these *G. gigantea* and *G. albida* were recorded from five out of seven sample plots.

Only *Sclerocystis clavispora* was recorded in soils from *D. latifolia* plots, suggesting the limited distribution of this genus, especially in soils with high nutrient status. *S. clavispora* was recorded from plots at Pulimunda, Nilambur Forest Range. Earlier, *Sclerocystis* species have been reported to be associated in natural stands with less disturbed soils (Sieverding, 1989). However, in the present study, where soil disturbance is comparatively very less in *D. latifolia* natural stands than that in plantations, only one out of seven reported genera of *Sclerocystis* was encountered. Also, the genus *Entrophospora* was poorly represented in the rhizosphere soils of *D. latifolia*. So far, no AM fungal association in *D. latifolia* has been reported from the State. All the Glomalean fungi recorded from the rhizosphere soils of *D. latifolia* are new record from the State.

3.3.2. Biodiversity indices

Relative abundance of AM fungi in *D. latifolia* soils measured using Shannon-Wiener index and Simpson's index were given for each sample plots separately (Tables 34). Shannon-Wiener index ranged from 2.1150 to 2.8007, whereas Simpson's index ranged from 5.4873 to 12.6168. Gamma diversity, and beta diversity of AM fungal species in *D .latifolia* plots were 46 and 6 respectively.

3.4. Sandal

3.4.1. Arbuscular mycorrhizal association in *Santalum album*

Santalum album (Sandal) natural stands at five localities in Marayoor and Nilambur Forest Ranges were selected for the study (Table 4). All the sampled *S. album* plants in different localities showed AM fungal association. However, per cent root infection was very low and ranged from 5 to 16.4 (Table 35). AM fungal spore density was also low and ranged from 58 to 88. Soil from sandal plots at Nilambur gave highest percent AM fungal root infection of 16.4 per cent. Rhizosphere soils from all the sample plots were moderately acidic; soil moisture content ranged from 2.65 to 12.9 per cent. Soils were rich in organic carbon which ranged from 1.55 to 4.07 per cent. Exchangeable cations viz., Na, Ca, Mg, K and available total nitrogen (N%) and phosphorus (P%) were also high in soil samples (Tables 35).

Table 35: AM fungal root infection in *S. album* and physical and chemical characteristics of soils

Sample plot No.	Locality	Root infection%	Spore count	MC%	Soil pH	OC %	K meq 100g	Na meq 100g	Ca meq 100g	Mg meq 100g	N %	P %
SA1	Nilambur	16.4	64	2.65	5.31	2.28	0.03	0.08	0.16	0.19	0.29	0.03
SA2	Marayoor	10	58	12.9	6.33	2.88	0.02	0.07	0.15	0.17	0.27	0.02
SA3	Nachuvayal	8.2	84	4.08	5.17	1.55	-	-	-	-	-	-
SA4	Manjapatty	18	70	3.74	5.67	4.07	-	-	-	-	-	-
SA5	Koolikadavu	5	75	11.26	5.01	3.34	-	-	-	-	-	-

- samples not analysed

3. 4.2. Biodiversity of AM fungi in rhizosphere soils of *Santalum album*

Glomalean fungal community in rhizosphere soils of *Santalum album* comprised of five genera with a total of 35 species (Table 36; Figure 20). In each sample plot, the AM fungal species composition ranged from 14 to 18 species belonging to all the five genera viz., *Glomus, Acaulospora, Gigaspora, Scutellospora,* and *Entrophospora* (Plates 2-9). Among these, *Glomus* was the most predominant genus which represented 19 species, however only two species viz., *G. fasciculatum* and *G. melanosporum* were found widespread with a spore density of 11.6 and 9 respectively. All the other species were sparsely distributed and represented by a very low spore density (Table 37). Four species of *Scutellospora* were recorded from rhizosphere soils of *Santalum album* and all the four species showed a very low spore density. *Scutellospora erythropa* and *S. nigra* were represented in four out of five soil samples. Even though, eight *Acaulospora* species were recorded, *Acaulospora*

appendicula and *A. scorbiculata* were the widespread ones with 6.6 and 2.4 spore density per sample respectively. *Sclerocystis* was not recorded from soils under *S. album*. This contradicts the observations of Sieverding (1989) that *Sclerocystis* species occur more in undisturbed soils than in plantations. *Entrophospora* sp. was recorded only in one soil sample. Three species of *Gigaspora* were recorded from *S. album* rhizosphere soils with a mean spore density of 2.4. All the Glomalean fungi recorded from rhizosphere soils of *Santalum album*, herein are new record from the State.

Table 36: Distribution of AM fungal genera in *S. album* stands in different parts of the State

Sl.No.	AM Fungal genus	No. of species	Mean No. of AMF spores	Total AM spore count
1	*Glomus*	19	44.80	224
2	*Scutellospora*	4	6.20	31
3	*Acaulospora*	8	13.0	65
4	*Entrophospora*	1	0.20	1
5	*Gigaspora*	3	2.40	12
6	Unidentified	-	3.6	18
	Total	35	70.20	351

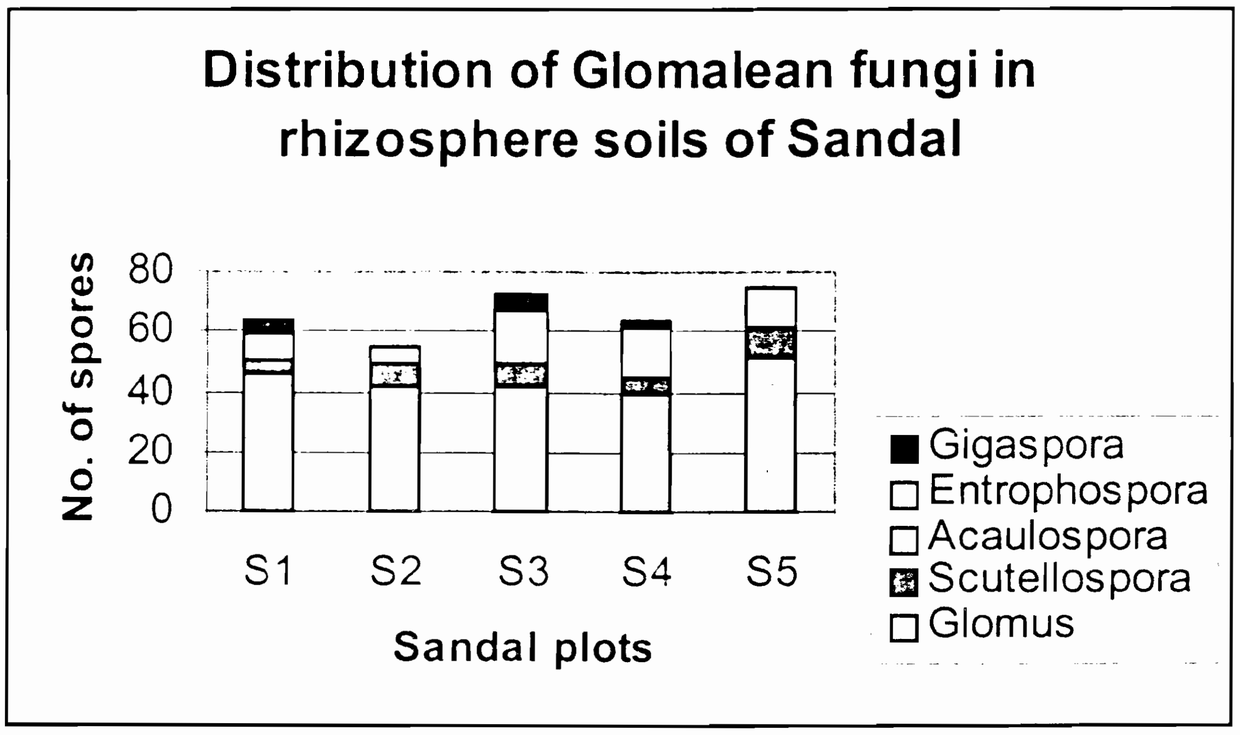


Figure 20: Distribution of Glomalean fungi in rhizosphere soils of sandal

3. 4.3. Biodiversity indices

Relative abundance of AM fungi in *Santalum album* soils measured using Shannon-Wiener index and Simpson's index are given for each sample plots separately (Tables 37). Shannon-Wiener index ranged from 2.2154 to 2.6724, whereas Simpson's index ranged from 6.7527 to 12.4225. Gamma and beta diversity of AM fungal species in sandal plots soils were 36 and 4 respectively.

Table 37: AM fungal diversity in rhizosphere soils of *Santalum album* stands

Sl.No.	AM fungi	Sandal plots				
		S1	S2	S3	S4	S5
1	*Glomus albidum*	2	3			
2	*G. australe*				4	
3	*G. botryoides*	5				
4	*G. canadense*			3		
5	*G. convolutum*		4			
6	*G. deserticola*	8				
7	*G. fasciculatum*	11	11	6	9	21
8	*G.globiferum*	2				
9	*G. lacteum*	1				
10	*G. macrocarpum*	6		3		
11	*G.maculosum*	3	1			
12	*G. melanosporum*	6	14	5	15	5
13	*G. microcarpum*		3	7	2	14
14	*G. mosseae*			4	3	6
15	*G. multicaule*					1
16	*G. reticulatum*	2	7	5	4	3
17	*G.tenebrosum*			7		
18	*G. tortuosum*		2	2		
19	*Glomus* sp.				2	2
20	*Scutellospora auriglobo*					4
21	*S. erythropa*		2	3	2	2
22	*S. nigra*		3	4	4	3
23	*S. persica*	4				
24	*Acaulospora appendicula*	3	2	12	7	9
25	*A. foveata*					1
26	*A. laevis*			2		
27	*A.morrowae*				1	
28	*A.myriocarpa*	2	2		6	
29	*A.rugosa*		2			
30	*A. scorbiculata*	1	2	4	2	3
31	*A.spinosa*	3				1
32	*Entrophospora* sp.	1				
33	*Gigaspora candida*	3		3	3	
34	*G. gigantea*	1				
35	*Gigaspora* sp.			2		
36	Unidentified			12	6	
	Total No. of species	18	14	17	15	14
	Shannon index	2.6458	2.3243	2.6724	2.5689	2.2154
	Simpson index	11.5706	7.7512	12.4225	10.3476	6.7527

3.5. Kumbil

3.5.1. Arbuscular mycorrhizal association in *Gmelina arborea*

Gmelina arborea (Kumbil) plantations at three localities in Nilambur, Vazhachal and Kollathirumedu Forest Ranges were selected for the study (Table 5). All the sampled *G. arborea* plants in all the three different localities showed arbuscular mycorrhizal association (Plate 1) and the per cent root infection ranged from 16.50 to 22.40. Highest per cent root infection was recorded in a 22-year-old plantation at Panjanamkuthu, Vazhachal Forest Range; highest AM fungal spore density was also recorded from this plot. Rhizosphere soils from all the sample plots were rich in organic carbon which ranged from 2.60 to 3.04 per cent (Table 38). All the soils were moderately to strongly acidic and soil moisture content ranged from 9.8 to 11.5%. However, no correlation could be drawn on the per cent root infection with the soil physical and chemical parameters. Presence of high per cent organic carbon may possibly be the factor responsible for the low AM fungal association with the *G. arborea* roots.

Table 38: AM fungal root infection in *Gmelina arborea*

Sample plot No.	Locality	Forest Range	Soil pH	Soil MC%	OC%	AMF root infection%	AMF spore count
G1	Arnadampadam	Nilambur	5.12	9.80	3.04	18.75	133
G2	Panjanamkuthu	Vazhachal	5.90	10.02	2.61	22.40	154
G3	Vachumaram	Kollathirumede	5.98	11.50	2.60	16.50	79

3.5.2. Biodiversity of AM fungi in *Gmelina arborea* plantations

Rhizosphere soil samples from all the three *G. arborea* plantations showed representation of all the six Glomalean genera. A total of 42 Glomalean fungal species were recorded from *Gmelina* rhizosphere soils (Tables 39,40; Figure 21). The Glomalean fungal species in each sample plot ranged from 22 to 26. The genus *Glomus* was represented by 22 species of which *Glomus mosseae* and *G. fasciculatum* were the widely distributed ones and had more than 60 per cent of the total spore density for the genus. All the other 20 species showed very low spore density and were found sparsely distributed. Four species of *Scutellospora* were recorded from the rhizosphere soils of *G. arborea* and all the four species showed a very low spore density. Among these, *Scutellospora nigra* was encountered in all the three soil samples. A total of nine *Acaulospora* species were recorded and *A. appendicula* and *A. scorbiculata* represented all the three sample plots. *Sclerocystis clavispora* Trappe and *S. pachycaulis* Wu & Chen were recorded from soils under *G. arborea* from

Arnadampadam, Nilambur and Panjanamkuthu, Vazhachal. *Entrophospora* sp. was recorded only in one soil sample. Four species of *Gigaspora* were recorded with a mean spore density of 7.6 per sample plot. *Gigaspora albida* was recorded from all the soil samples and all the *Gigaspora* species were found sparsely distributed in soils under *G. arborea*. So far, no Glomalean fungi have been reported from *G. arborea*. All the AM fungi recorded form rhizosphere soils of *G. arborea* herein are new record from the State.

Table 39: Distribution of AM fungal genera in *G arborea* plots in different parts of the State

Sl. No.	AM fungal genus	No. of species	Mean No. of AMF spores / plot	Total AM spore count
1	*Glomus*	22	24	72
2	*Sclerocystis*	2	39.3	118
3	*Scutellospora*	4	5.33	16
4	*Acaulospora*	9	11	33
5	*Entrophospora*	1	1	3
6	*Gigaspora*	4	7.66	23
	Total	42	88.33	265

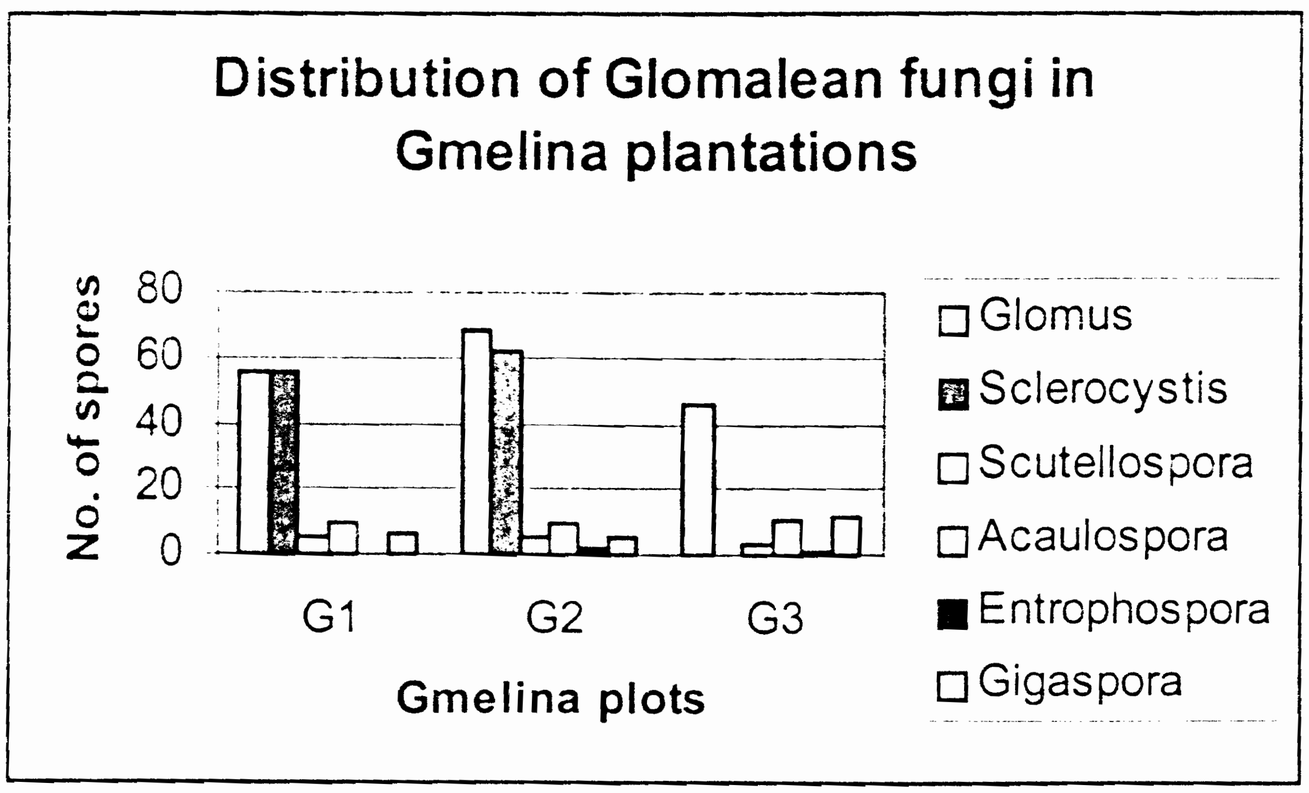


Figure 21: Distribution of Glomalean fungi in rhizosphere soils of *Gmelina arborea*

3.5.3. Biodiversity indices

Relative abundance of AM fungi in *G. arborea* soils measured using Shannon-Wiener index and Simpson's index are given for each sample plots separately (Tables 40). Shannon-Wiener index ranged from 2.2169 to 2.9106, whereas Simpson's index ranged from 4.7133 to 14.6847. Gamma diversity of AM fungi in *G. arborea* rhizosphere soils was 44, whereas beta diversity was 2.

Table 40: AM fungal diversity and their relative abundance in *Gmelina arborea* plantations

Sl.No.	AM fungi	*Gmelina* plots		
		G1	G2	G3
1	*Glomus aggregatum*	9		
2	*G. albidum*		2	
3	*G. australe*		1	3
4	*G. botryoides*		6	9
5	*G. canadense*	2	2	2
6	*G. convolutum*	1		1
7	*G. deserticola*		8	6
8	*G. fasciculatum*	2	13	11
9	*G. geosporum*	4	1	
10	*G. globiferum*	1		
11	*G. glomerulatum*			2
12	*G. intraradices*			3
13	*G. lacteum*	3		
14	*G. macrocarpum*	8	8	
15	*G. maculosum*		2	
16	*G. melanosporum*	3	6	
17	*G. microcarpum*		6	
18	*G. mosseae*	19	11	4
19	*G. multicaule*	3		
20	*G. pulvinatum*		1	
21	*G. reticulatum*	1	2	2
22	*G. tortuosum*		1	3
23	*Sclerocystis clavispora*	56		
24	*Scl. pachycaulis*		62	
25	*Scutellospora erythropa*			3
26	*S. heterogama*		2	2
27	*S. nigra*	3	3	1
28	*S. persica*	2		
29	*Acaulospora appendicula*	4	2	7
30	*A. biretticulata*	3		1
31	*A. foveata*		1	
32	*A. laevis*	1		
33	*A. myriocarpa*			1
34	*A. rehmii*		1	
35	*A. rugosa*		2	
36	*A. scorbiculata*	2	4	2
37	*A. spinosa*			2
38	*Entrophospora* sp.		2	1
39	*Gigaspora albida*	2	2	4
40	*G. decipiens*		3	2
41	*G. gigantea*	3		6
42	*G. margarita*	1		
	Total No. of species	22	26	23
	Shannon index	2.2169	2.4023	2.9106
	Simpson index	4.7133	5.3342	14.685

3.6. Acacias

3.6.1. Arbuscular mycorrhizal association in *Acacias*

Plantations of five different species of *Acacia* viz., *Acacia aulacocarpa, A auriculiformis, A. crassicarpa, A. mangium* and *A. mearnsii,* in different localities were selected for the study (Table 6). Altogether ten plantations belonging to five species were selected and all the sampled *Acacia* spp. showed a very high arbuscular mycorrhizal association (Plate 1) which ranged from 88.6 to 96.1 per cent. Highest per cent AM fungal root infection of 96.1 per cent was recorded in *A. mangium* plantation at Decentmukke, Kulathupuzha. Rhizosphere soils from all the ten *Acacia* plantations were strongly acidic and soil pH ranged from 3.5 to 5.32. All the soils were rich in organic carbon and ranged from 2.8 to 9.2 per cent and their relative status with total Nitrogen (N) per cent was also very high. Per cent available Nitrogen (N%) varied from 0.401 to 0.631 per cent. All the exchangeable cations viz., Na, Ca, K, Mg also showed variation in different soil samples. Available phosphorus (P%) ranged from 0.0406 to 0.1504 per cent (Table 41).

Table 41: AM root infection and physical and chemical characteristics of rhizosphere soils from different *Acacia* species

Sl.No.	Species	AMF root infection %	AMF spore count	Soil MC%	Soil pH	OC %	Na meq/ 100g	K meq/ 100g	Ca meq/ 100g	Mg meq/ 100g	N %	P %
A1	*A. auriculiformis*	92.4	204	12.2	4.74	3.01	0.08	0.053	1.313	0.094	0.409	0.0406
A2	*A. mangium*	96.1	103	5.02	5.31	5.1	0.067	0.05	0.445	0.08	0.631	0.1525
A3	*A. aulacocarpa*	92.3	408	4.24	5.3	4.7	0.066	0.039	0.356	0.069	0.549	0.1016
A4	*A.crassicarpa*	90.6	87	3.89	5.32	3.3	0.056	0.044	0.306	0.067	0.401	0.1504
A5	*A. mearnsii*	93.1	212	18.8	4.48	5.1	-	-	-	-	-	-
A6	*A. mearnsii*	92.1	72	14.4	4.32	8.2	-	-	-	-	-	-
A7	*A. mearnsii*	94.8	142	16.1	4.81	9.2	-	-	-	-	-	-
A8	*A.auriculiformis*	88.7	173	15.2	4.01	4.1	-	-	-	-	-	-
A9	*A.mangium*	91.6	91	14.1	4.92	2.8	-	-	-	-	-	-
A10	*A.auriculiformis*	88.6	211	14.9	3.5	5.8	-	-	-	-	-	-

\- samples not analysed

AM fungal spore density varied from 72 to 408 with a mean spore density of 170. 5 per plot. Highest AM fungal spore density of 408 was recorded from *A. aulacocarpa* plantation in Kulathupuzha, whereas lowest spore density of 72 was recorded from *A. mearnsii* at Vattavada, Devikulam. Besides the mycorrhizal association, all the *Acacia* species studied exhibited *Rhizobium* nodules. *Acacia crassicarpa* and *A. aulacocarpa* showed very high per cent rhizobial nodulation. The high infection percentage with fungal and bacterial (*Rhizobium*) symbiotic partners indicates the efficiency of the *Acacia* species in nutrient mobilization as well as uptake.

3.6.2. Biodiversity of AM fungi in *Acacia* plantations

Rhizosphere soil samples from all the ten *Acacia* plantations belonging to five species showed representation of all the six Glomalean fungal genera with a total number of 59 species (Table 42). Glomalean fungal community in the *Acacia* rhizosphere soils comprised of 19 to 31 species belonging to six Glomalean genera. *Glomus* was the most predominant genus represented by 29 species including unidentified species. Of these *Glomus australe, G. botryoides, G. deserticola, G. mosseae, G. fasciculatum, G. multicaule* and *G. melanosporum* were the widely distributed ones. All the other 22 species showed low to moderate spore density and were sparsely distributed (Table 43).

Table 42: Distribution of AM fungal genera in *Acacia* plantations in different parts of the State

Sl. No.	AM Fungal genus	No. of species	Mean No. of AMF spores	Total AM spore count
1	*Glomus*	29	83.9	839
2	*Sclerocystis*	3	50.2	502
3	*Scutellospora*	8	6.5	65
4	*Acaulospora*	11	22.3	223
5	*Entrophospora*	1	1.0	10
6	*Gigaspora*	7	5.8	58
7	Unidentified	-	0.8	8
	Total	59	170.5	1705

Seven species of *Scutellospora* were recorded from rhizosphere soils of *Acacia* species and among them only *Scutellospora erythropa* was found widely distributed in *Acacia* plantations with a moderate spore density. Of the eleven species of *Acaulospora* recorded, *A. appendicula* represented all the ten sample plots. *A. scorbiculata* was recorded in all the *Acacia* plots, except in *A. mearnsii*. *Sclerocystis clavispora, S. microcarpus* and *S. pachycaulis* were recorded from soils under *Acacia* species. *S. clavispora* was recorded from *Acacia mearnsii* and *A. auriculiformis*, while *S. pachycaulis* was encountered in soils of *A. aulacocarpa*. *S. microcarpus* was recorded from rhizosphere soils of *A. auriculiformis* and *A. aulacocarpa*. *Entrophospora* sp. was recorded from five out of ten sample plots with a very low spore density (Figure 22). Of the seven species of *Gigaspora* recorded, *G. albida, G. decipiens* and *G. gigantea* showed moderate frequency of occurrence (Table 43). Earlier, from *Acacia auriculiformis* plantations, a few species of *Glomus* (*G. albidum, G. claroideum, G. formosanum, G. fasciculatum, G. heterosporum, G. intraradices, G. macrocarpum, G. radiatum*) were recorded (Sankaran *et al.*, 1993). All the AM fungi recorded in different *Acacia* species in the present study, except those mentioned above in *A. auriculiformis*, are new record from the State.

Table 43: AM fungal diversity in soil under different *Acacia* species in the State

Sl.No.	AM fungi	Number of AM fungal spores in soils of *Acacia* plantations									
		A.auriculiformis A1	*A.mangium* A2	*A.aulacocarpa* A3	*A.crassicarpa* A4	*A.mearnsii* A5	*A.mearnsii* A6	*A.mearnsii* A7	*A.auriculiformis* A8	*A.mangium* A9	*A.auriculiformis* A10
1	*G.aggregatum*		6	9		12			9		8
2	*G. albidum*		1	2	2		2	4		2	
3	*G. australe*	11	2	4	3	6		2	2	3	4
4	*G. botryoides*	4	6	6		7		6	8		12
5	*G. caledonium*										2
6	*G. canadense*	1				2	3	3	1	1	4
7	*G. claroideum*								2		
8	*G. convolutum*						1		3	3	
9	*G. delhiense*	3								2	
10	*G. deserticola*	14	5	9		12	4		14	6	9
11	*G. fasciculatum*	61	23	18	17	37	14	11	22	13	36
12	*G. fulvum*								1		
13	*G. geosporum*			2		3		2	3	2	2
14	*G. globiferum*				3	4		1			
15	*G. intraradices*		4			2					3
16	*G. lacteum*		1								2
17	*G. macrocarpum*	4	2			6	3			6	
18	*G. maculosum*	3	2			2		3	4		
19	*G. melanosporum*	12		7		7		7	6	3	
20	*G. microcarpum*	4							11	7	
21	*G. mosseae*	14	11	11	6	13	7	9	3	12	11
22	*G. multicaule*		6	3	26	2	3	2			9
23	*G. multisubtensum*		2								
24	*G. radiatum*							4			2
25	*G. reticulatum*		3		5	2	4			2	3
26	*G. tenue*							14			
27	*G. tortuosum*	3				2	1		2	3	1
28	*G.vesiculiferum*						2				2
29	*Glomus* sp.			4							
30	*Sclerocystis clavispora*					62					68
31	*S. microcarpus*	48		240					4		
32	*S. pachycaulis*			76							
33	*Scut. aurigloba*						2				
34	*S. erythropa*	2	2	1	2	1	3		1	1	3
35	*S. gilmorei*									1	2
36	*S. gregaria*		3	2			2		3		
37	*S. heterogama*		2					2			2
38	*S. nigra*					4	2	3	2	2	3
39	*S. persica*			1		2	1	4		3	1
40	*Scutellospora* sp.							2			
41	*A. appendicula*	4	6	1	6	8	4	39	1	3	6
42	*A. biretticulata*	1			1				2	1	
43	*A. delicata*					1					2
44	*A. denticulata*								2		

45	*A. foveata*		1							2	3
46	*A. laevis*					3					
47	*A. myriocarpa*						2	14			
48	*A. rehmii*	4	1		3	1			3	1	1
49	*A. rugosa*					4	8	3			
50	*A. scorbiculata*	5	4	3	6				48	5	4
51	*A. spinosa*		1				2				
52	*Entrophospora* sp.			2	1		2		3		2
53	*Gigaspora albida*		4	2	1	1		2	1	1	1
54	*G. candida*								2		
55	*G. decipiens*		3	2	3	1		3	4	2	
56	*G. gigantea*		•	1		5		2		4	2
57	*G. margarita*								6		
58	*G. rosea*										1
59	Gigaspora sp.		2		2						
	Unidentified	6		2							
	Total No. of species	19	25	23	16	28	21	23	29	26	31
	Shannon index	2.654	2.721	2.692	2.610	2.725	2.653	2.663	2.724	2.663	2.723
	Simpson's index	11.63	12.45	12.01	9.352	12.561	10.653	10.263	12.862	12.85	12.54

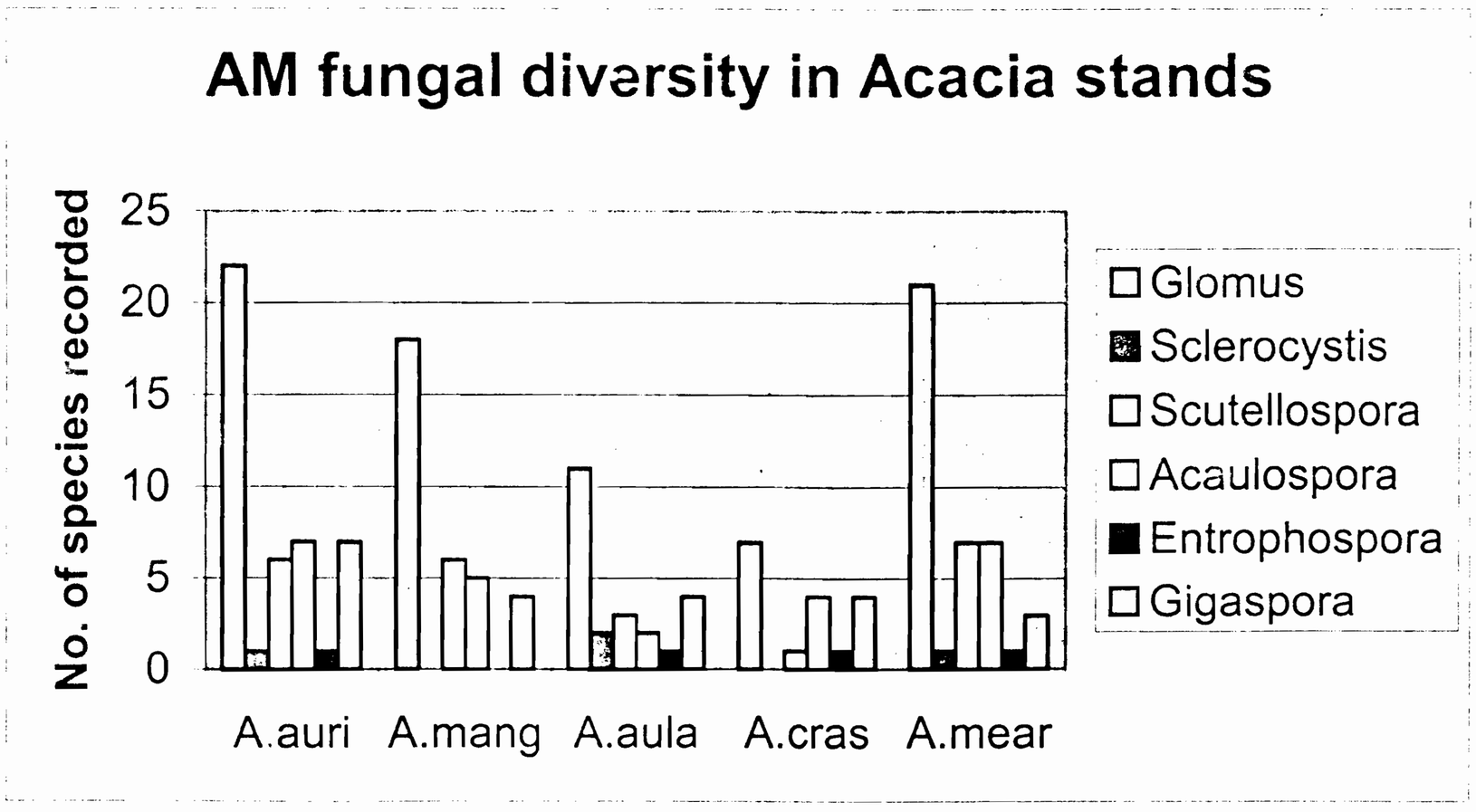


Figure 22: Distribution of Glomalean fungi in *Acacia* plantations

3.6.3. Biodiversity indices

Relative abundance of AM fungi in *Acacia* plantations soils measured using Shannon-Wiener index and Simpson's index were given for each sample plots separately (Tables 43). Shannon-Wiener index ranged from 2.610 to 2.725, whereas Simpson's index ranged from 9.352 to 12.862. Gamma diversity of AM fungi in *Acacia* plots was 42, whereas beta diversity was 3.

3.7. Albizia

3.7.1. Arbuscular mycorrhizal association in *Paraserianthes falcataria* plantations

A total of four *Paraserianthes falcataria* (=*Albizia falcataria*) plantations in different localities in the State were selected for the study (Table 7). All the sampled *P. falcataria* plantations showed a moderate arbuscular mycorrhizal association (Plate 1) and the AM fungal root infection ranged from 17.50 to 36.36 per cent. Highest per cent root infection of 26.36 per cent was recorded in a plantation at Manalar, Achenkoil Forest Range. Rhizosphere soils from all the four *Paraserianthes* plantations were moderately to strongly acidic and soil pH ranged from 3.7 to 5.49. Soils were rich in organic carbon which ranged from 1.109 to 3.241 per cent. Soil moisture content ranged from 9.36 to 16.74 per cent.

AM fungal spore density varied from 69 to 153 with a mean spore density of 100.5 per plot. Highest AM fungal spore density of 153 was recorded in soil samples from a 5-year-old plantation at Idinjar, Peringamala. Presence of high organic carbon in rhizosphere soils was found associated with high soil moisture content. The AM fungal root infection as well as AM fungal spore density were found comparatively low in plantation soils with high organic carbon than with low organic carbon (Table 44). All the *Albizia* root samples also showed high level of Rhizobial nodulation which indicates the high level dependency on dual symbiotic partners.

Table 44: AM fungal root infection and physical and chemical properties of rhizosphere soil in *Paraserianthes falcataria* sample plots

Sample plot No.	Locality	Forest Range	Root infection %	Spore count	OC%	Soil pH	Soil MC%
Alb1	Anamukku	Kollathirumedu	21.82	74	3.241	4.52	16.54
Alb2	Arippa	Kulathupuzha	17.50	69	3.039	3.7	16.74
Alb3	Manalar	Achenkoil	36.36	109	2.120	5.49	11.8
Alb4	Idinjar	Peringamala	22.50	132	1.109	4.49	9.36

3.7.2. Biodiversity of AM fungi in *Paraserianthes falcataria* plantations

Rhizosphere soil samples from *P. falcataria* plantations showed representation of only five Glomalean genera. Glomalean fungal community comprised of 28 species (Table 45; Figure 23). *Glomus* was the most predominant AM fungal genus in all the four rhizosphere soil samples which

represented 14 species and with a mean spore density of 51.25 per plot. *Glomus fasciculatum*, *G. mosseae*, *G. melanosporum*, *G. reticulatum* and *G. multicaule* were the widely distributed ones. *Glomus fasciculatum* showed the highest mean spore density of 14.5 per sample plot. All the other nine species showed low to moderate spore density and were sparsely distributed. Four species of *Scutellospora* recorded from rhizosphere soils showed very sparse distribution. Five species of *Acaulospora* were recorded and of these *A. appendicula* represented all the four sample plots. *Sclerocystis clavispora* was recorded from soil samples taken from Manalar, Achenkoil. *S. pachycaulis* was encountered from Anamukku, Kollathirumedu and Idinjar, Peringamala. *Entrophospora* sp. was not detected in any of the soil samples studied. Three species of *Gigaspora* were recorded; *G. albida* and *G. decipiens* showed moderate frequency of occurrence (Table 46). From *Paraserianthes falcataria*, so far, no AM fungi have been reported. All the Glomalean fungi recorded herein are new record from the State.

Table 45: Distribution of AM fungal genera in *Paraserianthes* plantations

Sl. No.	AM fungal genus	No. of species	Mean No. of AMF spores	Total AM spore count
1	*Glomus*	14	51.25	205
2	*Sclerocystis*	2	22	88
3	*Scutellospora*	4	3.75	15
4	*Acaulospora*	5	15.75	63
5	*Gigaspora*	3	7.75	31
	Total	28	100.5	402

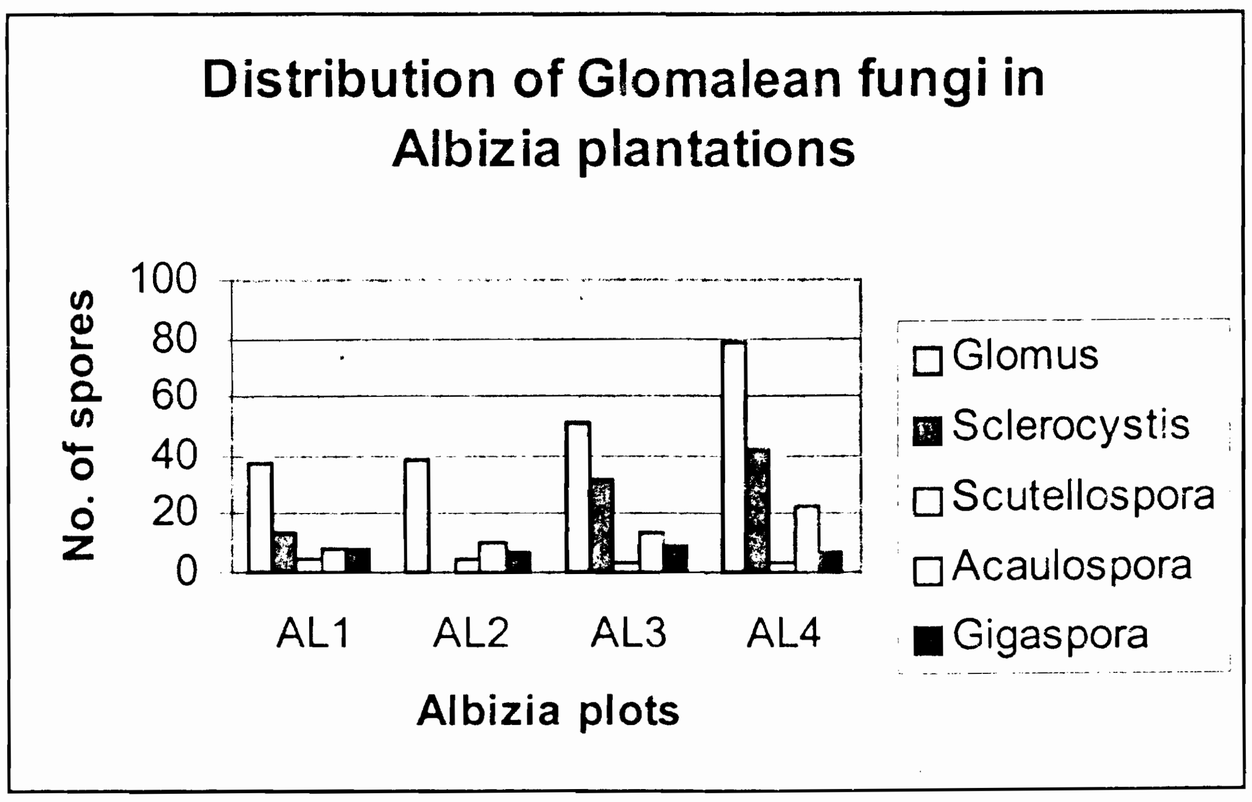


Figure 23: Distribution of Glomalean fungi in *Paraserianthes* plantations

Table 46: AM fungal diversity in *Paraserianthes falcataria* plantations in the State

Sl.No.	AM fungi	*Paraserianthes* plantations			
		Al 1	Al 2	Al 3	Al 4
1	*Glomus aggregatum*	4	2		
2	*G. albidum*	2			4
3	*G. australe*		6	2	9
4	*G. botryoides*	3	1		
5	*G. deserticola*	2	3	4	7
6	*G. fasciculatum*	9	12	16	21
7	*G. geosporum*	2		2	6
8	*G. intraradices*	1		3	3
9	*G. macrocarpum*		3	4	3
10	*G. maculosum*	1		1	5
11	*G. melanosporum*	2	1	4	7
12	*G. mosseae*	5	6	9	8
13	*G. multicaule*	3	4	2	2
14	*G. reticulatum*	3	1	4	3
15	*Sclerocystis clavispora*			32	
16	*S. pachycaulis*	14			42
17	*Scut. erythropa*	3		2	2
18	*S. heterogama*		3		
19	*S. nigra*	1		1	1
20	*S. persica*		2		
21	*Acaulospora appendicula*	6	8	12	15
22	*A. biretticulata*	1	1		
23	*A. foveata*		3		1
24	*A. rehmii*		2		6
25	*A. scorbiculata*	1	4	2	1
26	*Gigaspora albida*	3	2	6	4
27	*G. decipiens*	2	5	1	2
28	*G. margarita*	3		2	1
	Total No. of species	21	19	19	22
	Shannon index	2.6542	2.6321	2.6632	2.6824
	Simpson's index	11.596	10.562	9.865	11.976

3.7.3. Biodiversity indices

Relative abundance of AM fungi in *P. falcataria* plantations rhizosphere soils measured using Shannon-Wiener index and Simpson's index were given for each sample plots separately (Tables 46). Shannon-Wiener index ranged from 2.6321 to 2.6824, whereas Simpson's index ranged from 9.865 to 11.976. Gamma diversity of AM fungi in *Paraserianthes* plots was 39, whereas beta diversity was 3.

3.8. Miscellaneous forestry species

3.8.1. AM fungal association and biodiversity in miscellaneous forestry species

Two plantations of *Bombax ceiba*, three plots of *Swietenia macrophylla* and one plantation/plot each of *Ailanthus triphysa, Pterocarpus santalinus* and *Terminalia paniculata* were selected for the study (Table 8). Rhizosphere soils collected from *Bombax ceiba* plantations were strongly acidic (soil pH 4.65-5.02) with low moisture content which ranged from 8.52 to 9.5 per cent. *B. ceiba* showed a low AM fungal infection in feeder roots; mean infection was 13.69 per cent. Seventeen Glomalean fungi belonging to four genera viz., *Glomus, Scutellospora, Acaulospora* and *Gigaspora* were recorded from *B. ceiba* plantations with an average spore density of 39 per plantation. Altogether 10 *Glomus* species were recorded which were found widely distributed with a low spore density. Three species of *Scutellospora*, four species of *Acaulospora*, and one species of *Gigaspora* were recorded from the rhizosphere soils of *B. ceiba*. The low per cent feeder root infection by AM fungi as well as low AM spore density suggest that *B. ceiba* may be less dependent on arbuscular mycorrhizal association.

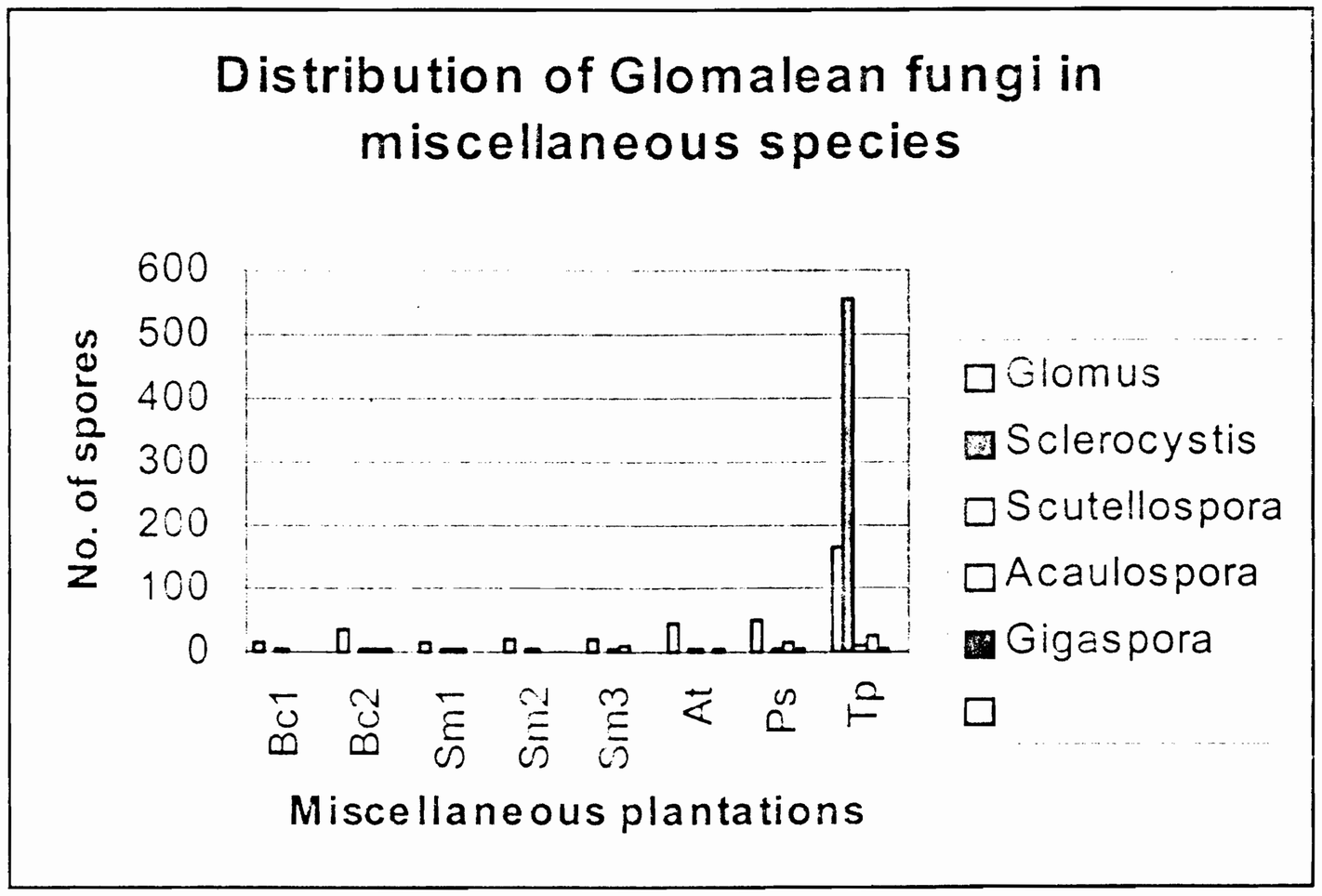
Swietenia macrophylla showed a very low AM fungal association in all the three sample plots studied with a mean root infection of 2.5 per cent. AM fungal spore density was also very low in the rhizosphere soil and mean spore count was recorded as 28 per sample plot. Eighteen Glomalean fungi were identified from the soil samples which showed a very sparse distribution. This includes: ten species of *Glomus*, four species of *Scutellospora*, three species of *Acaulospora* and one species of *Gigaspora*. *Swietenia macrophylla* seems to be a weak arbuscular mycorrhizal dependent plant species.

Ailanthus triphysa showed 15.5 per cent AM fungal root infection and the rhizosphere soil sample recorded 11 Glomalean fungi with a total spore density of 48 per sample. The Glomalean fungi include: seven species of *Glomus,* two species of *Scutellospora* and one species each of *Acaulospora* and *Gigaspora*. All the eleven AM fungi were found sparsely distributed (Tables 47, 48; Figure 24).

Pterocarpus santalinus showed 16 per cent AM fungal root infection and rhizosphere soil yielded a total of 16 Glomalean fungi with a total spore density of 71 (Tables 47,48). The AM fungal community consisted of eight species of *Glomus*, three species of *Scutellospora*, four species of *Acaulospora* and one species of *Gigaspora*. *Glomus deserticola* and *G. botryoides* showed a comparatively a very high spore density than the other species.

Table 47: Details on sample plots of *Bombax ceiba, Swietenia macrophylla, Ailanthus triphysa, Pterocarpus santalinus, Terminalia paniculata,* AM fungal root infection and physical and chemical properties of rhizosphere soils

Sample plot No..	Species	Locality	AMF root infection %	AMF spore count	Soil MC%	Soil pH
B1	*Bombax ceiba*	Irumpupalam	14.50	33	9.5	5.02
B2	*Bombax ceiba*	Kumbarakadavu	12.86	46	8.52	4.65
Sw1	*Swietenia macrophylla*	Nellikuthu	2.50	22	16.04	5.31
Sw2	*Swietenia macrophylla*	Chaliarmukku	3.00	26	15.96	5.37
Sw3	*Swietenia macrophylla*	Panayamkode	2.00	36	13.02	5.17
At1	*Ailanthus triphysa*	Velianthode	15.50	48	11.76	4.72
Ps1	*Pterocarpus santalinus*	Palappilly	22.80	71	7.05	5.01
Tp1	*Terminalia paniculata*	Mundathikode	32.50	765	5.28	5.20



* Bc1, 2: *B. ceiba*, Sm1-3: *S. macrophylla*, At: *A. triphysa*, Ps: *P. santalinus*, Tp: *T. paniculata*

Figure 24: Distribution of Glomalean fungi in miscellaneous forest plantations

Terminalia paniculata showed 32.50 per cent AM fungal root infection and a very high AM fungal spore density (Tables 47,48; Figure 24). Twenty five Glomalean fungi were recorded in the rhizosphere soil and most of the species recorded a very high spore density. Among 15 *Glomus* species recorded, *G. fasciculatum, G. mossseae, G. maculosum* Miller & Walker and *G. botryoides* showed high spore density. *Sclerocystis clavispora* and *S. microcarpus* were also recorded from the soil samples. Among *Acaulospora* species, *A. scorbiculata* was the most widely distributed species.

Of the miscellaneous forestry species studied, *Pterocarpus santalinus* and *Terminalia paniculata* were found highly depended on AM mycorrhizal fungi which is evident from the per cent root infection by AM fungi as well as the AM fungal spore count in the rhizosphere soils. *Terminalia paniculata* recorded an exceptionally high spore count of 765 /10 g of soil and a rich AM fungal community with about 25 species.

Table 48: AM fungal diversity in *Bombax ceiba, Swietenia macrophylla, Ailanthus triphysa, Pterocarpus santalinus,* and *Terminalia paniculata* rhizosphere soils

Sl. No.	AMFungi	*Bombax ceiba*		*Swietenia macrophylla*			*A.triphysa*	*P.sanatalinus*	*T.paniculata*
		B1	B2	Sw1	Sw2	SW3	At1	Ps1	Tp1
1	*G.aggregatum*		6						3
2	*G. albidum*						1		2
3	*G. australe*	4	2			3			
4	*G. botryoides*	1	3	3	4			14	18
5	*G.caladonium*						3		
6	*G. canadense*			2	3	2			
7	*G.constrictum*							2	
8	*G. deserticola*							15	9
9	*G. fasciculatum*	4	6	8	2	7	32	4	65
10	*G. geosporum*		2					2	4
11	*G. globiferum*					1			3
12	*G. intraradices*						1		2
13	*G. macrocarpum*	1	3		2		1	6	11
14	*G. maculosum*		2						4
15	*G. melanosporum*				5				9
16	*G. microcarpum*		2			1			6
17	*G. mosseae*	5	7	2	3	9	2	4	13
18	*G. multicaule*								7
19	*G. reticulatum*	2	1		1		5	2	9
20	*Sclerocystis clavispora*								46
21	*S. microcarpum*								510
22	*Scutellospora erythropa*	1			3	2	2	1	3
23	*S. heterogama*		2	1				1	4
24	*S. nigra*	3	1			2	1	3	2
25	*S. persica*			2					3
26	*A. appendicula*		2	3		7		6	6
27	*A. biretticulata*		1				7	2	
28	*A. rehmii*	1				2		3	7
29	*A. scorbiculata*		2	1	2		2	6	13
30	*Gigaspora gigantea*	2	4		1		4	3	6
31	*G. margarita*								
	Total No. of species	10	15	8	11	10	11	16	25
	Shannon index	2.242	2.4321	2.2132	2.3824	2.2632	2.421	2.5932	2.741
	Simpson's index	10.596	10.676	9.4396	10.2736	9.8165	9.7665	11.986	12.576

So far, no Glomalean fungi were recorded from *Bomabax ceiba, Swietenia macrophylla, Ailanthus triphysa, Pterocarpus santalinus* and *Terminalia paniculata*. This is the first record of AM fungal association in these hosts. All the AM fungi recorded from the above host plants are new record from the State.

3.8.2. Biodiversity indices

Relative abundance of AM fungi in *Bombax ceiba, Swietenia macrophylla, Ailanthus triphysa, Pterocarpus santalinus, Terminalia paniculata* plantations soils measured using Shannon-Wiener index and Simpson's index were given for each sample plots separately (Tables 48). Shannon-Wiener index for *Bombax ceiba* ranged from 2.242 to 2. 4321 whereas Simpson's index ranged from 10.596 to 10.676. Shannon-Wiener index for *Swietenia macrophylla* ranged from 2.2132 to 2. 3624, whereas Simpson's index ranged from 9.4396 to 10.2730. Shannon-Wiener index for *Ailanthus triphysa* was 2.421 and Simpson's index was 9.7665. Shannon-Wiener index for *Pterocarpus santalinus* was 2.5932 and Simpson's index was 11.986. Shannon-Wiener index for *Terminalia paniculata* was 2.741 and Simpson's index was 12.576.

3.9. AM fungi associated with different forest plantation species in Kerala

Arbuscular mycorrhizal fungi belong to Class Zygomycetes. In the recent classification (Morton and Benny, 1990) arbuscular mycorrhizal fungi have been transferred from the Order Endogonales to a new order Glomales. The Glomales is characterized by the unique ability of its members to form vesicular arbuscular mycorrhizae in mutualistic symbiosis with living plants. The order Glomales contains two new Sub-orders, Glomineae and Gigasporineae. The Glomineae contains two families, Glomaceae (Pirozynski and Dalphe, 1989) and Acaulosporaceae. The family Glomaceae contains two genera, *Glomus* and *Sclerocystis*. The family Acaulosporaceae contains two genera *Acaulospora* and *Entrophospora*. The sub-order Gigasporineae contains the sole family Gigasporaceae which includes two genera *Gigaspora* and *Scutellospora*. The revised classification is based on pattern of common descent in AM fungi, spore morphology with particular emphasis on the morphology of subtending hypha or sporiferous saccule, spore wall structure, ontogeny of spores and mode of spore germination. In the present study all the six genera of Glomalean fungi viz., *Glomus, Sclerocystis, Acaulospora, Entrophospora, Gigaspora*, and *Scutellospora* were recorded from the rhizosphere soils of forest plantation species.

3.9.1. The genus *Glomus*

The genus *Glomus* was recorded from the rhizosphere soils of all the forest plantation species studied and it was the most widespread AM fungi in forest plantations and represents more than 47 species and a few unidentified ones (Table 49; Plates 2-4). Identification of taxa in *Glomus* is most difficult as it has the largest number of recorded species (about 72) among genera in Glomales. Spores of some species are also having overlapping morphological characteristics. Moreover, changes in number of spore wall layers with developmental stages in fungi pose another practical problem in identification of spores from field soil samples. From teak plantations a total of 44 species of *Glomus* were recorded, while in *Eucalypts* soils 41 species of *Glomus* were recorded. In *Dalbergia latifolia, Santalum album, Gmelina arborea, Acacia* spp., and *Paraserianthes falcataria* soils, a total of 23, 16, 21, 29 and 14 species of *Glomus* respectively were encountered (Appendix I; Plates 2-4). Many chlamydospores belonging to *Glomus* could not be identified up to species level due to lack of specific characteristic features or overlapping morphological characteristics. Earlier eight species of *Glomus* were recorded from *Acacia auriculiformis* plantations in the State (Sankaran *et al.*, 1993). All the *Glomus* species recorded herein are new record from the State.

The genus *Glomus* was erected by Tulasne and Tulasne (1845). The genus, as it stands today includes those species of AM fungi which produce chlamydospores borne terminally, intercalarily or laterally on an undifferentiated non-gametangial hypahe. Chlamydospores of *Glomus* species are formed individually or in sporocarps in soil and/or in roots. Sporocarp morphology varies from single spore enveloped in a hyphal mantle (*G. tortuosum* Schenck & Smith) to clusters of orderly (*G. ambisporum* Smith & Schenck) or disorderly aggregated spores (*G. intraradices*) or true sporocarp with (*G. mossease*) or without (*G. epigeum* Danniels & Trappe) a peridium.

Table 49: *Glomus* species recorded from different plantation species

Glomus	T	Egl	Eg	Et	Ec	Ep	Eu	Ed	Ete	Er	Dl	Sa	Ga	Aa	Am	Aau	Ac	Ame	Pf	Bc	Smt	At	Ps	Tp
G. aggregatum	x	x	x	x					x	x	x			x	x	x		x	x	x				x
G. albidum	x		x	x					x		x	x	x		x	x	x	x	x			x		x
G. ambisporum	x		x						x		x													
G. australe	x	x	x	x	x	x		x		x	x	x	x	x	x	x	x	x	x	x	x			
G. boreale	x	x	x																					
G. botryoides	x	x	x	x					x		x	x	x	x	x	x		x	x	x	x		x	x
G. caledonium	x		x	x			x		x		x			x								x		
G. canadense	x		x	x	x	x	x	x		x	x	x	x	x	x			x			x			

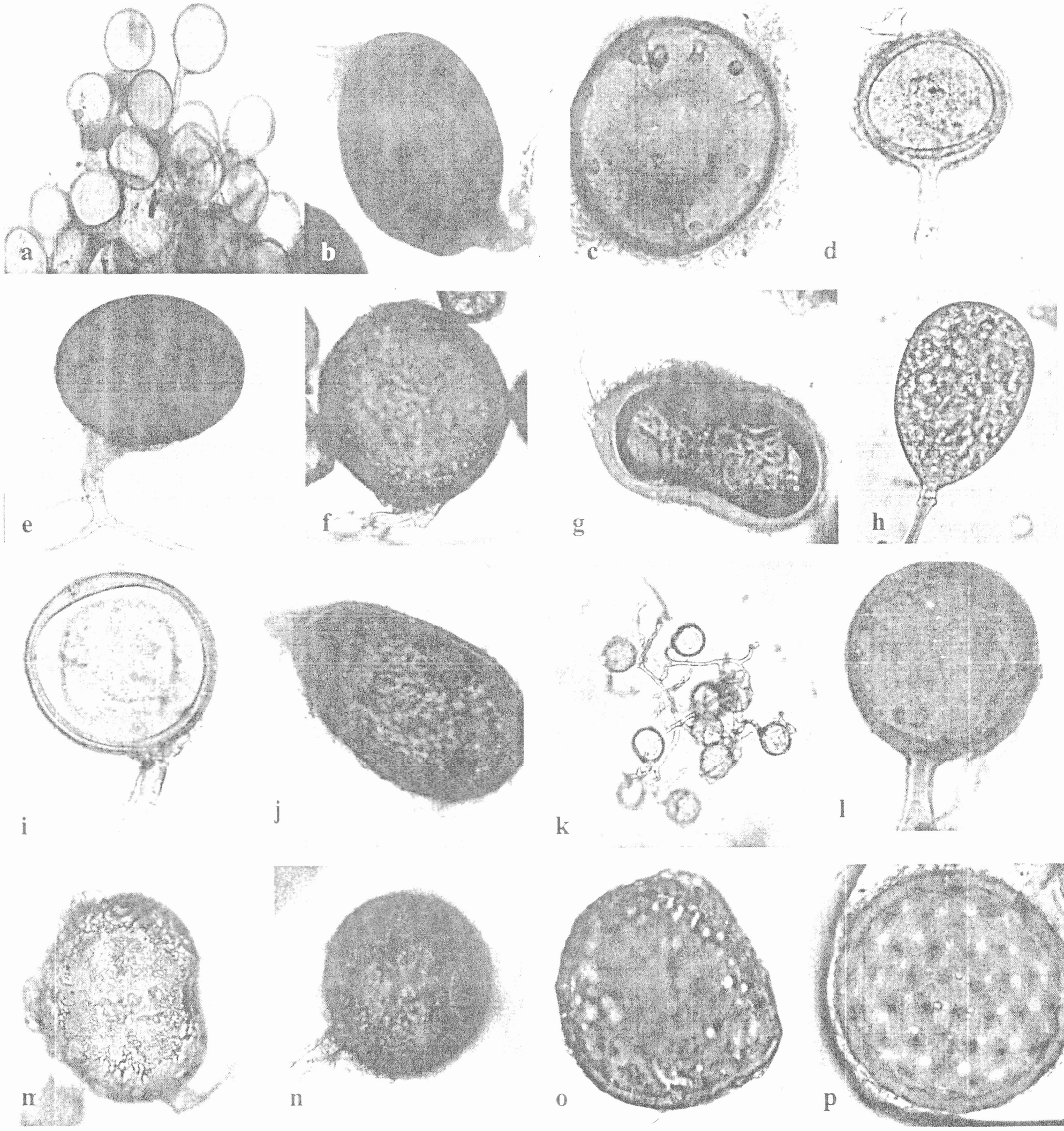


Plate 2. a: *Glomus aggregatum*, b:*G.multicaule*, c:*G. maculosum*,d: *G. invermaium*, e: *G.geosporum*, f:*G melanosporum*, g:*G. flavisporum*,h: *G.fulvum, i G. intraradices*, j: *G. tenebrosum*, k: *G. microaggregatum*, l: *G deserticola*, m: *G. tortuosum*, n:*G. multisubtensum*, o, p: *G. maculosum*

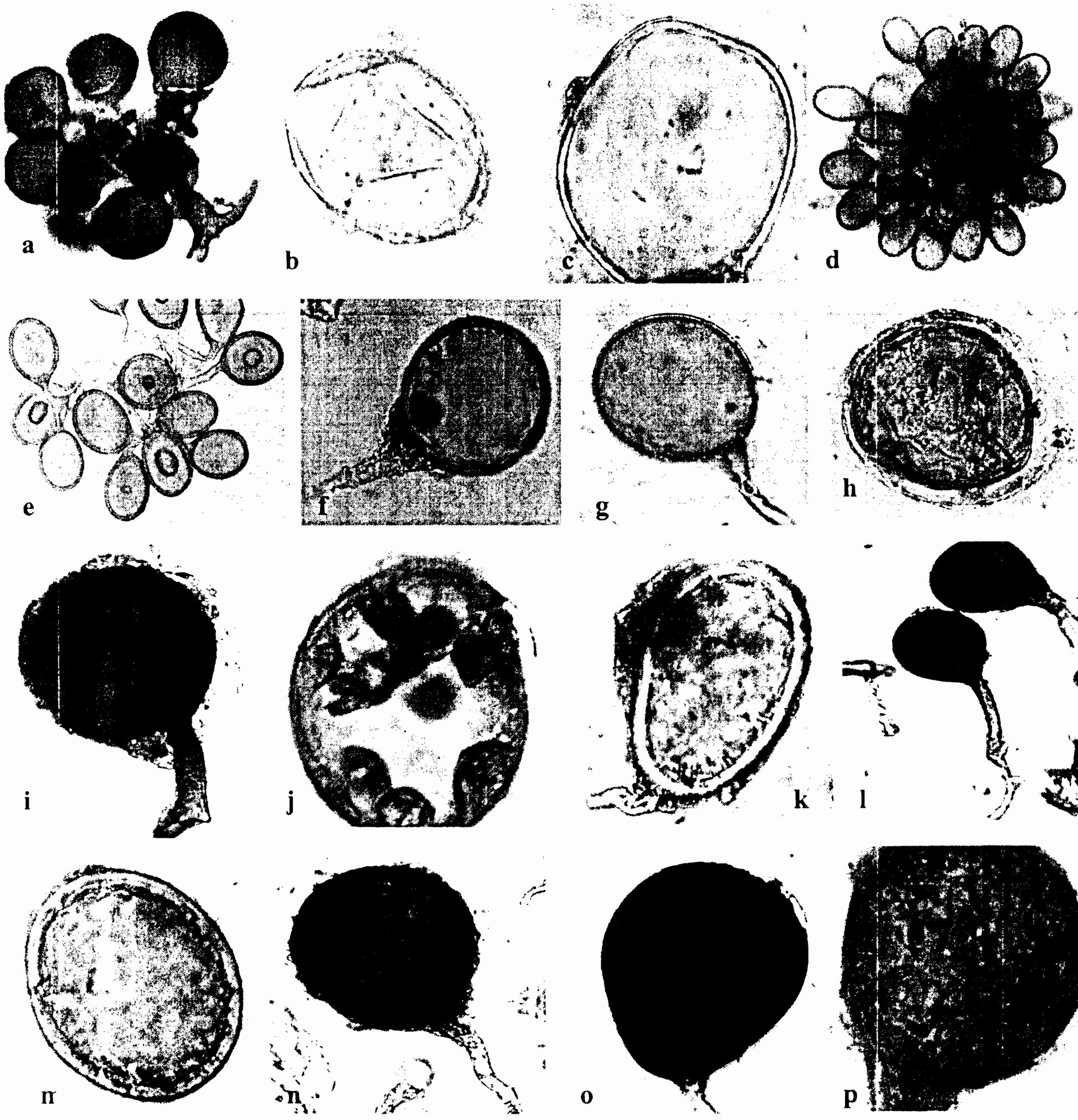


Plate 3: a: *Glomus botryoides,* b: *G. albidum,* c: *G. lacteum,* d: *G.fasciculatum*, e: *G. fasciculatum,* f: *G. claroideum,* g: *G. macrocarpum,* h: *G. pansihalos,* I: *G.,constrictum,* j:*G.. pustulatum,* k: *G. canadense*, l:*G. botryoides,* m:*G. maculosum,* n: *G. globiferum,* o:*G.mosseae,* p: *G. tortuosum*

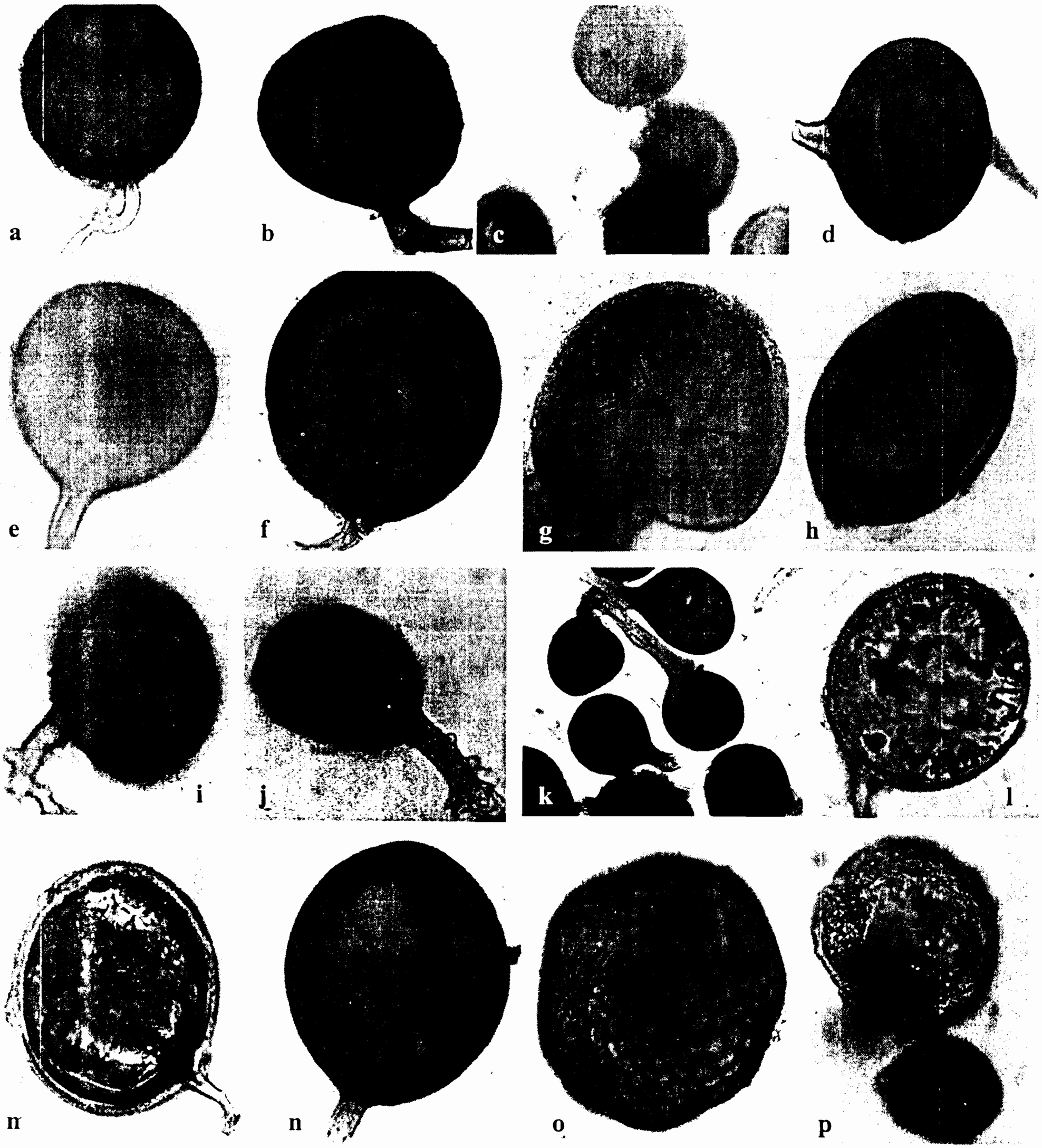


Plate 4: a,b: *Glomus constrictum, c,d: G. glomerulatum,* e: *G. macrocarpum,* f: *Glomus* sp., g: *Glomus* sp., h: *G. boreale,* I, j: *G. australe,* k: *G. botryoides,* l: *G.. maculosum,* m: *G. mosseae,* n: *G. deserticola,* o: *G. reticulatum,* p: *Entrophospora* sp.

Glomus	T	Egl	Eg	Et	Ec	Ep	Eu	Ed	Ete	Er	Dl	Sa	Ga	Aa	Am	Aau	Ac	Ame	Pf	Bc	Smt	Ats	Tp
G. citricolum			x	x					x														
G. claroideum	x		x	x	x		x							x									
G. constrictum	x																					x	
G. convolutum	x	x	x	x	x	x		x			x	x	x		x			x					
G. delhiense	x													x	x								
G. deserticola	x		x	x	x	x	x	x	x	x	x	x	x	x	x	x		x	x			x	x
G. diaphnum	x		x					x															
G. eutunicatum					x						x												
G. fasciculatum	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
G. fulvum	x		x	x					x					x									
G. geosporum	x	x	x	x	x		x	x	x	x	x		x	x	x	x	x	x	x	x		x	x
G. globiferum	x		x	x								x	x				x	x			x		x
G. glomerulatum	x		x	x									x										
G. hoi	x		x																				
G. intraradices	x	x	x	x				x		x	x		x	x	x			x	x			x	x
G. invermaium	x																						
G. lacteum	x	x	x	x							x	x	x	x	x								
G. macrocarpum	x	x	x	x	x	x	x		x		x	x	x	x	x			x	x	x	x	x	x
G. maculosum	x	x	x	x	x		x		x	x			x	x	x			x	x	x			x
G. magnicaule	x				x																		
G. melanosporum	x	x	x	x				x	x		x	x	x	x	x	x		x	x		x		x
G. microaggregatum			x								x												
G. microcarpum	x		x	x	x	x	x	x		x	x	x	x	x	x								
G. monosporum	x																			x	x		x
G. mosseae	x	x	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
G. multicaule	x		x	x	x			x			x	x	x	x	x	x	x	x	x				x
G. multisubtensum	x		x												x								
G. occultum	x		x					x			x												
G. pallidum	x		x	x																			
G. panshihalos	x		x																				
G. pulvinatum	x		x	x									x										
G. pustulatum	x			x																			
G. radiatum	x													x				x					
G. reticulatum	x	x	x	x	x	x	x	x			x	x	x	x	x	x	x	x	x	x	x	x	x
G. tenebrosum	x		x	x	x	x	x		x	x		x											
G. tenue	x		x	x	x		x	x										x					
G. tortuosum	x	x	x	x		x			x	x	x	x	x	x				x					
G. tubeforme	x																						
G. scieuliferum	x		x	x	x		x							x				x					
Glomus sp.	x										x	x				x							

X: Species recorded; T: teak; Eg: *E. grandis*; Et: *E. tereticornis*; Ec: *E. camaldulensis*; Ed: *E.deglupta*; E.gl: *E. globulus*; Eg: *E. grandis*; Ep: *E. pellita*; Er: *E. regnans*; Ete: *E tessellaris*; Eu: *E. urophylla*; Dl: *D. latifolia*; Sa: *Santalum album*; Ga: *Gmelina arborea*; Aa: *Acacia auriculiformis*; Aau:*A. aulacocarpa*; Ac: *A. crassicarpa*; Am: *A. mangium*; Ame: *A. mearnsii*; At: *Anthus triphysa*; Pf: *Paraserianthes falcataria*; Ps: *Pterocarpus santalinus*; Tp: *Terminalia paniculata*

3.9.2. The genus *Sclerocystis*

The genus *Sclerocystis* was recorded from most of the rhizosphere soils samples studied and it represents seven species viz., *Sclerocystis clavispora, S. coremioides, S. dussii, S. microcarpus, S. pachycaulis, S. rubiformis, S. sinuosa,* and an unidentified species (Table 50; Appendix I, Plate 5). The genus *Sclerocystis* was erected by Berkeley and Broome (1875). Recently, Almedia and Schenck (1990) revised this genus, which now contains a single species *S. coremioides* Berkeley & Broome. The single species of *Sclerocystis* is known to form unbranched sporophores around a central plexus of sterile hyphae with each sporophore bearing a single spore occluded by a basal septum. The rest eight species viz., *S. clavispora* Trappe, *S. pachycaulis* Wu & Chen, *S. coccogena* (Pat.) Von Hohn., *S. pakistanika* Iqbal & Bushra, *S. rubiformis* Gerd. & Trappe, *S.dussii* (Pat.) Von Hohn., *S. sinuosa* Gerd. & Bakshi and *S. microcarpus* Iqbal & Bushra included earlier, have been transferred to *Glomus*. Germination in *S. coremioides* has not been reported so far. Confusion still prevails with regard to the present status of this genus and so there is a need to study the ontogeny and germination characteristics in *Sclerocystis* to affirm its placement in the Order Glomales. Almedia and Schenck (1990) applied Medeline's (1979) mode of sympodial conidial formation to distinguish the spore ontogeny of *Glomus* from *Sclerocystis*. Furthermore, Almedia and Schenck (1990) indicated similarities in spore ontogeny in several *Sclerocystis* and *Glomus* species. However, recent studies on spore ontogeny and sporocarp formation in several *Sclerocystis* species by Wu (1993) indicated the affinity of *S. coremeoides* to other *Sclerocystis* species and retained all the transferred species under *Sclerocystis*. The arrangement of spores in sporocarps in *Glomus* is random compared with the orderly arrangement in *Sclerocystis*. Hence the dimorphic species of *Glomus* probably represents a transitional taxa linking *Glomus* and *Sclerocystis*. So far, no *Sclerocystis* species have been recorded from the State. All the seven *Sclerocystis* species recorded from different host species are new record.

Table 50: *Sclerocystis* species recorded from different plantation species

Sl. No.	*Sclerocystis*	T	Eg	Et	Etes	Dl	Ga	Aa	Aau	Ame	Pf	Tp
1	*Sclerocystis clavispora*	x	x	x	x	x	x	x	x	x	x	x
2	*S. coremeoides*	x										
3	*S. dussii*	x	x									
4	*S. microcarpus*	x	x	x					x	x		x
5	*S. pachycaulis*	x	x				x		x		x	
6	*S. rubiformis*	x										
7	*S. sinuosa*	x										

X: Species recorded; T: teak; Eg: *E. grandis*; Et: *E. tereticornis*;Etes: *E. tessellaris*; Dl: *D. latifolia;* Ga: *G. arborea*; Aa: *A. auriculiformis*; Aau:*A. aulacocarpa*; Ame: *A. mearnsii*; Pf: *P. falcataria*; Tp: *T. paniculata*

Plate 5: a,b,c,d: *Sclerocystis microcarpus*, e,f: *S.clavispora*, g,h: *S. dussii*, i,j: *S. sinuosa*, k: *S. rubiformis*, l: *S. pachycaulis*

3.9.3. The genus *Acaulospora*

The genus *Acaulospora* was recorded from all the rhizosphere soil samples studied and it was the most widespread AM fungi after *Glomus* in forest plantations and represents more than 16 species and a few unidentified ones (Table 51; Appendix I, Plates6,7). *Acaulospora* was erected by Gerdemann and Trappe (1975) to include all those species of AM fungi which produce spores, borne laterally on the proximal part of a sporiferous saccule. Formation of aggregates of spores (sporocarp) has been reported in *A. sporocarpia* Berch, *A. myriocarpa* Spain, Sieverding & Schenck and *A. trappei* Ames & Linderman. Germination in spores of three species, *A. scorbiculata* Trappe, *A. rehmii* Sieverding & Toro and *A. tuberculata* Janos & Trappe take place by the formation of germination shield prior to the emergence of the germ tube. Although, pattern in germination shields formed in *Acaulospora* superficially resembles to that in *Scutellospora*, distinct differences have been observed in their mode of formation. *Acaulospora appendicula, A. scorbiculata, A. rehmii, A. bireticulta*, etc. were the most widespread species in forest plantation soils. So far, no *Acaulospora* species have been recorded form the State. All the *Acaulospora* species recorded herein are new record from the State.

Table 51: *Acaulospora* species recorded from different plantation species

Acaulospora	T	Eg	Egl	Et	Ec	Ed	Ep	Er	Ete	Eu	Dl	Sa	Ga	Aa	Aau	Ac	Am	Ame	Pf	Bc	Sm	At	Ps	Tp
A. appendicula	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		x	x
A. bireticulata	x	x		x	x			x			x		x	x		x	x		x	x		x	x	x
A. delicta	x	x		x							x			x				x						
A. denticulata	x	x		x				x						x										
A. elegans	x	x																						
A. foveata	x	x		x		x					x	x	x	x			x		x					
A. laevis	x	x						x			x	x	x					x						
A. longula	x						x																	
A. morrowae	x	x		x								x						x						
A. myriocarpa	x	x		x			x		x		x	x						x						
A. rehmii	x	x		x	x		x			x	x		x	x		x	x	x	x	x	x		x	x
A. rugosa	x	x	x	x								x	x					x						
A. scorbiculata	x	x		x	x	x	x		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
A. spinosa	x	x	x	x					x			x	x				x							
A. trappei	x																							
A. tuberculata											x													

X: Species recorded; T: teak; Eg: *E. grandis*; Egl: *E. globulus*;Et: *E. tereticornis*; Ec: *E. camaldulensis*; Ed: *E. deglupta*; Ep: *E. pellita*; Er: *E. regnans*; Ete: *E. tessellaris*; Eu: *E. urophylla*; Dl: *D. lagolia*; Sa: *S. album*; Ga: *G. arborea*; Aa: *A. auriculiformis*; Aau:*A. aulacocarpa*; Ac: *A. crassicarpa*; Am: *A. mangium*; Ame: *A. mearnsii*; At: *Ailanthus triphysa*; Pf: *P. falcataria*; Ps: *P. santalinus*; Tp: *T. paniculata*

3.9.4. The genus *Entrophospora*

Among the Glomalean fungi recorded in forest plantation soils, the genus *Entrophospora* was represented by two species viz., *E. colombiana* and *E. infrequens* (Table 52; Appendix, I). Many spores belonging to *Entrophospora* could not be identified up to species level due to lack of characteristic features. The genus *Entrophospora* was erected by Ames and Schneider (1979) to include those species of AM fungi which formed spores inside the sporiferous saccule rather than at the side of the saccule neck. The spores of *Entrophospora* remain enclosed by the expanded saccule wall layer, even though, they may become detached from the saccule.

So far, only three species viz. *Entrophospora infrequens* (Hall) Ames & Schneider, *E. schenckii* Sieverding & Toro, and *E. columbiana* have been reported in this genus. *E. columbiana* however, can be a confusing species as its spore show wide variation in shape and size. Moreover, this fungus may form different races even at the same location (Mehrotra, 1995). So far, no *Entrophospora* species were reported from the State. *Entrophospora colombiana, E. infrequens* and an unidentified *Entrophospora* species recorded in the present study from teak, eucalypts, rosewood, sandal, kumbil and acacias are new record from the State.

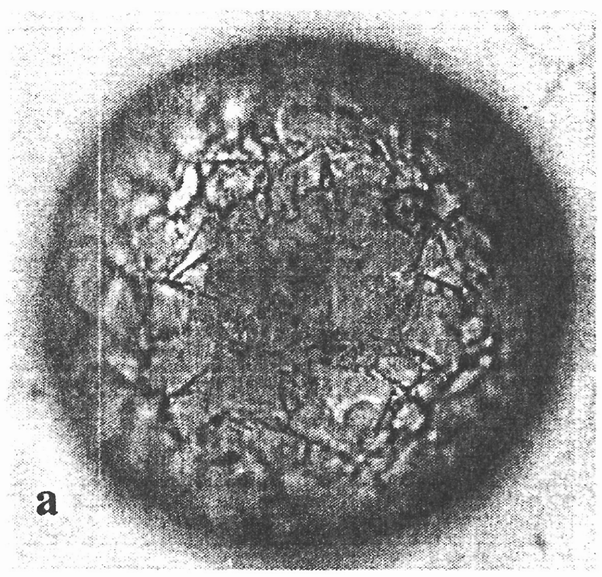
Table 52*: Entrophospora* species recorded from different plantation species

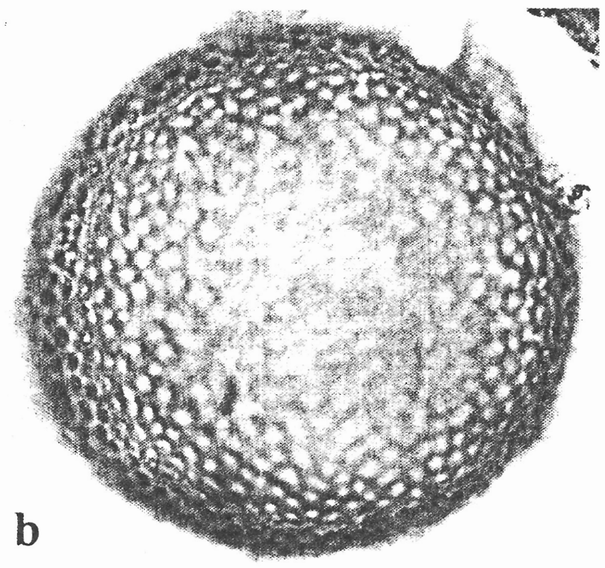
Entrophospora	T	Eg	Egl	Et	Ec	Ete	Dl	Sa	Ga	Aa	Aau	Ac	Ame
E. colombiana	x												
E. infrequens	x												
Entrophospora sp.	x	x	x	x	x	x	x	x	x	x	x	x	x

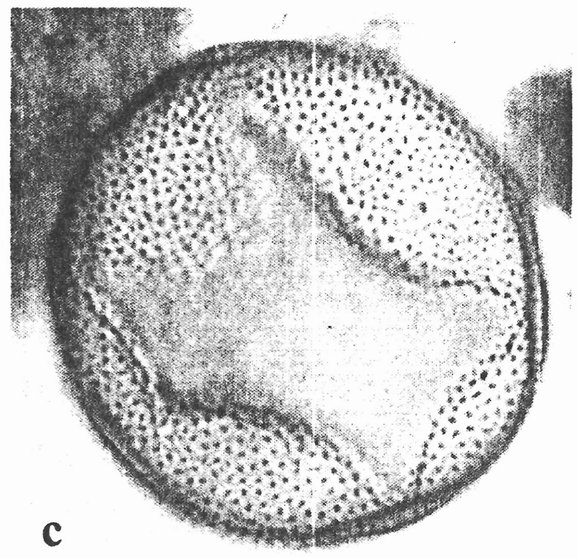
X: Species recorded; T: teak; Eg: *E. grandis*; Egl;*E. globulus*; Et: *E. tereticornis*; Ec: *E. camaldulensis*; Etes: *E. tessellaris*; Dl: *D. latifolia*; Sa: *S.album*; Ga: *G. arborea*; Aa: *A. auriculiformis*; Aau:*A. aulacocarpa*; Ac: *A. crassicarpa*; Ame: *A. mearnsii*

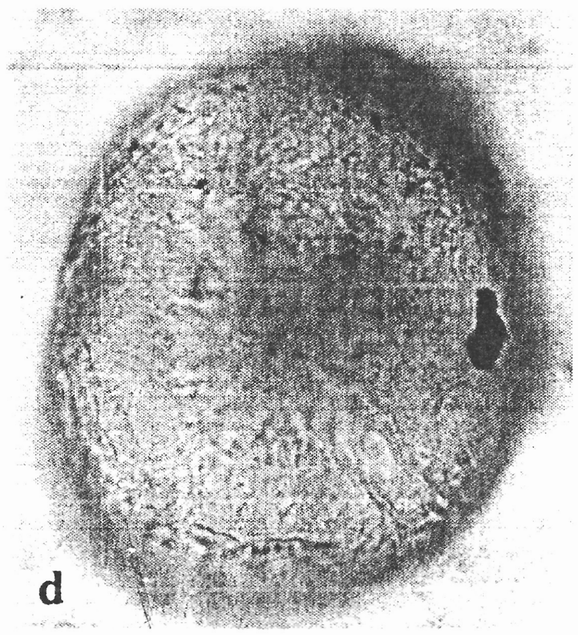
3.9.5. The genus *Gigaspora*

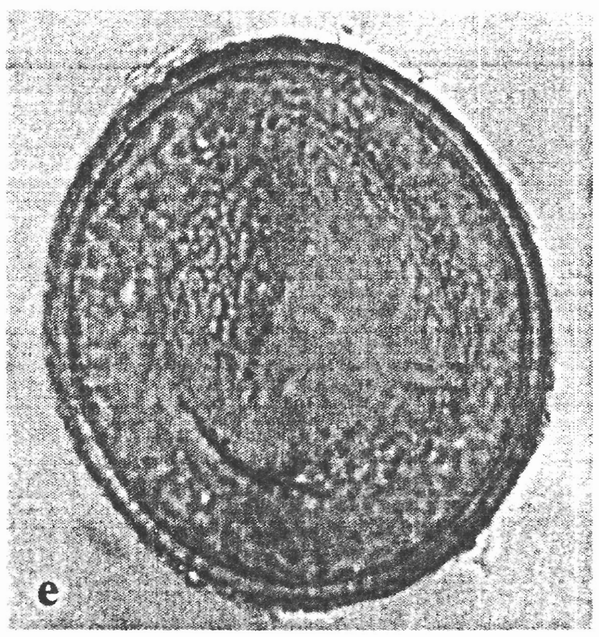
The genus *Gigaspora* was recorded from all the rhizosphere soil samples studied and represents more than 7 species and a few unidentified ones. Among these, *Gigaspora albida, Gig. candida, Gig. decipiens, Gig. gigantea,* were the most widely distributed species (Table 53; Appendix I; Plate 8). *Gigaspora* was erected by Gerdemann and Trappe (1974) to encompass all those species of AM fungi which produce spores borne on bulbous hyphal attachment. The bulbous hyphal attachment has been variously termed as bulbous suspensor (Old *et al.*, 1973), a suspensor-like cell (Gerdemann and

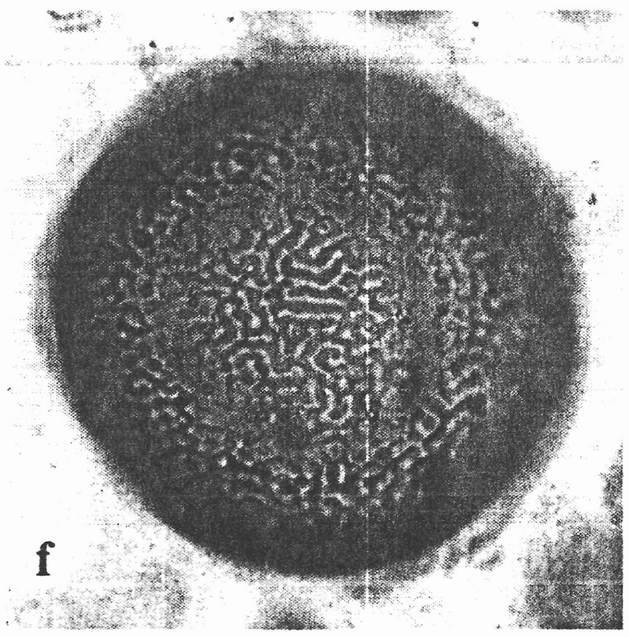


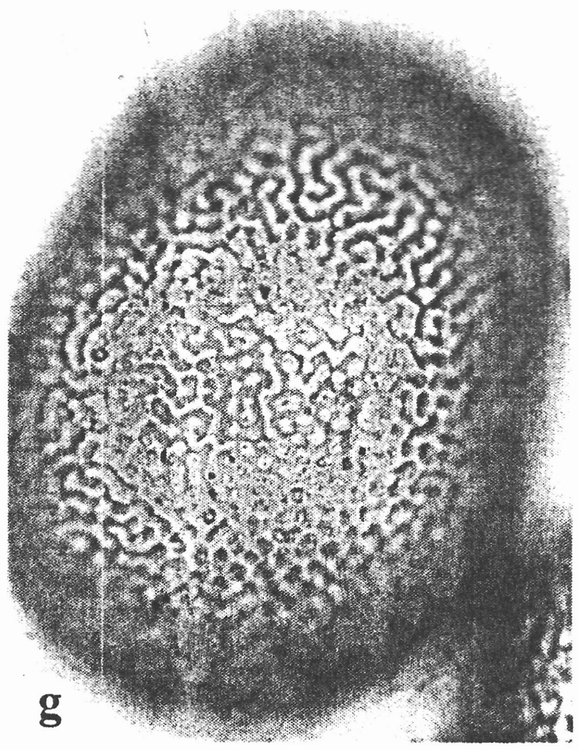


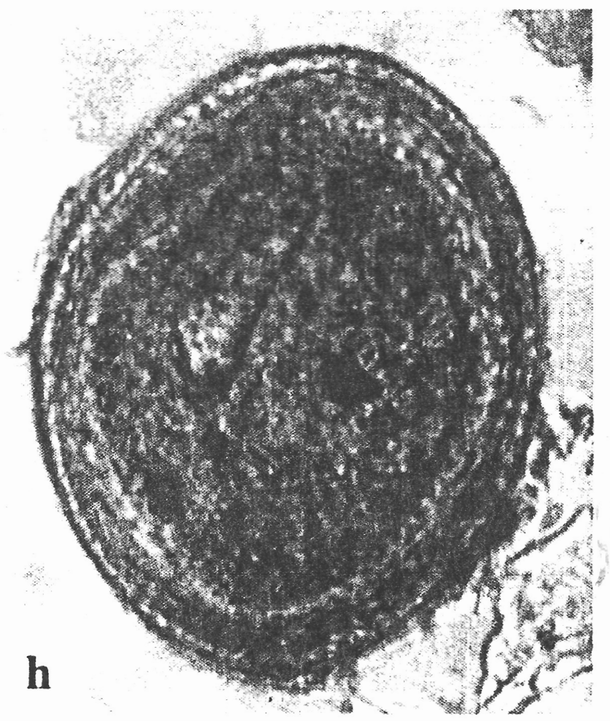












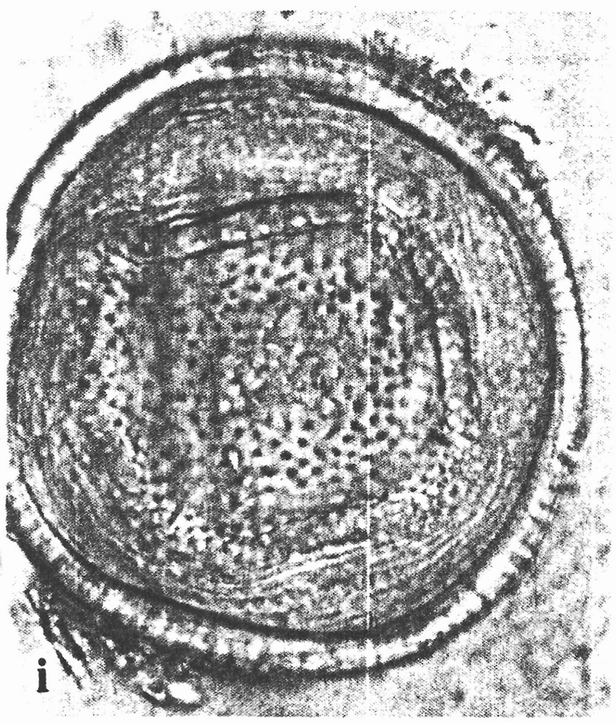


Plate 6: a: *Acaulospora appendicula,* b,c*: A. scorbiculata,* d:*A. delicata,* e: *A. spinosa,* f,g*: A. rehmii,* h*: A. dilatata* i: *A. denticulata*

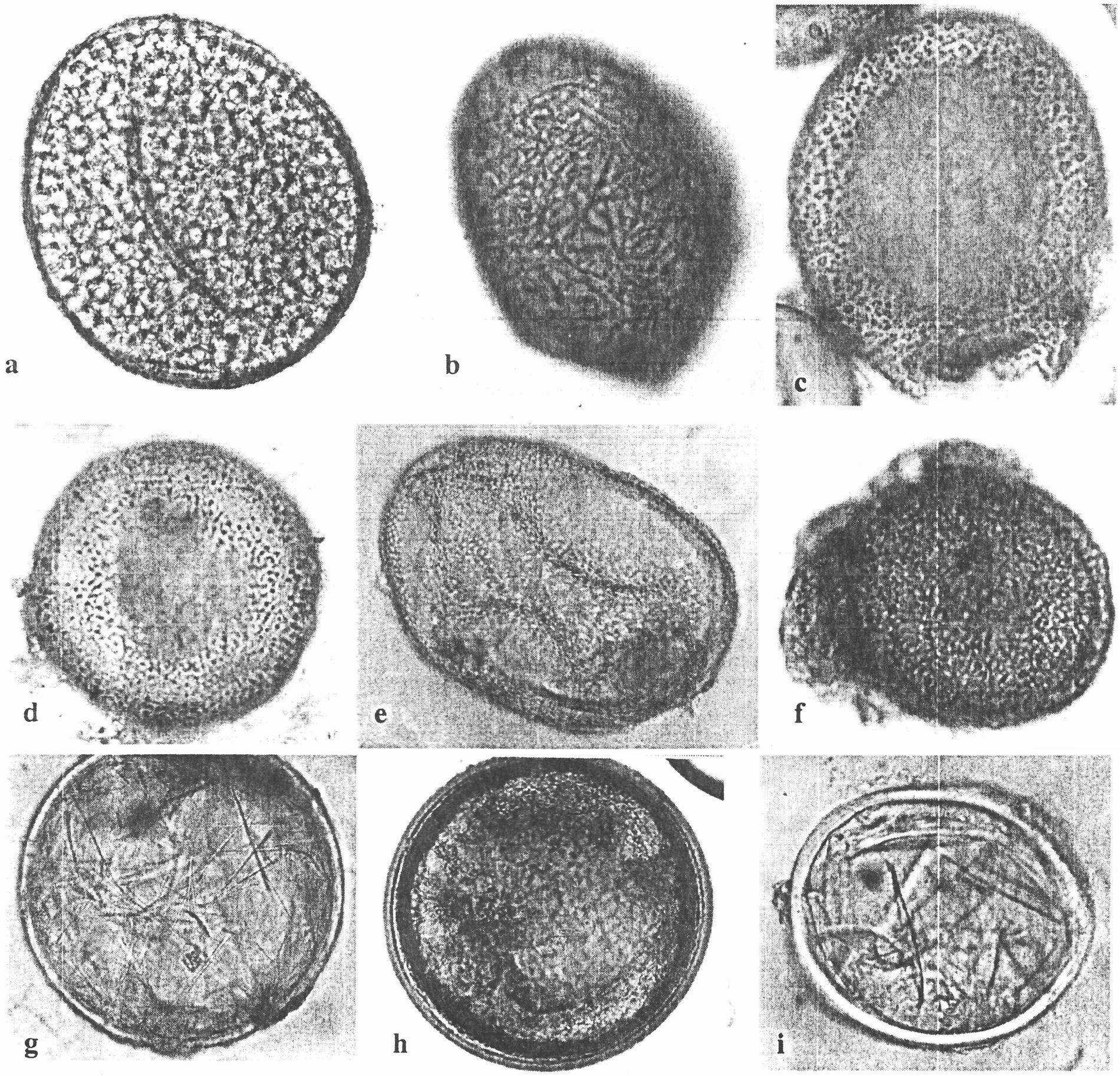


Plate 7: a: *Acaulospora laevis*, b: *A. foveata*, c,d: *A. bireticulata*, e: *A. spinosa*, f: *A. tuberculata*, g: *A. rugosa*, h: *A. morrowae*, i. *A. delicata*

Plate 8: a,b,c: *Gigaspora decipiens*, d: *G. albida*, e,f: *G. margarita*, g: h, : *G. gigantea*, i: *Gigaspora candida,* j, k: *G. rosea*, l: *Gigaspora* sp.

Trappe, 1974), or a sporogenous cell with a sporophore. Walker (1992) suggested that the bulbous suspensor is not a cell because it is continuos with the walls of the spore and its originating hypha and also believes that the spore including the bulbous suspensor is a type of sporophore and that a thin-walled sporangium developed internally.

Gigaspora, as it stands today, has spores composed of rigid wall layers (unit or laminated) in a single group. Recently, Maia (1991) confirmed the presence of germinal wall layer in *Gigaspora*. It is possible that remnant of germination shield, formed in *Gigaspora* spp., with germinal wall layer, is a transitional character linking *Scutellospora* and *Gigaspora*. Germination in *Gigaspora* is by the formation of one or more germ tubes arising directly from the spore wall, usually near the spore base.

Earlier, one *Gigaspora* sp. was recorded from *Acacia auriculiformis* plantation soils from the State (Sankaran *et al*., 1993). All the seven *Gigaspora* species recorded from different host plants herein are new record from the State.

Table 53: *Gigaspora* species recorded from different plantation species

Gigaspora	T	Eg	Egl	Et	Ec	Ed	Ep	Er	Ete	Eu	Dl	Sa	Ga	Aa	Aau	Ac	Am	Ame	Pf	Bc	Sm	At	Ps	Tp
G. albida	x		X	x	x		x		x	x	x		x	x	x		x	x	x					
G. candida	x	x		x	x						x	x		x	x	x		x						
G. decipiens	x	x	X	x				x		x			x	x	x		x	x	x					
G. gigantea	x	x	x	x		x			x	x	x	x	x	x						x	x	x	x	x
G. margarita	x		x	x	x						x		x	x			x		x					
G. rosea	x	x						x		x	x			x										

X: Species recorded; T: teak; Eg: *E. grandis*; Egl:*E. globulus*; Et: *E. tereticornis*; Ec: *E. camaldulensis*; Ed: *E. deglupta*; Ep: *E. pellitta*; Er: *E. regnans*; Etes: *E. tessellaris*; Eu: *E. urophylla*; Dl: *D. latifolia*; Sa: *S.album*; Ga: *G. arborea*; Aa: *A. auriculiformis*; Aau:*A. aulacocarpa*; Ac: *A. crassicarpa*; Am: *A. mangium*; Ame: *A. mearnsii*; At: *Ailanthus triphysa*; Pf: *P. falcataria*; Ps: *Pterocarpus santalinus*; Tp: *T. paniculata*

3.9.6. The genus *Scutellospora*

The genus *Scutellospora* was recorded from all the rhizosphere soil samples studied and represents more than 15 species and a few unidentified ones. Among these, *Scutellospora erythropa, S. nigra, S. persica*, were the most widespread species (Table 54; Appendix I; Plate 9)). Since young spores of *Scutellospora* are identical in wall structure to those of *Gigaspora* young or old spores, often

identification of this taxa becomes difficult. *Scutellospora* was erected by Walker and Sanders (1986) to separate those species from *Gigaspora*, which produce spores that germinate by means of a germination shield formed in an inner wall group of flexible wall layers (membranous or coriaceous). It has been reported that the germination shield is not formed before all spore wall layers are fully mature (Morton and Benny, 1990).

So far, no *Scutellospora* species have been recorded from the forest plantations in the State. All the 15 *Scutellospora* species recorded from different plantation species are new record from the State.

Table 54: *Scutellospora* species recorded from different plantation species

Scutellospora	T	Eg	Egl	Et	Ec	Ed	Ep	Eu	Ete	Er	Dl	Sa	Ga	Pf	Aa	Aau	Ac	Am	Ame	Bc	Sm	At	Ps	Tp
S. alborosea	x	x																						
S. aurigloba	x											x							x					
S. calospora	x	x		x																				
S. coralloida							x																	
S. dipapillosa		x																						
S. erythropa	x	x		x			x	x	x		x	x	x		x	x	x	x	x	x	x	x	x	x
S. gilmorei	x	x		x					x						x			x						
S. gregaria		x		x	x					x	x				x	x		x	x					
S. heterogama	x	x		x							x		x	x						x	x			
S. minuta	x	x		x	x																			
S. nigra	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		x	x	x	x	x	x	x
S. pellucida	x			x																				
S. persica	x	x	x	x	x	x				x	x	x	x	x	x	x			x		x			x
S. reticulata	x	x									x													
S. trycalypta											x													

X: Species recorded; T: teak; Eg: *Eucalyptus grandis*; Egl: *E. globulus*; Et: *E. tereticornis*; Ec: *E. amaldulensis*; Ed: *E. deglupta*; Ep: *E. pellitta*; Er: *E. regnans*; Etes: *E. tessellaris*; Eu: *E. urophylla*; Dl: *Dalbergia latifolia*; Sa: *Santalum album*; Ga: *Gmelina arborea*; Aa: *Acacia auriculiformis*; Aau:*A. aulacocarpa*; Ac: *A. rassicarpa*; Am: *A. mangium*; Ame: *A. mearnsii*; At: *Ailanthus triphysa*; Pf: *Paraserianthes falcataria*; Ps: *Pterocarpus santalinus*; Tp: *Terminalia paniculata*

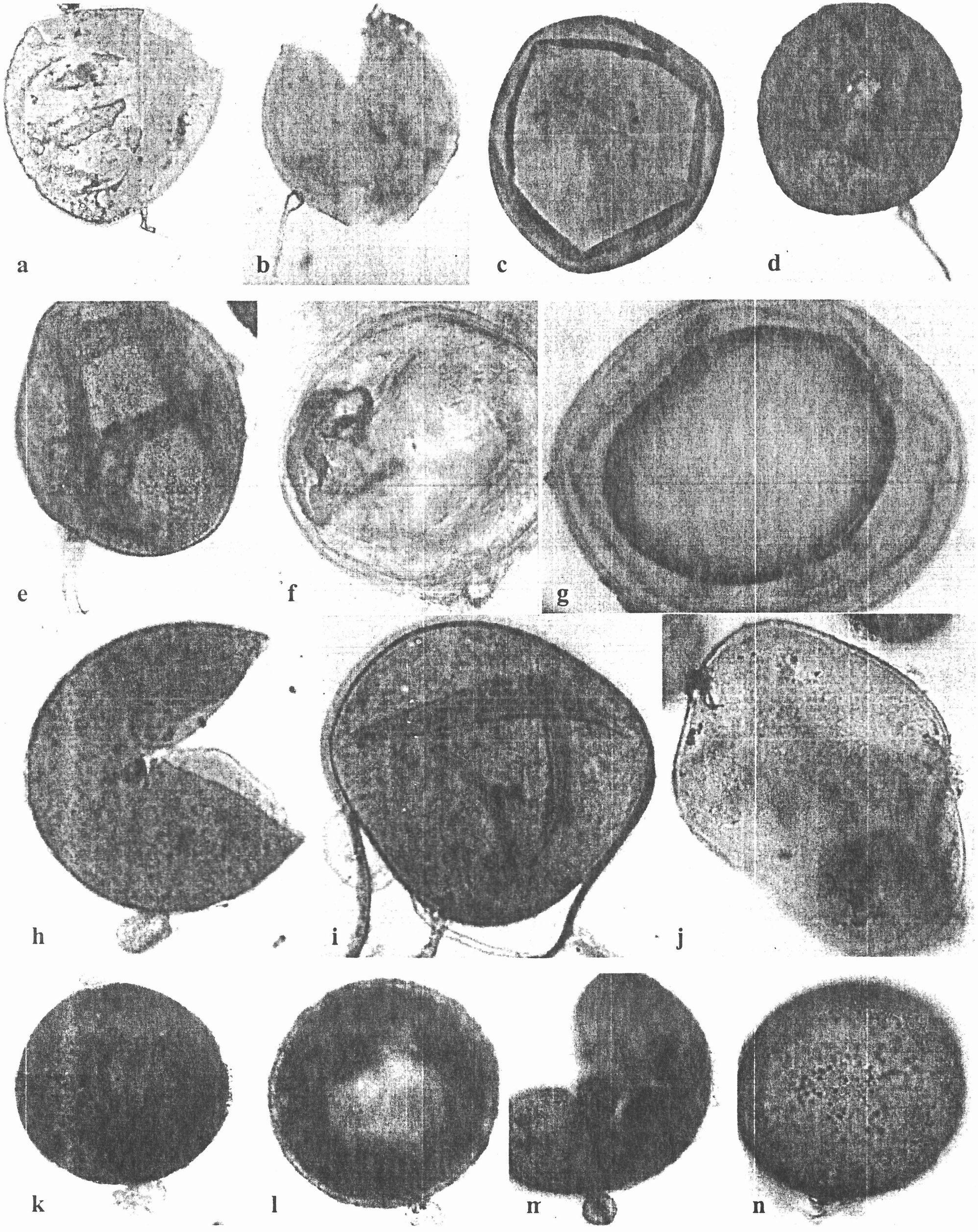


Plate 9: a,b,c: *Scutellospora gregaria*, d: *S. heterogama*, e: S. gigantea, f: *S. fulgida*, g: *S. aurigloba*, h: *S. persica*, i: *S. erythropa*, j: *Scutellospora sp*. k: *S. verrucosa*, l: *S. nigra*, m: *S. reticulata*, n: *Scutellospora* sp.

3.10. Ectomycorrhizae

3.10.1. Ectomycorrhizal association and biodiversity of ECM fungi in forest stands

Among various forestry species surveyed, ectomycorrhizal (ECM) association was observed in eucalypts, acacias, teak, *Dalbergia latifolia* and *Gmelina arborea* stands. Ectomycorrhizal association consisted of soil mycelial system, linking mycorrhizal roots and fructifications of the associated fungus. Ectomycorrhizal roots were characterized by the presence of a mantle and 'Hartig net', but often these structures were not well developed in many hosts. Ectomycorrhizal association were observed predominantly on the fine root tips of the host plants, which were unevenly distributed throughout the soil profile and more abundant in the topsoil layers containing humus. All the above mentioned forestry species showed a modified lateral root branching pattern. In general, the ectomycorrhizal root system consisted of short mycorrhizal lateral roots supported by a network of thicker, long roots.

The marked differences in the morphological characteristics of the ectomycorrhizal roots suggests the involvement of large number of different ectomycorrhizl fungi. In eucalypts, the infection observed on the fine ultimate lateral roots and various morphological patterns of mycorrhizae were observed. The simplest form comprised of short, blunt ended, cylindrically swollen roots. The pyramidal type of ectomycorrhizal roots, a compact recemose system having multiple branches at close intervals was the most common type of ectomycorrhizal roots encountered in eucalypts. The multiple ectomycorrhizal root apices bound together by fungal tissues forming a compact tuberculate or nodular structure was also observed. In certain cases, irregular patterns of branching of mycorrhizal roots give rise to a coralloid appearance. The superficial ectomycorrhizae, where roots of normal morphology are heavily covered by loose wefts of fungal hyphae that spread throughout the adjacent soil or litter was also observed. In eucalypts all the above types of mycorrhizal roots were observed in both high and low elevated areas. All the eucalypts studied viz., *E. grandis, E. tereticornis, E. camaldulensis, E. pellitta, E. deglupta, E. urophylla, E. regnans* and *E. tessellaris* showed ectomycorrhizal association, however, among these, *E. grandis* and *E. tereticornis* exhibited a very high ectomycorrhizal association with varying patterns of heterorhizy.

In *Acacia auriculiformis*, *A. mangium* and *A. crassicarpa*, pyramydal, coralloid and tuberculate types of ectomycorrhizal roots were common. In teak and *Gmelina arborea*, both blunt ended, cylindrically swollen type and pyramidal types of ectomycorrhizal roots were observed. In *Dalbergia latifolia*, pyramidal, coralloid and highly irregular shaped ectomycorrhizal roots were observed. Usually, the

ectomycorrhizae showed a fungal mycelial covering with a fluffy appearance and yellow, pink, brown or black pigmentation. The rhizomorphs and hyphal strands of the associated fungi extend from ectomycorrhizal roots along uninfected roots or radiate out into the surrounding soil. In the present study, frequent association of sporocarps (Hilton *et al.*, 1989) with the eucalypts, teak, acacias and *G. arborea* in plantations and detection of hyphal connection between sporocarps and mycorrhizal roots (Chilvers, 1968, 1973) were taken into consideration as evidence for a fungus as ectomycorrhizal.

The survey revealed a large number of ectomycorrhizal fungi associated with eucalypts, especially *Eucalyptus grandis* and *E. tereticornis*. From *E. camaldulensis, E. deglupta, E. urophylla, E. pellita, E. regnans, Acacia auriculiformis, A. crassicarpa* and *A. mangium* plantations only a few ectomycorrhizal fungi were collected. A total of 37 fungi belonging to Sclerodermatales, Lycoperdales, Aphyllophorales, and Agaricales were collected from eucalypts plantations through out the State (Table 55; Plates 9-10).

Eucalyptus grandis plantations recorded 19 genera of ectomycorrhizal fungi, whereas *E. tereticornis* recorded 10 ectomycorrhizal fungi. In *E.grandis* plantations at high elevated areas, especially in Munnar Forest Division (Vattavada, Surynelli, Matupetty, etc.), *Laccaria* spp. were the predominant ectomycorrhizal fungi, followed by *Scleroderma* species. While in *E. tereticornis* plantations in low elevated areas, *Pisolithus tinctorius* was the major ectomycorrhizal fungus followed by *Ramaria* and *Scleroderma* species. In general, *Laccaria* spp., *Pisolithus tinctorius, Ramaria* spp., and *Scleroderma* spp. were the most widely distributed ectomycorrhizal fungi in eucalypts plantations (Plates 9-10). Earlier, *Pisolithus tinctorius* has been recorded from eucalypts (*Eucalyptus camaldulensis, E. tereticornis*) and acacia (*Acacia. auriculiformis, A. holoseicea, A. mangium*) plantations in southern India (Natarajan *et al.*, 1988; Sampangiramaiah and Bhatta, 1996; Vijayakumar *et al.*, 2000).

The occurrence and diversity of ectomycorrhizal fungi depend largely on the environmental factors, especially the soil moisture and atmospheric humidity. High soil moisture and presence of leaf litter encourage the production of fruiting bodies of ectomycorrhizal fungi like *Laccaria, Lactaria, Scleroderma*, etc., while moderate soil moisture and removal of litter from the ground thereby exposing the ground to direct sun light encourage the production of fructifications of *Pisolithus tinctorius* and *Ramaria* spp.

From teak plantations association of *Boletus* sp., *Scleroderma verrucosum, Thelephora terrestris, Hygrocybe* sp., *Gomphus* sp., etc. was recorded. However, the distribution of the ectomycorrhizal fungi was found limited to moist areas in plantations. In *Gmelina arborea* plantation at

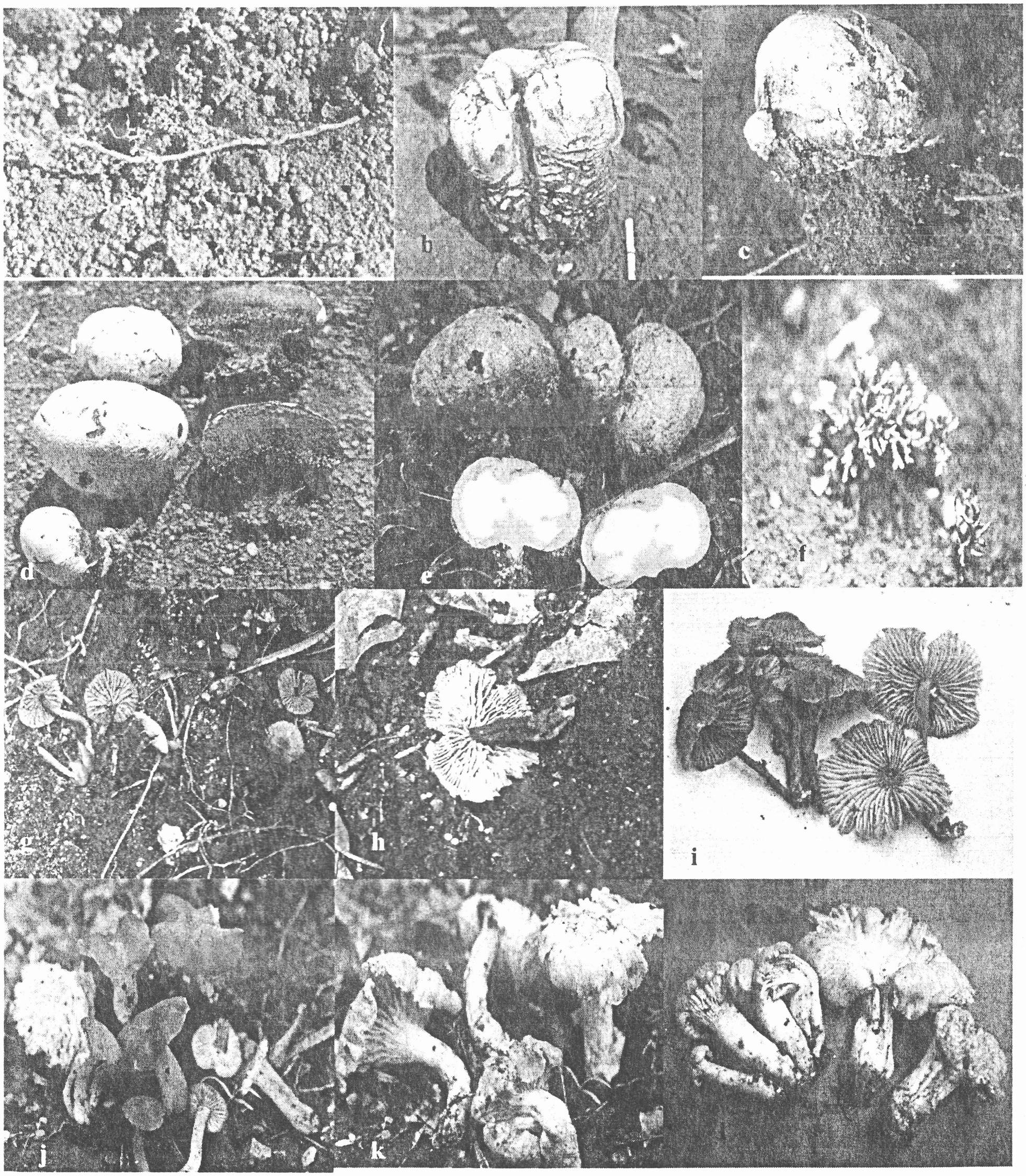


Plate 10: a: Ectomycorrhizal root of *Eucalyptus tereticornis*, b,c,d: *Pisolithus tinctorius*, e: *Pisolithus* sp., f: *Ramaria* sp., g: *Laccaria laccata*, h, i: *Collybia* sp., j: *Hygrocybe coccinea*, k,l: *Cantherellus* sp.

Panjanamkuttu, Vazhachal, ectomycorrhizal association was very prominent and ectomycorrhizal fructifications were collected during the post-monsoon period. From *Dalbergia latifolia* plots, only a few ectomycorrhizal fungi were encountered. Of these *Cantharellus* sp. was found most widespread, especially in Nilambur Forest Range. In *Acacia auriculiformis* and *A. mangium* plantations, *Pisolithus tinctorius* was the major ectomycorrhizal fungi. *Scleroderma verrucosum, Scleroderma citrinum, Scleroderma* sp., *Ramaria* sp., *Nematoloma* sp., etc. were also encountered.

Table 55: Macro fungi collected from different forest plantations and their ectomycorrhizal status

Sl. No.	Macro fungi	*Eg*	*Et*	*Tg*	*Dl*	*Ga*	*Aa*	*Am*
1	*Boletes sp.* ♣			♣		♣		
2	*Cantherellus cibarius* ♣				♣			
3	*Cantharellus* sp. ♣	♣						
4	*Chlorophyllum molibdatus*							
5	*Clathrus* sp.							
6	*Clavaria* sp.							
7	*Clavulina* sp. ♦	♦						
8	*Clavulinopsis* sp. ♦	♦	♦	♦	♦		♦	♦
9	*Collybia* sp.							
10	*Conocybe* sp.							
11	*Coprinus* spp.							
12	*Cortinomyces* sp.							
13	*Descolea* sp. ♣	♣						
14	*Descomyces* sp. ♣	♣	♣					
15	*Entoloma* sp.							
16	*Geastrum triplex* ♦	♦	♦	♦		♦		
17	*Geastrum* sp. ♦	♦	♦	♦			♦	♦
18	*Gomphus clavatus* ♣			♣				
19	*Hygrocybe coccinea* ♦	♦	♦					♦
20	*Hygrocybe* sp.							
21	*Hysterangium* sp. ♣	♣						
22	*Inocybe* sp. ♣	♣						
23	*Laccaria canaliculata* ♣	♣						
24	*Laccaria laccata* ♣	♣	♣					
25	*Laccaria proxima* ♣	♣						
26	*Laccaria* sp. ♣	♣	♣					
27	*Lactarius* sp. ♣	♣						
28	*Lepiota* sp.							
29	*Lycoperdon* sp. ♦	♦						
30	*Marasmius sp.*							
31	*Nematoloma* sp. ♦	♦						
32	*Oedemansiella* sp.							
33	*Pisolithus tinctorius* ♣	♣	♣				♣	♣
34	*Pisolithus sp.* ♣				♣			
35	*Psathyrella* sp.							
36	*Ramaria* sp. ♣	♣	♣	♣		♣	♣	♣

37	*Ramariopsis* sp. ♣		♣		♣			
38	*Rhizopogon occidentalis* ♣	♣						
39	*Rhizopogon* sp. ♣	♣						
40	*Scleroderma albidum* ♣							
41	*Scleroderma citrinum* ♣	♣	♣				♣	♣
42	*Scleroderma geaster* ♣	♣						
43	*Scleroderma verrucosum* ♣	♣	♣				♣	♣
44	*Scleroderma* sp. ♣	♣	♣				♣	
45	*Termitomyces microcarpus* □	□			□	□	□	
46	*Thelephora terrestris* ♣			♣				
47	*Tricholoma* sp. ♣	♣	♣					
	Total No. of macrofungi	39	21	12	8	14	8	9
	Total No. of ectomycorrhizal fungi	19	10	6	3	3	5	4

♣ mycorrhizal fungus; ♦ mycorrhizal status doubtful; □ not mycorrhizal; *Et: Eucalyptus grandis; Et: E. tereticornis; Tg: Tectona grandis; Ga: Gmelina arborea; Dl: Dalbergia latifolia, Aa: Acacia auriculiformis; Am: A. mangium*

The ectomycorrhizal survey showed that large number of ectomycorrhizal fungi recorded were associated with the exotic forestry species, especially eucalypts and acacias and there would be a possible competition among the ectomycorrhizal fungi for colonization of roots. So far, no ectomycorrhizal fungi have been reported from forest plantation species, especially, eucalypts and acacias from the State. All the ectomycorrhizal fungi reported herein are new record from the State.

More than 150 fungal species in over 60 genera have been reported as ectomycorrhizal association with eucalypts (Chilvers, 2000). Of these, most belong to Basidiomycetes (89%); a few belong to Ascomycota (9%) or Zygomycota (2%). Among the Basidiomycota, most are agarics. A few species have been reported as forming hypogeous sporocarps belonging to the genera *Gymnomyces, Hysterangium, Hymenogaster, Thaxterogaster*, etc. *Pisolithus* and *Scleroderma* are the important epigeous sporocarps forming genera under Gasteromycetes. Many of the ectomycorrhizal fungi, including species of *Hydnangium, Hymenogaster, Labrynthomyces, Laccaria, Pisolithus, Scleroderma* have been reported as forming typical branching ectomycorrhizae complete with 'Hartig net' and elongate epidermal cells (Malajczuk *et al.*, 1982).

Pisolithus, Scleroderma, and *Laccaria* species are generally viewed as cosmopolitan mycorrhizal fungi with broad host ranges (Marx, 1977). Also it has been reported that within the genus *Eucalyptus*, there is no evidence of host specificity, and an ectomycorrhizal fungus from one eucalypt appearing capable of forming mycorrhizae with any other species of eucalypts providing the conditions are suitable (Chilvers, 1973; Malajczuk *et.al.*, 1982).

3.10.2. Ectomycorrhizal synthesis

Experimental synthesis of mycorrhizae following inoculation of eucalypt seedling roots with pure cultures of different ectomycorrhizal fungi prepared from sporocarps was carried out and re-isolation of the respective fungus from synthesized mycorrhizae was done as equivalent to satisfying the Koch's rules of proof of causation as applied to pathogens. However, this has been achieved for only three isolates of fungi viz., *Pisolithus tinctorius, Scleroderma verrucosum* and *Laccaria laccata*. All the ECM fungi treated eucalypt seedlings showed development of ectomycorrhizal infection in their root system. However, the rate of ectomycorrhizal infection was inconsistent; in a few seedlings the entire root system was found colonized by the fungus, while in others only mild infection was recorded. Earlier, successful synthesis of ectomycorrhizae between various strains of *P. tinctorius* and *L. laccata* and several host species has been demonstrated (Bougher and Malajcsuk, 1990).

Other fungi referred to as ectomycorrhizal fungi satisfied only the criteria such as frequent association of sporocarps with plants in the field and detection of hyphal connection between sporocarps and mycorrhizal roots. This has proved to be reasonably reliable indicator where the fungus belongs to a genus already known to contain mycorrhiza forming species (Hilton *et al.*, 1989).

3.11. Improvement of planting stock through mycorrhizal application

3.11.1. Selection of AM and ECM fungi and forestry species for mycorrhization studies

Tectona grandis, Dalbergia latifolia and *Santalum album* were selected for preliminary trials on artificial mycorrhization using AM fungi. While *Eucalyptus grandis, E. tereticornis* and *Acacia mangium* were selected for mycorrhization trials using ECM fungus. Selection of host species was based on their mycorrhizal status as well as economic importance. Even though, the present study on association and biodiversity of AM fungi with different forestry species showed no host specificity, AM fungal candidates for each host species were selected on the basis of their occurrence as well as their biodiversity status in the respective rhizosphere soils. Similarly, though, many ectomycorrhizal fungi including different species of *Scleroderma, Laccaria, Rhizopogon*, etc. were found potential candidates for improving the planting stock, *Pisolithus tinctorius*, the most potential species based on their occurrence as well as mycorrhizal status under various edaphic and environmental conditions was selected.

3.11.2. Mycorrhization of teak, sandal and rosewood seedlings using AM fungi

Four Glomalean fungi viz., *G. fasciculatum* (Pot culture No. T18), *G deserticola* (T20), *G. mosseae* (T26), *A. appendicula* (T21) retrieved from the teak rhizosphere soils and inocula prepared by pot cultures using maize seedlings were utilized for the mycorrhization trials on teak. *G. fasciculatum* (Pot culture No. D06), *A. appendicula* (D09) retrieved from *Dalbergia latifolia* rhizosphere soils and inocula prepared by pot cultures using maize seedlings were utilized for the mycorrhization trials on *D. latifolia*. *G. fasciculatum* (Pot culture No. S02), *G. mosseae* (S11), *A. appendicula* (S14) retrieved from the *Santalum album* rhizosphere soils and inocula prepared by pot cultures using maize seedlings were utilized for the mycorrhization trials on *S. album* (Plate 12).

3.11.2.1. Teak

In teak, measurements on seedling height recorded from the inoculation trials showed that *G. fasciculatum* and *A. appendicula* treated seedlings recorded maximum mean height of 12.24 cm and 11.83 respectively, whereas control plants recorded a mean height of 10.53 cm (Table 50). No difference was observed on mean number of leaf pairs in treated and non-treated seedlings. In general, AM fungi treated teak seedlings recorded more bio-mass than the untreated control seedlings (Table 56; Figure 25). As far as the mycorrhizal inoculation effect (MIE) is concerned, *Acaulospora appendicula* treated seedlings recorded 60.29% MIE. *G. fasciculatum* and *G. deserticola* treated seedlings gave 38.23% and 22.05% MIE respectively. While *G. mosseae* treated seedlings gave only 7.35% MIE.

Table 56: Effect of AM fungal inoculation on growth of teak seedlings

Sl. No.	Treatment	Mean height (cm) and number of leaf pairs						Wet wt (g)	Dry wt (g)	Difference in wt (g)	%MIE
		30 d	160 d	180 d	200 d	220d	240 d				
1	G. *fasciculatum* (T18)	6.22 (4.4)	10.85 (4.65)	11.07 (3.74)	11.16 (4.79)	11.44 (5)	12.24 (3.84)	3.2	0.94	2.26	38.23
2	*G. deserticola* (T20)	5.18 (5.06)	9.13 (4.33)	9.15 (4)	9.37 (4.47)	9.38 (4.64)	10.26 (3.29)	2.95	0.83	2.12	22.05
3	*A. appendicula* (T21)	7.91 (5)	9.91 (4)	9.92 (3.76)	10.45 (3.38)	10.7 (3.76)	11.83 (3.24)	3.62	1.09	2.53	60.29
4	*G. mosseae* (T26)	5.73 (3.63)	8.78 (3.8)	8.86 (3.6)	8.72 (3.6)	9.34 (3)	9.6 (3)	2.44	0.73	1.71	7.35
5	Control	5.15 (4.69)	9.35 (3.54)	9.36 (2.69)	9.57 (3.38)	9.68 (3.38)	10.53 (3.15)	2.44	0.68	1.76	

* Mean value of height of 48 seedlings in each treatment; figures in parenthesis are mean value of number of leaf pairs

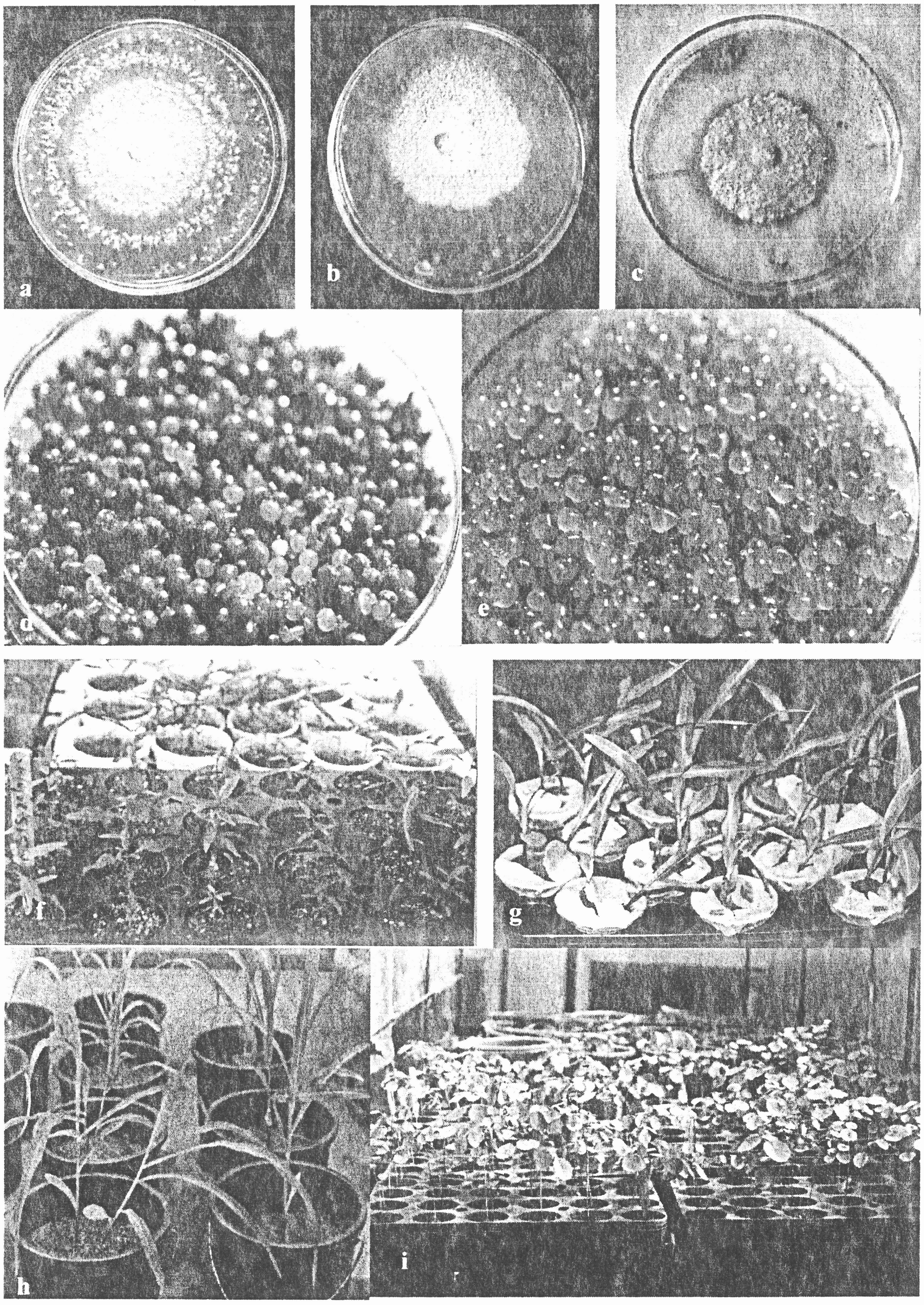


Plate 12: a: Petri dish culture of *P. tinctorius*, b: *S. verrucosum*, c: *L.laccata*, d: encapsuled mycelia of *P. tinctorius*, e: encpsuled spores of *P. tinctorius*, f: ECM treated *Eucalyptus* seedlings, g: AM spore multiplication using maize seedlings (funnel technique), h: AM pot culture, i: AM inoculum treated *D. latifolia* seedlings

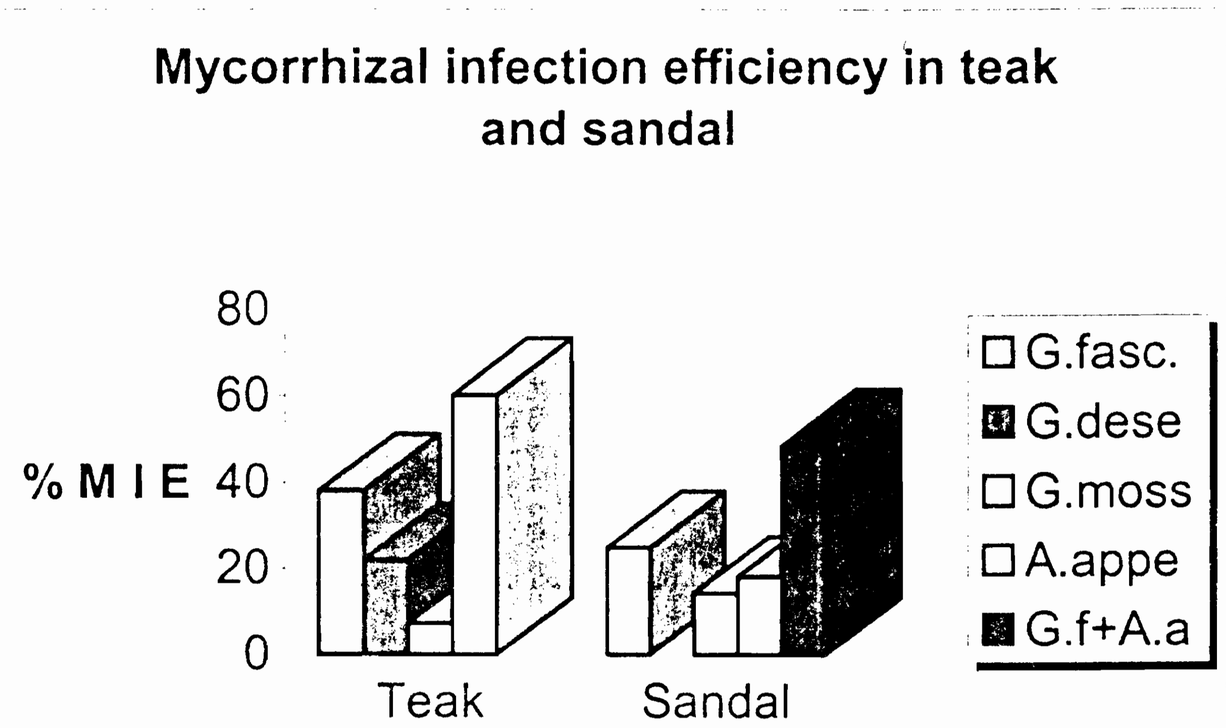


Figure 25: Mycorrhizal infection efficiency in teak and sandal seedlings

The results show that teak seedlings are well responding to the artificial inoculation with AM fungi at the early seedling phase. Earlier, better seedling growth, biomass and percentage of root infection have been recorded in artificial inoculation trials with different AM fungi viz., *Gigaspora margarita, Glomus versiforme, G. fasciculatum, G. mosseae, Sclerocystis dussii*, separately or mixed with *Azospirillum* sp., rock phosphate, etc. (Gurumurthy and Sreenivasa, 1998, 2000; Verma and Jamaluddin, 1995; Durga *et al.*, 1995; Rajan *et al.*, 2000). Even though, no species specificity for AM fungi was recorded, for optimizing the mycorrhization of teak seedlings and thereby improving the quality of planting stock, an in-depth study involving more AM fungal species under various nursery conditions has to be carried out.

3.11.2.2. Sandal

Santalum album L., a semi root parasite is one of the important forestry species being used by the Forest Department in afforestation programmes. In the present study, attempts were made to accelerate the growth of sandal seedlings by applying two species of AM fungi viz., *Glomus fasciculatum* and *G. mosseae.* Measurements on seedling height recorded from the trials showed that *G. mosseae* and *G. fasciculatum* treated seedlings recorded maximum mean height of 18.61 cm and 16.34 cm respectively, whereas control plants recorded a mean height of 15.60 cm (Table 57). No marked difference was observed on mean number of leaf pairs in treated and non-treated seedlings.

All the AM fungi treated sandal seedlings recorded more bio-mass (dry weight) than the untreated control seedlings (Table 57; Figure 25). In a treatment where the inoculum consisted of mixture of *G. fasciculatum* and *Acaulospora appendicula* recorded highest percentage of mycorrhizal inoculation effect (Table 57). All the other treatments gave 14 to 25 per cent MIE.

Table 57: Effect of AM fungal inoculation on growth of *Santalum album* seedlings

Sl. No.	Treatment	Mean height and mean No. of leaf pairs			Biomass wet wt (g)	Biomass dry wt (g)	Differenc e in wt (g)	%MIE
		20 d	40 d	60 d	0.49	0.24	0.25	25.00
1	G. *fasciculatum* (S02)	13.04 (4.7)	15.4 (6.0)	16.34 (6.56)				
2	*A. appendicula* (S14)	8.5 (4.0)	10.99 (6.14)	11.63 (7.5)	0.52	0.22	0.30	18.18
3	G. *fasciculatum*+ *A. appendicula*	12.49 (4.22)	14.54 (5.33)	15.89 (5.88)	0.99	0.35	0.64	48.57
4	*G. mossese* (S11)	14.32 (4.56)	16.04 (6.0)	18.61 (7.25)	0.44	0.21	0.23	14.28
5	Control	12.04 (4.0)	14.30 (7.0)	15.60 (7.67)	0.51	0.18	0.33	

* Mean value of height of 24 seedlings in each treatment; figures in parenthesis are mean value of number of leaf pairs

Recently, Nelson *et al.* (2000) recorded improvement on growth of sandal seedlings by inoculation with *Glomus fasciculatum* and *G. aggregatum*. Maximum growth promotion was recorded in *G. fasciculatum* treated seedlings in which the shoot length increased by 66.2 per cent, fresh weight by 96.4 per cent, and seedling biomass by 94.7 per cent over the control seedlings. The results of the present trial showed that sandal seedlings are well responding to artificial AM fungal application and thus the sandal planting stock can be improved by application of efficient AM fungi.

3.11.2.3. Rosewood

In *Dalbergia latifolia*, all the AM fungi treated seedlings recorded more height than control seedlings (Table 57). *Glomus fasciculatum* treated seedlings recorded maximum mean height of 11.61 cm after 60 days of inoculation, whereas control seedlings recorded a mean height of 9.2 cm (Table 58). Differences in seedling height ranged from 1.03-1.35 cm. No marked difference was observed on mean number of leaf pairs in treated and non-treated seedlings; however, *Acaulospora appendicula* + *G. fasciculatum* treated seedlings recorded a mean number of leaves 18.2 (Table 58). All the treated seedlings showed AM fungal root infection as well as rhizobial nodules. AM inoculation trials gave positive results. Maximum MIE was recorded in *G. fasciculatum* + *A. appendicula* inoculum mixture

applied seedlings. The results on this preliminary trial show that *D. latifolia* seedlings can be improved by AM fungal application. Data on mycorrhization trials with AM fungi in *Dalbergia sissoo* are available (Sumana *et al.*, 1996; Gurumurthy *et al.*, 1999; Jamaluddin *et al.*, 1998). However, information on AM fungal mycorrhization of *D. latifolia* is meagre. Sumana and Bagyaraj (1998) reported greater plant height, stem girth, dry weight and P content in AM fungi inoculated *D. latifolia* seedlings than non-inoculated seedlings. Among eight AM fungi used for inoculation trials, *Glomus leptotichum* and *G. fasciculatum* were found to be the best.

Table 58: Effect of AM fungal inoculation on growth of *D. latifolia* seedlings

Sl. No.	Treatment	At the time of treatment		After 20 days of treatment 20dafetr		After 60 days of treatment		Biomass dry wt. (g)	%MIE
		Mean ht (cm)	Mean No. of leaves	Mean ht (cm)	Mean No. of leaves	Mean ht (cm)	Mean No. of leaves		
1	*G. fasciculatum*	10.13	19.083	10.4	20.875	11.16	14.76	0.41	29.26
2	*A. appendicula*	9.02	17.52	9.33	18.57	10.17	18.2	0.40	27.50
3	*A. appendicula* + *G. fasciculatum*	8.81	17.78	9.864	22.09	10.16		0.48	39.58
4	Control	8.61	15.136	9.00	20.14	9.8	15.73	0.29	

3.11.3. Improvement of planting stock by ectomycorrhizal application

3.11.3.1. Eucalypts

Ectomycorrhizal fungal inocula prepared using *Pisolithus tinctorius* as described under Section 2.9 were screened for their mycorrhization efficiency in forestry seedlings. *Eucalyptus grandis* and *E. tereticornis* seedlings raised in root trainers filled with soil-sand (50:50) medium were treated with various forms of inocula. In general, seedling growth in terms of height increment and number of leaf pairs produced was comparatively higher in all ECM fungal treatments than the control sets. *E.grandis* seedlings treated with *P. tinctorius* spore-sand inoculum showed a mean height of 33.68 cm and mean leaf pair of 9.24 at 240 days of growth, while the mean seedling height and mean number of leaf pair in control were only 23.67 cm and 7.26 respectively (Table 59). Treatments with PT-mycelial beads and PT- encapsulated spores also showed a better seedling growth than in control. Results on seedling biomass in various treatments also showed similar trends. PT- spore-sand inoculum treated seedlings recorded a mean dry weight of 0.93 g, while that of control seedlings was only 0.62 g. Mycorrhizal inoculation effect (MIE) was also recorded maximum in PT- spore-sand inoculum applied seedlings (Table 59). *Eucalyptus tereticornis* seedlings treated with different

ectomycorrhizal inocula also showed similar trends. Seedling height, biomass as well as mycorrhizal inoculation effect were highest in PT-spore-sand inoculum treatment (Table 60).

Table 59: Effect ectomycorrhizal treatments on growth of *E. grandis* seedlings

Sl. No.	Treatment	Mean Height (cm) and number of leaf pairs						Biomass wet wt (g)	Biomass dry wt (g)	% MIE
		30 d	160 d	180 d	200 d	220 d	240 d			
1	PT-spore-sand	5.56 (6.29)	24.17 (6.5)	27.4 (7.62)	30.86 (7.33	32.18 (8.38)	33.68 (9.24)	1.89	0.93	50
2	PT-spore slurry	4.72 (5.71)	18.44 (5.86)	20.43 (6.14)	21.64 (6.77)	22.85 (7.27)	24.64 (7.95)	1.23	0.62	0
3	PT-mycelial beads	4.80 (5.75)	18.85 (6.65)	22.59 (7.38)	25.45 (7.53)	26.97 (8.07)	29.12 (9.5)	1.62	0.77	24.20
4	PT-spore encapsulated	3.85 (5.21)	18.57 (6.17)	21.71 (6.54)	23.25 (6.71)	25.37 (7.52)	27.24 (7.70)	1.48	0.68	9.67
5	Control	3.98 (5.75)	17.22 (4.23)	18.16 (5.09)	19.7 (6.05)	23.28 (7.32)	23.67 (7.26)	1.4	0.62	

- Mean value of observations from 96 plants; PT: *Pisolithus tinctorius*

Table 60: Effect of ectomycorrhizal treatments on growth of *E. tereticornis* seedlings

Sl. No.	Treatment	Mean height (cm) and number of leaf pairs						Bio-mass Wet wt (g)	Bio-mass Dry wt (g).	MIE %
		30 d	160 d	180 d	200 d	220 d	240 d	1.89	0.9	91.48
1	PT-spore-sand	6.40 (6.46)	24.48 (7.29)	27.30 (9.04)	27.40 (10.61)	27.97 (12.22)	28 (8.45)			
2	PT- spore slurry	5.13 (6.21)	19.72 (6.83)	20.06 (7.17)	22.42 (9.09)	23.34 (9.35)	23.80 (7.13)	1.42	0.78	65.95
3	PT-mycelial beads	5.47 (5.92)	20.26 (6.87)	21.41 (7.67)	22.82 (8.35)	23.85 (9.65)	23.88 (6.27)	1.51	0.8	70.21
4	PT-spore encapsuled	4.84 (6.04)	15.73 (5.83)	16.55 (6.9)	17.80 (8.3)	18.65 (9.70)	18.82 (6.94)	1.16	0.55	17.02
5	Control	4.62 (5.87)	18.01 (6.27)	21.12 (8.10)	21.70 (8.62)	22.62 (9.62)	24.18 (8.55)	0.68	0.47	

* Mean value of observations from 96 plants; figures in parenthesis are mean number of leaf pairs

Pisolithus tinctorius has been extensively used for mycorrhization trials in eucalypts and other hosts in different parts of the world and varying degrees of success in improving the planting stock has been reported (Marx, 1981; Marx and Kenney, 1982; Marx *et al.*, 1984; Bougher and Malajczuk, 1990:; Grove *et al.*, 1995; Tam and Griffiths, 1993; Mohanan, 2002a). Since, *P. tinctorius* forms a very high level of ectomycorrhizal symbiosis with eucalypts, especially with *E. tereticornis* in medium and low elevated areas, an in-depth study employing this fungus for improving the eucalypts planting stock is warranted.

3.11.3.2. Acacia

Acacia mangium seedlings raised in root trainers filled with soil-sand (50:50) medium were treated with various forms of *Pisolithus tinctorius* inocula viz., spore-sand mixture, spore slurry, mycelial beads and encapsuled spores. In general, all the mycorrhization treatments have significant effect on seedling height increment, number of leaf pairs (phyllodes), and also in seedling bio-mass production. Maximum seedling height of 11.22 cm and number of leaf pair (4.47) were recorded in PT-spore-sand inoculum treatments, while those in control were 9.4 cm and 3.4 respectively. Seedling biomass as well as mycorrhizal inoculation effect (MIE) were highest in PT-spore-sand treatment (Table 61). Among the various ectomycorrhizal inoculum preparations tried, PT-spore-sand inoculum was found very effective in mycorrhization as well as boosting the growth of seedlings in terms of seedling height and biomass.

Table 61: Effect of ectomycorrhizal fungal treatments on growth of *Acacia mangium*

Sl. No.	Treatment	Mean Height (cm) and number of leaf pairs						Bio-mass wet wt (g)	Bio-mass dry wt (g).	MIE %
		30 d	160 d	180 d	200 d	220 d	240 d			
1	PT-spore-sand	5.6 (5.8)	10.36 (3.43)	9.88 (3.55)	10.31 (4.17)	10.59 (4.81)	11.22 (4.47)	1.15	0.38	123.52
2	PT-spore slurry	5.46 (5.63)	8.08 (3.05)	7.79 (3)	7.89 (2.67)	8.65 (3.54)	9.64 (4)	1.0	0.29	70.58
3	PT-mycelial beads	4.12 (5.52)	7.27 (3.48)	7.53 (3.6)	7.61 (3.68)	7.64 (4)	8.78 (4.75)	0.91	0.29	70.58
4	PT-spore encapsuled	3.73 (4.91)	5.56 (2.94)	5.82 (3.19)	5.89 (2.93)	5.91 (3.08)	5.98 (3.17)	0.67	0.22	29.41
5	Control	5.20 (5.46)	8.23 (3.09)	8.29 (2.1)	8.31 (2.56)	8.4 (3.25)	9.4 (3.4)	0.49	0.17	

* Mean value of observations from 96 plants; PT: *Pisolithus tinctorius*

Pisolithus tinctorius is naturally distributed in *Acacia* plantations in the State. Recently, a pilot-scale study employing *Pisolithus tinctorius* inoculum (Mohanan, 2002a) revealed that *Acacia auriculiformis* and *A. mangium* are equally responding to the artificial inoculation in nurseries. As *P. tinctorius* has a broad host range and is widely distributed in tropical areas, further studies are required to improve the planting stock through mycorrhizal manipulations.

4. GENERAL DISCUSSION

Mycorrhizal symbiosis formed between plant roots and mycorrhizal (AM or ECM) fungi is of great interest due to its potential influence on ecosystem processes, its role in determining plant diversity in natural communities as well as ability of the fungi to induce a wide range of growth responses in co-existing plant species. In general, mycorrhizal association is beneficial to plants in many fold, since it increases the area of rhizosphere for water and nutrient absorption by plants, decreases disease susceptibility, increases tolerance to adverse environmental conditions and increases biomass and productivity of stands. However, very little attention has been paid to study the ecological significance of the diversity of mycorrhizal fungi and this is mainly attributed to the difficulties in identification and inability to culture the AM fungi on artificial medium.

The mycorrhizal status of the Indian flora, especially forest vegetation is largely unexplored, though scattered information is available on mycorrhizal status of aquatic and marshy vegetation (Ragupathy *et al.*,1990; Sengupta and Chaudhuri, 1990), tropical forests (Mohankumar and Mahadevan, 1987; Sankaran *et al.*, 1993; Sharma *et al.*, 1996; Muthukumar and Udaiyan, 2000; Mohanan and Manoj Sebastian, 1999; Mohanan, 2002 a,b), vegetation in semi-arid soils (Sahay *et al.*, 1991). The present study covered 23 forestry species, both indigenous and exotic, raised in forest plantations/plots. Of these, teak and eucalypts, the prime forestry species in the State cover more than 75,000 and 40, 000 ha respectively. The extensive survey made in teak plantations through out the State encompassing 70 sample plots having different edaphic, environmental and host factors showed a very clear picture about the mycorrhizal status and diversity of the associated fungi. It is very interesting to note that AM fungal root infection in teak plantations ranged from 2 to 86 per cent and highest level of AM fungal association was recorded in 11-to 20-year-old plantations, irrespective of the prevailing edaphic and climatic factors.

Teak rhizosphere soils also exhibited a large number (85) of Glomalean fungal species and the AM fungal community in each sample plot represented 12 to 39 species. This is in accordance with the observations of Johnson *et al.* (1991), who have recorded 12 to 22 different AM fungal species per site, but contrary to the observation of Allen *et al.* (1995), who have reported that none of the 68 sites they have surveyed in Western United States contained more than a dozen AM fungal species. Also, from teak rhizosphere soils, only a very few (11) AM fungi were recorded from Tamil Nadu

(Mohankumar and Mahadevan, 1987; Raman *et al.*, 1997), Madhya Pradesh (Verma and Jamaluddin, 1995), Karnataka (Gurumurthy and Srinivasa, 2000) and Andhra Pradesh (Kanakadurga *et al.*, 1990). *Eucalyptus grandis* and *E. tereticornis* are the two major eucalypts raised on large-scale in the State in high and low to medium elevated areas respectively. More than 81 Glomalean fungal species were recorded in eucalypts with a distribution of 12 to 35 species per plantation (Table 62). Thus, eucalypts, the most widely planted exotic species exhibited more AM fungal diversity than the other forestry species, except teak in the State. In eucalypts, dual infection by AM and ECM fungi were recorded and ectomycorrhizal infection was more pronounced in mature plantations than the young ones. This is in conformity with the earlier observations on mycorrhizal status of eucalypts (Chilvers *et al.*, 1987; Boudarga *et al.*, 1990; Gardner and Malajczuk, 1988).

Table 62: AM fungal root infection and diversity of AM fungi in forest stands

Forest plantation species	Mean AM root infection %	Total No. of AMF species recorded	AMF species per plot recorded
Teak	32.4	85	12-39
Eucalypts	25.18	81	12-35
Dalbergia latifolia	23.92	45	14-22
Santalum album	11.52	35	14-18
Gmelina arborea	19.21	42	22-26
Acacias	92.3	59	16-31
Paraserianthes falcataria	24.54	28	19-22
Bombax ceiba	13.68	18	10-15
Swietenia macrophylla	2.5	17	8-10
Ailanthus triphysa	15.5	11	11
Pterocarpus santalinus	22.80	16	16
Terminalia paniculata	32.50	25	25

Earlier studies on dual symbiosis of eucalypts reported a temporal replacement of AM by ectomycorrhiza with host aging, and arbuscular mycorrhiza are generally considered as the predominant mycorrhizal form of the early growth stages of eucalypts (Boudarga and Dexheimer, 1988). Contrary to this observation, Bhattacharya *et al.* (2000) reported that *E. tereticornis* may not be an AM dependent host at early developmental stage, although it is infected by AM fungi freely, improving its phosphorus acquisition efficiency in low-phosphorus soil. It seems that the dispute regarding the functional ability of different forms of mycorrhizal association has to be proved, especially when dual infection by AM and ECM takes place.

In all other forestry species, except acacias comparatively low AM root infection was recorded and Glomalean fungal diversity was also found lower than those recorded for eucalypts and teak (Table

56). All the five acacias viz., *Acacia auriculiformis, A. mangium, A. aulacocarpa, A. crassicarpa* and *A. mearnsii* exhibited remarkably very high AM fungal root infection. Distribution of AM fungal species per plot was also very high. In *A. auriculiformis* and *A. mangium*, dual infection by AM and ECM fungi was also recorded. *Pisolithus tinctorius, Ramaria* sp. and *Scleroderma* spp. are the common ectomycorrhizal fungi associated with acacias. *Acacia* spp. also possess symbiotic association with nitrogen fixing bacteria and it has been reported that arbuscular mycorrhizae markedly improve nodulation and nitrogen fixation by bacteria mainly by providing high phosphorus requirement for fixation process.

Santalum album, a root semi-parasite was earlier included under non-host for AM fungi. However, in the present study, AM fungal association was recorded in all the five plots selected in different parts of the State with diversity of 14 to 18 AM fungi per plot. In a recent study, AM fungal infection in *S. album* along with a large number of disputed hosts of AM fungi was recorded by Lakshman *et al.* (2001). However, Muthukumar and Udaiyan (2000) reported *S. album, A. auriculiformis* and *E. globulus*, as non-host of AM fungi.

Arbuscular mycorrhizae have been observed in more than 1000 genera of plants representing some 200 families and about 300, 000 receptive hosts in world flora (Kendrick and Berch, 1985). So far, about 120 species of AM fungi have been reported (Schenck and Perez, 1984). Although, AM fungi have extremely wide host range (Mosse, 1973), the existence of host preference has been suggested by many researchers (Bagyaraj *et al.*, 1988). At present we do not have a good explanation for the variation in mycorrhizal dependency of different host plants. One possibility suggested by St. John (1980) is that plants with coarse and relatively fewer hairs are more dependent on AM mycorrhiza compared to those plants with fine roots and long hairs.

The AM fungi occur ubiquitously in tropical soils in association with diverse plant communities. Communities of arbuscular mycorrhizal fungi within plant communities have been reported up to about 30 species. In the present study, 10 to 39 AM fungal species were recorded in forest plantations of different species. Most AM communities reported have fewer species than this, because of the technique employed often underestimates the number of species. Due to lack of specificity between species of AM fungi and their host plants (Harley and Smith, 1983), several species may simultaneously occupy the roots of the same plant. The fungi depend on the host plant, at least for carbon and hence AM fungi may compete for resources from a plant colonized simultaneously by more than one fungus (Wilson and Tommerup, 1992). Most AM fungi occur in

soil as spores and hyphae with attached vesicular structures (external vesicles). There are differences between species and between different stages of the life cycle within a species, in their relative dependence on spores, hyphae or existing mycorrhizas for initiating new mycorrhizas on the same or another plant. Soil disturbance may result in more or fewer opportunities for interaction to occur between mycorrhizal fungi and can lead to a change in the relative abundance of species of fungi in a community. In general, AM fungal population was reported more in cultivated soil than in virgin soil (Mosse and Bowen, 1968). This is true in the case of *Dalbergia latifolia* and *Santalum album*, where comparatively less number of AM species was encountered in the present study. AM fungi are mostly seen in topsoil (15-30 cm depth) and their number decreases remarkably below the top 15 cm (Mohanan, 2002 b).

The factors affecting the distribution of AM fungi are poorly understood, except in a few cases and it is believed that AM fungal population varies with climatic and edaphic environment as well as landuse patterns. In the present study, soil pH and soil nutrient status were found highly influencing the AM fungal root infection and also the distribution. In fact, soil pH was the most important factors influencing the AM root infection and accounted for about 35 per cent of the total variability in teak.

Usually, studies on ecological diversities are restricted to species richness, that is a straight forward count of the number of species present and the relative abundance of species. In nature, no community consists of species of equal abundance and hence majority of species are rare, while others are moderately common with the remaining few species being very abundant. A variety of species abundance distributions have been proposed to describe the observed patterns (Maguran, 1988). Species richness index is one of the species diversity measures which measure number of species in a defined sampling unit. Indices based on the proportional abundance of species provide an alternative approach to the measurement of diversity.

Shannon-Weiner index and Simpson's index, the most widely used measure of diversity are used in the present study. The Shannon-Weiner index assumes that individuals are randomly sampled from a 'indefinitely large' population. The index also assumes that all species are represented in the sample. The value of the Shannon-Weiner diversity index is usually found to fall between 1.5 and 3.5 and only rarely surpasses 4.5. The Simpson's index (Simpson, 1949) is referred to as dominance measure, since it is weighted towards the abundance of commonest species rather than providing a measure of species richness and it is one of the most satisfactory diversity measures available (Maguran, 1988).

So far, a large number of biodiversity models have been proposed to account for different species abundance patterns but often the biological assumptions on which these are based are discredited or unproven. In the present study, apart from species diversity (Shannon-Weiner and Simpson's indices), Gamma and Beta diversities of AM fungal species in selected forest plantation species were also recorded (Table 63).

Table 63: Biodiversity indices of AM fungi in forest stands

Host plant	Shannon-Weiner index	Simpson's index	Gamma diversity	Beta diversity
Tectona grandis	1.5532 –3.0032	3.0505 – 16.6012	98	69
Eucalypts	1.9245 – 2.9253	3.9218 – 13.7619	84	40
Dalbergia latifolia	2.1150 – 2.8007	5.4873 – 12.6168	46	6
Santalum album	2.2154 – 2.6724	6.7527 – 12.4225	36	4
Gmelina arborea	202169 – 2.9106	4.7133 – 14.6847	44	2
Acacias	2.6100 –2.7250	9.3520 – 12.8620	42	3
Paraserianthes falcataria	2.6321 – 2.6824	9.8650 – 11.9760	39	3

Measures of niche width describe the diversity of resources that an organism or fungal species utilizes. Similarly, habitat diversity is an index which measures the structural complexity of the environment or the number of communities present. Gamma diversity is the number of species that occur in a heterogenous region. Within this region, the fungi are adapted for the general conditions, but within different habitats they may have specialized for exploiting different resources. In the present study, highest Gamma and Beta diversities were recorded for teak and eucalypts (Table 63). Beta diversity is defined as the degree of change in species diversity along a transect or between habitats. Beta diversity is the most widely studied scale of differentiation of diversity and is often applied to any investigation which looks at the degree to which the species composition of the samples, habitats or communities differ (Southwood, 1978). Thus, beta diversity can be used to give the overall diversity of the area (Routledge, 1977).

Earlier, mycorrhizal research was basically confined to survey of geographical areas for biodiversity studies, however, at present it has a wider spectrum. Inoculating seedlings with mycorrhizas is widely accepted as a key process in the production of fast growing forest plantation species (Trappe, 1977) and is being practised in many forest nursery operations through out the world (Hu Hongdao, 1979;

Guo Xiuzhen and Bi Guochang, 1989). Sustainability of soil-plant systems requires a balanced, functional below ground microbial ecosystem. Mycorrhizal fungi are key members of the soil microbiota and perform activities which are crucial to plant establishment, development, nutrition and health (Azcon-Aguilar *et al.*, 1992). The hyphal network of AM fungi within the soil is a vital component of the soil ecosystem. This mycelium is the functional organ for the uptake and translocation of nutrients to and from mycorrhizae. Many studies have well established the role of the extraradical mycelium in the uptake of water and minerals nutrients, especially phosphorus, and the mechanisms of transfer of these elements to the plant in exchange for carbon metabolites derived from photosynthesis.

Interest in AM fungi has reached a peak in recent years. The ability of these fungi to produce dramatic responses in plant growth is well documented. However, application of this technology in forestry sector in India has been minimal. One of the main reasons for this is the difficulty of inoculum production, the fungi being obligate symbionts. The results on AM fungal infection studies on teak, sandal and rosewood revealed the differences between non-inoculated and inoculated seedlings and confirmed that mycorrhizae can help in better seedling growth. As forestry seedlings are being produced on a large-scale by employing the root trainer technology, there is immense scope for mycorrhization of seedlings by using the efficiency proven isolates of AM fungi as well as ECM fungi.

Pisolithus tinctorius, a widely exploited ECM fungus, has a broad host range and wide geographical distribution (Marx, 1977; Cairney and Chambers, 1997). Although most *Pisolithus* isolates have been widely regarded as conspecific and grouped as *P. tinctorius*, recent molecular analyses indicate that the group displays much genetic diversity, and in fact, comprises a complex of numerous species (Anderson *et al.*, 1998a,b). In the present study also sporocarps of *P. tinctorius* collected from different hosts in different locations vary greatly in their morphological and cultural characteristics.

Isolates of *P. tinctorius* have been shown to enhance tree growth, relative to uninfected trees, in both nursery and field studies (Bougher and Malajczuk, 1990). Physiological and ontogenetic aspects of interactions between *P. tinctorius* and its host have been investigated in detail and, although the fungus has become a model organism in the study of molecular basis of ECM associations, we know little regarding the ecology of the mycobiont. *P. tinctorius* is an early colonizer (Gardner and Malajczuk, 1988) and is generally regarded as being poorly competitive with other ECM fungi (Marx *et al.*, 1984; McAfee and Fortin, 1986). It is perhaps for these reasons that *P. tinctorius* persists best

in forestry inoculation programmes on sites subject to edaphic stresses (Marx *et al.*, 1984). Most isolates of *P. tinctorius* produce an extensive extramatrical mycelial phase which can create a significant surface area for nutrient acquisition in soil (Rousseau *et al.*, 1994). Marked intraspecific variation potential exists, however, in terms of the density of extramatrical mycelia of *P. tinctorius* and the degree to which hyphae aggregate to form rhizomorphs (Agerer, 1991; Lamhamedi and Fortin 1991). Despite this general understanding of *P. tinctorius* mycelia, we remain largely ignorant of the spatial organization of mycelial systems in field soil. Nitrogen availability is frequently a major factor limiting the forest growth and the contribution of ectomycorrhizal fungi to the nitrogen nutrition of their host plants has been well demonstrated (Bowen and Smith, 1981; Thomson *et al.*, 1994; Genere, 1995). The ability of the external mycelium to assimilate a wide range of inorganic and organic nitrogen compounds has been reported (Melin and Nilson, 1953; Finlay *et al.*, 1989). Several ectomycorrhizal fungi including *Laccaria laccata, P. tinctorius* (Plassard *et al.*, 1991), can easily take up and assimilate nitrate. The nitrate-reducing capacity differs among mycorrhizal species and difference between species and strains depend on the concentration of substrate available to the fungus.

Recently, for mycorrhization of forestry species, various forms of inocula of *P. tinctorius* have successfully been used by many workers (Marx and Kenney, 1982; Mohanan, 2002a). Encapsulation of spores and hyphal fragments of ECM fungi is a new technology applied in the mycorrhizal manipulations (Mohanan, 2002a). Encapsulation of mycelial fragments from aseptic culture within beads of alginate gel is a more advanced form of inoculum where fungal hyphae are allowed to continue growth within these beads. This technique allows mycelium to recover from fragmentation before application, so the encapsulated mycelium act as more effective propagules and efficient in seedling mycorrhization.

So far, no systematic mycorrhizal investigations in forest plantation species, except in *Acacia auriculiformis* (Sankaran *et al.*, 1993), in the State have been undertaken. The present investigation has generated a wealth of knowledge base on mycorrhizal association in different forest plantation species in the State and also biodiversity of AM and ECM fungi in forest stands. A large number of hitherto unrecorded AM and ECM fungi have been recorded from different forest plantation species. Many of them have potential for improving the productivity of the forest stands. The pilot-scale study of selected AM and ECM fungi has shown their efficacy in improving the quality of planting stock. Hence, an in-depth study on mycorrhization and improvement of planting stock of forestry species and their field screening under various edaphic and climatic stress conditions is warranted.

5. CONCLUSIONS

The study carried out in 148 forest plantations/plots in the State generated valuable information on mycorrhizal status of the forestry species as well as the biodiversity of AM and ECM fungi in forest plantations. All the 23 forestry species studied exhibited arbuscular mycorrhizal (AM) association in their feeder roots. All typical AM features, such as arbuscules, vesicles, intra-cellular hyphal coils, extra- and intra-radical hyphae, etc. were detected in feeder roots. The prime species like teak, eucalypts and acacias showed a high level of arbuscular mycorrhizal association. Analysis of root samples from 70 teak plantations in the State showed a mean AM root infection of 32.4 per cent. Teak plantations belonging to the age group of 11 to 20-years showed an average AM root infection of 38.5 per cent, whereas young plantations (1 to 10-year-old) as well as old plantations (>40-year-old) exhibited moderate AM root infection.

All the nine species of eucalypts viz., *Eucalyptus camaldulensis, E.deglupta, E. globulus, E. grandis, E. pellita, E. regnans, E. tereticornis, E. tessellaris* and *E. urophylla* showed AM association and overall extent of AM root colonization ranged from 2 to 58 per cent. Among the eucalypts, *E. grandis* registered highest per cent (58) AM root infection.

All the five species of acacia studied viz., *Acacia aulacocarpa, A. auriculiformis, A. crassicarpa, A. mangium* and *A. mearnsii* exhibited an exceptionally high level of AM root infection which ranged from 90 to 96 per cent. Of these, *Acacia mangium* registered the highest (96%). Other species like *Dalbergia latifolia, Santalum album, Gmelina arborea, Paraserianthes falcataria, Ailanthus triphysa, Pterocarpus santalinus, Bombax ceiba, Swietenia macrophylla* and *Terminalia paniculata* recorded low to moderate level of AM association.

Dual infection by ectomycorrhiza (ECM) and arbuscular mycorrhiza (AM) was observed in eucalypts and acacias and to a lesser extent in teak, *D. latifolia* and *G. arborea*. Marked differences in the morphological characteristics of the ectomycorrhizal roots were observed in different host plants, especially in eucalypts.

Arbuscular mycorrhizal fungi showed a high level of species diversity in forest plantations in the State. More than 91 Glomalean fungi belonging to six genera viz., *Glomus, Acaulospora, Scutellospora, Gigaspora, Sclerocystis* and *Entrophospora* were recorded from the rhizosphere soil samples. Most of them are new record from the State. The rhizosphere soil samples from teak

registered the highest number of Glomalean fungi (85) followed by eucalypts (81) and acacias (59). The AM fungal community in rhizosphere soil consisted of 10 - 39 species per sample plot. The rhizosphere soils from teak yielded the highest number (12 - 39) of AM fungal species per sample plot followed by eucalypts (12 - 35) and acacias (16 - 31). In teak, the AM fungal spore density ranged from 65 – 810 / 10 g soil with a mean of 211 spores; in eucalypts the AM fungal spore density ranged from 58 – 333 / 10 g soil and in acacias 72 – 408/ 10 g soil with a mean of 170 spores/ 10 g soil.

Glomus and *Acaulospora* were the most predominant AM fungal genera associated with different forestry species followed by *Scutellospora* and *Gigaspora*. More than 47 species of *Glomus* were identified from the rhizosphere soils of different forestry plantation species and of these 24 species were found widespread in the State. *Glomus australe, G. botryoides, G. deserticola, G. fasciculatum, G. geosporum, G. mosseae, G. multicaule,* and *G. macrosporum* were the most frequently encountered species. Of the 16 *Acaulospora* species recorded, *Acaulospora appendicula, A. scorbiculata* and *A. rehmii* were the most widespread species in forest plantations. The genus *Sclerocystis* represented seven species and mostly observed in teak and eucalypts soils. A total of six species of *Gigaspora* were recorded and of these *Gigaspora albida, G. candida, G. decipiens* and *G. gigantea* were the most frequently encountered species. Altogether 15 species of *Scutellospora* were recorded and among these *Scutellospora erythropa, S. heterogama*, and *S. persica* were the most widespread species.

Shannon-Weiner index, a measure of species richness and Simpson's index, the most widely used dominance measure were used to assess the biodiversity of AM fungi in each host plantation/plot. Gamma and Beta diversities were also worked out for AM fungi associated with each of the plantation species studied. Among these, teak and eucalypts showed a high level of Gamma and Beta diversity of AM fungi. Even though, host specificity was not observed, the AM fungal community size and species composition varied among the host plants as well as within the same host plant in different localities, possibly influenced by the host factor including age of the host plant and edaphic and environmental factors.

Among the edaphic factors, soil pH, soil moisture content, exchangeable cations, organic carbon, available nitrogen and phosphorus were found influencing the AM fungal root infection as well as AM fungal distribution and diversity. The rhizosphere soil pH in most of the forestry species was moderately acidic to highly acidic. The soil pH alone accounted for around 35 per cent variability in

AM root infection in teak. Among the cations, Mg and Na influenced the AM root infection in teak, while Ca was found to be the influential variable affecting the AM root infection in eucalypts. Heavily worked plantation sites of teak, eucalypts and acacias showed high AM fungal diversity than comparatively less disturbed stands of *Santalum album* and *Dalbergia latifolia*.

Ectomycorrhizal fungi also showed high level of diversity and eucalypts were found to be the more ECM-dependent hosts. Of the 37 ECM fungi recorded, 20 fungi were recorded from eucalypt stands; *Eucalyptus grandis* plantations recorded 19 genera of ECM fungi, whereas *E. tereticornis* recorded 10 genera of ECM fungi. *Pisolithus tinctorius, Scleroderma verrucosum, S. citrinum* and *Laccaria laccata* were the most predominant and widely distributed ECM fungal species. Distribution and diversity of ECM fungi were also largely governed by edaphic and environmental factors, especially soil pH, humidity and precipitation.

Mycorrhization experiment with selected AM fungi viz., *Glomus fasciculatum, G. mosseae, G deserticola* and *Acaulospora appendicula* yielded promising results for teak, rosewood and sandal seedlings. Inoculum of *Acaulospora appendicula* treated seedlings registered maximum (>60%) mycorrhizal inoculation effect (MIE).

Ectomycorrhization of seedlings of *Eucalyptus grandis, E. tereticornis* and *Acacia mangium* with different forms of *Pisolithus tinctorius* inoculum viz., encapsuled mycelial bits, encapsuled spores, spore-sand mixture, spore slurry, mycelial slurry, etc. exhibited their potential in improving the planting stock. *Pisolithus tinctorius* (PT) spore-sand mixture was found to be the most efficient inoculum which gave maximum per cent of MIE in *E. tereticornis* (>90%), *E. grandis* (>50%) and *Acacia mangium* (>123%). However, more in-depth studies are required for selecting efficient AM and ECM fungal candidates for improving the forestry planting stock.

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APPENDIX 1

ARBUSCULAR MYCORRHIZAL FUNGI RECORDED FROM RHIZOSPHERE SOILS OF FORESTRY SPECIES

1. *Gigaspora albida* Schenck & Smith

Azygospore dull white with a pale greenish-yellow tint, mostly spherical, 140-335 (-358) µm dia with a mean dia of 260 µm; occasionally ellipsoidal 230-250 x 232-252 um. Spore wall continuous, except for occluded pore from 4-12 µm thick with one (in young spore) to six walls; outer wall thin, smooth, 1-2 µm thick, readily cracking under pressure, usually two or three but occasionally 4 -5 inner walls, inseparable of varying thickness. Spore attached to single, hyaline bulbous suspensor, 24-50 (36) µm attached to a septate hyphae with hyphal branches. Extramatrical vesicles hyaline to yellow, obovate, clavate, 18-40 (28µm dia formed in clustures; vesicle apex echinulate with spines 2.5-10 µm; spines septate and occasionally bifurcate.

2. *Gigaspora candida* Battacharjee, Mukerji, Tiwari & Skoropad

Azygospores white, globose 200-300 µm dia (av. 230 um); spore wall smooth, 2 layered, distinctly visible in fractured spore; outer layer 1 µm thick and with a few laminations, inner layer up to 6 µm thick. Suspensor-like cell white, globose to sub-globose, 30-50 µm dia, usually detached during wet sieving.

3. *Gigaspora decipiens* Hall & Abbott

Azygospores hyaline to yellowish (young) or pale orange, pale greenish yellow or light brown (mature), globose or rarely irregular, 320-495 µm dia. Spore wall 20-35 um thick of 3 layers; 35-48 µm (up to 48 µm) thick in old spores (up to 15 layers of dissimilar thickness). Muronym: A(UL) or A(L) or A(LL). Subtending hypha light brown, bulbous up to 65 µm wide with attached lateral hypha about 10 µm wide and 22 um long. Auxillary cells spherical and found in clusters 35-55 µm dia.

4. *Gigaspora gigantea* (Nicol.& Gerd.) Gerd. & Trappe

Azygospores globose to ellipsoid, greenish yellow with a thin outer wall tightly covering an inner wall; inner wall 5-7µm thick continuous except for a occluded pore at the attachment. Muronym: A(UL). Spore 350-370 x 345-400 µm. Suspensor-like cell bulbous, 42- 50 µm with slender hypha projecting to the spore. Auxillary cells spherical to clavate 20-40 x 20-35 µm, echinulations at the tip of the cells.

5. *Gigaspora margarita* Becker & Hall

Azygospore white, globose to irregular 260-480 µm dia. Spore wall smooth, hyaline composed of 4-8, rarely 10 fused laminations; number of laminations increased with maturity of spores; 5-25 um thick in mature spore, each lamination 1.5 to 4 µm thick, Spore content white with many small oil droplets. Subtending hypha septate below the suspensor-like cell. Suspensor-like cell hyaline to pale brown, smooth 28-60 µm broad, wall 1-5 µm thick; thicker at point of attachment. Auxillary cells in clusters up to 25-35 µm dia with warty projections (4 um high, 5 µm wide), light brown.

6. *Gigaspora rosea* Nicol. & Schenck

Azygospore globose occasionally sub-globose, white to cream with a rose to pink tint on the wall near the hyphal attachment, 230-305 µm dia. Walls 2.5-7.5 um thick with 2-5 inseparable layers; outer wall smooth. Suspensor-like cell smooth, spherical, 30-40 µm dia. Subtending hypha 7-14 µm wide, hyphal wall 1-2 µm

thick and septate. Auxillary cells 20-35 µm wide, echinulate with spines up to 5 µm long and 3 µm wide. Muronym: A (L).

7. *Acaulospora appendicula* Spain, Sieverding & Schenck

Azygospore borne on short hyphal pedunculate protruberance, 30-100 µm long, 20-50 µ m wide, arising from a tapering hypha terminating in a globose, swollen hyphal terminus 190-380 (250) µm dia with a wall 1-6 µm thick. Hyphal terminus usually persisting on young spores. Azygospore white-opaque when young, dull yellow to cream to orange when mature, 170-390 (250) µm dia. Hyphal pedunculate attached to the reticulate inner wall and form a appendage on the spore; spore walls 2; outer wall 8-16 (20) µm thick, roughened, becoming yellow to brown with age, with irregular reticulate pattern of fine cracks that serve as fracture lines when spore is crushed. Second wall 2-6 µm thick with an alveolate reticulum
which is 8-12 x 4-8 µm; third wall hyaline, 4-8 µm thick also with alveolate reticulum similar to the second wall. Inner wall hyaline, smooth, 2-10 µm thick. Outer wall firm and difficult to break on young spores (turning orange red in colour with Melzer's reagent).

8. *Acaulospora bireticulata* Rothwell & Trappe

Azygospore globose, hyaline to sub-hyaline, becoming brown by maturity, 150-160 µm. Spore surface ornamented with polygonal reticulum, the ridges 2 x 1.5 – 2 µm with sinuous dark greyish green sides and paler depressed central stratum; polygons 6-18 µm long. Spore wall three layers, each one 1 um thick; outer layer dark greyish green to greyish brown; inner layer hyaline.

9. *Acaulospora delicata* Walker, Pfeiffer & Bloss

Azygospore borne singly on the neck of a sporiferous saccule. Spore hyaline to pale yellowish cream, globose to sub-globose, ovoid to obovoid, 80-125 (-150) x 80-110 (-140) µm. Spore walls: 4 walls in 2 groups (A&B).A: consists of thin, hyaline outer evanescent wall 1 µm thick, closely attached to wall 2 (2.5-3.5 µm)., laminated with up to 6 sub-equal laminations. B: 2 thin membraneous walls (wall 3& 4 0.5-0.75 µm thick). Membraneous wall rapidly turn to orange red in Melzer's reagent. Wall 1 not positive to Melzer's and wall 2 becomes dark yellow in colour.

10. *Acaulospora denticulata* Sieverding & Toro

Azygospores globose to sub-globose, yellow brown to dark brown, 110-170 µm dia. Spore walls consists of 4 walls (1-4) in 2 groups. A: composed of 1 wall- yellow brown to red brown, 2.5 µm thick, consisits of polygonal segments, 4-6 sided, 3-6 x 5-10 µm dia. B: composed of 3 hyaline membranous wall (2,3 &4), 0.5-1.5 µm thick. Spore contents hyaline.

11. *Acaulospora elegans* Trappe & Gerd.

Azygospores dark brown, globose to sub-globose, ellipsoid or reniform, 140-285 x 145-330 µm. Spore surface ornamented with crowded pale brown spines 2 x 0.5 µm, develops in alveolate reticulum of hyaline ridges 5-6 z 1 µm superimposed on the spines; alveoli 4-8 µm long. Spore wall continuous, except for the occluded opening; outer layer brown, up to 12 µm thick enclosing 3 hyaline walls total up to 15 µm thick.

12. *Acaulospora foveata* Trappe & Janos

Azygospores yellowish brown to light reddish brown(young) becoming reddish to brownish black at maturity, glosbose to ellipsoid, 185 (310) –410 x 215-350 (-480) µm. Spore surface uniformly pitted with round to oblong or irregular depressions 4-8 (12) x 4-16 µm deep with rounded bottoms, separated by ridges 1-12 um broad. Spore walls: outer wall yellowish or reddish brown to brown (11-15 µm thick); inner wall hyaline 3 µm thick, adhering but separate. Spore content small hyaline guttules; in Melzer's reagent spore becomes orange brown.

13. *Acaulospora laevis* Gerdemann & Trappe

Azygospore dull yellow, deep yellowish brown, reddish brown to dark olive brown, globose to sub-globose, ellipsoid or reniform, smaoothsurfaced, 120-300 x 120-520 µm. Spore wall continuous, except for occluded opening consists of 3 layers.1: a rigid, yellow brown to red-brown outer wall, 2-4 µm thick. 2: hyaline inner walls- the innermost often minutely roughened. Spore contents globose to polygonal.

14. *Acaulospora longula* Spain & Schenck

Azygospores hyaline to pale yellow, globose to sub-globose (55) 75-90 (-100) µm to ellipsoid, 100-115 x 66-100 µm. Spore wall 2.5 –5 µm thick. Outer wall: muscilagenous, ephemeral 0.5-3 µm thick; wall 2: 2-3 µm thick inseparable from wall 3; wall 3: 0.5 µm thick; wall 4: hyaline 0.5-1 µm thick, usually attached to wall 5; Wall 5: membranous 0.5-1 µm thick turning pale purple in Melzer's reagent. Spore content hyaline to sub-hyaline.

15. *Acaulospora morrowae* Spain & Schenck

Azygospores pale yellow, globose to sub-globose 65-120 (80-92) µm to irregular, 85-100 x 65 –95 µm dia. Spore contents, globular, transparent. Spore walls 2-4 (6) µm thick consisting of several wall layers readily apparent on broken spores; outer wall: 0.5-1 µm thick; wall 2: pale yellow to yellow, 1.5-3 µm thick; wall 3: brittle, hyaline 0.5 µm thick; wall 4: membranous (0.5 µm thick); wall 5: membranous (0.5 µm thick). Spore stains dark maroon in Melzer's reagent.

16. *Acaulospora myriocarpa* Spain, Sieverding & Schenck

Azygospores single, hyaline, globose to sub-globose, 30-90 µm dia, or irregular. Spore contents hyaline, granular; spore wall hyaline, 1.5-3.5 µm thick of 3 walls in one group; wall1 rigid, 0.8-2 µm thick, wall2 rigid up to 1.5 µm thick; spore wall staining pale yellow in Melzer's reagent. Wall3 membranous closely appressed to wall 2. Spores produced in sporocarps without a peridium.

17. *Acaulospora spinosa* Walker & Trappe

Azygospores single, sessile attached by a collar 8-15 µm broad to the side of a funnel-shaped cylindrical hypha; hypha terminating in a globose vesicle about the same size as the spore and sometimes with thin tapering hyphal projections, becoming empty and shrunken at spore maturity. Spores yellowish brown to dark brown, globose to sub-globose, 100-300 x 100-335µm dia, but occasionally reniform. Spore surface ornamented with crowded blunt spines 1-4 µm high, 1 µm in dia at the polygonal base. Spore wall continuous, except for the occluded openings, 3 layered; outer layer yellowish brown to reddish brown, 4-10 µm thick including spines and encrustations; inner walls membranous.

18. *Acaulospora trappei* Ames & Linderman

Azygospores single, minutely roughened, globose to ellipsoid, hyaline, 40-95 µm dia. Spore contents globose to polygonal oil globules. Spore wall single, 1.4-2.5 µm thick.

19. *Acaulospora tuberculata* Janos & Trappe

Azygospores single, yellowish brown to dark brown, globose to sub-globose, 250-320 x 255- 340 µm. Spore surface uniformly covered with tubercles 0.8-1.5 µm tall. Spore wall consisted of 3 layers; outer clear yellow layer 7-12 µm thick; yellowish brown middle layer, hyaline inner layer of 1.5-3 µm thick. Spore contents globose to ellipsoid, hyaline guttules 8-20 µm long. Spore orange brown in Melzer's reagent.

20. *Acaulospora rugosa* Morton

Azygospores hyaline to straw coloured, globose to sub-globose, 50 –120 µm dia. Spore walls: 5 walls in three groups (ABC). A: 2 walls (1,2), hyaline outer wall (1-1.5 µm thick) often forming folds 2-10 µm deep surrounding intact spores, separating readily from spore wall 2 in crushed spore in water; wall 172 adherent, appearing wrinkled or rugose; wall 2 pale yellow, laminated, 1.2-3 µm thick; B: a semirigid, hyaline wall, 1-1.3 µm thick; C: two hyaline walls with beaded appearance.

21. *Acaulospora rehmii* Sieverding & Toro

Azygospore pale yellow to brown, older spores brown to blac, globose to subglobose, 85-175 µm dia. Spore walls: 4 walls in 3 groups

22. *Acaulospora scorbiculata* Trappe

Azygospores hyaline, pale olive to pale brown, globose to ellipsoid, 100-240 x 100-200 µm. Spore surface evenly pitted with depressions 1-1.5 x 1- 3 µm, separated by ridges 2-4 µm thick, the mouths of the depressions circular to ellipsoid or occasionally linear to Y-shaped. Spore walls: 4 layers: 1: rigid, pitted, sub-hyaline to pale greenish yellow outer layer, 3-6 um thick; 2: adhering but separable, smooth, hyaline layer of 0.2-0.5 µm thick; 3: adhering but separable, hyaline layer 0.5-1 µm thick; 4 separated, hyaline inner layer 0.2-1 µm thick Spore contents small, uniform guttules. Outer wall layer becomes yellow in Melzer's reagent; inner layer quickly becomes deep red.

23. *Glomus aggregatum* Schenck & Smith

Chlamydospores hyaline, pale yellow with a greenish tint in transmitted light, globose, sub-globose to irregular, (50) 75 (90) µm, (70) 90 (110) x (60) 70 (80) µm when sub-globose. Spore wall yellow to brown, 1.2-2.4 µm thick, outer wall laminated, slightly thick, pale in colour than the inner wall. Spore content confluent with hyphal contents, pore not occluded by hyphal wall thickening.

24. *Glomus albidum* Walker & Rhodes

Chlamydospores hyaline to off white; yellowish to pale brownish yellow by transmitted light in compound microscope, globose to sub-globose, ovoid or irregular, 95 (85) – 165 (200) x 95 (85)-165 (175) µm. Young spores in Melzer's reagent become pink to orange red. Spore wall continuous with hyphal wall, clearly double in young, outer hyaline (0.5-2 µm thick), inner wall finely laminated, pale yellow (0.5 –2 µm). Outer wall of mature spore crumble and expand and becomes as much as 8 um thick. Subtending hyphae 2- walled, outer wall thickened and at spore base (3) 5-15 µm wide, usually straight and simple. Spore contents (oil droplets) crowded and become angular and give reticulate appearance.

25. *Glomus ambisporum* Smith & Schenck

Sporocarps brown to black, sub-globose highly variable in size. Spores develop from a central core of thick interwoven hyphae. Chlamydospores dark brown to black, globose, 80-150 µm. Spore walls 3; Inner membranous wall (1 µm thick), middle laminated wall, dark brown (3-4 µm thick), outer reticulate wall.

26. *Glomus australe* (Berk.) Berch

Chlamydospores in loose clusters, globose to sub-globose, ovoid to obovoid, (120) 166 (-185) µm, yellowish brown. Spore walls 2, outer wall hyaline, pale yellow 4 um thick; inner wall pale to dark brown 7 (150 µm thick. At the point of attachment to the spore, the subtending hyphae is broad (20-25 µm) and thick-walled. Subtending hyphae bears laterally projecting short or swollen hypha.

27. *Glomus borealis* (Thaxter) Trappe & Gerdemann

Chlamydospores chocolate brown to reddish brown, broadly and rather symmetrically elliptical, 125- 145 x 105-115 µm. Spore wall thick, reddish brown, 8 um thick.

28. *Glomus botryoides* Rothwell & Victor

Chlamydospores occur singly or in tight clusters, reddish brown to black at maturity, 145-250 µm dia. Spore wall 2; outer wall yellowish brown, 3-5 µm thick, outer surface roughened, become fragile and readily separable under pressure. Inner wall laminated 2 µm thick with fine projections up to 1 µm long and unevenly distributed over the outer surface. Subtending hyphae straight to recurved, point of attachment frequently inflated, 40-45 µm dia, tapering to 20-25 µm dia with yellowish brown wall 4-6 µm thick.

29. *Glomus citricolum* Tang & Zang

Chlamydospores single or in loose clusters, globose, sub-globose, ovoid or irregular, 35-70 µm wide and 60- 90 µm long, pale brown. Spore wall smooth or with projections of 0.2-0.8 µm dia; 2 layered- inner layer 0.8-2 µm thick, outer layer 3-7 µm thick.

30. *Glomus caledonium* (Nicol & Gerd.) Trappe & Gerd.

Chlamydospores single in soil or in sporocarp, pale yellow to brown, globose to sub-globose, ellipsoid to irregular, 130-285 x 120-270 µm. Spore wall 6-10 um thick composed of hyaline thin outer wall thickened at the hyphal attachment and extending along the attached hypha for some distance. Spore contents separated by a thin, yellow curved wall at the hyphal attachment or occasionally about 15 µm below the attached hypha from point of attachment.

31. *Glomus canadense* Thaxter

Chlamydospores hyaline to pale yellow, ovoid to ellipsoid or asymmetrical, 70-85 x 55-60 µm, rarely 100 x 70 µm, subtending hypha characteristically slender, 5-6 µm clearly defined septum. Sporocarp irregularly shaped with a well defined peridial layer and a dark brown gleba.

32. *Glomus clarum* Nicholson & Schenck

Chlamydospores single or in clusters, hyaline, globose to sub-globose, 70-300 µm dia, mostly 200 µm, pore with a bulging septum. Spore contents hyaline, consisting of globules of variable size. Composite wall 7-30 µm wide. Inner wall (2-9µm) several layers (2-5 layers), outer wall (5-20 µm) not separate readily. Some spores show outer mucilagenous coat (0.5-2 µm) with age become verrucose or rugose. Subtending hypha 15-70 um wide, with thick walls (7-39 µm) extending up to 400 µm below the spores.

33. *Glomus claroideum* Schenck & Smith

Chlamydospores single or in loose clusters, hyaline to pale yellow, globose (70) 130 (180) µm dia, occasionally sub-globose to irregular 60-130 x 70-145 µm. Spore wall 1 or 2 with the outer wall laminate and usually thicker than the inner wall (4.5) 7.6 (10.5) µm; spore wall hyaline to yellow becoming yellow brown with age; outer wall smooth. Spore contents hyaline to pale yellow. Subtending hyphae 7.5 – 15 µm wide at the spore attachment. Branching of subtending hyphae usually occurs 5—150 µm below the spore.

34. *Glomus constrictum* Trappe

Chlamydospores single or in loose clusters, dark brown to black, globose to sub-globose, 150-340 µm. Spore wall 7-12 µm thick. Spore contents oil globules varying in size, subtending hyphae straight or recurved. Point of

attachment with dark brown wall, 3-6 µm thick. Just below the point of attachment the hypha constricted to 10-22 µm dia; just beyond the constriction the hypha inflated to 15-30 µm dia with yellowish brown wall

35. *Glomus convolutum* Gerd. & Trappe

Chlamydospores pale yellow to yellow, globose to obovoid, 80-195 x 70-195 µm. Spore tightly enclosed in a mantle 5-50 µm thick of intertwined thin-walled hyphae 1.5-5µm broad. Spore contents deep yellow, oil globules. Sporocarp2-9 mm broad, much lobed, infolded and verrucose, hard, brittle, bright orange; peridium absent, gleba approximately 2 mm thick.

36. *Glomus constrictum* Trappe

Chlamydospores single or in loose clusters, dark brown to black, globose to sub-globose, 150-330 µm. Spore wall 1 or 2 layered, 7-12 (15 µm) thick. Subtending hyphae straight or occasionally with a short funnel-shaped projection; attachment occluded by wall thickening. Hyphae straight or recurved, point of attachment with dark brown wall, 3-6 µm thick; just beyond the constriction, the hyphae inflated to 15-30 µm dia with yellow-brown wall. Spore contents widely varying in size (oil globules).

37. *Glomus deserticola* Trappe, Bloss & Menge

Chlamydospores single or in loose clusters, shining, reddish brown, globose to sub-globose, (48) 55-115 x (40) 55-105 µm. Spore wall smooth, shining reddish-brown, laminated wall (1.5) 2-2.5 (4) µm thick. Subtending hyphae 6-12 µm dia, somewhat funnel-shaped, reddish brown, especially thick adjacent to the spore, but not occluding the hypha.

38. *Glomus delhiense* Mukerji, Bhattacharjee & Tewari

Chlamydospores in loose clusters, yellowish brown, globose, 100-125 µm. Spore walls 2; outer wall 5-7 µm, yellowish brown, laminate and slightly roughened; inner wall 5 µm, hyaline. Subtending hyphae up to 15 µm wide at the point of attachment with cross wall present either at the pore itself or 25-30 µm along the subtending hyphae. Spore contents granular.

39. *Glomus diaphanum* Mortar & Walker

Chlamydospores single or in loose clusters, hyaline, globose to sub-globose, 40-120 µm dia. Spores appear transparent under reflected light, spore contents of one to many oil globules. Spore walls 2; wall 1 4.5 µm thick, brittle and finely laminated; wall 2 not adherent to wall 1, membranous 0.8 µm thick.tends 5-15 µm into the subtending hypha and forms a septum enclosing the spore contents.

40. *Glomus fasciculatum* (Thaxter *sensu* Gerd.) Gerd. & Trappe

Chlamydospores single or in loose clusters, globose (35-100 µm) dia, sub-globose (75-150 x 35-100 µm) or obovoid, ellipsoid or irregular, smooth. Spore wall variable in thickness (3-17 µm), hyaline to yellow or yellowish brown. The thicker walls often minutely perforated with thickened inward projections. Subtending hyphae 4-15 µm dia, occluded at maturity, hyphal wall often thickened 1-4 µm at the attachment.

41. *Glomus fulvum* (Berk. & Broome) Trappe & Gerd.

Chlamydospores pale yellow, ellipsiod to ovoid or sub-pyriform, 125 x 55 µm or 50-125 x 45-75 µm; spore attachment sub-lateral; subtending hyphae is often somewhat narrower, just below the point of attachment.

42. *Glomus geosporum* (Nicol. & Gerd.) Walker

Chlamydospores single, pale yellow to brown, transparent to translucent when young, dark yellowish brown to reddish brown at maturity, globose , sub-globose or broadly ellipsoid, 110-300µm, smooth. Spore wall 4-18

µm, 3 layered; outer wall thin, hyaline, tightly adherent(<1 um); middle wall, yellowish brown, laminated (3-15µm); inner wall membranous, yellowish brown (<1 µm) that form a septum separating the spore contents from the lumen of the subtending hypha. Walls become perforated with age. Subtending hypha straight to recurved to slightly funnel-shaped, 200µm long, 10-25 µm wide with dark yellowish brown thickening that extends 30-100µm along the hypha from the spore base. Spore contents uniform oil droplets, cut off by a thick septum that protrudes slightly into the subtending hypha.

43. *Glomus globiferum* Koske & Walker

Chlamydospores single or in pairs or triplets adhering to each other by common peridial hyphae, orange brown to reddish brown, globose to sub-globose, 150-260 x 150-270 µm excluding the peridium. Spore wall loose peridium with septate hyphae surrounding 3 or 4 walls (walls 1-4) in 1 or 2 groups. Subtending hyphae thick walled, straight or funnel-shaped, 15-25 µm wide at spore base. The peridial hyphae and their associated vesiculated swellings are particularly important features.

44. *Glomus glomerulatum* Sieverding

Chlamydospores yellow to brown, globose to sub-globose, 40-70 µm dia; Sporocarp dark brown with greenish tint, globose, or irregular (3000 400 x 500 (680) µm dia. Sporocarps formed by interwoven hyaline hyphae. Spore composite wall in one group; outer wall yellow to brown, laminated 4-10 µm, on surface hypha is adherent; inner wall hyaline, membranous, 0.5 µm thick, adherent to wall 1. Spore formed only in sporocarps. All spores have two hyphal attachments due to pattern of spore formation.

45. *Glomus hoi* Berch & Trappe

Chlamydospores single, globose, sub-globose to ellipsoid, 50-120 x 45-140 µm. Spore wall 2 layers, separable; outer layer yellowish orange, 4-7 µm with an outer surface that fractures and sloughs; inner wall hyaline to pale yellow, membranous, 1 µm thick. Subtending hypha cylindrical, slightly flared towards the point of attachment to the spore. Pore in subtending hypha occluded by a fine curved septum at or somewhat below its point of attachment to the spore.

46. *Glomus intraradices* Schenck & Smith

Chlamydospores single or in clusters, yellow to pale brown, globose 100 µm dia. Spore wall 3-15 µm thick, yellow to pale brown, appearing greenish brown in transmitted light, with a-4 laminated walls. Inner walls darker than the outer wall. Spore contents granular, yellow to pale brown.

47. *Glomus invermaium* Hall

Chlamydospores in loose sporocarps without peridium, pale brown to dark brown, globose, 50-70 um dia. Spore walls 2; outer hyaline 1-1.5 µm thick, inner pale brown, 3-6 µm thick; outer wall extending down the subtending hypha for up to 100 µm, walls inseparable. Subtending hypha 6-14 µm dia, slightly pinched at the point of attachment, pore without septum.

48. *Glomus lacteum* Rose & Trappe

Chlamydospores single, milky white, globose to sub-globose, 150-220 µm dia. Spore wall single, 3-5 µm thick, hyaline. Subtending hyphae 1-3 per spore, 6-14 µm dia, straight, hyaline with wall slightly thickened only for a short distance from the spore. In most spores two hyphae merge near the spore to form a single attachment. Spore content hyaline, granular.

49. *Glomus macrocarpum* Tul. & Tul.

Chlamydospores pale yellow, sub-globose to globose to irregular, slightly longer than wide (90) 120 (-140) x (70) 110 (-130) µm. Spore wall consists of 2 different layers; outer layer thin (1-2um), hyaline; inner layer

yellow, 6-12 µm thick with a series of lamination, occasionally visible or rarely appearing as two distinct layers. Spores taper to the point of attachment of the single persistent hypha. The average dia of hypha at this point is 16 µm; the inner wall at maturity thickens to occlude the pore of attached hypha, and the wall thickening continuous into the subtending hypha for up to 90 µm from the spore.

50. *Glomus maculosum* Miller & Walker

Chlamydospores single, hyaline to pale straw coloured, globose to sub-globose. Spore walls(1-3) in two groups; the group1 consists of outer thin unit wall, hyaline(wall1) 0.3-1 um, tightly adherent to wall 2, a brittle, pale yellow coloured laminated, 4-13 µm thick; innermost wall (wall3) unit wall and often forming a septum the spore base. The group 2 consists of membranous, thin (0.3-1 µm) thick. The most distinct feature is that wall 3 in many older spores bear dome shaped ingrowth, 6-15 µm dia up to 12 µm deep, consisting of 2-8 concentric bulging discs increasing in dia towards the inside of the spore.

51. *Glomus magnicaule* Hall

Chlamydospores brown, globose to sub-globose, 125-175 µm dia. Spore wall double, outer wall brown, finely laminated in young spore, 9-20 µm thick; inner layer up to 4 um thick, hyaline to pale brown. Subtending hyphae 35-60 µm wide, often slightly pinched in at the point of attachment; pore 4-10 µm wide; plug of wall-like material gradually built up on inner wall of subtending hypha till pore occludes completely at maturity.

52. *Glomus melanosporum* Gerd. & Trappe

Chlamydospores dark reddish brown or nearly black, sub-globose to obovoid, broadly ellipsoid, embedded in coarse thin-walled hyphae, 170-280 x 130-250 µm. Spore wall 8-13 µm thick, laminate, reddish brown at outer surface and pale yellow near the inner surface. Subtending hypha thin-walled, difficult to observe, 15-20 µm dia at spore base, broadening to 25 um or more at a short distance from spore.

53. *Glomus microaggregatum* Koske, Gemma & Olexia

Chlamydospores single or in clusters in soil, or inside dead spores of other Glomales, hyaline to pale yellowish brown, 30(-50) x (15) 30 (-40) µm dia. Spore wall one or two walls in one group. Wall 1 smooth, brittle, unit wall, hyaline to pale yellow to brownish yellow, 0.5-1.2 µm; wall 2 membranous, or unit wall, hyaline 0.5-1.2 µm thick. Subtending hypha hyaline, straight or infundibuliform, 1.8-3 (-4.5) µm wide at spore base, wall up to 1.5 µm thick; pore usually open, sometimes closed by a septum formed by wall 2.

54. *Glomus microcarpum* Tul & Tul.

Chlamydospores in loose clusters, pale yellow, globose, sub-globose, ellipsoid, ovoid or irregular, 35-50 µm dia. Spore wall up to 7 µm thick, laminate, hyaline to pale yellow, smooth or appearing roughened from adherent debris; opening into subtending hypha nearly occluded in mature spores by wall thickening. Spores firmly embedded in glebal hyphae. Subtending at the point of attachment 4-8 µm wide.

55. *Glomus monosporum* Gerd. & Trappe

Chlamydospores pale brown, globose to sub-globose, 140-330 µm dia, in sporocarps bearing 1-3 spores. Peridium of branched interwoven hyphae. Spore walls 4-10 µm thick; outer wall thin, pale brown; outer wall laminate with minute abundant to scattered echinulations that protrude into the outer wall; thickening of inner wall extending into subtending hypha. Subtending hypha 8-12 µm dia, strongly recurved and appressed to spore walls.

56. *Glomus mosseae* (Nicol. & Gerd.) Gerd. & Trappe

Chlamydospores yellow to dark brown, globose, ovoid, obovoid, to irregular, 105-310 x 110-305 µm with one or occasionally two funnel-shaped bases, 20-30 (-50) µm dia divided by subtending hypha by a curved septum. Spore wall 2-7 µm thick, with a thin, often barely perceptible hyaline outer membrane and a thick brownish yellow inner layer. Sporocarp globose to ellipsoid, 1-10 spored, up to 1 mm dia; peridium loosely interwoven, irregularly branched, hyaline, septate, hyphae 2-12 µm dia; wall up to 0.5 µm thick.

57. *Glomus multicaule* Gerdemann & Bakshi

Chlamydospores dark brown, ellipsoid, broadly ellipsoid, sub-globose or occasionally triangular 150-260 x 120-170 µm, with 1-4 hyphal attachments generally at opposite ends of spores. Spore wall9-35 µm thick at point of hyphal attachment; globose projections of 1.2-3.7 µm long regularly distributed over the wall surface.

58. *Glomus multisubtensum* Mukerji, Bhatacharjee & Tewari

Chlamydospores single or in compact clusters of 5-10 spores, globose, pale brown, 110-150 µm dia; spore wall 10-15 µm thick with two inseparable layers; outer layer 10-12 µm thick, brown; inner layer 1-4 µm thick and pale yellow brown. Subtending hypha 2-4 in numbers attached at one end of the spore, hyaline to yellow, thin-walled, 10-15 µm wide at the point of attachment

59. *Glomus pallidum* Hall

Chlamydospores single or in clusters. Sporocarp hyaline to off white turns to yellow with poorly developed peridium. Spores globose to sub-globose, 30-80 x 30-70 µm. Spore wall 1-8 um thick, laminated. Subtending hypha 5-15 (-20) µm dia with pore partially occluded. Mature glebal hyphae, spore wall and subtending hyphae laminated.

60. *Glomus pansihalos* Berch & Koske

Chlamydospores single or in loose clusters, globose, sub-globose, ellipsoid or irregular, yellowish brown to dark brown, 110- 200 x 110-180 µm. Spore wall consisted of inseparable 3 walls; wall1 hyaline, 3-8 µm thick, expanding, granular, swells in PVA; wall2 yellowish orange to brown, 3-15 µm, laminate; wall 3

61. *Glomus pustulatum* Koske, Friese, Walker & Dalpe

Spores single, pale yellow to yellowish brown to orange brown, globose to irregular, (40) 85-140 (70) 90-140µm. Spore wall 3 layered (walls 1-3) in one group. Wall1, yellowish brown unit wall, 1-5 um thick with circular blister-like areas (up to 40 µm across) on the outer surface. Wall 2, pale yellow, laminated 3-10 µm thick. Wall 3, a thin, membranous wall, <1um thick, adherent to wall 2. Subtending hyphae straight or recurved, pale yellow to brown, continuous with wall2, 6-12 µm dia at spore base.

62. *Glomus pulvinatum* (P. Henn.) Trappe & Gerd.

Chlamydospores golden yellow, 55-90 x 55-95 µm in dia. Not aggregated, spherical to pyriform, thin walled (2-4 µm). Spore contents yellow, densely granular. Spore wall 2; hyaline to pale yellow slightly roughened outer wall and hyaline to pale yellow smooth inner wall. Smooth pale yellow septum up to 1 um thick separate the spore from sporophores which is wide (12-18 µm) long, straight or with a bulbous expansion below the spore.

63. *Glomus radiatum* (Thaxter) Trappe & Gerd.

Sporocarp flattened and lobed, greyish yellow without peridium, 8 x 7 x 3 mm. Chlamydospores thin walled, ellipsoid to oblong, obovoid, rarely globose, arranged in distinct radial pattern, grouped or widely dispersed in a matrix of coarse thin-walled hyphae, 60-110 (120) x 50-80 (-90) µm. Spore wall 4-8 µm thick, laminate, pale yellow. The stricking radial arrangement of spores from the sporocarp bas eis a unique feature of this species.

64. *Glomus reticulatum* Bhattacharjee & Mukerji

Chlamydospores single, dark brownish black, globose, 130-170 µm dia. Spore wall 10-15 um dia; outer wall 5-7 µm thick, two layered and fissured; outermost layer 1-2 µm thick and inner layer 4-5 µm thick. Inner wall with rectangular geometric reticulate markings (5-10 um apart) on its outer surface. Subtending hypha funnel-shaped, 8-10 µm wide at the point of attachment. Wall thickening extends down the subtending hypha to a distance of 40 µm.

65. *Glomus tenebrosum* (Thaxter) Berch.

Chlamydospores yellowish brown to dark brown, globose to sub-globose, 200-270 µm dia. Spore wall single, 14-26 µm thick, laminated, surface smooth or with flattened tubercules. Subtending hypha 16-40 µm wide at the point of attachment, the pore opened.

66. *Glomus tenuis* (Greenall) Hall

Chlamydospores hyaline turning dark brown with age, globose, 10-12 µm dia. Spore wall up to 2.5 um thick; subtending hypha swollen into a sphere of 1.5 µm dia.

67. *Glomus tortuosum* Schenck & Smith

Chlamydospores single, hyaline, pale yellow to dull greyish brown, globose to sub-globose, 120-210 µm dia with a mantle of sinuous hyphae closely appressed to the spore and flattened, 4-10 µm wide, forming layers of hyphae on the spore surface up to 25 µm thick. Mantle hyphae hyaline to brown. Spore wall single thin laminated, 0.5-2 µm thick; spore contents globular.

68. *Glomus vesiculiferum* (Thaxter) Gerd. & Trappe

Chlamydospores pale yellow, produced in tubercles, globose to sub-globose, 30-85 µm dia. Spore wall 4-8 µm thick, laminate, pale yellow; thickening of spore wall extending into the subtending hypha and nearly occluding the opening into the spore.

69. *Scutellospora alborosea* (Ferr. & Herr.) Walker & Sanders

Azygospores single, globose to sub-globose, 200-290 µm dia, young spores hyaline to pink; mature spores pinkish to brown. Spore walls 2; outer wall with two layers pinkish, 4-10 µm thick; the inner layer yellow 1.5-5.5 µm thick; inner wall mambranous 0.8-1.2 µm thick. Subtending hyphae pyriform to clavate, 20-50 µm wide. A narrow hyphae arise from subtending hyphae that grows towards the spore.

70. *Scutellospora aurigloba* (Hall) Walker & Sanders

Azygospores globose, pale yellow, transparent and shining, 200-400 x 140-420 µm; Spore wall2-4 layered; outer pale yellow,6-16 µm thick, inner walls 1 um thick, colourless to pale yellow. Spores formed on a bulbous suspensor, 40-70 µm dia; subtending hyphae with a poorly developed lateral projection.

71. *Scutellospora calospora* (Nicol. & Gerd.) Walker & Sanders

Azygospores single formed terminally on a bulbous suspensor-like cell, translucent, hyaline to pale greenish-yellow, globose to ellipsoidal 115-290 (-500) x 110-400 (-500) µm; Spore walls 4 (1-4) in two groups. Group 1 consists of an inner.hyaline brittle pale yellow, very finely laminated wall (wall2) 3-5 µm thick surrounded by a thin, closely appressed hyaline unit wall (wall1) 0.5-1µm thick. Group 2 consists of two membranous walls (wall3 & 4) 0.5-1.5 µm thick. Wall 4, 1-1.5µm thick staning red in Melzer's reagent. Germination shield oval, 40-70x 50-90 µm dia, often invaginations along the margin. Suspensor-like cell 35-50µm dia.

72. *Scutellospora dipapillosa* (Walker & Koske) Walker & sanders

Azygospores formed singly, sub-terminal to laterally on a bulbous suspensor; pale orange brown to dark orange brown, globose to sub-globose 135-160x 135-180 µm. Spore wall structure of 5 walls (1-5) in 2 groups. Numerous hyaline, blunt, bacilliform, larger projections 2-6 (-10) µm dia arise from wall 1. Wall 2brittle, orange brown, finely laminated; wall 3 brittle, hyaline. Group 2 consisting of a thick coriaceous wall (wall4) closely associated with a thin membranous wall (wall 5). An oval germination shield 60-80 x 85-100 µm forms on wall group2. Suspensor-like cell terminal on a coenocytic to sparsely septate subtending hyphae, 30-40 µm wide. Short, stout, peg-like hyphal protrutions up to 10 um long found on subtending hyphae.

73. *Scutellospora erythropa* (Koske & Walker0 Walker & Sanders

Azygospores formed singly, terminally on a bulbous suspensor-like cell, globose, sub-globose to ellipsoid, (170) 220-360 (-550) x 200-310 (-660) µm, often broader than long, orange-brown to dark red brown. Spore walls 4 in 2 groups; group 1 with smooth, outer unit wall (wall 1), enclosing 1-2 unit walls (wall 2, & 3); wall 1 brittle, translucent, coloured, 2-7 um thick, wall 2 and wall 3 brittle, less than 0.5 um thick. Group 2 consisted of a laminated wall (wall 4) enclosing a membranous wall (wall 5). Wall 4 pliable, pale yellow of 2-4 loose laminations, 2-9 µm thick; Laminae of wall 4 separate to form a complex germination shield, 125-200 x 170-190 µm. Wall 5 hyaline, less than 5 µm thick enclosing the spore contents. Suspensor cell thin-walled, 60-125 x 30-60 µm, yellowish brown; suspensor-like cell with a septate peg-like hyphal protrusion 40-100 x 4-10 µm extending towards the spore base.

74. *Scutellospora gilmorei* (Trappe & Gerd.) Walker & Sanders

Azygospores formed singly, hyaline, globose to sub-globose, 200-320 µm dia. Spore wall readily separating into an inner and outer wall. Outer wall hyaline, brittle up to 10 µm thick, consisting of thin outer layer up to 1 um and a thick inner layer. Inner wall hyaline, flexible up to 8 µm thick consisting of a thin outer membrane and 3 inner layers. Suspensor-like cell 30-40 µm, pale brown, clavate, the wall slightly thickened near the spore, generally septate near the swollen apex.

75. *Scutellospora gregaria* (Schenck & Nicol.) Walker & Sanders

Azygospore formed singly in soil, reddish brown to dark brown, globose, 250-450 µm dia with irregular shaped projections 1-7 x 3-12 µm over the spore surface; spore wall 11-15 um thick enclosing a membrane 1-2 µm; outer wall dark brown, 6-10um thick including projections; inner wall 5-7 µm thick, pale brown and transparent. Suspensor-like cell bulbous, pale brown, 40-90 µm wide.

76. *Scutellospora heterogama* (Nicol. & Gerd.) Walker & Sanders

Azygospore formed singly in soil, pale yellowish brown to reddish brown, globose to sub-globose, 150-220 µm dia. Spore walls 4 in 2 groups; group 1 with an outer ornamented unit wall (wall 1) tightly adherent to an inner laminated wall (wall 2); wall 1 brittle, pale yellowish brown, 1-1.5 µm thick. Warts small, very densely crowded on the spore surface. Wall2 yellowish brown, finely laminated, 4-7 µm thick. Group 2 consisted of two membranous walls (3 & 4) separated by an apparent amorphous cementing layer; each wall hyaline, <1 µm thick. Suspensor-like cell 20-40 µm wide, yellowish brown; one or more peg-like projections present.

77. *Scutellospora nigra* (Redhead) Walker & Sanders

Azygospores formed singly in soil, dark brown to black, globose, 300-500 µm dia, with an inner and outer walls. Outer wall dark brown to black, pitted with larger pores, 7-10 µm dia; inner wall light brown, transparent, of several laminae but continuous. Suspensor-like hyphal attachment brown, attached laterally, 40-60 x 80-120 µm, often producing a peg-like hypha extending to the spore wall.

78. *Scutellospora pellucida* (Nicol & Schenck) Walker & Sanders

Azygospores formed singly in soil, hyaline to pale gray, globose, ellipsoid to irregular, 60-180 (-250) x 60-240 (-410) µm. Spore wall 6 in 3 groups; group 1 with an outer smooth, brittle, hyaline, unit wall (wall 1), 1-2 um thick; inner wall laminated (wall 2), 2-7 (-16) µm thick. Group 2 consisted of a hyaline membranous wall (wall3), 1 um thick, closely adherent to two hyaline unit walls (wall 4 & 5). Group 3 consisted of hyaline amorphous wall (wall 6). Suspensor-like cell30-50 µm broad, hyaline.

79. *Scutellospora persica* (Koske & Walker) Walker & Sanders

Azygospores formed singly in soil, pale pinkish orange to brownish orange, globose to ellipsoid, 270-350 x 280-380 µm. Spore walls three in two groups; groups 1 with an outer ornamented unit wall (wall 1), tightly adherent to a laminated wall (wall2); wall 1 brittle, hyaline, 0.5-0.8 um thick covering with rounded warts, 0.25-0.5 µm high and mostly 0.5 µm dia. Wall 2 with 5-12 laminations, brittle, pinkish orange to brown, 2-10 µm thick, turning dark reddish brown in Melzer's reagent. Group 2 consisted of membranous hyaline wall (wall 3), which turns yellow in Melzer's reagent. Germination shield circular to sub-circular 130-240 x 60-180µm. Suspensor-like cell sub-globose 50-60 x 50-125 µm, pale brown.

80. *Scutellospora reticulata* (Koske, Miller & Walker) Walker & Sanders

Azygospore single, orange brown to dark reddish brownglobose to sub-globose, 200-470 x 190-340 µm. Spore wall consisted of 2 groups; outer wall three layered, outer layer 0.5-1 µm thick, orange brown to red brown, supporting raised, straight to sinuous interconnecting ridges that form a reticulum 0.5-1 µm high, with 4 to 8 sided meshes 2-24 x 2-30 µm across. Spore surface between ridges covered with polyhedral, conical or sub-cylindrical spines, or narrow straight, curved or angular ridges 0.5-2 µm high. Middle layer hyaline to pale yellow, 5-11um thick. Inner wall group 3 layered, consisting of membranous inner and outer hyaline layers each 1 um thick, connected by a hyaline amorphous middle layer 2 um thick. Suspensor–like cell 45-90 x 85-140 µm, with a peg-like protrusion extending 10-20 µm towards the spore wall.

81. *Scutellospora tricalypta* (Herr. & Ferr.) Walker & Sanders

Azygospores formed singly, dark greyish brown to brown, globose 300-380 µm dia. Spore wall composed of 3 easily separable layers, dark brown outer layer 5 µm thick, yellow to yellowish brown middle layer wit yellowish spines up to 10 x 2 µm formed towards the outside and hyaline membranous inner layer 3 um thick surrounding the reticulate cytoplasm. Subtending hyphae flattened and attached laterally to the spore, 15-50 µm dia, and up to 20 µm high.

82. *Scutellospora weresubiae* Koske & Walker

Azygospores formed singly terminally on a bulbous suspensor-like cell, translucent, glistening, pale pink to deep pink, globose to sub-globose 125-265 x 135-410 m. Spore walls 1-6 in three groups. Group 1 with an outer, smooth, brittle, hyaline, unit wall (wall 1) up to 0.5 um thick tightly adherent to an inner brittle, pink laminated wall (wall 2), 3-9 µm thick which turns red in Melzer's reagent. Group 2 consisted of 2 membraneus walls of 1 um thick; group 3 formed by a thick hyaline coriaceous wall (wall 5), 2- um thick surrounding a hyaline membranous innermost wall (wall 6), 0.5 µm thick which turns red in Melzer's reagent. Suspensor-like cell 30-50 um broad, hyaline to pale brown. One or two hyphal pegs up to 30 µm observed on suspensor-like cell and projecting towards the spore base.

83. *Entrophospora colombiana* Spain & Schenck

Azygospores produced singly, pale yellow to golden brown, globose 100-135 µm dia. Interconnecting hyphae between the azygospores and swollen hyphal terminus 50-125 um long having a dumbbel-shaped configuration. Spore wall 3-7 µm thick consisting of 2-3 separable walls; outer wall confluent with the wall of hyphal stalk, ephemeral, 0.5-2 um thick found only in young spores; wall 2 yellow brown to golden brown, 2-3 µm thick,

laminated; wall 3 hyaline 1 um thick; wall 4 membranous with a beaded appearance, 0.5µm thick, hyaline; wall 5 membranous, 1µm thick, hyaline turning to dark purple in Melzer's reagent. Spore contents yellow granular or reticulate.

84. *Entrophospora infrequens* (Hall) Ames & Schneider

Azygospore formed singly, within a smooth, hyphal terminates in a sub-globose to ellipsoid vesicle, 120-210x 150-225 µm dia; spores dull orange to brown, globose to sub-globose 70-180 (-220) µm dia, Spore wall one layer with vacuolated spines, 2.5-5 µm long, continuous except for funnel-shaped connection to the mother vesicle which plugged with thickened wall material.

85. *Sclerocystis clavispora* Trappe

Sporocarps globose to sub-globose, 460-750X590-780 µm brownish black to black, minutely verrucose from exposed tips of spores formed radially in a single, tightly packed layer around a central plexus of hyphae; base indented, peridium absent. Chlamydospores brown 140-185 x 25-50 µm, clavate to sub-cylindric, tapering to a hyphal attachment 7-10 µm dia. Spore walls 1.5-5 µm thick on the sides, at the spore apex to 20-25 µm at the base thickened to 5-10 µm and occluding the attachment at maturity.

86. *Sclerocystis coremioides* Berk. & Broome

Sporocarps dull brown, globose to pulvinate 340-600 µm, flattened at base; sporocarps fused together laterally and one above the other to about 4 sporocarps thick. Peridium 20-70 µm thick of interwoven hyphae. Chlamydospores yellowish brown, 50-86 (-100) x 35-50 (-80) µm obovoid, ellipsoid to oblong-ellipsoid, often not always cut off from subtending hypahe by septa just below spore base, arranged in a single layer, tightly grouped in a hemisphere around a central plexus of hyphae. Spores absent at base of sporocarps. Spore wall 4 µm thick at base and 2 µm thick at apex, brown.

87. *Sclerocystis dussii* (Pat.) von Hohn.

Sporocarps single to fused together laterally and vertically, yellowish brown to tan, sub-globose to hemispheric, 265-540 µm dia, Upper surface covered with thin-walled vesicles up to 340 x 80 µm, globose when young, becoming ellipsoid to broadly clavate and rounded at the tip. Peridium 20-60 µm thick. Chlamydospores 50-80 x 30-50 µm, clavate, cut off from subtending hyphae by septa just below spore base, tightly grouped in a single layer in hemisphere around a central plexus of hyphae.

88. *Sclerocystis microcarpus* Iqbal & Bushra

Sporocarps dark brown, globose to sub-globose, 100-420 µm dia, minutely verrucose from exposed tips of spores formed radially in a single, tightly packed layer around a central plexus of hyphae; peridium lacking. Chlamydospores clavate, cylindric-clavate, 95-115 x 40-60 µm with a small pore opening into the thick-walled subtending hyphae. Spore wall laminate, brown, 15-25µm thick at the apex 3.5um thick at the sides, generally thickest at the apex.

89. *Sclerocystis pachycaulis* Wu & Chen

Sporocarps pale yellow to yellowish brown, globose to sub-globose, 170-230 x 175-270 µm, consisting of chlamydospores radially arranged on central plexus of hyphae. Chlamydospores yellow to yellowish brown, obovoid to ellipsoid, 30-60 x 40-90 µm. Spore wall yellowish brown, 1-5 µm thick with a hyaline separable outer layer, 0.5-1 µm thick. Spore contents separated by 1-2 advanture septa below the attachment. Spores often perforated. Attached hypha thicker than the spore wasll with a narrow lumen.

90. *Sclerocystis rubiformis* **Gerd. & Trappe**

Sporocarps dark brown, sub-globose to ellipsoid, 180- 680 µm dia, consisting of single layer of chlamydospores surrounding a central plexus of hyphae. Peridium absent, individual spores partially enclosed in a thin network of tightly appressed hyphae. Chlamydospores dark brown, obovoid to ellipsoid, or sub-globose, 40-125 x 30-90µm, with a small pore opening into the thick-walled subtending hyphae. Spore wall laminate, 3-8 µm thick, up to 14 µm thick at spore base, often perforated with thick perforated projections on the inner surface.

91. *Sclerocystis sinuosa* **Gerd. & Bakshi**

Sporocarps brown, globose, sub-globose to pulvinate, 250-410 um dia. Peridium 6-20 µm thick, tightly enclosing sporocarps, composed of thick walled sinuous hyphae. Chlamydospores 45-120x30-80 µm, obovate, elliptical to clavate, radiating out in a single layer from a central plexus of hyphae. Spore wall brown, 1.5-5µm thick, generally thickest at spore base.