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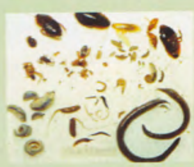
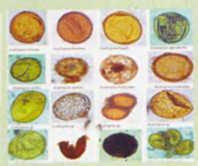
Conservation and Sustainable Management of Belowground Biodiversity in the Kerala Part of Nilgiri Biosphere Reserve - Phase I





U.M. Chandrashekara
M. Balasundaram
K.V. Sankaran
M.P Sujatha
R.V. Varma
B.K. Senapati
Manvika Sahgal



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Kerala Forest Research Institute, Peechi, Thrissur, Kerala

(An Institution under Kerala State Council for Science, Technology and Environment)

CONTENTS

EXECUTIVE SUMMARY

The benchmark site of the Project on Conservation and Management of Belowground Biodiveristy (BGBD Project) established in the Keraal part of Nilgiri Biosphere Reserve (latitude 10°50' and 12°16'N and longitudes 76° and 77°15'E), is located in the micro-watershed of Chaliyar River. The study site covers landuse systems such as primary forests, secondary forests, managed plantations, agroforestry systems and annual crop based systems. Among different landuse systems, the semi-evergreen forests with 67 tree species are rich in tree species diversity. These forest patches are free from human disturbance as indicated by the RISQ value (1.16) and closed canopy nature (LAI 4.24 to 4.92). On the other hand, moist deciduous forest patches are being repeatedly disturbed and trees of smaller girth classes are lesser than those of higher girth classes and the RISQ value is significantly more (3.83) than that in semi-evergreen forest patches. Forest patches closer to the agricultural lands are highly degraded with the total density and basal area of tree community accounting for less than 25% of that recorded in the semi-evergreen forests and 10% of that recorded in moist deciduous forests. Repeated extraction of poles and other biomass and grazing are responsible for the degradation of these patches. In the teak plantation, density and basal area of teak are significantly less in water-logged area than in uplands. Growth of teak in these plantations is generally poor as indicated by the tree gbh which is less than 20% of the expected value for the trees of same age (25-year-old). In tree- based cropping systems, tree density, basal area and species number vary from farm to farm depending on the crop combination, age of the farm and management practices adopted by farmers. When different subsystems of tree-based cropping systems are compared for the contribution of trees maintained for green leaf manure production to the total IVI of tree community, the values are high in polyculture homegardens followed by polyculture farm lands. In many plantations, cultivation and management of green leaf manure species are totally absent.

Out of 171 vascular plant species recorded during the course of this study, 25 species are legumes. Wherever the contribution of leguminous shrubs is relatively more it is due to the growth of *Cassia occidentalis* and *Desmodium gangeticum*. On the other hand, wherever the contribution of leguminous herbs is relatively more it is due to the profuse growth of *Mimosa pudica, Centrosema pubescens* and *Desmodium triflorum* in poorly managed systems. In well managed systems generally *Vigna unguiculata* is being cultivated and thus it contributes much to the IVI of herb community. In case of cashew plantations with poor soil and exposed laterite blocks, *Desmodium trifloram* (a leguminous herb) forms almost a thick carpet covering the soil. Further studies on the role of *Desmodium trifloram* in soil and water conservation and soil fertility improvement are needed.

The moist deciduous forest located near human habitation are highly degraded and possess sparse vegetation and nutrient poor compact soil when compared to the similar kind of forests located away from the human habitation. Though these two forests are originally similar in terms of aboveground vegetation, the degraded forests showed relatively higher value for ant density and diversity. Thus ants, particularly *Lobopelta* sp. and *Leptogenys* sp., could be considered as indicator species of forest disturbance. In the study area, majority of the current landholdings were under paddy cultivation about 25 years back. Thus, similarity in terms of belowground biodiversity between paddy fields and other landuse systems derived from paddy fields could be pronounced. However, absence of some of the soil faunal elements in certain landuse systems recorded in the study area could be attributed to the differences in the crop combinations and management practices. For instance, low density of earthworm in annual crops and arecanut mixed with annual crops may be attributed to the excess use of inorganic fertilizers and pesticides. It may be pointed out here that among the endogeic worms *Parryodrilus lavelee and Pontoscolex corethrurus* showed maximum availability in a variety of landuse patterns. It may also be concluded that since these two species have a wide tolerance to landuse changes, they may be suitable for land restoration purpose. It may also be mentioned here that apart from the season of sampling, landuse history, landuse pattern, crop combination etc. the sampling technologies adopted decide the qualitative and quantitative information that can be obtained on each group of soil fauna. Thus the sampling technologies to estimate different faunal groups need to be standardized considering both the faunal group under study and the landuse systems.

In the study area, plantations of teak, rubber and cashew are located in almost similar terrain to that of moist deciduous forest. Moreover, age of these plantations ranged from 3 to 25 years and before that they too were representing either degraded or good moist deciduous forests. Comparatively high diversity of AM fungi in soils in cashew plantations, degraded forests and teak plantations than that in moist deciduous forests situated away from human habitation indicate that conditions in these soils are highly suitable for the proliferation of a host of mycorrhizal fungi. Though more studies would be required to arrive at any firm conclusions, the available data show that plant dependency on mycorrhiza is apparently more in highly degraded sites.

In general, dependency of majority of the farmers in the study area on croplands for the livelihood is relatively low, either due to small size of the landholding or due to attractive economic return from their non-farming activities. Studies carried out in the cultivated lands also indicated that organic carbon, exchangeable calcium, magnesium and potassium were considerably lesser than the level required for the optimum crop yield. It was also recorded that the contribution of trees and understorey species maintained for green leaf manure production to the total Importance Value Index of tree and understorey plant communities are significantly low or nil. Further analysis of the crop management systems in the region also revealed the fact that cultivation and management of leguminous crops with a view to obtain green manure and soil fertility management in almost all croplands are neglected. Even the application of green leaf manure, farmyard manures, cultivation of cover crops which are required to sustain the crop yield and soil fertility are not being adopted adequately. Over-harvest of biomass without sufficient nutrient input is leading to the loss of nutrients from the crop lands. Similarly, application of heavy dose of chemical pesticides at frequent intervals into croplands can be attributed to the loss of below ground biodiversity. In forest teak plantations, removal of litter from soil surface for fuel and mulching has been identified as one of the major causes for the decline in the soil moisture, extractable phosphorus, exchangeable potassium and exchangeable magnesium. Studies also revealed that some of the faunal characteristics are either absent or sparsely represented in a given landuse system. It was recorded that in the unmanaged systems the root colonization of VAM fungi were more than in some of the well managed mono-cropping systems. Thus it was clear that in unmanaged systems plants are more dependent on mycorrhiza for growth. Further analysis of data indicated that majority of the landuse systems were not significantly different from the un-managed plantations in terms of per cent root colonization by mycorrhiza indicating that these plots are also poorly managed.

Results of quantitative estimation and diversity of soil legume nitrogen fixing bacterial (LNB) population in different landuse systems in the study area indicated the fact that the rhizobial population in polyculture systems was significantly more than in annual crop based systems. The higher population of rhizobia in soil during pre-monsoon season than in post-monsoon, in all the landuse systems indicated that pre-monsoon season would be an ideal season for soil rhizobium estimation. Among the thirteen species of naturally growing legumes in the study area, *Desmodium triflorum* produced most profuse nodulation. Thus the wild legumes such as *Desmodium triflorum* could be a potential source of green cover crops. Conventional physiological and morphological techniques indicated that the LNB isolates belonged to five genera viz. *Rhizobium*, *Mesorhizobium*, *Sinorhizobium*, *Bradyrhizobium* and *Allorhizobium*. The study also revealed the fact that the most of the isolates which originated from degraded forests, teak plantation and paddy field utilized the sugars better than isolates from other sites.

Genetic diversity studies of inter box elements using box primers involving the eighty LNB isolates showed that 100 percent of the loci were polymorphic indicating high level of genetic diversity among the isolates. Gene diversity varied from 0.0722 to 0.4888 with a mean diversity of 0.2949. Molecular studies based on partial 16S rDNA sequencing and analysis of sequence data could identify 4 LNB isolates from Kerala part (KFRI isolates). These isolates belonged to *Klebsiella* sp., *Agrobacterium tumefaciens*, *Burkholderia cepacia* and *Burkholderia* sp. Further studies on the genetic diversity studies conducted at G.B Pant University of Agriculture and Technology on 13 LNB cultures isolated from trap plants (cow pea) showed that the LNB isolates from Kerala part of NBR were more diverse genetically than the isolates from Karnataka part of Nilgiri Biosphere Reserve and from Nanda Devi Biosphere Reserve.

In the study area, the respondents are literate and have the tendency to imbibe new knowledge and techniques to improve their croplands. Thus attempts to promote suitable activities for the conservation and management of belowground biodiversity are expected to become successful. In this context, post-project meetings were organized to present the results of the study before the farmers and land managers. The participants agreed with the fact that continuous cultivation without external application of organic manures and lack of efforts to conserve organic matters in the systems are the reasons for low productivity and soil organic matter depletion in different cropping systems. Farmers also recognized the competition between the weed community and crop community as an important cause for difficulty in maintaining the optimum crop yield. As already indicated in the landscape of Chaliyar River Watershed, the study recorded a faster rate in landuse and land cover changes. The farming community also expressed the view that the conversion of one cropping system to another is more frequent resulting in the increased soil erosion and runoff rates. Considering these aspects, four strategies viz. a) application of green leaf manure, b) application of plant growth promoting microorganisms and earthworm rich compost, c) reduction of nutrient loss from the croplands, and d) growth of leguminous and/ or biomass transfer species in the crop lands for maintaining soil fertility, sustainable yield and to enhance density and diversity of soil biota in different cropping systems, have been identified. During the second phase of the project on-farm participatory experiments to demonstrate the usefulness of these strategies and also disseminate information and technology to the wider user groups may be undertaken.

1. INTRODUCTION

The Nilgiri Biosphere Reserve (NBR) (latitude 10°50' and 12°16'N and longitudes 76° and 77°15'E) is the first Biosphere Reserve established in India. This Biosphere Reserve covering an area of 5520 km^2 of Nilgiri plateau in southwest portion of the Western Ghats falling in three southern States (Kerala, Karnataka and Tamil Nadu) (Figure 1). The Kerala part of NBR covers an area of 1455 km^2 including Wayanad Wildlife Sanctuary, Silent Valley National Park, Nilambur Reserved Forests, New Amarambalam Reserved Forests, Attappady Valley and Muthikulam Reserve Forests (Figure 2). Natural vegetation in the Kerala part of NBR is highly diverse and represented by wet evergreen forests, montane shola and grassland, semi evergreen forests, moist/dry deciduous forests and scrub forests. A high degree of biodiversity in the region and associated biophysical and socio-economic factors has been dealt in a number of publications (KFRI, 1980; Pillai, 1981; Nair and Balasubramanyan, 1985; Centre for Ecological Sciences, 1990; KFRI, 1990; KFRI, 1991; Easa and Basha, 1995; Muraleedharan *et al.*, 1999). The planned economic development initiated in 1950's together with adoption of forest policies focusing raw material demands of wood-based industries led to massive conversion of natural mixed forests to monoculture tree plantations. Implementation of land reforms initiated during 1960's led to large scale shifts in landuses on both agricultural and forest lands. For example, in 1971, the Kerala Government passed the Private Forest (Vesting and Assignment) Act, 1971 which empowered it to take over thousands of square kilometers of private forests without paying any compensation to the owners. Anticipating this move, the private owners alienated vast areas of forest during the late sixty's., leading to radical changes in the landscape structure and pattern (Centre for Ecological Sciences, 1990). The present landscapes in the Biosphere Reserve are mosaics consisting of natural forests with various degrees of disturbances, forest plantations, traditional farming systems and extensive mono-cultural crop lands. However, systematic studies to compare and contrast different landuse in terms of vegetation structure, management of aboveground and belowground biodiversity for maintaining the soil fertility and sustainable productivity are lacking.

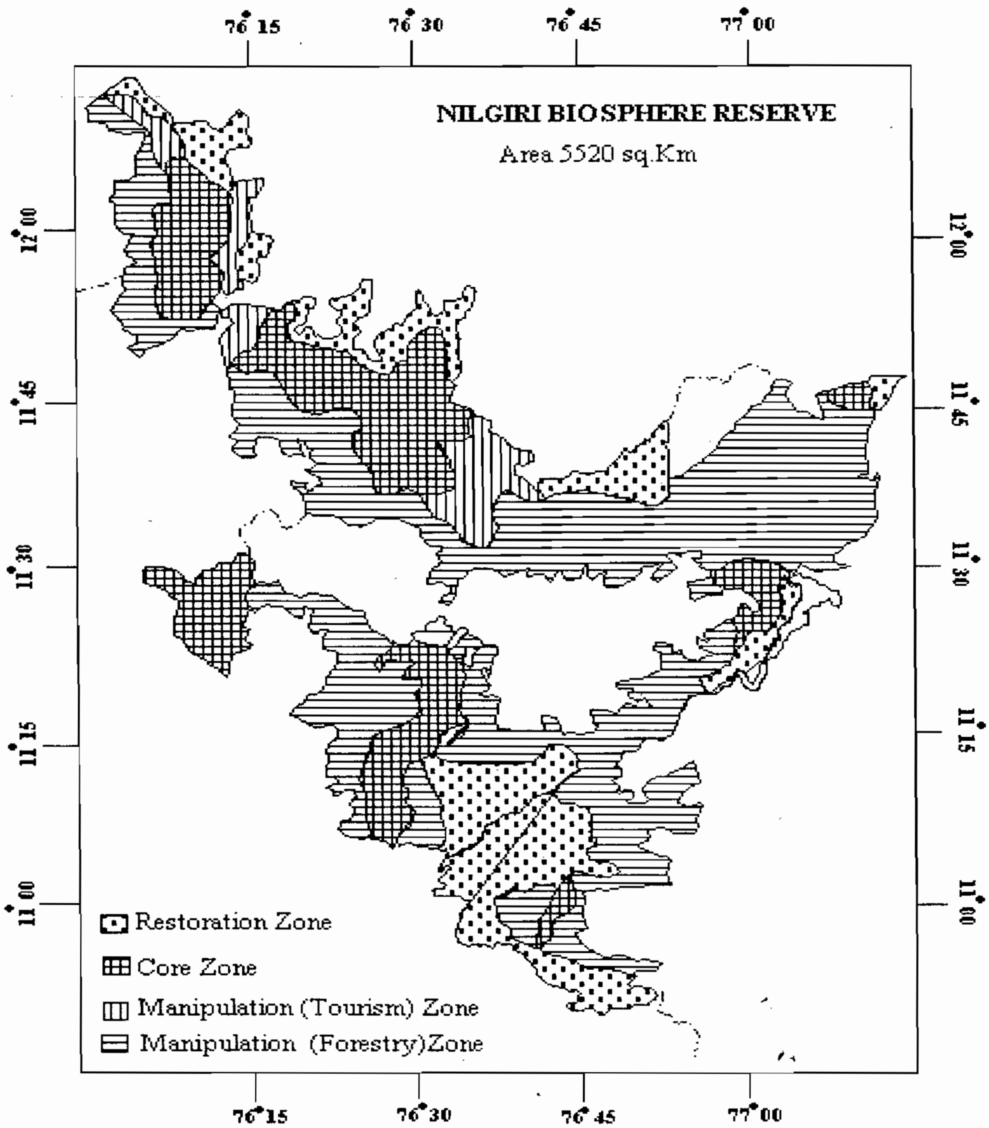


Figure 1. Map of the Nilgiri Biosphere Reserve, India

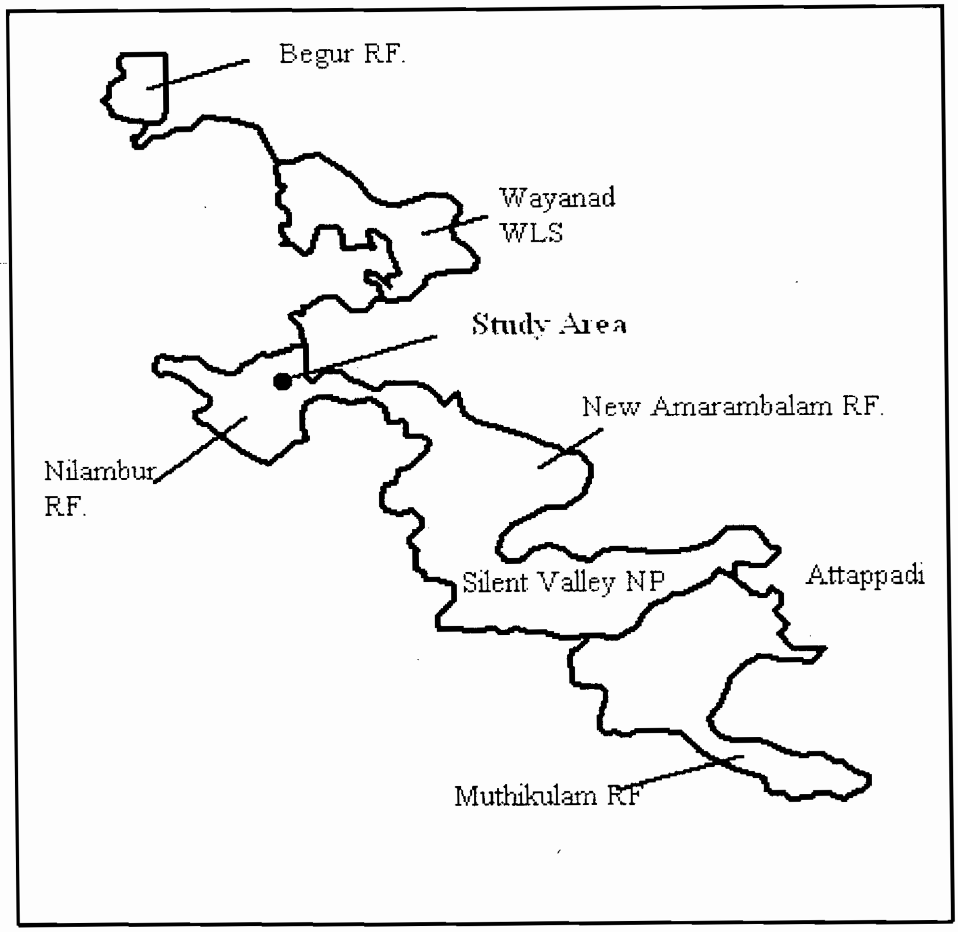


Figure 2. Map showing the Kerala part of Nilgiri Biosphere Reserve

The survival and growth of vegetation on a soil under favourable climatic condition is controlled mainly by the characteristics of the soil. If once the vegetation could survive and proliferate, later it produces its own impact on soil, can be either beneficial or detrimental. Soils of an undisturbed natural forest are supposed to have an ideal growing condition contributed by the maximum diversity of the flora and fauna in the system. Hence, any disturbance to the natural forest often paves the way to the loss of its biotic potential gradually resulting in the degradation of soil properties. Cultivation of agricultural crops either as mono crop or inter crop through high input management practices often leads to the deterioration of the quality of soil, water, environment and also the agricultural produce.

The decline of soil quality is a global problem, though the nature, magnitude and causal factors of this decline vary. Pando-Moreno *et.al.* (2004) observed a decline in soil organic matter but increase in bulk density following conversion of forests to agricultural landuse in Brazil. Conversion of an extensive Iranian forest in lowlands into paddy cultivation resulted in a decrease of soil organic matter, change in volume and type of voids, creation of reducing condition, damage to soil structure and development of fragipan, thus making it impossible to carry out reforestation (Akef *et.al.*, 2003). In Sumatra, landuse following forest clearance lowered saturated hydraulic conductivity by 85%, porosity by 10.5%, soil water content at field capacity by 34%, organic carbon by 27%, total N by 26%, inorganic N by 37%, soil microbial biomass C by 32%, mineralisable C by 22% and particulate organic matter by 50% (Handayani, 2004). Similar studies on the changes in soil properties caused by converting natural forest to cultivated lands were conducted in southern Cameroon (Birang, 2004), China (Guo- Xu Dong *et al.*, 2004), Nigeria (Mbagwu and Piccolo, 2004) Portugal (Araujo *et al.*, 2004) and Ghana (Braimoh and Velk, 2004). Depletion of soil fertility following intense human disturbances in natural forests has been reported in a number of Indian studies (Rai and Sharma, 2003; Chaudhuri, *et al.*, 2003; Narian *et al.*, 2003). The Western Ghats region of India, an important niche of biological diversity in the country is also under the severe threat of soil fertility loss due to the change of land cover. Thus a comparative study would be useful to evaluate soil fertility under varied landuse-land cover types in the Kerala part of Nilgiri Biosphere Reserve.

According to Giller (1996), in a given ecosystem, the magnitude of underground biodiversity is much more than aboveground biodiversity. The information on soil fauna in India was reviewed by Singh (1978). This work also substantiate the fact that compared to aboveground fauna, belowground fauna is poorly understood. Bingham (1903) reported many soil dwelling ants, while Imms (1912) described new collembolans from India. Most information on soil dwelling organisms, especially that of micro-arthropods have come from the agricultural fields and tea plantations and very few studies have been conducted in the tropical rain forests. Sanyal (1995) has reviewed the work on ecology of oribatid mites in India. Information on soil/litter micro arthropods of forests has been limited to the works by Singh and Singh (1975), Prabhoo (1976), and Hazra (1982). While reviewing the role of earthworm in the decomposer system, Dash (1973) pointed out that the earthworms can be abundant in mull type of soil, in base –rich grass alnds and crop lands. According to him, the eartworm density in some Indian grassland and pasture soils range from 6,32,010-79,11,000 ha^{-1}. But such data are scanty from forest soils. Mishra and Dash (1984) studied the seasonal variation in eartworm density and reported that maximum density (131 m^{-2}) during October and minimum in May (24 m^{-2}). Accoriding them in tropical and sub-tropical regions the earthworm activity mainly restricted to rainy and post-rainy season between June and November. Belowground organisms contribute to ecosystem services though their influence on soil fertility and primary productivity (Dangerfield and Milner, 1996; Lawton *et al.*, 1996; Barros *et al.*, 2004). For instance, Dash and Patra (1977) earthworms in tropical soil can contribute more than 25% of soil metabolism. Changes in above ground biodiversity can have dramatic effects upon soil invertebrate communities (Beare *et al.*, 1997; Fragoso *et al.*, 1997; Senapati and Dash, 1981;Decaens *et al.*, 2004) and may therefore lead to alterations in soil functioning. There is paucity of such information in the context of Biosphere Reserve in India.

Soil microorganisms play a vital role in mobilization of non-available forms of nutrients to available forms. Landuse and land management are known to influence the diversity and effectiveness of mycorrhizal fungi (Strzemska, 1975; Ocampo and Hayman, 1980; Mulligan *et al.*, 1985; Thompson, 1987). Some microbes such as legume nodulating Rhizobia are crucial in that they fix atmospheric nitrogen in forms which improve not only the health and vigour of the legume but also contribute to maintenance of soil fertility which adds to the benefit of following or associated crops. The legume-Rhizobium symbiosis is responsible for 180 x 10^6 tonnes per year of biological nitrogen fixation world wide (Sahgal and Johri, 2003). The genus Rhizobium comprises gram negative, non-sporulating motile rod shaped bacteria which infect root hairs and form nodules in several leguminous plants. There are 35 species of symbiotic nitrogen fixing bacteria associated with legumes belonging to seven genera viz., *Allorhizobium, Azorhizobium, Bradyrhizobium, Mesorhizobium, Methylobacterium, Sinorhizobium* and *Rhizobium* (Sahgal and Johri, 2003). Soil contains native species of rhizobium, but all of them are not capable of forming nodules. Some of the strains are highly specific to certain species while others are promiscuous (i.e., they can form nodules with a wide range of legumes). The present study aims to assess the population and diversity of rhizobia/legume nodulating bacteria in different landuse systems situated in a micro-watershed in the Kerala part of Nilgiri Biosphere Reserve.

Arbuscular mycorrhiza (AM) is an ubiquitous symbiosis between plant roots and glomalean fungi (Brundrett, 1991). AM fungi enhance plant growth through improved nutrition and protection from pathogens (Dehne, 1982 ; Abbott and Robson, 1984). Quite a few efforts have been made to characterise the diversity of AM fungi in India, e.g., studies made by Ragupathy *et al.* (1990); Sen Gupta and Chaudhury (1990) and Mohankumar and Mahadevan (1987) in marshy vegetation, by Muthukumar and Udayan (2000) and Mohanan (2002) in natural tropical forests and by Sankaran *et al.* (1993), Sharma *et al.* (1996) and Mohanan (2003) in forest plantations. There has been no previous attempt to compare the diversity of AM fungi in soils under diverse landuse systems in India.

The objectives of this study were:

1. To identify different types of agricultural and agroforestry systems on a landscape and micro-watershed level in the Kerala part of Nilgiri Biosphere Reserve
2. To analyse the nature and pattern of landuse changes

3. To document the aboveground and belowground biodiversity in different agricultural and agroforestry landuse systems

4. To identify strategies for sustainable management of soil fertility, belowground biodiversity and overall productivity of different landuse systems

2. STUDY AREA AND CLIMATE

The study was conducted in the watershed area of Karakkode rivulet, one of the tributaries of Chaliyar River (Figure 3). The watershed can be divided into fertile, relatively flat valley along the rivulet and surrounding uplands with medium to steep slopes. Valley area around the rivulet is by and large under agriculture. Forests are mainly confined to higher slopes and consist of both natural forests and teak and bamboo plantations. Rural people, with different social and economic conditions, area are primarily dependent on agriculture for their livelihood.

The climate is typically monsoonic with annual rainfall varying from 1621mm to 3271 mm (mean over 1990-2004: 2312mm). More than 65% of annual rainfall is drawn from the southwest monsoon during June- August period. The northeast monsoon, which sets in October and lasts till the end of November, accounts for much less rainfall (hardly 25% of annual rainfall) (Figure 4). The mean annual maximum and minimum temperatures are 35°C and 15°C, respectively.

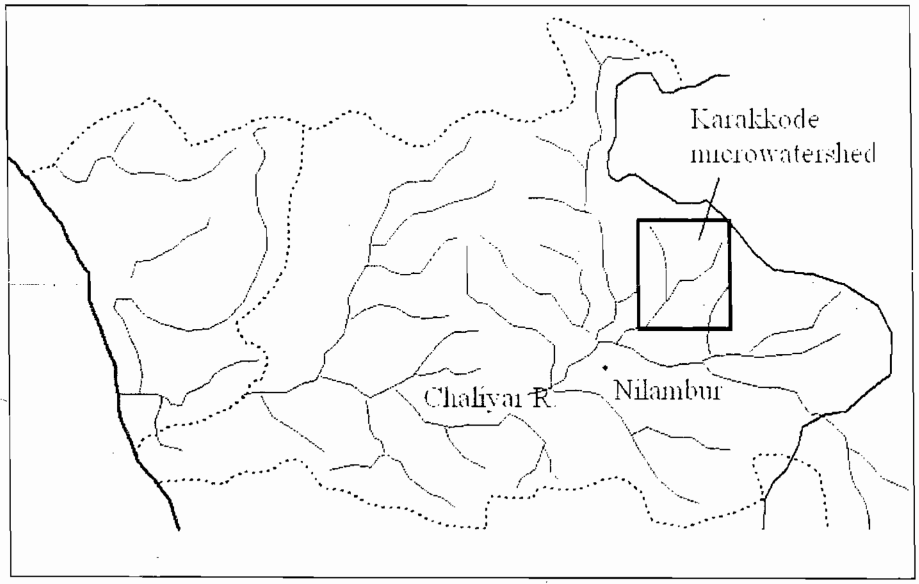


Figure 3. Study site in the Karakkode micro-watershed of Kerala part of Nilgiri Biosphere Reserve

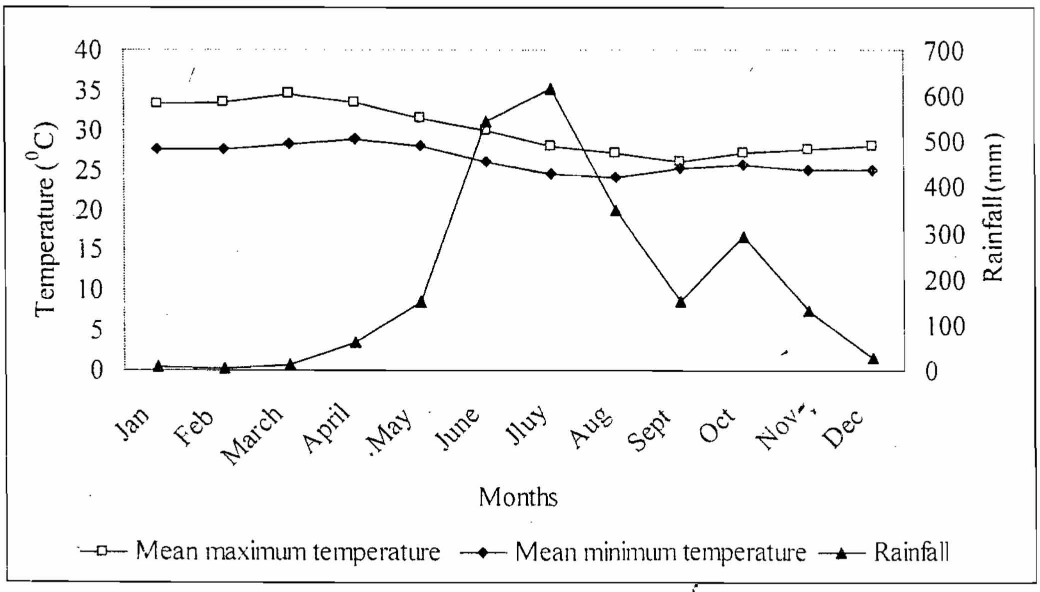


Figure 4. Monthly rainfall and temperature patterns in the study site of Kerala part of Nilgiri Biosphere Reserve

3. METHODS

3.1.1. Site selection

An area of 2.6 km and 1.4 km in size in the Karakkode micro- watershed was selected for detail studies. The area was divided into 200 m x 200 m grid and the grid intersection points were marked using a Geographical Positioning System. Out of the 72 grid intersection points, 24 points which fell in landuse-land cover types other than agriculture/forestry were excluded. Out of 48 selected points that were sampled, four points were covered in highly degraded forests under the control of the Kerala Forest Department and located in Manalpadam village (Figure 5). The remaining 44 points, also in the same village covered a variety of agroecosystems/agroforestry systems (Table 1). Another 12 points, four each in semi-evergreen forest, moist deciduous forest and teak plantations were sampled in Nadukani, Pattakarimbu and Kariem-muriem respectively so as to cover the whole spectrum of landuse systems in the Kerala part of the NBR.

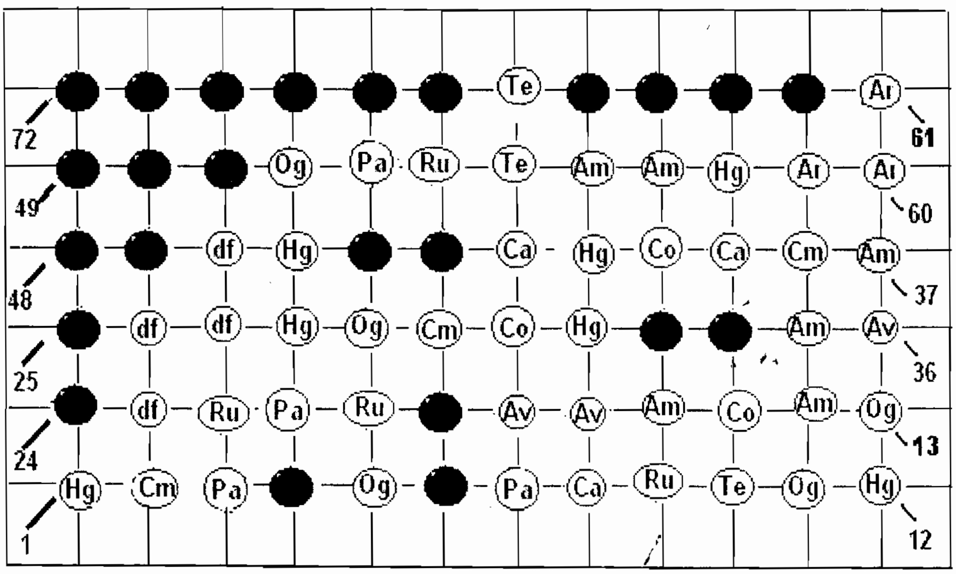


Figure 5. Landuse systems found at each point in the Window established in the Kerala part of Nilgiri Biosphere Reserve

Pa: Annual crop based system, Hg: polyculture homegarden, Og: Polyculture farm, Av: Arecanut with annual crops, Am: Arecanut with perennial crops, Cm: Coconut with perennial crops, Ar: Arecanut plantation, Co: Coconut plantation, Ca: Cashew plantation, Ru: Rubber plantation, Te: Teak plantation, Df: Degraded forest, ● Non sample points.

Table 1. Landuse classification and sample points in each landuse systems in the Kerala part of the Nilgiri Biosphere Reserve

Landuse systems	Characteristic features of landuse systems
A. Natural forests	
A1. Semi-evergreen forest	Comprises a mixture of evergreen and deciduous trees. Between 40% and 80% trees are evergreen.
A2. Moist deciduous forest	Deciduous trees are dominant. Up to 40% trees are evergreen.
A3. Degraded forest	As in A2, deciduous trees are dominant, but trees sparsely distributed. Tree regeneration is poor.
B. Forest plantation	
B1. Teak plantation	Monoculture of teak (about 25-year-old) maintained by the Kerala Forest Department
C. Crop-based systems	
C1. Annual crop based systems	Annual crops like paddy and vegetables dominant and perennials like banana constitute minor crops
C2. Tree based systems	Tree crops are dominant. The system may be monoculture or polyculture
C2.1. Polyculture homegardens	Land cultivated around the farmer's dwelling place with annual, biennial and tree crops, mostly integrated with animal husbandry.
C2.2. Polyculture farm	Land cultivated away from the farmer's dwelling place with annual, biennial and tree crops, sometimes integrated with animal husbandry.
C2.3. Plantations of a tree crop with some other associated crops (annual, biennial or perennial)	Area is dominated by one tree species, along with some annual/perennial crops.
	C2.3.1. Arecanut plantation integrated with cultivation of some annual crops
	C2.3.2. Arecanut plantation integrated with cultivation perennial crops
	C2.3.3. Coconut plantation integrated with some perennial crops
C2.4. Monoculture plantations	Mono-specific tree plantations.
	C2.4.1. Arecanut plantation
	C2.4.2. Coconut plantation
	C2.4.3. Rubber plantation
	C2.4.4. Cashew plantation
	C2.4.5. Teak plantation (private)

3.2. Phytosociological analysis

The tree community structure, composition, distribution pattern and diversity were studied in all sixty sample points. In each point, three transects each of 40 m x 10 m in size were marked. Each transect was divided into four quadrats, each of 10m x 10 m of size. Trees present in the quadrat were marked, identified, counted and their GBH (girth measured at 1.37m above the ground level) was recorded. Parameters such as approximate tree height and bole height were also recorded. Maximum length and breadth of each tree (gbh <10.1 cm) was measured and the crown area was calculated. Sum of the crown area of all trees in a unit land area was divided by the land area to obtain crown to land ratio (CLR).

Shrub density and girth (measured at the ground level using Vernier calipers) were measured in four sub-quadrats, each of 5m x 5 m of size, nested in each of the quadrats laid for tree enumeration.

Herb density was estimated in four sub-quadrats (1 m x 1 m), nested in each of the quadrats laid for tree enumeration. Since herb density was more and measurement of girth of individual plant of herbs, particularly of trailing herbs was tedious and time consuming, their biomass was estimated. All plants within each sub-quadrat were uprooted, sorted into different species and weighed after air drying for the constant weight.

3.3. Determination of forest stand quality index of natural forest sites

One of the landuse categories to be sampled in the benchmark area of each country is the natural forest. The natural forest may be primary or secondary and may be experiencing different level of disturbance. It is also expected that the forest stand quality determines the soil characteristics and above ground and belowground diversity. Thus it is also required provide quantified information on forest stand quality. In this context, the Ramakrishnan Index of Stand

Quality (RISQ) was calculated for the natural forests (semi-evergreen forests, moist deciduous forests and degraded forests) sampled in the study area of the Kerala part of the NBR following the method (Chandrashekara, 1998) given here. Considering the life history patterns, tree species can be categorised in to primary species (shade tolerant evergreen species), late secondary species (evergreen species which regenerate under medium sized canopy gaps), early secondary species (evergreen heliophytic species which regenerate in large canopy gaps or open area) and deciduous species. The pioneer index value assigned to primary species, late secondary species, early secondary species and deciduous species was 1, 2, 3 and 4 respectively. Contribution of each category of species to the total IVI was multiplied by its pioneer index value. Sum of the values obtained for four categories of species was the RISQ.

$$RISQ = \sum\{(n_i/N)\} \text{ X species pioneer index}$$

Where n_i = IVI of a given category of species, N= Total IVI of species of all category and species pioneer index 1, 2, 3, and 4 for primary species, late secondary species, early secondary species and deciduous species respectively. RISQ value of a given site can be vary from 1.0 (undisturbed stand) to 4.0 (highly disturbed stand).

3.4. Determination of Leaf Area Index (LAI)

Leaf area index (LAI) is an important parameter to understand the canopy cover of different landuse systems. Thus LAI of different landuse systems prevailing in benchmark area were analyzed after the south-west monsoon (September-October 2004) using canopy analyzer (LI COR,USA).

3.5. Soil sampling and analysis

Soil sampling was done in sample points during October - November 2004 covering various landuse types. In each sampling point, one transect of 40 m x 5 m was laid and divided into 5 blocks each of 8 m x 5m. Five soil core samples were collected from each of three blocks and thus a total of 15 samples were there from one sampling point. The soil filled cores were carried to the laboratory and pushed by a RAM (pneumatically operated soil pusher). Extracted soil was separated into two depths viz., 0-10 cm and 10-30 cm and samples for moisture determination were kept apart. Rest of the samples were air dried and analysed for pH (H_2O), pH (KCl), organic carbon, exchange acidity, total N, extractable P, exchangeable K, Ca and Mg by adopting the methodology described in the TSBF working manual.

The data with respect to each soil property was subjected to univariate analyses using the SPSS (10 version) soft ware. The significance of each property between landuse system were tested through ANOVA and mean comparison was made using LSD. Values for a given parameter in two soil depths in a given landuse system were compared using Student's t-test.

3.6. Belowground biodiversity

3.6.1. Soil fauna

For sampling of mesofauna, protocols suggested by TSBF were followed (Swift and Bignell, 2001). Transect of area 40 x 5 m was marked in each landuse system, which was divided in to 4 sections, each of 10 x 5 m dimension. The monoliths for sampling faunal elements were marked in each section (a total of 4 in each landuse) each of 25 x 25 x 30cm in dimension. The monolith was delimited by removing soil around the monolith area. Each monolith was divided into three layers, each of size 25 x 25 x 10 cm and mesofaunal elements were hand sorted at site and preserved in alcohol. Thus soil fauna from three layers of soil, *viz*. 0-10 cm, 10-20 cm, 20-30 cm, were collected during the post-monsoon period (September to November) of 2004 and preserved.

Soil samples were brought to the laboratory for the extraction of mesofauna. Tullgren Funnel Extraction method was followed. The funnels containing soil was illuminated with an electric bulb of 60W. Organisms like mites, collembola etc., that will move away from the light source were collected in the beaker containing alcohol, placed below the tail end of the funnel.

Nematode extraction was carried out by water migration technique. Twenty gm of soil was placed over a filter paper placed above wire gauze with soil just touching the water column. This unit was kept undisturbed overnight and the nematodes that will migrate from soil to water were collected. Thus the number of nematodes per volume of soil was obtained.

For sampling of macrofauna, at each sampling point, a metallic frame (25 X 25 cm^2) was placed over the soil; the litter was then collected and its soil fauna hand-sorted. A trench was then dug around frame to a depth of 30 cm to get a soil monolith. Soil monoliths were divided into three layers (0-10, 10-20 and 20-30 cm) and macro invertebrates were then hand-sorted separately from each layer. Hand sorted soil was wet sieved to get small macrofauna. All organisms were preserved in 5% formalin. Soil invertebrates were then grouped in larger units, *i.e.,* earthworms, Coleoptera (beetles), Isoptera (termites), Hymenoptera (ants, wasps etc.), Dermaptera (earwigs), Orthoptera (hoppers, crickets, mole crickets), Hemiptera (bugs, coccides, cicadas etc.), Isopoda (woodlice), Chilopods (centipeds), Diplopods (millipeds), Decapoda (crabs) and Arachnida (spiders), other macrofauna invertebrates. Density and biomass of each of these major groups were determined.

In addition to the hand sorting method to collect termites, a one time line transect sampling was also employed for termites. Transect was 40 m long and 2.5 m wide, and divided into 10 contiguous sections (each 4 m x 2.5 m in area). Each section was sampled for one hour. Within each section, the following microhabitats were searched- surface soil up to 10 cm depth, dead logs, dead branches and twigs; mud plaster on dead logs and tree stumps. All castes of termites were collected if present, and care was taken to collect the soldier caste, as they are required for species identification. The collected termites were kept in vials containing 80 per cent ethanol and labeled with the section number.

The transect protocol provides a measure of the relative abundance of termites based on the number of encounters with each species in a transect. The protocol is being accepted and followed widely in the tropical forest ecosystems (Jones and Eggleton, 2002). The sampling protocol is particularly advantageous as the sampling effort and area are standardized. Thus a more meaningful and accurate comparison becomes possible among the landuse systems in terms of termite diversity.

3.6.2. Soil microflora

3.6.2.1. Arbuscular mycorrhizal (AM) fungi

Soil samples (depth - 20 cm) from different landuse systems were collected following a systematic grid based sampling (200 m x 200 m grid) design at two points of time, the month of April-May (pre-monsoon season) and August-September (post-monsoon season). A plot (40 x 20 m) was laid at each sample point. The plot was divided into 5 equal blocks, 12 soil cores (0-20 cm) were obtained from each block and all samples from a plot mixed together to get a composite sample for a given plot. The samples were air dried for 24 hrs in shade. Fine roots from each soil sample were collected and stored in separate polythene covers. The soil samples were then sieved through 2 mm sieve and 1 kg of each soil sample stored at 4°C till they were analysed for spore abundance or degree of root infection.

Isolation of AM spores was done following wet sieving and decanting technique (Gerdemann and Nicolson, 1963). To start with, 10 g of the soil samples was suspended in water and stirred thoroughly. The soil suspension was allowed to stand undisturbed for 1 min and then passed through 750, 500, 250, 100 and 45 um sieves arranged one below the other in the same order. The contents from the last three sieves were filtered through filter papers and the filtrate observed under a stereoscope and spores of fungi enumerated from each soil sample.

Feeder roots (1 cm long) collected from the soil samples were stained using the method of Phillips and Hayman (1970) and colonization by AM fungi assessed. A total 100 root pieces were examined from each soil sample. Root bits showing vesicles / arbuscules were considered as being colonized by AM fungi. The per cent mycorrhizal colonization was computed using the following formula

$$\% \text{ AM colonization} = \frac{\text{Total number of root bits positive for AM colonization} \times 100}{\text{Total number of bits observed for AM colonization}}$$

Trap plant method was used to estimate diversity of AM fungi in different landuse systems. In this method, 400 g of test soil was mixed with 400 g of sterilized sand: soil mixture (1:1 ratio) taken in pots and seeds of sorghum, maize/ cowpea sown. The plants were maintained in the glasshouse by periodic watering up to a period of 3 months after which the soil in each pot was wet sieved and the spores observed under a compound microscope. Identification of the spores was done using the Manual for the identification of VAM fungi by Schenck and Perez (1990) and INVAM website by Joe Morton.

Infective propagules in the soil consist of (1) spores (2) dead roots with AM colonization and (3) net work of AM fungi. Estimation of the number of infective propagules would indicate the capability for mycorrhization of each type of soil (Porter, 1979).The procedure employed for estimating the number of infective propagules was as follows. Thirty g of the test soil taken in a polythene bag was added with 270 g of sterilized sand soil mixture (1:1). This mixture was shaken thoroughly to get 10^{-1} dilution. From this dilution, 30 g of soil was transferred to another polythene bag and added with 270 g of sterilized sand soil mixture (1:1) to get 10^{-2} dilution. This procedure was repeated to get dilutions of 10^{-3}, 10^{-4}, 10^{-5} and 10^{-6}. Each dilution was replicated five times. Seeds of sorghum were sown in the poly bags and the plants maintained for six weeks in the glass house. Presence or absence of colonization was determined by staining (Phillips and Hayman, 1970). MPN number was determined referring to MPN table (Fischer and Yates, 1963).

Duncan's Multiple Range Test was used to analyse differences in number of AM spore and per cent colonization of roots by AM fungi in different landuse systems. Correlation analyses were carried to make out any relationships between population of AM spores and various soil parameters. Shannon - Weiner indices (Shannon and Weiner, 1963) of AM fungal species diversity was determined for each landuse system using the formula **H' = -Σpi Inpi** where 'pi' is the proportional abundance of the i^{th} species = (ni/N), ni= abundance of the individual species and N=total abundance.

The data reported in this paper are mostly from the soil and root samples collected during the pre-monsoon season except for enumeration of AM spores which was carried out for both pre- and post- monsoon soil samples.

3.6.2.2. Soil legume nitrogen fixing bacteria

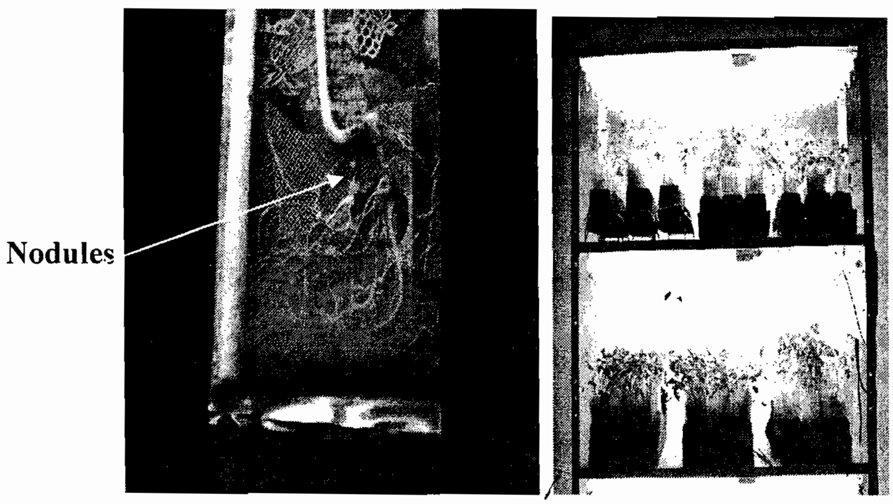
In each landuse system, soil (0-20cm depth) was sampled once during pre-monsoon period (March-April, 2004) and once during post-monsoon period (November-December, 2004) following a systematic grid (200 m x 200 m) sampling design. Soil samples were stored at 4^0C till they were used for rhizobium population estimation.

Rhizobial population was estimated based on Most Probable Number (MPN) method (Vincent, 1970) using Cowpea var. Kanakamony as a trap plant. The range of serial dilution used was 10^{-1} to 10^{-6}.

As large number of plants had to be grown on nitrogen free Jensen's agar slants (5 replicates for each dilution level), use of conventionally used test tubes of size 25 cm x 3 cm seemed impractical. So the plants were grown in polythene pouches of size 8 cm x 20 cm. The polythene bags along with seedlings were inserted in brown paper bags of size 10 x 10 cm and kept under artificial fluorescent lighting 1600 lux for 16 hours per day (Figure 6).

Jensen's nutrient solution was added at regular intervals. After 2-3 weeks time, presence/absence of nodulation in each pouch was recorded, number of nodules in each pouch was counted and the most probable number of rhizobium in one gram of soil was estimated (Brockwell, 1963).

Nodule bearing plants were gently removed from the plastic pouches, washed with water and morphological characters of the nodules examined. Morphologically healthy and apparently nitrogen fixing nodules on each plant root was counted. These nodules were either immediately used for bacterial isolation or stored at 40C in plastic vials containing silica gel.



a b

Figure 6. Plant infection test using polythene tubes. a. Root nodules formed in polythene tubes. b. Polythene bags kept on racks under fluorescent light.

Nodules of leguminous as well as non-leguminous plants were also collected from the field, covering different landuse types for observing morphological features and isolation of rhizobia.

The nodules were surface-sterilized by treating them with 95% ethyl alcohol for 5-10 sec followed by 0.01% acidified $HgCl_2$ treatment for 3 min. After washing 5-6 times in sterilized distilled water, the healthy nodules were crushed in a sterile glass tube with 0.5 ml of sterilized water using a sterile glass rod. A loopful of culture was taken and streaked on Yeast extract mannitol agar plates incorporated with congo red. The plates were kept for incubation for 2-3 days at 28 ± 1^0C. Typical unstained rhizobial colonies were further sub cultured, purified and stored on Yeast Extract Mannitol agar slants at 4^0C.

Morphological characters of rhizobial colonies that were observed included number of days required for colony formation, shape, elevation, colour and margin of colony, and slime production. Biochemical characters such as acid and alkali production was tested by Bromothymol blue test. Change of media colour from green to yellow indicated acid producers and green to blue indicated alkali producers.

The isolates were identified upto generic level based on conventional methods of morphological and physiological characterization. The relative abundance of the genera of leguminous nitrogen fixing bacteria (LNB) among the total number of 173 cultures isolated from different landuse systems were estimated.

Data obtained from Most Probable Number method using plant infection test were subjected to statistical analysis using Microsoft excel packages to interpret the results. Average population, percentage count of rhizobia and SD values were also calculated.

Detailed studies on carbon utilization, sodium chloride tolerance and genetic diversity of the isolates were conducted on eighty isolates randomly selected from 173 isolates. The ability to utilize various sugar sources were studied using Hicarbohydrate kit (HiMedia, Bombay), a standardized calorimetric system utilizing 35 carbohydrates. The carbohydrates tested were lactose, xylose, maltose, fructose, dextrose, galactose, raffinose, trehalose, melibiose, sucrose, L-arabinose, mannose, inulin, sodium gluconate, glycerol, Salicin, Glucosamine, Dulcitol, Inositol, Sorbitol, Mannitol, Adonitol, α-Methyl-D-Glucoside, Ribose, Rhamnose, Cellobiose, Melezitose, α-Methyl-D-Mannoside, Xylitol, ONPG, Esculin, D-Arabinose, Citrate, Malonate, Sorbose. Sodium chloride tolerance was studied by incorporating NaCl, 2 to 12 per cent in yeast extract mannitol agar medium. Growth in the medium, if any after one week incubation was recorded as tolerance to that concentration of NaCl.

Genetic diversity studies were carried out at Department of Microbiology, G.B. Pant University of Agriculture and Technology, Pantnagar by doing PCR amplification of inter box elements using box primers. Twenty LNB isolates, randomly selected from trap plants were used for molecular characterization and species identification.

The genomic DNA was isolated from 15 isolates. Universal primers were used for the amplification of 1492 bp region of the 16s rDNA gene in a thermal cycler (PTC 100, M.J Research, USA). Amplified fragments from the 15 isolates were subjected to restriction digestion using *Rsa* I, *Alu* I and *Taq* I and the products electrophoresced. The DNA bands generated were used to construct a UPGMA dendrogram using NTSYS pc version 2.0 software calculating Euclidean distance coefficient.

The 1.5 kb size IGS regions of 13 isolates were amplified using forward and backward primers. The amplified fragments were electrophoresced using 0.8 % agarose gel.

Species identification of the isolates was attempted for 5 isolates through partial sequencing of 16S rDNA gene using single capillary based ABI 310 genetic analyzer. The nucleotide sequences obtained were compared with the sequence databases of the identified cultures available in the web site of National Centre for Biotechnology Information (NCBI), USA for species identification.

3.7. Landuse and land cover mapping

Multispectral images taken in the year 1973 and 1990 from NASA LANDSAT-1 MSS GLCF Data (Resolution 50m) and in 2000 from IRS-3 image (resolution 23m) and Survey of India (SOI) topographical map (58 A/7 -1:50,000 scale) were used for the time series analysis. The raw satellite data was geometrically corrected giving enough ground control points with the help of toposheet. Geometrically corrected data was subjected to enhancement. False composite colour (FCCs) images have been interpreted to prepare the landuse map for different period and change detection analysis. The spectral images verified from ground truth through field checks considering prominent spectral signatures.

3.8. Socio-economic surveys

One hundred families were randomly selected for administering a questionnaire for gaining an understanding of the socio-economic profile of people and their perceptions on BGBD. Information related to landuse, labour, technical assistance, household composition, land quality, crops, soil and water management were sought through this questionnaire.

3.8.1. Wealth ranking

For wealth ranking, 100 families selected. The name of each household head was written on a separate card later, 5 informants were chosen and they were then approached individually. After a discussion with each informant of the local definition of the wealth, the informant was asked to sort the cards into piles representing the wealth of each household. Informants were advised that household they consider to be roughly equal wealth should be grouped together in one pile or wealth class. The piles were reviewed and verified at the end of this stage and notes made of the position of each household from respondents of the 5 informants, an average score was computed for each household. The scores were then grouped and ranked. All 5 informants were in agreement over on the feature of household livelihood. In general, the most wealthy were thought to own agriculture land, be involved livestock, own transport vehicles, be involved in commercial activity or be receiving remittance from overseas. Those of middling wealth were involved in farming, but mainly as sharecroppers, and might on a livestock; and the poorest households were those relaying mainly upon agriculture laboring as a source of income along with a small landholding.

3.8.2. Landuse and land-cover in the past

Village data for over 25 years were collected using semi-structured interviews with three teams of two elder villagers aged 62 to 75. Afterwards, four elders with clearest recall were regrouped to reach consensus on estimates. Thus the traditional period estimates by village elder interviews (senior citizen interviews) provided information on the number of households, types of landuses existed in the past, changes in both size and number of landuse types and also reason for such changes.

3.8.3. Analysis of management of croplands

Based on responses to questionnaires supplemented with interviews with key farmers and personal observations, 12 attributes were identified to be the most important one from the point of soil fertility and belowground biodiversity management concerns for sustainable farm management: 1) source of farm labour, 2) land ownership, 3) purpose of cropping, 4) irrigation, 5) fertilizer input, 6) pesticide input, 7) mulching, 8) weeding, 9) soil quality improvement, 10) experience in traditional methods of crop management, 11) willingness to information updating, and 12) harvesting procedures. Farmers' meetings were conducted to rank the above mentioned twelve attributes. After thorough discussions and subsequent consensus. attributed were ranked with over a scale of 1-12 i.e.. an attribute with value of 1 means least important and of 12 means most important, as given in Table 2.

Subsequently, farmers were asked to identify sub-categories for a given attribute and rate them over a scale as in case of the major attribute, e.g., farmers identified three scenarios as far as laborer input to farm was concerned – (a) all work done by the family members (b) farm work done partly by the family members and partly by the hired labourers (c) all farm work done by the hired labourers, scenario 'a' being the most appropriate and 'c' being least appropriate for sustainable soil fertility and belowground biodiversity management (Table 2). The sum of scores then divided by the total number of attributes. i.e., 12 to obtain management value index (MVI). The expected minimum and maximum management value index are 3 and 18 respectively. Thus, higher the value, the better will be management of crop lands.

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Table 2. Attributes for sustainable management of soil fertility and belowground biodiversity identified and ranked by the participants of PRA exercises in the study area in the Kerala part of the Nilgiri Biosphere Reserve

Attributes	Score	Sub attributes	Score
Source of farm labour	12		
		Family members	12 x 3
		Partly family members and partly hired labour	12 x 2
		Hired labour	12 x 1
Land ownership	11		
		Own land	11 x 2
		Leased land	11 x 1
Purpose of cropping	10		
		For subsistence/self-consumption	10 x 3
		For subsistence and also for income	10 x 2
		For cash income	10 x 1
Irrigation	9		
		Regular	9 x 3
		Infrequent	9 x 2
		No irrigation	9 x 1
Fertilizer input	8		
		Organic only	8 x 3
		Both organic and inorganic	8 x 2
		Inorganic fertilizer at recommended dose (KAU. 2002) for a given crop	8 x 1
		Inorganic fertilizer at more than recommended dose (with a notion that over-dose application of fertilizer leads to high productions)	8 x 0
		None	8 x 0
Mulching or incorporation of crop residues	7		
		Yes	7 x 2
		No	7 x 1
Pesticide input	6		
		Bio-pesticides only	6 x 3
		Both bio- and chemical pesticides	6 x 2
		Chemical pesticides at recommended dose (KAU. 2002) for the given crop	6 x 1
		Chemical pesticides at more than the recommended dose	6 x 0
		None	6 x 0
Weeding	5		
		Manual	5 x 3
		Mechanical	5 x 2
		None	5 x 1
		Weedicide application	5 x 0
Soil quality improvement	4		
		Wherever required (wherever farmers felt that the soil quality and crop productivity in their farm is below normal)	
		By physical means	4 x 2
		By chemical means	4 x 1
		Not undertaken	4 x 0
		Wherever not required (wherever farmers felt that soil quality and productivity in the farm is above normal and satisfactory)	4 x 1
Experience in traditional methods of crop management	3		
		Yes	3 x 1
		No	3 x 0
Willingness to information updating	2		
		Yes	2 x 1
		No	2 x 0
Harvesting procedure	1		
		Sustainable	1 x 1
		Unsustainable	1 x 0

4. RESULTS AND DISCUSSION

4.1. Characterization of vegetation and belowground biodiversity

4.1.1. Phytosociology of benchmark area

4.1.1.1. Tree community in natural forests and forest plantation

In the semi-evergreen forest, mean tree density is1300 individuals ha^{-1} (Table 3) with the value ranged from 1142 to 1500 individuals ha^{-1}. Here the mean tree basal area is 45.2 m^2 ha^{-1} with the value ranged from 38.1 to 57.6 m^2 ha^{-1}. Significant variation between plots established in this forest for a given parameter could be attributed to the fact that while some plots are representing the mature phase of the forest growth cycle, others are representing gap and building phases with more number of young trees recruited after the natural gap formation. The girth class distribution indicated the negative logarithmic trend with clear preponderance of trees of smaller girth classes. In this forest, 67 tree species are recorded with *Knema attenuata*. *Hopea racophloea* and *Myristica malabarica* as the dominant species (Appendix I). The RISQ value obtained for this forest is 1.16, which indicates that the forest is relatively undisturbed. The canopy of the forest is thick and closed as indicated by the Leaf Area Index (LAI) value (LAI = 4.56 ± 0.18).

In the moist deciduous forest, 33 tree species are encountered, *Xylia xylocarpa*, *Terminalia paniculata* and *Grewia tiliifolia* being the most dominant ones (Appendix II). Here the total tree density is only one third and basal area is only half of that recorded in the semi-evergreen forests (Table 3). Density of trees of smaller girth classes is lower than that of larger girth classes, while the RISQ value obtained is 3.83. These two observations clearly indicate that the forest is highly disturbed. As evident from LAI (3.49 ± 0.22) and crown to land ratio (112.1 ± 6.5), the canopy is also sparse as compared to that in the semi-evergreen forest.

The degraded forest patches, located generally close to the agricultural lands, consist of only four tree species. *Terminalia paniculata* is the most dominant species contributing about 97% to the total IVI of tree community (Appendix III). Both tree density and basal area are significantly lower than in the semi-evergreen forests (Table 3). On the other hand, the tree density in the degraded forest and in moist deciduous forest plots are comparable but basal area of degraded forest is substantially lower than that of moist deciduous forests. Trees are sparsely distributed as indicated by the low values for LAI (1.20 ± 0.16) and crown to land ratio (27.6 ± 6.3).

Table 3. Basic statistics of tree community in different types of natural forests and teak plantation in the Kerala part of Nilgiri Biosphere Reserve.

Parameter	Sites			
	Semi-evergreen forests	Moist deciduous forest	Degraded forest	Teak plantation
Number of species	67	33	4	11
Tree density (individuals ha^{-1}; Mean ± SE)	1300 ± 75	492 ± 80	327 ± 26	242 ± 34
Basal area (m^2 ha^{-1}; Mean ± SE)	45.2 ± 4.3	23.4 ± 1.5	3 ± 1.4	13.7 ± 1.2
Girth class distribution (individuals ha^{-1}; Mean ± SE)				
Class A : (10.1-30 cm)	540 ± 31	126 ± 20	221 ± 19	16 ± 2
Class B: (30.1-60 cm)	445 ± 26	125 ± 16	70 ± 5	12 ± 2
Class C: (> 60 cm)	315 ± 18	241 ± 39	35 ± 3	210 ± 30
Species diversity index (H) (Mean ± SE)	2.89 ± 0.14	2.05 ± 0.23	0.43 ± 0.08	0.53 ± 0.06
Species dominance index (C) (Mean ± SE)	0.11 ± 0.01	0.21 ± 0.06	0.88 ± 0.05	0.80 ± 0.02
Leaf Area Index (LAI) (Mean ± SE)	4.56 ± 0.18	3.49 ± 0.22	1.20 ± 0.16	1.50 ± 0.27

In the 25-yr- old teak plantation, 11 tree species were recorded and teak had IVI of 250 (Appendix IV). The tree density varied from 175 to 308 individuals ha^{-1} while the basal area ranged from 10.6 to 15.8 m^2 ha^{-1}. A wide range of density or basal area values in the plantation could be attributed to huge environmental heterogeneity with the plantation area variability. The expected gbh of 25-yr old teak tree is about 104 cm. On the other hand the average girth of teak trees in the study area is only 86 cm indicating the poor growth and productivity. The PRA exercises indicated that in teak plantations poor growth and productivity is mainly due to absence of any management practice to conserve the nutrient within the systems. Teak leaf being slow decomposer, washed away from the system during rainy season before incorporating into the soil. Thus, the participants of the PRA exercises felt that trenching between rows of teak trees would be useful to conserve tree litter and associated nutrients and also soil moisture. As expected in old teak plantations, the canopy is rather open with low values for the crown to land ratio (38%), and also the LAI (1.50 ± 0.27).

4.1.1.2. Tree community in tree-based cropping systems

Out of 44 sample points in the croplands, 40 points represent tree-based farms while the remaining 4 points represent annual crop based systems. Thus the tree community analysis is based on 40 tree-based farms. In polyculture homegardens, the tree density varied from 483 to 1400 individuals ha^{-1} (mean density: 885 individuals ha^{-1}) and tree basal area from 0.8 to 18.7 m^2 ha^{-1} (mean basal area: 12.1 m^2 ha^{-1}) (Table 4). This wide variation could be mainly attributed to huge variation in crop combinations in homegardens. Tree species rich homegardens, have higher density and basal area compared to the tree species poor ones. Farmers interested in growing annual crops in their homegardens maintain less number of trees. While the contribution to total IVI by trees maintained for prune their leafy twigs for manuring (green leaf manure species) in species rich homegarden is about 15% to 18%, those in single or few crop species dominant homegardens is only about 5 (Appendix V). In this system, generally farmers maintain partially closed canopy in order to cultivated light demanding understorey crops along with tree crops (LAI= 3.19 ± 0.23).

In polyculture farms which resemble homegardens except for being located at a distance from the dwellings, farmers maintain partially closed canopy in order to cultivate light demanding understorey crops along with tree crops (LAI = 2.50 ± 0.25). In this system, tree density varied from 691 to 1216 individuals ha^{-1} (mean density: 954 individuals ha^{-1}) and tree basal area from 7.4 to 18.8 m^2 ha^{-1} (mean basal area: 13.66 m^2 ha^{-1}) (Table 4). As in case of polyculture homegardens, here also species richness is positively linked with the more density and basal area of trees. The study also revealed that the contribution to total IVI by the green leaf manure species in polyculture farmlands ranges from 2.7% to 11.7%. These values are generally less than in polyculture homegardens (Appendix VI).

Table 4. Density, basal area, species diversity and species dominance of tree community in different cropping systems in the Kerala part of Nilgiri Biosphere Reserve. Values are Mean ± SE.

Cropping systems	Density (individuals ha^{-1})	Basal area (m^2 ha^{-1})	Species diversity index (H)	Species dominance index (C)	Leaf Area Index (LAI)
Homegardens	885 ± 316	12.1 ± 5.7	1.95 ± 0.29	0.33 ± 0.05	3.19± 0.23
Polyculture farms	954 ± 224	13.7 ± 4.3	1.03 ± 0.16	0.18 ± 0.04	2.50± 0.25
Arecanut with annuals	1058 ± 293	14.4 ± 4.6	0.86 ± 0.39	0.18 ± 0.07	1.59± 0.04
Arecanut with perennials	928 ± 367	19.6 ± 12.2	0.94 ± 0.10	0.15 ± 0.06	3.26± 0.11
Coconut with perennials	316 ± 148	12.7 ± 2.9	1.07 ± 0.16	0.18 ± 0.03	1.99± 0.25
Arecanut plantation	956 ± 294	12.1 ± 4.7	0.46 ± 0.25	0.08 ± 0.03	1.25± 0.13
Coconut plantation	200 ± 50	18.8 ± 10.9	0.71 ± 0.71	0.23 ± 0.15	2.11± 0.32
Rubber plantation	433 ± 62	10.5 ± 3.0	0.16 ± 0.17	0.09 ± 0.04	4.35± 0.06
Cashew plantation	189 ± 18	7.2 ± 2.3	1.00 ± 0.52	0.26 ± 0.10	1.25± 0.44
Teak plantation	1378 ± 584	10.5 ± 5.2	0.72 ± 0.56	0.21 ± 0.14	3.80± 0.19

In arecanut plantations where understorey annual crops are also grown, tree density varied from 783 to 1366 individuals ha^{-1} (mean density; 1058 individuals ha^{-1}) and tree basal area from 9.1 to 17.3 m^2 ha^{-1} (mean basal area: 14.4 m^2 ha^{-1}). The contribution to total IVI by the trees maintained for green leaf manure species in this system ranges from 0% to 6% (Appendix VII).

In arecanut plantation mixed with other tree species tree density varies from 467 to 1256 individuals ha^{-1} (mean density; 928 individuals ha^{-1}) and tree basal area from 10.1 to 40.0 m^2 ha^{-1} (mean basal area: 19.6 m^2 ha^{-1}) (Table 4). In majority of the plots, no trees are being maintained as the source of green leaf manure (Appendix V to VII). Leaf area index value for the farms with arecanut mixed with tree crops (3.26 ± 0.11) is significantly more than that in farms with arecanut and annual crops (1.59 ± 0.04).

In farms dominated by coconut mixed with some tree species such as mango, tree density varied from 183 to 475 individuals ha^{-1} (mean density; 316 individuals ha^{-1}) and tree basal area from 9.6 to 15.4 m^2 ha^{-1} (Table 4). In some farms, green foliage of trees like mango and jackfruits are pruned to use as mulch, otherwise generally, no other trees are being maintained as the source of green leaf manure.

In a given type of monoculture plantations also a wide range in density, basal area and crown to land ratio was observed. For instance, in areca plantation; tree density ranged from 525 to 1517 individuals ha^{-1} when the tree basal area ranged from 6 to 21.3 m^2 ha^{-1}. Similarly, in coconut plantation the tree density ranged from 150 to 300 individuals ha^{-1} when the tree basal area ranged from 5.5 to 40.4 m^2 ha^{-1}. In the rubber plantation, tree density ranged from 300 to 600 individuals ha^{-1} when the tree basal area ranged from 2.1 to 15.2 m^2 ha^{-1}. The tree density in cashew plantations ranged from 167 to 225 individuals ha^{-1} when the basal area was 2.6 to 10 m^2 ha^{-1}. Even in teak plantation the tree density varied from 678 to 2538 individuals ha^{-1} with the basal area ranging from 0.04 to 16 m^2 ha^{-1}. The wide range in the values in a given type of plantation could be attributed to the factors such as age of the plantation, farmers' own decision on maintaining the plant to plant distance, mortality of trees and thus reduction in number of trees due to diseases like wilt disease in case of coconut, yellow leaf disease in arecanut and pink disease in rubber. Crown to land ratio also varied from plantation to plantation of a given crop in relation to the age of the plantation with more value for older plantations (Table 4). In general, no trees are being maintained as the source of green leaf manure .

4.1.1.3. <u>Shrub and herb communities</u>

The shrub community in the semi-evergreen forest is dominated by P*avetta indica* and *Memecylon wallichii* while that in the moist deciduous forest, degraded forest and teak plantation is dominated by *Clerodendrum viscosum* and *Helicteres isora* (Appendix VIII). However, herb community in all the plots was dominated by *Curcuma neilgherrensis* and *Amorphophalus dubius* (Appendix IX). When the number of herb species encountered in semi-evergreen forest was 18, in other plots it ranged from 8 to 10. Density and basal area of shrubs were more in moist deciduous forest followed by semi evergreen forest, degraded forest and teak plantation (Table 5). On the other hand, herb density and biomass were more in the moist deciduous forest followed by degraded forest, teak plantation and semi evergreen forest.

Phytosociological analysis of shrub and herb community in different crop systems in the study area does not give clear picture of density and basal cover due to the fact that in majority of the farms weeding is being done either regularly or irregularly throughout the year. Even then, certain trends in the density and basal area/biomass of the understorey plants can be observed (Table 5). For instance, in poorly managed farms, density and biomass/basal area of understorey non-crop species are higher compared to that in well managed farms. Croplands also differ in terms of relative abundance of exotic (e.g., *Chromolaena odorata* and *Lantana camera)* and native species *(Hyptis capitata, Cassia tora, Ficus asperima, Urena lobata, Clerodendron* *paniculatum,* and *Helicters isora*) (Appendix V to XV). The harvested biomass of herbs and shrubs are being either used as mulch for the major crops or left as such.

Out of 171 vascular plant species recorded during the course of this study, 25 species are legumes (Table 6). Wherever, the contribution of leguminous shrubs is relatively more (Table 7), it is due to the growth of *Cassia occidentalis and Desmodium gangeticum.* On the other hand, wherever, the contribution of leguminous herbs is relatively more it is due the profuse growth of *Mimosa pudica, Centrosema pubescens* and *Desmodium tiflorum* in poorly managed systems.

Table 5. Density and basal area of shrub and density and biomass of herb component in the different landuse systems in the Kerala part of Nilgiri Biosphere Reserve. Mean ± SE or SD

Landuse systems	Shrubs		Herbs	
	Density (individuals ha^{-1})	Basal area (m^2 ha^{-1})	Density (individuals m^{-2})	Biomass (gm m^{-2})
Semi evergreen forest	2699±456 (2012-2956)	298±83 (77-660)	186 ± 62 (112-256)	108 ± 33 (76-129)
Moist deciduous forest	5812 ± 361 (4232-6613)	587± 102 (77-660)	486 ±15 (444 -512)	862 ± 26 (850-894)
Degraded forest	1733 ± 121 (1643-1834)	202± 56 (186-243)	424 ±8 (412-448)	746 ± 16 (702-778)
Teak plantation (Government)	1211 ± 56 (1133-1432)	167± 54 (132-198)	281 ± 36 (246-278)	553 ± 76 (450-689)
Homegardens	469±115 (155-931)	298±83 (77-660)	56 ± 16 (54-101)	782± 70 (482-1007)
Polyculture farms	609±299 (0-1628)	350±180 (0-970)	78±11 (42-101)	675±86 (434-955)
Arecanut with annuals	610±250 (247-1089)	857±387 (135-1458)	411± 345 (64-1100)	1450± 743 (537-2922)
Arecanut with perennials	3619±1029 (0-6648)	1044±309 (0-2004)	149± 65 (34-464)	2222± 623 (784-5095)
Coconut with perennials	698± 389 (0-1344)	650± 329 (0-1060)	216± 47 (122-265)	1515± 330 (1119-2170)
Arecanut plantation	4223±664 (2973-5236))	4484±476 (3534-5010)	127 ± 15 (106-156)	2414± 377 (1843-3127)
Coconut plantation	2919±1918 (0-6535)	2345±1635 (0-5492)	87 ± 33 (24 -136)	1433± 499 (666-2369)
Rubber plantation	684±397 (0-1467)	1161±749 (0-3141)	122 ± 41 (92-240)	1082± 283 (668-1917)
Cashew plantation	976±299 (599-1567)	2336±419 (1729-3140)	1182 ± 536 (1443 - 1952)	1373± 242 (934-1768)
Teak plantation (private)	4717±1156 (2480-6339)	4313±286 (4045-4885)	322±200 (121-722)	3751± 634 (2867-4981)

In well managed systems generally *Vigna unguiculata* is being cultivated and thus it contributes much to the IVI of herb community. It may be mentioned here that in cashew plantation raised in plots with poor soil and exposed laterite blocks, *Desmodium triflorum* forms almost a thick carpet covering the soil. Thus it is worth to study further its role in soil and water conservation and soil fertility improvement in such lands.

Table 6. Leguminous species recorded in different cropping systems of the Kerala part of Nilgiri Biosphere Reserve.

Trees	Shrubs	Herbs
Adenanthera pavonina	*Abrus precatorius*	*Cassia tora*
Butea monosperma	*Acacia intsia*	*Calapagonium mucunoides*
Cassia fistula	*Caesalpinia pulchherima*	*Centrosema pubescens*
Dalbergia latifolia	*Cassia occidentalis*	*Crotalaria striata*
Gliricidia sepium	*Desmodiun gangeticum*	*Desmodium triflorum*
Erythrina indica	*Desmodium gyrans*	*Mimosa pudica*
Peltophorum vogelianum	*Indigofera purpurea*	*Vigna unguiculata*
Pongamia pinnata	*Pseudarthria viscida*	
Tamarindus indicus		
Xylia xylocarpa		

Table 7. IVI contribution (Mean ± SE) of shrub and herb leguminous species in different cropping systems of the Kerala part of Nilgiri Biosphere Reserve

Cropping systems	Contribution (in %) to total IVI by leguminous species	
	Shrub community	Herb community
Homegardens	13 ± 5.7	13 ±2
Polyculture farms	14 ± 10	14 ± 6
Arecanut with annuals	26 ± 13	19 ± 10
Arecanut with perennials	4.5 ± 3.2	14 ± 5.8
Coconut with perennials	13 ± 6.6	31 ± 7.7
Arecanut plantation	11.3 ± 5.1	22.7 ± 14.5
Coconut plantation	21 ± 10.7	25.3 ± 7.7
Rubber plantation	2 ± 2	21.3 ± 9.2
Cashew plantation	8 ± 8	32 ± 11.7
Teak plantation (private)	9.7 ± 4.9	17 ± 1.2

4.1.2. Soil properties in benchmark area

4.1.2.1. Soil moisture

The soil moisture status of various landuse systems varied between 3.5-33.6% indicating a wide variation between the land covers (Table 8). Significantly higher (32.8%-33.6%) content of soil moisture was recorded in polyculture farms and moist deciduous forests and lower in landuse systems like annual crops, arecanut with perennial crops and plantations of teak, cashew and rubber plantations (3.5-9.5%). The significantly low status of soil moisture in the soils of cashew and rubber plantations in spite of higher content of organic carbon might be due to the coarse texture of soil as revealed in the profile study. In most of the landuse systems, except in some of the polyculture, soil moisture was lower in subsurface layer compared to surface layer. Relatively higher content of organic carbon present in the surface soil might be retaining more moisture than the sub surface layer.

Table 8. Soil moisture (%) in the soils of different landuse systems in the Kerala part of Nilgiri Biosphere Reserve. Values (mean ± S.E), in a given landuse system, with same alphabets in the superscript are not significantly different (P>0.05).

Landuse systems	Sampling depth	
	0-10 cm	10-30 cm
Semi evergreen forest	21.1 ± 0.4^a	19.9 ± 0.5^b
Moist deciduous forest	32.8 ± 1.0^a	21.2 ± 3.5^b
Degraded forest	16.9 ± 1.5^a	16.1 ± 0.9^a
Teak plantation of the Forest Department	14.0 ± 0.8^a	17.2 ± 0.8^b
Annual crops	3.5 ± 0.9^a	2.6 ± 1.0^a
Homegardens	12.3 ± 0.2^a	16.5 ± 0.5^b
Polyculture farms	33.6 ± 6.8^a	35.6 ± 3.5^a
Arecanut with annuals	26.5 ± 1.3^a	27.5 ± 1.2^a
Arecanut with perennials	9.5 ± 4.3^a	7.6 ± 1.2^a
Coconut with perennials	30.9 ± 6.0^a	25.9 ± 0.4^a
Arecanut plantation	13.0 ± 4.4^a	10.1 ± 1.2^a
Coconut plantation	23.6 ± 0.2^a	21.5 ± 0.5^b
Rubber plantation	7.8 ± 1.2^a	4.1 ± 0.5^b
Cashew plantation	5.0 ± 0.6^a	3.6 ± 0.3^a
Teak plantation (private)	8.5 ± 2.7^a	6.2 ± 0.3^b

4.1.2.2. pH

Among the various landuse systems home garden, private teak plantations, areca with perennial crops, forest teak plantation, areca with annual crops and polyculture farm recorded significantly higher ($P<0.05$) values (6.0-6.2) than soils of moist deciduous forests, degraded forests and rubber plantations recorded the least (5.5-5.6). The effect of soil depth on soil pH was statistically not significant ($P > 0.05$). In general the pH (KCl) was relatively lower than pH (H_2O) in all the landuse systems (Table 9).

Table 9. Soil pH in the soils of different landuse systems in the Kerala part of Nilgiri Biosphere Reserve. For a given type of pH, values (mean ± S.E) in a given landuse system, with same alphabets in the superscript are not significantly different (P>0.05).

Landuse systems	pH (H_20)		pH (KCl)	
	Sampling depth		Sampling depth	
	0-10 cm	10-30 cm	0-10 cm	10-30 cm
Semi evergreen forest	5.5 ± 0.05^a	5.9 ± 0.10^a	5.1 ± 0.09^a	4.9 ± 0.09^a
Moist deciduous forest	5.5 ± 0.09^a	5.3 ± 0.08^a	5.5 ± 0.08^a	5.2 ± 0.09^b
Degraded forest	5.5 ± 0.08^a	5.7 ± 0.04^b	4.4 ± 0.08^a	4.3 ± 0.02^a
Teak plantation of the Forest Department	6.1 ± 0.11^a	6.1 ± 0.06^a	5.2 ± 0.10^a	5.2 ± 0.06^a
Annual crops	5.6 ± 0.14^a	5.9 ± 0.09^b	4.7 ± 0.14^a	5.0 ± 0.18^b
Homegardens	6.2 ± 0.07^a	6.3 ± 0.09^a	5.6 ± 0.12^a	5.6 ± 0.09^a
Polyculture farms	6.1 ± 0.13^a	6.1 ± 0.12^a	5.1 ± 0.09^a	5.1 ± 0.07^a
Arecanut with annuals	6.0 ± 0.16^a	5.8 ± 0.17^a	4.9 ± 0.15^a	4.8 ± 0.13^a
Arecanut with perennials	6.1 ± 0.13^a	6.3 ± 0.02^a	5.3 ± 0.02^a	5.2 ± 0.03^a
Coconut with perennials	5.7 ± 0.12^a	5.8 ± 0.13^a	4.7 ± 0.09^a	4.7 ± 0.12^a
Arecanut plantation	5.6 ± 0.13^a	5.7 ± 0.12^a	4.6 ± 0.13^a	4.7 ± 0.13^a
Coconut plantation	5.8 ± 0.08^a	5.8 ± 0.11^a	4.9 ± 0.10^a	4.7 ± 0.12^a
Rubber plantation	5.6 ± 0.15^a	5.6 ± 0.09^a	4.7 ± 0.08^a	4.6 ± 0.04^a
Cashew plantation	5.8 ± 0.11^a	5.8 ± 0.06^a	4.5 ± 0.08^a	4.4 ± 0.08^a
Teak plantation (private)	6.1 ± 0.15^a	6.0 ± 0.14^a	4.9 ± 0.17^a	4.7 ± 0.14^a

4.1.2.3. Organic carbon

Among the fifteen landuse systems studied, the moist deciduous forest and cashew plantation recorded significantly higher ($P < 0.05$) soil organic carbon (2.5%) followed by teak plantation (2.2%), semi evergreen forests (1.8%), degraded forests (1.8%) and coconut plantations (1.8%) (Table 10). On the other hand, the organic carbon content in the annual crop fields (0.79%), home garden and coconut with perennial crop farms (0.97%) was comparatively low. In majority of the landuse systems, no significant decline ($P > 0.05$) in the soil organic carbon with increase in soil depth was recorded. The data in general indicate the need of organic matter enrichment in landuse systems like annual crop based system, homegardens, polyculture farms, arecanut with annual crops, arecanut with perennial crops and areca plantation to maintain a higher level of soil organic carbon as in other landuse systems.

Table 10.. Soil organic carbon (%) in the soils of different landuse systems in the Kerala part of NBR. Values (mean ± S.E), in a given landuse system, with same alphabets in the superscript are not significantly different (P>0.05).

Landuse systems	Sampling depth	
	0-10 cm	10-30 cm
Semi evergreen forest	1.8 ± 0.09^{a}	1.4 ± 0.11^{b}
Moist deciduous forest	2.5 ± 0.21^{a}	2.1 ± 0.15^{b}
Degraded forest	1.8 ± 0.2^{a}	1.6 ± 0.13^{a}
Teak plantation of the Forest Department	1.6 ± 0.19^{a}	1.6 ± 0.24^{a}
Annual crops	0.8 ± 0.14^{a}	0.6 ± 0.11^{a}
Homegardens	1.0 ± 0.07^{a}	0.8 ± 0.03^{b}
Polyculture farms	1.0 ± 0.10^{a}	1.0 ± 0.07^{a}
Arecanut with annuals	1.0 ± 0.14^{a}	0.9 ± 0.13^{a}
Arecanut with perennials	1.4 ± 0.12^{a}	1.3 ± 0.11^{a}
Coconut with perennials	1.0 ± 0.17^{a}	0.9 ± 0.15^{a}
Arecanut plantation	1.1 ± 0.07^{a}	0.8 ± 0.09^{b}
Coconut plantation	1.8 ± 0.08^{a}	1.6 ± 0.10^{a}
Rubber plantation	1.5 ± 0.20^{a}	1.4 ± 0.08^{a}
Cashew plantation	2.5 ± 0.19^{a}	2.3 ± 0.17^{a}
Teak plantation (private)	2.2 ± 0.23^{a}	2.0 ± 0.20^{a}

4.1.2.4. Exchange acidity

Exchange acidity is a quantitative measure of the exchangeable Al+ and H+ in the soil. Among the different landuse systems, significantly higher content was recorded in annual crop based systems and degraded forests (4.3-5.1 cmol (+)/kg) and was lower in homegarden and arecanut with perennial crop systems (1.4 cmol (+)/kg) (Table 11). Even though the depth wise variation was significant ($P > 0.05$) its trend was not definite in most of the systems. In evergreen forests, moist deciduous forests and several monoculture plantations it was increasing with depth while in others it was decreasing towards lower layers. In order to reduce the level of exchange acidity of degraded forests, it is better to do afforestation measures with some moist deciduous species along with the application of organic manures. The leaf litter of moist deciduous species which are rich in bases on decomposition release the bases and thus help to reduce the soil acidity.

Table 5. Exchangeable acidity (c mol (+) kg^{-1}) in the soils of different landuse systems in the Kerala part of Nilgiri Biosphere Reserve. Values (mean ± S.E), in a given landuse system, with same alphabets in the superscript are not significantly different ($P>0.05$).

Landuse systems	Sampling depth	
	0-10 cm	10-30 cm
Semi evergreen forest	2.8 ± 0.21^{a}	4.8 ± 0.46^{b}
Moist deciduous forest	2.6 ± 0.15^{a}	3.8 ± 0.12^{b}
Degraded forest	4.3 ± 0.21^{a}	3.8 ± 0.13^{b}
Teak plantation of the Forest Department	2.1 ± 0.06^{a}	2.2 ± 0.08^{a}
Annual crops	5.1 ± 0.25^{a}	4.0 ± 0.26^{b}
Homegardens	1.4 ± 0.08^{a}	2.6 ± 0.22^{b}
Polyculture farms	2.0 ± 0.13^{a}	1.6 ± 0.13^{b}
Arecanut with annuals	2.6 ± 0.12^{a}	3.0 ± 0.25^{a}
Arecanut with perennials	1.4 ± 0.14^{a}	3.8 ± 0.22^{b}
Coconut with perennials	2.5 ± 0.05^{a}	1.8 ± 0.06^{b}
Arecanut plantation	4.2 ± 0.37^{a}	4.8 ± 0.46^{b}
Coconut plantation	2.7 ± 0.21^{a}	2.7 ± 0.24^{a}
Rubber plantation	3.8 ± 0.16^{a}	4.6 ± 0.17^{b}
Cashew plantation	3.8 ± 0.16^{a}	4.7 ± 0.39^{a}
Teak plantation (private)	3.4 ± 0.27^{a}	5.1 ± 0.45^{b}

4.1.2.5. Total nitrogen

The total N content of the soils of various landuse systems was relatively low varying from 0.05-0.13% (Table 12). Along with semi evergreen forests (0.12%) and degraded forests (0.13%), homegardens, coconut plantation and rubber plantation (0.11%) also recorded significantly higher content than the other landuses and in most of the cases there was a tendency to decrease from surface to sub surface layer .it was not statistically significant. The low values of N observed in the study are supposed to be due to the intake of more N by the plants during the growing season.

Table 12. Total nitrogen (%) in the soils of different landuse systems in the Kerala part of Nilgiri Biosphere Reserve. Values (mean ± S.E), in a given landuse system, with same alphabets in the superscript are not significantly different (P>0.05).

Landuse systems	Sampling depth	
	0-10 cm	10-30 cm
Semi evergreen forest	0.12 ± 0.02 [a]	0.10 ± 0.02 [b]
Moist deciduous forest	0.10 ± 0.01 [a]	0.08 ± 0.01 [b]
Degraded forest	0.13 ± 0.02 [a]	0.12 ± 0.02 [b]
Teak plantation of the Forest Department	0.09 ± 0.01 [a]	0.08 ± 0.01 [b]
Annual crops	0.80 ± 0.02 [a]	0.09 ± 0.03 [b]
Homegardens	0.12 ± 0.02 [a]	0.11 ± 0.02 [b]
Polyculture farms	0.10 ± 0.01 [a]	0.10 ± 0.02 [a]
Arecanut with annuals	0.08 ± 0.02 [a]	0.08 ± 0.02 [a]
Arecanut with perennials	0.05 ± 0.02 [a]	0.07 ± 0.02 [b]
Coconut with perennials	0.08 ± 0.02 [a]	0.06 ± 0.01 [b]
Arecanut plantation	0.09 ± 0.0 1 [a]	0.08 ± 0.02 [b]
Coconut plantation	0.11 ± 0.02 [a]	0.08 ± 0.02 [b]
Rubber plantation	0.11 ± 0.03 [a]	0.10 ± 0.02 [a]
Cashew plantation	0.09 ± 0.02 [a]	0.09 ± 0.02 [a]
Teak plantation (private)	0.09 ± 0.02 [a]	0.06 ± 0.01 [b]

4.1.2.6. Extractable phosphorus

The content of Bray-II extractable Phosphorus was significantly higher (13.6-14.0 ppm) in mixed garden and arecanut with annual crops and lower in forest teak plantations, degraded forests, coconut with perennial crops and rubber plantation (2.6-4.4 ppm) (Table 13). While comparing depths, no definite trend was noticed between surface and sub surface layers. Results reveal the necessity of enriching soil P in teak plantations, coconut with perennial crops, rubber plantations and degraded forests.

Table 13. Bray-II Extractable phosphorus (ppm) in the soils of different landuse systems in the Kerala part of Nilgiri Biosphere Reserve. Values (mean ± S.E), in a given landuse system, with same alphabets in the superscript are not significantly different (P>0.05).

Landuse systems	Sampling depth	
	0-10 cm	10-30 cm
Semi evergreen forest	6.1 ± 0.58 [a]	5.9 ± 0.65 [a]
Moist deciduous forest	4.9 ± 0.18 [a]	4.9 ± 0.67 [a]
Degraded forest	3.6 ± 1.08 [a]	2.7 ± 1.09 [a]
Teak plantation of the Forest Department	2.6 ± 0.13 [a]	2.8 ± 0.19 [a]
Annual crops	6.2 ± 1.06 [a]	5.7 ± 1.02 [a]
Homegardens	9.6 ± 0.96 [a]	8.5 ± 1.79 [a]
Polyculture farms	14.0 ± 3.31 [a]	14.3 ± 2.20 [a]
Arecanut with annuals	13.6 ± 2.17 [a]	8.7 ± 1.97 [b]
Arecanut with perennials	7.4 ± 1.43 [a]	6.8 ± 1.23 [a]
Coconut with perennials	4.4 ± 0.57 [a]	5.0 ± 0.77 [a]
Arecanut plantation	6.2 ± 0.57 [a]	5.6 ± 0.69 [a]
Coconut plantation	7.1 ± 0.67 [a]	7.9 ± 1.10 [a]
Rubber plantation	3.9 ± 1.66 [a]	3.5 ± 1.24 [a]
Cashew plantation	4.2 ± 0.79 [a]	5.6 ± 0.57 [a]
Teak plantation (private)	11.9 ± 0.89 [a]	12.6 ± 2.5 [a]

4.1.2.7. Exchangeable potassium

1N NH_4OAC Exchangeable K was significantly higher (0.38-0.49 cmol (+)/kg) in moist deciduous forests and semi evergreen forests and significantly lower in (0.02-0.15 cmol (+)/kg) degraded forests, forest teak plantations, coconut with perennials, arecanut with perennials, arecanut plantations and home gardens (Table 14). Generally, there was no significant difference between tow soil depth for the value of this nutrient ($P<0.05$). The data reveals the importance of enriching the soils of forest teak plantations and poly cultures with external application of potassium through manures.

Table 14. 1N NH_4OAC Exchangeable potassium (cmol (+)/kg) in the soils of different landuse systems in the Kerala part of Nilgiri Biosphere Reserve. Values (mean ± S.E), in a given landuse system, with same alphabets in the superscript are not significantly different ($P>0.05$).

Landuse systems	Sampling depth	
	0-10 cm	10-30 cm
Semi evergreen forest	0.38 ± 0.05^{a}	0.28 ± 0.05^{b}
Moist deciduous forest	0.49 ± 0.04^{a}	0.28 ± 0.04^{b}
Degraded forest	0.02 ± 0.01^{a}	0.03 ± 0.01^{a}
Teak plantation of the Forest Department	0.04 ± 0.01^{a}	0.02 ± 0.01^{a}
Annual crops	0.30 ± 0.04^{a}	0.12 ± 0.03^{b}
Homegardens	$0.15 \pm 0,02^{a}$	0.32 ± 0.03^{b}
Polyculture farms	0.20 ± 0.02^{a}	0.18 ± 0.03^{a}
Arecanut with annuals	0.22 ± 0.04^{a}	0.21 ± 0.02^{a}
Arecanut with perennials	0.15 ± 0.03^{a}	0.13 ± 0.02^{a}
Coconut with perennials	0.12 ± 0.03^{a}	0.10 ± 0.02^{a}
Arecanut plantation	0.15 ± 0.03^{a}	0.13 ± 0.04^{a}
Coconut plantation	0.23 ± 0.02^{a}	0.23 ± 0.02^{a}
Rubber plantation	0.24 ± 0.04^{a}	0.20 ± 0.04^{a}
Cashew plantation	0.20 ± 0.02^{a}	0.19 ± 0.02^{a}
Teak plantation (private)	0.19 ± 0.04^{a}	0.17 ± 0.05^{a}

4.1.2.8. Exchangeable calcium

Exchangeable Ca content was significantly higher (7.4 -9.2 cmol(+)/kg) in degraded forests and moist deciduous forests and the lower content was noticed (2.1-2.6 cmol(+)/kg) in annuals, coconut with perennials, cashew and rubber plantations (Table 15). In some plots a significant decrease of this nutrient from surface to sub surface layer ($P>0.05$) was observed. Significantly higher content of Ca in degraded forests and moist deciduous forests might be due to the release from base rich litter of tree species.

Table 15. Exchangeable calcium (cmol (+)/kg) in the soils of different landuse systems in the Kerala part of Nilgiri Biosphere Reserve. Values (mean ± S.E), in a given landuse system, with same alphabets in the superscript are not significantly different ($P>0.05$).

Landuse systems	Sampling depth	
	0-10 cm	10-30 cm
Semi evergreen forest	4.9 ± 0.53^{a}	3.4 ± 0.49^{b}
Moist deciduous forest	9.2 ± 0.48^{a}	7.1 ± 0.67^{b}
Degraded forest	7.4 ± 0.88^{a}	5.6 ± 0.54^{b}
Teak plantation of the Forest Department	6.5 ± 1.03^{a}	6.2 ± 0.31^{a}
Annual crops	2.3 ± 0.63^{a}	2.0 ± 0.30^{a}
Homegardens	4.7 ± 0.58^{a}	5.1 ± 0.48^{a}
Polyculture farms	4.3 ± 0.38^{a}	3.8 ± 0.18^{b}
Arecanut with annuals	3.6 ± 0.32^{a}	2.1 ± 0.63^{b}
Arecanut with perennials	4.8 ± 0.79^{a}	4.3 ± 0.84^{a}
Coconut with perennials	2.1 ± 0.40^{a}	2.6 ± 0.40^{a}
Arecanut plantation	2.6 ± 0.31^{a}	2.2 ± 0.30^{a}
Coconut plantation	3.6 ± 0.35^{a}	3.6 ± 0.27^{a}
Rubber plantation	2.6 ± 0.18^{a}	3.2 ± 0.37^{b}
Cashew plantation	2.3 ± 0.26^{a}	2.7 ± 0.31^{a}
Teak plantation (private)	4.5 ± 1.08^{a}	4.2 ± 1.15^{a}

4.1.2.9. Exchangeable magnesium

As in the case of Ca, moist deciduous forests and degraded forests (2.0-3.7 cmol +/kg) contained higher content of Mg than the other landuse types (Table 16). Decrease in the values with increase in soil depth in majority of the landuse systems was not significant ($P>0.05$).

Table 16. Exchangeable magnesium (cmol (+)/kg) in the soils of different landuse systems in the Kerala part of Nilgiri Biosphere Reserve. Values (mean ± S.E), in a given landuse system, with same alphabets in the superscript are not significantly different ($P>0.05$).

Landuse systems	Sampling depth	
	0-10 cm	10-30 cm
Semi evergreen forest	1.8 ± 0.18^{a}	2.0 ± 0.21^{a}
Moist deciduous forest	3.7 ± 0.33^{a}	2.7 ± 0.26^{b}
Degraded forest	2.0 ± 0.37^{a}	2.1 ± 0.14^{a}
Teak plantation of the Forest Department	0.9 ± 0.12^{a}	1.0 ± 0.15^{a}
Annual crops	0.7 ± 0.12^{a}	0.7 ± 0.10^{a}
Homegardens	1.4 ± 0.27^{a}	1.2 ± 0.19^{a}
Polyculture farms	0.8 ± 0.05^{a}	0.7 ± 0.06^{a}
Arecanut with annuals	0.7 ± 0.10^{a}	0.5 ± 0.05^{a}
Arecanut with perennials	1.0 ± 0.14^{a}	0.9 ± 0.13^{a}
Coconut with perennials	0.8 ± 0.91^{a}	0.7 ± 0.07^{a}
Arecanut plantation	0.6 ± 0.06^{a}	0.4 ± 0.05^{b}
Coconut plantation	0.8 ± 0.09^{a}	0.6 ± 0.11^{a}
Rubber plantation	0.8 ± 0.09^{a}	0.9 ± 0.19^{a}
Cashew plantation	0.6 ± 0.06^{a}	0.5 ± 0.07^{a}
Teak plantation (private)	1.0 ± 0.10^{a}	1.0 ± 0.12^{a}

4.1.2.10. Influence of landuse systems on soil properties

Results of the present study revealed the influence of each landuse system on the soils of the study area. Among the natural forests, moist deciduous forests contained higher content of soil moisture, organic carbon, exchangeable Ca and Mg than the evergreen forests. This is mainly because of the accumulation of litter on the soil surface due to periodic leaf fall and subsequent decomposition and release of bases which is characteristic of moist deciduous forests. Similar observations were also reported by Thomas (1991) in the forest soils of Kerala. In degraded forests, the thick grassy cover helped to maintain a higher level of organic carbon as that of evergreen forests, but the health of soil was declining as indicated by lower levels of soil moisture, extractable P, exchangeable K and higher level of exchange acidity. Lack of adequate vegetation probably might have caused less retention of moisture and more leaching of nutrients through run off water finally resulting in more acidity. Elsy (1989) also reported depletion of nutrients due to loss of forest cover under Kerala condition. Growing some moist deciduous species, which can enrich the base status of the soil, is the best option to restore the lost fertility and reduce the acidity in degraded forests. Drastic depletion of soil moisture, extractable phosphorus, exchangeable K and exchangeable Mg were observed in forest teak plantations compared to benchmark soils. In forest teak plantations, removal of nutrients by the growing trees together with the disruption of nutrient cycling by the removal of litter from soil surface for fuel might be the probable reason for depletion of nutrients. Hence measures need to be adopted to let the fallen litter remain and decompose on the same site as in private teak plantations.

In cultivated lands, drastic reduction in organic carbon, soil moisture, exchangeable Ca and Mg and increase in exchange acidity occurred due to cultivation of annuals; significant reduction in organic carbon, exchangeable K and Mg in poly cultures and increase of exchange acidity together with decrease in exchangeable K, Ca and Mg in monoculture plantations. In annuals and poly cultures, continuous cultivation without external application of organic manures might have caused drastic depletion of organic matter from the soil. So application of organic manures is the feasible management practice to promote the organic matter and moisture status and reduce exchange acidity in these soils. Application of lime also suggests to decrease the exchange acidity in these soils. In this study, monoculture plantations except arecanut contained higher content of organic carbon as that of evergreen forests contributed mainly by the luxurious leguminous under growth, but there was a drastic depletion of exchangeable K, Ca and Mg resulting in higher acidity in the exchange complex. So application of lime together with muriate of potash is recommended to improve the health of soil in these plantations. In arecanut plantations incorporation of organic manure is essential to improve the soil organic matter status.

4.1.3. Soil Fauna

Present work has resulted in reporting a total of 22 species of ants (Hymenoptera), 14 species of beetles (Coleoptera), 9 species of termites (Isoptera) and 14 species of earthworms (Oligochaete) (Table 17). Among the 13 species of earthworms, considering functional categorization *Megascolex insignis* and *Drawida ghatensis* belong to epigeic category where as *Lampito mauritii* is an anecic species. Among the endogeic worms *Parryodrilus lavelee and Pontoscolex corethrurus* showed maximum availability in a variety of landuse patterns. Thus it may be concluded that since these two species have a wide tolerance to landuse changes they may be suitable for land restoration purpose.

The abundance of major mesofaunal elements in different landuse systems is presented in Table 18. The density of ants ranged from 0 to 3716 individuals m^{-2}. Among different landuse systems, degraded forests showed relatively higher value for ant density. However, the values were not different for rubber and private teak plantations. Ants could not be collected from the plantations like cashew and coconut mixed with perennial crops, based on the method adopted. In the degraded forests, population of *Lobopelta sp.* and *Leptogenys sp.* to the total density of ants was around 60-70 per cent. This may be due to preference of the genera to occupy open canopy system and warm humid conditions.

Table 17. Soil fauna in the Kerala part of the Nilgiri Biosphere Reserve

Hymenoptera (Ants)	
Anoplolepis sp.	*Myrimicaria brunnea*
Camponotus oblongus	*Odontomachus haematodes*
Camponotus paria	*Oecophylla smaragdina*
Cardiocondyla sp.	*Pachycondyla rufipes*
Centromyrmex feae	*Paratrechina* sp.
Crematogaster sp.	*Pheidole malinsi*
Diacamma vagans	*Pheidologeton affinis*
Leptogenys sp.	*Plagiolepis longipes*
Lobopelta sp.	*Pseudoponera* sp.
Meranoplus bicolar	*Tetramorium* sp.
Monomorium	*Tetraponera* sp.
Coleoptera (Beetles)	
Apogonia sp.	*Globaria* sp.
Atactogaster sp.	*Gonocephalum* sp.
Autoserica sp.	*Holotrichia* sp.
Balboceras sp.	*Oides affinis*
Cicindela belli	*Onthophagus* sp.
Coccinella transversalis	*Pheropsophus* sp.
Copelalus sp.	*Prionomma atrotum*
Isoptera (Termites)	
Dicuspiditermes sp.	Odontotermes obesus
Heterotermes sp.	*Odontotermes* sp.
Labiocapritermes	*Pericapritermes* sp.
Microtermes sp.	*Trinervitermes*
Odontotermes hornei	
Oligochaeta (Earthworms)	
Dichogaster affinis	*Lampito mauritii*
Drawida modesta	Megascolex *insignis*
Drawida barwelli impertusa	*Megascolex triangularis*
Drawida ghatensis	*Octochaetona beatrix*
Drawida *grandis*	*Parryodrilus lavellei*
Glyphidrilus annandalei	*Plutellus variabilis*
Haplochetalla sp.	*Pontoscolex corethrurus*

Table 18. Abundance (individuals m^{-2}) soil mesofauna in different landuse systems in the Kerala Part of Nilgiri Biosphere Reserve. Values are mean± SE. The range of values is given in parenthesis

Landuse system	Groups of mesofauna				
	Ants	Termites	Earthworms	Millipedes	Centipedes
Moist-deciduous forest	5.3±5.3 (0-16)	279.3±151.79 (0-522)	214.6±121.1 (76-456)	1.3±1.3 (0-4)	6.6±3.52 (0-12)
Degraded forest	1878±1838 (40-3716)	1630±1622 (8-3252)	2±2 (0-4)	8±8 (0-16)	16±0 (16-16)
Forest teak plantation	4±4 (0-8)	150±66 (84-216)	84±4 (80-88)	0	8±4 (4-12)
Annual crops	26±26 (0-52)	10±10 (20-32)	24±8 (0-16)	2±2 (0-4)	6±2 (4-8)
Homegardens	7.2±2.9 (0-16)	6.4±6.4 (0-32)	46.4±26.2 (0-148)	0.8±0.8 (0-4)	8.8±8.8 (0-44)
Polyculture farms	6.4±5.45 (0-28)	16±6.54 (0-52)	60.2±25.1 (16-148)	3.2±3.2 (0-16)	0
Arecanut with annuals	9.3±7.42 (0-24	5.3±5.3 (0-16)	26.7±16.7 (8-12)	9±5.5 (8-19)	2.7±2.6 (0-8)
Arecanut with perennials	14±7 (0-24)	4±2 (0-8)	55±27.5 (4-136)	15±7.5 (0-24)	3±1.5 (0-4)
Coconut with perennials	0	28±28 (0-56)	294±118 (176-412)	2±2 (0-4)	0
Arecanut plantations	2.67±2.67 (0-8)	18.7±18.7 (0-56)	157.3±71.2 (60-296)	0	2.3±1.3 (0-4)
Coconut plantations	6±6 (0-12)	0	36±36 (0-72)	2±2 (0-4)	0
Rubber plantations	228±224 (4-452)	158±122 (36-280)	50±10 (40-60)	4±4 (0-8)	4±4 (0-8)
Cashew plantations	0	32±32 (0-64)	150±134 (16-284)	2±2 (0-4)	0
Teak plantations	86.6±43.3 (0-132)	121.3±121.3 (0-364)	46.6±38.94 (0-124)	4±4 (0-12)	10.6±5.81 (0-20)

As in the case of ants, density of termites ranged from 0 to 3252 individuals m^{-2}, with relatively higher values in degraded forests, followed by moist deciduous forest and teak plantation. In almost all landuse systems, there were a few replicates in which termites were not recorded. Complete absence of termites in the samples collected from coconut plantation could be due to tillage just before sampling, because of which termites may move down even below the sampling depth. In the present study, seven genera of termites were recorded (Table 17). The genus *Dicuspiditermes* was collected from a private teak plantation, during the line-transect sampling.

Table 19. Abundance (individuals m^{-2}) soil microfauna in different landuse systems in the Kerala Part of Nilgiri Biosphere Reserve. Values are mean± SE. The range of values is given in parenthesis

Landuse system	Groups of microfauna				
	Diplura	Protura	Collembola	Mites	Nematodes
Moist-deciduous forest	304±304 (0-910)	911±526 (0-1851)	304±304 (0-910)	6677±2484 (1821-10015)	341115±55599 (267513-450102)
Degraded forest	0	911±911 (0-1821)	456±455 (0-911)	5953±4973 (980-10926)	Not studied
Forest teak plantation	2731±1820 (910-552)	455±455 (0-910)	0	3742±1921 (1821-5663)	276006±72186 (203820-348192)
Annual crops	2732±0 (2732-2732)	1366±1366 (0-2732)	0	5008±3187 (1821-8195)	Not studied
Homegardens	2914±1664 (0-8194)	911±576 (0-2731)	546±546 (0-2731)	7648±3265 (0-18210)	285348±91145 (46708-518042)
Polyculture farms	8194±4860 (910-6373)	182±182 (0-910)	1275±681 (0-3642)	7466±3093 (910-10015)	155412±17175 (93417-186835)
Arecanut with annuals	3642±2102 (0-7284)	1518±1518 (0-4552)	304±304 (0-910)	10016±3680 (5463-17299)	292991±116829 (169850-526535)
Arecanut with perennials	3870±1308 (0-5463)	1180±546 (165-2731)	1366±872 (0-3642)	11581±5381 (827-26405)	32908±47622 (131633-326961)
Coconut with perennials	123±122 (0-245)	0	123±123 (0-245)	5918±5918 (0-11836)	Not studied
Arecanut plantations	2732±1391 (0-4552)	2732±1391 (0-4552)	2732±1391 (0-4552)	2732±1390.9 (0-4552)	175551±117724 (0-399206)
Coconut plantations	2732±2731 (0-5463)	455±455 (0-910)	455±455 (0-910)	455±455 (0-910)	312099±61571 (250528-373670)
Rubber plantations	2732±1821 (910-4553)	4097±4097 (0-8194)	1821±1821 (0-3642)	9561±455 (9106-10015)	690015±36093 (653922-726108)
Cashew plantations	2732±911 (1821-3642)	0	1366±1366 (0-2731)	4097±3187 (910-7284)	418255±166983 (399147-437363)
Teak plantations	1214±1214 (0-3642)	1214±607 (0-1821)	607±607 (0-1821)	4294±304 (3642-4552)	605798±90884 (424625-709123)

Density of earthworm was relatively low in landuse systems like annual crops, areca mixed with annuals and degraded forests. Low density of earthworm in annual crops and arecanut mixed with annual crops may be attributed to the excess use of inorganic fertilizers and pesticides. On the other hand, in several plots of other landuse systems like coconut plantations, homegardens, and private teak plantations, earthworms could not be collected. Apart from the sampling technique, there are other reasons for the absence of earthworm in these sample points. For instance, in one of the coconut plantations, sampling was done just after tillage. In these plots during hand sorting, several dead cocoons were collected. Those individuals, which survived the tillage, might have moved below the sampling depth. In one of the homegardens also earthworm was absent and this could be due to poor soil condition. Absence of earthworm in young teak plantation may also be attributed to the fact that this plot was a degraded land earlier with laterite blocks and thin layer of soil. Wherever soil is relatively rich with organic materials, earthworm density ranged from 124-412 individuals m^{-2}. Thus, even in a given landuse system, the earthworm density showed variation in different sampling points due to differences in soil characteristics, management and time factor taken to develop the cropping system.

The density of millipedes estimated in different landuse systems ranged from 0 to 24 individuals m^{-2}. On the other hand, density of centipedes ranged from 0 to16 individuals m^{-2}. All the millipedes and centipedes collected were small creamy white, with poorly developed appendages. This indicates that at the time of sampling, only juvenile forms of these groups are available.

Abundance of major microfauna is presented in Table 19. Density of diplura in different landuse systems ranged from 0 to 7284 individuals m^{-2}. Generally no significant difference between different landuse systems for diplurans density was recorded. Similarly, even the density of protura and collembola showed wide variation both within and between different landuse systems. Generally in each landuse system, contribution of acarina (mites) and collembolans to the total density of microfauna was significantly high ($P<0.05$).

To estimate nematode density, the water migration method was adopted. It seems that by adopting this method only active living individuals can be extracted. Absence of nematodes (active living forms) in sampling points in annual cropping systems could be due to the excess use of pesticides. In the degraded forests also no nematodes were collected during the study period, which may be due to less soil moisture and organic content.

In the present study abundance of different soil biota from different landuse systems in the Kerala part of Nilgiri Biosphere Reserve were estimated by adopting TSBF protocol. The data presented here is based on the sampling carried out during the post monsoon season and a similar set of data for the wet season could generate further useful information on the abundance and the diversity of belowground fauna. Absence of some of the soil faunal elements in certain landuse systems also be attributed to the changes in the landuse pattern and management system. Apart from the season of sampling, sampling methods adopted also decide the qualitative and quantitative information that can be obtained on each group of soil fauna. Thus the sampling technologies to estimate different faunal groups need to be standardized considering both the faunal group under study and the landuse systems. There is also a need for capacity building in soil faunal systematics for inventorying and quantifying the soil dwelling organisms.

4.1.4. Soil microflora

4.1.4.1 Arbuscular Mycorrhiza

Number of arbuscular mycorrhizal spores recovered from the field soil samples was the highest in the cashew plantation during both the pre- and post monsoon seasons compared to other landuse systems ($p < 0.001$) (Table 20). Soils sampled from the degraded forests also contained higher number of AM spores compared to other ecosystems (except cashew plantation) during both the seasons. The lowest spore counts were recorded from paddy field and one of the moist deciduous forests during the pre- and post monsoon seasons, respectively. The number of spores showed a significant increase during post monsoon season compared to pre monsoon in nine landuse systems including cashew plantation, degraded forest, semi evergreen forest, paddy field and home garden.

Table 20. Number of AM spores per 10 g of soil in different landuse systems (pre-monsoon and post-monsoon samples) in Kerala part of NBR. In a column, means with a same letter in the superscript, and in a row, means with same number in the superscript are not significantly different at 1% level.

Landuse system	Number of spores per 10 g of soil	
	Pre-monsoon samples	Post-monsoon samples
Semi-evergreen forest	$88 \pm 6^{a.1}$	$215 \pm 17^{a.2}$
Moist-deciduous forest	$70 \pm 5^{a.1}$	$69 \pm 13^{b.1}$
Degraded forest	$258 \pm 30^{b.1}$	$832 \pm 15^{c.2}$
Forest teak plantation	$178 \pm 13^{c.1}$	$138 \pm 45^{d.1}$
Homegardens	$85 \pm 24^{a.1}$	$303 \pm 20^{e.2}$
Polyculture farms	$126 \pm 34^{d.1}$	$137 \pm 7^{d.1}$
Arecanut plantation	$116 \pm 47^{d.1}$	$125 \pm 3^{d.1}$
Arecanut with annuals	$105 \pm 21^{d.1}$	$97 \pm 5^{b.1}$
Arecanut with perennials	$125 \pm 35^{d.1}$	$130 \pm 17^{d.1}$
Coconut plantations	$77 \pm 22^{a.1}$	$146 \pm 11^{d.2}$
Coconut with perennials	$158 \pm 40^{d.1}$	$156 \pm 17^{d.1}$
Rubber plantations	$117 \pm 43^{d.1}$	$180 \pm 5^{f.2}$
Cashew plantations	$544 \pm 28^{e.1}$	$1212 \pm 44^{g.2}$
Banana plantation	$83 \pm 9^{a.1}$	$329 \pm 35^{e.2}$
Paddy field	$54 \pm 23^{a.1}$	$194 \pm 15^{a.2}$

Data on per cent root colonization (pre-monsoon samples) showed that the landuse system with areca nut and coconut mixed with other tree crops had the highest per cent of roots colonized by AM fungi followed by the cashew plantation and areca nut plantation ($p < 0.001$). The least AM colonization was in roots recovered from the home garden (Table 21). Some of the moist deciduous and degraded forests and teak plantations also had a higher root colonization compared to other landuse systems. In the combined analyses (landuse systems grouped together into ecosystems), roots from the managed mixed cropping system showed the highest colonization. Differences in colonization of roots between other ecosystems were not significant due to large variations in the data between landuse systems included in each ecosystem.

Data on number of infective propagules of AM fungi (Table 21) showed that cashew plantation had significantly high number of infective propagules ($p < 0.001$) compared to other landuse systems. This was followed by degraded forests and teak plantation. The paddy field contained the lowest number of infective propagules.

Table 21. Percentage colonization and number of infective propagules of AM fungi in soils of different landuse systems in the Kerala part of NBR. In a column, means with a same letter in the superscript are not significantly different at 1% level.

Landuse system	% colonization of AM fungi in roots	Number of infective propagules per g. of soil
Semi-evergreen forest	62 ± 7^{a}	106 ± 14^{a}
Moist-deciduous forest	67 ± 6^{a}	140 ± 55^{a}
Degraded forest	$54 \pm 5a^{b}$	332 ± 54^{b}
Forest teak plantation	65 ± 16^{ab}	212 ± 41^{c}
Homegardens	66 ± 11^{b}	133 ± 32^{a}
Arecanut plantation	66 ± 6^{b}	163 ± 40^{a}
Arecanut with annuals	56 ± 4^{ab}	183 ± 45^{a}
Arecanut with perennials	81 ± 8^{c}	170 ± 45^{a}
Coconut plantations	55 ± 7^{ab}	123 ± 44^{a}
Coconut with perennials	80 ± 5^{c}	196 ± 62^{a}
Rubber plantations	46 ± 15^{ab}	132 ± 85^{a}
Cashew plantations	73 ± 28^{c}	928 ± 181^{d}
Banana plantation	52 ± 6^{ab}	121 ± 34^{a}
Paddy field	47 ± 6^{ab}	73 ± 23^{e}

The AM fungi recorded from soils (after growing trap plants) under the different landuse systems belonged to 3 genera and 84 species. Spores of some of the speceis are given in Plate 1. Of these, the genus *Glomus* was represented by 59 species, *Acaulospora* by 22 species and *Gigaspora* by 3 species. Over 30% of the total species were recorded from 7 or more landuse systems. Species of the genus *Glomus* had the highest density of spores in the soils compared to the other genera (Table 22). Among *Glomus* species, *G. maculosum* was the most widespread fungus which was recorded from 13 landuse systems. It also showed the highest density in cashew plantation, degraded forest, home garden and banana plantation. *Glomus mosseae, G. fasciculatum* and *G. citricolum* were the other widespread AM fungi landuse. The cashew plantation had the highest spore density of all these fungi compared to other landuse systems.

Table 22. Diversity of AM fungi in different landuse systems in the Kerala part of NBR. No. of spores of individual fungi in 10 g of soils from each landuse system is also shown.

AM Fungi	Landuse systems code*												
	1	2	3	4	5	6	7	8	9	10	11	12	13
Acaulospora appendicula	-	-	-	-	-	-	-	-	4	3	-	-	2
A. bireticulata	-	1	3	1	11	1	3	2	1	2	2	2	2
A. denticulata	2	-	2	-	-	-	12	2	7	5	-	-	-
A. dilatata	1	1	1	-	-	-	2	-	-	-	-	-	-
A. elegans	-	1	-	-	-	-	1	-	-	-	-	-	-
A. lacunosa	-	2	6	-	-	3	6	2	1	4	1	4	-
A. laevis	-	-	-	-	-	1	1	1	1	-	-	-	-
A. longula	3	3	1	-	-	2	3	1	-	-	1	5	-
A. mellea	2	2	3	-	-	2	3	4	-	6	2	5	-
A. morrowae	1	-	-	-	-	-	4	-	1	-	-	4	-
A. myriocarpa	1	1	-	-	-	-	5	-	-	-	-	-	-
A. rehmii	-	-	-	-	-	-	-	-	-	-	-	-	2

*, 1, Moist Deciduous forest; 2, Arecanut plantation; 3,Banana plantation; 4, Paddy field; 5,Home garden; 6, Degraded forest; 7, Cashew plantation; 8,Teak plantation; 9,Rubber plantation; 10,Coconut with perennials; 11,Semi evergreen forest; 12. Polyculture farms: 13,Coconut plantation

Table 22 (cont'd). Diversity of AM fungi in different landuse systems in the Kerala part of NBR. No. of spores of individual fungi in 10 g of soils from each landuse system is also shown.

AM Fungi	Landuse systems code*												
	1	2	3	4	5	6	7	8	9	10	11	12	13
A. rugosa	-	1	1	-	9	-	4	4	-	-	-	-	-
A. scrobiculata	3	-	13	-	-	12	13	2	5	8	-	2	4
A. spinosa	-	1	-	-	-	-	-	-	1	1	-	1	-
A. tuberculata	-	-	-	-	-	-	8	4	2	1	-	7	-
Acaulospora sp.1	2	-	-	-	-	-	2	2	1	2	2	3	1
Acaulospora sp.2	1	-	-	-	-	2	2	-	-	3	-	3	1
Acaulospora sp.3	2	-	-	1	5	1	3	1	-	2	-	1	-
Acaulospora sp.4	-	-	-	-	-	1	-	1	-	1	-	-	-
Acaulospora sp.5	-	-	-	-	-	1	-	2	-	1	-	-	-
Acaulospora sp.6	-	-	-	-	-	-	-	-	-	6	-	-	-
Gigaspora albida	-	-	-	-	-	-	-	-	-	-	-	-	2
G. decipiens	-	-	-	-	-	-	-	-	-	1	-	-	-
G. gigantea	-	-	-	-	-	-	-	-	-	1	-	-	-
Glomus albidum	1	-	-	-	-	1	-	-	-	-	1	-	-
G. aggregatum	2	5	5	2	3	5	5	-	-	-	-	1	-
G. ambisporum	3	-	3	1	3	9	1	2	-	-	-	1	-
G. botryoides	-	-	-	-	-	-	-	2	-	1	-	-	-
G. canadense	-	-	-	-	2	2	4	2	-	-	-	3	3
G. citricolum	-	-	-	1	-	8	11	4	1	9	1	2	2
G. claroideum	2	-	-	-	-	1	3	-	-	-	-	-	-
G. clarum	1	-	3	3	3	1	7	-	1	-	-	-	-
G. constrictum	-	-	-	-	-	-	3	-	-	-	-	-	-
G. convolutum	-	-	-	-	-	4	-	-	-	-	-	-	-
G. delhiense	1	2	-	-	-	-	-	-	-	-	-	-	-
G. diaphanum	-	2	-	-	1	-	-	-	-	-	-	-	-
G. etunicatum	3	-	3	-	-	2	3	-	1	-	-	-	-
G. fasciculatum	1	-	2	2	7	9	1	2	-	4	4	-	1
G. fragile	-	-	-	-	-	3	3	3	-	8	1	4	2
G. geosporum	3	-	1	-	-	3	12	-	3	5	-	-	-
G. halonatum	-	-	-	-	-	5	1	-	-	-	-	-	-

*, 1, Moist Deciduous forest; 2, Arecanut plantation; 3,Banana plantation; 4, Paddy field; 5,Home garden; 6, Degraded forest; 7, Cashew plantation; 8,Teak plantation; 9,Rubber plantation; 10,Coconut with perennials; 11,Semi evergreen forest; 12. Polyculture farms: 13,Coconut plantation

Table 22 (cont'd). Diversity of AM fungi in different landuse systems in the Kerala part of NBR. No. of spores of individual fungi in 10 g of soils from each landuse system is also shown.

AM Fungi	Landuse systems code*												
	1	2	3	4	5	6	7	8	9	10	11	12	13
G. heterosporum	-	-	1	2	1	-	2	-	-	-	-	-	-
G. hoi	-	-	-	-	-	-	-	-	-	-	-	-	2
G. intraradices	1	-	4	4	-	3	7	-	4	11	4	-	-
G. invermaium	2	-	-	-	-	1	4	-	-	-	-	-	-
G. leptotichum	1	-	-	-	-	-	2	-	-	-	-	-	-
G. macrocarpum	-	-	1	-	2	7	12	-	-	1	-	5	2
G. maculosum	4	4	14	6	15	15	16	5	8	4	2	5	3
G. monosporum	-	-	-	-	-	-	1	-	-	-	-	-	-
G. mosseae	-	-	3	-	2	5	15	3	5	2	2	2	1
G. multicaule	-	3	1	-	-	5	8	2	3	4	1	4	2
G. multisubstensum	-	-	-	-	-	2	12	2	-	-	4	-	-
G. occultum	-	-	-	-	-	-	1	-	2	-	-	-	-
G. pallidum	-	-	-	-	-	-	2	-	-	-	-	1	-
G. pansihalos	3	-	-	-	-	3	2	-	2	1	-	-	-
G. pulvinatum	-	2	-	-	-	5	4	-	-	-	-	1	-
G. pustulatum	-	-	2	-	-	7	2	-	3	-	-	-	-
G. radiatum	-	-	-	-	-	5	4	5	3	1	2	-	3
G. reticulatum	2	-	-	-	-	-	2	2	1	-	2	-	-
G. scintillans	1	-	-	-	-	2	10	-	1	-	-	-	-
G. segmentatum	-	-	-	1	-	2	5	-	-	4	1	3	1
Glomus sp. 1	2	1	1	1	-	6	1	-	1	1	3	4	4
Glomus sp. 2	6	-	1	1	-	1	4	1	1	1	2	1	4
Glomus sp. 3	2	-	2	1	-	1	5	3	1	1	1	1	2
Glomus sp. 4	2	-	2	1	-	2	2	2	1	1	1	1	5
Glomus sp. 5	2	-	2	1	-	6	3	4	1	5	2	-	5
Glomus sp. 6	2	-	1	-	-	2	1	1	1	4	1	-	4
Glomus sp. 7	-	-	1	-	-	2	2	1	-	-	1	-	1
Glomus sp. 8	-	-	1	-	-	1	2	1	-	9	1	-	-
Glomus sp. 9	-	-	2	-	-	2	2	1	-	-	-	-	-
Glomus sp.10	-	-	1	-	-	3	2	2	-	-	-	-	-
Glomus sp.11	-	-	1	-	-	1	2	3	-	-	-	-	-

*, 1, Moist Deciduous forest; 2, Arecanut plantation; 3,Banana plantation; 4, Paddy field; 5,Home garden; 6, Degraded forest; 7, Cashew plantation; 8,Teak plantation; 9,Rubber plantation; 10,Coconut with perennials; 11,Semi evergreen forest; 12. Polyculture farms: 13,Coconut plantation

Table 22 (cont'd). Diversity of AM fungi in different landuse systems in the Kerala part of NBR. No. of spores of individual fungi in 10 g of soils from each landuse system is also shown.

AM Fungi	Landuse systems code*												
	1	2	3	4	5	6	7	8	9	10	11	12	13
Glomus sp.12	-	-	1	-	-	3	3	3	-	-	-	-	-
Glomus sp.13	-	-	-	-	-	2	3	1	-	-	-	-	-
Glomus sp.14	-	-	-	-	-	1	2	-	-	-	-	-	-
Glomus sp.15	-	-	-	-	-	1	-	-	-	-	-	-	-
Glomus sp.16	-	-	-	-	-	1	-	-	-	-	-	-	-
Glomus sp.17	-	-	-	-	-	1	2	-	-	-	-	-	-
Glomus sp.18	-	-	-	-	-	2	4	-	-	-	-	-	-
Glomus sp.19	-	-	-	-	-	1	2	-	-	-	-	-	-
Glomus sp.20	-	-	-	-	-	1	-	-	-	-	-	-	-
Glomus *sp. 21*	-	-	-	-	-	-	-	-	-	1	-	-	-
Glomus sp. 22	-	-	-	-	-	1	-	-	-	-	-	-	-
	39	32	89	29	64	182	279	82	68	125	45	76	61

*, 1, Moist Deciduous forest; 2, Arecanut plantation; 3,Banana plantation; 4, Paddy field; 5,Home garden; 6, Degraded forest; 7, Cashew plantation; 8,Teak plantation; 9,Rubber plantation; 10,Coconut with perennials; 11,Semi evergreen forest; 12. Polyculture farms: 13,Coconut plantation

Of the species of the genus *Acaulospora, A. bireticulata* can be considered widespread having recorded from 12 landuse systems. This was followed by *A. scrobiculata* and *A. mellea* (recorded from 10 landuse systems each). *A. scrobiculata* had the highest spore density in cashew and banana plantation followed by degraded forest. *A. bireticulata* and *A. rugosa* had the highest spore density in home gardens compared to other ecosystems. The species of *Gigaspora* were rather restricted in distribution.

Overall, it is evident from the data that the diversity of AM fungi was the highest in the cashew plantation (2 genera and 64 species) followed by the degraded forest (2 genera and 56 species). The Shanner-Weiner diversity index was the highest for cashew (3.87). The diversity indices for the degraded forest (3.71) and teak plantation (3.48) were also higher than other landuse systems but lower than that of cashew plantation (Table 23). The landuse system with coconut mixed with other tree crops also showed a comparatively high diversity of AM fungi (diversity index- 3.31). Interestingly 2 species of AM fungi, viz., *Gigaspora decipiens* and *G. gigantea* were restricted to this site. The fungal diversity was the least in the paddy field (2 genera and 16 species).

Table 23. Shannon-Weiner indices of species diversity of arbuscular mycorrhizal spores in soils from different landuse systems in the Kerala part of NBR.

Landuse system	Shannon-Weiner index vlaue
Semi-evergreen forest	3.09
Moist-deciduous forest	2.78
Degraded forest	3.71
Forest teak plantation	3.48
Homegardens	2.58
Arecanut plantation	2.61
Coconut plantations	3.09
Coconut with perennials	3.31
Rubber plantations	3.08
Cashew plantations	3.87
Banana plantation	3.09
Paddy field	2.41

The number of AM fungal spores from each landuse system was not correlated ($P \geq 0.05$) with any of the soil parameters tested viz., total N, available P, organic carbon, potassium, calcium and magnesium levels and pH of the soil. Also, there was no significant correlation between spore count and percentage colonisation of roots by AM fungi (Figure 7).

The results of this study indicate that soils under unmanaged plantations (cashew and teak) and degraded forests supported the highest number of spores and infective propagules of AM fungi. This could be ascribed to the poor nutrient status of these soils, lack of soil operations, lack of fertilizer applications and other soil amendments. Application of fertilizers, tillage and other soil disturbance have been shown to decrease mycorrhizal colonization in plants (Kruckelmann, 1975; Reeves *et al.*, 1979 ; Hayman, 1980 ; Mulligan *et al.*, 1985).

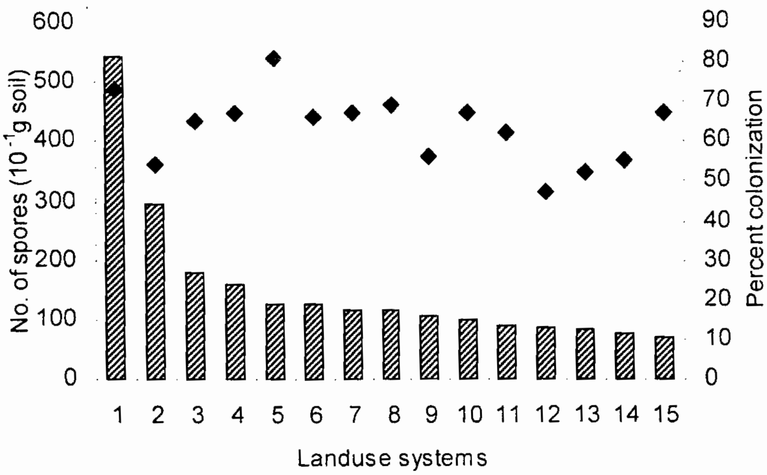

Figure 7. Correlation between spore count and percentage colonization in soils collected from different landuse system in the Kerala part of NBR.

1, Cashew plantation; 2, Degraded Forest; 3, Teak plantation; 4, Coconut with perennials; 5,Arecanut with perennials; 6, Polyculture farms; 7, Rubber plantation; 8,Arecanut plantation; 9, Arecanut mixed with annual crop; 10,Moist deciduous forest; 11,Semi-evergreen forest; 12, Home garden; 13, Banana plantation; 14, Coconut plantation; 15,Moist deciduous forest.

According Skinner and Bowen (1974) and Schenck *et al.*, (1989), agricultural systems contained fewer species of AM fungi than natural grasslands. The low number of AM spores and infective propagules in semi-evergreen and moist deciduous forests show they are inherently fertile and less dependent on mycorrhizae for plant growth. Frequent soil amendments would explain the low number of AM spores (during both the seasons) and infective propagules in managed plantations and mixed cropping systems. A significant increase in number of spores in the paddy field during post-monsoon season can be related to the fact that the paddy field was fallow and dry during the time of sampling and the new crop was ready for harvest during the post monsoon sampling. The significant increase in the number of spores in the intensively managed home garden during the post monsoon season demands further studies.

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. The present study clearly demonstrates the variation in AM fungal population between different landuse patterns. A significant increase in AM spores in some of the landuse systems during post monsoon is apparently due to an increase in soil moisture. In others, where the spore numbers were not significantly higher during the post monsoon, soil moisture may not have been adequate or other factors may have been limiting for inducing any significant change. Further studies on the post monsoon samples may be required to clarify this.

Per cent colonization of roots by AM fungi was more in areca nut/coconut mixed with other tree crops. This observation is interesting since plants with a tap root system are known to be more dependent on mycorrhizae than those with fibrous root systems (St. John, 1980). This could perhaps be an effect of mixing tree crops and most of the roots analysed for root colonization may have come from the other tree crops and not areca or coconut. The mixture of species may also explain the comparatively higher root colonization in natural forests compared to mono crops like coconut, banana and rubber. The high root colonization in cashew and teak plantations compared to banana, coconut and rubber plantations may be due to the fact that these plants in these unmanaged plantations are more dependent on mycorrrhiza for growth. There was no correlation between per cent colonization of roots by AM fungi and number of spores in soil since factors governing root infection and multiplication of spores are perhaps different and all the available spores need not cause an infection. However, the intensively managed cropping system had the lowest percent of root colonization which confirm the observation that frequent soil operations do affect root colonization by AM fungi (Kruckelmann, 1975; Hayman, 1980).

Eighty four species of AM fungi could be recovered from soils under different landuse systems in the Kerala part of the NBR. This figure is close to the 91 species of AM fungi recorded from soils under various forest plantation species in Kerala (Mohanan, 2003). The preponderance of species of *Glomus and Acaulospora* in Indian soils has been reported by several authors (Thapar and Khan, 1985, Ragupathy and Mahadevan, 1993, Muthukumar and Udayan, 2000, Mohanan, 2003). This could probably be associated with the acidic nature of the soils in the landuse systems studied. Porter *et. al.*, (1987) have reported that *Glomus* spp. was of rare occurrence in soils in Western Australia due to high soil pH. Mohanan (2003) recorded 47 species of *Glomus* and 16 species of *Acaulospora* from soils under forest plantations in Kerala State. Earlier, Sankaran *et al.* (1993) recorded eight species of *Glomus* from *Acacia auriculiformis* plantations in Kerala. During this study, 57 species of *Glomus* and 22 species of *Acaulospora* were recovered. The rarity of the species of *Gigaspora* is in accordance with the report of the other workers from India (Ragupathy and Mahadevan, 1993, Muthukumar and Udayan, 2000, Mohanan, 2003, Sankaran *et al.*, 1993). The high density of *Glomus fasciculatum*, *G. mosseae* and *Acaulospora scorbiculata* in soils of the Kerala part of NBR was also reported as high density species in soils under forest plantations in the State (Mohanan, 2003).

The high diversity of AM fungi in soils under cashew plantation, degraded forest and teak plantation compared to other landuse systems indicate that conditions in these soils are highly suitable for the proliferation of a host of mycorrhizal fungi since soil operations/ amendments are not being carried out to disturb the ecosystem. Though more studies, especially during the post-monsoon season, would be required to arrive at any firm conclusions, the available data show that plant dependency on mycorrhiza is apparently more in highly degraded sites. The high species diversity, high spore load and higher number of infective propagules in unmanaged plantations and degraded ecosystems during the pre-monsoon season indicate that to promote the growth of beneficial mycorrhizal fungi in any type of landuse system, deleterious soil treatments (use of pesticides and fertilizers, water logging, compaction etc.) may be avoided or at kept at a minimum level possible. Intensive management apparently results in low inoculum potential of AM fungi and plants tend not to depend on mycorrhiza for growth and establishment.

4.1.4.2. Soil legume nitrogen fixing bacteria

Rhizobium populations for 15 landuse types are given in Table 24. Though the rhizobium is present in all samples, a high degree of variability within a broad landuse system was observed, more so during pre-monsoon period. When the natural forests such as semi evergreen forest, moist deciduous forest located away from human habitation, degraded moist deciduous forest, and teak plantation (about 25-year-old) are considered the moist deciduous forest showed highest value for the bacterial count followed by degraded forest, teak plantation and the semi-evergreen forest. Teak plantation of the Forest Department in the study area is comparable to moist deciduous forest plots in terms of topography as well as the original vegetation structure and composition. The present study indicated that the rhizobial count in teak plantation was significantly lower than that in moist deciduous forest. However, number of nodules formed was not different significantly when the soils of teak plantation and moist deciduous forest were used for plant infection test and population count.

In the study area, sample plots in banana plantation, polyculture systems such as homegarden and farmland, single crop dominant systems such as arecanut mixed with annuals, arecanut mixed with perennials and coconut mixed with perennials, as well as pure plantations of arecanut and coconut have been evolved from the paddy fields. Thus, comparison was made between the paddy field and other landuse systems derived from it for the bacterial count during the pre-monsoon season. No significant difference ($P \geq 0.05$) between sample plots in paddy field, banana plantation, arecanut mixed with annuals and pure plantations of arecanut and coconut was observed for the bacterial count (LSD= 145.4). On the other hand the bacterial count was significantly more in polyculture systems such as homegarden than in other systems (Table 24). Thus, it may be concluded that the multi-species cultivation with comparatively less input of chemical fertilizer as well as minimum tillage favor relatively more growth of rhizobia (Hungria and Vargas, 2000). Contrary to this observation, in the semi evergreen forest which is also a multi-species and multi-tiered system with closed canopy recorded significantly low number of rhizobial cells per unit gram of soil. The reason for low rhizobial count in semi evergreen forest soil could be due to poor representation of leguminous species in both tree and understorey communities. In addition, bacterial competitiveness and the plant genotypes of the trap-host influence the population counts (Michiels *et al.*, 1998; Vasquez-Arroyo *et. al.*, 1998). Thus, it can also be expected that several rhizobia could not be isolated in the present study using the conventional trap plants.

Table 24. Rhizobial count of pre-monsoon and post-monsoon soil samples from different components of each landuse types

Sample site	Cells g^{-1} (Mean ± SD) of soil	
	Pre – monsoon soil sample	Post – monsoon soil sample
Semi-evergreen forest	42.0± 19.2	0.97± 0.34
Moist deciduous forest	583.3 ±166.1	0.95± 0.39
Degraded forest	100.0 ±37.9	0.62± 0.35
Teak plantation of the Forest Department	314.0 ±105.9	1.05± 0.41
Paddy field	30.0 ±7.1	0.69± 0.57
Banana plantation	124.0 ± 47.0	0.53±0.26
Polyculture homegardens	1278.0 ± 373.4	1.44±0.64
Polyculture farm lands	348.0 ± 94.9	1.35±1.01
Arecanut mixed with annual crops	114.0 ± 48.3	0.77±0.41
Arecanut mixed with other tree crops	166.0 ± 67.3	1.03±0.59
Coconut mixed with other tree crops	16.0 ± 5.3	0.85±0.33
Arecanut plantation	80.0 ± 53.9	1.07±0.52
Coconut plantation	148.0 ± 51.7	0.67±0.27
Rubber plantation	76.0 ± 39.1	1.19±0.45
Cashew plantation	753.3± 353.2	1.30±0.39

In cashew plantation, higher bacterial count was reported when compared to other mono-cropping systems which might be due to the presence of *Desmodium triflorum*, a leguminous crop. The higher bacterial count might also be due to the more virulent bacterial cells found in cashew plantations. It could be concluded that there was a positive relationship between growth of leguminous plants and chance of improved nodulation of legumes.

The bacterial counts obtained from post-monsoon samples were nearly 100 times lesser than pre-monsoon counts in most of the landuse systems (Table 24). The plant infection and the nodule formation on the trap plant roots from post-monsoon soil samples also were extremely low. However, in the field-grown legumes, nodules were found more during post monsoon period and extremely low during pre-monsoon period. This indicated that during pre-monsoon period, even though the number of nodules per plant was less, there was higher bacterial cell count in the soil. This may be because during pre-monsoon period, i.e., during summer, nodules disintegrate and dry up releasing infective cells in the soil. During post-monsoon period when the soil moisture is high, the conditions are optimum for increased vegetation growth and root colonization by rhizobium to form nodules. Hence, for estimating soil bacterial population pre-monsoon period is the optimum period.

Figure 8 indicates the pre-monsoon rhizobial population estimated through plant infection test and number of nodules produced in polythene pouches using the same soil sample. The Figure shows that the nodule number is directly proportional to the bacterial cells g^{-1} of soil with a positive coefficient of correlation ($r = 0.81$).

It is evident that soil properties such as pH, OC, N, P, K, Ca and Mg individually are not having any significant influence ($P \geq 0.05$) on the rhizobial population size as indicated by the lack of any correlation between these two factors (Table 25).

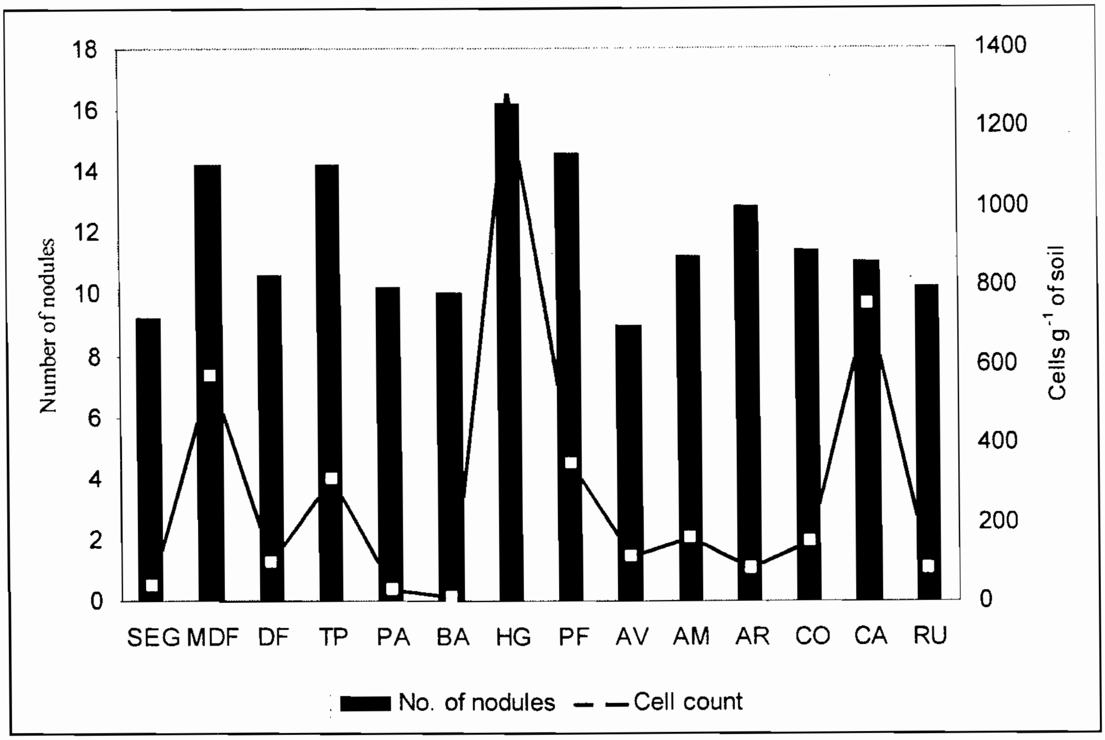

Figure 8. Mean number of nodules produced and rhizobial population in the soils of different landuse systems in the Kerala part of Nilgiri Biosphere Reserve. SEG :Semi-evergreen forest; MDF : Moist deciduous forests; DF: Degraded forests; TP: Teak plantation; PA: Paddy field; BA: Banana plantation; HG: Homegarden ; PF: Polyculture farm ; AV: Arecanut mixed with annual crops; AM: Arecanut mixed with perennial crops ; AR: Arecanut plantation; CO: Coconut plantation; CA : Cashew plantation; RU : Rubber plantation.

Table 25. Correlation coefficient between per-monsoon rhizobial count and soil parameters in the sample plots established in different landuse systems in the Kerala part of Nilgiri Biosphere Reserve.

Soil parameters	**Correlation coefficient value between rhizobial count and soil parameter**
pH	0.47
Organic carbon	0.09
Kjeldahl N	0.03
Available P	0.30
Exchangable K	-0.16
Exchangable Ca	-0.21
Exchangable Mg	-0.15

A total of 173 bacterial cultures were isolated in pure culture. Of these 144 were obtained from field growing leguminous plants and 29 from the leguminous trap plant root nodules (cow pea). When the 15 sample sites were classified into five broad groups based on landuse pattern and rotation age of the crop, majority of the isolates were found originated from monoculture tree based system and poly culture tree based system (Table 26 and 27). Most of the isolates belonged to *Rhizobium/Mesorhizobium/Sinorhizobium group*, followed by *Bradyrhizobium* and then *Allorhizobium*.

Table 26. Number of LNB isolates from plant infection test host (cow pea) from different landuse systems in Kerala part of NBR.

Landuse systems	Bradyrhizobium	Mesorhizobium/ Rhizobium/ Sinorhizobium
Natural forest	3	2
Forest plantation	2	-
Annual crop based system	3	-
Poly culture tree based system	7	2
Monoculture tree based system	6	4
Total	21	8

Table 27. Number of LNB isolates from host plants from different landuse systems in Kerala part of NBR.

Landuse systems	*Allorhizobium*	*Bradyrhizobium*	*Mesorhizobium/ Rhizobium/ Sinorhizobium*
Natural forest	-	14	12
Forest plantation	-	9	6
Annual crop based system	-	-	6
Poly culture tree based system	3	11	39
Monoculture tree based system	3	13	28
Total	6	47	91

From field grown legumes (Table 28), 144 LNB isolates were obtained. Among the leguminous plants, *Desmodium triflorum*, followed by *Centrosema pubescens*, *Mimosa pudica* and *Mucuna prurita* were commonly seen in all sample plots. In some sample plots, a few non-leguminous plants belonging to family Tiliaceae, Euphorbiaceae, Gentianaceae, Amarantaceae, Asteraceae, Capparidaceae and Lamiaceae were found to produce root nodule like structures. But most of them were found to be formed due to nematode infection.

Classical methods of identification based on morphological and physiological characters revealed that the 173 LNB isolates belonged to 5 genera namely, *Allorhizobium*, *Bradyrhizobium* and *Rhizobium/Mesorhizobium/Sinorhizobium* (Table 27). It was not possible to differentiate between the isolates of *Rhizobium*, Mesorhizobium and Sinorhizobium. Out of these, 6 isolates belonged to *Allorhizobium* sp., 69 to *Bradyrhizobium* sp. and 98 to *Rhizobium / Mesorhizobium / Sinorhizobium* sp. Out of 173 isolates, 144 were from leguminous host plants while 29 were isolated from nodules of cow pea which was used for plant infection test.

Various morphological characters of rhizobial colonies obtained by plant infection test are provided in Table 29. All isolates were fast growing, forming colonies within 2-3 days. Number of acid producer isolates were more from the trap plants than from the wild legumes. Similarly about 93% of isolates from trap plants were slime producers compared to 49% of isolates from wild legumes. Most of the colonies appeared to be circular with convex elevation except those from *Vigna unguiculata* and *Mimosa pudica*, which indicated pulvate type of elevation. Of total 173 cultures, colonies of 135 cultures were starchy white, 28 milky white, 7 yellow coloured and 3 silvery white. Rhizobium is supposed to be the major genus except six isolates from *Desmodium triflorum*, *Desmodium gangeticum*, *Calapagonium phaseoloides*, *Canscora diffusa*, *Vernonia cinerea* and *Centrosema pubescens* which produced yellow coloured colonies and are supposed to belong to the genus *Allorhizobium*.

Table 28. List of leguminous host species commonly growing in different landuse systems in the Kerala part of Nilgiri Biosphere Reserve and their probable genera

Host species	Number of isolates		
	Allorhizobium	*Bradyrhizobium*	*Rhizobium/ Mesorhizobium /Sinorhizobium*
Abrus precatorius	-	1	-
Acacia sp.	-	-	2
Calapagonium sp.	2	2	5
Canscora diffusa	-	1	-
Centosema pubescens	1	8	24
Crotalaria quinquefolia	-	-	3
Desmodium gangeticum	-	1	3
Desmodium sp.	2	8	6
Desmodium triangulare	-	1	2
Desmodium triflorum	1	3	8
Gliricidia glabra	-	1	-
Mimosa pudica	-	8	25
Mucuna prurita	-	6	5
Tephrosia purpurea	-	-	3
Vigna bourneae	-	2	-
Vigna sp.	-	5	4
Vigna ungiculata	-	-	1
Total isolates	6	47	91

Table 29. Plate characteristics of rhizobia obtained from plant infection test from different landuse systems in the Kerala part of Nilgiri Biosphere Reserve.

	Growth rate (%)		Slime production (%)		Acid/Alkali production (%)	
	Fast	Slow	Slimy	Non-slimy	Acid	Alkali
From trap plants	100	0	93.1	6.9	85.7	14.3
From field grown legumes	100	0	48.7	51.3	60.5	39.5

Carbon utilization studies using 35 sugars showed that most of the isolates which originated from degraded forests, teak plantation and paddy field utilized the sugars better than isolates from other sites (Figure 9). Isolates from semi-evergreen forests and polyculture farmlands were poor utilizers of sugars.

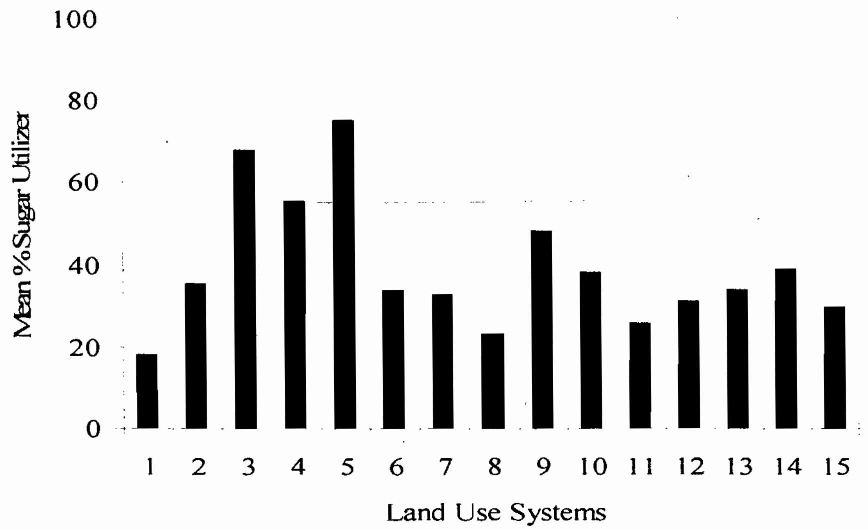

Figure 9. Mean per cent sugar utilizers among eighty LNB isolates which originated from different various landuse types in the Kerala part of NBR.

1, Semi-evergreen forest; 2, Moist deciduous forest; 3, Degraded forest; 4, Teak plantation; 5, Paddy field; 6, Banana plantation; 7, Polyculture homegardens; 8, Polyculture farm lands; 9, Arecanut mixed with annual crops; 10, Arecanut mixed with other tree crops; 11, Coconut mixed with other tree crops; 12, Arecanut plantation; 13, Coconut plantation; 14, Rubber plantation;15, Cashew plantation

Sodium chloride tolerance showed very interesting result. Most of the isolates tolerated 2 per cent NaCl. A few of the LNB cultures from coconut, arecanut and rubber plantation could tolerate 12 % NaCl. It was interesting to observe the very high NaCl tolerance of LNB from coconut, arecanut and rubber plantations. Probably, repeated application of chemical fertilizers in these plantations might have caused an increased adaptability of the isolates to high salt concentrations. Similarly, the higher capability of sugar utilization by LNB from degraded forests, teak plantation and paddy field are remarkable. Probably, this could be another mechanism of the isolates to overcome adverse impact of site degradation on survival o the organism.

The genetic diversity studies conducted at G.B Pant University of Agriculture and Technology on 13 LNB cultures isolated from trap plants (cow pea) showed that the LNB isolates from Kerala part of NBR were more diverse genetically than the isolates from Karnataka part of NBR and from Nanda Devi. While most of the isolates from Karnataka and Nanda Devi were grouped in respective single clusters, Kerala isolates were dispersed in different clusters of the dendrogram arising out of the three restriction enzymes (Figure 10 a and b).

Molecular studies based on partial 16S rDNA sequencing and analysis of sequence data could identify 4 LNB isolates from the Kerala part of NBR. These isolates belonged to *Klebsiella* sp., *Agrobacterium tumefaciens*, *Burkholderia cepacia* and *Burkholderia* sp. (Table 30).

Table 30. List of LNB isolates from the Kerala part of NBR identified based on nucleotide sequence identity from the host

Host species from which isolated	% of similarity with known culture	Species identified
Vigna unguiculata	97 %	*Klebsiella* sp.
Mucuna pruriens	98 %	*Agrobacterium tumefaciens*
Centrosema pubescens	99 %	*Burkholderia cepacia*
Mimosa pudica	98 %	*Burkholderia* sp.

Genetic diversity studies of inter box elements using box primers involving eighty LNB isolates randomly selected from the total number of 173 LNB cultures from Kerala part of NBR showed 22 DNA bands ranging in size from 100-1000 base pairs. Assuming that each RAPD product represented a single locus, 100 percent of the loci were found to show polymorphism indicating high level of genetic diversity among the isolates. The estimation of the gene diversity index (h) (Nei, 1973) showed that gene diversity varied from 0.0722 to 0.4888 with a mean diversity of 0.2949. Since the cluster analysis did not show any specific pattern of grouping of the 80 isolates (Figure 10), it can be presumed that diversity is distributed thoughout the landuse patterns.

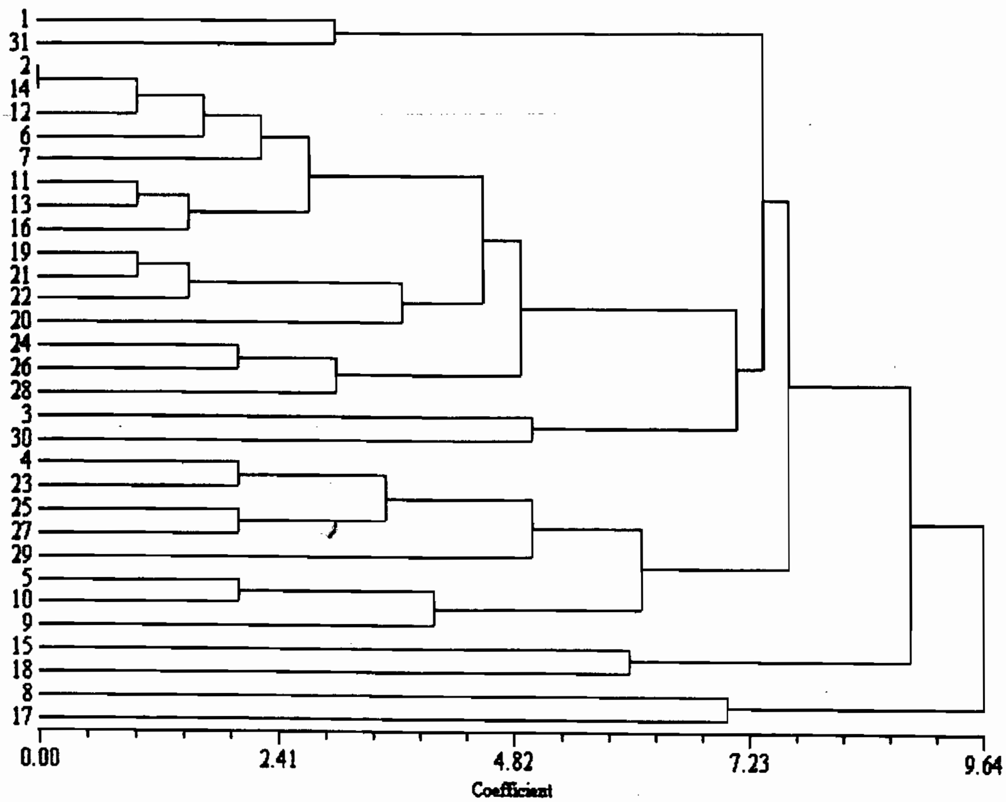

Figure 10. UPGMA dendrogram of isolates from different landuse systems in Nilgiri and Nanda Devi Biosphere Reserves based on 16SrDNA with AluI, TaqI and RsaI. Isolate number 1-13 for Kerala part of NBR, 14-25 for Karnataka part of NBR and 26-35 for Nanda Devi Biosphere Reserve.

Traditional methods of species identification showed a probable number of 5 genera. However, it was not possible to differentiate between *Rhizobium /Mesorhizobium/ Sinorhizobium*. But only two species could be identified based on molecular methods. When the genetic diversity of the isolates revealed through amplification of inter gene elements using box primers, and diversity based on 16S rDNA are considered, there is chance for more number of

LNB species (Plate 3). Traditional methods of species identification showed a probable number of 5 genera. However, it was not possible to differentiate between *Rhizobium /Mesorhizobium/Sinorhizobium.* But only two species could be identified based on molecular methods. When the genetic diversity of the isolates revealed through amplification of inter gene elements using box primers, and diversity based on 16S rDNA are considered, there is chance for more number of LNB species. Since the cluster analysis done based on genetic distance coefficients between the eighty isolates did not show any definite pattern of grouping, it can be presumed that diversity is distributed though out the landuse patterns.

The higher population of rhizobia in soil during pre-monsoon season in all landuse systems indicated the presence of efficient infective propagules in soil during summer. Considering this factor, along with other favourable factors such as low soil moisture content, pre-monsoon season could be the appropriate season for soil sampling and enumeration of bacterial population. The presence of large number of wild legumes with profuse nodulation provides an opportunity for identification of potential green cover crops for rapid recovery of soil fertility in degraded areas.

4.2. Landuse change patterns and their influence on soil properties and belowground biodiversity

Over the last three decades landuse pattern and land-cover under difference land-uses changed tremendously (Figures 11, 12 and 13). The area under degraded forest remained same indicating that rehabilitation programmes so far undertaken in the region are not successful and the pressure on degraded forest patches in the form of grazing, firewood and small timber collection is still prevailing. Satellite imagery analysis also indicated that area under arecanut plantation decreased over the last 30 years (Table 31). Such a decline in area under pure plantation of arecanut can be attributed to many factors. For instance decline in the market price of areca in 1990s led many farmers to convert arecanut plantation into either mixed plantation or even into monoculture of rubber. Some of the plantations were also converted into homegardens due to splitting of joint families into many nuclear families.

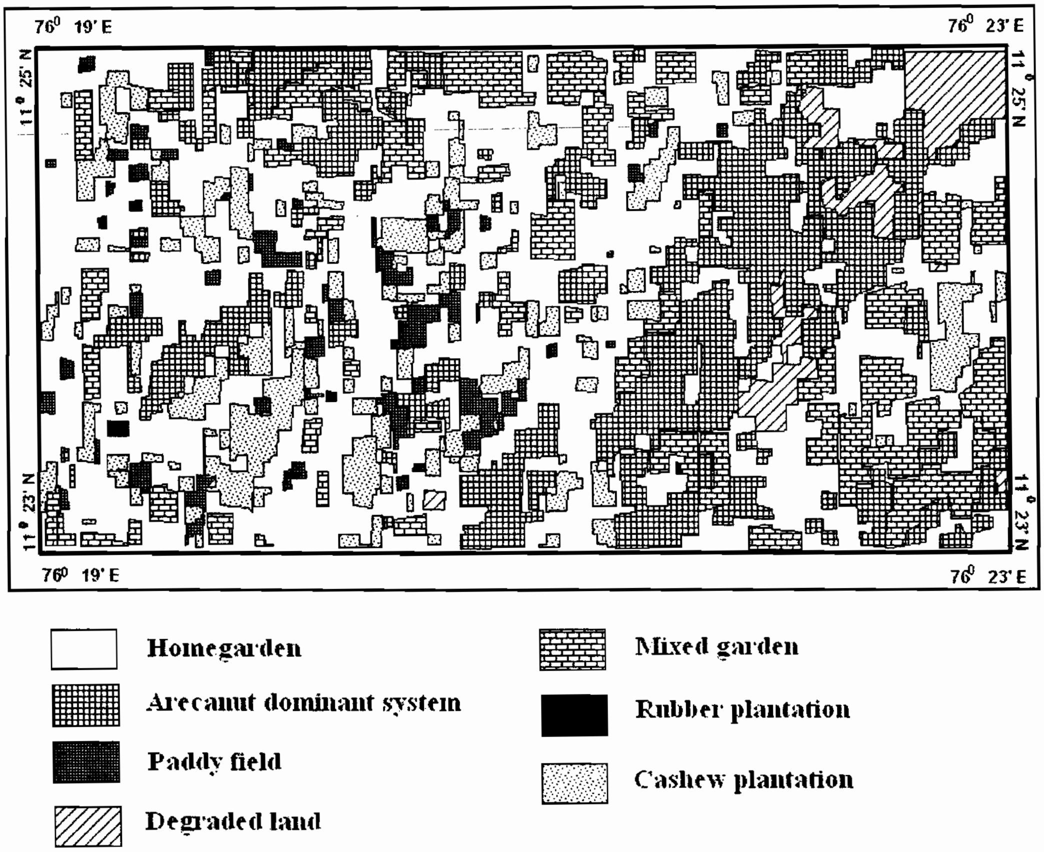

Figure 11. Landuse and landcover of Karakkode micro-watershed of the Kerala part of Nilgiri Biosphere Reserve in 1973

The study also revealed that some of the mixed gardens were changed into coconut dominant gardens in 1990s due to increase in demand and price of coconut. Thus area under mixed plantation declined in 1990s as compared to that in 1970s. However, due to Mandari disease (caused by coconut eriophyid mites), yield of coconut decreased drastically and pure plantations of coconut became unsustainable. Thus during late 1990s farmers again started introducing several other crops along with coconut leading to considerable increase in mixed plantations.

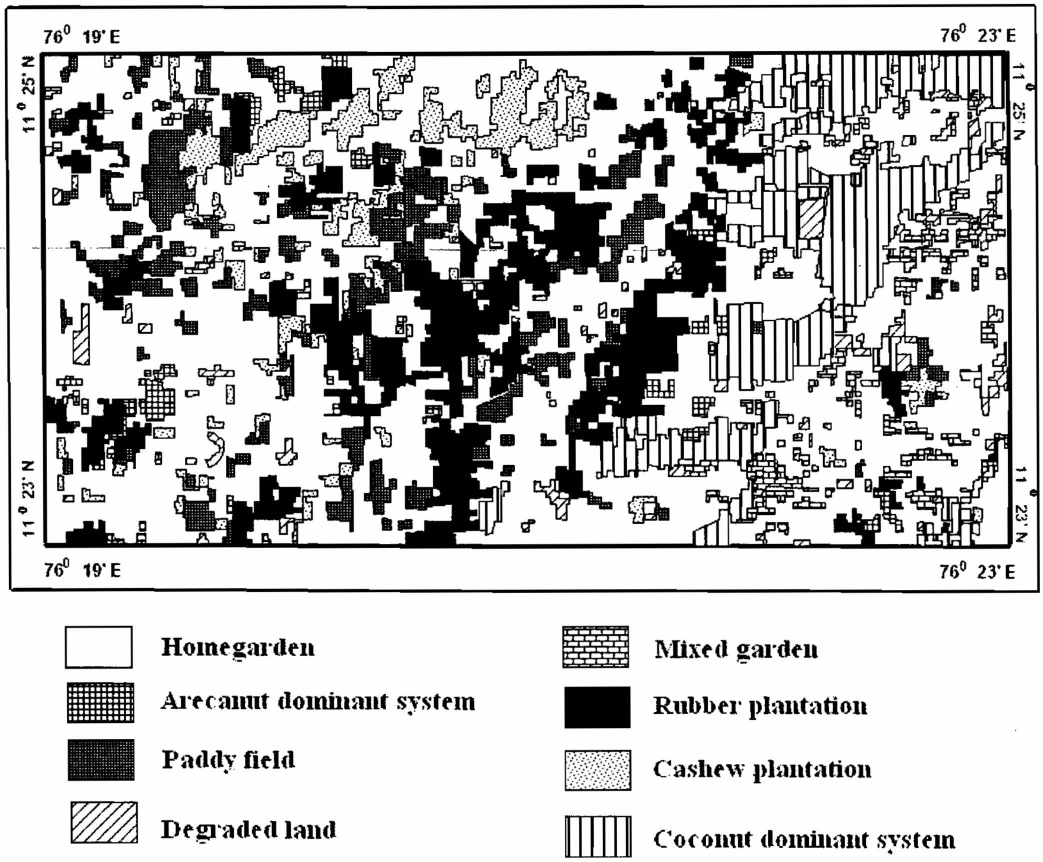

Figure 12. Landuse and landcover of Karakkode micro-watershed of the Kerala part of Nilgiri Biosphere Reserve in 1990.

Over the last 30 years increase in number of landuse types in the study area was also observed. For instance, rubber and private teak plantations which were once either totally absent or represented in small area are common now. Diversification of landuse types driven by policy, socio-cultural and economic changes were also reported elsewhere in Kerala State (Thampi, 1995). As also reported elsewhere in the State, a large area once under paddy cultivation was transformed into perennial cropping systems. Since this kind of transformation of annual crop systems into agroforestry and farm forestry systems is recent one, in the present study, we have recorded generally no significant between different landuse systems for the soil properties and belowground diversity.

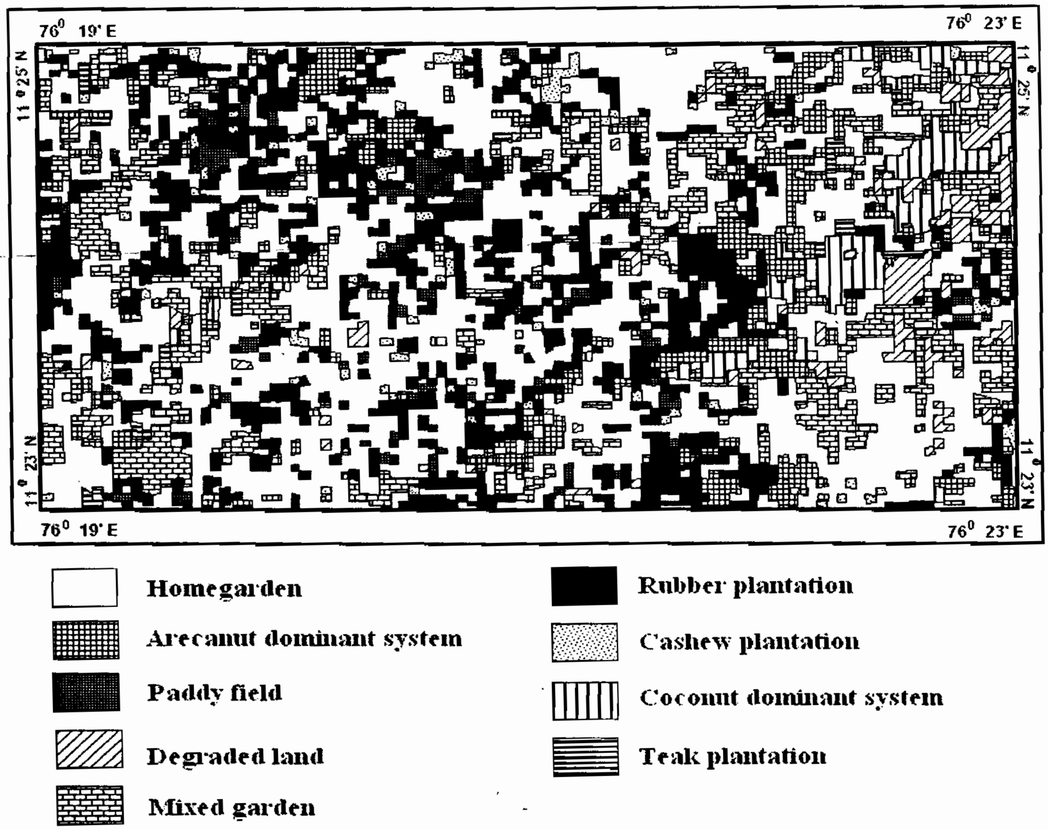

Figure 13. Landuse of Karakkode micro-watershed of the Kerala part of Nilgiri Biosphere Reserve in 2000.

Table 31. Area statistics of landuse in the Karakkode micro-watershed area in the Kerala part of Nilgiri Biosphere Reserve. Values in parentheses are % of total land area.

Landuse	Area (km^2) of different landuse systems in different years		
	1973	1990	2000
Paddy fields	5.51 (20.60)	2.06 (7.71)	0.55 (2.07)
Homegardens	9.35 (35.01)	11.99 (44.88)	12.85 (48.10)
Polyculture farms	2.99 (11.20)	2.23 (8.35)	3.20 (11.97)
Arecanut dominant systems	5.06 (18.93)	1.98 (7.41)	2.28 (8.55)
Coconut dominant systems	0 0)	2.58 9.65)	1.09(4.09)
Rubber plantation	0.03 (0.12)	3.55 (13.29)	4.90 (18.32)
Cashew plantation	2.77 (10.36)	1.33 (4.98)	0.45 (1.69)
Teak plantation (private)	0 (0)	0 (0)	0.38 (1.43)
Degraded forest	1.01 (3.78)	1.00 (3.74)	1.01 3.78)

4.3. Socioeconomic factors influencing landuse change and biodiversity management

In the study area, the average family size is 4.1 individuals. When adult male and female members of each family are considered, 99% of them are literate and among them 10% are post-graduates, 40% are graduates while the rest are with primary or secondary education. The survey also revealed agriculture to be the main occupation of only 48% families. Based on wealth ranking exercise, respondents were categorized into poor, medium and rich families of the locality. Proportion of poor, medium and rich families is 40%, 50% and 10%, respectively.

The details of landholdings in the study area are given in Table 32. Polyculture homegarden is the most extensive landuse followed by polyculture farmsteads (Table 33). The senior citizen interviews also substantiated the landuse changes recorded using the remote sense data. Based on these interviews it was revealed that in some areas about 25 years back even around 91% of total landholdings were under paddy cultivation (Table 34). Over the last 15 years, a substantial area under paddy has been put to pure or mixed coconut plantations. Rubber and cashew plantations have also been raised in paddy area but not as extensively as coconut plantations (Figure 14).

Table 32. Number of landholdings under different classes in the study site at Kerala part of Nilgiri Biosphere Reserve. N=100 landholdings.

Landholding classes [a]	Number of landholdings
Marginal (<1ha)	78
Small (1 - 2 ha)	19
Semi-medium (2 - 4 ha)	0
Medium (4 - 10 ha)	3

[a] Kerala Agricultural Department Annual Diary, 2004

Since majority of the landholdings are marginal/small, annual food crop yields are meant for household consumption (Table 35). Irrespective of the size of the landholdings, arecanut and rubber are sold for cash income. A shift in area under crops consumed locally to those supplied in the market means more and more export of biological produce outside the production system.

Table 33. Present landuse systems, frequency and range of size of landholdings under different landuse types in the Kerala part of Nilgiri Biosphere Reserve. N= 100 landholdings.

Landuse systems	Number of landholdings	Rang of landholding size (ha)	Number of land holdings in different landholding classes [a] (%)			
			Marginal (<1ha)	Small (1-2 ha)	Semi-medium (2- 4 ha)	Medium (4 -10 ha)
Annual crops	7	0.10 - 0.40	100	0	0	0
Homegardens	19	0.04 - 0.60	100	0	0	0
Polyculture farms	15	0.40 - 1.96	40	60	0	0
Arecanut with annuals	7	0.40 - 1.00	100	0	0	0
Arecanut with perennials	12	0.20 - 1.20	83	17	0	0
Coconut with perennials	8	1.40 - 6.00	0	67	0	33
Arecnut plantation	5	0.40 - 1.20	67	33	0	0
Coconut plantation	9	0.20 - 1.60	67	33	0	0
Rubber plantation	10	0.10 - 0.40	100	0	0	0
Cashew plantation	5	0.20 - 0.40	100	0	0	0
Teak plantation (private)	3	0.40 - 0.60	100	0	0	0

[a] Kerala Agricultural Department Annual Diary, 2004

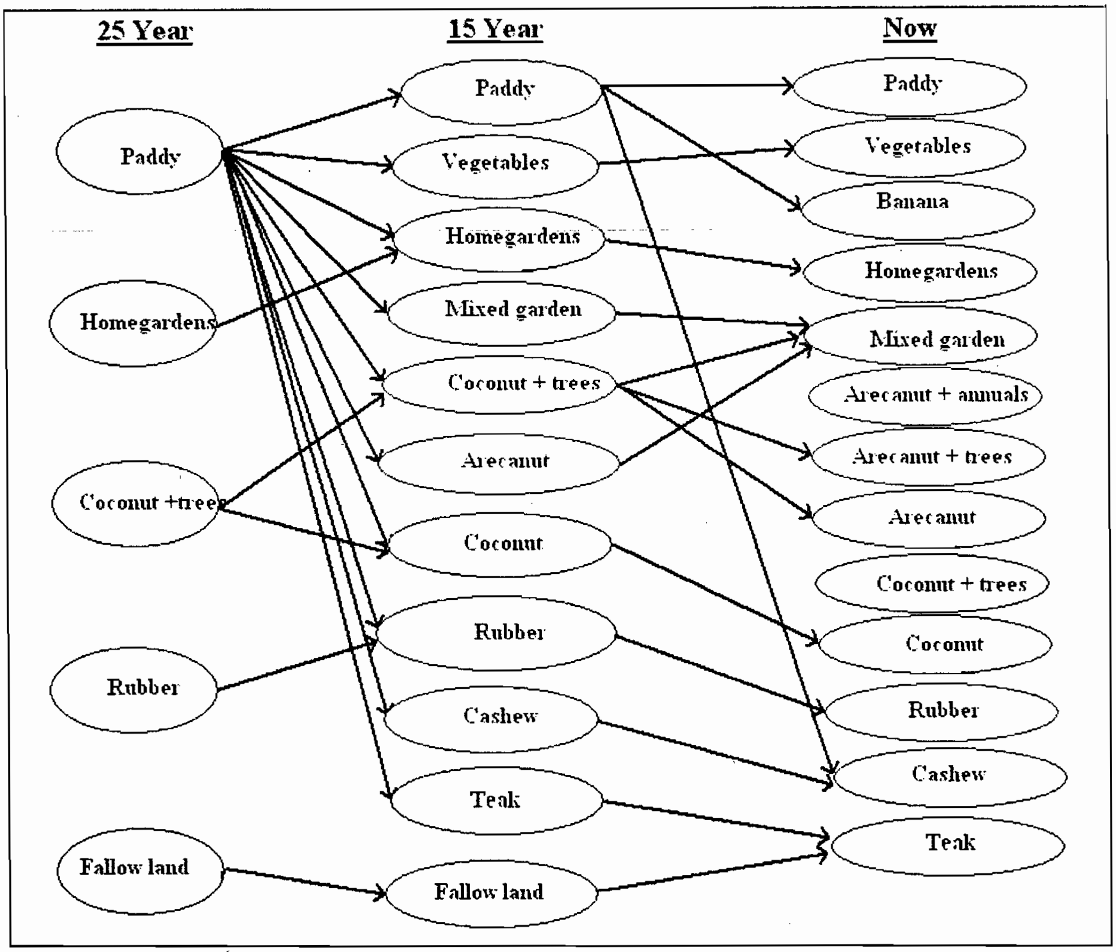

Figure 14. Landuse change pattern in the study area at Kerala part of Nilgiri Biosphere Reserve

Except in case of cashew and teak plantations, application of fertilizers are in cropping systems is common (Table 36). Organic fertilizers include cow dung, farmyard manure, bone meal, coconut cake, groundnut cake etc., and are generally purchased. In the traditional paddy cultivation, nutrient input was in the form of compost and green leaf manure. However, now inorganic fertilizer application, at the rate of 100- 150 kg ha^{-1} is common. PRA exercises indicated that more than 60% of the farmers in the region use inorganic fertilizer above the recommended dose for a given crop (KAU, 2002).

Table 34. Cropping systems in Karakkode village in the Kerala part of Nilgiri Biosphere Reserve. N= 100 landholdings

Cropping systems	Number of landholding under different cropping systems		
	About 25 yrs back	About 15 yrs back	At present
Annual crop based systems			
Paddy	91	14	2
Vegetables	--	14	3
Banana	--	--	2
Polyculture systems			
Polyculture homegardens	2	7	19
Polyculture farmlands	--	--	15
Plantations associated with other crops			
Arecanut with annuals	--	--	7
Arecanut with perennials	--	--	12
Coconut with perennials	2	16	8
Plantation of tree crops			
Arecanut Plantation	--	2	5
Coconut Plantation	--	35	9
Rubber Plantation	2	6	10
Cashew Plantation	--	2	5
Teak plantation	--	2	3
Fallow land	3	2	--
Total number of landholdings	100	100	100

Application of green leaf manure is a general practice in polyculture systems and tree crop dominant systems. PRA exercises also indicated that many farmers aware of the usefulness of incorporation of crop residues and mulching to improve the soil fertility. Farmers also have the traditional knowledge related to the properties of foliage of difference species and their usefulness in maintaining soil quality and fertility. For instance, according to some farmers, leaves of species like *Terminalia paniculata*, *Macaranga peltata* and

Helictres isora and *Calycoptreris floribunda* decompose quickly and release the nutrients to the soil. On the other hand, teak leaves can be incorporated into the soil to reduce the soil moisture in places where the water logging is common. However both quality and frequency of green leaf manuring vary from farm to farm. For instance, in homegarden, the range of application is between 0 kg ha^{-1} – 3,750 kg ha^{-1}. In addition, only about 28% of total respondents apply green leaf manure. Lack of cultivation of green leaf manure species and also non-availability of sufficient quantity of green leaf manure in the nearby area are responsible for its low and irregular application.

Table 35. Use of yield of different landuse systems in the Karakkode village in the Kerala part of Nilgiri Biosphere Reserve

Cropping systems	Use of yield (%)		Range of use of yield (%)	
	For household	For sale	For household	For sale
Annual crops	75.0	25.0	55 - 100	25 - 45
Polyculture systems				
Homegarden	70.8	29.3	45 - 100	20 - 55
Mixed garden	77.5	22.5	45 - 100	20 - 55
Plantations associated with other crops				
Arecanut with annuals	11.7	88.3	0 - 35	65 - 100
Arecanut with perennials	12.5	87.5	20 - 40	60 - 100
Coconut with perennials	8.3	91.7	0 - 25	75 - 100
Monoculture systems				
Arecanut	0.0	100.0		100
Coconut	20.0	80.0	0 - 60	40 - 100
Rubber	0.0	100.0		100
Cashew	30.0	70.0	25 - 35	65 - 75
Teak	0.0			

Table 36. Use of fertilizers and green manure in different landuse systems in the Kerala part of Nilgiri Biosphere Reserve

Landuse types	Frequency of fertilizer use (%)			Mean and range of quantity of fertilizer (kg ha^{-1})		
	Inorganic	Organic	Green leaf manure	Inorganic	Compost	Green leaf manure
Annual crops	100	25	0	437 (100 – 750)	250 (0 - 1000)	0 (0)
Polyculture systems						
Homegarden	14	71	43	71 (0 - 500)	2905 (2000 - 8333)	1476 (0 - 3750)
Mixed garden	80	100	80	502 (250 - 1136)	1386 (455 - 2500)	2944 (1719 - 5682)
Plantations associated with other crops						
Arecanut with annuals	33	100	33	111 (0 - 333)	1736 (1042 - 2500)	1667 (0 - 5000)
Arecanut with perennials	67	67	50	407 (314 - 833)	1845 (0 - 3571)	3750 (2143 - 6250)
Coconut with perennials	33	100	67	167 (0 - 500)	1421 (1333 - 1500)	1000 (1000 - 2000)
Monoculture systems						
Arecanut	67	100	0	236 (208 - 500)	3347 (1667 - 6500)	0 (0)
Coconut	67	100	33	244 (0 - 406)	3645 (938 -5000)	417 (0 - 1250)
Rubber	100	50	0	217 (150-300)	1037 (0 - 2000)	0 (0)
Cashew	0	0	0	0 (0)	0 (0)	0 (0)
Teak	0	0	0	0 (0)	0 (0)	0 (0)

Pesticides application was common in about 50% of landholdings (Table 37). Majority of the farmers use inorganic pesticides; and the tendency of use of pesticides, including some of the banned pesticides, above the recommended dose (KAU, 2002) is also increasing in the region.

Table 37. Use of pesticides in different landuse systems in the Kerala part of Nilgiri Biosphere Reserve

Landuse types	Number of farmers (%) using pesticides			
	Bio-pesticides	Chemical pesticides	Both	None
Annual crops	0	75	25	0
Polyculture systems				
Homegarden	0	29	29	43
Mixed garden	0	40	20	40
Plantations associated with other crops				
Arecanut with annuals	0	67	0	33
Arecanut with perennials	33	33	0	33
Coconut with perennials	33	67	0	0
Monoculture systems				
Arecanut	0	0	0	100
Coconut	0	33	0	67
Rubber	0	100	0	0
Cashew	0	0	0	100
Teak	0	0	0	100

In the study area, rainfed paddy cultivation was prevailing about 25 years back. Irrigation systems in the region were expanded in due course of time in order to provide water for growing paddy in two or three seasons. However, the relative paddy became unfavourable and that appears to be the main reason for substitution of paddy by other crops. In addition, continuous availability of water through canals also tempted the farmers to cultivate economically profitable crops like coconut, arecanut, banana and vegetables in the paddy field and to abandon the paddy cultivation. Expansion of irrigation facilities thus indirectly lead to the conversion of paddy field into tree-based systems in the region. At present about 67% of the farmers use canal water (Table 38) and another 13% well water for irrigation. Cashew and teak plantations are not being irrigated.

It may be mentioned here that in general, application of both cow dung and farmyard manure to improve soil fertility and crop yield is significantly low due to absence of animal husbandry. Only 30% of total number of landholdings studied possesses one or two individuals of domestic animals like cattle, goat and hen.

Table 38. Water use in different landuse systems in the Kerala part of Nilgiri Biosphere Reserve. N= 100 landholdings

Landuse types	Source of water		
	Canal	Well	Rain
Annual crops	0	25	75
Polyculture systems			
Homegarden	29	14	57
Mixed garden	80	20	0
Plantations associated with other crops			
Arecanut with annuals	100	0	0
Arecanut with perennials	100	0	0
Coconut with perennials	67	33	0
Monoculture systems			
Arecanut	100	0	0
Coconut	100	0	0
Rubber	25	25	50
Cashew	0	0	100
Teak	0	0	100

Using the perceptions of participants of PRA exercises on different parameters which have bearing on overall management of crop lands, the Management Value Index (MIV) in a scale of 3 to 18 was derived. In the present study, MIV obtained for different croplands ranged from 7.48 to 13.18. In each sample landuse system, the value declined over the last 25 years; the decline could be as high as 29% of MIV in the past (Table 39). It may be noted here that according to the informants, if the farm was own land of a farmer, management will be better as compared to that in the leased land. In fact, at present most of the farms studied are own lands of the respondents while majority of them were leased lands in olden days. Thus, it is clear that MIV is not directly linked with the ownership of farms. The major reasons in the study sites for decline in MIV can thus be attributed to factors like change in cropping patterns with more emphasis on perennial cash crops or food crops, less importance attached to agriculture as it is becoming a secondary occupation to most of the farmers, tolerance of perennial crops to moderate to poor management and use of pesticides and weedicides beyond recommended dosage. Therefore, modern methods of farm management prevailing in this area as against to organic farming system in the past is expected to have different impact on soil fertility and belowground biodiversity.

Table 39. Mean Management Index Value (MIV) for different landuse systems in the Kerala part of Nilgiri Biosphere Reserve. Values in parentheses are the range.

Landuse types	Management Index value (MIV)	
	Present	Past (about 25 years back)
Annual crops	11.4 (10.2-13.17)	14.4 (13.1-16.4
Polyculture systems		
Homegarden	13.2 (10.3-15.3)	14.1 (12.9-15.5)
Mixed garden	12.7 (11.2-13.3)	13.8 (11.2-15.3)
Plantations associated with other crops		
Arecanut with annuals	12.5 (11.3-14.0)	13.1 (12.2-14.2)
Arecanut with perennials	10.3 (8.0-11.3)	12.1 (10.1-13.6)
Coconut with perennials	9.9 (8.7-11.2)	11.4 (10.3-12.4)
Monoculture systems		
Arecanut	10.4 (9.0-12.7)	11.6 (9.6-13.0)
Coconut	11.1 (9.4-13.4)	12.0 (10.6-13.7)
Rubber	9.0 (7.0-12.2)	11.6 (9.5-13.7)
Cashew	8.4 (6.3-9.7)	11.8 (11.3-12.9)
Teak	7.5 (4.4-9.6)	7.8 (4.4-10.4)

About 89% of the respondents are aware of soil fauna like earthworms, termites, millipedes and centipedes, and only about 20% aware about soil microbes. Among those aware about earthworms, 80% considered it as a beneficial organism, while the rest were not aware of their positive or negative role. Among those aware about termites, 25% considered it as useful organism in breaking down the litter accumulated while 20% regarded it as harmful as they attack propagules and seedlings of many crops. None of the farmers found positive or negative role of millipedes or centipedes in the soil. Even those aware about soil microbes, do not know about their role in the soil.

5. STRATEGIES FOR CONSERVATION AND MANAGEMENT OF BELOWGROUND BIODIVERSITY

Based on studies conducted on vegetation structure and composition, soil properties and of soil flora and fauna in different landuse systems of the project area, certain conclusions can be drawn. The moist deciduous forest located near human habitation are highly degraded, possesses sparse vegetation, compacted and nutrient poor soil when compared to the similar kind of forest located away from the human habitation. Though these two forests are originally similar in terms of aboveground vegetation, the degraded forests showed relatively higher value for ant density and diversity. Thus ants particularly *Lobopelta sp.* and *Leptogenys sp.* could be considered as indicators species of forest disturbance. In the study area, plantations of teak, rubber and cashew are located in almost similar terrain to that of moist deciduous forest. Moreover, age of these plantations ranged from 3 to 25 years and before that they were also representing either degraded or good moist deciduous forests. Comparatively high diversity of AM fungi in soils under cashew plantation, degraded forest and teak plantation than that in moist deciduous forests situated away from human habitation indicate that conditions in these soils are highly suitable for the proliferation of a host of mycorrhizal fungi Though more studies would be required to arrive at any firm conclusions, the available data show that plant dependency on mycorrhiza is apparently more in highly degraded sites. In the study area, majority of the current landholdings were under paddy cultivation about 25 years back. Thus, similarity in terms of belowground biodiversity between paddy fields and other landuse systems derived from paddy fields could be pronouncing. However, absence of some of the soil faunal elements in certain landuse systems recorded in the study area could be attributed to the differences in the crop combinations and management practices. For instance, low density of earthworm in annual crops and arecanut mixed with annual crops may be attributed to the excess use of inorganic fertilizers and pesticides. It may be pointed out here that among the endogeic worms *Parryodrilus lavelee and Pontoscolex corethrurus* showed maximum availability in a variety of landuse patterns. Thus it may be concluded that since these two species have a wide tolerance to landuse changes they may be suitable for land restoration purpose. It may also be mentioned here that apart from the season of sampling, landuse history, landuse pattern. crop combination etc. the sampling technologies adopted decide the qualitative and quantitative information that can be obtained on each group of soil fauna. Thus the sampling technologies to estimate different faunal groups need to be standardized considering both the faunal group under study and the landuse systems.

In general, dependency of majority of the farmers in the study area on croplands for the livelihood is relatively low either due small size of the landholding or due to attractive economic return from their non-farm activities. Studies carried out in the cultivated lands also indicated that organic carbon, exchangeable calcium, magnesium and potassium were considerably lesser than the level required for the optimum crop yield. It was also recorded that the contribution of trees and understorey species maintained for green leaf manure production to the total Importance Value Index of tree and understorey plant communities are significantly low and nil. Similarly cultivation and management of leguminous crops with a view to obtain green manure and soil fertility management in almost all croplands are neglected. Even the application green leaf manure, farmyard manures, cultivation of cover crops which are required to sustain the crop yield and soil fertility are not being adopted adequately. Over-harvest of biomass without sufficient nutrient input is leading to the loss of nutrients from the crop lands. Similarly, application at frequent interval of heavy dose of chemical pesticides into croplands can be attribute to the loss of below ground biodiversity. Thus it was concluded that continuous cultivation without external application of organic manures is identified as the reason for low productivity and soil organic matter depletion in different cropping systems. Similarly, in forest teak plantations, removal of litter from soil surface for fuel and mulching has been identified as one of the major causes for the decline in the soil moisture, extractable phosphorus, exchangeable potassium and exchangeable magnesium. In addition, growth of teak in these plantations was in general poor as indicated by low tree gbh, 20% less than the expected value for the trees of same age. Studies also revealed that some of the faunal characteristics are either absent or sparsely represented in a given landuse systems. It was recorded that in the unmanaged systems the root colonization of VAM fungi were more than in some of the well managed mono-cropping systems. Thus it was clear that in unmanaged systems plants are more dependent on mycorrhiza for growth. Further analysis of data indicated that majority of the landuse systems were not significantly different from the un-managed plantations in terms of per cent root colonization by mycorrhiza indicating that these plots are also poorly managed. Since the respondents are literate and have the tendency to imbibe new knowledge and techniques to improve their croplands, attempts to promote suitable activities for the conservation and management of belowground biodiversity are expected to become successful. In this context, post-project meetings were organized to present the results of the study before the farmers and land managers. The participants agreed with the fact that continuous cultivation without external application of organic manures and lack of efforts to conserve organic matters in the systems are the reasons for low productivity and soil organic matter depletion in different cropping systems. Farmers also recognized the competition between the weed community and crop community as an important cause for difficulty in maintaining the optimum crop yield. As already indicated in the landscape of Chaliyar River Watershed, the study recorded a faster rate in landuse and land cover changes. The farming community also expressed the view that the conversion of one cropping system to another is more frequent resulting in the increased soil erosion and runoff rates. Considering these aspects, four strategies namely, a) application of green leaf manure, b) application of plant growth promoting microorganisms and earthworm rich compost, c) reduction of nutrient loss from the croplands, and d) growth of leguminous and/ or biomass transfer species in the crop lands for maintaining soil fertility, sustainable yield and to enhance density and diversity of soil biota in different cropping systems have been identified. During the second phase of the project on-farm participatory experiments to demonstrate the usefulness of these strategies and also disseminate information and technology to the wider user groups may be undertaken.

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Appendix I. Mean density, basal area, and Importance Value Index (IVI) of trees in a semi evergreen forest at Nadukani, in the Kerala part the Nilgiri Biosphere Reserve.

Sl. No.	Name of the Species	Density (individuals ha^{-1})	Basal area (m^2 ha^{-1})	IVI
1	*Knema attenuata*	316	4.984	47.83
2	*Hopea racophlea*	174	4.266	32.71
3	*Myristica malabarica*	190	1.420	29.23
4	*Fahrenheitia zeylanica*	76	2.510	17.03
5	*Vateria indica*	64	1.565	13.42
6	*Cinnamomum malabatrum*	44	1.626	10.99
7	*Syzygium gardneri*	20	2.879	9.95
8	*Kingiodendron pinnatum*	46	0.970	9.64
9	*Polyalthia fragrans*	28	1.793	9.37
10	*Calophyllum polyanthum*	20	2.581	8.75
11	*Baccaurea courtallensis*	44	0.257	8.37
12	*Syzygium mundagam*	4	3.000	7.70
13	*Aglaia* sp.1	18	0.508	7.22
14	*Artocarpus hirsutus*	14	1.532	6.40
15	*Holigarna arnottiana*	12	1.696	6.36
16	*Bischofia javanica*	6	1.817	5.40
17	*Polyalthia coffeoides*	16	0.993	5.32
18	*Hydnocarpus pentandra*	16	0.539	4.28
19	*Mallotus beddomei*	20	0.169	4.26
20	*Mangifera indica*	12	0.675	3.50
21	*Actinodaphne bourdillonii*	8	0.472	2.73
22	*Actinodaphne anguistifolia*	8	0.286	2.31
23	*Diospyros bourdillonii*	10	0.020	2.11
24	*Aglaia lawii*	6	0.487	2.09
25	*Croton malabaricus*	6	0.307	1.94
26	*Diospyros* sp.3	8	0.111	1.91
27	*Toona ciliata*	2	0.650	1.90
28	*Palaquium ellipticum*	8	0.083	1.84
29	*Nothopegia racemosa*	8	0.051	1.77
30	*Drypetes oblongifolia*	6	0.216	1.73
31	*Lagerstroemia microcarpa*	2	0.571	1.72
32	*Ficus beddomei*	2	0.559	1.69
33	*Orophea erythrocarpa*	8	0.009	1.67
34	*Litsea mysorensis*	4	0.357	1.64
35	*Spondias pinnata*	2	0.528	1.62
36	*Nothopegia* sp.	6	0.107	1.48
37	Unidentified 410	2	0.456	1.46
38	*Garcinia morella*	6	0.075	1.41

-cont'd---

Appendix I (Cont'd). Mean density, basal area, and Importance Value Index (IVI) of trees in a semi evergreen forest at Nadukani, in the Kerala part the Nilgiri Biosphere Reserve.

Sl. No.	Name of the Species	Density (individuals ha^{-1})	Basal area ($m^2 ha^{-1}$)	IVI
39	*Diospyros oocarpa*	4	0.210	1.31
40	*Cullenia exarillata*	4	0.146	1.16
41	*Ficus drupacea*	2	0.204	1.14
42	*Syzygium densiflorum*	4	0.127	1.12
43	*Holigarna grahamii*	2	0.252	0.99
44	*unidentified 174*	2	0.221	0.92
45	*Unidentified 162*	2	0.187	0.84
46	*Unidentified 490*	2	0.179	0.82
47	*Unidentified 649*	2	0.139	0.73
48	*Vitex altissima*	2	0.125	0.70
49	*Unidentified 455*	2	0.117	0.68
50	*Cassia fistula*	2	0.098	0.64
51	*Otonephelium stipulaceum*	2	0.089	0.62
52	Unidentified 591	2	0.082	0.60
53	*Macaranga peltata*	2	0.060	0.55
54	*Trewia polycarpa*	2	0.050	0.53
55	*Artocarpus gomezianus*	2	0.043	0.51
56	*Meiogyne pannosa*	2	0.039	0.50
57	*Diospyros paniculata*	2	0.036	0.50
58	*Litsea glabrata*	2	0.030	0.48
59	*Alstonia scholaris*	2	0.019	0.46
60	*Canthium angustifolium*	2	0.017	0.45
61	*Drypetes elata*	2	0.012	0.44
62	*Diospyros assimilis*	2	0.011	0.44
63	*Xanthophyllum arnottianum*	2	0.009	0.43
64	*Gmelina arborea*	2	0.001	0.42
65	*Cyathocalyx zeylanica*	2	0.002	0.42
65	*Mallotus stenanthus*	2	0.002	0.42
67	*Flacourtia montana*	2	0.003	0.42

Appendix II. Mean density, basal area, frequency and Importance Value Index (IVI) of tree species moist deciduous forest at Pattakkarimbu in the Kerala part of the Nilgiri Biosphere Reserve

Sl No	Species	Density (individuals ha^{-1})	Basal area ($m^2 ha^{-1}$)	IVI
1	*Xylia xylocarpa*	96.30	3.48	54.59
2	*Terminalia paniculata*	66.67	3.24	49.05
3	*Grewia tiliaefolia*	45.37	4.21	42.65
4	*Tectona grandis*	26.85	2.79	26.12
5	*Terminalia crenulata*	21.30	1.73	20.17
6	*Terminalia bellerica*	7.41	1.91	13.12
7	*Dillenia pentagyna*	19.44	0.62	13.01
8	*Schleichera oleosa*	23.15	0.34	11.43
9	*Stereospermum colais*	16.67	0.63	11.20
10	*Mitragyna parviflora*	12.04	0.55	8.45
11	*Dalbergia latifolia*	11.11	0.22	6.73
12	*Holarrhena pubescens*	10.19	0.03	4.70
13	*Bridelia retusa*	6.48	0.24	4.52
14	*Lagerstroemia flos-reginae*	4.63	0.43	4.34
15	*Wrightia tinctoria*	7.41	0.04	4.07
16	*Wendlandia thyrsodea*	6.48	0.02	3.17
17	*Bauhinia malabarica*	3.70	0.17	2.87
18	*Emblica officinalis*	3.70	0.15	2.81
19	*Lagerstroemia microcarpa*	2.78	0.23	2.63
20	*Sapindus laurifolius*	3.70	0.01	1.84
21	*Mallotus philippinensis*	2.78	0.03	1.72
22	*Odina wodier*	1.85	0.12	1.60
23	*Cyclostemon confertiflorus*	2.78	0.03	1.43
24	*Sterculia guttata*	2.78	0.03	1.41
25	*Careya arborea*	1.85	0.02	1.14
26	*Haldinia cordifolia*	0.93	0.13	1.14
27	*Adavakkadan*	0.93	0.04	0.69
28	*Pterocarpus marsupium*	0.93	0.02	0.61
29	*Butea monosperma*	0.93	0.01	0.59
30	*Cordia myxa*	0.93	0.01	0.58
31	*Ricinocarpodendron* sp.	0.93	0.01	0.55
32	*Unidentified 2*	0.93	0.003	0.54
33	*Strychnos nux-vomica*	0.93	0.001	0.53

Appendix III. Mean density, basal area and IVI of tree species in the degraded forest located in the Manalpadam village in the Kerala part of the Nilgiri Biosphere Reserve.

Sl. No.	Species	Density (Individuals ha^{-1})	Basal area (m^2ha^{-1})	IVI
1	*Terminalia paniculata*	279	3.956	278.635
2	*Macaranga peltata*	4	0.004	6.022
3	*Dalbergia latifolia*	4	0.015	6.308
4	*Strychnos nux-vomica*	13	0.013	9.032

Appendix IV. Mean density, basal area and IVI of tree species in the teak plantation at Kariem-muriem in the Kerala part of the Nilgiri Biosphere Reserve

Sl No	Species	Density (individuals ha^{-1})	Basal area (m^2ha^{-1})	IVI
1	*Tectona grandis*	165	10.36	245.31
2	*Terminalia paniculata*	5	0.02	6.13
3	*Wrigthia tinctoria*	6	0.02	7.51
4	*Bombax ceiba*	5	0.15	8.08
5	*Holarrhena antidycenterica*	1	0.00	1.38
6	*Dalbergia latifolia*	1	0.06	1.82
7	*Miliusa tomentosa*	1	0.00	1.38
8	*Careya arborea*	1	0.00	1.38
9	*Strychnos nux-vomica*	2	0.01	2.82
10	*Dillenia pentagyna*	1	0.00	1.39
11	*Alstonia scholaris*	1	0.01	1.43
12	*Bambusa bambos*	5	1.80	21.37

Appendix V. Contribution to total IVI of tree communities by different species of polyculture homegardens and polyculture farmlands in the Kerala part of Nilgiri Biosphere Reserve.

	Species	Polyculture homegardens	Polyculture farm lands
1.	*Anona squamosa*	4.4	2.2
2.	*Areca catechu*	4.7	1.6
3.	*Artocarpus heterophyllus*	97.7	152.2
4.	*Bauhinia pupurea*	9.3	2.6
5.	*Bombax ceiba*	0.9	0
6.	*Bridelia rhetusa*	0.7	0
7.	*Careya arborea*	3.4	0
8.	*Citrus* sp.	1.6	0
9.	*Cocos nucifera*	0.9	2
10.	*Coffea robusta*	79.7	81.4
11.	*Cordia myxa*	0.7	31.2
12.	*Dalbergia latifolia*	1.7	0
13.	*Erythrina indica*	1.1	0
14.	*Eugenia jambosa*	1.6	0
15.	*Garcinia gummigutta*	1.9	0
16.	*Gliricidia sepium*[a]	1.9	0.6
17.	*Glochidion malabaricum*	1.1	0
18.	*Haevea brasiliensis*	0.0	2
19.	*Haldina cordifolia*	20.6	0
20.	*Hibiscus tiliaceus*	5.7	0
21.	*Holarrhena antidysenterica*	0.0	1.2
22.	*Ixora coccinea*	1.3	0
23.	*Macaranga peltata*[a]	1.0	0
24.	*Mangifera indica*	16.9	4
25.	*Mitragyna parviflora*	9.9	6.4
26.	*Moringa oleifera*	2.1	0.6
27.	*Myristica fragrans*	1.4	0
28.	*Peltophorum species*	1.7	6.6
29.	*Psidium guava*	0.9	0
30.	*Schleichera oleosa*	2.7	2.2
31.	*Strychnos nux -vomica*	2.1	0
32.	*Swietenia macrophylla*	0.0	0
33.	*Symplocos acuminata*	4.4	0
34.	*Tamarindus indica*	1.0	0.6
35.	*Tectona grandis*	1.6	0
36.	*Terminalia cattapa*	11.3	0
37.	*Terminalia paniculata*[a]	0.9	0
38.	*Trema orientalis*	5.0	0
39.	*Xylia xylocarpa*[a]	0.0	2

[a], species maintained as source of green leaf manure.

Appendix VI. Contribution to total IVI of tree communities by different species in farm lands where a dominant tree crop associated with other crops in the Kerala part of NBR

	Species	IVI contribution by trees in different landuse systems		
		Areca with annuals	Areca with perennials	Coconut with perennials
1	*Areca catechu*	202.7	146.0	63.0
2	*Artocarpus heterophyllus*	0.0	4.2	3.7
3	*Cocos nucifera*	75.0	144.0	195.3
4	*Erythrina indica*	6.0	0.0	0.0
5	*Garcinia gummigutta*	3.3	0.0	0.0
6	*Gliricidia sepium*	0.0	1.2	0.0
7	*Macaranga peltata*[a]	2.3	2.8	0.0
8	*Mangifera indica*	0.0	0.0	30.0
9	*Psidium guava*	4.3	0.0	0.0
10	*Tamarindus indica*	2.0	0.0	0.0
11	*Tectona grandis*	5.3	0.8	5.3
12	*Terminalia cattapa*	0.0	0.0	3.0
13	*Terminalia paniculata*[a]	0.0	1.3	0.0

[a], species maintained as source of green leaf manure.

Appendix VII: Contribution to total IVI of tree communities by different species in monoculture plantation in the Kerala part of NBR

	Species	Arecanut	Coconut	Rubber	Cashew	Teak
1	*Aegle marmelos*	0.0	0.0	0.0	0.0	2.0
2	*Anacardium occidentale*	0.0	0.0	0.0	241.7	0.0
3	*Anona squamosa*	0.0	2.7	0.0	0.0	3.7
4	*Areca catechu*	224.0	3.0	0.0	0.0	0.0
5	*Artocarpus heterophyllus*	0.0	6.7	0.0	0.0	0.0
6	*Careya arborea*	0.0	0.0	0.0	0.0	2.0
7	*Carica papaya*	0.0	2.7	2.0	0.0	0.0
8	*Cocos nucifera*	73.3	267.0	11.8	8.0	0.0
9	*Cordia myxa*	0.0	4.0	0.0	0.0	4.0
10	*Dalbergia latifolia*	0.0	0.0	0.0	7.7	3.7
11	*Haevea brasiliensis*	0.0	0.0	265.5	0.0	0.0
12	*Haldina cordifolia*	0.0	3.3	0.0	7.3	3.0
13	*Macaranga peltata* [a]	0.0	0.0	1.8	0.0	0.0
14	*Mangifera indica*	1.3	0.0	0.0	0.0	0.0
15	*Myristica fragrans*	2.7	0.0	0.0	0.0	0.0
16	*Peltophorum species*	0.0	0.0	0.0	0.0	4.0
17	*Plumeira alba*	0.0	0.0	0.0	0.0	3.0
18	*Psidium guava*	0.0	0.0	0.0	7.3	0.0
19	*Strychnos nux -vomica*	0.0	6.3	0.0	0.0	4.0
20	*Symplocos acuminata*	0.0	0.0	0.0	3.3	0.0
21	*Tamarindus indica*	0.0	0.0	0.0	0.0	3.7
22	*Tectona grandis*	0.0	0.0	5.5	0.0	241.0
23	*Terminalia cattapa*	0.0	0.0	0.0	0.0	0.0
24	*Terminalia paniculata* [a]	0.0	0.0	0.0	24.0	16.7
25	*Trema orientalis*	0.0	0.0	0.0	0.0	2.7
26	*Wrightia tinctoria*	0.0	0.0	0.0	0.0	3.7
27	*Xylia xylocarpa* [a]	0.0	0.0	0.0	0.0	3.7

[a], species maintained as source of green leaf manure.

Appendix VIII. Contribution to total IVI of shrub communities by different species in semi evergreen forests in the Kerala part of NBR

Species	Semi evergreen forest	Moist deciduous forest	Degraded forest	Teak Plantation
Abelmoschus moschatus	----	----	16.4	18.7
Alangium salvifolium	3.1	---	---	---
Allophylus cobbe	----	2.6	----	----
Ardisia solanacea	9.2	---	---	---
Ardisia solanacea	----	5.4	----	----
Atalantia wightii	4.9	---	---	---
Breynia retusa	3.9	---	---	---
Chromolaena odorata	----	50.4	49.3	60.2
Clerodendrum viscosum	----	68.1	64.1	64.7
Embelia tsjerium-cottam	----	5.8	----	----
Glycosmis arborea	3.0	---	---	---
Gomphandra tetrandra	23.0	---	---	---
Gomphostemma heyneanum	----	33.2	30.2	----
Helictris isora	----	63.4	59.6	61.1
Leea crispa	----	30.1		----
Memecylon wallichii	108.4	---	---	---
Pavetta indica	127.8	---	---	---
Pavetta tomentosa	----	3.9	----	----
Pithecellobium gracile [a]	3.8	---	---	---
Rauvolfia serpentina	----	----	----	13.3
Syzigium zeylanicum	2.6	---	---	---
Urena lobata	----	----	19.5	21.1
Zanthoxylum ovalifolium	10.3	---	---	---
Ziziphus oenoplea	----	10.2	21.2	24.6
Ziziphus rugosa	----	26.9	26.9	36.3

[a], leguminous species

Appendix IX. Contribution to total IVI of herb communities by different species in semi evergreen forests in the Kerala part of NBR

Species	Semi evergreen forest	Moist deciduous forest	Degraded forest	Teak Plantation
Amorphophalus dubium	38.1	67.3	63.2	59. 4
Asystasia gangetica	4.3	----	----	----
Borreria pusilla	1.6	1.7	2.0	8.1
Curculugo orchioides	7.7	12.2	13.5	17.2
Curcuma neilgherrensis	52.3	73.1	71.3	63.3
Elphantopus scapber	23.8	34.1	49.1	49.0
Geophila repens	34.6	37.3	29.3	37.0
Impatiens chinensis	8.0	----	----	----
Leucas eriostorma	1.6	----	----	----
Murdennia simplex	3.6	----	----	----
Nervilia prainiana	27.5	----	----	----
Oldenlandia auricualta	10.2	18.9	3.8	----
Ophiorrhiza hirsutula	13.2	----	---0	----
Peristylus avistatus	7.1	----	----	----
Remusatia vivipara	27.3	----	----	----
Rostellaria japonica	35.7	48.6	57.7	54.8
Scutellaria discolor	4,0	6.8	3.4	
Sida rhombifolia	---	----	6.7	11.2
Sonerila rheedii	3.4	----	----	----

Appendix X. Contribution to total IVI of shrub community polyculture homegardens and polyculture farmlands in the Kerala part of Nilgiri Biosphere Reserve

	Species	Polyculture homegardens	Polyculture farm lands
1	*Caesalpinia pulcherrima* [a]	2.7	0
2	*Caliandra brivipes* [a]	2	0
3	*Calicopteris floribunda*	10.7	75
4	*Clerodendron paniculatum*	6.2	12
5	*Eupatorium odoratum*	112	82.8
6	*Ficus asperima*	13.3	38.8
7	*Gardenia jasminoides*	8	0
8	*Glycosmis pentaphylla*	16	8.4
9	*Helicteres isora*	16	27.6
10	*Hibiscus rosa sinensis*	9.3	0
11	*Holarrhena antidysenterica*	4.7	8.6
12	*Ixora coccinea*	12	0
13	*Lantana camera*	46.2	33
14	*Lawsonia inermis*	12.8	0
15	*Mallotus philippinensis*	0	0
16	*Mussaenda frondosa*	4.3	0
17	*Peltophorum* sp. [a]	5.7	0
18	*Ricinus communis*	12.5	2.4
19	*Streblus asper*	0	0
20	*Urena lobata*	5.6	11.2

[a], leguminous species

Appendix XI. Contribution to total IVI of shrub communities by different species in farm lands where a dominant tree crop associated with other crops in the Kerala part of Nilgiri Biosphere Reserve.

	Species	Areca with annuals	Areca with perennials	Coconut with perennials
1	*Calicopteris floribunda*	12	14	29.8
2	*Clerodendron paniculatum*	5.3	28	41
3	*Clerodendron viscosum*	79	16.6	17.3
4	*Eupatorium odoratum*	61	82.2	0
5	*Ficus asperima*	28.3	37	42
6	*Gardenia jasminoides*	0	0	0
7	*Helicteres isora*	12	5.2	14.5
8	*Hibiscus suratensis*	0	1.6	0
9	*Holarrhena antidysenterica*	18.3	3.4	27.9
10	*Ixora coccinea*	0	7.2	0
11	*Lantana camera*	34.7	9.6	10.7
12	*Lawsonia inermis*	0	0	0
13	*Mallotus philippinensis*	0	11.2	16.2
14	*Mussaenda frondosa*	0	1.8	27.8
15	*Ricinus communis*	0	3.2	3.2
16	*Streblus asper*	0	2.8	3.2
17	*Urena lobata*	31.7	49.2	48.7

[a], leguminous species

Appendix XII. Contribution to total IVI of shrub communities by different species in monoculture plantation in the Kerala part of Nilgiri Biosphere Reserve

	Species	Arecanut	Coconut	Rubber	Cashew	Teak
1	*Caesalpinia pulcherrima* [a]	0	0	5.8	0	15.7
2	*Calicopteris floribunda*	34	63.3	6.8	23.7	12.7
3	*Clerodendron paniculatum*	0	0	3.8	0	0
4	*Eupatorium odoratum*	89.3	88.3	32.5	64.3	136
5	*Ficus asperima*	16.3	16	27.8	11	27.3
6	*Gardenia jasminoides*	0	0	10.3	0	0
7	*Glycosmis pentaphylla*	0	16.7	5.5	18.7	31
8	*Helicteres isora*	10.7	4	9.3	44	6.3
9	*Hibiscus rosa sinensis*	0	0	2.5	0	0
10	*Holarrhena antidysenterica*	3.3	10.7	29.8	17	0
11	*Ixora coccinea*	0	0	24	0	4.3
12	*Lantana camera*	32.7	46.2	29	0	32.3
13	*Lawsonia inermis*	0	0	0	45.7	0
14	*Mallotus philippinensis*	8.3	7.2	19	6.3	0
15	*Ricinus communis*	0	0	0	0	18.7
16	*Streblus asper*	8.3	22	47.2	5.3	5
17	*Urena lobata*	12	0	0	25.7	0
18	*Zizyphus oenoplea*	0	8	7.5	4	7.3
19	*Zizyphus rugosa*	0	0	16.3	0	0

[a], leguminous species

Appendix XIII. Contribution to total IVI of herb community by different species in polyculture homegardens and polyculture farmlands in the Kerala part of Nilgiri Biosphere Reserve

	Species	Polyculture homegardens	Polyculture farm lands
1.	*Abelmoscus esculentus*	2.1	0
2.	*Adiantum* sp.	1.7	1.2
3.	*Aerva lanata*	2.7	0
4.	*Ageratum conyzoides*	5.7	5
5.	*Asclepias curassavica*	0.7	0
6.	*Capsicum annum*	0.1	0.4
7.	*Cardamine hirsuta*	3	6.6
8.	*Cardiospermum haalicacabum*	1.4	0
9.	*Cassia occidentalis* [a]	3.3	0
10.	*Cassia tora* [a]	35	41.6
11.	*Centrosema pubescens* [a]	2.7	2
12.	*Ceratopteris sp.*	1.1	3.4
13.	*Cleome viscosa*	1.1	0.6
14.	*Coleus aromaticus*	2.6	0
15.	*Commelina benghalensis*	0.6	3.8
16.	*Corchorus acutangulus*	3.6	0.8
17.	*Cuphaea hyssopifolia*	0.9	0
18.	*Cyathula prostrata*	2.9	0
19.	*Cyclea peltata*	0.9	0
20.	*Cynadon dactylon*	6.9	4.4
21.	*Cynotis cristata*	0	1.2
22.	*Cyprus disformis*	13	9
23.	*Cyprus rotundus*	4.6	9.4
24.	*Desmodium triflorum* [a]	3.7	20.6
25.	*Eclipta alba*	12	2.8
26.	*Euphorbia rosea*	2.1	1
27.	*Euphorbia hirta*	7	5.2
28.	*Gomphrena decumbens*	5.1	0
29.	*Heliotropium indicum*	1	1.2
30.	*Hemidesmus indicus*	0.6	2.8
31.	*Hygrorrhiza* sp.	0	1.6
32.	*Hyptis capitata*	11.8	42.8
33.	*Hyptis sauveolens*	2.1	0
34.	*Ichnocarpus frutiscens*	1.7	0
35.	*Impatiens balsamina*	4.6	0
36.	*Isachne* sp.	0	7.2
37.	*Ischaemum* sp.	0.4	13

[a], leguminous species

--cont'd---

Appendix XIII (cont'd). Contribution to total IVI of herb community by different species in polyculture homegardens and polyculture farmlands in the Kerala part of Nilgiri Biosphere Reserve

	Species	Polyculture homegardens	Polyculture farm lands
38.	*Justicia simplex*	2.3	4
39.	*Knoxia sp.*	2.3	0
40.	*Laportea crenulata*	8	2.8
41.	*Leucas aspera*	1.7	0
42.	*Lindernia ciliata*	1.3	0
43.	*Lindernia crustacea*	2	2.6
44.	*Ludwigia parviflora*	8.1	20.6
45.	*Lygodium* sp.	8	2
46.	*Mimosa pudica* [a]	4.3	5.2
47.	*Mollugo pentaphylla*	5.6	1.8
48.	*Oldenlandia umbellata*	2	1.2
49.	*Oplisminus compositus*	3.7	26.6
50.	*Osbeckia minor*	2	0
51.	*Paspalam* sp.	7.4	8.2
52.	*Peperomia pellucida*	4.7	4.2
53.	*Phyllanthus amarus*	3.1	0
54.	*Phyllanthus urinaria*	2.3	0.8
55.	*Physalis minima*	0	0
56.	*Pilea microphylla*	12	0.6
57.	*Pouzolzia indica*	0.9	2.8
58.	*Pseudarthria viscida*	6	0
59.	*Pteris* sp.	1.3	2.4
60.	*Ruellia prostrata*	8	0
61.	*Salvia splendens*	2.6	0
62.	*Scoparia dulcis*	3.9	3.2
63.	*Selaginella* sp.	2	0.6
64.	*Sida rhombifolia*	5.4	2
65.	*Solanum nigrum*	4.4	0
66.	*Sphaeranthus sp.*	0.8	0.4
67.	*Spilanthus acmella*	0.9	0.8
68.	*Synedrella nodiflora*	22.1	3.6
69.	*Tridax procumbens*	5.3	0
70.	*Vernonia cinaera*	1.6	0.6
71.	*Vigna unguiculata.* [a]	5.3	0
72.	*Waltheria indica*	0	15.4

[a], leguminous species

Appendix XIV. Contribution to total IVI of herbs communities by different species in farm lands where a dominant tree crop associated with other crops in the Kerala part of Nilgiri Biosphere Reserve

	Species	Arecanut with annuals	Arecanut with perennials	Coconut with perennials
1	*Achyranthus aspera*	1.7	2	0
2	*Adiantum* sp.	0	12.5	0
3	*Aerva lanata*	0	2	0
4	*Ageratum conyzoides*	2.3	4.3	0
5	*Amaranthus viridis*	0	0	3.3
6	*Biophytum sensitivum*	4.3	8	0
7	*Borreria hispida*	2	0	10.3
8	*Calapagonium* sp.[a]	0	8	0
9	*Canscora diffusa*	0	1	1
10	*Capsicum annum*	0.3	0	0
11	*Cardamine hirsuta*	0	2	0
12	*Cardiospermum haalicacabum*	10	0	0
13	*Cassia occidentalis*[a]	7	14	0
14	*Centrosema pubescens*[a]	79	16.6	17.3
15	*Ceratopteris* sp.	2.7	2.3	0
16	*Cissampelos pareira*	0	0.8	0
17	*Coleus aromaticus*	5	0	0
18	*Commelina benghalensis*	2	0	0
19	*Corchorus acutangulus*	3.7	2.5	0
20	*Cuphaea hyssopifolia*	2	0	3.7
21	*Curculigo orchioides*	0	0	9.3
22	*Cyclea peltata*	2.7	8	0
23	*Cynadon dactylon*	0	0	0
24	*Cynotis cristata*	14.7	0	11
25	*Cyprus disformis*	0	1.2	20.7
26	*Cyprus rotundus*	1	1.7	2
27	*Dactyloctenium aegyptium*	1	7.2	0
28	*Desmodium gangeticum*[a]	0	0	0.7
29	*Desmodium sp.*[a]	1.3	0	0
30	*Desmodium triflorum*[a]	0	2.2	0
31	*Digitaria* sp.	31	17.3	8.7
32	*Dioscorea esculenta*	1	0	21.3
33	*Elephantopus scaber*	0	1.5	2
34	*Emilia zonchifolia*	0	0	2
35	*Eriochola* sp.	0	1	0
36	*Euphorbia rosea*	0	7	12
37	*Gloriosa superba*	0	0	2

[a], leguminous species

----cont'd---

Appendix XIV(cont'd). Contribution to total IVI of herbs communities by different species in farm lands where a dominant tree crop associated with other crops in the Kerala part of Nilgiri Biosphere Reserve

	Species	Arecanut with annuals	Arecanut with perennials	Coconut with perennials
38	*Gomphrena decumbens*	0	0	4
39	*Heliotropium indicum*	0	0	12
40	*Heteropogon* sp.	0	0	6
41	*Hygrorrhiza* sp.	1	0	0
42	*Hyptis capitata*	4	15.2	0
43	*Hyptis sauveolens*	2	0	0
44	*Impatiens balsamina*	2	0	3
45	*Ipomea aquatica*	1	1	0
46	*Isachne* sp.	18	6.8	18
47	*Ischaemum* sp.	11.7	17.3	12
48	*Justicia simplex*	0	3.5	0
49	*Knoxia* sp.	0	1.8	2.7
50	*Laportea crenulata*	0	0	7.3
51	*Leucas aspera*	2.7	15	2.3
52	*Lindernia ciliata*	0	8	0
53	*Lindernia crustacea*	1	12	1.3
54	*Ludwigia parviflora*	7.3	6.7	0
55	*Lygodium* sp.	0	1	7.7
56	*Mimosa pudica*[a]	12.3	2.5	0
57	*Mitracarpus verticellatus*	12	1.3	15.7
58	*Mollugo pentaphylla*	2	2	5
59	*Mucuna pruriens*	0	3.7	0
60	*Naregamia alata*	6	1	6
61	*Oldenlandia umbellata*	2.7	16	8
62	*Oplisminus compositus*	21	5	22
63	*Oryza sativa*	0	0	4
64	*Osbeckia minor*	0	2	0
65	*Paspalam* sp.	8	18.3	0
66	*Peperomia pellucida*	0	5.7	6.7
67	*Phyllanthus amarus*	3	8	13
68	*Phyllanthus urinaria*	5.3	8	3
69	*Physalis minima*	0	0.8	0
70	*Pilea microphylla*	0	2	3
71	*Portulaca oleracea*	0	6	0
72	*Pouzolzia indica*	2	0.3	6
73	*Pseudarthria viscida*	0	6	2

[a], leguminous species

----cont'd---

Appendix XIV(cont'd). Contribution to total IVI of herbs communities by different species in farm lands where a dominant tree crop associated with other crops in the Kerala part of Nilgiri Biosphere Reserve

	Species	Arecanut with annuals	Arecanut with perennials	Coconut with perennials
74	*Pteris* sp.	3.0	1.0	2.7
75	*Ruellia prostrata*	2.7	1.7	0.0
76	*Salvia splendens*	0.0	0.0	0.0
77	*Scoparia dulcis*	5.3	1.2	0.0
78	*Selaginella* sp.	0.0	6.8	1.7
79	*Sida rhombifolia*	6.7	0.0	5.7
80	*Solanum nigrum*	0.0	0.0	4.0
81	*Sporobolus* sp.	1.0	0.0	2.0
82	*Synedrella nodiflora*	12.3	26.2	0.0
83	*Tragea involucrata*	0.7	0.0	18.3
84	*Tridax procumbens*	0.0	1.8	0.0
85	*Vernonia cinaera*	4.7	4.0	0.0
86	*Vigna unguiculata* [a]	0.7	0.3	0.0
87	*Waltheria indica*	0.0	0.0	7.3

[a], leguminous species

Appendix XV. Contribution to total IVI of herb communities by different species in monoculture plantation in the Kerala part of Nilgiri Biosphere Reserve

	Species	Arecanut	Coconut	Rubber	Cashew	Teak
1	*Abelmoscus esculentus*	0	0	0	6.7	0
2	*Achyranthus aspera*	4	1	5.8	0	12
3	*Adiantum sp*	0	1.3	0	0	8
4	*Aerva lanata*	0	1.3	9	9.3	6
5	*Ageratum conyzoides*	13	10	7.3	0	13
6	*Amaranthus viridis*	0	0	0	1	0
7	*Ammomum* sp.	0	0	0	0	6
8	*Asclepias curassavica*	0	0	0	2.7	0
9	*Biophytum sensitivum*	3.3	5.3	1.3	1.7	4.7
10	*Borreria hispida*	0	1.7	0	0	9
11	*Calapagonium* sp [a]	0.7	0	14.3	0	8
12	*Canscora diffusa*	0	0	0	0	2
13	*Cardiospermum haalicacabum*	0	1	0	7	13
14	*Cassia occidentalis* [a]	0.7	0.7	10.5	1.3	4.3
15	*Cassia tora* [a]	34	63.3	0	23.7	12.7
16	*Centrosema pubescens* [a]	0	1	6	0	0.7
17	*Ceratopteris* sp.	1	0	0	0	0
18	*Cissampelos pareira*	0	1	2.3	0	0
19	*Cleome viscosa*	1	0	1	0.	0.7
20	*Commelina benghalensis*	12	3.3	1.3	6.7	2
21	*Corchorus acutangulus*	0	4	4	0	4.3
22	*Cuphaea hyssopifolia*	0	0	0	10.3	0
23	*Curculigo orchioides*	0	0	6.3	0	0
24	*Cyathula prostrata*	0	0.7	3.8	7	2.7
25	*Cyclea peltata*	0	0	6.8	10.7	0
26	*Cynadon dactylon*	8.7	7	24.8	1.3	6.3
27	*Cynotis cristata*	1	2.3	12	0	0
28	*Cyprus disformis*	0.7	1.3	8	1.3	0
29	*Cyprus rotundus*	4.7	2	3.8	1	12.7
30	*Dactyloctenium aegyptium*	0	1.7	0	0	0
31	*Desmodium gangeticum* [a]	0	6	0	0	0
32	*Desmodium* sp [a]	4.7	3.7	0	46.7	0
33	*Desmodium triflorum* [a]	31	32.7	0	0	12.3
34	*Digitaria* sp.	0	12	0	0	0
35	*Dioscorea esculenta*	0	0	0	0	1.7
36	*Eclipta alba*	0.3	0	0	0	0
37	*Emilia zonchifolia*	5.3	0	0	0	0
38	*Eriochola* sp.	0	9	0	0	0
39	*Euphorbia rosea*	0	0.7	0	1.7	0

[a], leguminous species

---cont'd---

Appendix XV (cont'd). Contribution to total IVI of herb communities by different species in monoculture plantation in the Kerala part of Nilgiri Biosphere Reserve

	Species	Arecanut	Coconut	Rubber	Cashew	Teak
40	*Euphorbia hirta*	9	3.3	0	1.3	0
41	*Gloriosa superba*	0	0	0	0	0.7
42	*Heliotropium indicum*	0	2	0	4.3	0.3
43	*Hemidesmus indicus*	0	4	0	7.2	13.3
44	*Heteropogon* sp.	0	1.3	9.3	8.3	0
45	*Hygrorrhiza* sp.	0	0	10	0	27.7
46	*Hyptis sauveolens*	0.3	0.7	0	3.7	0
47	*Ichnocarpus frutiscens*	0	0.7	0	3	1.7
48	*Indigofera purpurea* [a]	0	0	0	0.7	0
49	*Ipomea aquatica*	0	1.3	0	7.7	4
50	*Isachne* sp.	6.3	16	0	0	2
51	*Ischaemum* sp.	4.7	6	30.8	0	2
52	*Justicia simplex*	0	0	0	0	1
53	*Knoxia* sp.	10	0	0	0	3
54	*Laportea crenulata*	2	1.7	0	0	0
55	*Leucas aspera*	0	6	0	0	32
56	*Leucas biflora*	0	4.7	0	0	0
57	*Lindernia ciliata*	0	0	0	2.3	0
58	*Lindernia crustacea*	6.7	1.3	0	0.7	0
59	*Ludwigia parviflora*	9.3	3.7	0	0	0
60	*Lygodium* sp.	1.3	1	0	6.3	1.7
61	*Mimosa pudica* [a]	7.7	8	0	2.7	3.7
62	*Mitracarpus verticellatus*	7	3.3	0	0	0
63	*Mollugo pentaphylla*	0	2	16	0	0
64	*Monochoria vaginalis*	2	0	0	0	0
65	*Mucuna pruriens*	2	0	0	9	0
66	*Naregamia alata*	2	0	0	2.3	2
67	*Oldenlandia umbellata*	0.3	1.3	12	11	0
68	*Oplisminus compositus*	11	16.7	22	0	3.7
69	*Oryza sativa*	0	0.7	0	0	0.8
70	*Osbeckia minor*	0	0.7	6	0	0
71	*Paspalam* sp.	26	5.7	0	20	0
72	*Peperomia pellucida*	1.7	3.7	0	0	2
73	*Phyllanthus amarus*	1	1	1	0	0
74	*Phyllanthus urinaria*	0.7	1	0	0	1.7
75	*Physalis minima*	0	0.7	1	8	1
76	*Pilea microphylla*	3	2.8	2	0	2
77	*Portulaca oleracea*	0	0	3	4	1

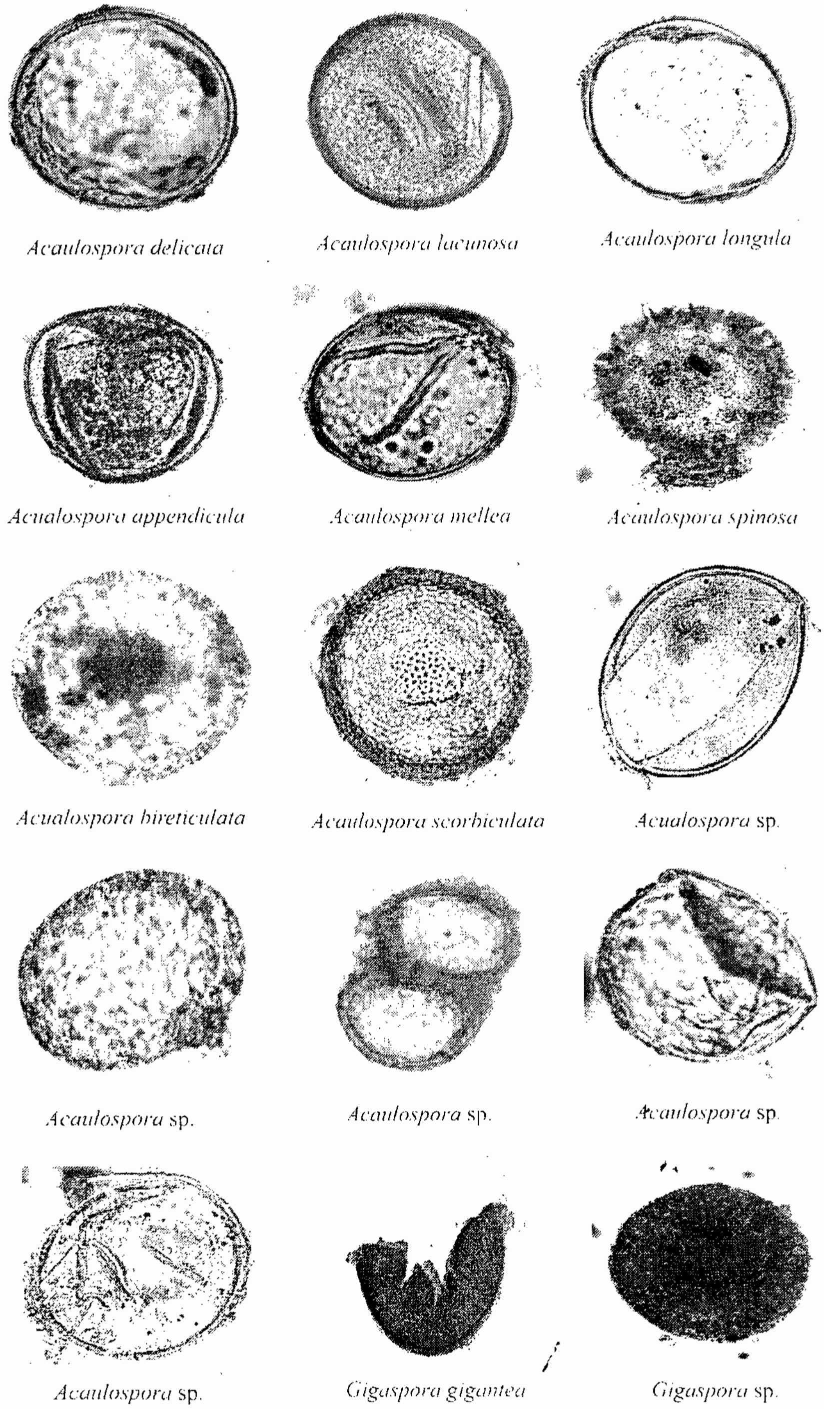
[a], leguminous species

---cont'd---

Appendix XV (cont'd). Contribution to total IVI of herb communities by different species in monoculture plantation in the Kerala part of Nilgiri Biosphere Reserve

	Species	Arecanut	Coconut	Rubber	Cashew	Teak
78	*Pouzolzia indica*	0.7	0.8	2	0	0
79	*Pseudarthria viscida*	0	0	2	1	3
80	*Pteris* sp.	1.3	1	1.3	1	7
81	*Ruellia prostrata*	0	1.7	5	0	1.7
82	*Salvia splendens*	0	0	0	2.3	0
83	*Scoparia dulcis*	9.7	1.3	2	0	0
84	*Selaginella sp.*	7	3.3	0	4.7	0
85	*Sida rhombifolia*	6	8	2	0	3.7
86	*Solanum nigrum*	0	1	0	0	0
87	*Sphaeranthus* sp.	0.3	1	0	0	0.3
88	*Spilanthus acmella*	12	2	6	0	6
89	*Sporobolus* sp.	0	0	21	1.7	12
90	*Stachytarpheta indica*	0	0	5	6.3	0
91	*Synedrella nodiflora*	15.7	2	12	12	8.7
92	*Tragea involucrata*	0	0	0.3	0	0
93	*Tridax procumbens*	0	0.7	0	2.3	0
94	*Vernonia cinaera*	1.3	1	0	2	4
95	*Vigna* sp. [a]	0	0.7	0	12	2
96	*Waltheria indica*	6	1	0	12	2

[a], leguminous species



Acaulospora delicata — *Acaulospora lacunosa* — *Acaulospora longula*

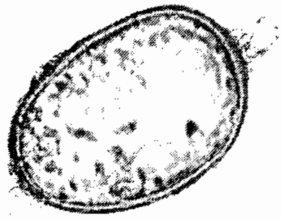
Acualospora appendicula — *Acaulospora mellea* — *Acaulospora spinosa*

Acualospora bireticulata — *Acaulospora scorbiculata* — *Acualospora* sp.

Acaulospora sp. — *Acaulospora* sp. — *Acaulospora* sp.

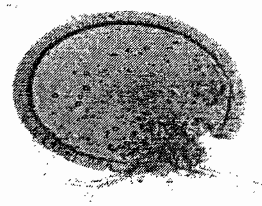
Acaulospora sp. — *Gigaspora gigantea* — *Gigaspora* sp.

Plate 1. Spore structure of some AM fungi collected from different landuse systems in the Kerala part of NBR.

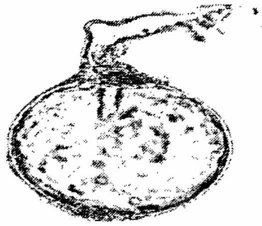


Glomuse candaense

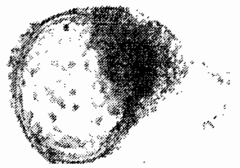
Glomus citricolum



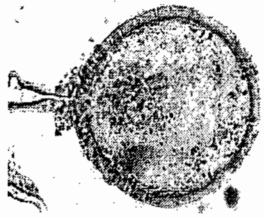
Glomus carum



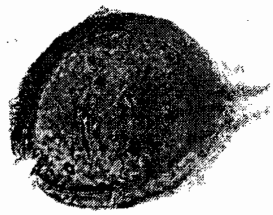
Glomus etunicatum



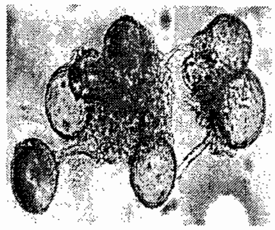
Glomus fragilis



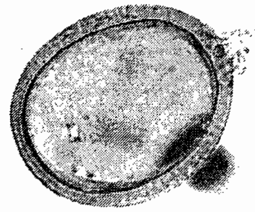
Glomus fasciculatum



Glomus geosporum

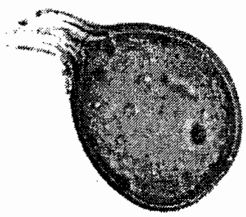


Glomus hoi

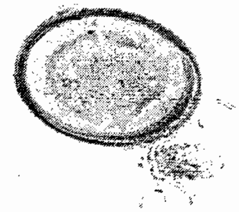


Glomus intraradices

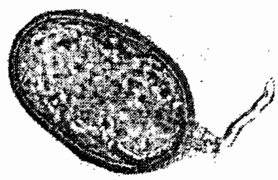
Glomus muticaule



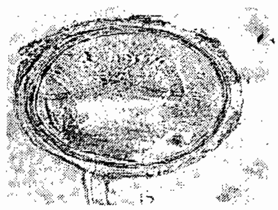
Glomus pallidum



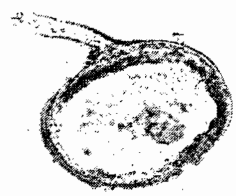
Glomus panishalos



Glomus raiatum

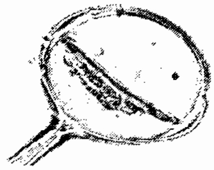


Glomus scintillans



Glomus segmentatum

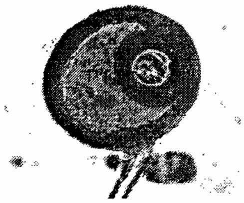
Plate 1 (cont'd). Spore structure of some AM fungi collected from different landuse systems in the Kerala part of NBR.



Glomus aggregatum

Glomus macrocarpum

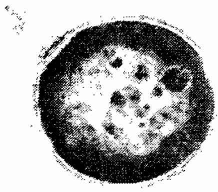
Glomus sp.



Glomus sp.

Glomus sp.

Glomus sp.

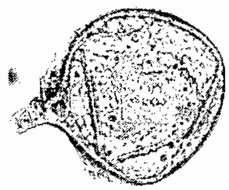


Glomus sp.

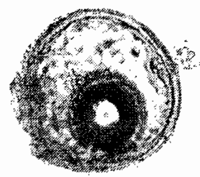
Glomus sp.

Glomus sp.

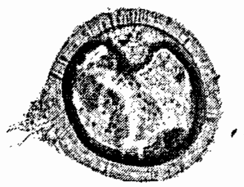
Glomus sp.



Glomus sp.

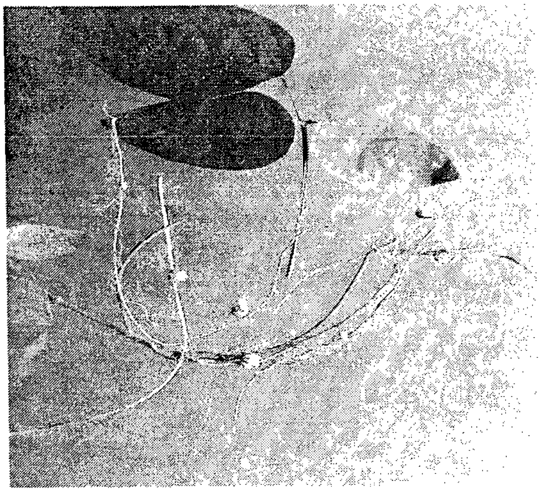


Glomus sp.

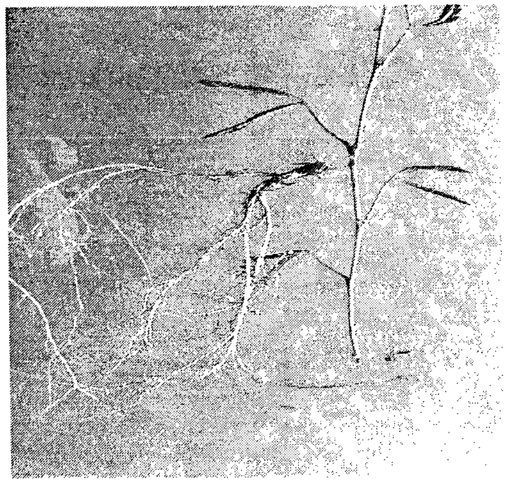


Glomus sp.

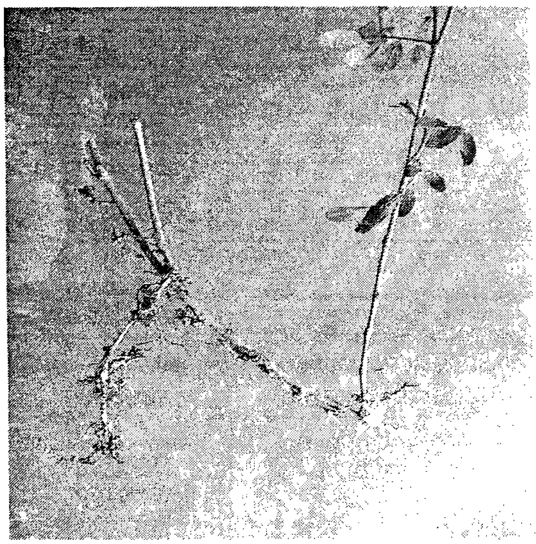
Plate 1 (cont'd). Spore structure of some AM fungi collected from different landuse systems in the Kerala part of NBR.



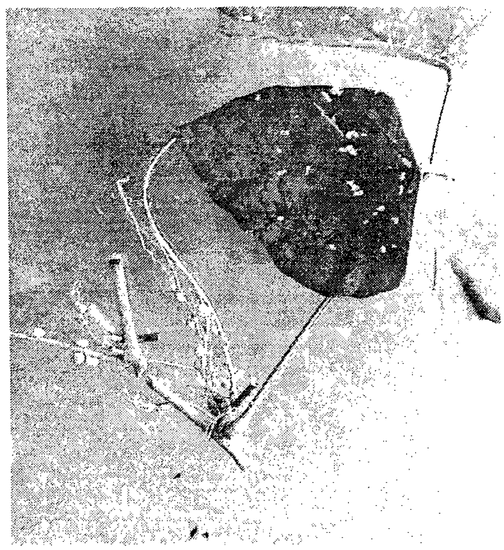
Centrosema pubscens



Mimosa pudica



Tephrosea purpurea



Vigna bourneae

Plate 2. Leguminous host species commonly growing in different landuse systems in the Kerala part of Nilgiri Biosphere Reserve.

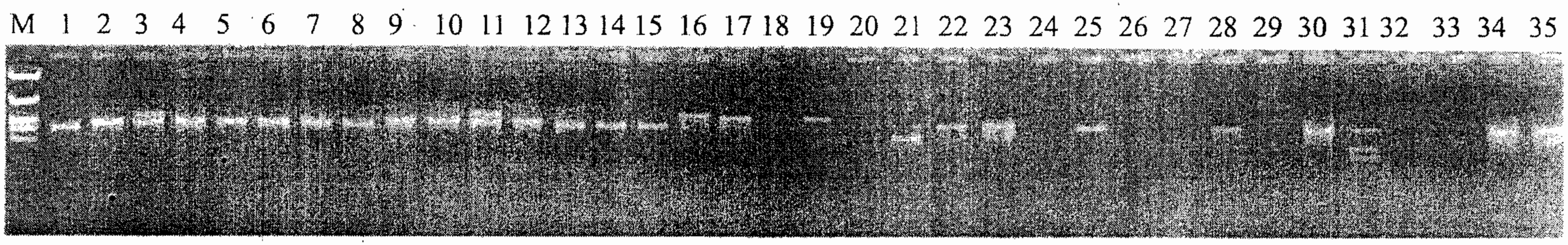


Plate 3. 16S-23S IGS Amplification of rhizobial isolates from different landuse systems in Nilgiri and Nanda Devi Biosphere Reserves. Isolates 1-13 for the Kerala part of NBR, 14-25 for the Karnataka part of NBR and 26-35 for the Nanda Devi Biosphere Reserve.