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# Conservation and Sustainable Managament of Belowground Biodiversity in the Kerala Part of Nilgiri Biosphere Reserve - Phase II

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# Executive Summary

Conservation and sustainable management of belowground biodiversity (CSM-BGBD) is a project executed by Tropical Soil biology and fertility of International Centre for Tropical Agriculture (TSBF-CIAT) with co-financing from Global Environmental Facility (GEF) and implementation support from United Nations Environment Programme (UNEP). This project has been initiated in seven countries including: Brazil, Cote d' Ivoire, India, Indonesia, Kenya, Mexico and Uganda. Benchmark areas have been selected that represent biodiversity rich regions with global significance such as Amazonian lowlands, Western Ghats of India and Himalayan highlands. The project's purpose was to offer means by which belowground biodiversity (BGBD) could be adequately managed and conserved in tropical agricultural landscapes as the basis for enhancing agricultural productivity and production. In order to achieve the goals the specific objectives that were set in the project include a) develop and publish internationally accepted standard methods for characterizing and evaluating BGBD, including a set of indicators for maintaining BGBD loss, b) research on sustainable and replicable management methods for BGBD conservation in diverse ecosystems and landuse types, c) install demonstration sites on farmers's fields in diverse but representative landuse types, d) recommend alternative landuse practices and advisory support systems, with policies that will enhance the conservation of BGBD, and e) build capacity of all associated research institutions, universities and stakeholders to implement strategies for the conservation and management of BGBD in a sustainable and efficient manner. As a part of this project, a benchmark site has been established at the Chaliar micro-watershed in the Kerala part of NBR. During the first phase of the project, different landuse systems in the benchmark area have been characterized for aboveground and belowground biodiversity. Certain strategies that need to be adopted for maintaining soil fertility, sustainable yield and enhancing density and diversity of soil biota in different cropping systems have also been identified. Thus, the second phase of the project was aimed to demonstrate certain BGBD management practices to the farming community through on-farm experiments. An ex-ante evaluation to formulate proposals for on-farm participatory activities for soil fertility improvement and belowground biodiversity conservation in the Kerala part of Nilgiri Biosphere Reserve has been conducted. The ex-ante evaluation process involved meetings of the participating farmers, project team members and representatives of the Agriculture Department. The team has identified two activities for on-farm participatory experiments namely a) growing leguminous/biomass

transfer species to reduce the weeds in the crop lands, and b) green leaf manure application to improve soil fertility and biodiversity. The evaluation process has been successful as it has ensured a close co-operation and an effective dialogue with the stakeholders for implementing different on-farm experiments to demonstrate the effectiveness of different soil fertility improvement methods.

The demonstration experiment on cultivation of three leguminous cover crops viz. *Arachis pintoi*, *Calpogonium mucunoides* and *Sesbania aculeata* was carried out in the coconut plantation of the BGBD benchmark site. Cultivation of leguminous crops changed soil chemistry significantly. For instance, comparison of soils of no-cover crop control plots and each of the three cover crop plots indicated a significant increase in organic matter, phosphorous and potassium in *A.pintoi* plots, total nitrogen in *A.pintoi* and *C.mucunoides* plots and calcium and magnesium in *A.pintoi* and *S. aculeata* plots. Significant increase was noticed in rhizobia and phosphate solubilising microbes throughout the study period and azatobactor, nine months after planting cover crops was noticed. The mean ground cover by weeds in coconut gardens ranged from 67% to 98% with grasses and sedge being dominant weeds. Thus weed management in the farms is a challenging task for the farmers. Leguminous cover crop cultivation suppressed weed community considerably. However, the mechanism by which cover crops suppress the weeds may differ. For instance, by cultivating *A.pintoi* and *C.mucunoides,* relative increment in biomass of weeds than the relative increment in weed density reduced at a faster rate. Whereas by cultivating S*. aculeata, the* relative increment in biomass and relative increment in density of weeds reduced almost in a same pace. On-farm experiments also revealed that *A. pintoi* and *C. mucunoides* give good early growth and ground cover within 3-4 months and has the ability to suppress annual grass and cyperaceous weeds. However, pruning biomass of *A. pintoi* reduces its ability to weed suppression. Therefore, it can be retained as a permanent cover by occasional trimming. *C. mucunoides* provides biomass for mulch; biomass harvest, 2-3 times per year, does not affect the growth and weed suppression ability of this cover crop. Thus it can be planted in sites where the established crop trees and palms are present. *S.aculeata* gives good early growth and ground cover within 1-2 months and continues to suppress weeds even 12 months after planting. Since *S.aculeata* is a short duration crop it can be planted in sites where the cultivation of seasonal crops after harvesting the cover crop is intended. This on-farm experiment demonstrated that growing leguminous cover crops in suitable microsites in farms can help farmers

to suppress weeds, improve soil fertility and also enhance the population of beneficial soil flora and fauna.

In the traditional agroforestry including homegardens of tropics the green mulch application is considered as a good source of nutrients. Green mulching plays an essential role in increasing soil organic matter reserves, promoting carbon sequestration and nutrient cycling. However, even in the given mulch, concentration of a given nutrient and nutrient cycling pattern may differ based on the constituent species. In this context, an on-farm experiment was conducted to characterize decomposition and nutrient release pattern of single and mixed species mulch. Initial concentration of nitrogen (N) and potassium (K) in the mixed species mulch are between those recorded in the mulch of individual species (*Calycopteris floribunda*, *Chromolaena odorata*, *Ficus asperima*, *Glycosmis pentaphylla*, *Helecteris isora, Terminalia panicualta)*. Whereas, the initial phosphorus (P) concentration in mixed species is much higher than that quantified in the mulch of individual species. Mixing of green mulch material of different species does not alter the population of enzyme producing microbes. However, the population of *Trichoderma* increased significantly. Green mulch with high initial N:P ratio can be considered as poor quality mulch for crops like coconut. Thus, the green mulch of species like *Calycopteris floribunda*, *Glycosmis pentaphylla* and *Terminalia paniculata* are of poor quality. Therefore, mixing the mulch material of different species can reduce the initial N:P ratio and provide required quantity of P to the crops. When equal quantity of mulch (150 kg of green foliage per palm) of individual species and mixture of species is considered, the mulch materials of *Chromolaena odorata* and *Terminalia paniculata* are unable to fulfil the $P_2O_5$ - fertilization recommended for coconut. Similarly, the mulch materials of species like *Calycopteris floribunda* and *Terminalia paniculata* are unable to fulfil the $K_2O$ fertilization recommended. On the other hand, the mulch of mixed species, consisting of nutrient rich and poor foliages of different species, is able to fulfil the recommended dose of N, $P_2O_5$ and $K_2O$ at an intermediate rate.

Application of compost to agricultural land is a common practice to improve soil quality, crop yield and quality. However, the preparation of quality compost within a short period of time during its mass requirement is a real challenge. Several studies indicated that better quality composts can be prepared at a relatively faster rate by using decomposer microbial inoculams, earthworms and biofertiliser microorganisms. An experiment was carried out to compare and contrast composts that area prepared in a conventional way and by adding microbes and earthworms for their quality as well as their influence on crop growth and yield. The chopped green foliage added

with rock phosphate and urea but without inoculating cow dung or decomposing microbes or earthworms took 56 days for decomposing. Whereas cow dung compost (C-C), decomposing microbial inoculated compost (DMI-C), cow dung and earthworm compost (CE-C) and DMI and earthworm compost (DMIE-C) were composted for 46 days, 42 days, 35 days and 30 days respectively. A significant increase in nitrogen content was observed in green foliage added with different inocula; it was highest for decomposing microbial and earthworm inoculated compost (DMIE-C) and lowest for control compost (CC). The C/N ratio of control compost (CC) was 43, while that of composts prepared by adding the cow dung slurry (C-C) and consortia of decomposing microbes (DMI-C) was 32 and 26.6 respectively. On the other hand, the C/N ratio recorded when earthworms were introduced in cow dung compost (CE-C) and consortia of decomposing microbes inoculated compost (DMIE-C) was less than 20, an acceptable level to indicate the maturity in the finished compost. After 12 days of composting the number of colony forming units (cfu/g of compost) for bacteria and actinomycetes was highest in decomposing microbial inoculated compost (DMI-C) and decomposing microbia and earthworm inoculated compost (DMIE-C). In the present study, two types of composts namely decomposing microbial inoculated compost (DMI-C) and decomposing microbial and earthworm inoculated compost (DMIE-C) were enriched with beneficial microorganisms such as vesicular arbuscular mycorrhizae (VAM), Phosphate solubilising bacteria (PSB), Azotobacter, Rhizobium, Potassium mobilizing bacteria (KMB) and trichoderma. In terms of ability to enhance plant growth, treatments added with biofertiliser-enriched DMIE compost consistently outperformed the treatments added with other kinds of compost. Factors responsible for the enhanced growth of plants in the treatments added with biofertiliser-enriched DMIE and biofertiliser-enriched DMIE composts are discussed.

One of the objectives of the Conservation and Sustainable Management of Belowground Biodiversity Project (CSM-BGBD Project) is to build capacity for the conservation and sustainable management of BGBD by encouraging South-South information exchange and providing training with support from international institutions. To fulfill this objective, the global committee of the CSM-BGBD Project suggested to each country partners to prepare a set of approach papers based on studies conducted in respective benchmark sites. Three approach papers namely a) soil health analysis using earthworms as the indicator- possibilities and constraints, b) landuse transformation and loss of belowground biodiversity- an analysis, and c)

litter decomposition as an ecosystem service were prepared. These papers also form the part of this report.

The approach paper on soil health discusses the soil physical, chemical and biological characters which are of general interest in the context of soil health determination. Among different biological elements, earthworm is considered as an important indicator of soil quality. However, certain studies did not find any apparent relationship between soil carbon content and earthworm abundance. In this context, the relationships between earthworm distribution and soil properties in different landuse systems in the Kerala part of Nilgiri Biosphere Reserve were analysed and possibilities and constraints of using earthworm in soil health analysis are discussed. In the benchmark area, mean earthworm abundance (individuals/$m^2$) ranges form 8 to 412, with highest value in a plot of coconut and perennial crops. Even in a given landuse system, a wide variation in earthworm abundance is recorded. Further analysis done to compare the earthworm abundance in paddy fields and plots of landuse systems which were transformed from paddy fields indicated that mean abundance of earthworms in areca mixed with perennials, coconut mixed with perennials, coconut and areca plantations were significantly higher than in paddy fields. It is reported that the soil type, pH, organic matter content and related physical/chemicals factors can influence survival, growth and reproduction of earthworms and soil that poor in organic matter are also poor in earthworm abundance. However, in the present study in general no such trend was observed. It was also noticed that at any given plot nutrient status is not stable and due to this instability, it is difficult observe any significant correlation with soil faunal abundance. Despite the fact that the earthworm abundance does not show positive significant correlation with several soil parameters which are generally considered while determining the soil health, earthworm abundance itself can be a good indictor of soil health as the building up of earthworm population in tree based/perennial crop based system.

In tropical countries, due to socioeconomic and cultural changes, several landuse systems are being transformed into some other landuse systems. Based on a case study conducted in the Kerala part of Nilgiri Biosphere Reserve the impact of transformation of paddy fields to other cropping systems on diversity and distribution pattern of AM fungi has been analysed and presented in another approach paper included in this report. Comparison of paddy fields and other landuse systems for AM fungal spore density revealed that the values are not significantly different ($P>0.05$); exception being in polyculture homegardens and arecanut mixed with perennial

cropping system. The AM fungal spore density in polyculture homegardens was more than that in paddy fields ($P<0.05$). On the other hand, significantly low spore density was recorded for arecanut mixed with perennial cropping system ($P<0.05$). The study also demonstrated the fact that the landuse transformation contributed for the appearance several new AM fungal species. However, even 5 to 25 yr after transformation of paddy fields, some of the AM fungi are common to both paddy fields and landuse systems derived from them suggesting that the composition change in belowground floral community due to landuse change is a slow process. In the approach paper the scope for a systematic study by adopting landuse-specific standard methods, for analyzing the links between belowground species composition and diversity changes in response to landuse transformation is also highlighted.

The third approach paper was prepared to discuss the issues related to decomposition and nutrient release pattern of mulch species in agroforestry systems. An array of variables such as temperature, moisture, soil physical and chemical properties, soil biota, vegetation type and composition, substrate quality etc. which control the litter decomposition are discussed. The approach paper also suggested following studies to evaluate a) the rate of decomposition of green leaf manure, comprising single species and/or a mixture of species by using single exponential and double exponential models, b) the nutrient release patterns in green leaf manure, comprising of single species and/or a mixture of species and understand the synchrony between nutrient release by manure and nutrient uptake by crops, c) litter decomposition rates in a given type of crop land (eg. homegardens) but transformed from different landuse systems (eg. forest, paddy field etc.), d) the relationship between the litter decomposition rate and quantity of light available in a given type of landuse systems, e) substrate quality in terms of carbon, nitrogen and lignin content in different green leaf manure species and their impact on litter decomposition rate, and f) variation in abundance and diversity of soil fauna during mulch decomposition.

# General Introduction

During the first phase of the research project on `Conservation and Sustainable Management of Belowground Biodiversity in the Kerala Part of Nilgiri Biosphere Reserve' (Chandrashekara et al., 2008), a benchmark site of the project has been established in the Kerala part of Nilgiri Biosphere Reserve. The benchmark site, located in the Chaliar Microwatershed, has been characterized for vegetation types, area under different landuse types and landuse and land cover change patterns. Majority of the current landholdings in the study area 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 was 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. 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. Studies also revealed that some of the faunal elements characteristics to a given landuse system are either absent or sparsely represented. Considering these aspects, the second phase of the project was aimed to identify certain important strategies that have to be adopted for maintaining soil fertility, sustainable yield and enhancing density and diversity of soil biota in different cropping systems. The project was also aimed to demonstrate such management practices to the farming community through on-farm experiments. Thus an ex-ante evaluation to formulate proposals for on-farm participatory activities for soil fertility improvement and belowground biodiversity conservation in the Kerala part of Nilgiri Biosphere Reserve has been conducted. In the present report, details of ex-ante evaluation process and

its outcome are presented in Section 1. The ex-ante analysis led to identify two on-farm participatory activities for soil fertility improvement and belowground biodiversity conservation. Results of the on-farm activities conducted during the project period are presented in Section 2.

Sustaining soil productivity has high priority in the tropical region. The decline in soil fertility and productivity due to excessive soil erosion, nutrient run-off, and loss of soil organic matter has stimulated interest in improving overall soil quality by the addition of composted organic matters to crop lands. Compost is nutrient rich, moisture absorbent leaves, twigs and branches, teeming with fungal, microbial and insect life. It serves as `nutrient bank', storing the nutrients contained organic matter and slowly making these nutrients available to plants. The appropriate methodologies in waste management for producing compost are the use of microbes and earthworms. It is a well known fact that by incorporating appropriate microbes the speed of composting could be enhanced and the nutrient status of the compost could be ensured. Similarly, available literature indicate that the result of the composting process through earthworms is a high quality humic product and that can be used as soil amendment as it improves physical, chemical and biological properties of the soil. However, attempts to use microbes and earthworm together for producing composting are scanty. Thus an experiment to assess the combined effects of microbes and earthworms on the quality of composted organic materials was conducted and the results are presented in Section 3.

The Conservation and Sustainable Management of Belowground Biodiversity Project (CSM-BGBD Project) is being implemented in seven tropical countries: Brazil, Côte d'Ivoire, India, Indonesia, Kenya, Mexico, and Uganda. The Project's main goal is to generate information and knowledge that can be used to better manage and conserve BGBD in tropical agricultural landscapes. The Project also aims to build capacity for the conservation and sustainable management of BGBD by encouraging South-South information exchange and providing training with support from international institutions. To fulfill these objectives, the global committee of the CSM-BGBD Project suggested to each country partners to prepare a set of approach papers based on studies conducted in respective benchmark sites. Thus three approach papers namely a) soil health analysis using earthworms as the indicator-possibilities and constraints, b) landuse transformation and loss of belowground biodiversity- an analysis, and c) litter decomposition as an ecosystem service were prepared. These papers are presented in Section 4.

# Section-1

# Ex-ante evaluation for the preparation of proposals for on-farm participatory activities related to soil fertility improvement and belowground biodiversity conservation

## 1. Introduction

Ex-ante evaluation is a process that supports the preparation of proposal for new actions (Todd and Wolpin, 2006). Its purpose is to gather information and carry out analysis that helps to define objectives, to ensure that these objectives can be met, that the instruments used are cost-effective and that reliable later evaluation will be possible. This method of evaluation has been effectively used for developing several projects in different fields. Thus an attempt has been made on ex-ante evaluation to formulate proposals for on-farm participatory activities for soil fertility improvement and belowground biodiversity conservation in the Kerala part of Nilgiri Biosphere Reserve. Ex ante evaluation may be done as in-house work, by a team including members from the responsible operative unit(s), project implementers and representatives from the line departments. In the study area, the ex-ante evaluation process involved four meetings where the participating farmers, project team members and representatives the agriculture department participated. Each meeting was designed to collect adequate information on the points listed below:

**a) Problem analysis and needs assessment**

- What is the problem to be solved and what are the main factors and actors involved?

**b) Objective setting**

- Have the general, specific and operational objectives been defined in terms of expected results?
- What indicators are planned for measuring inputs, outputs, results and impacts?

**c) Alternative delivery mechanisms and risk assessment**

- What alternative instruments were considered and why was the proposed one chosen?
- What risks are involved in the implementation of the intervention and what countermeasures have been taken?

**d) Added value of Community involvement**

- Is the proposed intervention complementary to and coherent with other interventions?
- Does it produce synergies with them?

**e) Lessons from the past**

- What evaluation, audit or study results/experiences of similar actions are available?
- How can these be applied to improve the design of the programme?

**f) Planning future monitoring and evaluation**

- Are the proposed methods for collecting, storing and processing the follow-up data sound?
- Is the monitoring system fully operational already from the outset of the programme implementation?
- What types of evaluations are needed and when should they be carried out?

During each meeting salient results of the first phase of the Project conducted in agricultural and agroforestry landuse systems in the Kerala part of Nilgiri Biosphere Reserve (Chandrashekara et al., 2008) were explained. The participants agreed the fact that continuous cultivation, without organic matter conservation and organic manure input, is the prime reason for low productivity and soil organic matter depletion in different cropping systems. In addition, weed community, which is generally rich in different landuse systems in the region, competes with crops for water and nutrients resulting in the crop production below optimum level. In the Landscape of Chaliyar River watershed, the study recorded a faster rate in landuse and land cover changes. Considering these aspects, the team has identified two activities for on-farm participatory experiments namely a) growing leguminous/biomass transfer species to reduce the weeds in the crop lands, and b) green leaf manure application to improve soil fertillty and biodiversity. The purpose of these on-farm experiments was to demonstrate the usefulness of these strategies and also disseminate information and technology to a wider user group. In order to assess the need and feasibility of each of the above mentioned on-farm experiments, ex-ante evaluation was conducted and the result of the evaluation is given below:

**Activity 1. Results of the ex-ante evaluation of experiment on growing leguminous/biomass transfer species**

| **Problem analysis and assessment** | |
|---|---|
| 1. What is the problem to be solved? | Weeds in the croplands are leading to poor crop yield and crop cultivation un-economical. |
| 2. What are the main factors involved? | • First phase of the study indicated that weed biomass in the crop lands ranged from 6,000 – 9,000 kg $ha^{-1}$.<br>• Estimated cost for weeding is about Rs. 4,000/- $ha^{-1}$ $yr^{-1}$.<br>• Often harvested weed biomass cannot be incorporated directly as they re-sprout and spread and compete with the major crops fro water, nutrients and light.<br>• Low under-storey coverage generally leads to poor biological activities, litter decomposition and nutrient cycling. |

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**Activity 1 (cont'd). Results of the ex-ante evaluation of experiment on growing leguminous/biomass transfer species**

| | | |
|---|---|---|
| 3. Who are the concrete target group? | • Homegardeners who are unable to manage weeds in the garden.<br>• Coconut, arecanut, teak, cashew, and rubber growers | |
| 4. What are its needs/interests? | • Replace weeds with suitable leguminous/biomass transfer species which are economically beneficial to them and at the same time improve the soil fertility and crop yield | |
| **Objective setting** | | |
| 1. General objective | ✓ To replace weeds with suitable cover crops for improving soil productivity and crop yield | |
| 2. Specific objective | ✓ To quantify the productivity of useful leguminous/biomass transfer species in the available land area by replacing weeds. | |
| 3. Operational objective | ✓ To demonstrate the effects of replacement of weeds by leguminous/biomass transfer species in terms of changes in soil organic matter (SOM) content and diversity and population of earthworms, termites and micro flora. | |
| **Alternative delivery mechanism and risk assessment** | | |
| | Alternative methods | Effects |
| 1. What alternative instruments were considered | Non-weeding | Leads to intensive competition with crops and reduce the crop yield and may also cause changing belowground biodiversity due to exotic weed dominance.<br>Many useful species particularly when unmanaged may become alternative host for pests and disease causing organisms of major crops |
| | Weedi-cide application | In Kerala, in general different landuse systems are intermixed without differentiation between the residential area and cultivating area, weedicide application will have harmful effects not only on belowground flora and fauna but also on livestock and human beings. |
| | Physical weed removal | Expensive particularly due to poor/non availability of labourers. |
| | Growing additional/ secondary crops | Farmers are not interested to cultivate additional or secondary crops due to lack of time and high cost of labour. |
| | Note: Considering all these drawbacks of the alternative methods of weed management, cultivation of leguminous/biomass transfer species is selected. | |

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**Activity 1 (cont'd). Results of the ex-ante evaluation of experiment on growing leguminous/biomass transfer species**

| | | |
|---|---|---|
| 2. What are the risks involved in implementation? | Risks | Counter measures |
| | 1. Farmers'disinterest in participating to implement the activity. | Arrange formal and non-formal meetings to ensure farmers participation by clearing their doubts related to the activities. |
| | 2. Non acceptance of species (leguminous/ biomass transfer species) by the farmers | Conduct formal and informal meetings to provide information on growth pattern and usefulness of the species based on available data. |
| | 3. Sustainability of cultivation of leguminous/ biomass transfer species. | • Select species which are known for their better growth, biomass production and nutrient release without adversely affecting crops.<br>• Select species which are easily available and propagate with less expenditure. |
| | 4. Competition of leguminous/biomass transfer species with major crops | Species known for their synergetic effects with major crops are selected.<br>Ensure planting design which will reduce any kind of competition between leguminous/ biomass transfer species and major crops. |
| **Added value of community involvement** | | |
| | Traditionally, the farming community in Kerala is aware of the importance of ground cover enrichment in order to reduce the weed growth and also to improve the soil fertility. Thus, during the proposed intervention, one can expect more practical inputs and knowledge from the farming community for the successful implementation of the programme. | |
| **Lessons from the past** | | |
| 1. What evaluation/ study results/ experiences of similar actions are available? | Farmers are successfully cultivating *Calapagonium mucunoides* in rubber plantations and *Sesbania aculeata* in paddy fields in order to control weeds and also improves the soil fertility. | |
| 2. How can these be applied to improve the design of the programme | In the Kerala, different cropping systems such as mixed species rich homegardens, single species rich homegardens, polyculture farmlands, monoculture plantations like coconut, arecanut, teak, rubber etc. are seen. However, cultivation of leguminous/biomass transfer species for weed control has not be attempted so far. | |

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**Activity 1 (cont'd). Results of the ex-ante evaluation of experiment on growing leguminous/biomass transfer species**

| **Planning future monitoring and evaluation** | | |
|---|---|---|
| | A Table showing output results and impact indicators which will be useful for future monitoring and evaluation is given below | |
| **Output indicators** | **Result indicators** | **Outcome/impact indicators** |
| 1. Participant farmers are selected | A list of participant farmers is available | Participants are involved in implementing the activity |
| 2. Farms are selected for on-farm experiment | Area, cropping system/ pattern, vegetation data are available | Activity are initiated in the field |
| 3. Selection of leguminous/biomass transfer species | A list of species selected and approved by the farmers to cultivate is available | Species are planted |
| 4. Monitoring of growth and yield of planted species | Data on growth, land coverage and biomass production of planted species are available | Farmers identified suitable species for different farming systems |
| 5. Weed biomass indicators | Data on growth, land coverage and biomass production by the weed species area prior to experiment and after the experiment are available | Reduction in the area covered by weeds. Satisfaction expressed by the target group/s |
| 6. Characterisation of farms for soil organic matter | Data on SOM in weedy area and area cultivated with leguminous/biomass transfer species are available | Soil organic matter contents in the experimental plots enhanced considerably |
| 7. Study on soil flora and fauna | Quantitative information on diversity and abundance of selected soil flora and fauna are available | Change in composition and diversity in soil flora and fauna |

**Activity 2. Results of the ex-ante evaluation of experiment on green leaf manure application**

| **Problem analysis and assessment** | |
|---|---|
| 1. Problem to be solved | Crop productivity is declining |
| 2. What are the main factors involved? | • In the Study area, about 30% of the farmers apply about 1,000 - 6,250 kg $ha^{-1}$ $yr^{-1}$ of green leaf manure as a method of nutrient input to their crop lands. However, due lack of information on the quality, nutrient status, decomposition rate and nutrient release pattern, farmers are not sure that whether they are using as mulch a right combination leaves of different species, mulching is done during right cropping period and there is synchrony between nutrient release from mulch and nutrient absorption by crop plants. |

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**Activity 2 (cont'd). Results of the ex-ante evaluation of experiment on green leaf manure application**

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| 3. Who are the concrete target group? | • Homegardeners, coconut, arecanut, teak, cashew, and rubber growers who are facing poor crop productivity due to poor soil quality | |
| 4. What are its needs/ interests? | • Improve the soil fertility, crop yield by using the right combination green leaf manure | |
| **Objective setting** | | |
| 1. General objective | ✓ Sustain the soil fertility for sustainable crop yield | |
| 2. Specific objective | ✓ To demonstrate improved soil conditions by the application of locally available green manure species.<br>✓ To understand the rate of decomposition of green leaf manure species supplied at different combinations, release pattern of different nutrients from the green leaf manure and measure the soil fertility by estimating the particulate organic matter (POM) content at regular interval after the green leaf manure application. | |
| 3. Operational objective | ✓ To demonstrate the effectiveness of green manure species in increasing soil organic matter and soil micro-flora and fauna. | |
| **Alternative delivery mechanism and risk assessment** | | |
| | **Alternative methods** | **Effects** |
| 1. What are alternative instruments were considered? | Enhance the quantity of green leaf manure to be used for mulching | Desired results may not be obtained if the quantity of mulch is increased without considering the right combination of leaves of green leaf manure species. |
| | Use coconut husk/cow-dung etc | Imbalance in the status of different nutrients the soil could be possible |
| | Use chemical fertilizers | Imbalance in the status of different nutrients the soil could be possible.<br>Economically loss due to use of external nutrient input instead of using nutrient sources available within the system. |
| | Note: Considering the drawbacks of the alternative methods, it was proposed to identify the right quantity and combination of leaves of a set of green leaf manure species the right combination of locally available green manure species | |
| 2. What are the risks involved in implement-ation? | **Risks** | **Counter measures** |
| | 1. Farmers disinterest in participating to implement the activity. | Arrange formal and non-formal meetings to ensure farmers participation by clearing their doubts |
| | 2. Non availability of leaves of a set of green leaf manure species | Ensured to select green leaf manure species whose leaves are available easily and locally |

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**Activity 2 (cont'd). Results of the ex-ante evaluation of experiment on green leaf manure application**

| | | |
|---|---|---|
| | 3. Improper selection of species | A list of potential green leaf manure species will be prepared. Available information, including traditional knowledge about the quality of the leaves of these species in terms of nutrient status and decay pattern will be collected. A set of species will be chosen in discussion with the participant farmers |
| **Added value of community involvement** | Farming community in Kerala has the tradition of using green leaf as mulch in different farming systems with aims to increase the crop yield and sustain the soil fertility their crops and also sustain the soil fertility. Since the present on-farm activity is aimed to give scientific input into the traditional practice, community involvement will be beneficial both to the successful implementation of the programme and demonstrate the results of the experiment to a wider farming community. | |
| **Lessons from the past** | | |
| 1. What evaluation/study results/experiences of similar actions are available? | Farmers are successfully using green leaf manure species like *Eupatorium odoratum*, *Artocarpus heterophyllus*, *Calicopteris floribunda*, *Gliricidia sepium*, *Macaranga peltata*, *Mangifiera indica* and *Terminalia paniculata* for enriching the soil nutrient. | |
| 2. How can these be applied to improve the design of the programme | In the Kerala, different cropping systems such as mixed species rich homegardens, single species rich homegardens, polyculture farmlands, monoculture plantations like coconut, arecanut, teak, rubber etc. are seen, and these green manure species are commonly growing in these farms may farmers locally making compost in their home for their local needs. However, application of different combination of green manure species has not attempted so far. | |
| **Planning future monitoring and evaluation** | | |
| | A Table showing output, results and impact indicators which will be useful for future monitoring and evaluation is given below: | |
| **Field of intervention: Green leaf manure application** | | |
| Output indicators | Result indicators | Outcome/impact indicators |
| 1. Participant farmers are selected | A list of participant farmers are available | Participants are involved in the implementing activity |
| 2. Different farms are selected | Area, cropping system/pattern, vegetation data are available | Activity are initiated in the field |
| 3. Selection of green manure species | A list of species selected and approved by the farmers to cultivate is available | Species ready for use |

--cont'd--

**Activity 2 (cont'd). Results of the ex-ante evaluation of experiment on green leaf manure application**

| | | |
|---|---|---|
| 4. Monitoring the rate of decomposition of green manure leaves | The rates of decomposition and nutrient releases both for individual and a combination of green leaf manure species are available | A set of species which have the ability to release nutrient synchronizing with the crop yield are identified. |
| 5. Nutrient status of the compost | Quantitative data on pH, N, P, K and organic carbon are available | Improvement in the nutrient status of the compost when compared to that of the conventional compost |
| 6. Characterisation for soil organic matter in farms for which the green leaf manure is incorporated | Data on SOM in control (green leaf manure not incorporated) plots and in plots where the green leaf manure is incorporated are available | Soil organic matter contents enhanced considerably in the experimental plots |
| 7. Study on soil flora and fauna | Quantitative information on diversity and abundance of selected soil flora and fauna are available | Change in composition and diversity in soil flora and fauna |

**2. Conclusion**

The ex-ante evaluation has been performed by adopting a participatory approach aiming at the pro-active involvement of different actors, and a dialogue-oriented relationship among the evaluator and the various stakeholders. The evaluation process has been successful as it has ensured a close co-operation and an effective dialogue with the stakeholders for implementing different on-farm experiments to demonstrate the effectiveness of different soil fertility improvement methods both for sustainable yield and conservation and management of belowground biodiversity.

# Section -2

# On-farm experiments

# Section -2a

## Leguminous cover crop cultivation for management of weed community, belowground biodiversity and soil fertility

## 1. Introduction

In the agricultural and agroforestry systems, weeds may not cause the rapid devastation that pests or diseases can. However, the weeds are more ubiquitous, and many farmers consider weeds their most serious problem. For instance, the weed biomass load in different cropping systems in Kerala may range, depending on the cropping pattern and crop age, from 6000 to 9000 kg $ha^{-1}$ (Chandrashekara *et al.,* 2006). Since weeding is labour intensive and expensive, majority of the farmers opt for either partial or no weeding. Thus, presence of rich weed biomass and their competition with crops are attributed as the factors for low farm productivity in the region. Apart from weeds, degradation of soil fertility is also a severe problem in the agrarian sector. Farmers are also realizing that the shortage and high cost of inorganic fertilisers have limited their use for crop production. Similarly, over-harvest of biomass without sufficient nutrient input is leading to the loss of nutrients from crop lands. During PRA meetings of the research project on conservation and management of belowground biodiversity in the Kerala part of Western Ghats, above mentioned factors responsible for low productivity and soil organic matter depletion in different cropping systems were discussed. During these meetings, certain strategies that have to be adopted in order to maintain soil fertility, sustainable yield and enhance diversity of soil biota were also identified. Cultivation of leguminous cover crop is one such strategy on which the farmers showed interest.

Intercropping trees with cover crop is a well-known strategy in several cash-crop production systems in the tropics. In tropical Asia, cover crops are frequently planted in oil palm plantations (Broughton, 1976) as well as with coconut (Bavappa, 1995), rubber (Watson *et al.,* 1964) and coffee (Bradshaw and Lanini, 1995). Cover crops may fulfil several purposes in cropping systems which have long been recognised (Bunting and Milsum, 1928). Through the permanent soil cover loss of soil nutrient and organic matter can be decreased as well as the soil structure can be improved (Lal *et al.,* 1991). Thus ample information exists about cover crops in crop rotation or intercropping with annual crops or commercial tree crop systems. However, comparative studies are lacking to provide answers for the following questions

1. How growth and biomass production of a set of leguminous cover crop species planted in a given cropping system vary
2. What is the effect of different leguminous cover species on structure, composition and diversity of weed community in a given cropping system, and

3. Whether different leguminous cover crops change the soil physical and chemical properties as well as soil biota in different ways.

Thus, experiments were designed to demonstrate the effects of cultivation of different leguminous cover crops in controlling weeds and improving soil fertility as well as to find out answers for the above mentioned questions.

## 2. Materials and Methods

### 2.1. Cover crop selection

Experiments were conducted in the coconut plantations of the BGBD benchmark site of the Kerala part of Nilgiri Biosphere Reserve. After ex-ante evaluation of the proposed activity, meetings of the farmers were organised to explain the proposed activity, getting their consent and selection of cover crop species preferred by the farmers. During this process, *Arachis pintoi*, *Calpogonium mucunoides* and *Sesbania aculeata* were selected.

*Arachis pintoi* (hereafter, *A. pintoi*) is a stoloniferous, perennial herb developing a strong taproot on the older crowns and forming a dense mat of stolons (Cook,1992). Stems initially prostrate and then become ascendant to 50 cm in height depending on environment. This species, native to South America, where generally occurs under low (open) forest native vegetation, is now grown throughout the wet tropics and subtropics, and the upland tropics up to about 1,400 m above mean sea level. *A. pintoi* grows in areas receiving an annual rainfall of about 1,000-2,000 mm. The species survives dry seasons of 4 months. Successful growth of this plant can be achieved in soils with pH ($H_2O$) ranging from about 4.5-7.2, although growth reduced below pH 5.4. The species prefers moderate to high fertility but can survive in infertile soils. Plants can be established from cuttings or from seeds. In subtropical Australia growing in pure stand cut to ground level every 4 weeks produced up to 6.5 t $ha^{-1}$ $yr^{-1}$ DM (dry matter). More recent work indicates cumulative yields up to 24 t $ha^{-1}$ DM over 2 years in Brazil. Results indicate that *A. pintoi* is a multiple-use ground cover crop with a high potential to contribute to sustainable agricultural systems (Ayarza *et al.*, 1998). The main agronomic features for that purpose are: wide adaptation range, persistence, easy vegetative establishment, good spread, shade tolerance and the choice of seeding or non seeding accessions. In some parts of the world like Hawaii, *A. pintoi,* known as Golden Glory, is becoming popular as landscape groundcover (Hensley *et al*., 1997). *A. pintoi* is a highly persistent palatable pasture legume with a high feeding value for humid tropical climates tolerant to heavy grazing and shade.

*Calapagonium mucunoides (C. mucunoides)* is a vigorous, creeping and twining, hairy herb forming a tangled mass of foliage 30 to 40 cm deep. This species, native to tropical South America is mainly used as cover crop in tropical tree plantations over the past 100 years. The plant prefers humid-tropical, low elevations but will grow up to altitudes of 2,000 m asl .The plant grows best at 32ºC maximum and 24ºC minimum daily temperatures, on a wide range of soil types, but prefers clay soils with pH 4.5-5.0. When the climate is hot and humid with annual rainfall exceeding 1,500 mm, individual plants may persist for 2-3 years. On the other hand in drier environments the species behaves as an annual. The species productivity is relatively constant at 60-100% light transmission. Under mature coconut plantations, it grows productively at 60-70% light transmission, but is not tolerant of heavy shade. Under regular cutting, annual yields of 4-6 t/ha are achieved when cut every 9-12 weeks. DM yields generally decline over time with repeated cutting or grazing, and yields may be substantially lower in the second and third years after planting. *C. mucunoides* is recognised as a valuable pioneer species, reducing erosion and improving soil fertility. Despite generally low palatability, cattle graze this plant during the latter part of the dry season in tropical Asia and Africa. This species is recognised as one of very few commercially available legumes, but used more as a cover crop rather than as forage.

*Sesbania aculeata (S.aculeata) is a* quick growing succulent green manure crop, which can be incorporated at about 8 to 10 weeks after sowing. This crop adapts to varying conditions of soil and climate. It can be grown even under adverse conditions of drought, water-logging, salinity etc. The species thrives in low to medium elevations (0–1200 m) and is reported to tolerate annual precipitation of 550 to 2210 mm, annual mean temperature of 19.9–27.3°C, and pH of 5.8–7.5. This cover crop generally cultivated for nutritive value to soil. It is cultivated in monsoon season almost throughout India. The green matter yield is 10-20 t/ha.

**2.2. Methods**

In the month of October 2007, fifteen plots, each of 25 m x 3 m in size were marked in the experimental site following the randomized complete block design. In each plot, ten quadrats each of 1m x 1 m were randomly laid to estimate the density and percentage frequency of distribution of each species in herb or shrub community.

From each plot, nine core soil samples were collected. 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 10-20 cm and samples for moisture determination were kept apart. Rest of the soil samples were air –dried and analysed for pH ($H_2O$), organic carbon, exchange acidity, total nitrogen, Bray extractable phosphorus, exchangeable potassium, calcium and magnesium by adopting methodology described in the TSBF working manual. A part of the soil samples collected from each plot was mixed separately and used to enumerate fungi, bacteria and actinomycetes using serial dilution plate method. One gram of soil sample was suspended and agitated in a test tube containing 9 ml of sterile water. Serial dilutions were made by transferring 1 ml into additional dilute blanks to prepare the dilutions $10^{-2}$, $10^{-3}$, $10^{-4}$ and $10^{-5}$. Transferred 0.1 ml aliquots from $10^{-3}$ into five Petri dishes for the enumeration of fungi and then poured the cooled ($45^0$ C) Rose Bengal Agar medium to each Petri dish followed by gentle rotation. For the enumeration of bacteria and actinomycetes, transferred 0.1 ml aliquots from $10^{-5}$ into five Petri dishes and then poured the cooled ($45^0$ C) nutrient Agar medium to each Petri dish followed by gentle rotation. Upon solidification of the media, all the plates were incubated in an inverted position at $25^0$ C for 2-7 days. The number of colonies on the dilution plates were counted, averaged and multiplied by dilution factor to find the number of cells per gram of sample.

Number of cells /ml = mean plate count x dilution factor/dry weight of soil

Quantification and identification of micro organisms in the soil was extended to rhizobium, azatobactor and phosphate solubilising microorganisms. Selected fifteen Petri plates and transferred 0.1 ml aliquots from $10^{-2}$ dilution to each plate. These fifteen plates were arranged into three sets each with five plates. For the Petri plates of first set poured the cooled ($45^0$ C) yeast extract mannitol agar medium for the quantification and identification of Rhizobium. The Jensen's Agar medium was poured into Petri dishes of the $2^{nd}$ set and while Pikovskaya's Agar was poured into Petri plates of the $3^{rd}$ set to quantify and identify Azatobactor and Phosphate solubilising microorganisms respectively. Upon solidification of the media, all the plates were incubated in an inverted position at $25^0$ C for 4-10 days. The number of cells per gram of soil was worked out.

From each plot, three soil monoliths, each of 25 cm x 25 cm and 30 cm depth were extracted. Earthworms present in each monolith were hand sorted and counted.

**2.3. Planting of leguminous cover crops**

As mentioned earlier, three leguminous cover crops namely *A. pintoi*, *C. mucunoides* and *S.aculeata* were selected for the study. On 20-25 October 2007, weeds of twelve plots were cut at ground level. The harvested biomass was segregated to species level and weighed separately. A sub sample of the fresh biomass was oven dried at $65^0$ C for 48 hours for dry matter estimation. However, the three plots were marked as `weed plots' and weeds were not removed. These plots were monitored the weed species composition, density and biomass at bi-monthly interval. Ground cover was estimated at monthly interval using a line-transect method (Daughtry *et al*, 1995). A cord marked at 5-cm intervals was stretched diagonally across the plot and the proportion of points in line with vegetation was covered.

Twelve plots from where the weed biomass was removed were used for three cover crop treatments and one no-cover crop control with three replications per treatment. In *A. pintoi* cover crop treatment plots, 100 rooted stem cuttings per 1 $m^2$ area were planted. Whereas, in *C.mucunoides* and *S.aculeata,* seedling of the respective species were transplanted at the rate of 100 seedlings per 1 $m^2$ area.

In the no-cover crop plot, every month, sub quadrats each of 1 m x 1m in replicates were marked. Weed species were identified and density, fresh biomass and dry matter yield were estimated. Species importance value index and Shannon's index of species diversity were also calculated following the standard method. Relative biomass increment rate (RBI) and relative density increment rate (RDI) of weeds were calculated using the following formulae

$$RBI = (\ln w_2 - \ln w_1)/ (t_2 - t_1)$$

$$RDI = (\ln d_2 - \ln d_1)/ (t_2 - t_1)$$

Where $w_1$ and $d_1$ are the biomass and density recorded at time $t_1$, $w_2$ and $d_2$ are the biomass and density recorded at time $t_2$.

In cover crop plots, biomass and relative density increment rate (RDI) and relative biomass increment rate (RBI) of both leguminous cover crops and weeds at monthly interval were estimated following the methods described above.

In both no-cover control plots and cover crop plots, soil samples were collected 3, 9 and 15 months after the establishment of plots to characterise soil chemical properties and enumerate and identify soil microorganisms. Similarly, earthworm density was estimated following the soil monolith extraction method. All data were subjected to suitable statistical tests.

## 3. Results and discussion

### 3.1. Soil properties

In coconut gardens, soil moisture at 0-10 cm depth was 24.6% while that in 10- 20 cm depth was 25.3%. Soil is acidic with mean pH value of 5.3 at surface soil (0-10 cm) and 5.5 at sub-surface soil (10-20 cm). Organic carbon content in the surface soil was 0.55% and in the sub-surface soil it was 0.58%. Values of other soil parameters are also given in the Table 1.

Table 1. Properties of soil in the coconut garden

| Soil parameter | Soil depth | |
|---|---|---|
| | 0-10 cm | 10-20 cm |
| Moisture (%) | 25.58±3.30 | 21.36±3.17 |
| pH ($H_2O$, 1: 2.5) | 5.27±0.08 | 5.50±0.04 |
| Organic carbon (OC) (%) | 0.55±0.03 | 0.58±0.04 |
| Total nitrogen (N) (%) | 0.10±0.01 | 0.09±0.01 |
| Extractable phosphorus (P) (mg/kg) | 11.17±2.12 | 13.23±2.70 |
| Exchangeable potassium (K) (mg/kg) | 25.67±2.39 | 17.00±3.24 |
| Exchangeable calcium (Ca) (meq/100g) | 2.27±0.20 | 2.73±0.07 |
| Exchangeable magnesium (Mg) (meq/100g) | 0.73±0.15 | 0.83±0.30 |
| Exchangeable acidity (EA) (meq/100g) | 0.27±0.05 | 0.30±0.05 |
| Cation exchange capacity (CEC) (meq/100g) | 61.30±3.61 | 50.73±4.06 |

Table 2. Properties of soil in the plots established for the experiment on cultivation of leguminous cover crop for weed control in the coconut gardens. Values are mean ± SE.

| Parameter | No- cover crop control plots | | Cover crop plots | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | *A. pintoi* | | *C. mucunoids* | | *S. aculeata* | |
| | 0-10 | 10-20 | 0-10 | 10-20 | 0-10 | 10-20 | 0-10 | 10-20 |
| Moisture (%) | 11.66 ±0.91 | 13.14 ±1.03 | 24.02 ±0.61 | 27.83 ±0.42 | 23.19 ±0.09 | 26.60 ±0.88 | 13.60 ±1.13 | 15.06 ±1.50 |
| pH | 5.12 ±0.18 | 5.29 ±0.04 | 5.25 ±0.05 | 5.44 ±0.01 | 5.19 ±0.04 | 5.34 ±0.09 | 5.16 ±0.11 | 5.27 ±0.07 |
| OC (%) | 0.72 ±0.05 | 0.65 ±0.06 | 0.06 ±0.03 | 0.05 ±0.03 | 0.65 ±0.03 | 0.61 ±0.05 | 0.58 ±0.07 | 0.70 ±0.09 |
| N (%) | 0.11 ±0.006 | 0.11 ±0.004 | 0.11 ±0.01 | 0.09 ±0.01 | 0.13 ±0.02 | 0.18 ±0.04 | 0.14 ±0.01 | 0.10 ±0.03 |
| P (mg/kg) | 16.20 ±1.05 | 14.70 ±2.18 | 15.03 ±0.20 | 15.03 ±0.85 | 16.23 ±0.27 | 13.43 ±0.69 | 16.00 ±1.00 | 15.77 ±1.53 |
| K (mg/kg) | 19.50 ±7.01 | 19.67 ±7.18 | 18.8 ±2.24 | 17.30 ±1.00 | 20.83 ±1.48 | 18.50 ±0.76 | 21.67 ±1.77 | 16.67 ±3.34 |
| Ca (meq/100g) | 2.10 ±0.12 | 2.60 ±0.12 | 2.33 ±0.07 | 2.60 ±0.20 | 1.93 ±0.07 | 2.33 ±0.20 | 2.33 ±0.19 | 2.33 ±0.21 |
| Mg (meq/100g) | 0.60 ±0.23 | 1.03 ±0.18 | 0.81 ±0.06 | 1.15 ±0.09 | 0.73 ±0.20 | 0.80 ±0.15 | 0.57 ±0.07 | 0.63 ±0.12 |

Soil properties at the time of establishment of plots such as no-cover crop control plots and cover crop plots are given in Table 2. These values form the benchmark values for soil properties in different experimental plots. Soil samples were also

collected 3, 9 and 15 months after the establishment experimental plots and analysed for their chemical properties (Figure 1).

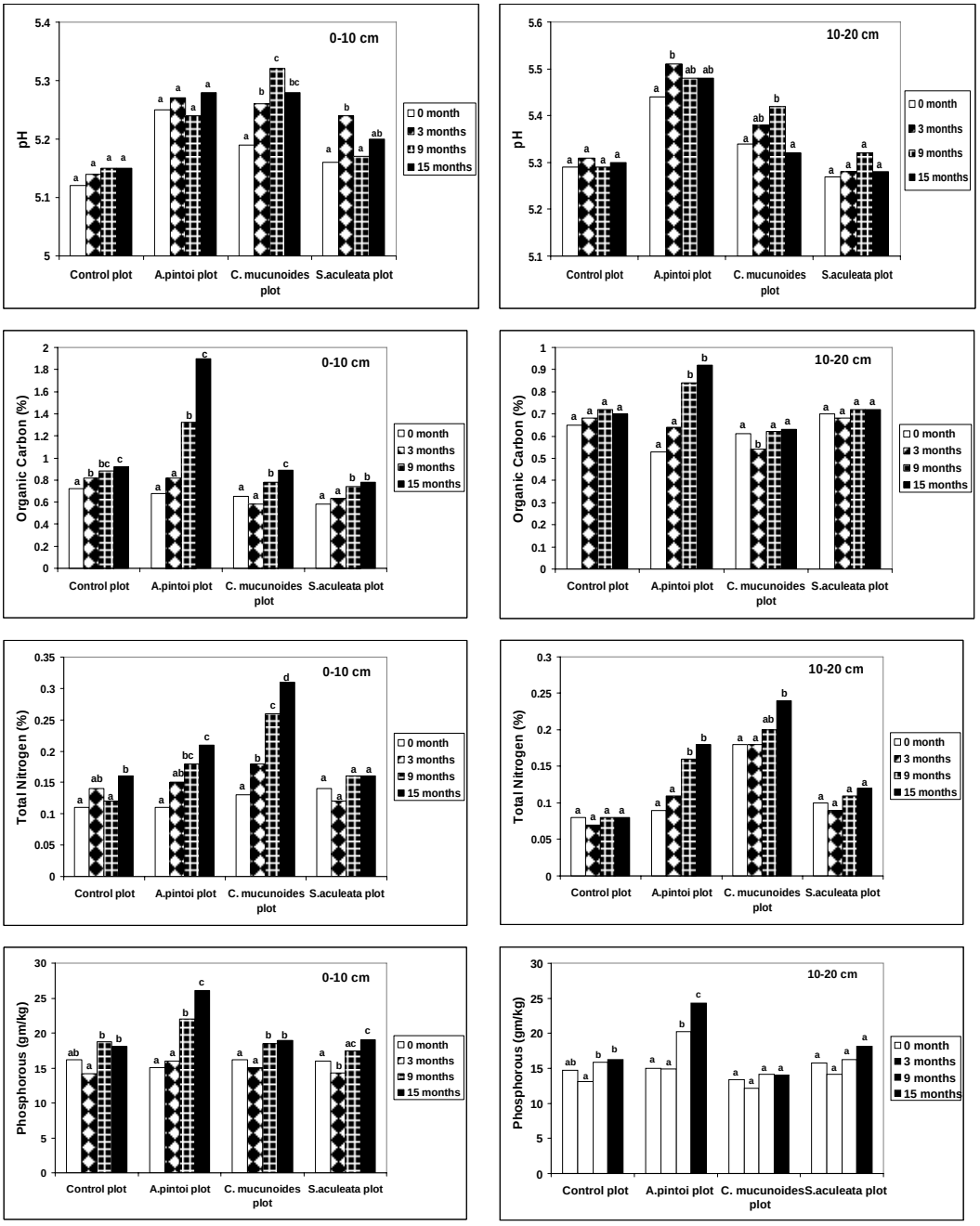


Figure 1. Soil properties in no-cover crop control and cover crop plots at different periods of experiment. In a given plot, value with same letter are not significantly different ($p > 0.05$; using LSD Fisher's Multiple Range Test).

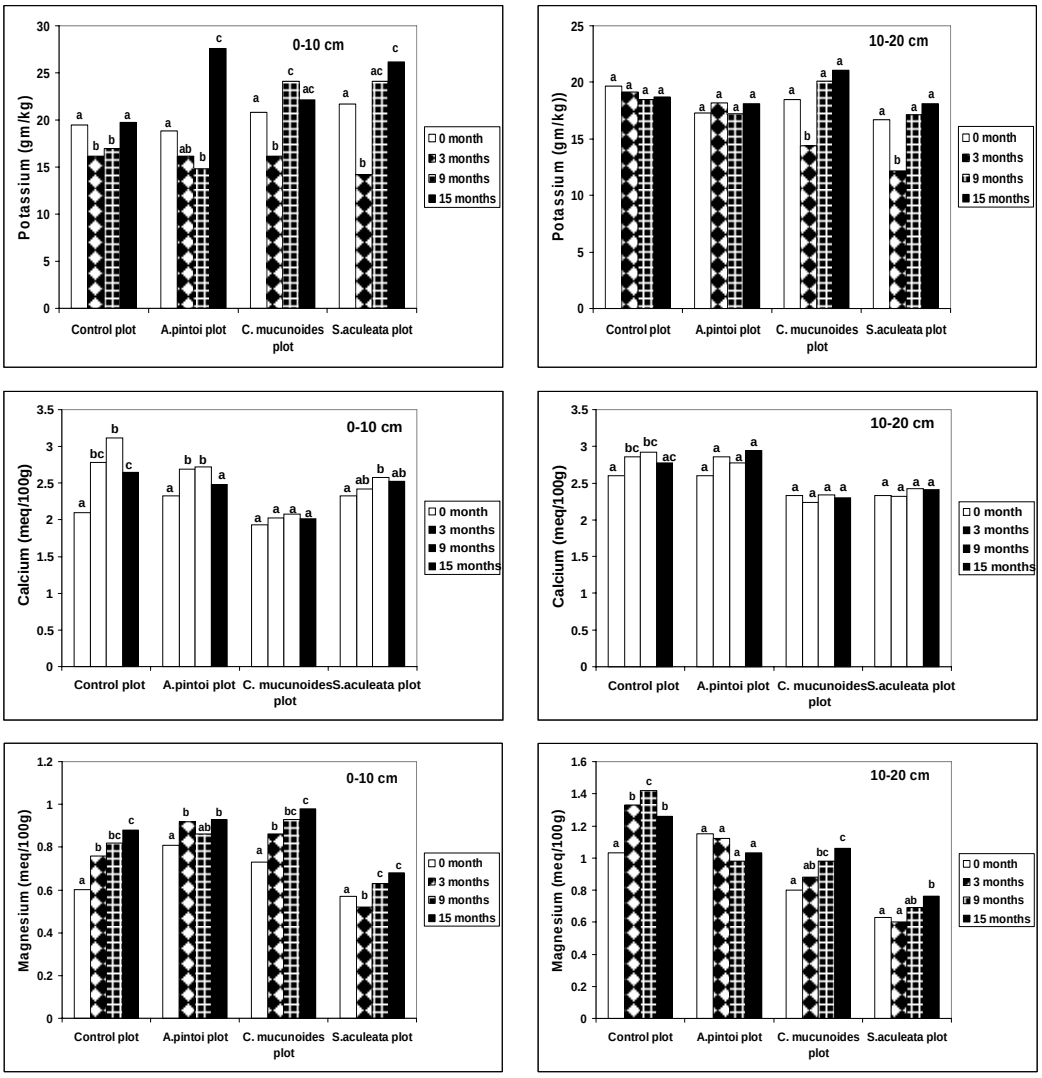


Figure 1 (cont'd). Soil properties in no-cover crop control and cover crop plots at different periods of experiment. In a given plot, value with same letter are not significantly different ($p > 0.05$; using LSD Fisher's Multiple Range Test).

Monitoring of pH in surface (0-10 cm) and sub surface (10-20 cm) soil in no-cover crop and cover crop experimental plots indicated that in each plot, pH did not change even 15 months after the commence of experiment ($p>0.05$). However, in all experimental plots, organic carbon content in the surface soil increased significantly in 15 months time when no such trend was observed in the sub-surface soil. Comparison of different experimental plots indicated that increase in the organic carbon content was significantly more in *A. pintoi* plot ($p<0.05$). With the growth of vegetation in the control plot as well as in the plots of *A. pintoi* and *C. mucunoides* total nitrogen content in the surface soil increased significantly ($p<0.05$). The study

also indicated that increase in N content is significantly more ($p<0.05$) in *C. mucunoides* plot than in *A. pintoi* plot and control plot. In the cover crop experimental plots, phosphorous content in the surface soil increased significantly with time ($p<0.05$). However, increase in phosphorous content in the sub-surface soil was recorded only in *A. pintoi*. Both in surface and sub-surface soils, increase in phosphorous content was significantly more ($p<0.05$) in *A. pintoi* than in other plots. Cultivation of leguminous cover crops like *A. pintoi* and *S. aculeata* also increased the potassium content, both in surface and sub-surface soil. However, generally the potassium level initially decreased in the first 3-9 months after planting cover crops, but later increased. Among different experimental plots, the plot of *A. pintoi* showed significantly high value for potassium ($p< 0.05$). In each cover crop plot, calcium content during the study period did not alter significantly ($p>0.05$). However, within 15 months after plots establishment, magnesium content in the soils of cover crop plots has increased considerably ($p<0.0.5$). While calcium content was more in *A.pintoi* plot and *S.aculeata* plot, magnesium content was more in the plots of *A.pintoi* and *C. mucunoides.*

The present study clearly indicates that within 9-15 months after the cultivation of leguminous cover crops like *A. pintoi* and *C. mucunoides*, total nitrogen contents in the soil increases considerably and thus its availability is enhanced. In the case of *A. pintoi,* soil organic carbon also enhanced along with total nitrogen. Some studies on leguminous cover crops demonstrated that for nutrients other than N which cannot be supplied by the legume from external sources like P, the cover crop may induce nutrient competition resulting in lower major crop nutrition. However, in the present study, cultivation of leguminous cover crops did not decrease the phosphorous content in the soil, though not able to enhance the phosphorous availability, with an exception being *A. pintoi* plot where the phosphorous content in the soil increased significantly. Similarly, though the potassium contents in the soil decreased initially, considerable increase there after clearly suggests that leguminous cover crop cultivation also enhance the potassium availability.

### 3.2. Soil microorganisms

Before introducing the leguminous cover crop, soil sample were collected from each selected plot to study the microbial population. Enumeration of bacteria, fungi, and actinomycetes was carried out by serial dilution plate method. The quantification of Rhizobium, Azotobacter, and Phosphate solubilising microorganisms of different experimental area were carried out using Yeast extract mannitol agar medium,

Jensen's Agar medium and Pikovskaya's Agar medium respectively. Data obtained are presented in the Table 3.

Table 3. Microbial population (cfu; mean ± SE, in log values) in the plots selected for leguminous cover crop experiments.

| Parameter | No- cover crop control plots | Cover crop plots | | |
|---|---|---|---|---|
| | | *A. pintoi* | *C. mucunoids* | *S. aculeata* |
| Bacteria (cfu) | 6.36±0.46 | 6.78±0.28 | 6.56±0.26 | 6.42±0.32 |
| Fungus (cfu) | 4.32±0.18 | 4.46±0.11 | 4.29±0.21 | 4.38±0.17 |
| Actinomycetes | 3.23±0.07 | 3.41±0.08 | 3.18±0.32 | 3.32±0.09 |
| Rhizobium | 3.89±0.11 | 3.94±0.12 | 3.92±0.14 | 3.86±0.09 |
| Phosphate soluble microbes | 3.72±0.16 | 3.84±0.21 | 3.69±0.18 | 3.79±0.19 |
| Azatobactor | 3.19±0.12 | 3.23±0.08 | 3.17±0.06 | 3.28±0.11 |

Each microbial group was studied to assess changes in their population size by collecting soil samples 3, 9 and 15 months after the establishment of plots (Figures 2 to 7). Both in the no cover crop control plot and in cover crop plots, bacterial population increased significantly in the first 3-9 months ($p<0.05$) and then drastically declined to reach the initial level. Even the fungal population either decreased or remained unaltered throughout the study period. On the other hand, significant increase in actinomycetes up to 15 months after the establishment of both in no-cover and cover crop plots has been noticed. However, though the acticnomyctes count was reduced later, values were significantly more than the initial values ($p<0.05$).

The rhizobial count in the control plot did not alter significantly during the study period ($p>0.05$). On the other hand, the rhizobial count has increased within 3-15 month after planting with leguminous cover crops. In general, phosphate soluble microbial count did not differ before establishing and 15 month after establishing plots. However, in control and *S. aculeata* plots, phosphate soluble microbial count drastically declined initially before increasing again. In all plots, azatobactor population was significantly high in the samples collected 9 months after the plots establishment.

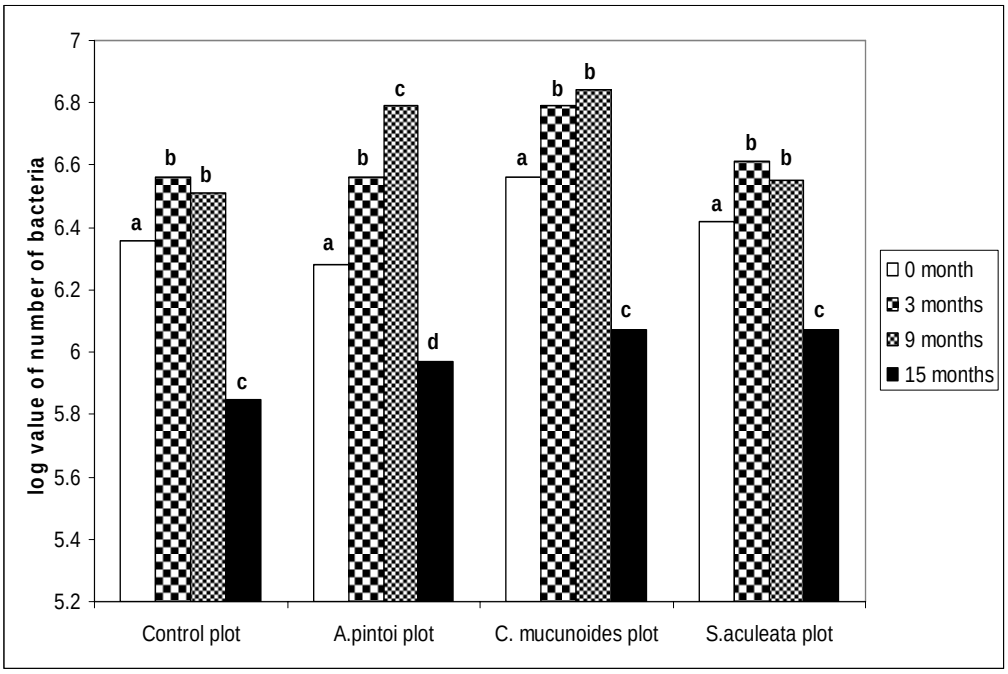


Figure 2. Bacterial population (cfu; mean in log values) in non- cover crop control and cover crop plots at different periods of experiment. In a given plot, value with same letter are not significantly different (p >0.05; using LSD Fisher's Multiple Range Test).

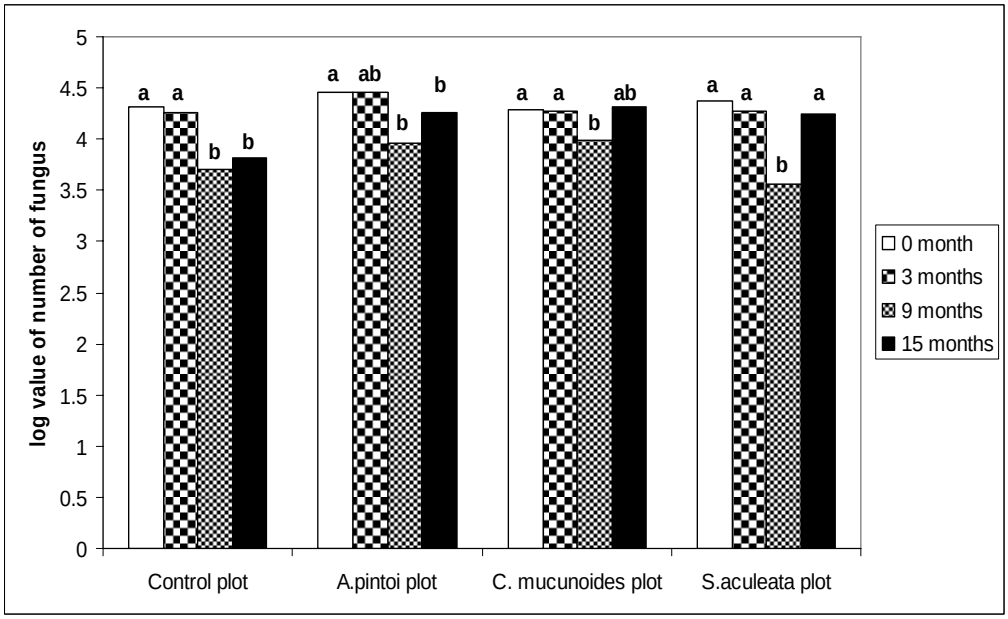


Figure 3. Fungal population (cfu; mean in log values) in non- cover crop control and cover crop plots at different periods of experiment. In a given plot, value with same letter are not significantly different (p >0.05; using LSD Fisher's Multiple Range Test).

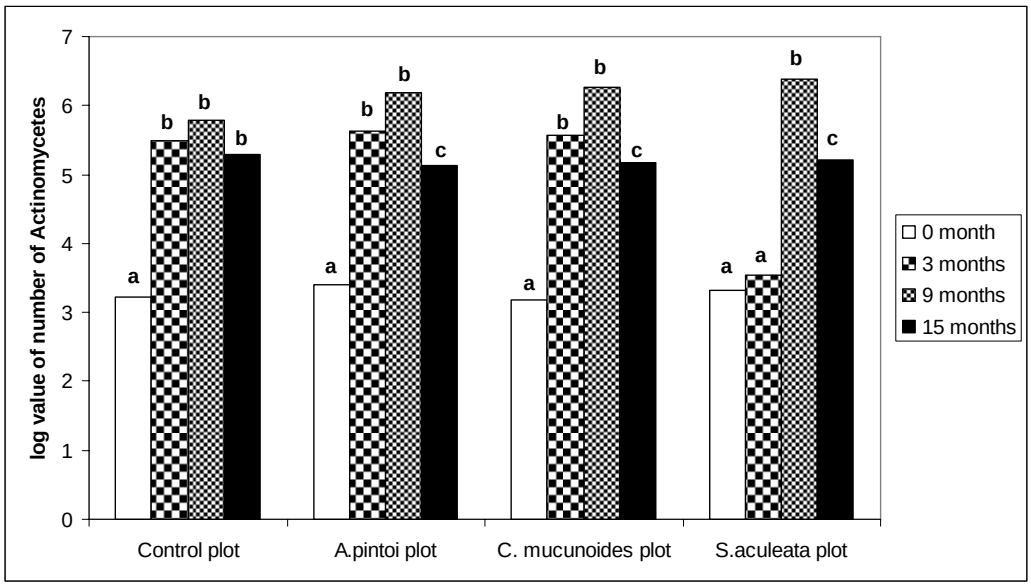


Figure 4. Population of actinomycetes (cfu; mean in log values) in non- cover crop control and cover crop plots at different periods of experiment. In a given plot, value with same letter are not significantly different (p >0.05; using LSD Fisher's Multiple Range Test).

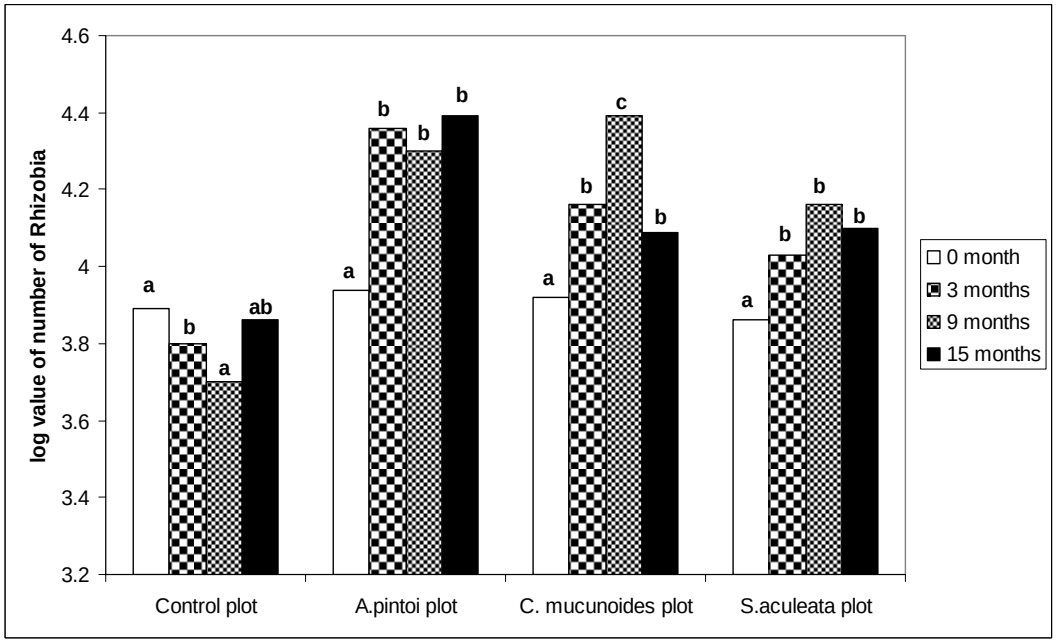


Figure 5. Population of rhizobia (cfu; mean in log values) in non- cover crop control and cover crop plots at different periods of experiment. In a given plot, value with same letter are not significantly different (p >0.05; using LSD Fisher's Multiple Range Test).

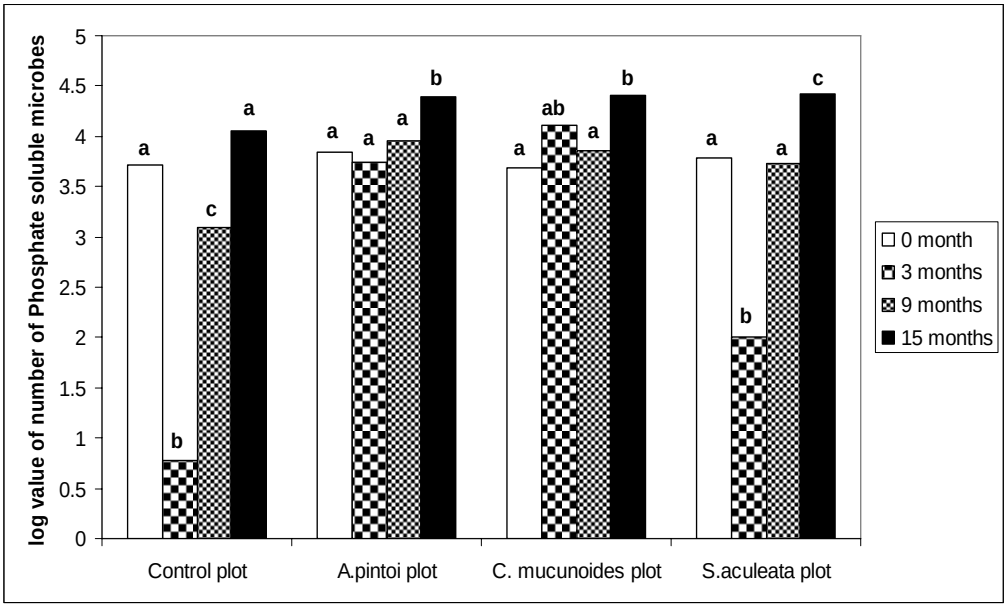


Figure 6. Phosphate soluble microbial population (cfu; mean in log values) in non-cover crop control and cover crop plots at different periods of experiment. In a given plot, value with same letter are not significantly different (p >0.05; using LSD Fisher's Multiple Range Test).

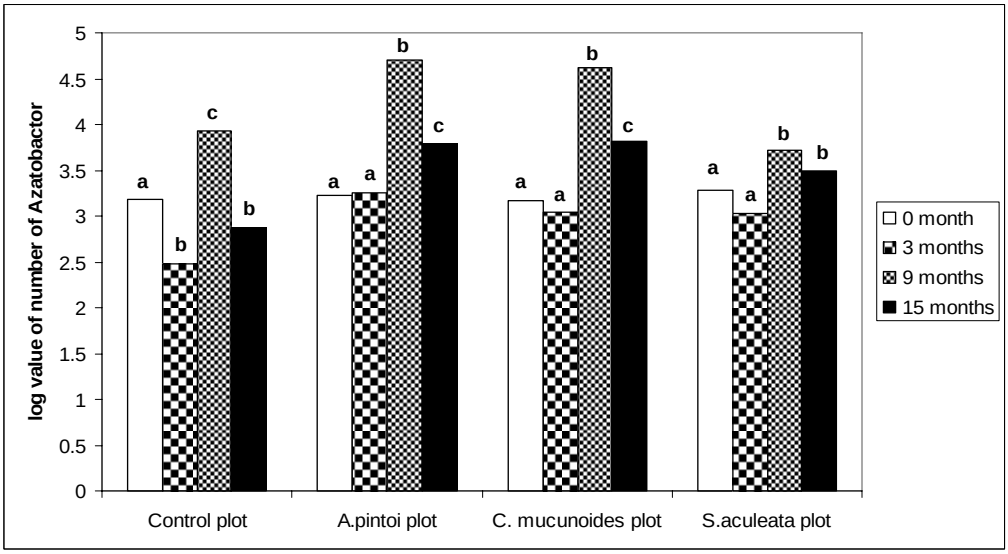


Figure 7. Population of azotobactor (cfu; mean in log values) in non- cover crop control and cover crop plots at different periods of experiment. In a given plot, value with same letter are not significantly different (p >0.05; using LSD Fisher's Multiple Range Test).

### 3.3. Soil Macrofauna

During the sampling period, earthworm abundance in the coconut garden and in experimental plots established in the coconut garden was studied. The earthworm abundance in coconut garden was 212±52 individuals $m^{-2}$. Values obtained for the earthworm abundance in the experimental plots at different periods of experiment are given in Table 4. In *A. pintoi* and *C. mucunoides* plots significant increase in the earthworm density was recorded up to 8 to 15 months after plots establishment. However, in the control and *S. aculeata* plots, the earthworm population remained same throughout the study period.

Table 4. Earthworm abundance (mean ± SE, individuals $m^{-2}$) in the plots established for the experiment on cultivation of leguminous cover crop for weed control in the coconut gardens in coconut garden.

| Time since plot establishment | Earthworm abundance (Individuals $m^{-2}$) | | | |
|---|---|---|---|---|
| | No- cover crop control plot | Cover crop plots | | |
| | | *A. pintoi* | *C. mucunoides* | *S. aculeata* |
| 0 month | 148±30[a] | 124±59[a] | 124±53[a] | 60±23[a] |
| 3 months | 158±15[a] | 138±26[a] | 122±24[a] | 89±16[a] |
| 9 months | 164±8[a] | 186±12[b] | 164±10[a] | 96±8[a] |
| 15 months | 172±6[a] | 198±6[b] | 186±9[b] | 88±3[a] |

### 3.4. Structure and composition of weed flora

In the coconut garden, mean ground cover by weeds ranged from 67% to 98% with comparatively sparse cover during December to April. During the study period, fifty three weed species belonging to twenty four angiosperm families and two fern pteridophyte families were recorded (Table 5). Number of species encountered in each bi-monthly observation ranged from eleven to forty four. *Digitaria timorensis*, *Ischane mileacea*, *Paspalum conjugatum*, *Paspalum scrobiculatum* and *Brachiaria burmanica*- all belonging to Poaceae were the dominant species throughout the study period. Weed species distributed in different taxonomic groups are given in Table 6. Among monocots, Araceae, Commelinaceae, Cyperaceae, Poaceae and Pontederiaceae were noticed in the study area. According to Nair and Chami (1963), the weed of the families Poaceae and Cyperceae, if dominant in a cropping system, are the most troublesome. In the present study area, Poaceae and Cyperaceae, by contributing together 61% to the total IVI of all plants of the weed community form the most dominant families and thus weed management in this farm is a challenging task for the farmers.

Table 5. Importance value index of weed species in the coconut garden

| Species | Family | Months* | | | | | |
|---|---|---|---|---|---|---|---|
| | | Oct '07 | Dec | Feb '08 | Apr | Jun | Aug |
| *Ageratum conyzoides* | Asteraceae | 9 | Ab | Ab | Ab | 4 | 6 |
| *Biophytum sensitivum* | Oxalidaceae | Ab | Ab | Ab | Ab | 1 | 1 |
| *Brachiaria burmanica* | Poaceae | 27 | 25 | 26 | 11 | 18 | 11 |
| *Brachiaria eruciformis* | Poaceae | 12 | 8 | 10 | 4 | 4 | 12 |
| *Centella asiatica* | Apiaceae | 5 | 4 | 6 | Ab | 2 | 2 |
| *Centrosema pubescens* | Fabaceae | Ab | Ab | Ab | Ab | 2 | |
| *Ceratopteris thalictroides* | Parkariaceae | Ab | Ab | Ab | Ab | 2 | 1 |
| *Cleome viscose* | Capparidaceae | | 4 | 6 | Ab | Ab | 3 |
| *Colocasia esculenta* | Araceae | 4 | 5 | 7 | Ab | 2 | 2 |
| *Commelina benghalensis* | Commelinaceae | Ab | Ab | Ab | Ab | 1 | 0.5 |
| *Cyanotis cristata* | Commelinaceae | Ab | Ab | Ab | Ab | 0.5 | 0.5 |
| *Cyathula prostate* | Amaranthaceae | Ab | Ab | Ab | Ab | 2 | 2 |
| *Cyclea peltata* | Menispermaceae | 5 | 3 | 6 | Ab | 4 | 3 |
| *Cynadon dactylon* | Poaceae | 6 | 8 | 9 | 5 | 2 | 2 |
| *Cyperus disformis* | Cyperaceae | 2 | 2 | 4 | 3 | 1 | 1 |
| *Cyperus rotundus* | Cyperaceae | 4 | 3 | 4 | 3 | 2.5 | 2 |
| *Cyrtococcum oxyphyllum* | Poaceae | 2 | 3 | Ab | Ab | Ab | 3 |
| *Desmodium gangeticum* | Fabaceae | 5 | Ab | Ab | Ab | Ab | Ab |
| *Desmodium gyrens* | Fabaceae | Ab | Ab | Ab | Ab | 0.5 | Ab |
| *Desmodium triangulare* | Fabaceae | 6 | 4 | 2 | Ab | 4 | 5 |
| *Desmodium triflorum* | Fabaceae | 12 | 8 | 9 | 18 | 10 | 7 |
| *Digitaria timorensis* | Poaceae | 26 | 28 | 24 | 83 | 46 | 40 |
| *Eclipta alba* | Asteraceae | Ab | Ab | Ab | Ab | 3 | 5 |
| *Elephantopus scaber* | Asteraceae | 3 | 3 | Ab | Ab | Ab | Ab |
| *Elusine indica* | Poaceae | 4 | 2 | 2 | Ab | Ab | 8 |
| *Emilia sonchifolia* | Asteraceae | Ab | Ab | 1 | Ab | Ab | Ab |
| *Eragrostis tenuifolia* | Poaceae | 2 | Ab | Ab | Ab | 3 | Ab |
| *Eupatorium odoratum* | Asteraceae | 4 | 5 | 7 | 5 | 2 | 2 |
| *Heliotropium indicum* | Boraginaceae | 8 | 6 | 8 | Ab | 2 | 7 |
| *Hyptis capitata* | Lamiaceae | 6 | 4 | 4 | Ab | 2.5 | 2 |
| *Ipomoea aquatic* | Convolulaceae | Ab | Ab | Ab | Ab | 1 | 2 |
| *Ischane miliacea* | Poaceae | 43 | 40 | 46 | 76 | 98 | 70 |
| *Knoxia corymbosa* | Rubiaceae | 2 | Ab | Ab | Ab | 4 | 7 |
| *Laportea interupta* | Urticaceae | Ab | Ab | Ab | Ab | 2 | 3 |
| *Leucas aspera* | Lamiaceae | Ab | 1 | 2 | Ab | 1 | 1 |
| *Leucas biflora* | lamiaceae | Ab | Ab | Ab | Ab | 2 | 4 |
| *Lindernia crustacean* | Scrophulariaceae | Ab | Ab | Ab | Ab | 1 | 1 |
| *Ludwigia parviflora* | Onagraceae | 3 | 7 | 8 | Ab | 7 | 8 |
| *Mimosa pudica* | Fabaceae | 6 | 10 | 14 | Ab | 8 | 6 |
| *Monochoria vaginalis* | Pontederiaceae | Ab | Ab | Ab | Ab | 2 | 2 |
| *Oplismenus composites* | Poaceae | 8 | 11 | 10 | 21 | 11 | 7 |
| *Paspalum conjugatum* | Poaceae | 28 | 36 | 29 | 46 | 26 | 20 |
| *Paspalum scorbiculatum* | Poaceae | 24 | 32 | 20 | 20 | 6 | 13 |
| *Peperomia pellucid* | Piperaceae | Ab | Ab | Ab | Ab | 1 | 2 |
| *Phyllanthus nirurii* | Euphorbuaceae | Ab | Ab | Ab | Ab | Ab | 1.5 |
| *Physalis minima* | Solanaceae | Ab | Ab | Ab | Ab | 0.5 | 2.5 |
| *Pteris sp.* | Pteridaceae | 10 | 12 | 5 | 5 | 2 | 8 |
| *Scoparia dulcis* | Scrophulariaceae | 3 | 2 | Ab | Ab | Ab | Ab |
| *Sida rhombifolia* | Malvaceae | 12 | 14 | 16 | Ab | 3.5 | 7 |
| *Synedrella nudiflora* | Asteraceae | Ab | Ab | Ab | Ab | 1.5 | 3 |
| *Triumfetta rhomboidea* | Tiliaceae | 9 | 10 | 15 | Ab | 1 | 2 |
| *Vernonia cinera* | Asteraceae | Ab | Ab | Ab | Ab | 0.5 | 2 |

*, Ab= Absent

Dominance of alien asteraceaous weeds in farms and fallow lands also considered to be a serious problem in maintaining the sustainability of the cropping system. However, in the present study area, contribution by *Ageratum conyzoides*, an exotic asteraceaous weed, was only 1.2% to the total species IVI value.

Table 6. Contribution (in %) by different plant families to the Importance value index of weed species in the coconut garden

| Dicotyledons | | | |
|---|---|---|---|
| Family | IVI | Family | IVI |
| Amaranthaceae | 0.57 | Malvaceae | 3.01 |
| Apiaceae | 1.09 | Menispermaceae | 1.21 |
| Asteraceae | 5.40 | Onagraceae | 1.89 |
| Boraginaceae | 1.78 | Oxalidaceae | 0.29 |
| Capparidaceae | 1.24 | Piperaceae | 0.43 |
| Convolvulaceae | 0.43 | Rubiaceae | 1.24 |
| Euphorbiaceae | 0.43 | Scrophulariaceae | 1.00 |
| Fabaceae | 8.94 | Solanaceae | 0.43 |
| Lamiaceae | 2.28 | Tiliaceae | 2.12 |
| | | Urticaceae | 0.72 |
| Monocotyledons | | | |
| Araceae | 1.15 | Cyperaceae | 1.51 |
| Commelinaceae | 0.36 | Poaceae | 59.45 |
| | | Pontederiaceae | 0.57 |
| Pteridophytes | | | |
| Parkeriaceae | 0.43 | Pteridaceae | 2.01 |

During the study period, both the density and biomass of weed community varied considerably (Table 7). Maximum weed density and biomass were recorded in the month of August and minimum during October to December. Shannon's index of weed flora diversity (H) in coconut plantation ranged from 2.888 to 4.425, with significantly low value ($P < 0.05$) during April. Sit *et al*. (2007) estimated the Shannon's index of weed flora diversity in the coconut gardens of plains of eastern Himalayan region of West Bengal. They divided the index value by $\log_2 n$ and obtained a value of 0.618 for the coconut garden. When similar procedure was followed in the present study, values obtained at bi-monthly intervals (October, 2007: 0.8891; December, 2007: 0.8719; February, 2008: 0.8973; April, 2008: 0.7804; June, 2008:0.7040; August, 2008: 0.8104) were more than that recorded by Sit *et al*. (2007) indicating that the weed flora of the present study area was comparatively more diverse than that of the coconut garden of West Bengal.

Table 7. Density, biomass and species diversity of weed community in the coconut plantation in the Kerala part of Nilgiri Biopshere Reserve. Values are mean ± S.E.

| | Number of weed species | Ground cover (%) | Density (individuals $m^{-2}$) | Biomass (gm $m^{-2}$) | Weed species diversity (H) |
|---|---|---|---|---|---|
| Oct, 2007 | 31 | 89±9 | 271±21 | 134.7±61.0 | 4.405±0.012 |
| Dec, 2007 | 29 | 76±6 | 271±38 | 232.3±32.8 | 4.236±0.008 |
| Feb, 2008 | 27 | 72±12 | 325±29 | 263.0±33.8 | 4.267±0.006 |
| Apr, 2008 | 13 | 67±7 | 356±33 | 301.3±37.9 | 2.888±0.011 |
| Jun, 2008 | 44 | 96±11 | 364± 36 | 325.7±92.1 | 3.844±0.013 |
| Aug, 2008 | 44 | 98±0.7 | 417±22 | 483.7±28.0 | 4.425±0.004 |

### 3.5. No-cover crop control plot

In the no-cover control plots, newly recruited weeds were monitored at monthly interval from November 2007 to October 2008. During the study period, twenty four weed species were recorded and among them *Ischane miliacea*, *Desmodium triflorum*, *Paspalum conjugatum*, *Cyperus disformis* and *Digitaria timorensis* were dominant and present throughout the study period (Table 8).

Table 8. Importance value index of weed species in the no-cover crop control plot in the coconut garden

| Species | Months* | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Nov' 07 | Dec | Jan '08 | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct |
| *Ageratum conyzoides* | 26 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 18 | 23 | 25 | 27 |
| *Brachiaria burmanica* | 31 | 27 | 26 | 29 | 14 | 13 | 0 | 0 | 15 | 12 | 18 | 24 |
| *Ceratopteris sp.* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 11 | 9 | 4 | 3 |
| *Cleome viscosa* | 0 | 9 | 11 | 0 | 0 | 0 | 0 | 0 | 0 | 7 | 3 | 2 |
| *Commelina benghalensis* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 9 | 5 | 3 | 0 |
| *Cyanotis cristata* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 12 | 8 | 2 | 1 |
| *Cynadon dactylon* | 26 | 36 | 38 | 34 | 29 | 31 | 33 | 28 | 21 | 11 | 18 | 14 |
| *Cyperus disformis* | 21 | 20 | 27 | 31 | 41 | 39 | 41 | 37 | 31 | 26 | 24 | 18 |
| *Desmodium triflorum* | 36 | 36 | 39 | 33 | 38 | 43 | 43 | 40 | 32 | 24 | 26 | 24 |
| *Digitaria timorensis* | 21 | 14 | 31 | 35 | 32 | 38 | 41 | 37 | 24 | 38 | 30 | 28 |
| *Eclipta alba* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6 | 7 | 12 | 8 |
| *Heliotropium indicum* | 19 | 21 | 30 | 38 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 16 |
| *Hyptis capitata* | 16 | 11 | 9 | 13 | 0 | 0 | 0 | 16 | 9 | 6 | 6 | 8 |
| *Ipomoea aquatica* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 7 | 7 | 7 |
| *Ischane miliacea* | 21 | 30 | 32 | 41 | 52 | 43 | 47 | 37 | 42 | 36 | 28 | 28 |
| *Laportea crenulata* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6 | 9 | 4 | 4 |
| *Leucas biflora* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 7 | 9 | 11 | 8 | 6 |
| *Lindernia crustacea* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5 | 5 | 4 | 5 |
| *Ludwigia parviflora* | 19 | 24 | 18 | 21 | 0 | 0 | 0 | 30 | 21 | 20 | 18 | 25 |
| *Oplismenus compositus* | 31 | 23 | 21 | 19 | 41 | 37 | 40 | 35 | 11 | 8 | 24 | 20 |
| *Paspalam conjugatum* | 29 | 41 | 18 | 6 | 53 | 56 | 55 | 30 | 8 | 18 | 13 | 12 |
| *Peperomia pellucida* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 5 | 12 | 11 |
| *Scoparia dulcis* | 4 | 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6 | 4 |
| *Synedrella nudiflora* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 3 | 5 | 4 | 5 |

The study also revealed that even after weeding, newly recruited weed community is dominated by Poaceae and Cyperaceae, whose contribution to total species IVI was around 69% (Table 9).

Table 9. Contribution (in %) by different plant families to the Importance value index of weed species no-cover crop control plots established in coconut plantations

| Dicotyledons | | | |
|---|---|---|---|
| Family | IVI | Family | IVI |
| Asteraceae | 3.03 | Lamiaceae | 3.57 |
| Boraginaceae | 3.60 | Onagraceae | 5.10 |
| Capparidaceae | 0.90 | Piperaceae | 0.27 |
| Convolvulaceae | 0.37 | Scrophulariaceae | 0.73 |
| Fabaceae | 12.13 | Urticaceae | 0.50 |
| Monocotyledons | | | |
| Commelinaceae | 1.13 | Poaceae | 58.20 |
| Cyperaceae | 10.47 | | |

Table 10. Density, biomass and species diversity of weed community in different months in the no-cover crop control plots established in coconut plantations in the Kerala part of Nilgiri Biosphere Reserve. Values are mean ± S.E.

| Months | Number of weed species | Density (individuals $m^{-2}$) | Biomass (gm $m^{-2}$) | Shannon's index of weed species diversity |
|---|---|---|---|---|
| Nov, 2007 | 13 | 22± 0.9 | 8.3±0.88 | 3.600±0.011 |
| Dec, 2007 | 13 | 55±4.4 | 28.0±2.31 | 3.548±0.010 |
| Jan,2008 | 12 | 85± 4.0 | 45.0±2.08 | 3.476±0.008 |
| Feb, 2008 | 11 | 110±8.0 | 90.0±2.65 | 3.332±0.012 |
| Mar, 2008 | 8 | 172±9.5 | 140.0±9.45 | 2.919±0.007 |
| Apr, 2008 | 8 | 191±9.7 | 170.0±15.1 | 2.923±0.009 |
| May, 2008 | 7 | 233±13.9 | 215.3±16.0 | 2.792±0.011 |
| Jun, 2008 | 11 | 251±13.1 | 263.0±13.4 | 3.269±0.012 |
| Jul, 2008 | 21 | 284±10.7 | 310.3±16.4 | 4.039±0.010 |
| Augt,2008 | 22 | 331±8.1 | 312.7±12.5 | 4.134±0.009 |
| Sept, 2008 | 20 | 356±7.3 | 321.7±6.12 | 4.230±0.006 |
| Oct, 2008 | 18 | 275±9.1 | 217.3±2.91 | 4.124±0.005 |
| Nov, 2008 | 19 | 53±3.7 | 44.7±4.37 | 3.730±0.011 |
| Dec 2008 | 16 | 105±3.5 | 93.7±1.20 | 3.458±0.010 |
| Jan, 2009 | 15 | 121±10.0 | 111.3±7.51 | 3.481±0.006 |
| Feb, 2009 | 14 | 144±5.5 | 134.0±5.29 | 3.352±0.010 |
| Mar, 2009 | 10 | 156±6.6 | 138.0±2.00 | 2.923±0.006 |
| Apr, 2009 | 8 | 196±3.8 | 185.3±6.36 | 2.910±0.007 |
| May, 2009 | 8 | 243±6.8 | 224.3±9.87 | 2.862±0.009 |
| Jun, 2009 | 7 | 358±6.4 | 333.3±12.72 | 3.199±0.010 |
| Jul, 2009 | 12 | 396±4.2 | 367.7±1.45 | 4.014±0.009 |
| Aug,2009 | 10 | 449±7.0 | 416.0±4.00 | 4.146±0.008 |
| Sept, 2009 | 15 | 423±10.7 | 406.0±4.16 | 4.220±0.004 |
| Oct, 2009 | 14 | 408±12.6 | 389.3±3.26 | 4.012±0.006 |

The mean maximum value for Shannon's index of diversity of weed flora in the no-cover control plot was 4.230 in September 2008 and the mean minimum value (2.792) was in May, 2008 (Table 10). Within 24 months, the mean weed density and biomass reached to 449 individuals $m^{-2}$ and 416 gm $m^{-2}$ respectively (Table 10).

Monthly variation in the relative density increment and relative biomass increment of weed community was also noticed (Figure 8). The estimated mean values for relative density increment (RDI) and relative biomass increment (RBI) of weed community was 0.134 plants $plant^{-1}$ $month^{-1}$ and 0.177 gm $gm^{-1}$ $month^{-1}$ respectively. A significant correlation ($r = 0.970$, $df=21$, $p>0.05$) noticed between RDI and RBI may be an indication that the increase in weed density and biomass over a period are not independent with each other.

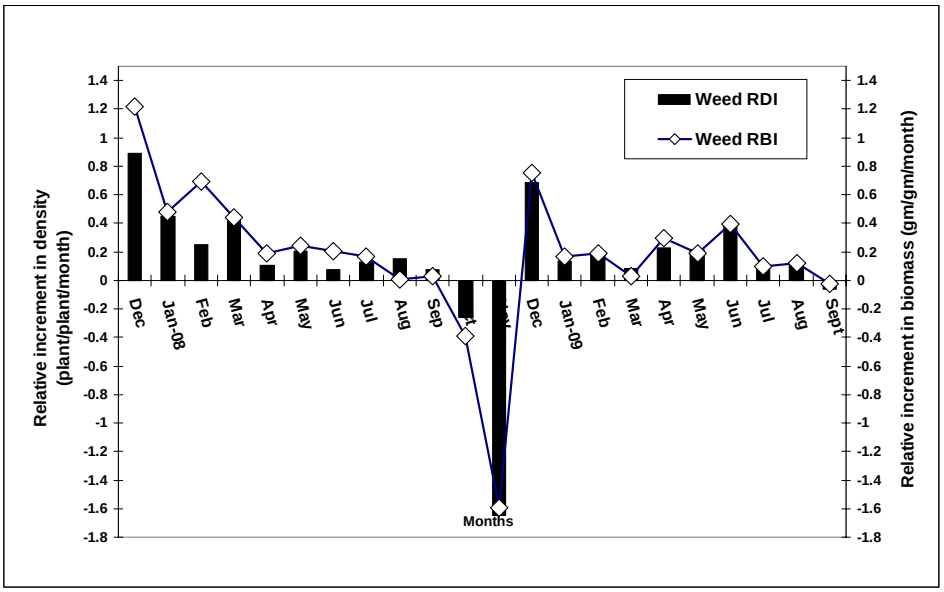


Figure 8. Mean Relative density increment and relative biomass increment of weed community in the no-cover crop control plots established in coconut plantations in the Kerala part of Nilgiri Biosphere Reserve.

### 3.6. Cover crop plants

#### *3.6.1. Arachis pintoi* plots

In these plots, apart from cover crop species, thirty six weed species were recorded (Table 11). Even though grasses like *Digitaria timorensis*, *Ischane miliacea*, *Oplismenus compositus* and *Paspalum conjugatum* showed initial dominance,

Desmodium triflorum became the first dominant species when the plots were seven month old and thereafter.

Table 11. Importance value index of weed species in the *A.pintoi* cover crop plot in the coconut garden

| Species | Months* | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Nov | Dec | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct |
| *Ageratum conyzoides* | Ab | Ab | Ab | Ab | Ab | Ab | Ab | 8 | 12 | 21 | 18 | 16 |
| *Biophytum sensitivum* | Ab | Ab | Ab | Ab | Ab | Ab | Ab | Ab | Ab | 4 | 8 | 7 |
| *Brachiaria burmanica* | Ab | 16 | 21 | Ab | Ab | Ab | Ab | Ab | Ab | Ab | Ab | Ab |
| *Brachiaria eruciformis* | Ab | Ab | 8 | 16 | Ab | Ab | Ab | Ab | 8 | Ab | Ab | 3 |
| *Ceratopteris sp.* | Ab | Ab | Ab | Ab | Ab | Ab | Ab | Ab | Ab | 7 | 6 | 4 |
| *Cleome viscosa* | Ab | 9 | 12 | 8 | 18 | 16 | 8 | Ab | Ab | 5 | 8 | 9 |
| *Commelina benghalensis* | Ab | Ab | Ab | Ab | Ab | Ab | Ab | Ab | 4 | 6 | 9 | 6 |
| *Cyanotis cristata* | Ab | Ab | Ab | Ab | Ab | Ab | Ab | Ab | 6 | 4 | 5 | 4 |
| *Cyathula prostata* | Ab | Ab | 6 | Ab | Ab | Ab | Ab | Ab | Ab | Ab | Ab | 3 |
| *Cynadon dactylon* | Ab | Ab | Ab | Ab | 20 | 36 | 41 | 26 | 19 | 13 | 15 | 16 |
| *Cyperus disformis* | Ab | Ab | Ab | Ab | 16 | Ab | Ab | 19 | Ab | 9 | 8 | 9 |
| *Cyperus rotundus* | Ab | Ab | 10 | Ab | 21 | 48 | 36 | 23 | 16 | 13 | 10 | 16 |
| *Desmodium triflorum* | Ab | Ab | Ab | 19 | 16 | 32 | 47 | 40 | 46 | 38 | 42 | 36 |
| *Digitaria timorensis* | 98 | 76 | 72 | 86 | 58 | 69 | 52 | 37 | 32 | 32 | 28 | 20 |
| *Eclipta alba* | Ab | Ab | Ab | Ab | Ab | Ab | Ab | 7 | 11 | 9 | 12 | 12 |
| *Elephantopus scaber* | Ab | 6 | Ab | Ab | Ab | Ab | Ab | Ab | Ab | Ab | Ab | 4 |
| *Elusine indica* | Ab | 6 | 8 | Ab | Ab | Ab | Ab | Ab | Ab | 11 | 14 | 12 |
| *Emilia sonchifolia* | Ab | Ab | 4 | Ab | Ab | Ab | Ab | Ab | Ab | Ab | Ab | 5 |
| *Eragrostis tenuifolia* | 16 | Ab | Ab | Ab | Ab | Ab | Ab | Ab | 4 | Ab | Ab | Ab |
| *Heliotropium indicum* | Ab | 9 | 11 | 12 | 14 | Ab | Ab | Ab | Ab | Ab | Ab | 2 |
| *Hyptis capitata* | Ab | 4 | 4 | 10 | 12 | Ab | Ab | 18 | 11 | 21 | 17 | 12 |
| *Ipomoea aquatica* | Ab | Ab | Ab | Ab | Ab | Ab | Ab | Ab | 6 | 5 | 4 | 6 |
| *Ischane miliacea* | 29 | 19 | 30 | 28 | 24 | 44 | 38 | 29 | 37 | 21 | 18 | 24 |
| *Laportea crenulata* | Ab | Ab | Ab | Ab | Ab | Ab | Ab | Ab | 5 | 3 | 4 | 3 |
| *Leucas biflora* | Ab | Ab | Ab | Ab | Ab | Ab | Ab | 6 | 4 | 7 | 8 | 8 |
| *Lindernia crustacea* | Ab | Ab | Ab | Ab | Ab | Ab | Ab | Ab | 4 | 3 | 4 | 4 |
| *Ludwigia parviflora* | 32 | 21 | 18 | 41 | Ab | Ab | Ab | 12 | 9 | 15 | 12 | 12 |
| *Mimosa pudica* | 19 | 26 | 20 | 36 | 41 | 26 | 32 | Ab | 5 | 6 | 5 | 5 |
| *Oplismenus compositus* | 52 | 48 | 40 | 31 | 32 | 29 | 46 | 30 | 24 | 19 | 21 | 21 |
| *Paspalam conjugatum* | 43 | 46 | 36 | 13 | 28 | Ab | Ab | 41 | 20 | 7 | 4 | 4 |
| *Peperomia pellucida* | Ab | Ab | Ab | Ab | Ab | Ab | Ab | Ab | 8 | 4 | 3 | 3 |
| *Phyllanthus nirurii* | Ab | Ab | Ab | Ab | Ab | Ab | Ab | Ab | Ab | 2 | 3 | 3 |
| *Physalis minima* | Ab | Ab | Ab | Ab | Ab | Ab | Ab | Ab | 3 | Ab | Ab | 1 |
| *Scoparia dulcis* | 11 | 14 | Ab | Ab | Ab | Ab | Ab | Ab | Ab | Ab | 4 | 5 |
| *Synedrella nudiflora* | Ab | Ab | Ab | Ab | Ab | Ab | Ab | 4 | 2 | 8 | 5 | 3 |
| *Vernonia cinera* | Ab | Ab | Ab | Ab | Ab | Ab | Ab | Ab | 4 | 7 | 5 | 2 |

* Ab, Absent

The density and biomass of *A.pintoi* showed an increasing trend until the plot age was around 13 months. Subsequently, values of both the parameters started declining, but remained significantly more than those in the initial months (Table 12).

Table 12. Density and biomass of *A. pintoi* and weed species in the *A. pintoi* cover crop plots established in coconut plantations in the Kerala part of Nilgiri Biosphere Reserve. Values are mean ± S.E.

| | *A. pintoi* | | Weeds | | | |
|---|---|---|---|---|---|---|
| Months | Density (individuals $m^{-2}$) | Biomass (gm $m^{-2}$) | Number of weed species | Density (individuals $m^{-2}$) | Biomass (gm $m^{-2}$) | Weed species diversity |
| Nov, 2007 | 100± 0 | 53.6±1.2 | 8 | 25±1.2 | 9.0±0.6 | 2.690±0.007 |
| Dec, 2007 | 98±0.9 | 69.5±1.6 | 13 | 69±1.8 | 22.0±1.2 | 3.210±0.003 |
| Jan,2008 | 132± 2.1 | 120.7±3.0 | 15 | 98±2.3 | 34.0±1.2 | 3.436±0.001 |
| Feb, 2008 | 199±2.1 | 242.1±9.9 | 11 | 80±1.9 | 56.0±1.2 | 3.097±0.003 |
| Mar, 2008 | 247±1.5 | 329.6±9.6 | 12 | 46±3.1 | 75.3±1.8 | 3.422±0.007 |
| Apr, 2008 | 263±3.6 | 386.9±7.1 | 8 | 53±2.4 | 62.0±1.1 | 2.886±0.005 |
| May, 2008 | 281±1.7 | 403.0±5.1 | 8 | 71±1.3 | 50.0±5.0 | 2.893±0.002 |
| Jun, 2008 | 294±4.4 | 425.3±4.1 | 14 | 64±1.2 | 46.7±1.3 | 3.544±0.001 |
| Jul, 2008 | 304±6.2 | 467.3±14.5 | 24 | 76±0.9 | 42.0±1.1 | 4.080±0.003 |
| Augt,2008 | 318±3.5 | 549.0±12.3 | 27 | 73±0.7 | 34.7±0.5 | 4.365±0.002 |
| Sept, 2008 | 324±6.3 | 593.3±6.9 | 28 | 79±1.0 | 35.0±1.73 | 4.121±0.003 |
| Oct, 2008 | 331±5.5 | 608.3±5.2 | 34 | 76±5.2 | 35.7±3.18 | 4.026±0.004 |
| Nov, 2008 | 334±9.7 | 609.3±4.7 | 33 | 73±8.2 | 47.0±0.58 | 3.263±0.003 |
| Dec 2008 | 335±5.9 | 599.7±5.6 | 36 | 70±7.6 | 53.7±0.67 | 3.152±0.004 |
| Jan, 2009 | 318±7.8 | 584.7±6.7 | 34 | 65±2.7 | 58.3±1.76 | 3.816±0.007 |
| Feb, 2009 | 308±5.0 | 576.7±4.4 | 31 | 66±3.1 | 64.7±1.76 | 3.969±0.005 |
| Mar, 2009 | 315±3.3 | 528.7±8.8 | 33 | 73±1.8 | 69.7±2.03 | 4.124±0.007 |
| Apr, 2009 | 316±2.0 | 521.3±5.8 | 36 | 75±1.8 | 65.3±5.46 | 4.265±0.002 |
| May, 2009 | 321±1.8 | 512.0±6.9 | 28 | 74±3.1 | 76.7±2.73 | 4.198±0.007 |
| Jun, 2009 | 326±2.7 | 531.0±20.5 | 29 | 72±3.1 | 88.0±1.00 | 4.156±0.011 |
| Jul, 2009 | 319±2.4 | 515.0±17.1 | 31 | 84±2.7 | 92.7±2.91 | 4.143±0.010 |
| Aug,2009 | 330±1.2 | 498.0±12.7 | 33 | 88±2.3 | 93.3±4.67 | 4.068±0.012 |
| Sept, 2009 | 321±4.8 | 484.7±10.9 | 32 | 95±1.8 | 87.3±4.37 | 4.096±0.014 |
| Oct, 2009 | 318± 5.4 | 503.4±8.6 | 35 | 86±1.3 | 84.9±5.18 | 4.136±0.015 |

Monthly variation in relative density and relative biomass increment in the cover crop species is depicted in Figure 9. The mean RDI and RBI of *A. pintoi* are 0.053 plants $plant^{-1}$ $month^{-1}$ and 0.100 gm $gm^{-1}$ $month^{-1}$ respectively. Values obtained for these two parameters correlate significantly ($r=0.913$, $df=21$, $P>0.05$) indicating the fact that the both density and biomass increased initially and but after a year of planting they declined together.

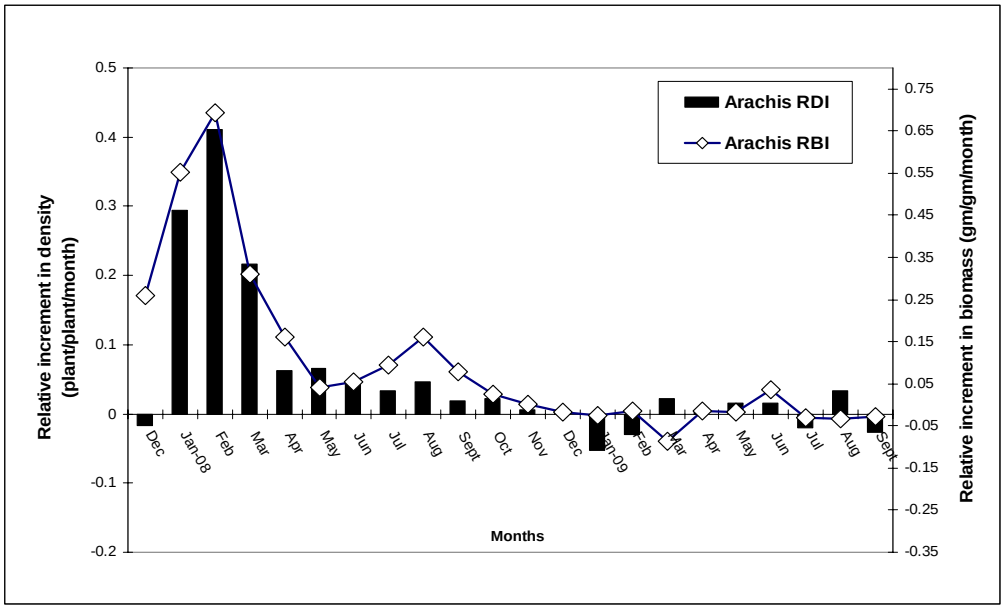


Figure 9. Mean Relative density increment (RDI) and relative biomass increment (RBI) of *A. pintoi* in the cover crop plots established in coconut plantations in the Kerala part of Nilgiri Biosphere Reserve.

In the first two months of the experiment, both density and biomass of weed community in *A.pintoi* cover-crop plots and in the no-cover crop control plot (Figures 10 and 11) did not show significant difference ($p>0.05$ with t-test). However, in subsequent months, except in November 2008, both weed density and biomass were significantly ($p<0.05$ with a t-test) low in *A.pintoi* plots than in no-cover control plot.

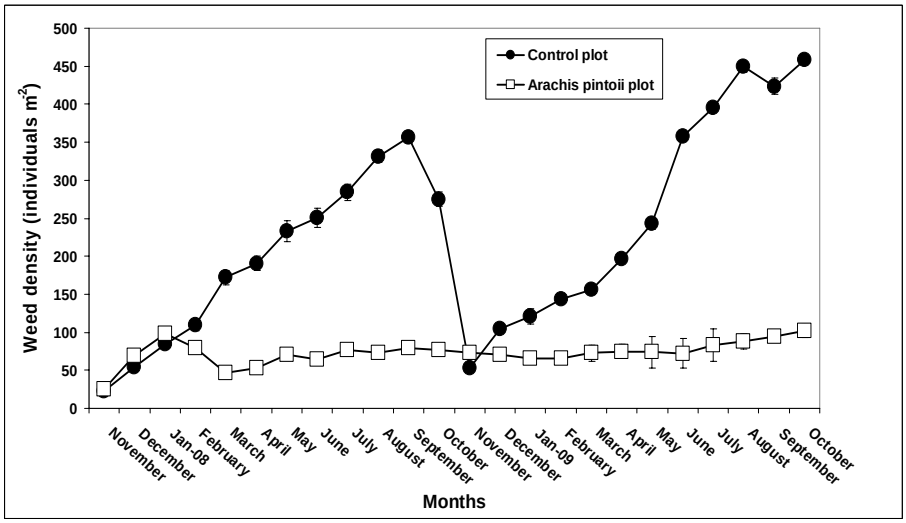


Figure 10. Density (individuals $m^{-2}$) of weed community in no-cover control plot and *A.pintoi* cover crop plot in the coconut garden.

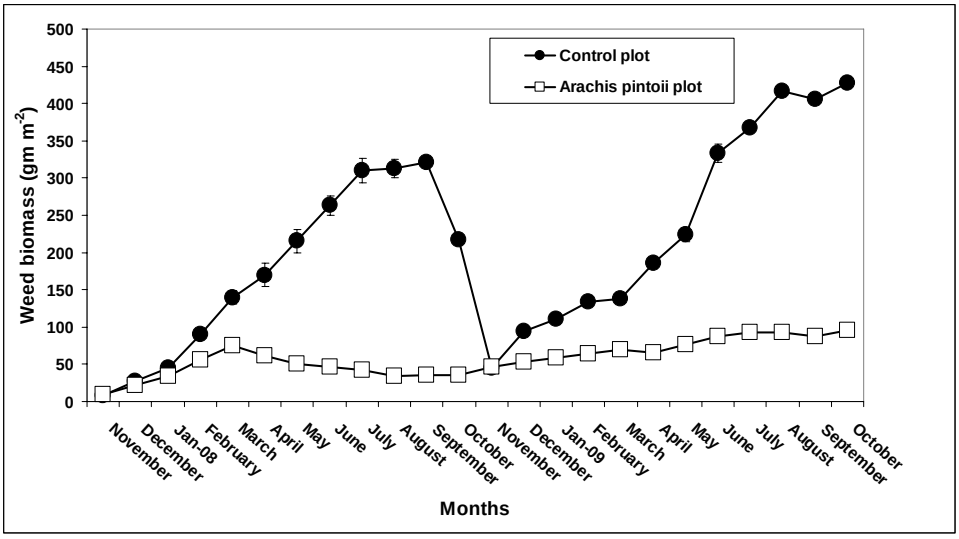


Figure 11. Biomass (gm $m^{-2}$) of weed community in no-cover control plot and *A.pintoi* cover crop plot in the coconut garden

In order to understand the effect of cover crop growth on weed growth, values of RDI and RBI of *A.pintoi* and those of weed community were correlated. The reduction in RDI of weeds did not correlate with the increase in RDI of *A.pintoi* (r=-0.45061, df= 21, p>0.05). On the other hand, reduction in RBI of weeds showed a significant correlation with increase in RBI of *A. pintoi* (r = 0.926, df= 21, p<0.05).

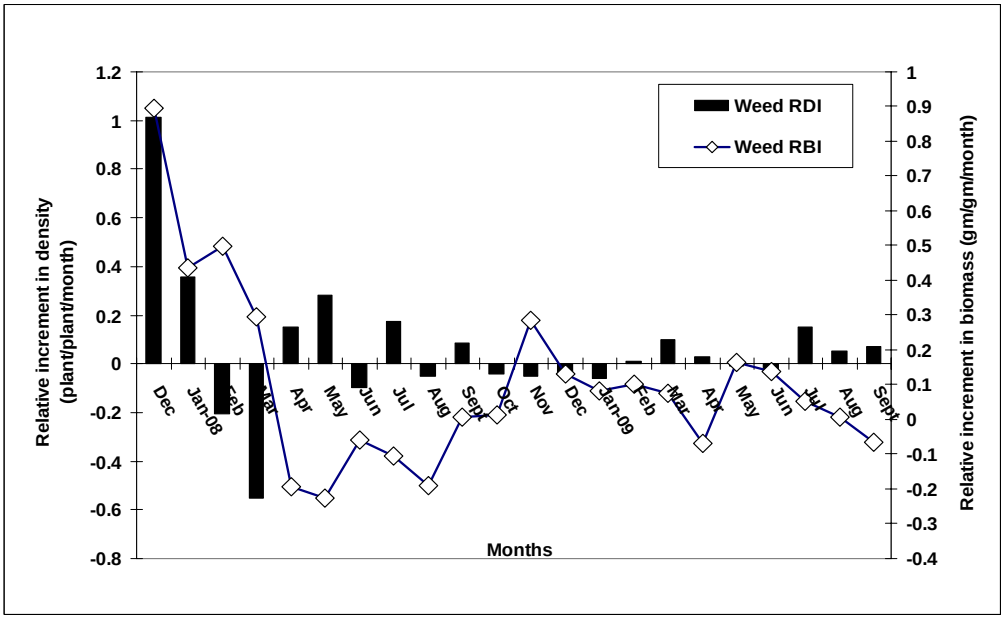


Figure 12. Mean Relative density increment and relative biomass increment of weed community in *A. pintoi* plots established in coconut plantations in the Kerala part of Nilgiri Biosphere Reserve

It has also been observed that the RDI and RBI of weed community (Figure 7) did not correlate significantly (r=0.356, df= 21, P>0.05). This may be an indication of the fact that cover crop cultivation leads to reduction in RBI values than RDI values of weed community comparatively at a faster rate.

### *3.6.2. Calapagonium mucunoides* plots

In these plots, during the study period, twenty seven species were recorded (Table 13). Even though grasses and cyperus were dominant in the initial period of the experiment, subsequently species like *Biophytum sensitivum*, *Commelina benghalensis* and *Laportea interrupta* were the dominant species.

Table 13. Importance value index of weed species in the *C.mucunoides* cover crop plot in the coconut garden

| Species | Months* | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Nov | Dec | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct |
| *Ageratum conyzoides* | 11 | Ab | Ab | Ab | Ab | 33 | 48 | Ab | Ab | Ab | Ab | Ab |
| *Biophytum sensitivum* | Ab | Ab | Ab | Ab | Ab | Ab | Ab | 78 | 124 | 92 | 83 | 78 |
| *Brachiaria burmanica* | 19 | 24 | 19 | 14 | Ab | Ab | 51 | Ab | Ab | Ab | Ab | 4 |
| *Centella asiatica* | 9 | 12 | 17 | Ab | Ab | Ab | Ab | 76 | Ab | Ab | 3 | Ab |
| *Cleome viscosa* | Ab | 15 | 18 | Ab | Ab | Ab | Ab | Ab | Ab | Ab | 2 | 2 |
| *Commelina benghalensis* | Ab | Ab | Ab | Ab | Ab | Ab | Ab | 41 | 63 | 93 | 87 | 82 |
| *Cyanotis cristata* | Ab | Ab | Ab | Ab | Ab | Ab | Ab | 29 | 17 | 11 | 16 | 18 |
| *Cyathula prostata* | Ab | Ab | 8 | 21 | 46 | Ab | Ab | Ab | Ab | Ab | Ab | Ab |
| *Cyperus disformis* | 21 | 17 | 24 | 29 | 51 | 37 | Ab | Ab | Ab | Ab | Ab | Ab |
| *Cyperus rotundus* | 31 | 20 | 23 | 35 | Ab | Ab | Ab | Ab | Ab | Ab | Ab | Ab |
| *Desmodium triflorum* | 26 | 39 | 33 | 51 | 50 | Ab | Ab | Ab | Ab | Ab | Ab | Ab |
| *Digitaria timorensis* | 17 | 14 | 23 | 28 | 56 | Ab | 63 | Ab | Ab | Ab | Ab | Ab |
| *Elephantopus scaber* | 4 | Ab | Ab | Ab | Ab | Ab | Ab | Ab | Ab | Ab | Ab | Ab |
| *Elusine indica* | 6 | Ab | 8 | Ab | Ab | Ab | Ab | Ab | Ab | Ab | Ab | 3 |
| *Eragrostis tenuifolia* | 3 | Ab | Ab | Ab | Ab | Ab | Ab | Ab | Ab | Ab | Ab | Ab |
| *Heliotropium indicum* | 7 | 19 | 25 | 18 | Ab | Ab | Ab | Ab | Ab | Ab | Ab | 8 |
| *Hyptis capitata* | 11 | 16 | 9 | Ab | Ab | Ab | Ab | Ab | Ab | Ab | Ab | Ab |
| *Ischane miliacea* | 31 | 24 | 27 | 20 | 57 | Ab | Ab | Ab | Ab | Ab | Ab | Ab |
| *Knoxia corymbosa* | 11 | Ab | Ab | Ab | Ab | Ab | Ab | Ab | Ab | Ab | Ab | Ab |
| *Laportea crenulata* | Ab | Ab | Ab | Ab | Ab | Ab | Ab | 76 | 96 | 92 | 82 | 78 |
| *Leucas biflora* | Ab | 9 | 16 | 4 | Ab | Ab | Ab | Ab | Ab | 12 | 15 | 18 |
| *Ludwigia parviflora* | 17 | 24 | 20 | 13 | Ab | Ab | 89 | Ab | Ab | Ab | 3 | 4 |
| *Mimosa pudica* | 21 | 23 | 11 | 18 | Ab | Ab | Ab | Ab | Ab | Ab | Ab | Ab |
| *Oplismenus compositus* | 26 | 19 | 9 | 21 | 18 | 100 | Ab | Ab | Ab | Ab | 9 | 5 |
| *Paspalum conjugatum* | 27 | 25 | 10 | 28 | 22 | 130 | 49 | Ab | Ab | Ab | Ab | Ab |
| *Scoparia dulcis* | 2 | Ab | Ab | Ab | Ab | Ab | Ab | Ab | Ab | Ab | Ab | Ab |

*, Ab=Absent

The density and biomass of C. mucunoides in the plot showed increasing trend with mean density of 533 individuals $m^{-2}$ and mean biomass of 1542 gm $m^{-2}$ when the plots were 12-month old (Table 14). Subsequent increase in density and biomass of cover crop was not significant (p>0.05). Monthly variation in the values of relative

density and relative biomass increment in the cover crop species is depicted in Figure 13

Table 14. Density and biomass of *C.mucunoides* and weed species in the *C. mucunoides* cover crop plots established in coconut plantations in the Kerala part of Nilgiri Biosphere Reserve. Values are mean ± S.E.

| | *C. mucunoides* | | Weeds | | | |
|---|---|---|---|---|---|---|
| | Density (plants $m^{-2}$) | Biomass (gm $m^{-2}$) | No. of weed species | Density (plants $m^{-2}$) | Biomass (gm $m^{-2}$) | Weed species diversity |
| Nov, 2007 | 100± 0 | 22.6±0.15 | 19 | 43±1.5 | 16.0±2.0 | 3.973±0.003 |
| Dec, 2007 | 99±0.7 | 48.7±2.54 | 15 | 40±1.5 | 39.1±3.0 | 3.825±0.005 |
| Jan,2008 | 99± 0.7 | 159.7±1.76 | 17 | 87±2.3 | 28.7±1.8 | 3.959±0.004 |
| Feb, 2008 | 228±2.3 | 674.8±5.76 | 13 | 41±1.9 | 42.3±1.9 | 3.531±0.009 |
| Mar, 2008 | 289±5.8 | 873.2±4.99 | 7 | 43±1.5 | 77.0±2.3 | 2.707±0.007 |
| Apr, 2008 | 288±7.1 | 1051.5±22.3 | 4 | 60±1.5 | 71.6±1.1 | 1.774±0.002 |
| May, 008 | 335±6.0 | 1181.9±24.2 | 5 | 42±1.0 | 78.3±1.9 | 2.277±0.003 |
| Jun, 2008 | 344±6.4 | 1211.0±20.2 | 5 | 38±1.2 | 36.3±8.7 | 2.227±0.005 |
| Jul, 2008 | 358±4.3 | 1244.4±6.35 | 4 | 33±0.9 | 15.9±3.4 | 1.760±0.003 |
| Augt,2008 | 384±4.0 | 1415.5±23.1 | 5 | 32±0.9 | 9.6±0.9 | 1.930±0.004 |
| Sept, 2008 | 472±7.0 | 1495.3±5 | 5 | 39±1.7 | 10.7±0.1 | 1.780±0.003 |
| Oct, 2008 | 512±5.8 | 1529.3±9 | 6 | 42±2.3 | 11.3±0.1 | 1.630±0.002 |
| Nov, 2008 | 533±10.4 | 1541.7±16 | 5 | 45±2.6 | 11.7±0.1 | 1.420±0.002 |
| Dec 2008 | 538±3.1 | 1558.7±13 | 8 | 43±0.3 | 12.1±0.2 | 1.230±0.002 |
| Jan, 2009 | 539±1.8 | 1552.3±18 | 6 | 42±0.9 | 12.6±0.3 | 1.120±0.003 |
| Feb, 2009 | 530±4.4 | 1548.0±25 | 5 | 45±0.9 | 10.7±0.1 | 1.680±0.002 |
| Mar, 2009 | 518±3.3 | 1560.3±22 | 4 | 40±1.2 | 10.5±0.3 | 1.320±0.002 |
| Apr, 2009 | 524±13.5 | 1575.0±31 | 5 | 38±0.6 | 10.2±0.4 | 1.280±0.002 |
| May, 2009 | 528±9.5 | 1597.7±24 | 7 | 40±0.9 | 9.5±0.1 | 1.220±0.003 |
| Jun, 2009 | 543±10.0 | 1610.7±14 | 6 | 40±2.0 | 9.3±0.7 | 1.610±0.002 |
| Jul, 2009 | 537±15.6 | 1601.3±12 | 10 | 36±1.2 | 9.8±0.4 | 1.120±0.002 |
| Aug,2009 | 523±11.4 | 1638.7±26 | 12 | 36±0.3 | 9.8±0.6 | 1.830±0.002 |
| Sept, 2009 | 535±5.4 | 1657.3±26 | 11 | 33±0.6 | 9.5±0.3 | 1.920±0.003 |
| Oct, 2009 | 533±6.8 | 1649.3±14 | 9 | 35±0.9 | 10.4±0.2 | 2.310±0.008 |

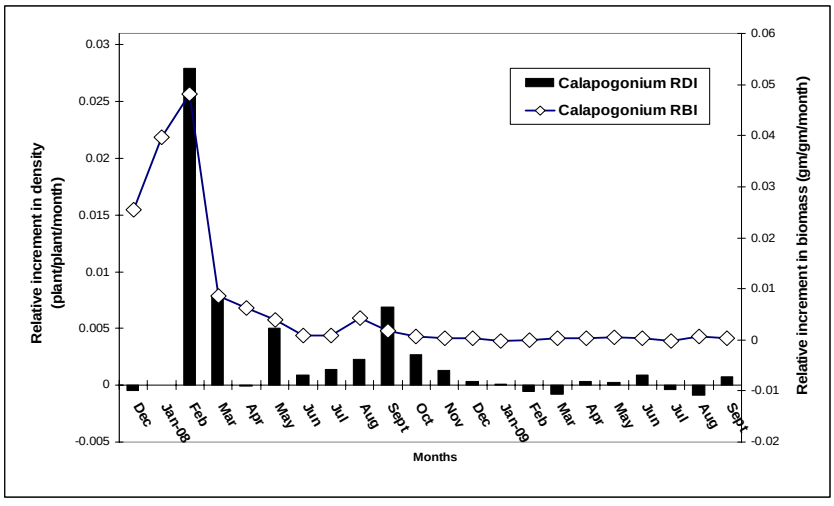


Figure 13. Mean Relative density increment and relative biomass increment of *C.mucunoides* in the cover crop plots established in coconut plantations in the Kerala part of Nilgiri Biosphere Reserve.

The mean values for relative density increment and relative biomass increment of *C. mucunoides* were 0.069 plants plant$^{-1}$ month$^{-1}$ and 0.4595 gm gm$^{-1}$ month$^{-1}$ respectively. These values did not correlate significantly (r = 0.5737, df=8, P>0.05), may be an indication of the fact that the cover crop biomass increment in the initial three months was faster than the relative density increment.

The control plot and the *C.mucunoides* plots were compared for weed density and biomass (Figures 14 and 15). Values for both parameters were significantly low (p<0.05 with t-tests) in the *C.mucunoides* cover crop plots, with an exception being the first three to four months and in November 2008 when the values in control and cover crop plots did not differ much (p >0.05). The study also revealed that as the relative density increment and relative biomass increment of *C.mucunoides* increased, values of these parameters of weeds declined significantly ( p<0.05 with t-tests).

The RDI and RBI of weed community in the cover crop plot (Figure 16) did not correlate significantly (r=-0.191, df= 21, p>0.05) may be because compared to the weed density, the weed biomass declined at a faster rate after the plots were 7 to 8 month old

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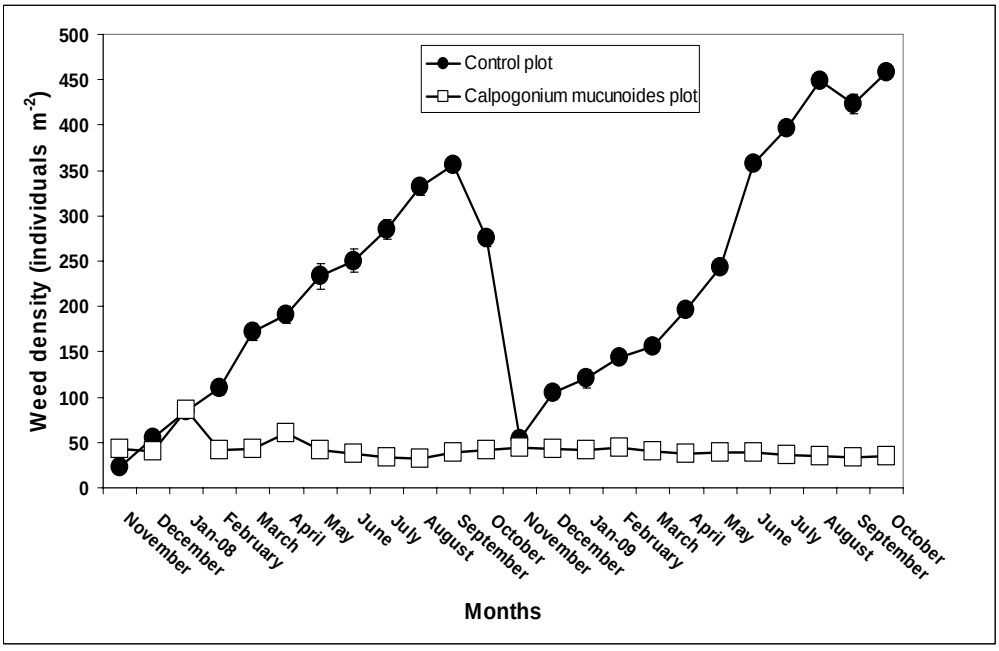


Figure 14. Density (individuals m$^{-2}$) of weed community in no-cover control plot and *C. mucunoides* cover crop plot in the coconut garden.

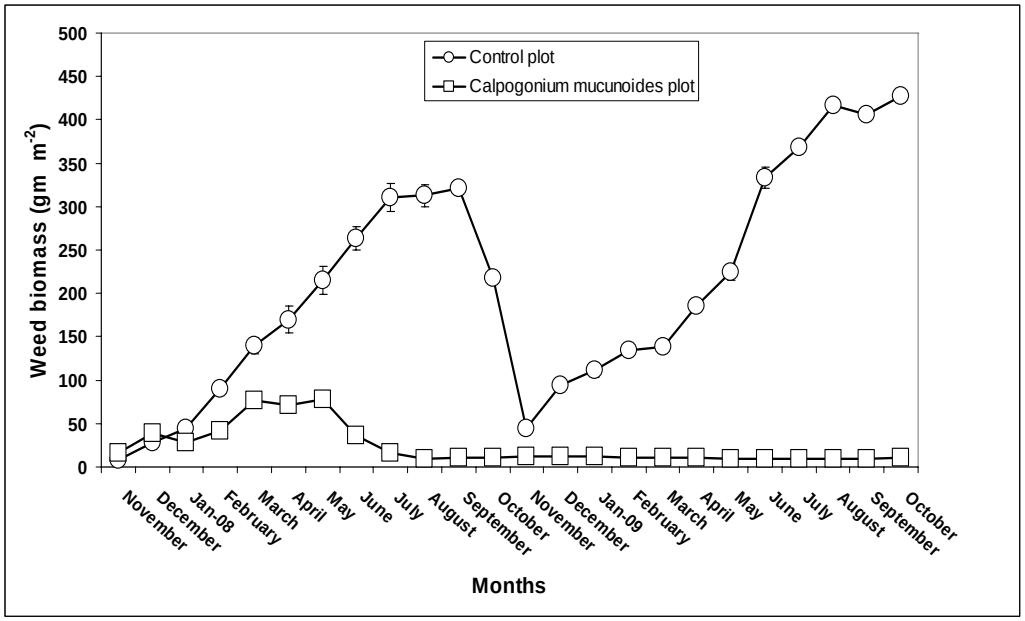


Figure 15. Biomass (gm $m^{-2}$) of weed community in no-cover control plot and *C.mucunoides* cover crop plot in the coconut garden.

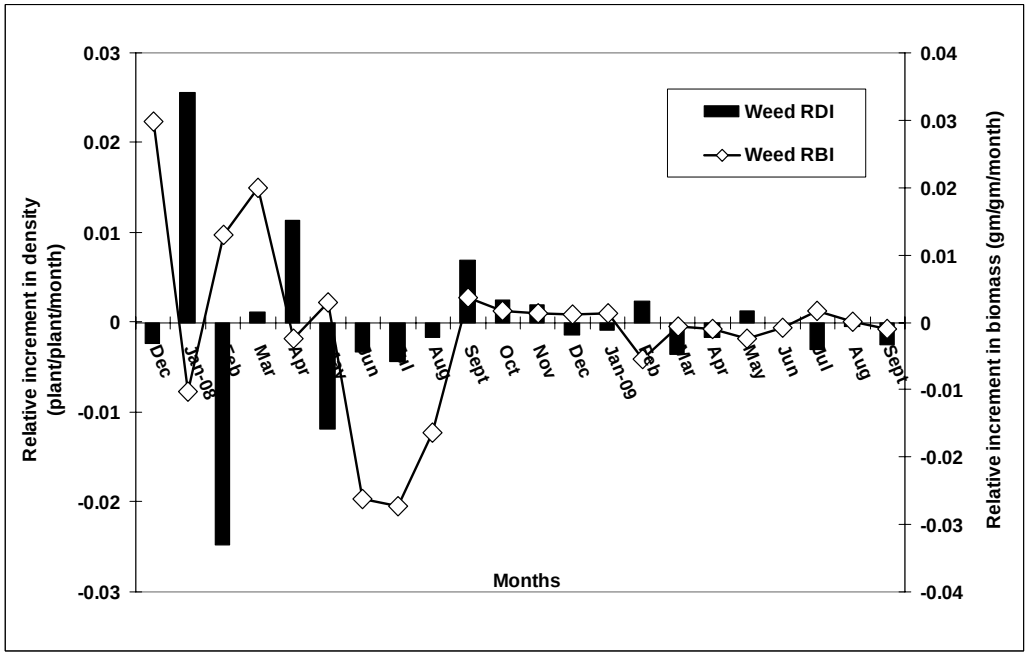


Figure 16. Mean Relative density increment and relative biomass increment of weed community in *C.mucunoides* plots established in coconut plantations in the Kerala part of Nilgiri Biosphere Reserve.

### *3.6.3. Sesbania aculeata* plots

In these plots, 34 weed species were recorded, with a general dominance of species of Poaceae through out the study period (Table 15). Unlike in *A.pintoi* and *C.mucunoides plots*, here initially the number of weed species recorded in a month declined and then increased when the plots were 8-month old.

Table 15. Importance value index of weed species in the *S.aculeata* cover crop plot in the coconut garden

| Species | Months* | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Nov | Dec | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct |
| *Ageratum conyzoides* | 12 | Ab | Ab | Ab | Ab | Ab | Ab | 17 | 6 | 9 | 6 | 8 |
| *Biophytum sensitivum* | Ab | Ab | Ab | Ab | Ab | Ab | Ab | Ab | 4 | 3 | 6 | 4 |
| *Brachiaria burmanica* | 27 | 29 | 38 | Ab | Ab | 61 | 53 | 48 | 40 | 32 | 28 | 32 |
| *Brachiaria eruciformis* | 22 | 17 | 29 | 37 | 63 | Ab | Ab | Ab | 26 | 31 | 28 | 26 |
| *Ceratopteris sp.* | Ab | Ab | Ab | Ab | Ab | Ab | 36 | 14 | 11 | 9 | 4 | 4 |
| *Cleome viscosa* | Ab | 19 | Ab | Ab | Ab | Ab | Ab | 9 | Ab | Ab | Ab | 4 |
| *Commelina benghalensis* | Ab | Ab | Ab | Ab | Ab | Ab | Ab | Ab | 4 | 3 | 6 | 8 |
| *Cyanotis cristata* | Ab | Ab | Ab | Ab | Ab | 29 | Ab | Ab | 4 | 7 | 5 | 3 |
| *Cynadon dactylon* | 33 | Ab | Ab | Ab | Ab | Ab | Ab | Ab | Ab | Ab | 2 | 4 |
| *Cyperus disformis* | Ab | Ab | Ab | Ab | Ab | Ab | 49 | 37 | 21 | 13 | 10 | 8 |
| *Cyperus rotundus* | 26 | Ab | Ab | 43 | Ab | Ab | 42 | 47 | 18 | 16 | 22 | 20 |
| *Desmodium triflorum* | 12 | Ab | Ab | Ab | 37 | 43 | Ab | Ab | 13 | 21 | 28 | 32 |
| *Digitaria timorensis* | 19 | 13 | 37 | 32 | 39 | 51 | 31 | 29 | Ab | Ab | Ab | Ab |
| *Eclipta alba* | Ab | Ab | Ab | Ab | Ab | Ab | Ab | 14 | 7 | 6 | 4 | 3 |
| *Elephantopus scaber* | 19 | 13 | Ab | Ab | Ab | Ab | Ab | Ab | Ab | Ab | Ab | Ab |
| *Elusine indica* | 15 | 19 | Ab | Ab | Ab | Ab | Ab | Ab | Ab | 3 | 2 | 1 |
| *Eragrostis tenuifolia* | 9 | Ab | Ab | Ab | Ab | Ab | Ab | Ab | 4 | Ab | Ab | Ab |
| *Heliotropium indicum* | 13 | 15 | 26 | 36 | 31 | Ab | Ab | Ab | Ab | Ab | Ab | Ab |
| *Hyptis capitata* | 7 | 9 | Ab | Ab | Ab | Ab | Ab | 13 | 8 | 13 | 14 | 9 |
| *Ipomoea aquatica* | Ab | Ab | Ab | Ab | Ab | Ab | Ab | Ab | 3 | 3 | 3 | 2 |
| *Ischane miliacea* | 11 | 16 | 44 | 39 | 63 | 69 | 56 | 41 | 29 | 11 | 8 | 9 |
| *Laportea crenulata* | Ab | Ab | Ab | Ab | Ab | Ab | Ab | Ab | 9 | 7 | 5 | 8 |
| *Leucas aspera* | Ab | 9 | 13 | 11 | Ab | Ab | Ab | Ab | 7 | 5 | 4 | 3 |
| *Leucas biflora* | Ab | Ab | Ab | Ab | Ab | Ab | Ab | 3 | Ab | Ab | Ab | Ab |
| *Lindernia crustacea* | Ab | Ab | Ab | Ab | Ab | Ab | Ab | Ab | 3 | 6 | 4 | 5 |
| *Ludwigia parviflora* | 17 | 21 | 37 | 41 | Ab | Ab | Ab | 8 | 12 | 21 | 18 | 16 |
| *Mimosa pudica* | 13 | 33 | 28 | 26 | Ab | Ab | Ab | Ab | 13 | 20 | 12 | 10 |
| *Monochoria vaginalis* | Ab | Ab | Ab | Ab | Ab | Ab | Ab | Ab | Ab | 3 | 4 | 5 |
| *Oplismenus compositus* | 19 | 41 | 48 | 35 | 67 | 47 | 19 | 10 | 21 | 27 | 36 | 28 |
| *Paspalum conjugatum* | 21 | 37 | Ab | Ab | Ab | Ab | 14 | 10 | 19 | 21 | 29 | 28 |
| *Peperomia pellucida* | Ab | Ab | Ab | Ab | Ab | Ab | Ab | Ab | 3 | 4 | 4 | 6 |
| *Scoparia dulcis* | 5 | 9 | Ab | Ab | Ab | Ab | Ab | Ab | Ab | Ab | Ab | Ab |
| *Synedrella nudiflora* | Ab | Ab | Ab | Ab | Ab | Ab | Ab | Ab | 7 | 3 | 4 | 8 |
| *Vernonia cinera* | Ab | Ab | Ab | Ab | Ab | Ab | Ab | Ab | 8 | 3 | 4 | 6 |

*, Ab= Absent

The density of *S.aculeata* in the plots began to decline within 2-month after planting and no plant was noticed after 8-months. However, biomass of *S.aculeata* reached a peak value of 159 gm $m^{-2}$ when the plots were 4-month old and then declined drastically (Table 16). A few individuals of *S.aculeata* were found during December 2008 to March 2009. Monthly variation in the values of relative density (RDI) and relative biomass increment (RBI) in the cover crop species is depicted in Figure 17. The mean RDI and RBI of *Sesbania* were -0.1574 plants $plant^{-1}$ $month^{-1}$ and -0.0845 gm $gm^{-1}$ $month^{-1}$ respectively. Compared to control plots, *S.aculeata* plots had significantly low density and biomass of weeds through out the study period (Figures 18 and 19). Decline in the RDI and RBI values of weeds did not correlate significantly ($r= 0.3682$, $df= 21$, $p>0.05$) (Figure 20).

Table 16. Density and biomass of *S.aculeata* and weed species in the *S.aculeata* cover crop plots established in coconut plantations in the Kerala part of Nilgiri Biosphere Reserve. Values are mean ± S.E.

| | *S.aculeata* | | Weeds | | | |
|---|---|---|---|---|---|---|
| | Density (individuals $m^{-2}$) | Biomass (gm $m^{-2}$) | No. of weed species | Density (individuals $m^{-2}$) | Biomass (gm $m^{-2}$) | Weed species diversity |
| Nov, 2007 | 100±0 | 40.1±0.7 | 18 | 58.0±2.0 | 19.4±0.4 | 4.036±0.005 |
| Dec, 2007 | 100±0 | 79.3±1.7 | 15 | 49.7±1.2 | 15.6±0.5 | 3.738±0.004 |
| Jan,2008 | 94±2 | 89.0±1.5 | 9 | 54.3±1.2 | 17.9±0.8 | 3.099±0.007 |
| Feb, 2008 | 91±3 | 159.2±2.8 | 9 | 63.0±1.5 | 22.2±0.8 | 3.103±0.002 |
| Mar, 2008 | 60±2 | 139.3±1.9 | 6 | 38.7±1.8 | 9.5±0.5 | 2.522±0.001 |
| Apr, 2008 | 31±4 | 132.5±2.4 | 6 | 37.0±1.0 | 8.7±0.3 | 2.536±0.003 |
| May, 2008 | 11±2 | 17.0±0.7 | 8 | 25.3±1.3 | 7.8±0.3 | 2.882±0.002 |
| Jun, 2008 | 2±2 | 3.5±3.5 | 14 | 34.7±1.3 | 7.7±0.3 | 3.461±0.004 |
| Jul, 2008 | 0±0 | 0±0 | 25 | 40.7±1.5 | 6.7±0.2 | 4.260±0.002 |
| Augt,2008 | 0±0 | 0±0 | 26 | 42.3±3.3 | 6.4±0.4 | 4.283±0.001 |
| Sept, 2008 | 0±0 | 0±0 | 22 | 47.7±1.2 | 7.0±0.5 | 4.191±0.003 |
| Oct, 2008 | 0±0 | 0±0 | 16 | 52.0±1.2 | 8.7±0.7 | 4.021±0.001 |
| Nov, 2008 | 0±0 | 0±0 | 14 | 65.3±0.9 | 6.8±0.3 | 3.943±0.004 |
| Dec 2008 | 14±1 | 12.9±1.3 | 14 | 81.0±6.1 | 6.0±0.4 | 3.892±0.002 |
| Jan, 2009 | 10±2 | 10.6±0.8 | 12 | 88.0±7.5 | 5.0±0.3 | 4.011±0.001 |
| Feb, 2009 | 8±1 | 7.3±1.0 | 16 | 94.7±4.4 | 6.0±1.5 | 4.024±0.001 |
| Mar, 2009 | 5±1 | 5.6±0.5 | 18 | 97.3±11.0 | 9.5±1.8 | 4.032±0.004 |
| Apr, 2009 | 0±0 | 0±0 | 21 | 104.7±9.5 | 17.2±0.6 | 4.121±0.005 |
| May, 2009 | 0±0 | 0±0 | 20 | 120.3±20.5 | 24.8±3.2 | 3.721±0.006 |
| Jun, 2009 | 0±0 | 0±0 | 15 | 111.7±19.7 | 29.8±4.8 | 3.883±0.001 |
| Jul, 2009 | 0±0 | 0±0 | 16 | 129.0±21.4 | 31.5±5.1 | 3.712±0.004 |
| Aug,2009 | 0±0 | 0±0 | 10 | 116.0±10.1 | 34.3±5.6 | 3.542±0.004 |
| Sept, 2009 | 0±0 | 0±0 | 12 | 103.0±2.9 | 40.2±3.5 | 3.763±0.002 |
| Oct, 2009 | 0±0 | 0±0 | 14 | 138.7±9.4 | 35.3±1.7 | 3.768±0.006 |

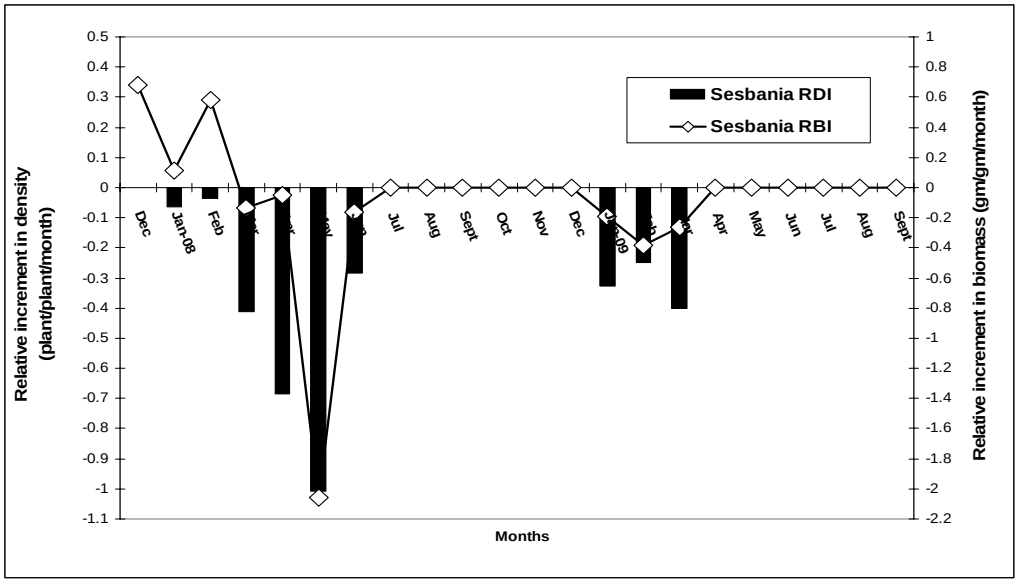


Figure 17. Mean Relative density increment and relative biomass increment of *S.aculeata* in the cover crop plots established in coconut plantations in the Kerala part of Nilgiri Biosphere Reserve.

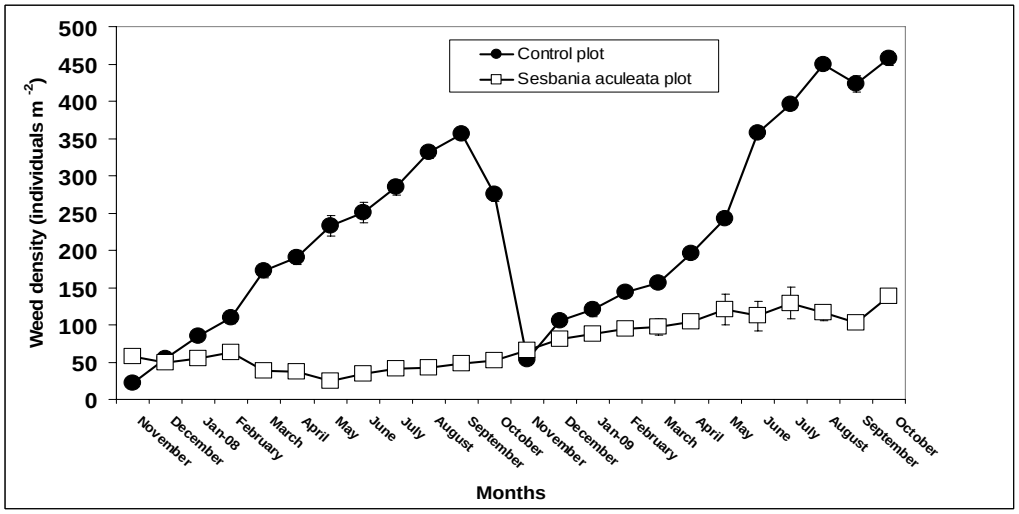


Figure 18. Density (individuals $m^{-2}$) of weed community in no-cover control plot and *S.aculeata* cover crop plot in the coconut garden.

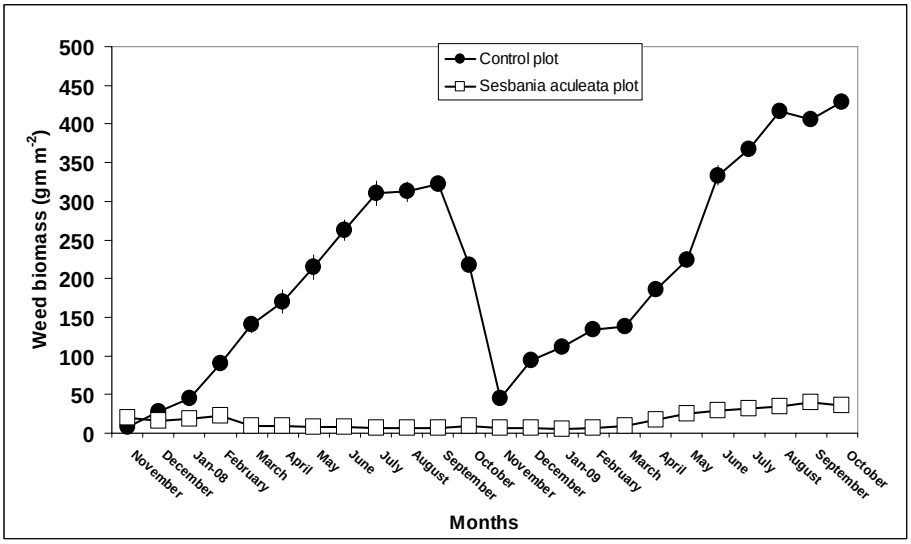


Figure 19. Biomass (gm $m^{-2}$) of weed community in no-cover control plot and *S.aculeata* cover crop plot in the coconut garden.

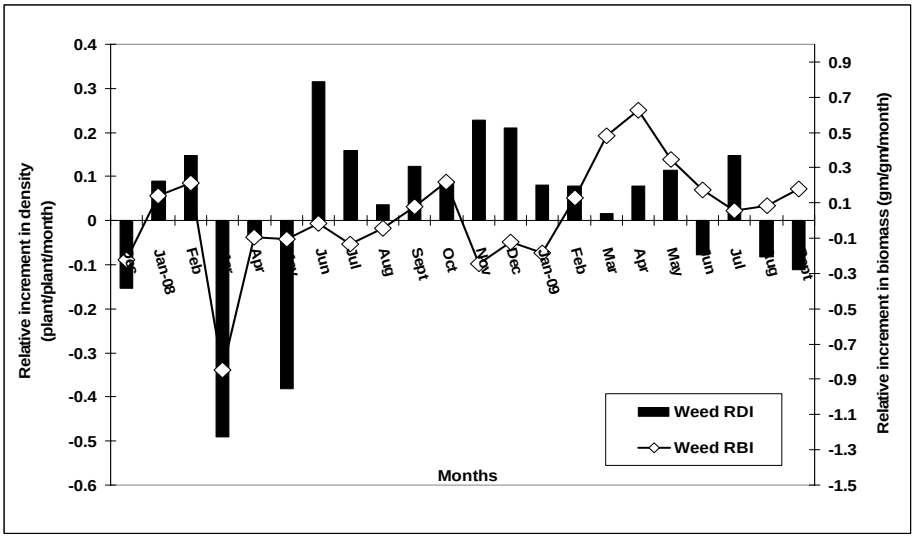


Figure 20. Mean Relative density increment and relative biomass increment of weed community in *S.aculeata plots* established in coconut plantations in the Kerala part of Nilgiri Biosphere Reserve.

Relative weed density increment and relative weed biomass increment values obtained in three cover crop species plots were compared using ANOVA and Boneferroni test. The test indicated that the relative weed density increment values in A*. pintoi* plot (0.0606 plants $plant^{-1}$ $month^{-1}$), *C. mucunoides* (-0.0004 plants $plant^{-1}$ $month^{-1}$) and *S. aculeata* plots **(**0.0261 plants $plant^{-1}$ $month^{-1}$) were significantly ($p<0.05$) different from each other. Among these three species, *C. mucunoides* suppresses the weed density significantly. Similarly, the relative weed biomass

increment values was significantly (P<0.05) low in *C. mucunoides* (-0.001 gm $gm^{-1}$ $month^{-1}$) followed by *S. aculeata* (0.0328 gm $gm^{-1}$ month $^{-1}$) and A*. pintoi* plots (0.1033 gm $g^{-1}$ $month^{-1}$). However, it may be noted here that the density and biomass of A*. pintoi* and *C. mucunoides* are increasing in the respective plots when *S. aculeata* already reached senescence. Moreover, twelve months after the plots establishment, the weed species recorded from A*. pintoi* plots, compared to those recorded from *S. aculeata* plots, are less hardy, seasonal and less spreading and thus they can be managed easily.

**4. Impact of demonstrations**

On farm experiments on leguminous cover crop cultivation in coconut gardens in the Kerala part of Nilgiri Biosphere Reserve have been carried out by selecting three cover crop species namely *Arachis pintoi*, *Calapogonium mucunoides* and *Sesbania aculeata.* All these three species were selected based on the input and consent of the farmers in the experimental area. The on-farm studies enabled to gather several important results which can be transmitted to the farming community through training programmes. Some important points which have been highlighted in four training course during September to November 2009 are as follows:

1. Due to cultivation of leguminous cover crops significant changes soil chemical properties have taken place in the plots. For instance, comparison no-cover crop control plots and each of the three cover crop plots as well as comparison made among cover crop plots indicated a significant increase in
   - organic matter, phosphorous and potassium in the soils of *A.pintoi* plots
   - total nitrogen in the soils of *A.pintoi* and *C.mucunoides* plots
   - calcium and magnesium in the soils of *A.pintoi* and *S. aculeata* plots

   Thus cultivation of leguminous cover crops enhances the availability of total nitrogen as well as other macro nutrients in soil for crops, apart from building up the soil organic matter.
2. Studies on soil microorganisms and earthworm in no-cover crop control plots and leguminous cover crop plots revealed that compare to control plots the leguminous cover crops will have significantly a large population of
   - rhizobia and phosphate solubilising microbes throughout the study period
   - azatobactor nine months after planting cover crops.
   - Earthworms in *A.pintoi* and *C.mucunoides* plots
3. In coconut gardens of the study area, due to luxurious growth, mean ground cover by weeds ranged from 67% to 98% with grasses and sedge being

dominant weeds. Thus weed management in the farms is a challenging task for the farmers.

4. Due to cultivation of leguminous cover crops, considerable decrease in density and biomass of weed community has taken place. However, the mechanism by which cover crops suppress the weeds may differ. For instance, by cultivating *A.pintoi* and *C.mucunoides,* relative increment in biomass of weeds than the relative increment in weed density reduced at a faster rate. Whereas by cultivating S*. aculeata,* relative increment in biomass and relative increment in density of weeds reduced almost in a same pace.
5. Twelve months after the plots establishment, in *A.pintoi* and *C.mucunoides* plots weed community is dominated by less hardy, seasonal and less spreading species. However, in S*. aculeata* plots twelve months after plot establishment several woody weedy species, grasses and sedges began to establish well.
6. On-farm experiments also revealed that *A. pintoi* and *C. mucunoides* give good early growth and ground cover within 3-4 months and has the ability to suppress annual grass and cyperaceous weeds. These two cover crop species are also suitable for moist and partially shaded sites and provides biomass for mulch. However, pruning biomass of *A. pintoi* reduces it ability to weed suppression. Therefore, it can be retained as a permanent cover by occasional trimming. *A. pintoi* has also an aesthetic value for its golden yellow flowers. *C. mucunoides* provides biomass for mulch; biomass harvest, 2-3 times per year, does not affect the growth and weed suppression ability of this cover crop. However, being a creeper and twiner, *C. mucunoides* grows over several crop plants. Thus it can be planted in sites where the established crop trees and palms are present. Unlike *A. pintoi* and *C. mucunoides, S.aculeata* gives good early growth and ground cover within 1-2 months. This cover crop is suitable for water-logged, moist and partially shaded sites and provides biomass for mulch within 2-3 months time. Continued weed suppression even 12 months after planting of this cover crop may be because of the presence of cover crop residue. Since this cover crop is a short duration crop it can be planted in sites where the cultivation of seasonal crops after harvesting the cover crop is intended.
7. Thus, cultivation of leguminous cover crops namely *A. pintoi* and *C. mucunoides* and *S.aculeata* in suitable microsites in farms can help farmers to suppress weeds, improve soil fertility and also enhance the population of beneficial soil flora and fauna.

Table 17 provides the details of training courses conducted where the above aspect were presented, discussed and received feedback from the participants.

Table 17. Details of the training courses conducted on leguminous cover crop cultivation in coconut gardens.

| | **Place of Training course conducted** | | | |
|---|---|---|---|---|
| | Karakkode | Moothedam | Vazhikkadavu | Manalpadam |
| Date of training course conducted | 14.09.2009 | 23.09.2009 | 29.10.2009 | 16.11.2009 |
| Number of participants | | | | |
| Farmers | 32 | 46 | 49 | 62 |
| Officials, representatives of NGOs | 4 | 2 | 1 | 1 |
| Number of farmers already adapting the technique | 2 | 0 | 0 | 0 |
| Number of farmers ready to adapt the technique | 16 | 32 | 24 | 29 |
| Number of farmers not ready to adapt the technique | 14 | 14 | 25 | 33 |

Around 20% of the total number of participants reported that they aware the effects of leguminous cover crops in improving soil fertility. However, only about 10% of the total participants know the use of leguminous cover crops in controlling weeds. Majority of them said that the on-farm experiments have helped to understand the three-fold benefits (i.e., weed control, soil fertility improvement and enhancing beneficial soil flora and fauna) of cover crop cultivation.

About 53% of total participants are willing to cultivate leguminous cover crops in their farms. However, 86 out of 189 participants of the training courses are not ready to adopt the technique due to various reasons (Table 18).

Fourteen participants were reluctant to adopt the technique primarily because propagules of cover crop species are not available in the required quantity and at the time of planting. Among these farmers, some have also given reasons such as scarcity of labourers to plant a manage cover crops and comparatively high cost for procuring and planting of cover crops for not for not intending to apply the technique. While for another fifteen farmers the scarcity of laborurers is the primary reason for their reluctance to adopt the technique, for twenty three farmers, high expenses to be incurred for collection and cultivation of cover crops green mulch is the primary concern.

Table 18. Reasons attributed by the participants for not ready to adopt green mulch as a nutrient management in crop lands.

| | Non availability of materials | Labour intensive | High cost | Preference for regular weeding over cover crop cultivation | Not convinced about benefits of leguminous cover crops over weed cover in soil fertility management |
|---|---|---|---|---|---|
| Non availability of materials | **14** | 4 | 6 | 0 | 0 |
| Labour intensive | | **15** | 7 | 3 | 0 |
| High cost | | | **23** | 5 | 2 |
| Preference for regular weeding over cover crop cultivation | | | | **10** | 4 |
| Not convinced about benefits of leguminous cover crops over weed cover in soil fertility management | | | | | **24** |

During the meetings, totally twenty four farmers expressed that they have not convinced about the results of the on-farm experiment on cover crop cultivation. According to them, the three species selected for the study are being cultivated both within and outside Kerala as cover crops in other cropping systems like paddy fields, rubber plantation, coffee plantations etc., However, instead of these species native leguminous cover crops should have been studied. Farmers also pointed out that in the present study, no attempt has been made to standardise the quantity plant propagules required and the frequency and timing of pruning of cover crops. Similarly, nutrients available from pruned materials in comparison with weed biomass have also not been quantified. Farmers also suggested that any intervention in the cropping systems should focus to enhance both aboveground and belowground biodiversity, which will help to optimise crop productivity. Thus, according to farmers, the present study failed to provide the results based on an experiment designed to enhance both above and belowground biodiversity and they suggested further studies in this direction.

# Section -2b

## Green mulch application for improving soil fertility and biodiversity

## 1. Introduction

In the tropical region, depletion of soil organic matter leads to a decline in agricultural and biomass productivity, poor environmental quality, soil degradation and nutrient depletion and ultimately to food insecurity (Lal, 2004). The soil organic matter depletion is the major concern both in small-scale agriculture and agroforestry systems and in plantation systems. World-wide concern about environmental degradation and depletion of productivity in crop lands has led to the need to evaluate sustainable agricultural practices including no-till farming, application of compost and mulch, legume cover crops and mixed farming (Leblanc, 2006).

In traditional agroforestry including homegardens of tropics, mulching is one of the most important ways to maintain soil fertility and crop productivity (Kumar and Nair, 2005). When the pruned materials of trees and shrubs are used as mulch, it can be called as green mulch (Schwendener et al., 2005). The green mulch is considered as a good source of nutrients, and is distinct from naturally fallen leaf litter in terms of leaf quality and leaf chemical composition (Palm et al., 2001). The green mulch also plays an essential role in increasing soil organic matter reserves, promoting C sequestration and nutrient recycling (Lal, 2004).

Pruning residues used in the green mulch can be of single species or a mixture of species. In the homegardeners of Kerala, use of the green mulch of mixture of species is a traditional practice of soil fertility management; while the use of green mulch of single species is also not uncommon (Chandrashekara, 2007). In fact several studies have been conducted to compare the decomposition parameters of leaf litter mixtures and mono-specific decomposing materials (Wardle et al., 1997; Salamanca et al., 1998, Prescott et al. 2000). However, most of the above studies have studied species from boreal and temperate areas, and little information has been published about fresh leaves from certain tropical areas (Gnankambary et al., 2008); while such information from the homegardens of tropics are totally absent.

Based on available information on decomposition and nutrients dynamics in leaf litter (Jamaludheen and Kumar, 1999; Issac and Nair, 2002), it is possible to expect that even in the green mulch, concentration of a given nutrient may differ based on the constituent species and that the nutrient release pattern is also related to the constituent species. In this context, a study was carried out to give an insight into the green mulch decomposition and the influence of green mulch chemistry on decomposition in a homegarden of Kerala. The specific objectives of the study were to: a) examine the decomposition rate and pattern in the common green mulch

species, *Calycopteris floribunda* (Combretaceae), *Chromolaena odorata* (Asteraceae), *Ficus asperima* (Moraceae), *Glycosmis pentaphylla* (Rutaceae), *Helecteris isora* (Sterculiaceae) and *Terminalia paniculata* (Combretaceae), b) to characterise the decomposition rate, patterns and microbial population in the green mulch of above mentioned species in mixture, c) clarify the important chemical components in the green mulch which determine the mulch decomposition, d) compare the green mulch materials for the nutrient release rates, and e) to disseminate the results of the experiments to the farming community.

## 2. Materials and methods

### 2.1. Study area and climate

The experiment was conducted in a homegarden of Vazhikkadavu Panchayat (76$^{o}$19' and 76$^{o}$ 23' longitude and 11$^{o}$23' and 11$^{o}$25' N latitude), Malappuram district, Kerala India. The study area comes under the Kerala part of Nilgiri Biosphere and enjoys a monsoonic climate with mean annual rainfall of 2312 mm. More than 65% of annual rainfall is drawn from the southwest monsoon during June- August period. The northeast monsoon, which sets in October and lasts till the end of November, accounts for much less rainfall (hardly 25% of annual rainfall). The mean annual maximum and minimum temperatures are 35$^{o}$C and 15$^{o}$C respectively. Soils are acidic (pH 5.6- 6.2) and gravelly clay loam. In general, soils are poor in total nitrogen (0.05-1.2%), available phosphorous (7.4-14.0 ppm), exchangeable potassium (0.15-0.23 Cmol (+)/kg) and organic carbon (1.0-2.0%) (Chandrashekara *et al*. 2008). The homegarden (0.75 ha in size) is dominated by areca nut and coconut. Plant density in the study plot is given in Table 1.

### 2.2. Selection of green mulch

In the study area, farmers prune the leaves and young twigs of *Calycopteris floribunda* and Chromolaena *odorata* growing in the homegardens, common lands and forest lands. They also prune trees and shrubs like *Ficus asperima, Glycosmis pentaphylla, Helictres isora, Macaranga peltata and Terminalia paniculata* to use the leaves as green mulch. In general, depending on the availability, farmers use green foliages of above mentioned species either in mixture or separately as mulch. The estimated quantity of fresh green mulch (excluding woody branches) applied to coconut palm ranges from 120 kg to 150 kg palm$^{-1}$ yr$^{-1}$ (N =11 homegardens). For the present study, seven treatments namely green mulch of *Calycopteris floribunda*, *Chromolaena odorata*, *Ficus asperima*, *Glycosmis pentaphylla*, *Helecteris isora, Terminalia panicualta* and mixture of these six species were considered.

Table 1. Plant density (individuals $ha^{-1}$) in the homegarden of Kerala part of Nilgiri Biosphere Reserve, India.

| Species | Family | Density (individual $ha^{-1}$) |
|---|---|---|
| *Anacardium occidentale* | Anacardiaceae | 25 |
| *Annona squamosa* | Annonaceae | 17 |
| *Areca catechu* | Arecaceae | 925 |
| *Artocarpus heterophyllus* | Moraceae | 32 |
| *Benincasa hispida* | Cucurbitaceae | 4 |
| *Cajanus cajan* | Fabaceae | 12 |
| *Citrus limon* | Rutaceae | 8 |
| *Coccinea grandis* | Cucurbitaceae | 6 |
| *Cocos nucifera* | Arecaceae | 150 |
| *Colocasia esculenta* | Araceae | 85 |
| *Eugenia jambos* | Myrtaceae | 4 |
| *Garcinia gummi-gutta* | Clusiaceae | 4 |
| *Hibiscus rosa-sinensis* | Malvaceae | 8 |
| *Ixora coccinea* | Rubiaceae | 4 |
| *Macaranga peltata* | Euphorbiaceae | 8 |
| *Mangifera indica* | Anacardicaeae | 83 |
| *Momordica charantia* | Cucurbitaceae | 6 |
| *Murraya koenigii* | Rutaceae | 2 |
| *Musa paradisiaca* | Musaceae | 65 |
| *Piper nigram* | Piperaceae | 36 |
| *Psidium guajava* | Myrtaceae | 4 |
| *Syzigium cuminii* | Myrtaceae | 8 |
| *Tectona grandis* | Verbenaceae | 50 |

**2.3. Mulch decomposition study**

In the homegarden, nine coconut palms of the same age were selected and under three palms the green mulch from mixed species was placed at the rate of 150 kg per palm. Similarly, green mulch from six individual species were placed separately under three palms each.

In order to study the mulch decomposition pattern, the standard litter bag technique (Anderson and Ingram, 1989) was adopted. One hundred gram of freshly pruned leaves and young twigs of a given treatment were put into nylon mesh bags (dimensions: 25 cm x25 cm; 2mm x 2mm mesh size) and bags were placed on the first week of December 2007, under corresponding green mulch established in the homegarden. At the time of transferring the leaves into bags, triplicate samples (treatment-wise) were also collected for estimating moisture content, based on which the oven-dry weight of the sample was estimated.

At monthly intervals, starting from January 2008 to August 2008, three litter bags of each treatment were carefully retrieved and returned to the laboratory. The bags were gently brushed to remove soil and other extraneous materials. The residual

mulch mass removed from the bags was oven-dried at 72$^{o}$C, until getting the constant weight, to determine the mass loss.

### 2.4. Chemistry of fresh leaves and decomposing mulch

The leaves of each treatment (triplicate samples per treatment) were characterised in terms of their intial total N (micro-kjeldhal method), P (vanado-molybdo phosphoric yellow colour method) and K (flame photometry) following Jackson (1958).

Contents of the litter bags (residual biomass pooled treatment-wise; triplicate samples) at monthly intervals of N, P and to determine nutrient release pattern from the decomposing mulch.

### 2.5. Microorganisms during mulch decomposition

Enumeration of microorganisms by serial dilution method using different media like nutrient agar, Rose Bengal agar and starch casein agar for Bacteria, Fungi and Actinomycetes respectively. Isolation, quantification and identification of enzyme producing microorganisms were also done. The different selective media like Czapek's mineral salt agar, Modified Melin Norkans agar, Starch agar and Nutrient agar were used for isolation of cellulase, phenole oxidase, amylase and catalase enzyme producing microorganisms respectively.

### 2.6. Statistical analysis and calculations

Decomposition rate constants (k) for the green mulch of three treatments (Calycopteris floribunda, Chromolaena odorata and mixed species) were calculated using the exponential decay model of Olson (1963):

$$X_t/X_0 = e^{-kt}$$

where, $X_0$ is the original mass, $X_t$ is the weight remaining at time t, t is time in year and k is the decay rate coefficient ($yr^{-1}$). This decay model was also used for the loss of nutrients during the studied decomposition period.

Half-lives ($t_{0.5}$) of decomposing mulch samples were estimated from the k-values using the equation: $t_{0.5} = \ln (0.5)/-k = 0.693/-k$

Correlation coefficients between k and the chemical properties of green mulch (initial N, P, K, Ca, Mg and N: P ratio) were also worked out. Differences in mass loss, decomposition constant, population of microorganisms and substrate chemistry between treatments were tested using one-way analysis of variance (ANOVA). Duncan's multiple range test was used to separate the means of different treatments as the $P<0.05$ level.

## 3. Results

### 3.1. Chemical characteristics of leaves

The initial chemical compositions of green mulch from seven treatments are given in Table 2. ANOVA showed significant effect of treatments on initial green mulch quality with the initial nutrient concentration showing the following trend.

Table 2. Initial nutrient concentrations (Mean ± SE) for seven green mulches studied in the homegarden of Kerala part of Nilgiri Biosphere Reserve, India.

| Treatments | N (%)* | P (%)* | K (%)* |
|---|---|---|---|
| Calycoptris | 3.11 ±0.03[a] | 0.44±0.01[a] | 0.46±0.02[a] |
| Chromolaena | 2.53±0.03[b] | 0.14±0.01[b] | 1.39±0.02[b] |
| Ficus | 1.90±0.09[c] | 0.36±0.02[c] | 1.43±0.06[b] |
| Glycosmis | 3.43±0.09[d] | 0.21±0.01[d] | 0.98±0.04[c] |
| Helicteres | 3.54±0.08[d] | 0.44±0.03[a] | 1.05±0.02[c] |
| Terminalia | 2.01±0.17[c] | 0.10±0.01[b] | 0.44±0.01[a] |
| Mixed species | 3.29±0.03[ad] | 0.45±0.02[a] | 1.18±0.03[d] |

*Values with different letters in a column indicate significant difference at P<0.05, among mulch treatments.

**Nitrogen:** *Helecteris isora* ≥*Glycosmis pentaphylla* ≥mixed species> C*alycopteris floribunda*> *Chromolaena odorata*> *Terminalia panicualta* ≥ *Ficus asperima*

**Phosphorous:** Mixed species ≥ *Helecteris isora* ≥ *Calycopteris floribunda* > *Ficus asperima*>*Glycosmis pentaphylla*≥*Chromolaena odorata*≥*Terminalia panicualta*

**Potassium:** *Ficus asperima*≥ *Chromolaena odorata*> mixed species> *Glycosmis pentaphylla* ≥ *Helecteris isora* > *Calycopteris floribunda* ≥ *Terminalia panicualta*

### 3.2. Mulching material decomposition

Loss of biomass of mulch displayed characteristic decomposition pattern, which appeared to approximate a negative exponential for the species measured (Figure 1 and 2). The dry mass remaining after 240 days varied significantly, with the mulch of *Chromolaena odorata* and *Helecteris isora* decomposed completely, whereas those of mixed species, *Calycopteris floribunda* and *Glycosmis pentaphylla* have lost only 40-50% of their initial dry weight.

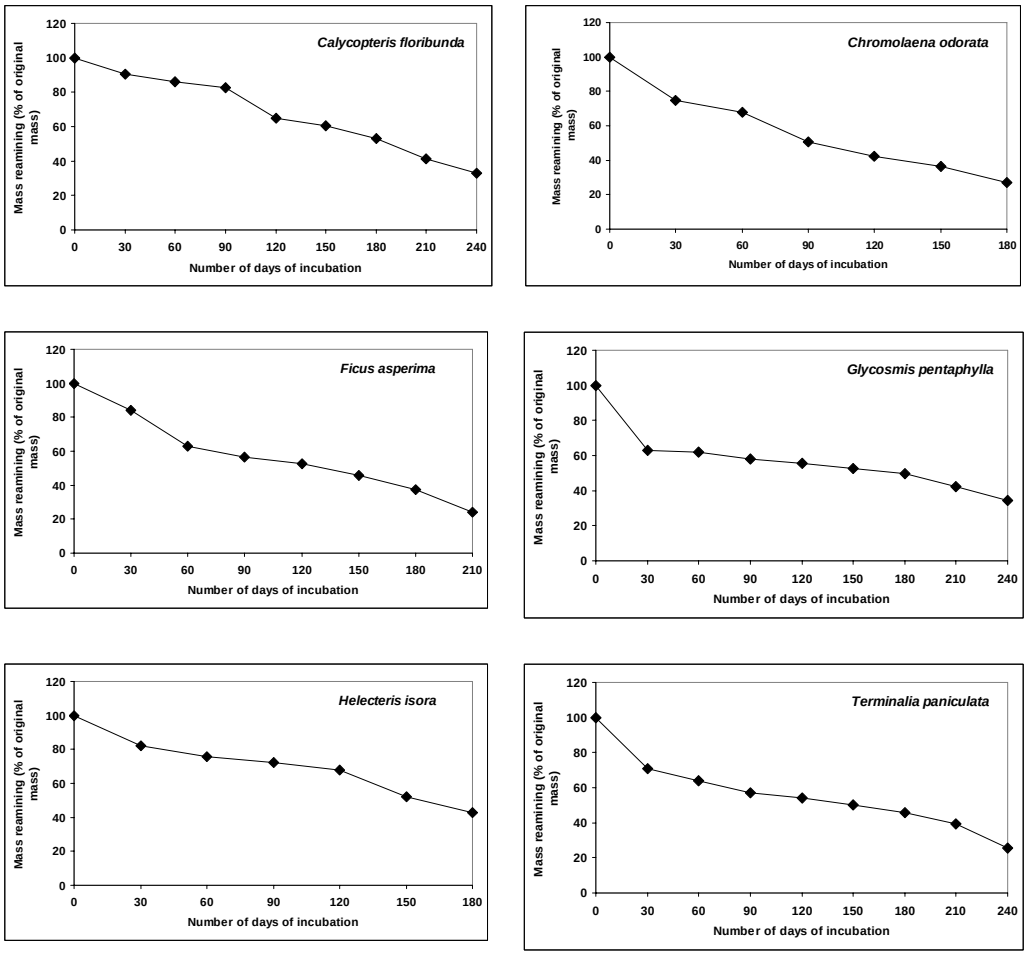


Figure 1. Percent original dry mass remaining with time for single species green mulches studied in the homegarden of Kerala part of Nilgiri Biosphere Reserve, India.

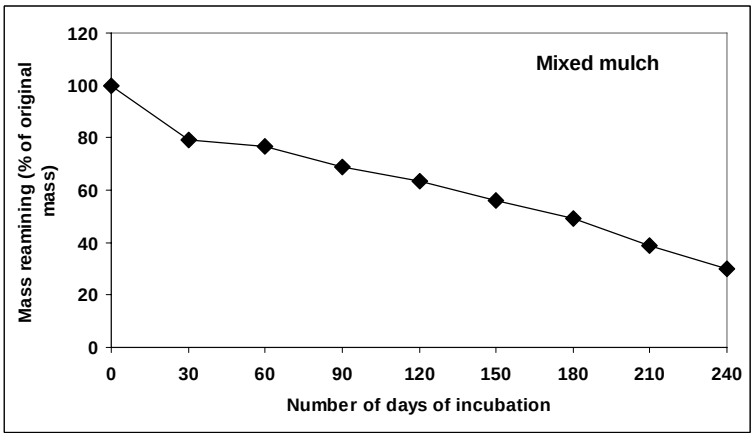


Figure 2. Percent original dry mass remaining with time for mixed green mulches studied in the homegarden of Kerala part of Nilgiri Biosphere Reserve, India.

A rapid initial phase of mass loss was observed for *Chromolaena odorata* and *Helecteris isora*, where about 40 to 50% of their original dry mass was lost after the first 3 months compared to only 15 to 25 % in other types of mulches. The average decay rate in the case of *Chromolaena odorata* is 0.55% of initial mulch mass/day which was significantly higher ($P<0.05$) than in other mulches (Figure 3). Significantly low value for the average decay rate was recorded for *Calycopteris floribunda* ($P<0.05$).

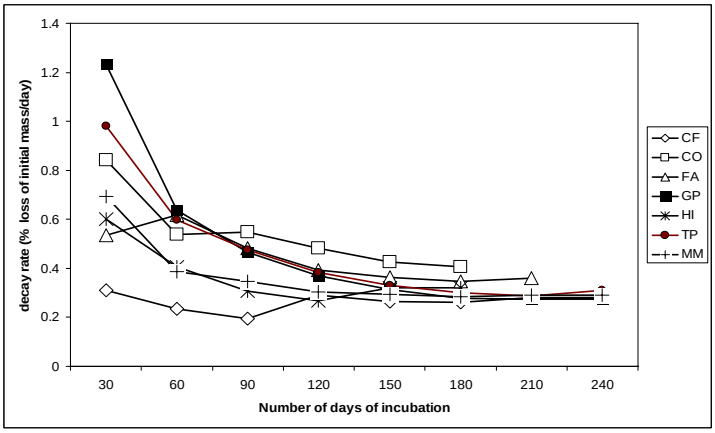


Figure 3. Decay rate for green mulches studied in the homegarden of Kerala part of Nilgiri Biosphere Reserve, India. CF: *Calycopteris floribunda,* CO: *Chromolaena odorata,* FA: *Ficus asperima,* GP *: Glycosmis pentaphylla,* HI: *Helecteris isora,* TP: *Terminalia panicualta,* MM: Mixed mulch.

Decomposition parameters for seven types of mulch are presented in Table 3. The mulch decay constant (k) was significantly higher in *Chromolaena odorata* than in other two types of mulch ($P<0.05$). The decay constant value for mixed species was between the values obtained single species much. The relationship between weight remaining (in percentage of the initial weight) and decomposition time (in year) was well described by the single exponential model ($R^2$=0.95 to 0.98).

Table 3. Mulch decay coefficient (k), $t_{50}$, single exponential model for decomposition and regression model values for seven green mulches studied in the homegarden of Kerala part of Nilgiri Biosphere Reserve, India.

| Mulch type | Average daily decay rate | k ($yr^{-1}$) | $T_{0.5}$ (yr) | Regression model value[✦] |
|---|---|---|---|---|
| *Calycopteris floribunda* | 0.26[a] | 1.25[a] | 0.55[a] | $Y= 125.86e^{-0.1351x}$ |
| *Chromolaena odorata* | 0.54[b] | 2.75[b] | 0.25[b] | $Y= 120.37e^{-0.2088x}$ |
| *Ficus asperima* | 0.44[c] | 2.23[c] | 0.32c | $Y= 119.14e^{-0.1781x}$ |
| *Glycosmis pentaphylla* | 0.48[bc] | 2.32[c] | 0.36c | $Y= 91.11e^{-0.0998x}$ |
| *Helecteris isora* | 0.37[d] | 1.66[d] | 0.42d | $Y= 113.41e^{-0.1278x}$ |
| *Terminalia panicualta* | 0.46[c] | 2.26[c] | 0.34c | $Y= 103.08e^{-0.1335x}$ |
| Mixed species | 0.36[d] | 1.71[d] | 0.43[d] | $Y= 115.22e^{-0.1340x}$ |

[✦] Y=% of mass remaining, X= time, in years

### 3.3. Nutrient dynamics

During decomposition of each type of mulch, the concentration and percentage of each nutrient in the remaining mass was found to show variable trends.

The nitrogen concentration (Figure 4) in the green mulch material of *Calycoptris floribunda*, *Glycosmis pentaphylla*, *Helecteris isora*, *Ficus asperima* and *Terminalia paniculata* decreased first and then increased before decreasing again. In the case of *Chromolaena odorata*, the nitrogen concentration decreased first and then stabilised before decreasing again 120 days after incubation. On the other hand the concentration of nitrogen in mixed species mulch remained same up 60 days and the decreased.

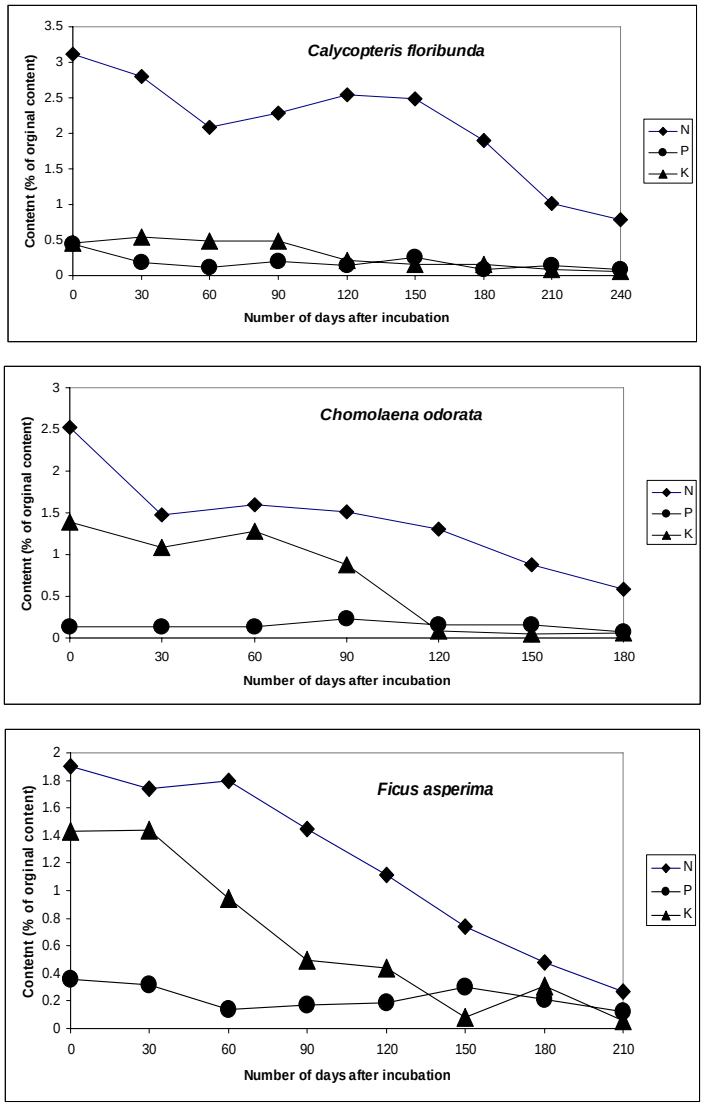


Figure 4. Concentration of nutrients (%) in green mulches studied in the homegarden of Kerala part of Nilgiri Biosphere Reserve, India

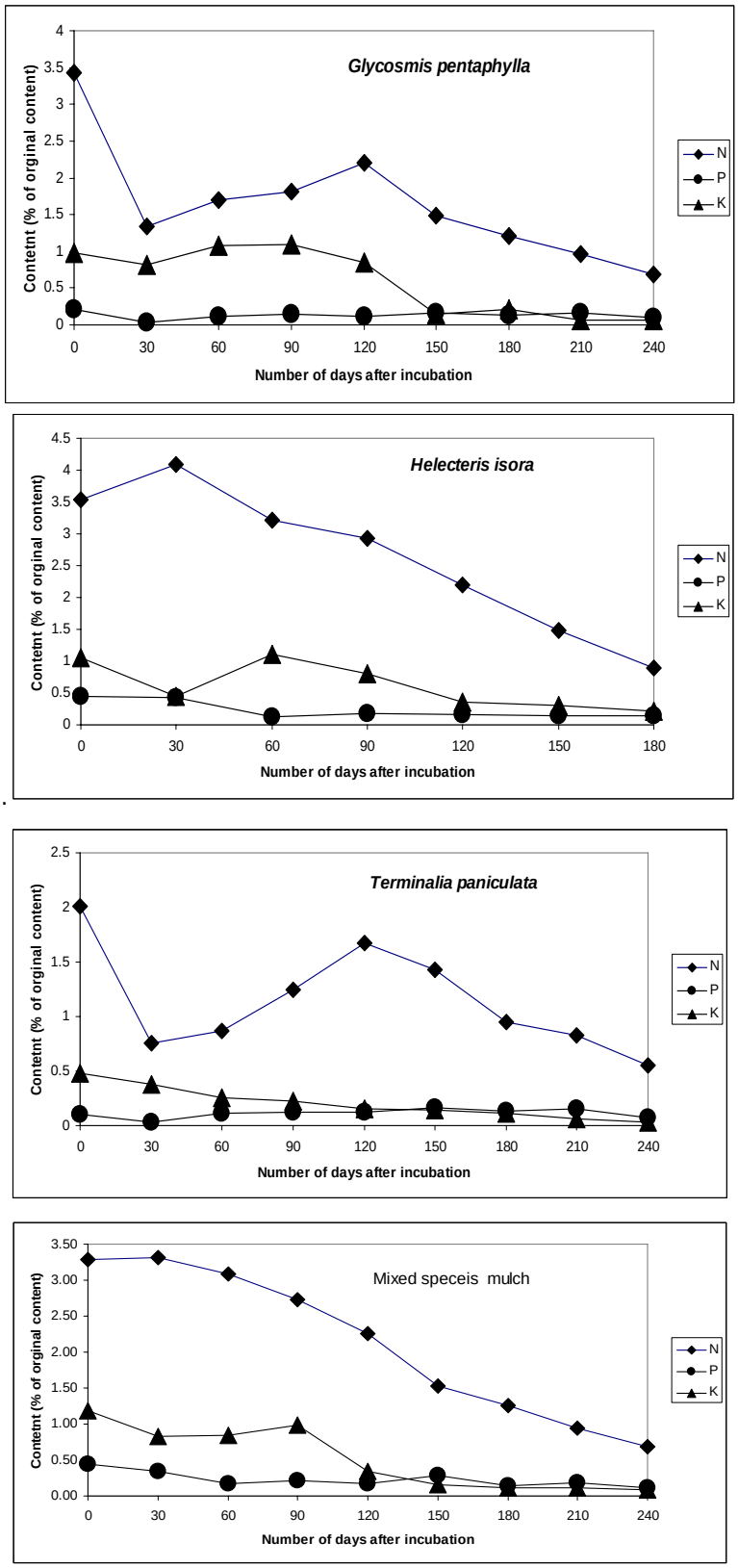


Figure 4 (cont'd). Concentration of nutrients (%) in green mulches studied in the homegarden of Kerala part of Nilgiri Biosphere Reserve, India.

The phosphorus concentration in mixed species mulch as well as in single species mulch of *Calicopteris floribunda*, *Ficus asperima* and *Terminalia paniculata* decreased first and then increased before decreasing (Figure 4). In the case of *Chromolaena odorata* the phosphorous concentration remained up to certain period of incubation and then increased before decreasing. On the other hand, in *Glycosmis pentaphylla* and Helecteris *isora* the concentration remained same up to certain period of incubation, but then decreased and stabilised.

The potassium concentration in the mulch of *Calicopteris floribunda* remained almost same throughout the period of incubation when in the case of *Ficus asperima* and *Terminalia paniculata* the concentration decreased during the last phase of decomposition (Figure 4). In the case of mulch of mixed species and that of individual species such as *Chromolaena odorata, Glycosmis pentaphylla* and *Helecteris isora,* the concentration of potassium showed decreasing- increasing- decreasing trend.

The nutrients in the decomposing mulch showed either tri-phasic or bi-phase release pattern (Figure 5).

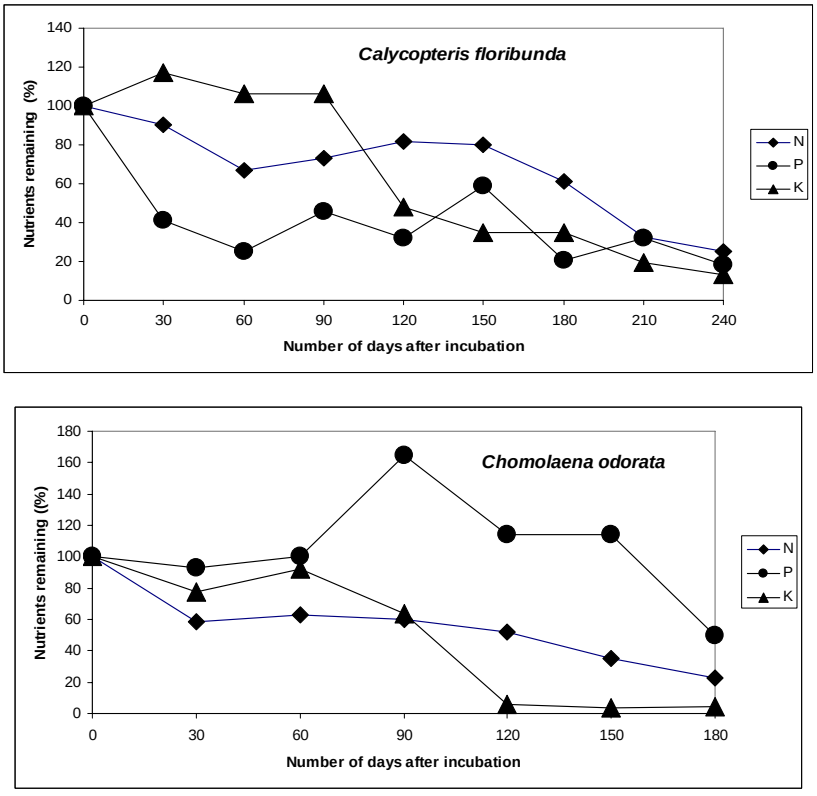


Figure 5. Nutrients remaining (in % of initial weight) in green mulches studied in the homegarden of Kerala part of Nilgiri Biosphere Reserve, India.

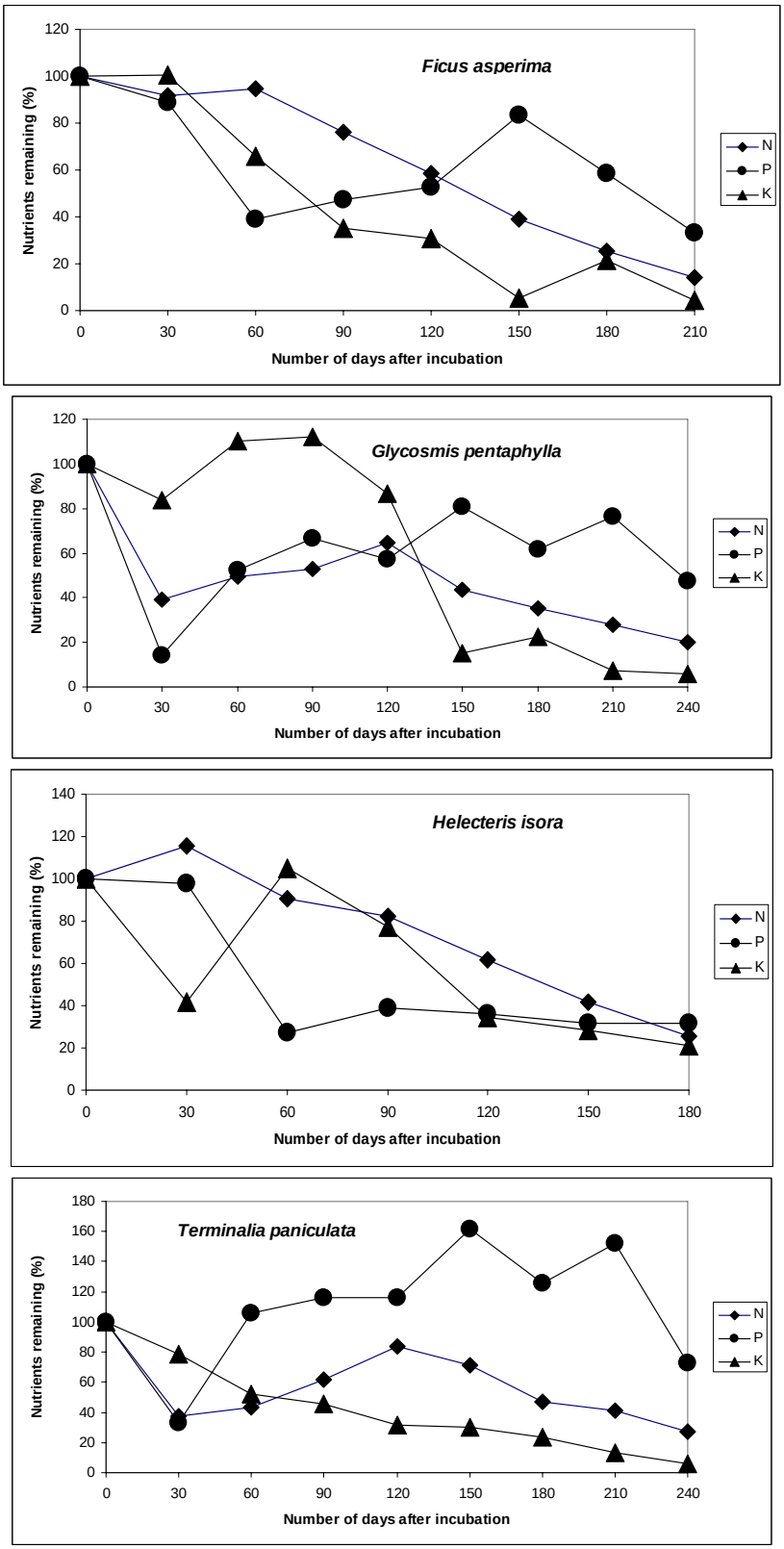


Figure 5 (Cont'd). Nutrients remaining (in % of initial weight) in green mulches studied in the homegarden of Kerala part of Nilgiri Biosphere Reserve, India.

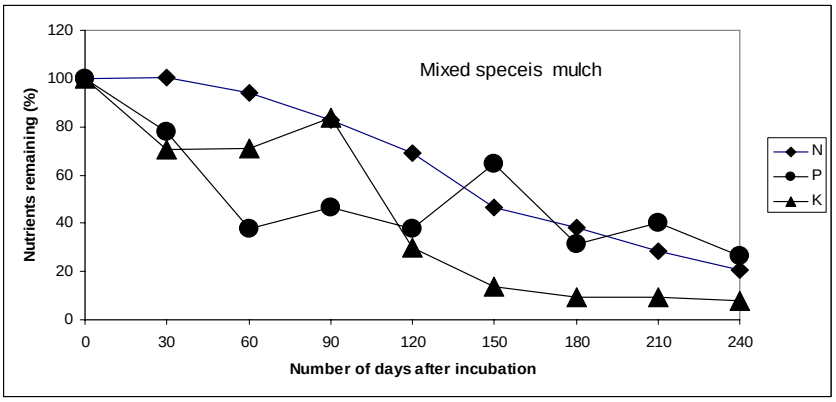


Figure 5 (Cont'd). Nutrients remaining (in % of initial weight) in green mulches studied in the homegarden of Kerala part of Nilgiri Biosphere Reserve, India.

Nitrogen in *Calycoptris floribunda, Chromolaena odorata, Ficus asperima, Glycosmis pentaphylla and Terminalia paniculata,* Phosphorus in mixed species mulch and in the mulch of Calicopteris floribunda, *Chromolaena odorata, Ficus asperima, Glycosmis pentaphylla and Terminalia paniculata*, and Potassium in mixed species much and in the mulch of *Chromolaena odorata, Ficus asperima, Glycosmis pentaphylla and Helecteris isora* showed tri-phasic release pattern with decrease-increase- decrease trend. On the other hand, nitrogen in mixed species and in Helicteris isora, phosophorus in Helicteris isora and potassium in *Glycosmis pentaphylla* showed bi-phasic pattern of nutrient release characterised by initial increase followed by decrease in the amount as the decomposition progresses.

### 3.4. Microbial population in the decomposing mulch

A significant increase ($P<0.05$) in the population of actinomycetes in each mulch type was observed as the period since incubation increased (Figure 6). This may be attributed to the fact that the mulching and mulch decomposition offer favourable conditions for the growth of actinomycetes. However, no clear difference in the population of bacteria and fungi during the two stages of mulch decomposition was noticed ($P>0.05$). The population of different biofertilizer groups of microorganisms (Rhizobium, phosphate solubilizing microbe and Azotobacter) showed to increase as the decomposition progresses (Figure 7). On the other hand, the population of enzyme producing microorganisms was more ($P<0.05$) in the initial stage than in the later stage of mulch decomposition (Figure 8). Due to mulching, the population of microbes which play important role in biological control of plant diseases increased significantly (Figure 9). However, no significant difference between mulch types was recorded for the population of any given microorganism ($P>0.05$).

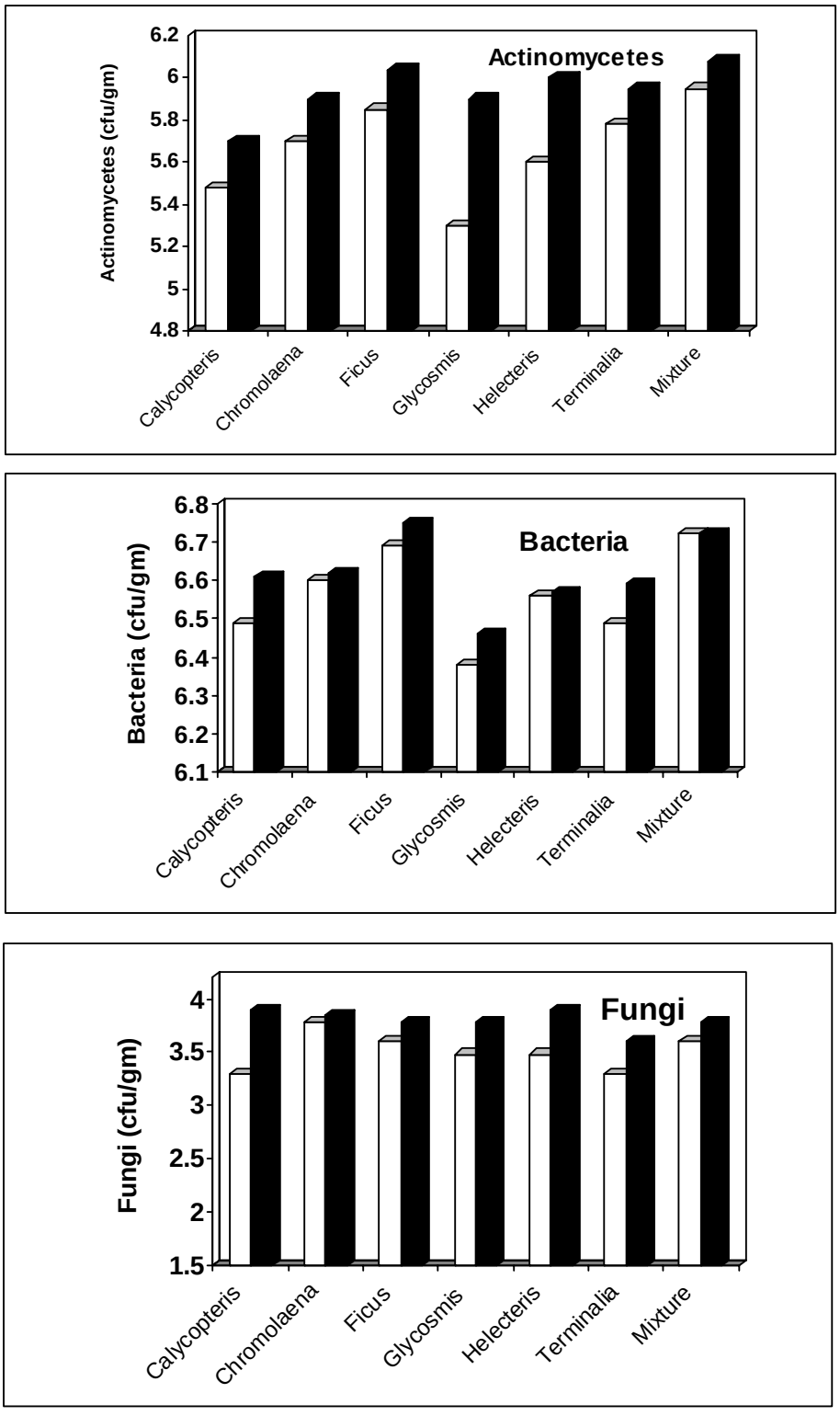


Figure 6. Population size (cfu/gm) of actinomycetes, bacteria and fungi after 4 months (□) and 10 months (■) of mulch decomposition.

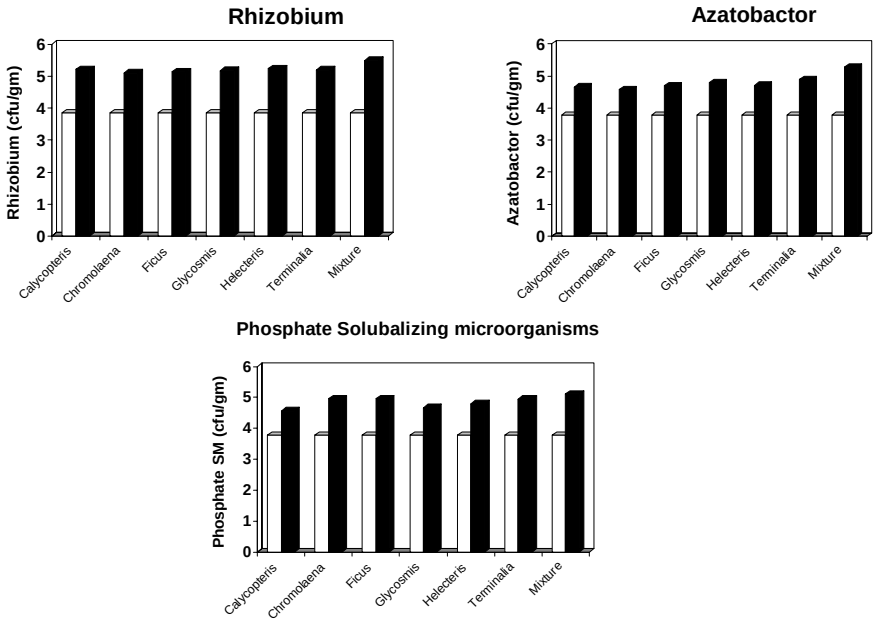


Figure 7. Population size (cfu/gm) of biofertilizer groups of microorganisms in the mulch 4 months (☐) and 10 months (■) after the decomposition different mulch types.

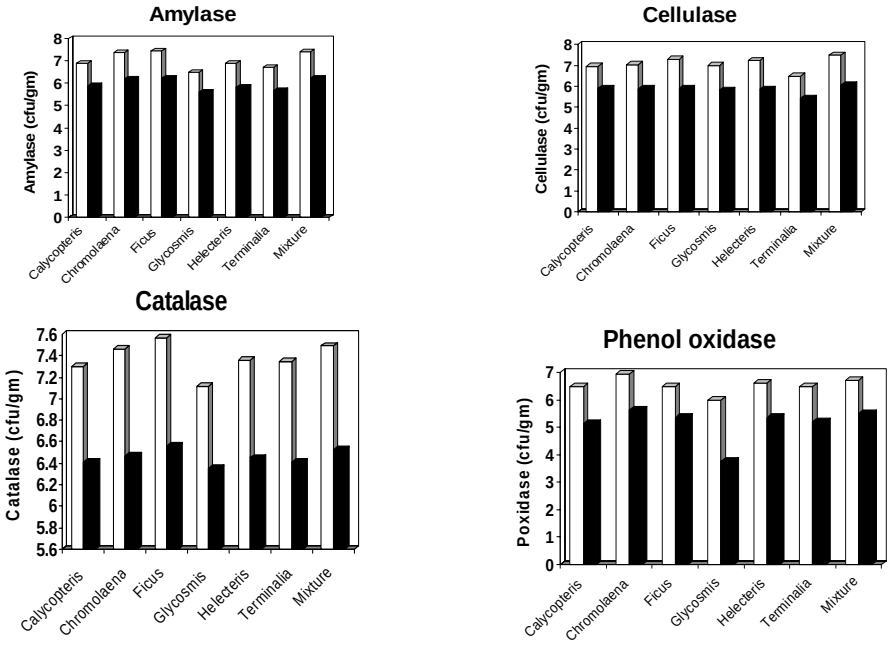


Figure 8. Population size (cfu/gm) of enzyme producing microorganisms in the mulch 4 months (☐) and 10 months (■) after the decomposition in different mulch types.

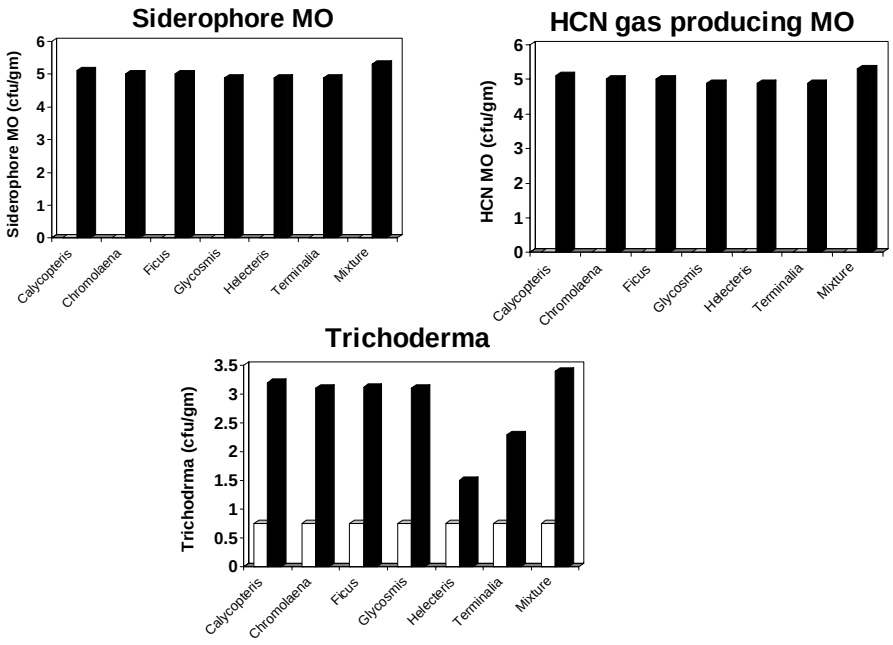


Figure 9. Population size (cfu/gm) of biocontrol microorganisms in the mulch 4 months (□) and 10 months (■) after the decomposition in different mulch types.

## 4. Discussion

### 4.1. Chemical composition and mass loss of mulch

The green mulch of individual species as well as mixed species showed a bi-phasic mass loss with initial rapid phase of decomposition in the first 90 days followed by a slower phase. Due to significantly faster rate of mass loss throughout the period of decomposition, green mulch of *Chromolaena odorata* and *Helecteris isora* showed complete decomposition within 210 days after incubation. Significantly faster decomposition rate noticed in the green mulch of *Chromolaena odorata* and *Helecteris isora* may be an indication of the presence of comparatively large quantity of labile or rapidly decomposing fractions (sugar, starches and proteins). In the traditional agricultural systems of the Western Ghats of India, the leaf extracts of *Calycopteris floribunda* is used to control insect pests (personal observation). Thus it is possible that the leaf mulch from *Calycopteris floribunda* resists biodegradation and shows comparatively slow rate of decomposition. The present study also revealed that the traditional method of application of mixed species mulch reduces the decomposition rate of fast decomposing mulches and enhances the decomposition of slow decomposing mulches. Thus, values obtained for daily decay

rate and mulch decay coefficient (k) in the mixed species were within the range of values obtained for its individual component species.

The decomposition rates recorded for all treatments are greater than 1.0, indicating that mulch turnover occurs in a year or less than a year. Available literature also indicates that the decay rate coefficients are substantially greater for the litter of tropical species (Singh, 1969; Sankaran, 1993; Sundarapandyan and Swamy 1999; Kumar, 2005) than for the temperate species (Cromack et al.1991). It is also important to note that our study was conducted using tissue collected live rather than naturally senesced leaves. Leaf litter is likely to decompose more slowly than the fresh leaves.

Nutrient concentration is considered as one of the important properties that decides the rate of decomposition of litter (Sariyildiz and Anderson, 2003). Thus a variety of litter quality indices based on the initial chemical have been used as decomposition predictors, such as N concentration or the C: N ratio and P Concentration, the lignin concentration, Lignin: N ratio etc. (Solono and Crohn, 2006). However, most of these relations have been established in temperate region, where the type of litter considered does not encompass a large biochemical and physical attributes (Xuluc-Tosola et al., 2003). Therefore, it is not always possible to generalise the indices to other kinds of vegetation. For instance, it was observed that the mulch with high initial N content decompose at a faster rate than with the material with low initial N content (Berg and Staaf, 1980). However, in the present study, despite the fact that the initial N concentration in the green mulch of *Calycopteris floribunda* and mixed species is significantly more than that in *Chromolaena odorata*, the rate of decomposition of mulch was significantly slower ($P<0.05$). Lack of significant relation between the initial N concentration in the mulch material and the rate of decomposition may be due to the fact that polyphenol and lignin bind strongly to organic-N (eg. amino acids and proteins), hence making the mulch of *Calycopteris floribunda* and mixed species comparatively resistant to decomposition (Berg, 2000). This observation is also an indication of the fact that N concentration is not a limiting factor for decomposition in these species. Gonzalez and Seastedt (2001) also noted that species with similar N concentration may decompose at different rates and the relation between decomposition rate and N concentration, is variable among species even within a forest. Therefore, they suggested that the structure of N and its availability to microbes and fungi may be more important in decomposition than the total N concentration.

In the present study, a significant correlation between the initial N:P ratio and decomposition rate in the green mulch material was recorded ($R^2$= 0.994; P= 0.048). Incidentally, the N:P ratio in fresh leaf of *Chromolaena odorata*, *Glycosmis pentaphylla* and *Terminalia paniculata* was higher compared with other green mulch (Figure 10). As the 10-15 is the ideal N:P ratio for decomposer (Vogt et al., 1986), the highest initial N:P ratio in the above mentioned three species indicated that P could be the more limiting in mulch decomposition in these species than in other much materials. Since, P is a major nutrient; a greater shortage of P relative to N makes the green mulch of *Chromolaena odorata*, *Glycosmis pentaphylla* and *Terminalia paniculata* poor quality mulch for coconut palm.

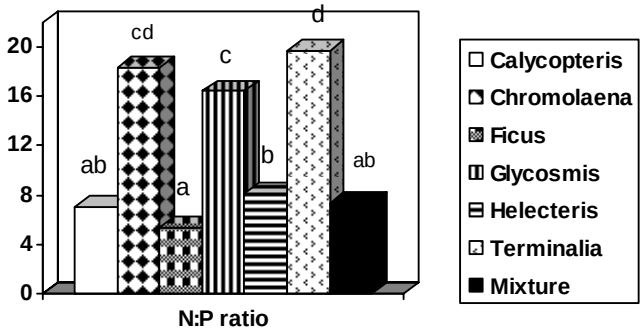


Figure 10. Initial N: P ratio in the green mulch of different type

### 4.2. Nutrients dynamics

Nutrient concentrations are known to vary to some extent between litter types (Jamaludheen and Kumar, 1999). The present study indicates that this observation seems applicable to the green mulch also. For instance, the green mulch of mixed species and in *Helecteris isora* showed a bi-phasic N release pattern with initial increase during decomposition, while that of *Calycopteris floribunda*, *Chromolaena odorata, Ficus asperima, Glycosmis pentaphylla* and *Terminalia panicualta showed* the tri-phasic N release pattern. However, in all treatments, N concentration in the mulch at least in one phase of the decomposition was significantly more than that in the previous phase. Such increase, even in the green mulch, could be due to addition of N from exogenous source into microbiomass (Melillo et al., 1982) or fungal translocation from the surrounding environment (Musvoto et al., 2000). The succeeding mass loss of N is biologically mediated by decomposer organisms (Swift et al., 1979). According to Palm and Rowland (1997), the critical threshold value of initial concentration is 1.7 to 2.0%, below which net immobilisation occurs during litter decomposition. However, in the present study, the initial N concentration in all

treatments with exception being Ficus *asperima* and *Terminalia paniculata* was above 2.0%. Thus the critical threshold value of N concentration in green mulch may be different from that in leaf litter.

During the decomposition period, either in the beginning or near the end of incubation, the P concentration in the mulch increased. Increase in P concentration during litter decomposition has been attributed to fungal translocation and or immobilisation of phosphorous (Cattanio, 2008). Significantly high N: P ratio in the initial mass as well as low k-value for P (1.36 $yr^{-1}$) recorded in the green mulch of *Chromolaena odorata* imply that P immobilised and its mineralisation takes place at a slower rate when compared to the mineralisation of organic-N in the same mulch.

Potassium in plants occurs mainly in a soluble ionic form (Tukey, 1990). Being a labile element, potassium showed a faster release rate compared to other elements in each treatment. In all three treatments, increase in Ca concentration during decomposition period was observed. This may be due to luxury uptake of Ca into fungal hyphae as documented by Cromack et al. (1978) and Swift et.al. (1981).

### 4.3. Agronomic considerations

In the homegardens of the study area, it is estimated that around 120 to 180 kg, with an average of 150 kg of fresh green leaves and young twigs are applied per coconut palm per year. The mean dry weight of mulch of three different treatments and quantity of N, $P_2O_5$ and $K_2O$ in the mulch were estimated and given in Table 4. The cumulative release N, $P_2O_5$ and $K_2O$ from each treatment is illustrated (Figures 1.10, 1.11 and 1.12)

Table 4. Dry weight of mulch applied and total quantity of nutrient in the mulch in the homegardens of Kerala part of Nilgiri Biosphere Reserve, Kerala

| Treatment | Dry mass of mulch applied (kg $palm^{-1}$ $yr^{-1}$) | Weight of nutrients in the applied mulch (kg) | | |
|---|---|---|---|---|
| | | N | $P_2O_5$ | $K_2O$ |
| *Calycopteris floribunda* | 94.8±6.9 | 2.96±0.8 | 0.94±0.02 | 1.05±0.03 |
| *Chromolaena odorata* | 45.3±1.3 | 1.15±0.2 | 0.14±0.01 | 1.52±0.08 |
| *Ficus asperima* | 53.3±2.8 | 1.05±0.3 | 0.34±0.01 | 0.62±0.01 |
| *Glycosmis pentaphylla* | 78.8±1.6 | 2.74±0.4 | 0.57±0.03 | 1.99±0.06 |
| *Helectris isora* | 60.8±2.1 | 2.14±0.4 | 0.29±0.02 | 1.43±0.07 |
| *Terminalia paniculata* | 83.3±2.3 | 1.65±0.3 | 0.34±0.01 | 2.87±0.03 |
| Mixed species | 65.6±1.8 | 2.16±0.5 | 0.54±0.01 | 1.24±0.04 |

The N dosage recommended by the Kerala Agricultural University (KAU, 2002) is 0.5 kg $palm^{-1}$ $yr^{-1}$. The time required for fulfil the N-fertilisation recommended by the KAU varies from treatment to treatment with about 30 days in *Glycosmis pentaphylla* and

*Terminalia paniculata*, 30 to 60 days in *Calycopteris floribunda*, 60 to 90 days in *Helecteris isora*, 90 to 120 days in *Chromoalena odorata* and mixed species mulch and around 150 days in *Ficus asperima* (Figure 11).

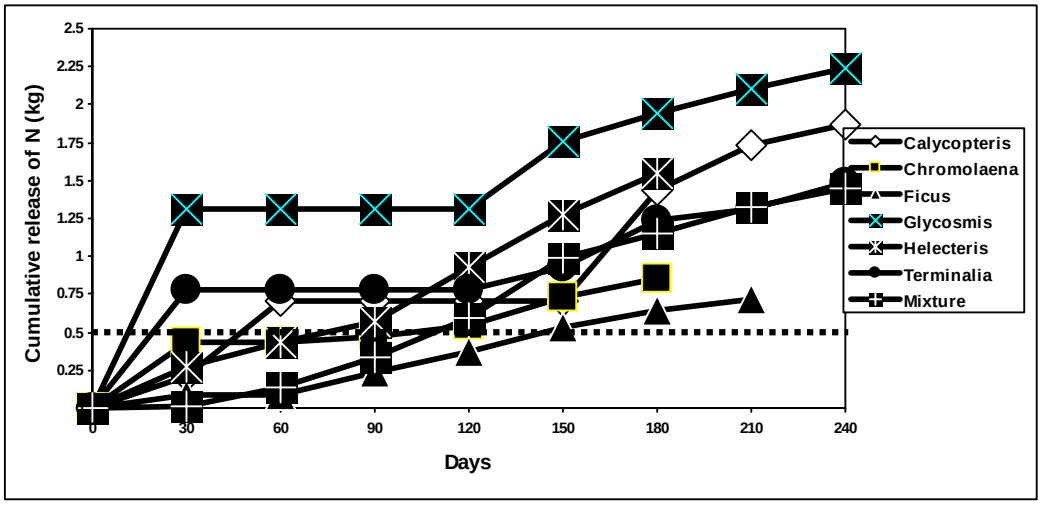


Figure 11. Cumulative nutrient release (Nitrogen) from 150 kg (fresh weight) each of seven mulches applied separately to coconut palms in the homegarden of Kerala part of Nilgiri Biosphere Reserve, India. Dotted line indicates the recommended dose (KAU, 2002) of a given nutrient per palm per year.

The recommended dose of $P_2O_5$ for coconut palm is 0.32 kg/palm/year (KAU, 2002). The mulch of Chromolaena odorata and *Terminalia paniculata* could not be able to fulfil the $P_2O_5$ –fertilisation recommended, while that of *Calycopteris floribunda, Glycosmis pentaphylla, Helecteris isora* and mixed species release the recommended quantity within 30 and 60 days respectively (Figure 12).

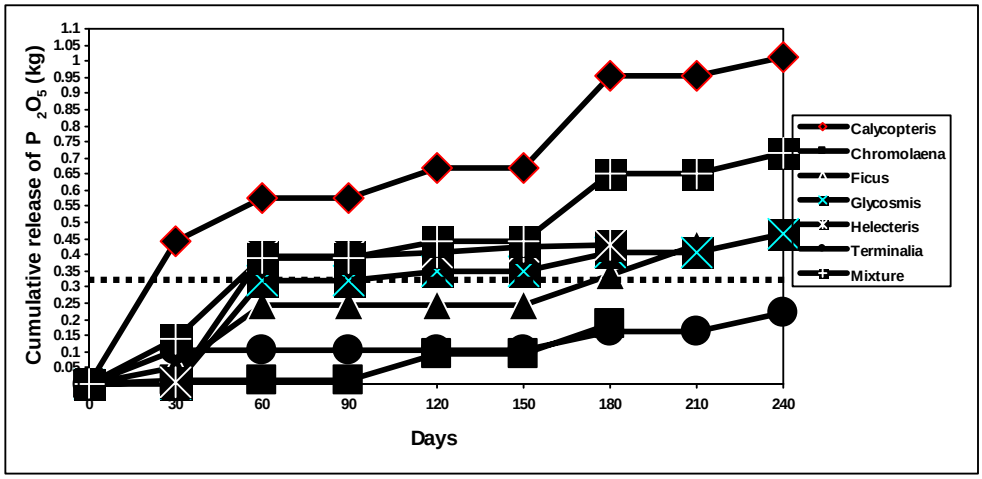


Figure 12. Cumulative nutrient release ($P_2O_5$) from 150 kg (fresh weight) each of seven mulches applied separately to coconut palms in the homegarden of Kerala part of Nilgiri Biosphere Reserve, India. Dotted line indicates the recommended dose (KAU, 2002) of a given nutrient per palm per year.

For the good management of coconut, 1.2 kg of $K_2O$ $palm^{-1}yr^{-1}$ is recommended (KAU, 2002). To fulfil this recommended dose of $K_2O$, the green mulch of *Chromolaena odorata*, *Helecteris isora* and mixed species mulch may need 90 to 120 days when Ficus asperima and Glycosmis pentaphylla need 120 to 150 days (Figure 13). The residual nutrients from the mulch are expected to slowly build up the nutrient content in the soil. However, the mulch of *Calicopteris floribunda* and *Terminalia paniculata* could not be able to fulfil the $K_2O$ –fertilisation recommended.

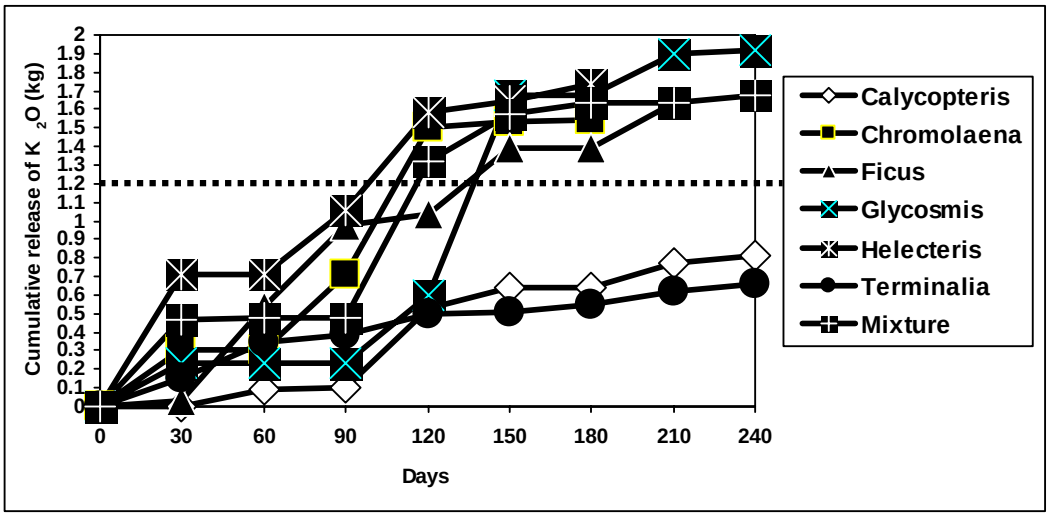


Figure 13. Cumulative nutrient ($K_2O$) release from 150 kg (fresh weight) each of seven green mulches applied separately to coconut palms in the homegarden of Kerala part of Nilgiri Biosphere Reserve, India. Dotted line indicates the recommended dose (KAU, 2002) of a given nutrient per palm per year.

From these observations, it is possible to conclude that with the present quantity of green mulch application, a) *Chromolaena odorata* and *Terminalia paniculata* are not providing the required quantity of P to the plant which is an important nutrient for plant growth and yield, b) *Calicopteris floribunda* and *Terminalia paniculata* are not providing the required quantity of K to the crop and c) the mixed species mulch consisting of nutrient rich and nutrient poor foliage of different species is able to fulfil the recommended dose of N, $P_2O_5$ and $K_2O$ at an intermediate rate.

## 5. Impact of demonstration experiment

On farm experiments on decomposition and nutrient release pattern of single and mixed species mulch has enabled to gather several important results which can be transmitted to the farming community through training programmes. Some important points which have been highlighted in training courses during the months of July – August 2009 are as follows:

1. Initial concentration of nitrogen (N) and potassium (K) in the mixed species mulch are between those recorded in the mulch of individual species.
2. Initial phosphorus (P) concentration in mixed species is much higher than that quantified in the mulch of individual species.
3. Mixing of green mulch material of different species does not alter the population of enzyme producing microbes.
4. Population of Trichoderma - a microbe which play an important role in biological control of plant diseases, is much higher in the mixed species mulch than in the mulch of certain individual species.
5. Phosphorus is a major nutrient required for better crop growth. Green mulch with high initial N:P ratio can be considered as poor quality mulch for crops like coconut. Thus, the green mulch of species like *Calycopteris floribunda*, *Glycosmis pentaphylla* and *Terminalia paniculata* are of poor quality. Therefore, by mixing the mulch material of different species can reduce the initial N:P ratio and provide required quantity of P to the crops.
6. When equal quantity of mulch (150 kg of green foliage per palm) of individual species and mixture of species is considered, the mulch materials of *Chromolaena odorata* and *Terminalia paniculata* are unable to fulfil the $P_2O_5$ - fertilization recommended for coconut. Similarly, the mulch materials of species like *Calycopteris floribunda* and *Terminalia paniculata* are unable to fulfil the $K_2O$ fertilization recommended. On the other hand, the mulch of mixed species, consisting of nutrient rich and poor foliages of different species, is able to fulfil the recommended dose of N, $P_2O_5$ and $K_2O$ at an intermediate rate.

Table 5 provides the details of training courses conducted where the above aspect were presented, discussed and feedback from the participants received. Around 28% of the total number participants reported that they aware the traditional practice nutrient management in crop lands using mixed species green mulch. They also stated that they prune the green foliage and young twigs of different species and apply them together as mulch material for crops like coconut and areca nut. However, majority of them said that due to on-farm experiment they understand the science behind the application of mulch of mixed species.

For about 56% of the total number of participants, information on the benefits of traditional practice of green mulch application is new. They are willing to apply the green mulch of mixed species. However, 39 out of 222 participants of the training courses are not ready to adopt the technique due to various reasons (Table 6).

Table 5. Details of the training courses conducted on decomposition and nutrient release patterns of single species and mixed species mulch.

| | **Place of Training course conducted** | | | | |
|---|---|---|---|---|---|
| | Karakkode | Vazhikkadavu | Moothedam | Munderi | Manalpadam |
| Date of training course conducted | 04.07.2009 | 08.07.2009 | 16.07.2009 | 28.07.2009 | 11.08.2009 |
| Number of participants | | | | | |
| Farmers | 56 | 23 | 38 | 76 | 29 |
| Officials, representatives of NGOs | 12 | 1 | 4 | 6 | 3 |
| Number of farmers already adapting the technique | 11 | 6 | 15 | 23 | 6 |
| Number of farmers ready to adapt the technique | 36 | 13 | 15 | 42 | 16 |
| Number of farmers not ready to adapt the technique | 9 | 4 | 8 | 11 | 7 |

Table 6. Reasons attributed by the participants for not ready to adopt green mulch as a nutrient management in crop lands.

| | Non availability of materials | Labour intensive | High cost | Preference for inorganic fertilisers | Not convinced about the benefits of the technique for crop nutrient management |
|---|---|---|---|---|---|
| Non availability of materials | **6** | 1 | 1 | 0 | 0 |
| Labour intensive | | **3** | 2 | 2 | 0 |
| High cost | | | **14** | 1 | 2 |
| Preference for inorganic fertilisers | | | | **3** | 0 |
| Not convinced about the benefits of the technique for crop nutrient management | | | | | **13** |

Six participants are reluctant to adopt the technique primarily because the mulch materials are not available in the required quantity and at the time of mulching. Among these farmers, some have also given reasons such as their preference to inorganic fertilisers over organic manure, scarcity of labourers to collect and apply green mulch and comparatively high cost for green mulch materials for not intending

to apply green mulch. While for another three farmers the scarcity of laborurers is the primary reason for their reluctance to adopt the technique, for fourteen farmers, high expenses to be incurred for collection and application of green mulch is the primary concern.

During the meetings, totally 13 farmers expressed that they have not convinced about the results of the on-farm experiment on mixed mulch decomposition and nutrient release patterns. According to them, some of the species for which the results are obtained through this study do not available in their vicinity to collect and use their green foliages for mulching. Thus, the study should be extended for a range of agroforestry species which yield green mulch materials. Farmers also pointed out that in the present study, equal proportion of green mulch of six species were mixed and used as the mixed species mulch, which in reality farmers do not do. Therefore, they suggested for undertaking studies considering different proportions of mulch materials of constituent species in the mixed species mulch system. In general, after pruning the branches of green mulch species, farmers do not segregate the foliage and small woody branches before spreading them around the base of crop plants. In the present study, only green foliage and small twigs (which are not woody) have been used. Thus, according to farmers, the present study failed to provide the results based on an experiment designed considering the actual way of mulch application in the traditional system and they suggested further studies in this direction.

# Section-3

# Combined effects of microbes and earthworms on the quality of composted organic materials

## 1. Introduction

Sustaining soil productivity has high priority in the tropical region. The decline in soil fertility and productivity due to excessive soil erosion, nutrient run-off, and loss of soil organic matter has stimulated interest in improving overall soil quality by incorporating composted organic matters to crop lands. Compost is nutrient rich, moisture absorbent leaves, twigs and branches, teaming with fungal, microbial and insect life. It serves as a `nutrient bank', storing the nutrients contained organic matter and slowly making these nutrients available to plants. Application of compost to agricultural land has proven beneficial to soil quality, crop yield and quality. Compost has been shown to improve soil texture and aggregation as a result of microbial contribution of polysaccharides, humic acid and other organic matter (Raviv, 1998). Enhanced nutrient cycling through increased microbial activity due to application of composts also contributes for plant nutrition. Compost increases soil water holding capacity and better water infiltration rates in soils (Buckerfield and Webster, 1998).

The preparation of quality compost within a short period of time during its mass requirement is a real challenge. Application of efficient decomposer microbial culture to compost raw materials can greatly overcome this problem. Inoculation of compost with bio-fertilizer group of microorganisms enriches compost quality. Similarly, available literature indicate that the result of the composting process through earthworms is a high quality humic product and that can be used as soil amendment as it improves the soil structure and chemical-physical and biological properties of the soil. However, very few attempts have been made to the use decomposer microbial inoculums, earthworms and biofertilisers microorganisms together for producing better quality composts. Studies are less to ascertain the nutrient status, population size of beneficial microorganisms in different types of composts and also efficiency of composts to improve crop growth and yield. The present study was aimed to compare and contrast composts prepared in conventional way and by adding beneficial microbes and earthworm for their quality as well as their influence on crop growth and yield.

## 2. Methods

### 2.1. Preparation of composts

Experiments were designed to prepare different types of composts and to test their ability to enhance growth and yield of crops in pot culture. Five types of composts

were prepared (Table 1) using understorey plant biomass, collected from homegardens and surrounding forest areas, as raw material.

To prepare a uniform feed material, fresh leaves and tender twigs of understorey plants were mixed thoroughly and chopped. About 1.5 tons of the chopped material was heaped out door and exposed to the temperature between 27 and $29^0$ C for one week period. Later the materials were divided into five heaps, each weighing approximately 250 kg and spread on a brick-laid floor in a temporary shed. In each heap, the materials were spread in stacks, one above the other. Each stack was 1.5 m wide, 1 m long and 0.15 m height and thus the total height of a heap was around 1 m. A mixture of urea and rock phosphate was sprinkled over each stack before spreading over it the chopped material as another stack. Total quantity of rock phosphate and urea used for every 250 kg of feed material was 1.25 kg and 0.25 kg respectively.

Table 1.Details of treatments

| | Components | | Compost name and symbol |
|---|---|---|---|
| | Feed material | Inoculum | |
| 1. | 250 kg of green foliage + 1.25 kg of rock phosphorous + 0.25 kg of urea | Nil | Control compost (CC) |
| 2. | As above | 5 kg of cow dung | Cow dung compost (C-C) |
| 3. | As above | 5 kg of cow dung + earthworms (375 worms) | Cow dung and earthworm compost (CE-C) |
| 4. | As above | 2.5 Kg of decomposing microbial consortium in the form of carrier (talc) based culture | Decomposing microbial inoculated compost (DMI-C) |
| 5. | As above | 2.5 Kg of decomposing microbial consortium in the form of carrier (talc) based culture + earthworms (1500 worms /ton of compost) | Decomposing microbial and earthworm inoculated compost (DMIE-C) |

However, for preparing cow dung inoculated composts (C-C and CE-C), in addition to rock phosphate and urea cow dung slurry was poured over each stack. Total quantity of cow dung used per heap was 5 kg. On the other hand, for preparing decomposer microbial inoculated composts (DMI-C and DMIE-C) the decomposer microbial inoculums (dmi) comprised of enzyme (amylase, cellulose, xylanase, phenol oxidase and catalase) producing bacteria, fungus and actinomycetes were added. These decomposer microbes were isolated from compost. The dmi were in the form of carrier (talc) based culture. The concentration of dmi used for composting was 2.5 kg per heap of feed materials.

The heat generated during the initial stages of decomposition, by the breakdown of complex bio-molecules raised the temperature above 60$^{o}$C i.e., to the thermophillic range. After this stage, a part of the cow dung inoculated composts and decomposer microbial inoculated composts were transferred to tanks and inoculated with earthworms (*Eudrilus euginae*) in a concentration 1500 worms/ton of compost. Turning was carried out twice a week. Watering was done based on requirement and the material was covered with moistened sack to retain the moisture. This has resulted in the production of cow dung and earthworm compost (CE-C) and decomposing microbial and earthworm inoculated compost (DMIE-C).

When the compost was ready by its physical appearance, as judged by development of a dark brown to black colour with uniformly disintegrated structure, watering was stopped. Time taken for composting, both by introducing earthworms and otherwise was noted. One or two days later, the compost was removed and the ratio of decomposed (<2mm) to un-decomposed (>2mm) content of the feed material by weight in the compost was determined by sieving. Compost samples were analysed for pH, total organic carbon, total nitrogen, phosphorus, potassium, C/N ratio, calcium and magnesium following Jackson (1958).

The total number of fungi, actinomycetes and bacteria present in different types of composts were estimated separately using serial dilution plate method (Allen 1953). One gram of compost sample was suspended and agitated in a test tube containing 9 ml of sterile water. Serial dilutions were made by transferring 1 ml into additional dilute blanks to prepare the dilutions $10^{-2}$, $10^{-3}$, $10^{-4}$ and $10^{-5}$. Transferred 0.1 ml aliquots from $10^{-3}$ into five Petri dishes for the enumeration of fungi and then poured the cooled ($45^{0}$ C) Rose Bengal Agar medium to each Petri dish followed by gentle rotation. For the enumeration of bacteria and actinomycetes, transferred 0.1 ml aliquots from $10^{-5}$ into five Petri dishes and then poured the cooled ($45^{0}$ C) nutrient Agar medium to each Petri dish followed by gentle rotation. Upon solidification of the media, all the plates were incubated in an inverted position at $25^{0}$ C for 2-7 days. The number of colonies on the dilution plates were counted, averaged and multiplied by dilution factor to find the number of cells per gram of sample.

Number of cells /ml = mean plate count x dilution factor/Dry weight of soil

The significant difference ($P< 0.05$) between values of each sample was performed using Duncan's multiple range test (Duncan, 1955).

### 2.2. Compost enrichment

The finished decomposer microbial inoculated composts (DMI-C and DMIE-C) were taken for biofertiliser enrichment. The compost from each of the two treatments was transferred to six different buckets in equal quantities and individual buckets were inoculated with six types of biofertilisers namely Vesicular arbuscular mycorrhizae (VAM), Phosphate solubilising microorganisms (PSM), Azotobacter, Rhizobium, Potassium mobilizing bacteria (KMB) and trichoderma. After 12 days of incubation, all six inoculated portions of given compost were mixed and incubated in a drum for maturation. Thus two enriched composts were prepared (Table 2).

Table 2. Details of biofertiliser enriched composts

| | Components | | Compost name and symbol |
|---|---|---|---|
| | Compost | Enrichment | |
| 1. | Decomposing microbial inoculated compost (DMI-C) | VAM+PSB+ Azotbacter+Rhizobium + Potassium mobilizing bacteria + trichoderma | Decomposing microbial inoculated compost enriched with biofertilisers (BIODMI-C) |
| 2 | Decomposing microbial and earthworm inoculated compost (DMIE-C) | VAM+PSB+ Azotbacter+Rhizobium + Potassium mobilizing bacteria + trichoderma | Decomposing microbial and earthworm inoculated compost enriched with biofertilisers (BIODMIE-C) |

All seven composts; Biofertiliser inoculated composts (BIODMI-C and BIODMIE-C) and other composts (CC, C-C, CE-C, DMI-C and DMIE-C) were analysed for total nitrogen, phosphorous and potassium contents and microbial population.

### 2.3. Plant growth trail

A plant growth trail was conducted at KFRI Peechi to evaluate composts enriched with biofertilisers (BIODMI-C and BIODMIE-C) and composts prepared by inoculating cow dung (C-C) and cow dung and earthworms (CE-C) and a compost without any inoculation (CC) as soil amendment in a pot experiment growing cow pea, okra and brinjal plants.

## 3. Results and discussion

### 3.1. Properties of composts

The chopped green foliage added with rock phosphate and urea but without inoculating cow dung or decomposing microbes or earthworms took 56 days for decomposing, with the end-point determined from the physical appearance, such as the development of a dark brown or black colour with uniformly disintegrated structure. Whereas cow dung compost (C-C), decomposing microbial inoculated

compost (DMI-C), cow dung and earthworm compost (CE-C) and DMI and earthworm compost (DMIE-C) were composted for 46 days, 42 days, 35 days and 30 days respectively. According to Senapati (1988) organic matter disintegration is faster in earthworm introduced compost than in normal compost. The passage of organic material through the earthworm gut results in physical decomposition due to the muscular grinding action of the gizzard. This provides enhanced surface area for subsequent microbial decomposition. Significantly faster decomposition of compost inoculated with DM and earthworm is due to combined effects of microbes and earthworm. Actinomycetes and bacteria (both cellulolytic and lignolytic) increase exponentially along the entire length of earthworm gut (Hazra, 1988). These microbes and also inoculated microbes together enhance the rate of humification of organic matter.

The finished composts from different treatments were compared for various chemical parameters (Table 3). The pH of control compost (CC), cow dung compost (C-C) and decomposing microbes inoculated compost (DMI-C) was acidic (6.3- 6-8). On the other hand, the pH of cow dung and earthworm compost (CE-C) and decomposing microbial and earthworm inoculated compost (DMIE-C) was alkaline (7.4). Secretion of $NH^+$ ions and activity of calciferous glands in earthworm are considered as the factors for alkaline condition of the compost. According to Kale et al. (1982), NH+ ions temporarily reduces the pool of H+ ions and the calciferous glands contain carbonic anhydrose which catalyse the fixation of $CO_2$ as $CaCO_3$, thereby preventing the fall of pH.

A significant increase in nitrogen content was observed in green foliage added with different inoculums (Table 3); it was highest for decomposing microbial and earthworm inoculated compost (DMIE-C) and lowest for control compost (CC). The increase in nitrogen in these composts is due to a) the higher degree of decomposition and mineralisation of nitrogen, b) increase in microbial population and thus accumulation of nitrogenous products, and c) fixation of atmospheric nitrogen by microorganism in the guts of earthworms.

The contents of P and K were also significantly higher in compost prepared with addition of different inoculums. The enhancement of phosphatase activity and the physical breakdown of materials results in greater mineralization (Mathur et al., 1980). Influence of enzymes of decomposer microbes that were inoculated and those associated with the gut of the earthworms are also responsible for variation in the concentration of a given nutrient in different types of composts.

Table 3. pH, nutrient composition and C/N ratio of different composts.

| Treatment | pH | OC | N | $P_2O_5$ | $K_2O$ | Ca | Mg | C/N ratio |
|---|---|---|---|---|---|---|---|---|
| Control compost (CC) | 6.4 | 51.6 | 1.2 | 0.6 | 0.4 | 1.35 | 0.8 | 43.0 |
| Cow dung compost (C-C) | 6.8 | 44.8 | 1.4 | 0.82 | 0.46 | 1.48 | 0.87 | 32.0 |
| Decomposing microbia inoculated compost (DMI-C) | 6.3 | 38.8 | 1.46 | 0.88 | 0.51 | 1.40 | 1.02 | 26.6 |
| Cow dung and earthworm compost (CE-C) | 7.4 | 22.4 | 1.72 | 0.96 | 0.55 | 1.68 | 1.04 | 13.2 |
| Decomposing microbia and earthworm inoculated compost (DMIE-C) | 7.4 | 21.9 | 1.86 | 0.98 | 0.56 | 1.72 | 1.03 | 11.8 |
| Critical difference (cd) | 0.2 | 3.8 | 0.12 | 0.04 | 0.02 | 0.21 | 0.04 | 1.26 |

The C/N ratio of control compost (CC) was 43, while that of composts prepared by adding the cow dung slurry (C-C) and consortia of decomposing microbes (DMI-C) was 32 and 26.6 respectively. On the other hand, a significant decrease in C/N ratio was recorded when earthworms were introduced in cow dung compost (CE-C) and consortia of decomposing microbes inoculated compost (DMIE-C) (Table 3). According to Jimenez and Garcia (1992) a C/N ratio <20 indicates acceptable maturity in the finished compost, but a ratio < 15 is preferred (Gaur and Sadasivam, 1989). Thus it is clear that addition of cow dung or decomposing microbes along with earthworms will produce compost with preferable C/N ratio. On the other hand, high value for C/N ratio recorded in other decomposing materials could be possibly due immobilisation of nitrogen.

After 12 days of composting the number of colony forming units (cfu/g of compost) for bacteria and actinomycetes was highest in decomposing microbial inoculated compost (DMI-C) and decomposing microbia and earthworm inoculated compost (DMIE-C) (Table 4 and 5). However, the fungal population did not show significant difference among different composts (Table 6) ($p>0.05$). Even after 23 days and 35 days of composting the number of cfu/g of compost for bacteria and actinomycetes remained high in the decomposing microbial inoculated compost (DMI-C) and decomposing microbia and earthworm inoculated compost (DMIE-C). However, the recorded values were significantly lower than those recorded for these composts in the previous interval. The higher microbial population present in decomposer microbial inoculum-added composts (DMI-C and DMIE-C) might be the reason for quicker composting as reported by Sary *et al*. (1992).

Table 4. Bacterial population (log transformed value) during different intervals of composting

| Treatment | Days after composting (DAC) | | |
|---|---|---|---|
| | 12 DAC | 23 DAC | 35 DAC |
| Control compost (CC) | 6.51[a] | 6.59[a] | 6.27[a] |
| Cow dung compost (C-C) | 6.77[b] | 6.72[b] | 6.49[b] |
| Decomposing microbial inoculated compost (DMI-C) | 7.07[d] | 6.89[c] | 6.68[c] |
| Cow dung and earthworm compost (CE-C) | 6.86[c] | 6.78[b] | 6.32 [a] |
| Decomposing microbial and earthworm inoculated compost (DMIE-C) | 7.10[d] | 6.95[c] | 6.33[a] |
| Critical difference (cd) | 0.06 | 0.08 | 0.06 |

* Values in a column followed by the same alphabets are not significantly different (P>0.05).

Table 5. Actinomycetes population (log transformed value) during different intervals of composting

| Treatment | Days after composting (DAC) | | |
|---|---|---|---|
| | 12 DAC | 23 DAC | 35 DAC |
| Control compost (CC) | 6.17[a] | 6.27[a] | 5.57[a] |
| Cow dung compost (C-C) | 6.45[b] | 6.34[a] | 6.01[b] |
| Decomposing microbial inoculated compost (DMI-C) | 6.79[c] | 6.68[c] | 6.08[b] |
| Cow dung and earthworm compost (CE-C) | 6.39[b] | 6.49[b] | 5.73[a] |
| Decomposing microbial and earthworm inoculated compost (DMIE-C) | 6.75[c] | 6.59[bc] | 6.17[b] |
| Critical difference (cd) | 0.09 | 0.08 | 0.09 |

* Values in a column followed by the same alphabets are not significantly different

Table 6. Fungal population (log transformed value) during different intervals of composting

| Treatment | Days after composting (DAC) | | |
|---|---|---|---|
| | 12 DAC | 23 DAC | 35 DAC |
| Control compost (CC) | 3.88[a] | 4.03[a] | 4.06[a] |
| Cow dung compost (C-C) | 4.06[a] | 4.19[a] | 4.14[a] |
| Decomposing microbial inoculated compost (DMI-C) | 4.13[a] | 4.18[a] | 4.25[ab] |
| Cow dung and earthworm compost (CE-C) | 4.10[a] | 4.13[a] | 4.06[a] |
| Decomposing microbial and earthworm inoculated compost (DMIE-C) | 4.09[a] | 4.22[a] | 4.34[b] |
| Critical difference (cd) | 0.32 | 0.20 | 0.19 |

*Values in a column followed by the same alphabets are not significantly different

### 3.2. Compost enrichment

In the present study, two types of composts namely decomposing microbial inoculated compost (DMI-C) and decomposing microbial and earthworm inoculated compost (DMIE-C) were enriched with beneficial microorganisms such as vesicular arbuscular mycorrhizae (VAM), Phosphate solubilising bacteria (PSB), Azotobacter, Rhizobium, Potassium mobilizing bacteria (KMB) and trichoderma. Twelve days and thirty five days after enrichment, different treatments were analysed for the nutrient

level and microbial population in the compost. There were no beneficial microorganisms such as Azotobacter and Trichoderma in control compost (CC) and cow dung inoculated compost (C-C) as per the data collected in samples on 12 days after complete composting. The treatments which were received decomposing microbial inoculants and earthworms (DMI-C and DMIE-C) were found to have beneficial microorganisms like PSB, Azotobacter, Rhizobium, KMB and Trichoderma. When the treatments DMI-C and DMIE-C were compared for Azatobacter population it was found that values were significantly more in DMIE-C (Table 7 and 8).

Table 7. Rhizobium and Azotobacter population 12 and 35 days after incubation (DAI)

| Treatment | Rhizobium | | Azotobacter | |
|---|---|---|---|---|
| | 12DAI | 35DAI | 12DAI | 35DAI |
| Control compost (CC) | 4.90$^{a}$ | 4.90$^{a}$ | 0.00$^{a}$ | 0.00$^{a}$ |
| Cow dung compost (C-C) | 5.00$^{a}$ | 4.90$^{a}$ | 0.00$^{a}$ | 0.00$^{a}$ |
| Decomposing microbial inoculated compost (DMI-C) | 5.72$^{b}$ | 5.12$^{b}$ | 4.78$^{b}$ | 4.86$^{b}$ |
| Cow dung and earthworm compost (CE-C) | 5.10$^{a}$ | 5.00$^{a}$ | 0.67$^{a}$ | 0.00$^{a}$ |
| Decomposing microbial and earthworm inoculated compost (DMIE-C) | 5.08$^{a}$ | 5.62$^{b}$ | 4.78$^{b}$ | 5.58$^{c}$ |
| Decomposing microbial inoculated compost enriched with biofertilisers (BIODMI-C) | 6.05$^{bc}$ | 5.69$^{c}$ | 5.76$^{c}$ | 5.62$^{cd}$ |
| Decomposing microbial and earthworm inoculated compost enriched with biofertilisers (BIODMIE-C) | 6.21$^{c}$ | 6.02$^{d}$ | 5.99$^{c}$ | 5.98$^{cd}$ |
| Critical difference (cd) | 0.51 | 0.06 | 0.72 | 0.81 |

Table 8. Phosphate solubilizing micro organisms (Psm) and Trichoderma population 12 and 35 days after incubation (DAI)

| Treatment | Psm | | Trichoderma | |
|---|---|---|---|---|
| | 12DAI | 35DAI | 12DAI | 35DAI |
| Control compost (CC) | 3.57$^{a}$ | 5.64$^{a}$ | 0.00$^{a}$ | 0.00$^{a}$ |
| Cow dung compost (C-C) | 3.59$^{a}$ | 3.78$^{a}$ | 0.00$^{a}$ | 0.00$^{a}$ |
| Decomposing microbial inoculated compost (DMI-C) | 5.96$^{b}$ | 5.67$^{b}$ | 5.48$^{b}$ | 4.32$^{b}$ |
| Cow dung and earthworm compost (CE-C) | 5.48$^{b}$ | 5.68$^{b}$ | 0.67$^{a}$ | 0.00$^{a}$ |
| Decomposing microbial and earthworm inoculated compost (DMIE-C) | 5.74$^{b}$ | 5.78$^{b}$ | 5.98$^{b}$ | 4.78$^{b}$ |
| Decomposing microbial inoculated compost enriched with biofertilisers (BIODMI-C) | 6.30$^{c}$ | 6.33$^{c}$ | 5.52$^{b}$ | 5.62$^{c}$ |
| Decomposing microbial and earthworm inoculated compost enriched with biofertilisers (BIODMIE-C) | 6.40$^{c}$ | 6.22$^{c}$ | 5.78$^{b}$ | 5.64$^{c}$ |
| Critical difference (cd) | 0.32 | 0.54 | 0.53 | 0.84 |

These results show that addition of earthworms has influenced the population of beneficial microorganisms since the compost contains high nutritive contents and growth promoters. The present study also showed that the microbial population was significantly more in treatments BIODMI-C and BIODMIE-C. These findings are similar to the results of Kapoor et al. (1983), who observed that there were 3 to 6-fold increase in the Azotobacter in population in three weeks after inoculation of

compost. They observed that Azatobacter inoculation could be done only after composting because it does not have the ability to survive the high temperature prevailing during composting. It was observed that the total nitrogen content greatly increased in the treatments where the biofertilisers were added to the compost (Table 9). The quantity of nitrogen content in the compost increased was increased with time.

Table 9. pH, nutrient composition and C/N ratio in different types of compost.

| Treatment | pH | OC | N | $P_2O_5$ | $K_2O$ | Ca | Mg | C/N ratio |
|---|---|---|---|---|---|---|---|---|
| Control compost (CC) | 6.5[a] | 48.8[a] | 1.36[a] | 0.63[a] | 0.42[a] | 1.38[a] | 0.84[a] | 35.9[a] |
| Cow dung compost (C-C) | 6.8[a] | 40.6[b] | 1.52[ab] | 0.84[b] | 0.48[ab] | 1.53[ab] | 0.90[a] | 26.7[b] |
| Decomposing microbial inoculated compost (DMI-C) | 6.8[a] | 33.6[c] | 1.54[b] | 0.90[c] | 0.51[b] | 1.48[a] | 1.01[a] | 21.8[c] |
| Cow dung and earthworm compost (CE-C) | 7.4[b] | 22.7[d] | 1.88[c] | 0.99[d] | 0.59[c] | 1.74[bc] | 1.08[a] | 12.1[d] |
| Decomposing microbial and earthworm inoculated compost (DMIE-C) | 7.4[b] | 21.0[d] | 1.90[c] | 0.86[b] | 0.61[c] | 1.77[bc] | 1.02[a] | 11.1[de] |
| Decomposing microbial inoculated compost enriched with biofertilisers (BIODMI-C) | 7.6[b] | 22.2[d] | 2.12[d] | 0.96[d] | 0.68[d] | 1.89[c] | 1.04[a] | 10.5[ef] |
| Decomposing microbial and earthworm inoculated compost enriched with biofertilisers (BIODMIE-C) | 7.6[b] | 20.2[d] | 2.26[d] | 0.98[d] | 0.78[e] | 1.96[c] | 1.08[a] | 8.9[f] |
| Critical difference (cd) | 0.4 | 5.2 | 0.18 | 0.03 | 0.06 | 0.26 | 0.20 | 2.3 |

During enrichment, the phosphorous content increased significantly in BIODMI-C and BIODMIE-C. The mechanism of conversion of insoluble P by P-solubilising organisms to available forms including altering the solubility of inorganic compound to the ultimate soluble form by production of acids and $H_2S$ under aerobic and anaerobic conditions and by mineralising organic compounds, with the release of inorganic phosphate (Rasal et al., 1988). Slight increases were also observed for other nutrients such as Ca and Magnesium, although these differences were insignificant according the CD criterion.

### 3.3. Plant growth trail

From the experiment we have described here, in treatments added with biofertiliser-enriched DMIE compost consistently outperformed the treatments added with other kinds of compost, that we have investigated in terms of its ability to enhance plant growth (Tables 10, 11 and 12). However, in case of cow pea and okra, the root biomass in treatments added with biofertiliser-enriched DMIE and biofertiliser-enriched DMIE composts did not differ significantly (P>0.05).

Table 10. Growth and yield of cowpea after 90 days of compost application

| Treatment | Root length (cm) | Root biomass (gm/plant) | Shoot length (cm) | Shoot biomass (gm/plant) | Collar diameter (cm) | Number of fruits per plant | Fruit biomass (gm/fruit) |
|---|---|---|---|---|---|---|---|
| Soil alone | 33.0$^{a}$ | 6.0$^{a}$ | 38.0$^{a}$ | 19.0$^{a}$ | 5.7$^{a}$ | 1.7$^{a}$ | 6.0$^{a}$ |
| Control compost (CC) | 57.2$^{b}$ | 6.8$^{a}$ | 89.4$^{b}$ | 42.2$^{b}$ | 9.4$^{b}$ | 7.0b | 23.4$^{b}$ |
| Cow dung compost (C-C) | 62.0$^{c}$ | 7.0$^{a}$ | 78.8$^{b}$ | 38.3$^{c}$ | 7.3$^{c}$ | 4.5$^{c}$ | 17.0$^{c}$ |
| Decomposing microbial inoculated compost (DMI-C) | 64.7$^{c}$ | 12.7$^{b}$ | 86.3$^{b}$ | 43.0$^{b}$ | 10.0$^{d}$ | 8.3$^{b}$ | 27.3$^{d}$ |
| Cow dung and earthworm compost (CE-C) | 52.7$^{d}$ | 6.3$^{a}$ | 49.0$^{a}$ | 37.7$^{c}$ | 7.3$^{c}$ | 5.7$^{bc}$ | 15.7$^{c}$ |
| Decomposing microbial and earthworm inoculated compost (DMIE-C) | 50.3$^{d}$ | 16.0$^{c}$ | 70.3$^{c}$ | 56.0$^{d}$ | 8.3$^{bc}$ | 10.7$^{d}$ | 32.0$^{d}$ |
| Decomposing microbial inoculated compost enriched with biofertilisers (BIODMI-C) | 67.2$^{e}$ | 17.8$^{d}$ | 89.2$^{b}$ | 54.9$^{d}$ | 12.8$^{e}$ | 12.6$^{e}$ | 34.6$^{e}$ |
| Decomposing microbial and earthworm inoculated compost enriched with biofertilisers (BIODMIE-C) | 69.3$^{e}$ | 18.1$^{d}$ | 78.3$^{c}$ | 61.3$^{e}$ | 13.9$^{f}$ | 14.8$^{f}$ | 36.9$^{f}$ |
| Critical difference (cd) | 2.6 | 1.2 | 10.3 | 1.8 | 1.1 | 1.2 | 1.4 |

Many factors, which impact plant growth, could be responsible for the enhanced growth of plants in the treatments added with biofertiliser-enriched DMIE and biofertiliser-enriched DMIE composts. These include presence of large concentration of nitrate and phosphate in the two composts. However, the differences in plant growth between treatments added with biofertiliser-enriched composts and other

composts may not simply a function of the difference in their nutritional contents. This is because biofertiliser-enriched composts are derived from the DMIE or DMI composts. It is thus clear that there are other inputs, such as increased enzyme activity and the presence of beneficial microorganisms or biologically active plant growth influencing substances that might be involved (Tomati and Gall, 1995).

Table 11. Growth and yield of okra after 90 days of compost application

| Treatment | Root length (cm) | Root biomass (gm/plant) | Shoot length (cm) | Shoot biomass (gm/plant) | Collar diameter (cm) | No.of fruits per plant | Fruit biomass (gm/fruit) |
|---|---|---|---|---|---|---|---|
| S | 39.3$^{a}$ | 2.7$^{a}$ | 37.3$^{a}$ | 13.3$^{a}$ | 6.0$^{a}$ | 0.7$^{a}$ | 5.3$^{a}$ |
| CC | 52.2$^{b}$ | 5.0$^{ab}$ | 61.0$^{b}$ | 37.6$^{b}$ | 9.4$^{b}$ | 2.6$^{b}$ | 18.0$^{b}$ |
| C-C | 54.7$^{b}$ | 6.7$^{b}$ | 66.7$^{c}$ | 58.7$^{c}$ | 8.7$^{b}$ | 2.0$^{b}$ | 33.3$^{c}$ |
| DMI-C | 70.3$^{c}$ | 11.3$^{c}$ | 65.3$^{c}$ | 61.0$^{cd}$ | 10.3$^{b}$ | 2.3$^{b}$ | 34.0$^{c}$ |
| CE-C | 48.3$^{b}$ | 6.7$^{b}$ | 56.3$^{d}$ | 37.3$^{d}$ | 8.3$^{b}$ | 2.7$^{b}$ | 28.0$^{d}$ |
| DMIE-C | 61.3$^{e}$ | 13.3$^{c}$ | 73.7$^{e}$ | 64.7$^{d}$ | 10.2$^{b}$ | 4.3$^{c}$ | 34.3$^{c}$ |
| BIODMI-C | 78.9$^{f}$ | 14.8$^{c}$ | 76.3$^{f}$ | 66.2$^{e}$ | 12.2$^{c}$ | 5.8$^{d}$ | 41.3$^{e}$ |
| BIODMIE-C | 79.6$^{f}$ | 16.9$^{c}$ | 76.8$^{f}$ | 69.2$^{f}$ | 14.8$^{d}$ | 6.8$^{e}$ | 46.2$^{f}$ |
| Critical difference (cd) | 6.9 | 3.6 | 3.2 | 1.8 | 2.1 | 0.9 | 3.6 |

Table 12. Growth and yield of Brinjal after 90 days of compost application

| Treatment | Root length (cm) | Root biomass (gm/plant) | Shoot length (cm) | Shoot biomass (gm/plant) | Collar diameter (cm) | No. of fruits per plant | Fruit biomass (gm/fruit) |
|---|---|---|---|---|---|---|---|
| S | 30.3$^{a}$ | 3.3$^{a}$ | 32.0$^{a}$ | 8.3$^{a}$ | 5.3$^{a}$ | 0.8$^{a}$ | 12.3$^{a}$ |
| CC | 56.2$^{b}$ | 12.8$^{b}$ | 55.0$^{b}$ | 43.6$^{b}$ | 8.6$^{b}$ | 1.6$^{bc}$ | 13.2$^{a}$ |
| C-C | 49.3$^{b}$ | 14.3$^{b}$ | 51.3$^{c}$ | 54.3$^{b}$ | 8.0$^{b}$ | 1.0a$^{b}$ | 36.3$^{b}$ |
| DMI-C | 58.3$^{b}$ | 17.7$^{c}$ | 55.7$^{b}$ | 73.7$^{c}$ | 8.0$^{b}$ | 1.0$^{ab}$ | 49.0$^{b}$ |
| CE-C | 56.0$^{b}$ | 16.0$^{c}$ | 41.0$^{d}$ | 43.7$^{b}$ | 7.0$^{ab}$ | 1.0$^{ab}$ | 30.3$^{b}$ |
| DMIE-C | 111.3$^{c}$ | 23.3$^{d}$ | 51.0$^{c}$ | 103.0$^{d}$ | 8.7$^{b}$ | 1.7$^{b}$ | 72.0$^{c}$ |
| BIODMI-C | 76.8$^{d}$ | 24.3$^{d}$ | 61.2$^{d}$ | 91.9$^{d}$ | 9.9$^{c}$ | 1.8$^{c}$ | 79.8$^{c}$ |
| BIODMIE-C | 132.6$^{e}$ | 28.9$^{e}$ | 68.9$^{e}$ | 118.2$^{e}$ | 10.8$^{c}$ | 1.9$^{c}$ | 81.6$^{c}$ |
| Critical difference (cd) | 15.6 | 1.8 | 4.6 | 11.8 | 1.1 | 0.6 | 8.6 |

Plants in control plots and compost plots showed significant difference for different biometric indicators. While the composting with cow dung and decomposing microbial inoculams tend to result in the release of nitrogen in the ammonium form, the vermin composting release most of the nitrogen in nitrate form (Edwards and Burrows, 1988), the form readily available for plant uptake. Composting with cow dung and earthworms also increased availability of phosphorous (Mackey et al., 1982). Use of cow dung and earthworms therefore stimulated multiplication of beneficial microorganisms. It can be concluded that by harnessing biofertiliser organisms and earthworms, crop growth and yield can be enhanced. Use of bio-nutrition can also help in the management of land without affecting ecological process. Thus it can help to achieve sustainable land management, the foundation of sustainable agriculture.

# Section- 4

# Approach papers

# Section- 4a

# Soil health analysis using earthworms as the indicator - Possibilities and constraints

## 1. Introduction

In agricultural context, soil health (SH) and soil quality are often use interchangeably and it is defined as the capacity of a soil to function, within ecosystem and land use boundaries, to sustain productivity, maintain environmental quality, and promote plant and animal health. However, the National Resource and Conservation Service (USDA-NRCS) defines soil quality or soil health similarly, but add inherent and dynamic soil quality to the definition. The inherent soil quality is defined as "the aspects of soil quality relating to a soil's natural composition and properties influenced by the factors and processes of soil formation, in the absence of human impacts." While dynamic soil quality "relates to soil properties that change as a result of soil use and management over the human time scale". This distinction between inherent soil health and dynamic soil health is important while correlating a given soil health parameter with the other parameter, where one parameter may be due to the inherent property of soil (example abundance of a indicator organism) and the other one may be due to human impacts (soil organic carbon). Some of the soil characteristics expected in healthy soil include god soil tilth, sufficient depth, sufficient but not excess supply of nutrients, small population of plant pathogens and insect pests, good soil drainage, large population of beneficial organisms, low weed pressure, free of chemicals and toxins that may harm the crop, resistant to degradation and resilience when unfavorable conditions occur. It is a well known fact that the management practice, cropping pattern, local climate etc. greatly contribute to the soil health. Similarly, a soil considered to be of good quality for a given crop may not be suitable for some other crops. In this context, defining the soil health for cropping systems and recommending good soil quality management practices for a set of landuse systems at a landscape level is complicated. However, minimum data sets of soil physical, chemical and biological properties that can be used as measurable to determine the soil health are needed. In the present paper, some of the soil physical, chemical and biological characters which are of general interest in the context of soil health determination are discussed. Subsequently, based on the results of a case study conducted in different landuse systems of the Kerala part of Nilgiri Biosphere Reserve (Chandrashekara *et al.,* 2008), possibilities and constraints of using earthworm in soil health analysis are discussed.

## 2. Determinants of soil health

### 2.1. Soil physical characters

Aggregate stability, available water capacity and field penetration resistance are the major soil physical characters that determine the soil health. Aggregate stability is a

measure of the extent to which soil aggregates resist falling apart when wetted and hit by rain drops. This method tests the soil's physical quality with regard to its capacity to sustain its structure during most impactful conditions: a heavy rain storm after surface drying weather. Soils with low aggregate stability tend to form surface crusts which can reduce both water infiltration and air exchange. This poor soil aggregation also makes the soil more difficult to manage, and reduces its ability to dry off quickly. In heavy soils, enhanced friability and crumbliness from good aggregation makes the soil seem lighter. Growing a green manure cover crop or adding animal manure can stabilize soil aggregates.

Water storage in soil is important for plant growth. Water is stored in soil pores and in organic matter. In the field, the moist end of water storage begins when gravity drainage ceases (field capacity). The dry end of the storage range is at the 'permanent wilting point'. Water held in soils that is unavailable to plants is called hygroscopic water. Clay soils tend to hold more water than sandy soils. Sandy soils tend to lose more water to gravity than clays. The available water capacity is an indicator of a soil's water storage capacity in the field. A common constraint of sandy soils is their ability to store water for crops between rains. The addition of composts or manures (green or animal) adds to the water storage, which is especially important during droughty periods. Note that total crop water availability is also dependent on rooting depth, which is considered in a separate indicator, penetration resistance. In heavier soils, the available water capacity is less critical because they naturally have high water retention ability. Instead, they are typically more limited in their ability to supply air to plant roots during wet periods. These soils often respond favorably to the addition of composts or manures (green or animal) but not in the same manner as the coarser textured soils above. Field penetration resistance is a measurement of the soil's strength measured (in psi) with a field penetrometer pushed through the soil profile. Field penetration resistance is a measure of soil compaction. The amount of pressure needed to push the probe through the soil can be measured at any desired depth but is most useful for identifying the depth of the compaction layer, if present. Roots can not penetrate the soil with penetrometer readings above 300 psi. Field profiles of penetration resistance can be created by recording the measured psi every inch through the soil profile and then plotting them on a chart.

### 2.2. Soil chemical characters

Active carbon, organic matter and macro and micro nutrients in the soil are generally measure to determine the soil health. Active carbon is an indicator of the fraction of soil organic matter that is readily available as a carbon and energy source for the soil

microbial community. Research has shown that active carbon is highly correlated with and similar to “particulate organic matter”, which is determined with a more complex and labor-intensive wet-sieving and/ or chemical extraction procedure. Active carbon is positively correlated with percent organic matter, aggregate stability, and with measures of biological activity such as soil respiration rate. Research has shown that active carbon is a good “leading indicator” of soil health response to changes in crop and soil management, usually responding to management much sooner (often, years sooner) than total organic matter percent. Thus, monitoring the changes in active carbon can be particularly useful to farmers who are changing practices to try to build up soil organic matter (e.g., reducing tillage, using new cover crops, adding new composts or manures).

Organic matter is any material that is derived from living organisms, including plants and soil fauna. Total soil organic matter (SOM) consists of both living and dead material, including well decomposed humus. As discussed earlier, soil organic matter in its various forms greatly impacts the physical, chemical and biological properties of the soil. It contributes to soil aggregation, water-holding capacity, provides nutrients and energy to the plant and soil microbial communities, etc. It has been argued that organic matter management is soil health management. Increasing the percent organic matter in the soil takes time and patience. It is unlikely that a single incorporation of a green manure or compost will noticeably increase the percent organic matter. However repeated use of organic amendments in combination with reduced tillage (depending on the constraints of the production system) will build soil organic matter levels.

The chemical analysis is integral part of the Soil Health test. It is a traditional soil fertility test analysis package that measures levels of pH and plant macro and micro nutrients. Measured levels are interpreted in the framework of sufficiency and excess but are not crop specific.

**2.3. Soil biological characters**

Root health assessment and measurement of diversity and abundance soil fauna are common while analyzing the soil health. Root health assessment is a measure of the quality and function of the roots as indicated by size, color, texture and the absence of symptoms and damage by root pathogens and plant-parasitic nematodes. Healthy roots are essential for vigorous plant growth and high yield by being efficient in mining the soil for nutrients and water, especially during stress-full conditions such as drought. Good soil tilth, and low populations and activities of root pathogens and

other pests are critical for the development of healthy roots. Healthy roots also contribute to the active fraction of soil organic matter, promote rhizosphere microbial communities, contribute to increased aggregation, and reduced bulk density and soil compaction.

Soil fauna is an integral part of living soil, which performs a variety of functions in soil. Not all the groups of soil fauna are equally important in terms of agricultural production and soil health. Invertebrate group like earthworms, termites, ants, nematodes etc. are thought to be most important biotic component of the living soil. Ground ants together with earthworms and termites; belong to the principal groups of invertebrates that influence soil processes in terrestrial ecosystems (Lavelle et. al. 1997) and they are often called ecosystem engineers (Jones et. al. 1994). Ecosystem engineers have a major influence on the structure of a soil, creating a network of pores and contributing to aggregation, or the way elementary soil particles (clay, silt and/or sand) stick together (Hairiah, 2001). Earthworms, termites and some ants can create macropores by pushing their bodies into the soil (and thus compacting a zone of soil around the channel that can persist for some time), or by eating their way through the soil and removing soil particles. Earthworms and other animals that feed on soil produce excrement that contains resistant organo-mineral structures that may persist for long periods of time (from months to years) and which profoundly affect the environment for smaller organisms. Earthworms and termites can do this because they have a gut flora of bacteria. These activities of soil biota, which include moving particles from one horizon to another, and which affect and determine the soil's physical structure and the distribution of organic material in the soil profile, are termed 'bioturbation'. This in turn can have an effect on plant growth. Ants change physical and chemical parameters of the soil by bioturbation and by accumulation of organic material (Dostal et. al. 2005).Due to the building of below-ground galleries, mounding and material mixing, the soil of ant nests is characterized by the impeded formation of soil horizons, increased porosity, drainage and aeration, reduced bulk density and modified texture and structure. Increased content of organic matter, N P, and K in the nests is due to food storage, aphid cultivation, and accumulation of faeces and ant remains (Lavelle et. al. 1997; Folgarait, 1998). Termites are important component of tropical soil (Basu et. al. 1996), which also contributes to litter degradation; nutrient cycling etc. and they are some time referred as tropical analogue of earthworms. They also make underground galleries, which help in water and air infiltration.

**3. Earthworms for soil health analysis**

Earthworms are the most important soil invertebrates in most soils worldwide, in terms of both biomass and activity (Rombke et. al. 2005). They help in litter degradation, soil bioturbation, water infiltration and much more. Earthworms are generally regarded as highly suitable bio-monitors because they fulfill these criteria (e.g. Stork and Eggleton, 1992; Abdul Rida and Boucher, 1995; Cortet et. al. 1999; Paoletti, 1999). Their main advantages are:

1. Nearly all earthworms are true soil inhabitants and many of them are key to ecosystem functioning, notably for decomposition and soil structure maintenance. Several species like *Lumbricus terrestris* (Lumbricidae) are considered ecosystem engineers (Lavelle et. al. 1997).
2. Earthworms are globally distributed, but at one site fewer than 20 species occur; i.e., such species numbers are practical. In Central Europe, usually up to 10 earthworm species are found at one site (Rombke et. al. 1997).
3. Identification keys are general available for almost all regions (e.g., Sims and Gerard, 1985).
4. Breeding and handling of some species are easy.
5. Standardized guidelines have been developed by OECD and International Organization for Standardization (ISO) for several levels of investigation
6. Because of their behavior and morphology, they are in contact with both the aqueous phase and the solid phase of the substrate.
7. Most species are not extremely sensitive to low levels of contamination.
8. Their reactions to stress are measurable and reproducible at various levels of organization, under both laboratory and field conditions.
9. There is a vast and growing body of knowledge on their biology, ecology, and eco-toxicology, and oligochaetes are non-controversial as test animals.

In addition, they are not highly mobile, and are sensitive indicators of anthropogenic stress factors (in particular chemicals). For example, they have been successfully used as bio-indicators for (at least): chemicals (e.g., pesticides, biocides, drugs) (Edwards and Bohlen, 1992; Edwards et. al. 1996), mixed soil contamination (e.g., heavy metals) (Carter et. al. 1980; Emmerling et. al. 1997; Stephenson et. al. 1998; Hund-Rinke and Wiechering, 2001), physical factors (e.g., compaction, hydrology) (Pizl, 1992; Lowe and Butt, 1999), and land use (e.g., agriculture, forestry, orchards) (Lee, 1985).

Though there are many advantages, few disadvantages make the concept difficult. A main constraint is the often quite small number of species which might complicate the differentiation between different sites or soil qualities. Therefore, despite their overwhelming ecological importance, soil classification and assessment with earthworms alone is not possible (Muys and Granval, 1997).

The idea to use earthworms as indicators of soil quality is old (Ghilarov, 1949), which was used in various forest sites was characterized. However, several ecological studies confirmed the close relationship between the occurrence of earthworm species and soil and site properties. For instance, Irmler (1999) was able to characterize earthworm communities from various habitats based on the abiotic soil parameters moisture, pH, calcium, carbon, and C:N. Such data may be used for the development of an indicator system because they allow, at least in principle, a comparison of the potentially occurring community with the actual one. Yet, because of the inherent complexity in field studies of oligochaete communities with respect to the relations between community composition, soil characteristics, and management practices, it is often problematic, if not impossible, to ascribe changes recorded to any particular factor or factors (e.g., Tarrant et. al. 1997). It is believed that, earthworms are more abundant in soil with high organic content. However, Rossi and others (2006) had gained no information on the dynamics of the earthworm spatial pattern or about carbon dynamics. Therefore the apparent relationship between soil carbon content and earthworm abundance remains to be supported by additional data. In this context, an attempt has been made to analyze the relationships between earthworm distribution and soil properties in different landuse systems in the Kerala part of Nilgiri Biosphere Reserve.

### 3.1. Case Study

The study area was located in Vazhikkadavu Panchayat ($76^0$ 19' to $76^0$ 23' E longitude and $11^0$ 23' to $11^0$ 25' N latitude), Malappuram District. Here, an area of 2.6 x 1.4 km in the Karakkode micro-watershed was selected where 12 landuse systems namely, paddy fields paddy fields (Pa), Areca farms mixed with annual crops (Av), Areca farms mixed with perennials (Am), coconut mixed with perennials (Cm), polyculture farms (Og), polyculture homegardens (Hg), Areca plantation (Ar), Coconut plantation (Co), rubber plantation (Ru), Cashew plantation (Ca), teak plantation (Te) and degraded forest (Df). For each landuse system, four plots were selected. In each plot, one transect of 40 x 5 m were laid which was further divided into four quadrats each of 10 x 5 m in size. From each quadrat, soil monolith of size

25 cm x 25 cm and 30 cm depth were excavated and all the worms were hand-sorted and counted.

In the study area, mean earthworm abundance (individuals/$m^2$) ranges form 8 to 412 (Table 1), with highest value in a plot of coconut and perennial crops (plot no. 2). Even in a given landuse system, a wide variation in earthworm abundance is recorded.

Table 1. Mean abundance (individuals/$m^2$) of earthworms in different plots in the Kerala part of Nilgiri Biosphere Reserve.

| Landuse type | Plot code no. | Earthworm abundance | Landuse type | Plot code no. | Earthworm abundance |
|---|---|---|---|---|---|
| Paddy fields (Pa) | 21 | 32 | Areca plantation (Ar) | 59 | 61 |
| | 53 | 16 | | 60 | 296 |
| | 7 | 32 | | 61 | 117 |
| | 6 | 37 | | 62 | 101 |
| Areca farms mixed with annual crops (Av) | 17 | 61 | Coconut plantation (Co) | 15 | 72 |
| | 18 | 29 | | 31 | 64 |
| | 36 | 8 | | 40 | 80 |
| | 14 | 30 | | 19 | 73 |
| Areca farms mixed with perennial crops (Am) | 56 | 237 | Rubber plantation (Ru) | 22 | 61 |
| | 57 | 13 | | 54 | 40 |
| | 16 | 40 | | 20 | 50 |
| | 37 | 40 | | 9 | 50 |
| Coconut mixed with perennial (Cm) | 2 | 412 | Cashew plantation (Ca) | 8 | 168 |
| | 30 | 80 | | 39 | 284 |
| | 38 | 176 | | 42 | 72 |
| | 43 | 64 | | 25 | 184 |
| Polyculture farms (Og) | 5 | 149 | Teak plantation (Te) | 10 | 125 |
| | 11 | 21 | | 66 | 13 |
| | 13 | 85 | | 55 | 16 |
| | 52 | 21 | | 67 | 51 |
| Polyculture homegardens (Hg) | 1 | 149 | Degraded forests (Df) | 46 | 64 |
| | 12 | 28 | | 26 | 64 |
| | 28 | 16 | | 23 | 48 |
| | 41 | 40 | | 48 | 46 |

Comparison of the mean abundance of earthworm in different landuse systems indicated that the values obtained for paddy field, degraded forest, teak plantation, rubber plantation, coconut plantation, areca mixed with perennials, areca with annuals, polyculture farms and homegarden are not different significantly. However, values in coconut mixed with perennials, areca plantation and cashew plantation were significantly different from those recorded for many other landuse systems, particularly paddy fields and areca with annuals (Table 2). It may be pointed out that, with exception being degraded forest, teak and cashew plantations, majority of the plots are the derivatives of the paddy fields. Thus further analysis was done to compare the earthworm abundance in paddy fields and plots of landuse systems which were transformed from paddy fields (Figure 1). The study indicates that mean

abundance of earthworms in areca mixed with perennials, Coconut mixed with perennials, coconut and areca plantations were significantly higher than in paddy fields.

Table 2. Abundance (mean ± SE) of earthworms in different landuse systems in the Kerala part of Nilgiri Biosphere Reserve. Values with same alphabet are not significantly different (p>0.05).

| | Landuse systems | Earthworm abundance (mean ± SE) |
|---|---|---|
| 1 | Paddy fields (Pa) | 28.8±4.2 |
| 2 | Areca farms mixed with annual crops (Av) | 32±10.9 |
| 3 | Areca farms mixed with perennial crops (Am) | 83.2±51.8 |
| 4 | Coconut mixed with perennial (Cm) | 182.4±80.2 |
| 5 | Polyculture farms (Og) | 68.8±30.6 |
| 6 | Polyculture homegardens (Hg) | 57.6±27.8 |
| 7 | Areca plantation (Ar) | 144±52.2 |
| 8 | Coconut plantation (Co) | 72±3.4 |
| 9 | Rubber plantation (Ru) | 51.2±4.3 |
| 10 | Cashew plantation (Ca) | 177.6±43.4 |
| 11 | Teak plantation (Te) | 51.2±26.1 |
| 12 | Degraded forests (Df) | 56.0±4.8 |

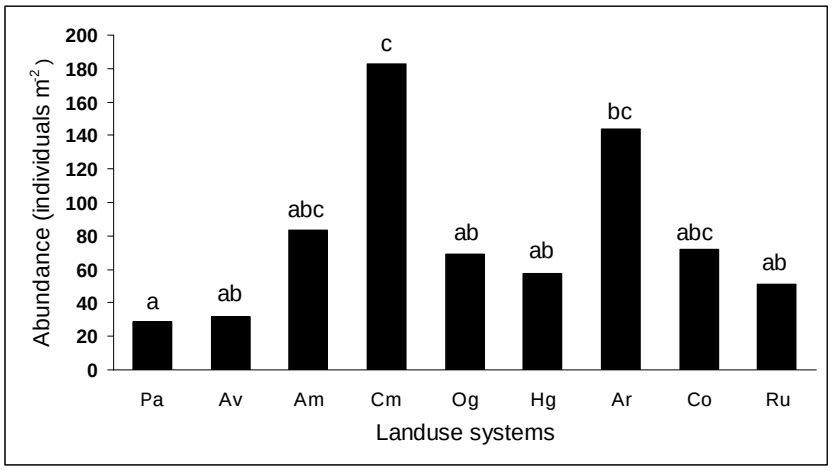


Figure 1. Abundance (mean ± SE) of earthworms in paddy fields and landuse systems derived from paddy fields in the Kerala part of Nilgiri Biosphere Reserve. Values with same alphabet are not significantly different (p>0.05). Symbols for different landuses are as in Table 1.

It is reported that the soil type, pH, organic matter content and related physical/chemicals factors can influence survival, growth and reproduction of earthworms (Kale, 2005) and soil that poor in organic matter are also poor in earthworm abundance (Kale, 1997). However, in the present study no such trend was observed, except in one or two landuse systems for one or few soil parameters. For instance, significant correlation ($p<0.05$) between earthworm abundance and

nitrogen and potassium was recorded only in areca with annual cropping systems. Organic carbon showed significant correlation ($p<0.05$) with earthworm abundance only in coconut mixed with perennial systems and teak plantations while correlation was observed between earthworm abundance and phosphorous in polyculture farms. In coconut plantation, significant correlation ($p<0.05$) was observed between earthworm abundance with exchangeable acidity, organic carbon, calcium and magnesium. In rubber plantations, significant correlation ($p<0.05$) was recorded between earthworm abundance and soil pH. According to Rombke and others (2005), establish the dependence of earthworms on most frequently studied soil parameters such as organic carbon, soil texture etc. is difficult. Rossi and others (2006) concluded that the lack of clear relation between earthworm abundance and soil parameters may be due to difference in spatial scales in terms of earthworm population and soil properties. It may also be pointed out here that soil nutrient status may vary both spatially and temporally as it depends on the type, quality, quantity, and frequency of nutrient input. Thus, any given plot may not be stable in terms of nutrient status. Due to this instability, it is difficult observe any significant correlation with soil faunal abundance.

As already pointed out, among different plots derived from paddy fields, one plot which is currently under coconut perennial crops (Plot code no. 2) showed highest earthworm abundance (412 individuals/$m^2$). Thus further analysis was made to characterize the agronomic aspects of different landuse systems by considering earthworm abundance in a gradient (Figure 2). The Plot no. 2 is characterized by sandy soil with high moisture content even during post monsoon. Here the organic input in the form of green leaf manure is regular with minimal disturbance to the soil. Inorganic fertilizer and pesticide application are totally absent in this plot. Some or all the above mentioned soil characters management practices are lacking in other plots. In this context, it is also possible to conclude that in the study area the landuse systems derived from paddy fields can become earthworm-rich provided the present management systems are re-oriented to enrich the soil with organic input and adopt several other appropriate management practices, which are discussed below.

Bare ground is prone to moisture loss and, high temperature and lacks a supply of organic material to feed soil organism. Keeping the soil covered with mulch, straw, or leaf litter is the first step to encourage the soil biota. Soil organic matter and other carbon sources are the premier source of food to the soil organisms and thus adding mulch or compost is the better practice to improve the soil.

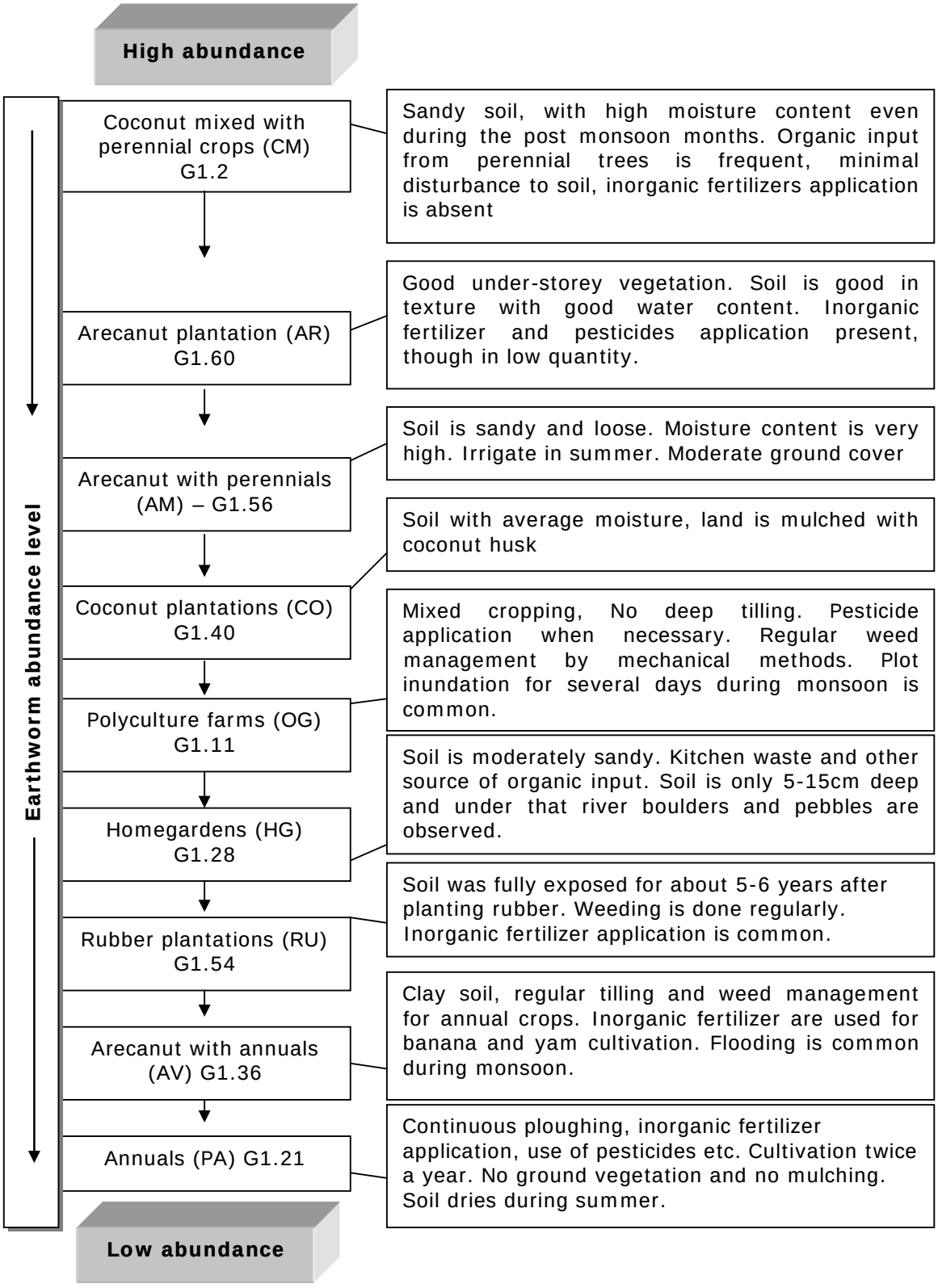


Figure 2. Schematic representation of earthworm abundance level in different landuse systems derived from the paddy fields in Kerala part of Nilgiri Biosphere Reserve

Compared to external imput of organic matter, the living ground cover of plant is better for soil biological diversity and activities. Thus, continuous removal of weed may be a mechanical stress to the soil, because it is persistent through out the year. It may cause the continuous mixing of the top soil- the soil part greatly supports soil biota. Thus replacing weed with suitable cover crops is recommended. The cover crops by replacing the weed biomass reduce the pressure of weeding and subsequent mechanical stress to the soil. At the same time cover crops will provide a mulch and organic source which directly enhance soil fauna. Water content in the soil play a key role in litter break down and survival of microorganisms, and microarthropods. Cover crops, mulching and SOM will help in retention of optimum moisture content in the soil.

It is a known fact that pesticides and agrochemicals affect the soil community negatively. Frequent use of chemicals may eliminate some soft bodied groups like earthworms. Some pesticides have long term residues which may cause total elimination of soil fauna. Similarly, when the chemical fertilizers are used in excess quantity they can cause pollution and contamination of the soil. Chemical fertilizers are also harmful to soil fauna. On the other hand, organic fertilizers are good source of beneficial microbes and also help in the build up SOM, which in turn enhances the soil physicochemical qualities as discussed above. Organic fertilizers also have no adverse impact on soil fauna and their application rather enhance earthworm abundance in the soil (Cenci and Jones, 2009). Based on the present study it is also possible to report that poor drainage causes water logging, subsequent damage to plant root and in turn poor habitat to many soil biota. Thus in such area the earthworm population declines considerably.

**4. Conclusion**

Despite the fact that the earthworm abundance does not show positive significant correlation with several soil parameters which are generally consider while determining the soil health, earthworm abundance itself can be a good indictor of soil health as we noticed in this study. Transformation of paddy fields into tree based/perennial crop based system seems to help in building up of earthworm population. However, when the suitable agronomic practices are adopted comparatively high earthworm abundance can be seen as recorded in the plot number 2 of the present study. Such plots can be considered as the benchmark plots. Necessary soil management practices may be adopted in other plots too to enhance the earthworm abundance similar to that recoded in the benchmark plot/s.

# Section- 4b

# Landuse transformation and loss of belowground biodiversity- An analysis

## 1. Introduction

In tropical countries, due to socioeconomic and cultural changes, several landuse systems are being transformed into some other landuse systems. For instance, in rural Kerala agricultural land has been going through transformation due to sprawls in agriculturisation, industrialization and globalization (Thampi 1995). Despite the fact that increase in area under cash crops help to increase farm income, changes in cropping pattern which favour perennial crops will have immediate and direct impact on the staple food security of State (Panikar 1980). Several efforts have been made to analyze the root causes and consequences of transformation of food crop based systems to cash crop based system of the State (Kannan and Pushpangadan 1988; Narayanan 1995; Baiju and Chandrashekara 2007). Such studies also highlighted the need for more site specific studies which would help to identify strategies, policy interventions and programmes for reviving the rural landscape of Kerala that was once dominated by paddy fields. Thus, though information on the impact of landuse transformation on the socioeconomic and cultural aspects of rural Kerala available, that on biodiversity in general, belowground biodiversity in particular are lacking.

Among belowground biota, Arbuscular Mycorrhizal fungi (AM fungi) which form obligate, mutualistic, symbiotic relationship with the roots of trees and crop plants facilitate host plant nutrient uptake. Similarly, AM fungi can also enhance tolerance or resistance to root pathogens or abiotic stress, such as drought and metal toxicities. In addition, AM fungi may play a vital role in the formation of stable soil aggregates, building up a macroporous structure of soil that allows penetration of water and air and prevents erosion (Miller and Jastrow 1992; Smith and Read 1997; Meharg and Cairney 2000). Quite a few efforts have been made in the tropical region to characterize the diversity of AM fungi and also their role in managing soil health (Mohankumar and Mahadevan 1987; Ragupathy et al. 1990; Sengupta and Chaudhuri 1990; Muthukumar and Udaiyan 2000; Dhar and Mridha 2007; Shi et al. 2007). It is reported that landuse and land management can influence the diversity and effectiveness of AM fungi (Strzemska 1975; Ocampo and Hayman 1980; Mulligan et al. 1985). According to Giller (1996), in an ecosystem landuse change can bring more changes in belowground biodiversity than in aboveground biodiversity. However, detailed studies on changes in density, distribution and diversity of AM fungi and other belowground due to transformation of landuse systems which were once dominated by annual crops to those dominated by perennial crops are lacking. In this paper, based on a case study conducted in the Kerala part of Nilgiri Biosphere Reserve (Chandrashekara et al., 2008), impact of

transformation of paddy fields to other croppig systems on abundance, diversity and distribution pattern of AM fungi are analysed.

**2. Case study**

The study was conducted in Vazhikadavu Panchayat, Malappuram District, Kerala. Here, four replicate plots each for paddy fields and agroecosystems/agroforestry systems namely polyculture farms, polyculture homegardens, arecanut mixed with annual crops, arecanut mixed with perennial crops, coconut plantations, rubber plantations and arecanut plantations, that have once been paddy fields were selected. The soil sample (0-20 cm) from each plot was collected by core sampling technique. The samples were air dried for 24 hrs in shade, sieved through 2 mm sieve and were stored at 4°C till they were analyzed for spore abundance. Isolation of AM spores was done using wet sieving and decanting technique and spores of fungi enumerated from each soil sample. Trap plant method was used to estimate the diversity of AM fungi in different landuse systems. Identification of the spores was done using the Manual for the identification of AM fungi by Schenck and Perez (1990) and INVAM website by Joe Morton. Species diversity index (H) of AM fungal species was determined for each land use system following the standard method. The significance of differences between paddy fields and landuse systems derived from paddy fields for both the number of AM fungal spores and species diversity index value of AM fungi were tested separately by Analysis of Variance (ANOVA). Differences were deemed to be significant when $P<0.05$ according to Least Significant Difference (LSD) test.

The mean AM fungal spore density in paddy fields and landuse system derived from paddy fields ranged from 50-67 spores per 10g of soil (Table 1). These values are within in the range of AM fungal spore density reported for natural forests of South India (Visalakshi 1997). Comparison of paddy fields and other landuse systems for AM fungal spore density revealed that the values are not significantly different ($P>0.05$); exception being in polyculture homegardens and arecanut mixed with perennial cropping system. The AM fungal spore density in polyculture homegardens was more than that in paddy fields ($P<0.05$). On the other hand, significantly low spore density was recorded for arecanut mixed with perennial cropping system ($P<0.05$).

It is also interesting to note that in arecanut mixed with perennial cropping system percentage of root colonization value of AM fungi was significantly more than that in paddy fields ($P<0.05$; Table 2). Therefore, it can be concluded that due to intensive

management adopted in arecanut mixed with perennial cropping system spore abundance may be decreased. On the other hand, when favourable conditions are available, AM fungal species may propagate well as we observed in root colonization studies conducted by collecting roots from the arecanut mixed with perennial cropping system.

Table 1. Spore density (number of spores per 10 g of soil, Mean ±SE) of AM fungi in soils of paddy field and landuse systems derived from paddy fields in the Kerala part of Nilgiri Biosphere Reserve. In a column, means with same alphabet in the superscript are not significantly different at 5% level.

| Landuse systems | Number of spores per 10 g of soil |
|---|---|
| Paddy fields | $50 \pm 7^{bc}$ |
| Polyculture farms | $50 \pm 5^{bc}$ |
| Polyculture homegardens | $67 \pm 3^{d}$ |
| Arecanut mixed with annual crops | $61 \pm 3^{cd}$ |
| Arecanut mixed with perennial crops | $35 \pm 1^{a}$ |
| Coconut plantations | $56 \pm 6^{cd}$ |
| Rubber plantations | $56 \pm 3^{cd}$ |
| Arecanut plantations | $41 \pm 1^{ab}$ |

Table 2. Percentage colonization and number of infective propagules of AM fungi in soils of paddy fields and landuse systems derived from paddy fields in the Kerala part of Nilgiri Biosphere Reserve. In a column, means with same alphabet in the superscript are not significantly different at 5% level.

| Landuse systems | % of colonization of AM fungi in roots | Number of infective propagules per g of soil |
|---|---|---|
| Paddy fields | $47\pm6^{a}$ | $73\pm23^{b}$ |
| Polyculture farms | $52\pm6^{a}$ | $121\pm34^{a}$ |
| Polyculture homegardens | $66\pm11^{a}$ | $133\pm32^{a}$ |
| Arecanut mixed with annual crops | $56\pm4^{a}$ | $183\pm43^{a}$ |
| Arecanut mixed with perennial crops | $81\pm8^{b}$ | $170\pm45^{a}$ |
| Coconut plantations | $55\pm7^{a}$ | $123\pm44^{a}$ |
| Rubber plantations | $46\pm15^{a}$ | $132\pm85^{a}$ |
| Arecanut plantations | $66\pm6^{a}$ | $163\pm40^{a}$ |

According to Oehl et al. (2003) the AM root colonization in the trap cultures established from different field sites can exhibit the pattern similar to spore abundance in different agroecosystems. However, in the present study correlation between percentage colonization of AM fungi in roots and number of infective propagules per g of soil is not significant ($r = 0.61$; $P>0.05$). At the same time, the values obtained for number of propagules per g of soil in different landuse systems are not significantly different (Table 2; $P>0.05$). This pattern observed for number of infective propagules can be attributed to the fact that a short period (about 2 months in this case) of trap culturing may not allow most of the species to sporulate. Thus,

further studies by prolonging the trap culture period may show the actual relationships between percentage colonization and number of infective propagules in each landuse system.

Fifty six species belonging to three genera namely, *Acaulospora*, *Gigaspora* and *Glomus* were recovered from the soils of paddy fields and landuse systems derived from it (Table 3).

Table 3. Mean spore abundance (spores per 10 g of soil) of AM fungi in paddy field and landuse systems derived for paddy field in the Kerala part of Nilgiri Biosphere Reserve.

| AM fungi | PA | PF | HG | AV | AM | CP | RP | AP |
|---|---|---|---|---|---|---|---|---|
| *Acaulospora appendicula* | 0.7 | 1.7 | 3.2 | 3.3 | 0.8 | 2.0 | 3.0 | - |
| *Acaulospora bireticulata* | 1.7 | 2.7 | 5.0 | 2.0 | 1.6 | 2.0 | 1.0 | 1.3 |
| *Acaulospora denticulata* | 1.0 | 1.0 | 1.6 | 2.0 | 0.6 | 1.0 | 3.3 | 1.0 |
| *Acaulospora dilatata* | 0.7 | - | 1.4 | 3.3 | 1.0 | - | 0.8 | 1.0 |
| *Acaulospora elegans* | - | 1.3 | 0.4 | 1.0 | 0.8 | 1.0 | - | 1.0 |
| *Acaulospora lacunose* | 2.7 | - | 0.6 | 1.3 | 1.4 | 1.0 | 2.0 | 2.0 |
| *Acaulospora laevis* | - | 1.0 | - | 2.3 | 0.2 | 1.5 | 1.8 | 0.3 |
| *Acaulospora longula* | 1.0 | 0.7 | 0.8 | 1.0 | 2.2 | 0.5 | 0.5 | 3.0 |
| *Acaulospora mellea* | 2.3 | 0.7 | 1.8 | 3.0 | 1.4 | - | - | 2.0 |
| *Acaulospora morrowae* | - | 1.3 | - | 1.0 | 0.5 | 1.5 | 1.0 | - |
| *Acaulospora myriocarpa* | 0.7 | - | 0.6 | 2.0 | 1.4 | - | 1.0 | 1.3 |
| *Acaulospora rehmii* | - | 1.3 | 0.2 | 0.7 | - | 2.0 | - | - |
| *Acaulospora rugosa* | 0.7 | 2.0 | 4.4 | 1.0 | 1.4 | - | - | 1.0 |
| *Acaulospora scrobiculata* | 6.0 | - | - | 1.3 | 0.2 | 4.0 | 3.5 | - |
| *Acaulospora spinosa* | - | 1.0 | 0.8 | 1.0 | 0.8 | 2.0 | 1.0 | 1.0 |
| *Acaulospora tuberculata* | 0.7 | - | 0.8 | - | - | - | 1.8 | - |
| *Gigaspora albida* | 0.7 | 0.7 | 0.4 | - | 0.8 | 2.0 | 0.3 | 0.7 |
| *Gigaspora decipiens* | - | 1.3 | 1.2 | 1.0 | 0.4 | - | 0.8 | - |
| *Gigaspora gigantean* | - | - | - | - | 0.6 | 1.1 | - | 0.3 |
| *Glomus albidum* | - | - | 0.6 | - | - | 0.5 | 0.8 | - |
| *Glomus aggregatum* | 3.0 | 1.7 | 2.6 | 3.3 | 2.6 | - | - | 4.3 |
| *Glomus ambisporum* | 2.0 | 1.7 | 1.6 | - | - | 1.0 | - | - |
| *Glomus botryoides* | - | - | - | 0.7 | 0.6 | - | 0.5 | - |
| *Glomus canadense* | - | 2.0 | 1.6 | 2.0 | 0.8 | 3.0 | - | 1.3 |
| *Glomus citricolum* | 1.0 | - | 0.6 | - | - | 2.0 | 1.0 | - |
| *Glomus claroideum* | - | 0.3 | 0.4 | 2.7 | - | - | - | 1.3 |
| *Glomus clarum* | 2.3 | 2.0 | 2.2 | 2.0 | 1.0 | 0.5 | 1.0 | - |
| *Glomus constrictum* | - | - | - | - | - | 2.0 | - | 0.7 |
| *Glomus convolutum* | - | - | 0.6 | 0.7 | - | - | 0.8 | - |
| *Glomus delhiense* | 0.7 | - | 0.6 | 2.0 | 1.2 | 1.5 | - | 2.0 |

PA: Paddy fields, PF: Polyculture farms, HG: Polyculture homegardens, AM: Arecanut with perennials, AV: Arecanut with annuals, CP: Coconut plantations, RP: Rubber plantations and AP: Arecanut plantations.

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Table 3. Mean spore abundance (spores per 10 g of soil) of AM fungi in paddy field and landuse systems derived for paddy field in the Kerala part of Nilgiri Biosphere Reserve.

| AM fungi | PA | PF | HG | AV | AM | CP | RP | AP |
|---|---|---|---|---|---|---|---|---|
| *Glomus diaphanum* | - | 1.7 | 1.0 | 2.0 | 1.4 | - | - | 2.0 |
| *Glomus etunicatum* | 1.7 | - | - | - | 0.2 | - | 1.0 | - |
| *Glomus fasciculatum* | 1.7 | 3.7 | 4.2 | 2.0 | - | 1.0 | - | 0.7 |
| *Glomus fragile* | - | - | - | - | 0.4 | 2.0 | 0.5 | 0.3 |
| *Glomus geosporum* | 0.7 | 1.3 | 1.8 | 0.7 | 1.0 | - | 2.0 | - |
| *Glomus halonatum* | - | - | 0.4 | - | 0.8 | 1.0 | - | - |
| *Glomus heterosporum* | 1.3 | 1.0 | 1.0 | 1.0 | - | - | 0.5 | 0.3 |
| *Glomus hoi* | - | - | - | 1.3 | - | 2.0 | - | 1.7 |
| *Glomus intraradices* | 3.3 | 2.0 | 2.4 | 1.0 | 0.6 | - | 2.8 | 0.3 |
| *Glomus invermaium* | - | - | 0.4 | - | - | 0.5 | - | - |
| *Glomus leptotichum* | - | - | - | 1.0 | 0.6 | 0.5 | 0.3 | - |
| *Glomus macrocarpum* | 0.7 | 2.0 | 2.0 | - | - | 2.0 | - | - |
| *Glomus maculosum* | 7.0 | 4.7 | 9.6 | 1.3 | 1.6 | 4.5 | 5.5 | 4.0 |
| *Glomus monosporum* | - | - | - | 1.3 | - | - | - | - |
| *Glomus mosseae* | 1.7 | 2.0 | 2.0 | - | - | 1.0 | 3.5 | - |
| *Glomus multicaule* | 0.7 | 0.7 | 1.2 | 1.3 | 1.4 | 2.0 | 2.5 | 2.7 |
| *Glomus multisubstensum* | - | - | - | - | 0.4 | - | - | 0.7 |
| *Glomus occultum* | - | 2.0 | 0.8 | 1.3 | 0.8 | - | 2.0 | - |
| *Glomus pallidum* | 0.7 | 0.7 | 1.2 | 1.3 | - | 2.0 | - | - |
| *Glomus pansihalos* | - | - | 0.8 | - | 0.2 | - | 2.0 | - |
| *Glomus pulvinatum* | - | 2.0 | 1.2 | 2.0 | 1.2 | 2.0 | - | 2.0 |
| *Glomus pustulatum* | 1.3 | - | 0.2 | - | 0.4 | - | 2.5 | - |
| *Glomus radiatum* | - | 1.0 | 0.8 | 1.0 | 0.4 | 2.0 | 2.5 | - |
| *Glomus reticulatum* | 0.7 | 0.3 | 0.8 | - | 0.8 | - | 1.3 | 1.0 |
| *Glomus scintillans* | - | 0.3 | 1.2 | 1.7 | 0.2 | 0.5 | 1.5 | - |
| *Glomus segmentatum* | 0.3 | 0.3 | - | - | - | 1.0 | - | - |

PA: Paddy fields, PF: Polyculture farms, HG: Polyculture homegardens, AM: Arecanut with perennials, AV: Arecanut with annuals, CP: Coconut plantations, RP: Rubber plantations and AP: Arecanut plantations.

*Glomus* and *Acaulospora* showed dominance in the present study with 37 and 16 species respectively. The preponderance of these two genera in Indian soils reported by several authors (Thapar and Khan 1985; Ragupathy and Mahadevan 1993; Muthukumar and Udaiyan 2000; Mohanan 2003) can be linked to acidic nature of the soil the landuse systems studied. It may also be pointed out here that the genus *Glomus* is of rare occurrence in Western Australia due to high soil pH (Porter et al. 1987). As in the present study, rare occurrence of *Gigaspora* in Indian soil has been reported elsewhere (Ragupathy and Mahadevan 1993; Sankaran et al. 1993; Muthukumar and Udaiyan 2000; Mohanan 2003). It is interesting to note that 6 out of

30 AM fungal species recorded from the natural forests of Kerala (Chandrashekara et al. 2008), were also recorded from paddy fields.

Comparison of AM fungal species composition in different landuse systems in the study area indicated that there are a few 'generalist' species and also 'highly specialist' species. For instance, species like *Acaulospora bireticulata*, *A. denticulata*, *A. longula*, *Glomus maculosum* and *G. multicaule* can be regarded as 'generalist' species as they are found in all landuse systems in the present study. On the other hand, *Glomus monosporum* can be considered as a 'highly specialist' species due to its occurrence only in soils of arecanut mixed with annual crops.

Out of 30 species recorded from paddy fields 7 species namely *Acaulospora lacunose*, *A. mellea*, *A. scrobiculata*, *Glomus aggregatum*, *G. clarum*, *G. intraradices* and *G. maculosum* are contributing to more than 50% of total spore abundance. However, when these species are present in other landuse systems, their spore abundance was lesser than that in paddy fields. Thus, due to landuse change the dominance of above mentioned species seems to decrease and at the same contribution to total spore abundance by the constituent species becomes uniform. These two changes lead to comparatively high species diversity index value in majority of the landuse systems derived from paddy fields (Table 3).

Similarity index value estimated for paddy field and landuse systems derived from it ranged from 0.55-0.74 with following order : homegardens (0.74) > polyculture fams (0.66) > rubber plantations (0.63) > arecanut mixed with perennial crops (0.61) > arecanut with annual crops (0.59) > arecanut plantation (0.58) > coconut plantation (0.55). Based on thse results it is concluded that transformation of paddy fields into different landuse systems did not alter drastically the AM fungal species composition. The study also demonstrated the fact that the landuse transformation contributed for the appearance several new AM fungal species. However, unlike the aboveground plant composition change, which is mainly triggered by the farmer's activities, belowground floral composition change appears to be a slow process, as even 5 to 25 yr after transformation of paddy fields, some of the AM fungi are common to both paddy fields and landuse systems derived from them. It may be pointed out here that the sampling pattern, frequency of sampling, seasonality etc., even for a given group of organisms may be different in different landuse system. Thus, there is a scope for a systematic study by adopting landuse-specific standard methods, for analyzing the links between belowground species composition and diversity change in response to landuse transformation.

# Section- 4c

# Litter decomposition as an ecosystem service

## 1. Introduction

In a broad sense, ecosystem services refer to the range of conditions and processes through which natural ecosystems, and the species that they contain, help sustain and fulfil human life (Daily, 1997). With a significant share of the world's remaining natural capital, the economies of developing countries are heavily reliant on natural resources and hence ecosystem services support life which include production of ecosystem goods and also following functions (Erlich and Erlich, 1980).

- purification of air and water
- mitigation of droughts and floods
- generation and preservation of soils and renewal of their fertility
- detoxification and decomposition of wastes
- pollination of crops and natural vegetation
- dispersal of seeds
- cycling and movement of nutrients
- control of the vast majority of potential agricultural pests
- maintenance of biodiversity
- protection of coastal shores from erosion by waves
- protection from the sun's harmful ultraviolet rays
- partial stabilization of climate
- moderation of weather extremes and their impacts
- provision of aesthetic beauty and intellectual stimulation that lift the human spirit

Importance of ecosystem services is clearer in the rural landscapes of the developing countries as a large proportion of the poor depends on ecosystem services for survival. It is estimated that of the 1.2 billion people living in extreme poverty, approximately 900 million live in rural areas, where biodiversity and ecosystem contribute to food security and nutrition, providing the raw materials that underpin health system (both formal and informal) (Wetlands International, 2005). For instance, in the Wayanad Wildlife Sanctuary, tribal communities mainly depend on non-wood forest products (NWFP) for their survival. It is estimated that the economic value of biomass of 11 NWFP species heavily harvested by tribal alone is about Rs. 49,32,633 (Chandrashekara et al., 2000). Furthermore, there are a number of reasons to indicate the relevance of ecosystem services to the rural community of the developing countries. For instance, for many rural Indian families, agriculture (often subsistence) is the main occupation and these families have limited access to alternative sources of income. Agricultural activities mean exposure to risks from pest

outbreak, flood and water scarcity. In addition, the rural poor are more likely to inhabit marginal, less agriculturally productive land, where harvest is more vulnerable to deterioration in soil and water quality. It may also be pointed here that even the economic growth alone may not be sufficient to reduce pressures on the environment. For instance in Nilgiri Biosphere Reserve (NBR), farmers who are somewhat better off make more use of ecosystem good and services in absolute terms (eg. as income grows so does application of green leaf manure).

Among different ecosystems services of terrestrial ecosystems such as natural forests, litter decomposition is a critical service that removes wastes, recycles nutrients, and renews soil fertility and carbon sequestration (Wall and Virginia, 2000). During the process of decomposition, dead organic matters convert into smaller and simpler compounds. The products of complete decomposition are carbon dioxide, water, and inorganic ions (like ammonium, nitrate, phosphate, and sulphate). In fact, the importance of litter decomposition as an ecological service that supports other ecosystem services is already recognized. For instance, biomass production, nutrient cycling and biodiversity conservation are a few among other ecological services for which the litter decomposition plays a central role. It may also be pointed out here that the forest ecologists have paid considerable attention to litter decomposition in relation to nutrient cycling and soil productivity. The obvious reason is that litter decay has a pronounced effect on the availability of nutrients, and nutrient availability is the basic determinant of biodiversity, plant growth and productivity.

Litter decomposition is mainly a biological process carried out by insects, worms, bacteria, and fungi, both on soil surface and in the soil. However, apart from soil micro- and macro faunal activity there are three more factors affecting litter decomposition. They include a) climatic factors, b) substrate and its quality, c) type of vegetation, and d) vegetation cover. In the present paper, the factors influencing litter decomposition, rate of litter decomposition and nutrient pattern are discussed.

In agroforestry systems of Kerala, green leaf manure is used as mulch. Green leaves of different forest tree species and shrubs will be incorporated either separately or in mixture. Since the soil physical and chemical properties may be different in different agroforestry systems, litter decay rate and nutrient release pattern of different mulch species may be different. In addition, even in a given type of agroforestry system, a wide variation can be seen in terms of soil physical and chemical properties and aboveground vegetation. In this context, in the present paper, available information

on litter decomposition are reviewed with a main objective to develop approaches to study the litter decomposition and nutrient release pattern of different mulch species.

**2. Methods to study litter decomposition**

Leaf litter decomposition is most commonly measured using the litter bag technique. A known quantity of leaf litter is placed into a mesh bag which is then inserted into the litter layer of a forest floor. Bags are harvested at periodic intervals, dried and reweighed to determine the amount of mass lost. By incubating the leaves in situ, they are exposed to the normal fluctuations in temperature and moisture. The litter bag technique has both advantages and disadvantages (Lousier and Parkinson, 1975, Woods and Raison, 1982). The advantage of this technique is it allows registering the litter weight loss in filed and the subsequent chemical and biological examination of the material involved (Weber, 1987). Typically, 1-2 mm mesh size and 10 x10cm to 30 x30 cm nylon bags or fibre glass screen or polyvinyl bags with 5-20 g (dry weight) samples are used (Anderson and Ingram, 1993). However, the mesh-size may hinder soil faunal activities. In this context, improved methods for litter decomposition studies need to be developed.

The decomposition rate constant, k, can be calculated from the decay curve using the following equation

$$\text{Ln } (M_0/M_t) = k * t$$

where $M_0$ = mass of litter at time 0, $M_t$ = mass of litter at time t, t= time of incubation, and k = decomposition rate constant.

Half lives ($t_{0.5}$) of decomposing litter samples are estimated from the values as follows:

$$t_{0.5} = 0.693/k$$

Similarly, time taken for 95% decay can be estimated as follows

$$t_{0.95} = 2.9957/k$$

According to McClaugherty and Berg (1987) the single exponential model described above may be suitable for homogeneous substrate, and the materials with high nutritional status especially nitrogen and less of complex organic constituents such as lignin and tannins. However, double exponential model (Bunnell and Tait, 1974) may be suitable for analyzing the decompositions data obtained for heterogeneous substrate.

Rate of decomposition can also be measured by calculating the ratio of annual litterfall to the equilibrium litter on the forest floor. Generally, the equilibrium (or the steady state) litter on the plots are measured biannually in two or more successive years. The average annual litter fall measured by adopting litter bag technique. According to Anderson and Swift (1983) the litter turnover coefficient calculated by this method is suitable for comparison of humid tropical forests. The other two methods commonly used for litter decomposition studies include a) measurement of carbon dioxide evolution or oxygen uptake (Reiners 1968), and b) determination of the microbial biomass in the litter layer.

As already indicated in the agroforestry systems of Kerala, green leaf manure consisting of leaves of single species or a mixture of species is incorporated. Thus the approach to determine the rate of decomposition should involve usage of both single exponential model and double exponential model.

### 3. Patterns of litter decomposition and nutrient release

Generally there are two steps in the litter decomposition, each one with different decomposition rates (Swift and Anderson, 1983). Berg and Co-workers (Berg and Staaf, 1980; McClaugherty and Berg, 1987) have shown that in the initial stages (0 to 3 months) of leaf breakdown small soluble carbon molecules like starches and amino acids are lost first leaving behind the more recalcitrant molecules like lignin. Decomposition during this first phase is rapid because these molecules are easy to breakdown and energy rich. The second stage of decomposition- the beak down of lignin- is much slower because lignin consists of very large and complex molecules. This rapid initial breakdown followed by a longer period of slow decomposition results in a mass loss curve that resembles an exponential decay curve.

During the process of decomposition, amount of different nutrients in the decomposing litter generally do not relate with litter biomass. For instance, in the tropical wet evergreen forest of Nelliampathy (Chandrashekara, 1992) nitrogen and phosphorous showed much fluctuation during the 1-year period, often exceeding the initial concentration. Potassium, calcium and magnesium showed a gradual decline with passage of time. The relative increase in the concentration of nitrogen and phosphorous in the leaf litter during the process of decomposition and their rapid fluctuation may be related to immobilization of these two nutrients by phylloplane microflora., so that they are released more slowly and at the same rate as organic matter loss (Gosz et al., 1973; Toky and Ramakrishnan, 1984). In contrast, labile element like potassium is released at a faster rate. It was also recorded that in

general nutrient levels at the end of one year was in the order of N>P>Mg>Ca>K. However, when different species are considered mobility of the nutrients from decomposing litter may show different order. In this context, studies related to decomposition and nutrient release patterns in green leaf manure (consisting of leaves single species or a mixture species) will have significance as the information thus generated could be useful to understand the synchronization of nutrient release by green leaf manure and the nutrient up take by crop species.

## 4. Factors affecting litter decomposition

The rate and patterns of litter decomposition are dependent on the interaction of climate, soil biota and quality and quantity of organic matter (Swift et al., 1979). One can predict gross estimates of decomposition based on the climate and the C:N:lignin rations organic matter (litter). The primary factors which affect litter decomposition are discussed under following heads: a) climate, b) vegetation, c) substrate and its quality and d) soil biota.

### 4.1. Climatic factors

Climate markedly modifies the nature and rapidity of litter decomposition. Moisture and temperature are among the most crucial variables (Brinson, 1977; Singh, 1969) because they affect both the development of plant cover and the activities of microorganisms which are highly critical factors in soil formation. Effects of soil moisture on litter decomposition are little complicated. Decomposition is inhibited in very dry soils because bacteria and fungi dry out. Decomposition is also slow in very wet soils because anaerobic conditions develop in saturated soils. Decomposition proceeds at faster rate at intermediate water contents. Kononova (1975), citing several other publications, concluded that the highest intensity of organic matter decomposition was observed when the soil moisture content of about 60-80% of its maximum water-holding capacity. According to Van der Drift (1963) moisture passing through the detritus may be important in speeding decomposition. Therefore, studies in litter decay should not be compared unless moisture regimes are the same.

Temperature is often the primary factor determining rates of litter decomposition (Meentemeyer, 1978, Anderson, 1991, Hobbie, 1996) and decomposition rate are generally more sensitive to temperature than are rates of net primary production (Lloyd and Taylor, 1994). Thus, the balance between ecosystem C fixation and decomposition may be altered under a warmer climate, potentially causing a dramatic increase in the flux of $CO_2$ from soils to the atmosphere (Cox et al., 2000).

For each $10^0$ C increase in temperature between 20 and $40^0$ C the rate of $CO_2$ production doubled (Wiant, 1967). No $CO_2$ production at all was detected at $10^0$ C and $50^0$ C or above it declined markedly. According to Kononova (1975) the highest intensity of organic matter decomposition was observed under conditions of moderate temperature (about $30^0$ C). Increase or decrease of temperature beyond the optimal levels brought about a decline in the rate of organic matter decomposition. Therefore, studies on litter decay should not be compared unless temperature regimes are the same. Differences in litter decomposition rate at various altitudes, due to variation in temperature were reported by William and Gray (1974). Shanks and Olson (1961) compared litter decay beneath natural stands at various elevations and concluded that there was an average decrease in breakdown of nearly 2% for each $1^0$ C drop in mean temperature. The influence of temperature on the decomposition of lignin is especially marked. At $37^0$ C, lignin decomposes rapidly, with 50-60% of it disappearing within 9 months (Waksman and Gerretsen, 1931). Meentemeyer (1978) used annual actual evapotranspiration as the index of predictor variable of decomposition rate.

The decomposition rates in different types of forests in the Western Ghats region appear to be correlated with rainfall. According to Swamy (1989) the rate of decomposition in rainfall rich forests is faster than in those where the rainfall is comparatively less. The percolating water from rainfall may leach the excrements and remains of organisms down to the lower horizons, where other specialized microbes will attack the remaining organic matter (Van der Drift, 1963).

The litter breakdown rate varies with season. Gholz et al. (2000) and Loomis (1975) found that decomposition was rapid in summer, whereas Lang (1974) estimated the leaf litter decay to 3.75 $g/m^2$/day during the autumn months and 0.80 $g/m^2$/day during the remainder of the year. Boonyawat and Ngamponsai (1974) supported Lang's result when they found that the highest decomposition of hill evergreen forest litter occurred in the late rainy season and early winter (0.36 t /ha/month) and the lowest rate in summer (0.14 t/ha/month). Madge (1965) concluded that litter disappearance in Nigeria occurred mainly during the wet season, owing to the activity of mites and collembolan.

It may be mentioned here that agroforesters of Kerala apply for their crop trees the green leaf manure generally during September-November and leaf litter during February-April. Apart from the availability of either green leaf manure or leaf litter, probably season of their application may have certain bearing on the litter

decomposition and nutrient release in relation to nutrient uptake by the crop trees, and this aspect needs to be investigated.

In the Kerala part of NBR, while some tree based farms are located in slightly elevated areas, other farms being transformed paddy fields inundate during the rainy season. Thus, a comparative study on the litter decomposition pattern in two types of farms (inundated and un-inundated) which are have same species as the dominant crop may provide information on the impact of water saturation on litter decomposition and biotic activities.

### 4.2. Growing Vegetation

In general, the decay rate in tropical plantations is lesser than those in natural forests (O'connell and Sankaran, 1997). One of the reasons for slow rate of decomposition is the lack of ground cover. The ground cover can provide favorable microclimate and promote the abundance and activities of soil fauna and microorganisms. However, there are reports to indicate that the presence of growing plant significantly alters decomposition dynamics and decreases the rates of decomposition (Dormaar, 1990). Living plants can decrease decomposition rate because a) microbes preferentially use labile material provided by living roots rather than more recalcitrant litter, b) roots release compounds that inhibit microbial activity, c) plants compete with microbes for uptake of nutrients and organic compounds and/ or d) exudates stimulate predation on microbes and thus decrease microbial populations. In contrast, growing plants can stimulate decomposition through inputs of labile carbon that increases the activity and turnover of microbes (Cheng and Coleman, 1990; Sallih and Bottner, 1988). Plants can also influence decomposition through their effects on soil temperature, moisture (Mack et al., 2001;Van der Krift et al., 2002) or oxygen concentration (Allen et al., 2002).

### 4.3. Vegetation type

The decay rate in general is faster in the tropical region than in the temperate region (Jennay et al., 1949). Even within the tropical region, leaf litter decomposition rates vary with the types of forests. For instance, in the Western Ghats of India, decay rate is faster in evergreen forest followed by semi-evergreen forest and moist deciduous forest (Swamy, 1989). Forest canopy gaps formed either by natural tree fall or branch fall or by human activities such as selective logging can also alter the process and the rate of litter decomposition (Chandrashekara, 1992). Canopy gap formation by natural means may lead to a situation where the microclimate is more favourable

than that in closed canopy area for litter decomposition. Thus, litter decomposing rate increased with increase in gap size. However, the rate of litter decomposition declined as the canopy gaps are closed owing to reduction in the light and temperature. A sharp decline in the litter decomposition rate, due to selective logging (Chandrashekara, 1992) and clear felling (Maheswaran and Gunatilleke, 1988), when compare to that in undisturbed forests could be attributed to the desiccation of leaves and surface soil under more intense disturbance of the vegetation.

It may be mentioned here that in Nilgiri Biosphere Reserve, even in a given type of farm, a wide variation can be seen between farms in terms of canopy opening. Thus, the pattern and rate of decomposition of litter and green leaf manure may be different in different farms. In this context, there is a scope to study the relation between canopy opening and litter decomposition rate in agroforestry systems in Kerala.

### 4.4. Substrate and its quality

The quality of the leaves as a food source for microbial decomposers is another important factor that determines the rate and pattern of litter decomposition. Substrate quality has been defined in many different ways-as the nitrogen concentration (N), as the lignin content, and as the C:N ratio (Moorehead et al., 1996). Researchers have found that decomposition of leaf litter can be predicted by the C: N ratio (Melillo et al., 1982). Basically, high quality leaves (nutrient rich-leaves) will decompose faster than low quality leaves (nutrient –poor leaves).

Many studies have shown striking difference in decomposition rates among species (Kumar, 2005; Cornelissen and Thompson, 1997). It is also reported that the decay rate coefficients of the tropical speceis are substantially greater than those of the temperate coniferous litter (Cromack et al., 1991; O'Connel and Sankaran, 1997). Relationship between the species successional status and the rate of decomposition has been studied by Chandrashekara (1992). The decay rate coefficients of primary species (k values of 0.61, 0.8 and 1.39 $yr^{-1}$ for *Cullenia exarillata*, *Mesua nagassarium* and *Palaquium ellipticum*) are substantially lesser than those of late secondary (k= 1.94 $yr^{-1}$ for *Actinodaphne bourdillonii*) and early secondary species ((k=3.21and 2.95 $yr^{-1}$ respectively for *Clerodendron infortunatum* and *Macaranga peltata*). The slower rate of decomposition of Cullenia exarillata- a primary species may partly be related to its hard and leathery leaves. In this species, leaves are comparatively nitrogen rich, but still decompose relatively slowly. This observation is different from what others have implicated with nitrogen status of the litter (Singh and Gupta, 1977, Tanner, 1981). The differential rate of decomposing of early secondary

and primary species may confer an advantage to the former in terms of a faster turnover rate of nutrients which is important for these exploitative early secondary species (Boojh and Ramakrishnan, 1982), but help in conserving nutrients of primary species through gradual release (La Caro and Rudd, 1985) so that the primary species with conservation strategy are able to utilize relatively slowly during their slow growth phase.

Generally speaking, the rate of decomposition is highest in species with maximum ash and nitrogen contents and minimal C: N ratios and lignin contents (Singh 1969). Broadfoot and Pierre (1939) found a highly significant correlation between litter decomposition and each of five independent variables: excess base, water-soluble organic matter, total nitrogen, total ash and total calcium. The multiple coefficients of correlation between percent decomposition and the three variables- total nitrogen, water-soluble organic matter, and excess base was found to be 0.86. Kucera (1959) also reported a positive correlation between both rapidity of decay and high ash content of hot water soluble materials. Since the chemical composition of litter affects its rate of decomposition, it is assumed also to have great significance in determining the release of nutrients.

### 4.5. Soil biota

Soil biota, primarily at a functional group level, is known to regulate ecosystem processes such as decomposition, carbon sequestration and nutrient cycling (Paustian et al., 2000). Soil biota, playing a meditative role, in decomposition may affect the type and availability of nutrients and thus community interactions. For example, Binkley and Christian (1998) state “the black box of the soil community can strongly affect the supply of nutrients --- a black box--- clearly needs to be taken apart and examined in greater detail”. Evidence from the 1980’s on deserts (Whitford et al., 1982) and from sub alpine and wet and dry tropical ecosystems (Gonzalez and Seastedt, 2001) again indicate that soil fauna are key to litter decomposition. It is also reported that the seasonal variation in rate of decomposition could be variation in abundance of soil fauna. For instance, Madge (1965) concluded that since more animals are there on the litter layer during the wet season than in dry season, rate of decomposition was faster in the former season. When animals were completely excluded for nine months, no visible breakdown of oak and beech leaf litter occurred (Edwards and Heath, 1963). The same investigators reported that in earthworms removed litter the decomposition rate is three times faster than the litter from where smaller invertebrates such as springtails, enchytraeids and dipterous larvae were

removed. A common carbomate insecticide (carbofuran), when applied at recommended dosage, reduced the decomposition rate of red maple to between 0.99 and 1.26 gm $m^{-2}$ $day^{-1}$, This is chiefly because such insecticides have been found to be highly toxic to earthworm (Weary and Merriam, 1978). Similarly Heneghan et al., (1999) and Gonzalez and Seastedt (2001) found that excluding micro invertebrates slowed decomposition rate of leaf liter in humid tropical forests.

## 5. Conclusions

Decomposition is a critical process for regulating nutrient cycling and production in all ecosystems. Though attempts are being made to assign economic value for some of the ecosystem services such as biomass production, aesthetic beauty of natural forests, pollination of crops and natural vegetation etc., such an attempt has not been made in the case of litter decomposition and associated ecosystem services. In fact, litter decomposition is one among several other ecosystem services which are not traded in markets and hence do not have prices, and thus are interpreted as having no value when it comes to making decision about their use. In this context, quantities evidence on economic value of litter decomposition needs to be generated. As a prerequisite, methods for analyzing the ecological economics of litter decompositions are need to be developed.

There is an array of variables such as temperature, moisture, soil physical and chemical properties, soil biota, vegetation type and composition, substrate quality etc. which control the litter decomposition. In the agroforestry systems of Kerala, green leaf manure application to crop lands is a common practice for improving soil fertility and crop yield. However, studies on influence of different above mentioned variables on the rate of litter decomposition and nutrient release are lacking. In this context, litter decomposition studies may be carried out to evaluate

a) the rate of decomposition of green leaf manure, comprising single species and/or a mixture of species by using single exponential and double exponential models,
b) pattern of nutrient release in green leaf manure, comprising of single species and/or a mixture of species and understand the synchrony between nutrient release by manure and nutrient uptake by crops,
c) litter decomposition rates in a given type of crop land (eg. homegardens) but transformed from different landuse systems (eg. forest, paddy field etc.),
d) the relationship between quantity of light available and litter decomposition rate in a given type of landuse systems,

e) substrate quality in terms of carbon, nitrogen and lignin content in different green leaf manure species and their impact on litter decomposition rate,

f) variation in the abundance of different soil fauna in the litter bag during the process of decomposition of different green leaf manure species, and

g) Variation in the litter decomposition rate and soil faunal diversity in the litter bags or containers having different mesh or holes size. To achieve this objective following method will be adopted. Plastic pots of same size and volume will be purchased. All around the surface of the pots holes will be made at equal distance. While one set of pots will have holes of 2 mm size, in the other set of pots the holes are of 5 mm in size. Containers will be filled with equal quantity of litter of a given green manure species and closed with the hole bearing lids. Thirty six litter containers each for a given sized holes will be placed amidst to the mulch to retrieve three containers at monthly interval for determining the decomposition rate, floral and faunal community.

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# References


Abdul Rida, A.M.M. and Bouche, M.B. 1995. The eradication of an earthworm genus by heavy metals in southern France. Appllied Soil Ecology, 2: 45–52.

Allen, A.P., Brown, J.H. and Gillooly, J.F. 2002. Global biodiversity, biochemical kinetics, and the energetic-equivalence rule. Science, 297: 1545–1548.

Anderson, J. M. 1991. The effects of climate change on decomposition processes in grassland and coniferous forests. Ecological Applications, 1:326–347.

Anderson, J.M. and Ingram, J.S.I. (Eds). 1993. Tropical Soil Biology and Fertility: A handbook of Methods. CAB International, Wallingford, UK. 171pp.

Anderson, J.M. and Ingram, J.S.I. 1989. Tropical Soil Ecology and Fertility: A Hand Book of Methods. CAB International, Oxon, UK.

Anderson, J.M. and Swift, M.J. 1983. Decomposition in tropical forests. In: Tropical Rain Forest: Ecology and Management. Sutton, S.L., Whitmore, T.C. and Chadwick, A.C. (Eds). Blackwell Scientific Publications, Oxford. 287-309pp.

Ayarza, M. A., Vilela, L. and Pizarro, E.A. 1998. Estratégias de cultivo de milho (*Zea mays*) sobre cobertura permanente de *Arachis pintoi*. *Pasturas Tropicales*, 20, 28-30.

Baiju EC, Chandrashekara UM (2007) Transformation of paddy fields to different landuse systems in Vazhikadavu Panchayat. In: Proceedings of 19th Kerala Science Congress, KSCSTE, Thiruvananthapuram . pp. 388-390

Basu, P., Blanchart, E. and Lepage, M. 1996. Termite (Isoptera) community in the Western Ghats, South India: influence of anthropogenic disturbance of natural vegetation. Europian Journal of Soil Biology, 32: 113-121.

Bavappa, K.V. A. 1995. Coconut based cropping system. Indian Coconut Journal, 25:6-8.

Berg, B. 2000. Litter decomposition and organic matter turnover in northern forest soils. Forest Ecology and Management, 133:13-22.

Berg, B. and Staaf, H. 1980. Decomposition rate and chemical changes of scot pine needle litter. II. Influence of chemical composition. Ecological Bulletin, 32:373-390.

Berg, B. and Staaf, H. 1981. Leaching, accumulation and release of nitrogen in decomposing forest litter. In Terrestrial nitrogen cycles: processes, ecosystem strategies and management impacts. Clark, F. E. and Rosswall, T. (Eds). O¨sterfa¨rnebo, Sweden, 251– 273pp.

Bhooj, R. and Ramakrishnan, P.S. 1982. Litterfall pattern in a subtropical evergreen montane forest in north-east India. Geo-EcoTropical, 6: 33-44.

Binkley, D. and G. Christian. 1998. Why do tree species affect soils? The warp and woof of tree-soil interactions. Biogeochemistry, 42: 89-106.

Bloomfield, J., Vogt, K.A. and Vogt, D.J. 1993. Decay rate and substrate quality of fine roots and foliage of two tropical tree species in the Luquillo Experimental Forest, Puerto Rico. Plant and Soil. 150: 230-245.

Boonyawat, S. and Ngampongsai, C. 1974. An analysis of accumulation and decomposition of litter fall in hill evergreen forest, Doi Pui, Chiangmai. Kogma Watershed Res. Bull., Kasetsart Universtiy Press, Thailand. 21 p.

Bradshaw, L. and Lanini, W.T. 1995. Use of perennial cover crops to suppress weeds in Nicaraguan coffee orchards. International Journal of Pest Management, 41: 185-194.

Brinson, M.M. 1977. Decomposition and nutrient exchange of litter in an alluvial swamp forest. Ecology, 58: 601-609.

Broadfoot, W.M. and Pierre, W.H. 1939. Forest soil studies: I. Relation of rate of decomposition of tree leaves to their acid-base balance and other chemical properties. Soil Science, 48: 329-348.

Broughton, W. J. 1976. Effects of various covers on the performance of *Elaeis guineensis* (Jacq.) on different soils. In: D.A. Earp and W.Newall, (Eds.) International Oil Palm Developments. Proceedings of the International Oil Palm Conference, Kuala Lumpur, pp.501-525.

Buckerfield, J.C. and Webster, K.A. 1998. Worm-worked waste boosts grape yields: prospects for vermicompost use in vineyards. Australian and New Zealand Wine Industry Journal, 13: 73-76.

Bunnell, F.L. and Tait, D.E.N. 1974. Mathematical simulation models of decomposition processes. In: Soil organisms and decomposition in tundra. Holding, A.J., Heal, O.W., MacLean, S.F. Jr. and Flanagan, P.W. (Eds). Tundra Biome Steering Committee, Stockholm, Sweden. 207–226 pp.

Bunting, G. and Milsum, J.N. 1928. Cover crops and green manures. Malayan Agriculture Journal, 16: 256-280.

Carter, A., Hayes, E.A. and Laukulich, L.M. 1980. Earthworms as biological monitors of changes in heavy metal levels in an agricultural soil in British Columbia. In: Dindal, D.L. (Ed.) Soil Biology as Related to Land Use Practices, pp. 344–357.

Cattanio, J.H., Kuehne, R. And Vlek, P.L.G. 2008. Organic material decomposition and nutrient dynamics in a mulch system enriched with leguminous trees in the Amazon. R. Bras. Ci. Solo., 32:1073-1086.

Cenci, R.M. and Jones, R.J.A. 2009. Holistic approach to biodiversity and bioindication in soil. EUR 23940 EN, Office for the Official Publications of the European Communities, 43pp.

Chandrashekara UM, Balasundaran M, Sankaran KV, Sujatha MP, Varma RV, Senapati BK, Sahgal M. 2008. Conservation and sustainable management of belowground biodiversity in the Kerala part of Nilgiri Biosphere Reserve - Phase I. KFRI Research Report No. 316. Kerala Forest Research Institute, Peechi, Kerala

Chandrashekara, U. M. 1992. Studies on Gap Phase Dynamics of a Humid Tropical Forest. Ph.D. Thesis, Jawaharlal Nehru University, New Delhi. 148pp.

Chandrashekara, U.M. 2007. Effects of pruning on radial growth and biomass increment of trees growing in homegardens of Kerala, India. Agroforestry Systems. 69:231-237.

Chandrashekara, U.M., Sibichan, V. and Muraleedaran,P.K. 2000. Ecological economics of non-wood forest product (NWFP) species in Wayanad Wildlife Sanctuary. In: Proceedings of the Twelfth Kerala Science Congress. M.R.Das (Ed.), Kerala State Science Technology and Environment Committee. Thiruvananthapuram. 598-603 pp..

Cheng, W. and Coleman, D.C. 1990. Effect of living roots on soil organic matter decomposition. Soil Biology and Biochemistry, 22: 781–787.

Cook, B.G. 1992. *Arachis pintoi* Krap. & Greg., nom. nud. In: L. 't Mannetje and R.M. Jones (Eds.) Plant Resources of South-East Asia No. 4. Forages. Pudoc Scientific Publishers, Wageningen, the Netherlands. pp. 48-50.

Cornelissen J, Thompson K. 1997. Functional leaf attributes predict litter decomposition rate in herbaceous plants. New Phytologist, 135: 109–14.

Cortet, J., Gomot-De Vauflery, A., Poinsot-Balaguer, N., Gomot, L., Texier, C. and Cluzeau, D. 1999. The use of invertebrate soil fauna in monitoring pollutant effects. European Journall of Soil Biology, 35: 115–134.

Cox, P. M., Betts, R. A., Jones, C. D., Spall, S. A. and Totterdell, I. J. 2000. Acceleration of global warming due to carbon-cycle feedbacks in a coupled climate model. Nature 408: 750.

Cromack, K. Jr., Entry, J.A. and Savage, T. 1991. The effects of disturbance by *Phellinus weirii* on decomposition and nutrient mineralisation in a *Tsuga mertensiana* forest. Biology and Fertility of Soils, 11: 245-249.

Cromack, K., Solllins, P., Tood, R.L., Fogel. R., Todd, A.W., Fender, W.M. and Crossley, D.A. 1978. The role of oxalic acid and bicarbonate in calcium cycling by fungi and bacteria: some possible implications for soil animals. Ecological Bulletin, 25:246-252.

Cromack, K.jr., Entry, J.A. and Savage, T. 1991. The effects of disturbance by Phellinus weirii on decomposition and nutrient mineralisation in a Tsuga mertensiana forest. Biology and Fertility of Soil, 11:245-249.

Daily, G. E. 1997. What Are Ecosystem Services? In: Nature's Services - Societal Dependence on Natural Ecosystems. Daily, G.E. (Ed). Island Press, Washington. 1-10 pp.

Daughtry, C.S.T., McMurtrey, J.E., Chappelle, E.W., Dulaney, W.P., Irons, J.R. and Satterwhite, M.B. 1995. Potential for discriminating crop residues from soil by reflectance and florescence. Agronomy Journal, 87: 165-171.

Dhar PP, Mridha MAU (2007) Biodiversity of arbuscular mycorrhizal fungi in different trees of Madhpur forest of Bangladesh. Journal of Forest Research, 17:201-205

Dormaar, J. 1990. Effect of active roots on the decomposition of soil organic materials. Biology and Fertility of Soils, 10: 121–26.

Dostal, P., Breznova, M., Kozlıckova, V., Herbena, T. and Kovar, P. 2005. Ant-induced soil modification and its effect on plant below-ground biomass. Pedobiologia 49: 127-137.

Duncan, G.B. 1955. Multiple range and multiple tests. Biometrics, 42: 1-42

Edwards, C.A. and Burrows, I. 1988. The potential of earthworm composts as plant media. In: Edwards, C.A., Neuhauser, E. (Eds.) Earthworms in Waste and Environmental Management. SPB Academic Press, The Hague, The Netherlands. 21-32 pp.

Edwards, C.A. and Bohlen, P.J. 1992. The effects of toxic chemicals on earthworms. Review of Environmental Contamination and Toxicology, 125: 23–99.

Edwards, C.A. and Heath, G.W. 1963. The role of soil animals in breakdown of leaf material. In: Soil Organisms. Doeksen, J. and Van der Drift, J. (Eds). North Holland Publishing Co., Amsterdam. 76–84 pp.

Edwards, C.A., Subler, S., Chen, S.K., Bogomolov, D.M., Van Straalen, N.M. and Krivolutsky, D.A. 1996. Essential criteria for selecting bioindicator species, processes, or systems to assess the environmental impact of chemicals on soil ecosystems. In: Van Straalen, N.M., Kriovolutsky, D.A. (Eds.) Bioindicator Systems for Soil Pollution. Kluwer Academic Publishers, Dordrecht, pp. 67–84.

Emmerling, C., Krause, K. and Schoder, D. 1997. Regenwurmer als Bioindikatoren fur Schwermetallbelastungen von Boden unter Freilandbedingungen. Z. Pflanzenern. Bodenkd. 160: 33–39.

Erlich, P. and Erlich, A. 1980 Extinction. The causes and consequences of the disappearance of species. Random House, New York, 305 pp.

Folgarait, P.J. 1998. Ant biodiversity and its relationship to ecosystem functioning: a review. Biodiversity Conservation, 7: 1221–1244.

Gaur, A.C. and Sadasivam, K.V.1993. Theory and practical considerations of composting of different wastes. In: Thampan, P.K. (Ed.) Organics in soil health and crop production.1-20 pp.

Ghilarov, M.S. 1949. Die Besonderheiten des Bodens als Lebensraum und seine Bedeutung fur die Evolution der Insekten. Moskau, Leningrad (in Russian).

Gholz, H.L., Wedin, D.A., Smitherman, S.M., Harmon, M.E. and Parton, W.J. 2000. Long-term dynamics of pine and hardwood litter in contrasting environments: toward a global model of decomposition. Global Change Biology, 6: 751-765.

Giller PS (1996) The diversity of soil communities, the 'poor man's tropical rainforest. Biodiversity Conservation, 5:135-168

Gnankambary, Z., Bayala, J., Malmer, A., Nyberg, G. and Hien, V. 2008. Decomposition and nutrient release from mixed plant litters of contrasting quality in an agroforestry parkland in the south-Sudanese zone of West Africa. Nutr.Cycl. Agroecosystems, 82:1-13.

Gonzalez, G. and Seastedt, T.R. 2001. Soil fauna and plant litter decomposition in tropical and subalpine forests. Ecology, 82:955-964.

González, G. and Seastedt, T.R. 2001. Soil fauna and plant litter decomposition in tropical and subalpine forests. Ecology, 82: 955-964.

Gosz, J.R., Likens, G.E. and Bormann, F.H. 1973. Nutrient release from decomposing leaf and branch litter in the Hubbard Brook Forest, New Hampshire. Ecological Monographs, 43: 173-191.

Gugino, B.K., Idowu, O.J., Schindelbeck, R.R., van Es, H.M., Wolfe, D.W., Thies, J.E. and Abawi, G.S. 2007. Cornell Soil Health Assessment Training Manual, Edition 1.2.1, Cornell University, Geneva, New York.

Hairiah, K., Williams, S.E., David Bignell, D., Swift, M. and van Noordwijk, M. 2001. Effects of land use change on belowground biodiversity. International Centre for Research in Agroforestry-Southeast Asian Regional Research Programme, Bogor, Indonesia.

Hazra, J.N. 1988. Enrichment of compost with microbial inoculants. In: Sen. Patil (Ed.) Biofertilizers-potentialities and problems. 248-254 pp.

Heneghan, L., Coleman, D.C., Zou, X., Crossley, D.A. and Haines, B.L. 1999. Soil microarthropod contributions to decomposition dynamics: Tropical-temperate comparisons of a single substrate. Ecology, 80: 1873-1882.

Hensley, D.,Yogi, J. and J. DeFrank. 1997. Perennial peanut groundcover. College of Tropical Agriculture and Human Resources. OF-23. 2pp.

Hesse, P.R. 1971. A Text Book of Soil Chemical Analysis. John Murray, London.

Hobbie, S. E. 1996. Temperature and plant species control over litter decomposition in Alaskan tundra. Ecological Monographs, 66: 503–522.

Hund-Rinke, K. and Wiechering, H. 2001. Earthworm avoidance test for soil assessments: an alternative for acute and reproduction tests. J. Soils Sediments 1: 15–20.

Irmler, U. 1999. Die standortlichen Bedingungen der Regenwurmer (Lumbricidae) in Schleswig-Holstein. Faun.-Okol. Mitt. 7: 509–518.

Isaac, S. and Nair, M. 2006. Litter dynamics of six multipurpose trees in homegarden in South Kerala, India. Agroforestry Systems, 67: 203-213.

Jackson, M.I. 1958. Soil Chemical Analysis. Prentice Hall Inc. Englewood Cliffs, NJ, USA. Reprint (1973) by Prentice Hall of India (Pvt) Ltd., New Delhi.

Jamaludheen, V. and Kumar, B.M. 1999. Litter of multipurpose trees in Kerala, Inda: variations in amount, quality, decay rates and release of nutrients. Forest Ecology and Management, 115: 1-11.

Jennay, H., Gessel, S.P. and Bingham, F.T. 1949. Comparative study of decomposition rates of organic matter in temperate and tropical regimes. Soil Science, 68: 419-432.

Jones, C.G., Lawton, J.H. and Shachak, M. 1994. Organisms as ecosystem engineers. Oikos, 69: 373–386.

Kale, R.D., Bano, K. And Krishnamoorthy, R.V. 1982. Potential of *Periyonix excavatus* for utilization of organic wastes. Pedobiologia, 23: 419-425.

Kale, R.D. 1997. Earthworms and soil. Proceedings of National Academy of Sciences, India. 67: 13-24.

Kale, R.D. 2005. Diversity and functional role of earthworms: the Indian context. In: Ramakrishnan, P.S., Saxena, K.G., Swift, M.J., Rao, K.S., Maikhuri, R.K. (Eds.) Soil Biodiversity, Ecological Processes and Landscape Management. Oxford & IBH Publishing Co. Pvt. Ltd. New Delhi, pp. 15-23.

Kannan KP , Pushpangadan K (1988). Agriculture stagnation and economic growth in Kerala: an explanatory analysis. Working Paper No. 227, Centre fore Development Studies, Trivandrum

Kapoor, K.K., Yadav, K.S., Singh, D.P., Mishra, M.M. and Tauro, P. 1983. Enrichment of compost by Azotobactor and phosphate solubilizing microorganisms. Agricultural Wastes, 5: 125-133.

Kerala Agricultural University (KAU), 2002. Package of Practices Recommendations: Crops.Kerala Agricultural University, Thrissur, India. 278pp.

Kononova, M.M. 1975. Humus of virgin and cultivated soils. In: Soil components, Vol. I, Gieseking, J.E. (Ed). Springer-Verlag, New York. 475-526pp.

Kucera, C.L. 1959. Weathering characteristics of deciduous leaf litter. Ecology, 40: 485-487.

Kumar, B.M. 2005. Litter dynamics in tropical plantation forests and agroforestry systems. In: Soil Biodiversity, Ecological Processes and Landscape Management. Ramakrishnan, P.S., Saxena, K.G., Swift, M.J., Rao, K.S. and Maikhuri, R.K. (eds.). Oxford and IBH Publishing Co.Pvt. Ltd., New Delhi. 87-112 pp.

Kumar, B.M. and Nair, P.K.R. 2004. The enigma of tropical homegardens. Agroforestry Systems, 61: 135-152.

La Caro, F. and Rudd, R. L. 1985. Leaf litter decomposition rates in Puerto Rican montane rain forest. Biotropica, 17: 269–276.

Lal, R., Regnier, E., Eckert, D.J., Edwards, W.M., and Hammond, R. 1991. Expectations of cover crops for sustainable agriculture. In: W.L. Hargrove (ed.) Cover crops for clean water. Proceedings of the Conference of the Soil and Water Conservation Society pp.1-11.

Lal. R. 2004. Soil carbon sequestration impacts on global climate change and food security. Science, 304:1623-1629.

Lang, G.E. 1974. Litter dynamics in a mixed oak forest on the New Jersey Piedmont. Bulletin of Torrey Botanical Club, 101: 277-286.

Lavelle, P., Bignell, D., Lepage, M., Wolters, V., Roger, P., Ineson, P., Heal, O.W. and Dhillion, S. 1997. Soil functions in a changing world: the role of invertebrate ecosystem engineers. European Journal of Soil Biology, 33: 159–193.

Leblanc, H.A., Nygren, P. and McGraw, R.L. 2006. Green mulch decomposition and nitrogen release from leaves of two Inga spp. in an organic alley-cropping practice in the humid tropics. Soil Biology and Biochemistry, 38: 349-358.

Lee, K.E., 1985. Earthworms: Their Ecology and Relationships with Soils and Land Use. Academic Press, Sydney.

Lloyd, J. and Taylor, J.A. 1994. On the temperature dependence of soil respiration. Functional Ecology, 8: 315–323.

Loomis, R.M. 1975. Animal changes in forest floor weights under a southeast Missouri oak stand. USFS Research Note, NC- 184. 3 p.

Lousier, J.D. and Parkinson, D. 1975. Litter decomposition in cool temperate deciduous forest. Canadian Journal of Botany, 54: 262-280.

Lowe, C.N. and Butt, K.R. 1999. Interspecific interactions between earthworms: a laboratory-based investigation. Pedobiologia 43: 808–817.

Mack, M., D'Antonio, C. and Ley, R. 2001. Alteration of ecosystem nitrogen dynamics by exotic plants: a case study of C4 grasses in Hawaii. Ecological Applications, 11:1323–35.

Mackey, A.D., Syres, J.A. and Gregg, P.E.H. 1982. Plant availability of phosphorus in superphosphate and phosphate rock as influenced by earthworms. Soil Biology and Biochemistry, 14: 281-287.

Madge, D.S. 1965. Leaf fall and litter disappearance in a tropical forest. Pedobiologia, 5: 273-288.

Maheswaran, J. and Gunatilleke, A.U.N. 1988. Litter decomposition in lowland rain forest and a deforested area in Sri Lanka. Biotropica, 20: 90-99.

Mathur, B.S., Sarkar, A.K. and Mishra, A.B. 1980. Release of N and P from compost charged with rock phosphate. Journal of Indian Society of Soil Science, 28: 206-207.

McClaugherty, C.A. and Berg, B. 1987. Cellulose, lignin and nitrogen concentrations as regulating factors in late stages of forest litter decomposition. Pedobiologia, 30: 101-112.

Meentemeyer, V. 1978. Macroclimate and lignin control of litter decomposition rates. Ecology 59: 465–472.

Meharg AA, Cairney JWG (2000) Co-evolution of mycorrhizal symbionts and their hosts to metal-contaminated environments. Advances in Ecological Research, 30:69-112

Melillo, J.M., Aber, J.D. and Muratore, J.F. 1982. Nitrogen and lignin control of hardwood leaf litter decomposition dynamics. Ecology, 63:125-128.

Melillo, J.M., Aber, J.D. and Muratore, J.F. 1982. Nitrogen and lignin control of hardwood leaf litter decomposition dynamics. Ecology, 63: 621-626.

Miller R.M., and Jastrow, J.D. 1992. The application of VA mycorrhizae to ecosystem restoration and recalamation. In: Allen MF (ed) Mycorrhizal Functioning. Chapman and Hall, Ltd., London, England, pp. 438-467

Mohanan, C. 2003. Mycorrhizae in forest plantations: association, diversity and exploitation in planting stock improvement. KFRI Research Report No. 252, Kerala Forest Research Institute, Peechi, Kerala

Mohankumar, V. and Mahadevan, A. 1987. Survey of vesicular arbuscular mycorrhizae in mangrove vegetation. Current Science, 55:936

Moorehead, D.L., Sinsabaugh, R.L., Linkins, A.E. and Reynolds, J.F. 1996. Decomposition processes: modeling approaches and applications. Science for the Total Environment, 183: 137–149.

Mulligan M.E., Smucker, J.M. and Safir, J.F. 1985. Tillage modifications of dry edible bean root colonization by VAM fungi. Agronomy Journal, 77:140-144

Musvoto, C., Campbell, B.M. and Kirchamann, H. 2000. Decomposition and nutrient release from mango and miombo woodland litter in Zimbabwe. Soil Biology and Biochemistry, 32:1111-1119.

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

Muys, B. and Granval, P. 1997. Earthworms as bioindicators of forest site quality. Soil Biology and Biochemistry, 29: 323–328.

Nair, R.G., and Chami, P. 1963. A survey of weeds in the fields of coconut research station, Kasaragod. Indian Coconut Journal, 17: 40-47.

Narayanan, N.C., 1995. Issues in sustainable landuse: a micro-level study in Madakkathara area, Trichur District. In: Pillai PP and Nair RP (eds) Understanding Ecologically Sustainable Economic Development. Institute of Planning and Applied Economic Research, Thrissur, Kerala, pp. 87-103

O'Connel, A.M. and Sankaran, K.V. 1997. Organic matter accretion, decomposition and mineralization. In: Management of Soil, Nutrients and Water in Tropical Plantation Forests. Nambiar, E.K.S. and Brown, A.G. (Eds). ACIAR, Canberraa, Australia. 443-480pp.

Ocampo J.A., Hayman, D.S. 1980. Effect of pesticides on mycorrhiza in field growm barley, maize and potatoes. Trans Brazilian Mycological Society, 74:413-416

Oehl F, Sieverding E, Ineichen K, Mäder P, Boller T, Wiemken A (2003) Impact of landuse intensity on the species diversity of arbuscular mycorrhizal fungi in agroecosystems of Central Europe. Applied Environmental Microbiology, 69:2816-2824

Olson, J.S. 1963. Energy storage and the balance of producers and decomposers in ecological systems. Ecology, 44: 323-331.

Palm, C.A. and Rowland, A.P. 1997. A minimum data set for characterization of plant quality for decomposition. In: Cadisch, G. and Hiller, K.E. (Eds.) Driven by Nature: Plant Litter Quality and Decomposition. CAB Internationational, London. pp 379-392.

Palm, C.A., Gachengo, C.N., Delve, R.J., Cadisch, G. and Giller, K.E. 2001. Organic inputs for soil fertility management in tropical agroecosystems: application of an organic resource database. Agriculture, Ecology and Environment, 83:27-42.

Panikar, P.G.K. 1980. Recent trends in area under production of rice in Kerala. Working Paper No. 116, Centre for Development Studies, Trivandrum

Paoletti, M.G. 1999. The role of earthworms for assessment of sustainability and as bioindicators. Agriculture Ecosystem and Environment, 74: 137–155.

Paustian, K., Six, J., Elliott, E. T., Hunt, H. W. 2000. Management options for reducing CO2 emissions from agricultural soils. Biogeochemistry, 48: 147–163.

Philips, J.M.and Hayman, D.S. 1970. Improved procedures for clearing and staining parasitic and vesicular arbuscular mycorrhizal fungi for rapid assessment of infection. Trans Brazilian Mycological Society, 55:158-161

Pizl, V. 1992. Effect of soil compaction on earthworms (Lumbricidae) in apple orchard soil. Soil Biology and Biochemistry, 24: 1573–1576.

Porter, W.M. 1979. The most probable number method for enumerating infective propagules of vesicular arbuscular mycorrhizal fungi in soil. Australian Journal Soil Research, 17:515-518.

Porter, W.M., Robson, A.D.and Abbot, L.K. 1987. Field survey of the vesicular-arbuscular mycorrhizal fungi in relation to pH. Journal Applied Ecology, 24:659-662.

Prescott, C.E., Zabek, L.M. and Kabzems, C.L.S.R. 2000. Decomposition of broad leaf and needle litter in forests of British Colombia: influence of litter type, forest type, and litter mixtures. Canadian Journal of Forest Research, 30:1742-1750.

Ragupathy, S. and Mahadevan, A. 1993. Distribution of vesicular-arbuscular mycorrhizae in plants and rhizosphere soils of tropical plains, Tamil Nadu, India. Mycorrhiza 3:123-136

Ragupathy, S., Mohankumar, V, and Mahadevan, A, 1990. Occurrence of vesicular arbuscular mycorrhizae in tropical hydrophytes. Aqua Botanica 36:287-291

Rasal, P.H., Kalbhor, H.B., Shingte, V.V. and Patil, P.L. 1988. Development of technology for rapid composting and enrichment. Biofertilizers Potentialities Problems, 254-258.

Reiners, W.A. 1968. Carbon dioxide evolution from the floor of three Minnesota forests. Ecology, 49: 471-483.

Rombke, J., Beck, L., Forster, B., Frund, H.C., Horak, F., Ruf, A., Rosciczewski, K., Scheurig, M. and Woas, S. 1997. Boden als Lebensraum fur Bodenorganismen und die bodenbiologische Standortklassifikation: Eine Literaturstudie. Texte und Berichte zum Bodenschutz 4/97. Landesanstalt fur Umweltschutz Baden-Wurttemberg, Karlsruhe.

Rombke, J., Jansch, S. and Didden, W. 2005. The use of earthworms in ecological soil classification and assessment concepts. Ecotoxicology Environtal Safety, 62: 249-265.

Rossi, J.P., Huerta, E., Fragoso, C. and Lavelle, P. 2006. Soil properties inside earthworm patches and gaps in a tropical grassland (la Mancha, Veracruz, Mexico) European Journal Soil Biology, 42:S284–S288.

Salamanca, E.F., Kaneko, N. and Katagiri, S. 1998. Effects of leaf litter mixtures on the decomposition of *Quercus serrata* and *Pinus densiflora* using field and laboratory microcosm methods. Ecological Engineering, 10: 53-73.

Sallih, Z. and Bottner, P. 1988. Effect of wheat (*Triticum aestivum*) roots on mineralization rates of soil organic matter. Biology and Fertility of Soils, 7: 67–70.

Sankaran KV, Balasundaran M, Thomas TP, Sujatha MP (1993) Litter dynamics, microbial associations and soil studies in *Acaia auriculiformis* plantations in Kerala, KFRI Research Report No. 91, Kerala Forest Research Institute, Peechi, Kerala

Sankaran, K.V. 1993. Decompostion of leaf litter of Albizia (Paraserianthes falcataria), eucalypt (Eucalyptus tereticornis) and teak (Tectona grandis) in Kerala, India. Forest Ecology and Management, 56:225-242.

Sariyildiz, T. and Anderson, J.M. 2003. Decomposition of sun and shade leaves from three deciduous tree species as affected by their chemical composition. Biology and Fertility of Soil, 37:137-146.

Schenck, N.C. and Perez, Y. 1990. Manual for the Identification of Mycorrhizal Fungi. Synergistic Publications, Gainesville.

Schwendener, C.M., Lehmann, J., de Camargo, P.B., Luizao, R.C.C. and Fernandes, E.C.M. 2005. Nitrogen transfer between high- and low-quality leaves on a nutrient-poor Oxisol determined by $^{15}N$ enrichment. Soil Biology and Biochemistry, 37: 787-794.

Senapati, B.K. 1988. Vermitechnology – an option for recycling of cellulosic wastes of India. New Trends of Biotechnology, 347-358.

Sengupta, A. and Chaudhuri, S. 1990. Vesicular-arbuscular mycorrhizal fungi in pioneer salt marsh plants in the Ganges River Delta in West Bengal (India). Plant and Soil 122:111-113

Shanks, R.E. and Olson, J.E. 1961. First year breakdown of leaf litter in Southern Appalachian forest. Science, 134: 370-376.

Shi, Z.Y., Wang, F.Y., Wei, Y.L. and Chen, Y.L. 2007. Observations of arbuscular mycorrhizas on Dipterocarpaceae grown in tropical rainforest in China. Journal of Agriculture and Environment Sci 2:247-254

Sims, R.W. and Gerard, B.M. 1985. Earthworms. In: Kermack, D.M., Barnes, R.S.K. (Eds.) Synopses of the British Fauna (New Series), No. 31. E. J. Brill/Dr. W. Backhuys, London.

Singh, K.P. 1969. Studies on decomposition of leaf litter of important trees of tropical deciduous forest at Varanasi. Tropical Ecology, 10:292-311.

Singh, O. and Gupta, S.R. 1977. Plant decomposition in terrestrial ecosystems. Botanical Review, 43: 449-528.

Sit, A.K., Bhattacharya, M., Sarkar, B., and Arunachalam, V. 2007. Weed floristic competation in palm gardens in plains of eastern Himalayan region of West Bengal. Current Science, 92: 1434-1439.

Smith, S.E. and Read, D.J. 1997. Mycorrhizal Symbiosis, 2nd edn. Academic Press Ltd., London, England

Solano, C.V. and Crohn, D.M. 2006. Are decomposition and N release from organic mulches determined mainly by their chemical composition? Soil Biology Biochemistry, 38:377-384.

Stephenson, G.L., Kaushik, A., Kaushik, N.K., Solomon, K.R., Steele, T. and Scroggins, R. 1998. Use of an avoidance-response test to assess the toxicity of contaminated soils to earthworms. In: Sheppard, S.C., Bembridge, J.D., Holmstrup, M., Posthuma, L. (Eds.) Advances in Earthworm Ecotoxicology. SETAC Press, Boca Raton, FL, pp. 67–81.

Stork, N.E. and Eggleton, P. 1992. Invertebrates as determinants and indicators of soil quality. American Journal of Alternate Agriculture, 7: 38–47.

Strzemska, J. 1975. Mycorrhiza in farm crops grown in monoculture. In: Sanders et al. (eds) Endomycorrhizas. Academic Press, London. pp. 527-537

Sundarapandyan, S.M. and Swamy, P.S. 1999. Litter production and decomposition of selected tree species in tropical forests of Kodayar in the Western Ghats, India. Forest Ecology Management, 123:231-244.

Swamy, H.R. 1989. Study of organic productivity, nutrient cycling and small watershed hydrology in natural forests and in monoculture plantations in Chikmagalore District, Karnataka. Report Submitted to Ministry of Environment and Forests, Govt. of India. Sri. JCBM College, Sringeri, Karnataka. 261pp.

Swift, M.J. and Anderson, M. 1983. Decomposition. In: Ecosystems of the world 14B; Tropical Rainforest Ecosystems. Leith, H. and Werger, M.S.A. (Eds). Elsevier, Amsterdam. 547-569 pp.

Swift, M.J., Heal, O.W. and Anderson, M. 1979. Decomposition in terrestrial ecosystems. Studies in ecology. Volume 5. University of California Press, Berkeley. California, USA.

Swift, M.J., Russel-Smith, A. and Perfect, T.J. 1981. Decomposition and mineral nutrient dynamics of plant litter in a regenerating bush-fallow in sub-humid tropical African Journal Ecology, 69:981-995.

Tanner, E.V.J. 1981. The decomposition of leaf litter in Jamaican montane rainforests. Journal of Ecology, 69: 263-273.

Tarrant, K.A., Field, S.A., Langton, S.D. and Hart, A.D.M. 1997. Effects on earthworm populations of reducing pesticide use in arable crop rotations. Soil Biology and Biochemistry, 29: 657–661

Thampi, C.J. 1995. Sustainable landuse; farming systems and land policy. In: Pillai PP and Nair RP (eds) Understanding ecologically sustainable economic development. Institute of Planning and Applied Economic Research, Thrissur, Kerala, pp. 75-86

Thapar H.S. and Khan S.N. 1985. Distribution of mycorrhizal fungi in forest soils of India. Indian Journal Forest, 8:5-7

Todd, P and Wolpin, K. 2006. Ex-Ante Evaluation of Social Programs. Working Paper 06-22, PIER (Penn Institute for Economic Research), University of Pennsylvania,Philadelphia.

Toky, O.P. and Ramakrishnan, P.S. 1984. Litter decomposition related to secondary succession and species type under slash and burn agriulture (Jhum) in north eastern India. Proceedings of the Indian National Science Academy, B50: 57-65.

Tomati, U. and Galli, E. 1995. Earthworms, soil fertility and plant productivity. Acta Zoologica Fennica, 196: 11-14.

Tukey, H.B. 1970. The leaching of substances from plants. Annual Review of Plant Physiology, 21:305-324.

Van der Drift, J. 1963. The disappearance of litter in mull and mor in connection with weather conditions and the activity of the macro-fauna. In: Soil organisms. Doeksen, J. and Van der Drift, J. (Eds). North Holland Publishing Co., Amsterdam. 124-133 pp.

Van der Krift, T.A.J., Kuikman, P.J. and Berendse, F. 2002. The effect of living plants on root decomposition of four grass species. Oikos, 96: 36–45.

Visalakshi, N. 1997. Dynamics of vesicular-arbuscular mycorrhizae in two tropical dry evergreen forests, South India. International Journal of Ecology and Environmental Science, 23:25-36

Vogt, K.A., Grier, C.C. and Vogt, D.J. 1986. Production, turnover, and nutrient dynamics of above and below ground detritus of world forests. Advanceds in Ecological Research, 15:303-377.

Waksman, S.A. and Gerretsen, F.C. 1931. Influence of temperature and moisture upon the nature and extent of decomposition of plant residues by microorganisms. Ecology, 12: 33-60.

Wall, D.H. and Virginia, R.A. 2000. The world beneath our feet: soil biodiversity and ecosystem functioning. In: Raven, P.R. and Williams, T. (Eds). Nature and human society: the quest for a sustainable world. National Academy of Sciences and National Research Council, Washington, DC. 225-241pp.

Wardle, D.A., Bonner, K.I. and Nicholson, K.S. 1997. Biodiversity and plant litter; experimental evidence which does not support the view that enhanced species richness improves ecosystem function. Oikos, 79:247-258.

Weary, G.C. and Merriam, H.G. 1978. Litter decomposition in a red maple woodlot under natural conditions and under insecticide treatment. Ecology, 59: 180-184.

Weber, M.G. 1987. Decomposition, litterfall and forest floor nutrient dynamics in relation to fire in eastern Ontario jack pine ecosystems. Canadian Journal of Forest Research, 17: 1496-1506.

Wetlands International, 2005. "Programme Proposal for Consideration under the DGIS Thematic Co-financing Programme", available from: http://www.wetlands.org/ wiseUse/ Poverty Reduction Project.pdf.

Whitford, W.G., Freckman, D.W., Santos, P.F., Elkins, N.Z. and Parker, L.W. 1982. The role of nematodes in decomposition in desert ecosystems. In: Nematodes in soil ecosystems. Freckman, D. W. (Ed). University of Texas Press, Austin, TX. 98-116pp.

Wiant, H.V. 1967. Contribution of roots to forest soil respiration. Advances in Frontier Plant Science, 18: 163–167.

William, S.T. and Gray, T.R.G. 1974. Decomposition of litter on the soil surface. In: Biology of Plant Litter Decomposition. Dickinson, C.H. and Pugh, G.J.F. (Eds). Academic Press, London. 611-635pp.

Woods, P.V. and Raison, R.J. 1982. An appraisal of techniques for the study of litter decomposition in eucalyptus forests. Australian Journal of Ecology, 7: 215-225.

Xuluc-Tosola, F.J., Vester, H.F.M., Ramirez-Marcial, N., Castellanos-Albores, J. and Lawrence, D. 2003. Leaf litter decomposition of tree speceis in three successional phases of tropical dry secondary forest in Campeche, Mexic. Forest Ecology and Management, 174: 401-412.