IMPACT OF ECO-RESTORATION ON NUTRIENT BALANCE IN EASTERN ATTAPPADY, KERALA

By

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THESIS

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DECLARATION

I hereby declare that this thesis entitled "**IMPACT OF ECO-RESTORATION ON NUTRIENT BALANCE IN EASTERN ATTAPPADY, KERALA**" is a bonafide record of research done by me during the course of research and the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title, of any other University or Society.

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CERTIFICATE

Certified that this thesis entitled **"IMPACT OF ECO-RESTORATION ON NUTRIENT BALANCE IN EASTERN ATTAPPADY, KERALA"** is a record of research work done independently by **Mr. Raneesh, C (2012-17-106)** under my guidance and supervision and it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to him.

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INTRODUCTION

INTRODUCTION

Natural areas everywhere are being converted and sacrificed for short-term economic gain at an ever-increasing rate by an ever-growing human population (MEA, 2005). The clearing of forests to use the land for other purposes, or to leave it as unused wasteland is one of the most widespread and important changes that people have made to the surface of the earth. There is a clear tendency in the tropics for addressing the problem of degraded lands through reforestation and afforestation projects. For example, the area of tree plantation in the 90 countries monitored by the Food and Agriculture Organization (FAO, 1993) increased by 150 percent at an annual rate of 2.6 million ha between 1980 and 1990 and 2.0 million ha between 1990 and 2000 (FAO, 2001). The main purpose of many of these plantations is for land protection or rehabilitation.

Ecological restoration is the process of assisting the recovery of an ecosystem that has been degraded, damaged or destroyed (SER, 2004). Ecological restoration becomes a fundamental component of conservation and sustainable development programs throughout the world by virtue of its inherent capacity to provide people with the opportunity not only to repair ecological damage, but also improve the human condition. It is now widely recognized that conservation of existing natural fragments will not be sufficient to maintain extant biodiversity or meet conservation goals. In such a situation, ecological restoration has been initiated as the main alternative to safeguard natural resources and to conserve biodiversity. Numerous literature reports of successes of both small and large-scale restoration projects in the tropics further demonstrate the greater relevance of tropical forest restoration. Nevertheless, the area subjected to restoration and rehabilitation is still small (13 percent) in comparison to the area deforested annually in the tropics (FAO, 2001).

Monitoring the restoration success is one of the major phase of ecological restoration. The knowledge about the objective of eco-restoration is a major factor in assessing the restoration success. Several authors have put forth various indicators for assessing an eco-restoration project. Most restoration projects measure some aspects of vegetation structure or diversity, arthropod diversity or nutrient pools (Ruiz-Jaén and Aide, 2005), but studies rarely assess more than one measure of each component. For assessing the impact of eco-restoration on a degraded land it is crucial to identify the environmental changes brought about by the restoration initiative on the ecosystem. These changes can be better evaluated using the indicators for measuring environmental success of an eco-restoration work. In assessing the environmental performance of restored land, many studies have focused on three major ecosystem attributes: vegetation structure, species diversity, and ecosystem processes, as these were identified as essential components for a long-term persistence of an ecosystem. Vegetation structure and species diversity provide information on habitat suitability, ecosystem productivity, help predict successional pathways and trophic structure necessary for ecosystem resilience. Measure of ecosystem processes of an eco-restored area mainly focus on the nutrient pool in an ecosystem perspective.

Nutrient balance is one among the important factor which determines the self-sustainability of a restored site as the availability of nutrients in an ecosystem depends on efficient recycling of nutrients within the ecosystem. Through this cycle, nutrients are returned to the soil in litter following the death of plant tissues, released from the litter through decomposition and mineralization, recycled through soil organisms and taken up by vegetation (Prescott, 2002). Quantification of the nutrient balance of an eco-restored area and comparing it with that of a reference site provide a reliable information for the assessment of the success of an ecological restoration intervention.

The present study area, Attappady, is located in the North eastern part of Palakkad district, in the Western Ghats region of Kerala. Although the two rivers, Bhavani and Siruvani control the drainage in Attappady, this region is considered to be one among the driest parts of Kerala Western Ghats. The forests of Attappady, which were once luxuriant, have been converted to various types of land uses during the past fifty years. Only a portion of the area received protection in the form of reservation by the British during the early 1900. Deforestation and unsuitable agricultural practices have caused almost irreparable damages to both the land and the people. There by resulted in extensive water shortage and loss of soil fertility. It was in these circumstances, the state government formed an autonomous society, 'Attappady Hill Area Development Society' (AHADS) with its headquarters at Agali for the implementation of the Project 'Attappady Wasteland Comprehensive Environmental Conservation Project' (AWCECOP) in 1995 with the objective of curbing the processes of ecological and social degradations and improving the livelihood of the affected communities, with special focus on the tribal communities. The major objectives of this project include ecological restoration of wastelands in Attappady, prevention of further ecological degradation, development of replicable models of participatory eco-restoration and promotion of sustainable livelihood options for the local people in harmony with the resource base (AHADS, 2011).

The present research entitled "Impact of eco-restoration on nutrient balance of eastern Attappady, Kerala" aims at assessing the impact of ecological restoration and monitoring the success of restoration by evaluating and comparing the nutrient pool and vegetation attributes in plantations, non-eco-restored areas and biomass conservation areas of Eastern Attappady.

REVIEW OF LITERATURE

2. Review of Literature

Forest ecosystem and biodiversity are declining throughout the world, since human initiated the manipulation of the natural world. Despite increasing efforts for sustainable forest management and conservation, the extent of forest habitat, in particular in the tropics, continues to decrease mainly by forest conversion to agriculture and urban land uses (De Fries *et al.,* 2010). Over a period of 5,000 years, the cumulative loss of forest land worldwide is estimated at 1.8 billion hectares, an average net loss of 360,000 hectares per year (Williams, 2003). Population growth and the burgeoning demand for food, fibre and fuel have accelerated the pace of forest clearance, and the average annual net loss of forest has reached about 5.2 million hectares in the past ten years (FAO, 2010). In the present scenario of conservation and management of the global forest cover, ecological restoration, otherwise termed as eco – restoration plays a significant role. At present, more abandoned agricultural land area is being restored by tree plantations than by secondary succession (FAO, 2011).

To meet the increasing demands for ecosystem services provided by forests, in particular, the many provisioning services, large-scale (passive or active) ecological restoration is probably the only solution that will be effective in the long term (Benayas *et al.,* 2009). Establishing short-rotation single or multiple species plantations on degraded soils, restoration plantings in secondary forests or assisted regeneration in selectively logged forest are a few examples of the wide spectrum of forest ecological restoration approaches (Lamb, 2010). They all have in common that they consist of management interventions that aim at recovering ecosystems that have been degraded, damaged or destroyed by human activities (Birch *et al.,* 2010). As ecological restoration can potentially contribute to the improvement of human livelihoods, as well as enhancing biodiversity, it is assuming an increasingly central role in global environmental policy (Ehrlich and Pringle, 2008). Although the science and practice of ecological restoration have developed rapidly, the emerging policy focus on ecosystem services represents a significant shift in the objectives of restoration (Bullock *et al.,* 2011).

2.1 ECOLOGICAL RESTORATION

The concept of Ecological restoration was initiated ever since the scientific world realized the importance of restoring ecosystem perspectives in the context of degrading natural forest cover. Restoration ecology provides the theoretical basis for this concept. Ecological restoration refers to the concept of re-establishing the main characteristics of an ecosystem that has been degraded, damaged or destroyed (Jordan *et al.,* 1987), and is usually carried out to enhance the conservation value or productivity of a given area (Hobbs and Norton, 1996). The Society for Ecological Restoration defined the Eco – restoration as the process of assisting the recovery of an ecosystem that has been degraded, damaged or destroyed (SER, 2004). Eco – restoration is therefore an important practice that may increase levels of biodiversity in human – altered ecosystems (Brudvig, 2011) and may mitigate the impact of climate change (Harris, 2009). Gilmour *et al.* (2000) gave a well-structured definition for ecological restoration as a process that re-establish the presumed structure, productivity and species diversity of the forest originally present at a site. The ecological processes and functions of the restored forest will closely match those of the original forest (Gilmour *et al.,* 2000).

There are various approaches for overviewing a restoration initiative. Aerts and Honnay (2011) describes three approaches to ecological restoration namely the community approach, ecosystem approach and the biodiversity – ecosystem function approach. Succession is an important guideline principle in the community approach to ecological restoration (Palmer *et al.,* 1997). The restoring forest is a dynamic ecosystem, with changing species composition and forest structure, but interventions and management steer the forest towards a desired climax or pre-disturbance community structure. These interventions are usually designed to accelerate natural succession or to bypass intermediate successional phases. The community approach mainly focussing on restoring forest biodiversity (Aerts and Honnay, 2011). In the ecosystem approach, restoration of ecosystem functions such as primary production, energy flows and nutrient cycles, is the guiding principle on which restoration efforts are based (Naeem, 2006). Basically this approach aims at restoring suitable abiotic conditions that allow (passive) recolonization of species (Aerts and Honnay, 2011). Restoration of degraded sites with trees that alter the physical and chemical characteristics of the soil and that affect the biochemical cycles through litter fall or root activity presents a typical example of the ecosystem approach to ecological forest restoration (Paul *et al.,* 2010).

The biodiversity – ecosystem function approach (BEF) is based on the ecological perspective of interaction between the species diversity and the ecosystem functioning. The functioning of an ecosystem incorporates processes such as decomposition of organic matter, fixation of carbon, nutrient and water cycling and degradation of toxic compounds. Meta-analyses of the results of mainly small-scale biodiversity experiments have shown than, on average, ecosystem functions increase with increasing species number (Aerts and Honnay, 2011). Naeem (2006) was the first to propose that restoration ecology may benefit from insights from the biodiversity – ecosystem function (BEF) framework, and this idea has been further elaborated by Wright *et al.* (2009).

2.2 ASSESSING ECOLOGICAL RESTORATION SUCCESS

Ecological restoration can help reverse some of the more severe impacts of forest loss and degradation by improved hydrological regulation and nutrient cycling, providing more diverse and better connected habitats, and thus supporting more biological diversity and options to increase the resilience and adaptability of existing natural systems (Maginnis and Jackson, 2002). Despite substantial expenditure on restoration, little information exists to indicate the success of restoration projects in achieving ecological and other benefits (Le *et al.,* 2011). Many existing restoration projects have partially or completely failed because the trees planted have not survived or have been rapidly destroyed by the same pressures that have caused forest loss and degradation in the first place. Ensuring long-term success is one of the greatest challenges facing many restoration initiatives in developing countries. Most evaluations of reforestation success have been narrowly focused on reaching planting area targets. Few evaluations have measured the environmental or socio-economic success of reforestation projects (Le *et al.,* 2011).

Knowing the objectives of reforestation is important for assessing success (Aronson *et al.,* 1993; Brown and Lugo, 1994; Hobbs and Harris, 2001). Restoring environmental values, ecosystem functions and ecosystem services are some of the important long-term objectives of restoration (Sala *et al.,* 2000). Reforestation projects typically progress through two main stages: an initial 'establishment' phase and a long-term 'building' phase (Kanowski and Catterall, 2007). Reforestation success can therefore be viewed as a continuum from the successful establishment of the initial planting through to maturation and realisation of the full environmental and socioeconomic benefits of the forest (Reay and Norton, 1999). This means that the measures of success will differ at different stages in a reforestation project. Undertaking assessments at an early stage of a reforestation project can only indicate likely future success (Reay and Norton, 1999). As the forest matures more information is required to make judgements about environmental and socio-economic success (King and Keeland, 1999; Reay and Norton, 1999).

2.2.1 Indicators for measuring Restoration success

Most restoration projects measure some aspects of vegetation structure or diversity, arthropod diversity or nutrient pools (Ruiz-Jaén and Aide, 2005), but studies rarely assess more than one measure of each component. Along with assessing many measures in a restored site, it is necessary to compare this information with similar data from pre-restored and reference sites (Hobbs and Norton, 1996). The pre-restored and reference sites should occur in the same life zone, close to the restoration project, and should be exposed to similar natural disturbances (Hobbs and Harris, 2001; SER, 2004). The use of reference points can help to identify whether the response of the restored site is caused by the restoration activity or by unassisted recovery (White and Walker, 1997).

A large number of qualitative and quantitative indicators have been either reported or proposed in the literature for the assessment of reforestation success. Le *et al.* (2011) proposed four major potential indicators for measuring restoration success. These include indicators for measuring establishment success, forest growth success, environmental success and socio-economic success. Vegetation structure, species diversity, and ecosystem processes have been identified as essential components for a long-term persistence of an ecosystem (Elmqvist *et al.,* 2003; Dorren *et al.,* 2004). In assessing the environmental performance of forests, many studies have focused on three major ecosystem attributes: vegetation structure (Salinas and Guirado, 2002; Jones *et al.,* 2004;

Kanowski *et al.*, 2008), species diversity (Peterson *et al.*, 1998; Kanowski *et al.*, 2008, 2009) and ecosystem functions (McKee and Faulkner, 2000; Davidson *et al.*, 2004). Measures of vegetation structure provide information on habitat suitability, ecosystem productivity, and help predict successional pathways (Jones *et al.*, 2004; Silver *et al.*, 2004; Wang *et al.*, 2004). Measures of species diversity provide information on susceptibility to invasions (e.g., proportion of native and exotic species), and trophic structure necessary for ecosystem resilience (Peterson *et al.*, 1998; Nichols and Nichols, 2003).

Measures of ecosystem processes provide information on biogeochemical cycles and nutrient cycling necessary for the long-term stability of the ecosystems (Herrick, 2000). Ecological restoration is based on the idea that a restored site should be self-sustaining, i.e., should require no inputs of energy or materials from external sources (Jackson *et al.*, 1995). Analysis of the fluxes of energy and materials into, out of, and within ecosystems is a hallmark of ecosystem analysis (Ehrenfeld and Toth, 1997).

2.2.2 Nutrient balance as a qualitative indicator

Energy flow and nutrient balance are essential for the functioning of an ecosystem. Nutrient cycling is a concept in ecological research that has made considerable progress since the seminal work of Nye and Greenland (1960) on nutrient flows and pools in shifting cultivation systems (Hartemink, 2005). It is often mentioned that the quantification of nutrient flows and stocks is an important step in the development of sustainable land use systems, especially on low-fertility soils of the humid tropics (Schroth *et al.*, 2001). The release of nutrients from decomposing litter is an important internal pathway for nutrient flux in forested ecosystems (Hartemink, 2005). The conversion of natural ecosystems to other land uses alters ecosystem functions that normally provide services critical to human well-being. Among these functions could be mentioned regulation functions, which involve the capacity of natural and semi-natural ecosystems to regulate essential ecological processes and life support systems through bio-geochemical cycles and other biospheric processes (e.g. nutrient regulation, water supply, water regulation, soil retention, soil formation) (Pelaez, 2012).

The availability of nutrients in forest ecosystems depends on efficient recycling of nutrients within the ecosystem. Through this cycle, nutrients are returned to the soil in litter following the death of plant tissues, released from the litter through decomposition and mineralization, recycled through soil organisms and taken up by vegetation (Prescott, 2002). The nutrient cycling in tropics is diverse. Variations in mineral cycling nonetheless follow coherent, explicable patterns in tropical forests (Vitousek and Sanford, 1986). These varying pathway of nutrient dynamics in tropical forest ecosystem depends on several factors which determine the rate of decomposition and nutrient mineralization. Rates of decomposition and nutrient mineralization are governed by temperature and moisture conditions, chemical and physical nature of the litter, species diversity depending on the species present (Prescott, 2002) and soil fertility (Vitousek, 1982).

The need for research on the nature of ecosystem processes in restoration projects is illustrated by the notion that restoration can be accomplished by the planting of appropriate plant species following well established agronomic guidelines for fertilization and irrigation. This approach to restoration is exemplified in many manuals of reclamation and restoration (Ehrenfeld and Toth, 1997). Restorations will be profoundly affected by both the forms and magnitudes of the fluxes of energy and materials into, out of, and within ecosystems (Ehrenfeld and Toth, 1997). Many of the restoration-reclamation interventions on degraded lands could be redirected towards re-establishing ecosystem health and human wellbeing, which can be achieved through nutrient recycling activation by utilizing integrative ecosystem management (Pelaez, 2012). Fluxes into and out of highly disturbed sites are likely to differ markedly in both quantity and quality from those of intact ecosystems (Hedin *et al.,* 1995). Ecosystems vary widely in the magnitude of fluxes across boundaries (Morris, 1991). As with energy fluxes across boundaries, the restorationist needs to evaluate the magnitude of these fluxes, both those currently existing on the site to be restored and those expected in the target ecosystem (Ehrenfeld and Toth, 1997). Gains and losses of nutrients depend not only on the nature of the ecosystem's boundaries, but also on internal mechanisms for the retention of these materials. Degraded ecosystems and bare sites requiring ecosystem creation are likely to have little capacity to retain materials, primarily because they tend to have little or no organic matter within the soil or in a surficial organic horizon (Ehrenfeld and Toth, 1997).

There is also a general consent that vegetation recovery can successfully restore soil nitrogen stocks (Silver *et al.*, 2005; Paul *et al.*, 2010b).

The rates at which nutrient transfers take place, the relative importance of various structural components as sources of long-term storage for nutrients within the system, and the efficiency with which a given ecosystem compartment utilizes its nutrients all are basic descriptors of ecosystem function (Ehrenfeld and Toth, 1997). These transfers have received extensive attention from ecosystems ecologists (Aber and Melillo, 1991; Coleman and Crossley, 1996). So these descriptors can be used extensively for evaluating and assessing the success of restoration projects throughout the world. Some nutrient cycling studies have revealed a higher nutrient supply to soils from native forests than from tree plantations. This appears to be an ecological advantage for recovering and maintaining the main ecosystem functioning features, which needs to be taken into account in restoration programs in highly degraded lands (Pelaez, 2012).

Passive and active restoration models for the recovery of degraded lands have been designed following structural and functional aspects of native and non-native ecosystems. Although passive restoration models based on natural regeneration processes are simple and cheap, they are not always successful (Perrow and Davy, 2002; Walker *et al.*, 2007). As an alternative, active restoration models permit the accelerated restoration of ecological processes, such as nutrient cycling and carbon seizure, in addition to restoring the habitat for biodiversity (Celentano *et al.*, 2011). The most common active restoration model involves planting trees in high densities, which has been proved to be advantageous for the recovery of soils and biological diversity in degraded tropical lands. This recovery occurs as a result of the reactivation of the biogeochemical cycle of litterfall production and decomposition (Garten Jr, 2002; Singh *et al.*, 2002). Regardless of the model, within the soil, the processes reactivated in these ecosystems through nutrient cycling increase organic matter and nutrients, regulate the pH, improve aggregate stability and provide greater water storage capacity (Chakraborty and Chakraborty, 1989; Leon *et al.*, 2011).

According to Pelaez (2012), nutrient cycling studies that examine these restoration models could include processes such as fine litterfall and litter decomposition rates, nutrient release rates and nutrient release patterns, above ground litter and nutrient accumulation, soil microorganism respiration, nutrient canopy exchange (leaching and washing processes), and nutrient losses (deep drainage and runoff). An effective utilization of these functional ecosystem parameters provide proper guidance for evaluating the sustainability of a restoration intervention in tropics.

2.2.2.1 Soil Nutrients status

Soil is the foundation of basic ecosystem functions. Soil and vegetation exhibit an integral relationship, where soil supports vegetation by providing moisture, nutrients and anchorage, and on the other hand vegetation provides protective cover for soil, by suppressing soil erosion, and maintaining soil nutrients through litter accumulation and nutrient cycling (Roby, 2013). Soil properties have a particularly large influence on the composition and structure of terrestrial flora (Tilman, 1982; Marx *et al.*, 1999; Iturbe, 2000). Several studies have shown that plant species differ in their capacity to modify soil properties (Gallardo and Merino, 1993; Vinton and Burke, 1995; Cornelissen *et al.*, 1999) since, plant functional traits such as growth form, biomass allocation, tissue chemistry and lifespan can significantly affect organic matter decomposition and nutrient dynamics (Hooper and Vitousek, 1998; Carrera *et al.*, 2009). Individual plant species can affect ecosystem processes and can influence nutrient dynamics by a variety of mechanisms (Hooper and Vitousek, 1998; Singh and Singh, 1999). The presence of certain tree species can result in better soil structure and increased soil nutrient availability (Sanchez *et al.*, 1985; Nair, 1989; Young, 1989; Montagnini and Sancho, 1990).

The soil and vegetation have a complex interrelation because they develop together over long period of time. The vegetation influences the chemical properties of soil to a great extent. The selective absorption of nutrient elements by different tree species and their capacity to return them to the soil brings about changes in soil properties (Singh *et al.*, 1986). There is a general consent that vegetation recovery can successfully restore soil nitrogen stocks (Alriksson and Olsson, 1995; Silver *et al.*, 2005; Paul *et al.*, 2010). Concentration of elements in the soils is a good indicator of their availability to plants. Their presence in soil would give good information towards the knowledge of nutrient cycling and bio-chemical cycle in the soil–plant ecosystem (Pandit and Thampan, 1988). This information can be effectively utilized in restoration studies for assessing the success of the projects. Differences in vegetation structure and composition between the reference site and the restored plots are likely to contribute to the differences observed in some of the studied soil chemical properties (Vinton and Burke, 1995; Cornelissen *et al.*, 1999; Cornwell *et al.*, 2008; Guo *et al.*, 2008).

Forests in general have a greater influence on soil conditions than most other plant ecosystem types, due to a well-developed ''O'' horizon, moderating temperature, and humidity at the soil surface, input of litter with high lignin content, high total net primary production, and high water and nutrient demand (Binkley and Giardina, 1998). Moreover, different tree species can differ significantly in their influence on soil properties as well as soil fertility (Augusto *et al.*, 2002). The properties of the soil are the important factor for the growth of the plants. Among them, the most important factor is soil fertility (Gairola *et al.*, 2012). Leaching is an important pathway for nutrient losses in soils of the humid tropics (Buresh and Tian, 1997; Grimme and Juo, 1985; Sollins, 1989).

i. Soil Organic Carbon (SOC)

Soil is the largest pool of terrestrial organic carbon in the biosphere, storing more C than is contained in plants and the atmosphere combined (Schlesinger, 1997). Organic C is important for the sustainability of vegetation (Dragovich and Patterson, 1995). Soil C and N are intimately linked and primary source of C and N in the soil is organic matter, in the form of plant and animal debris (Aber and Melillo, 1991). The quality and quantity of Soil Organic Matter (SOM) determines the production potential of the soil. Soil Organic Matter (SOM) is responsible for building a major portion of the Soil Organic Carbon (SOC) pool, which regulates physical, chemical, and biological properties of the soil (Woomer *et al.*, 1994).

Soil organic matter is influential in augmenting and enhancing plant growth (Omodt *et al.*, 1975). Soil organic carbon is a function of the quantity of dry matter deposition as litter fall. Soil Organic Carbon (SOC) storage is controlled by the balance of C inputs from plant production and outputs through decomposition (Jenny, 1941; Schlesinger, 1977). Giardina *et al.* (2001) documented that high quality litter leads to the formation of high quality organic C and N in the mineral soil. The abundance of organic C in the soil affects and is affected by plant production, and its role as a key control of soil fertility and agricultural production has been recognized for more than a century (Dokuchaev, 1883; Hilgard, 1906; Jenny, 1941; Tiessen *et al.,* 1994).

Climate plays an important role in Soil Organic Carbon (SOC) of sites. Precipitation constrains plant production and decomposition in arid to subhumid ecosystems (Webb *et al.,* 1978; Sala *et al.,* 1988; Amundson *et al.,* 1989), with a greater response of plant production relative to decomposition (Austin and Vitousek, 2000). In addition to climate, soil texture plays an important role, with increasing clay content decreasing C outputs through its stabilizing effect on soil organic carbon (Paul, 1984). As expected from these controls, regional patterns of soil organic carbon are positively associated with mean annual precipitation and clay content, and are negatively correlated with mean annual temperature in a diverse array of soils and vegetation types (Jobbagy and Jackson, 2000). The Soil organic carbon concentration varies across the landscape but more soil C variability is found at varying elevations (Powers and Schlessinger, 2002). Generally, the increase in Soil Organic Matter (SOM) with increasing altitude is due to the addition of leaf litter annually and slow decomposition rates of organic residues under low temperature (Dimri *et al.,* 1997).

ii. Soil Nitrogen

Nitrogen is an essential element for all growth processes in plants. If it is not available, the plant remains stunted and comparatively undeveloped. The soil stores more than 90% of the Nitrogen in the terrestrial biosphere (Schlesinger, 1986). Soil N is supposed to be the most limiting nutrient in a majority of ecosystems (Fenn *et al.,* 1998). The values of total N varied significantly in different forest types (Gairola *et al.,* 2012). N is mostly present in the form of nitrates in the soil, which is very mobile and get moved freely with moisture (Gupta and Sharma, 2008). The availability of N depends to a large extent on the amount and properties of organic matter (Hann, 1977). The amount of mineral N in the soil depends mainly on the balance between rates of mineralization and immobilization (Killham, 1994; Accoe *et al.,* 2004).

Nitrogen has a special place in soil processes, because it does not occur in a mineral form, and is therefore absent from the primary minerals (Bradshaw, 1997). Therefore, N is a key element in soil restoration (Bradshaw *et al.,* 1982; Kendle and Bradshaw, 1992). According to Richter *et al.* (1999), an aggrading forest ecosystem is a strong carbon sink and the increasing demand by the aggrading plant biomass may not permit the mineral N and P to accumulate. Venkateswaran and Parthasarathy (2003) compared the nutrient status at different soil depths of the natural forests and man-made plantations of Nilgiris in Tamil Nadu and observed that the total nitrogen status was very high in 0-15 cm soil layer.

iii. Soil Potassium

The mineral potassium (exchangeable K) is found in soluble form in all parts of plants, and is responsible for the carbohydrate and protein formations. Potassium activates the enzymes of the plants, which in turn help in the metabolism of the plants, starch synthesis, nitrate reduction, and also plays a role in sugar degradation (Gairola *et al.,* 2012). Potassium performs very vital processes like regulating transpiration and respiration, influencing enzyme action, and synthesis of carbohydrates and proteins, etc. (Brady, 1996). The decrease of K is caused by leaching and drainage, which results in the destruction of vegetation (Basumatary and Bordoloi, 1992). Basumatary and Bordoloi (1992) and Boruah and Nath (1992) reasoned that a layer of organic matter significantly improves the retention of K in the soils. Janssens *et al.* (1998) studied the relationship between plant biodiversity and different soil chemical factors in numerous sites located in grassland ecosystems of temperate regions and observed higher soil K content in sites with higher species diversity.

iv. Soil Phosphorous

Available P is inevitable for the vital growth processes in plants. It is observed that P is found in all terrestrial systems in the form of organic and inorganic matter, while organic P forms are the major available source of phosphorus (Gairola *et al.,* 2012). Soil organic matter has the organic form of P transformed into insoluble form in many soils. The rates of weathering also control P availability to plants. Phosphorus in turn controls the input levels of plant residues (Brown *et al.,* 1994). The C–P and N–P ratios vary according to the parent material, which depends upon degree of weathering and by other means (Paul and Clark, 1996). The amount of P indicates the character of soil to allow specific plants to grow at a particular site, which is also useful to identify the vegetation type of the area. So that available P is an in evitable entity for assessing the progress of a restoration site. It has been reported that a large proportion of P is stored in the forms that are unavailable to plants (Murphy, 1958), for example, H_2PO_4, which becomes available at low pH values and suffers from fixation by hydrous oxides and silicate minerals (Soromessa *et al.*, 2004).

v. Cation exchange capacity (CEC)

Cation exchange capacity (CEC) is a parameter of soil which represents the capability of soil to attract, retain and hold exchangeable cations (K^+, Na^+, Ca^{2+}, Mg^{2+}, Al^{3+} etc.). Foth (1990) stated that among various parameters influencing the soil exchangeable capacity, soil pH is an important parameter which is positively correlated. Other parameters include soil texture, organic matter content etc. Generally, tropical soils have low CEC, especially for high sandy and low pH soils. Minerals as oxides of aluminium, iron and manganese that are very abundant in tropical soils also contribute to the low CEC. Balagopalan (1987) studied the soil properties of natural forest and plantations of Trivandrum forest division and reported that in natural forest sequence exchangeable bases, exchangeable acidity, CEC and base saturation were higher in moist decidous forest.

2.2.2.2 Litter characteristics and nutrient transfer

Litterfall is a fundamental process in nutrient cycling and it is the main means of transfer of organic matter and mineral elements from vegetation to the soil surface (Vitousek and Sanford, 1986; Regina *et al.*, 1999). The analysis of litter quality and quantity and its rate of decomposition is highly important for the understanding of energy flow, primary productivity and nutrient cycling in forest ecosystems (Oladoye *et al.*, 2008). Several authors have defined litter quality in terms of initial N concentrations, the C/N ratio, initial lignin concentrations, and the lignin/N ratio. Litter quality affects not only the rates of mass loss, but also the patterns and rates of nutrient immobilization or release (Regina *et al.*, 1999). Knowledge of the amounts of nutrients cycled through litter-fall can be most useful because litter-fall represents a major process for transferring nutrients from aboveground vegetation to soils, and the relative rate at which forest vegetation loses organic matter versus particular nutrients provides an index of the efficiency of nutrient use within vegetation (Hirose, 1975; Vitousek, 1982). The nutrient concentration of litter depends on the availability in the soil and/or the uptake capacity of the plants (Hartemink, 2005). The breakdown of litter and soil organic material release of nutrients into forms available to plants and microorganisms completes the nutrient cycle in forest ecosystems (Vitousek and Sanford, 1986).

Quantification of the nutrient flux associated with litter-fall is important for the understanding of ecosystems dynamics. The maintenance of natural systems or soil fertility in tropical forest ecosystems is achieved by high and rapid circulation of nutrients through the fall and decomposition of litter (Oladoye *et al.*, 2008). Decomposition is a key process in the control of nutrient cycling and formation of soil organic matter (Berg and McClaugherty, 2002). Decomposition of leaf litter is also an integral and significant part of biochemical (i.e. intra system) nutrient cycling and food webs; this refers to both the physical and chemical breakdown of litter and the mineralization of nutrients (Terrell *et al.*, 2001). The decomposed litter is the basis of many food chains in tropical forests and is a principal source of energy for the saprobiota of the forest floor and soil, where the trophic chain of detritus predominates (Oladoye *et al.*, 2008; Regina *et al.*, 1999).

Nutrients may be released from litter by leaching or mineralization (Swift *et al.*, 1979). Nutrient release from decomposing litter affects the primary productivity of ecosystems (Blair, 1988) since these nutrients then become available for plant uptake and are not lost from the system. Decomposition refers to the physical breakdown of the material, while mineralization refers to the release of inorganic nutrients available for plant uptake. Decomposition is primarily a biological process resulting from enzymatic activities of soil microorganisms and influenced in a variety of ways by activities of the soil fauna (Visser, 1985; Prescott, 2005).

Melillo *et al.* (1989) present a general model of the decomposition process from litter to humus in two phases. During the early stage, there is rapid loss of water-soluble components followed by rapid loss of cellulose from the litter. There is little loss, or possibly even a gain of insoluble decay products (collectively referred to as lignin. During the early phase, carbon is relatively available and nutrients are limiting, and there is immobilization of the limiting nutrient (usually N). Once the litter reaches the late stage of decomposition, it is considered to be humus and it is distinguished by a stabilized content and slow decay of all components. The late stage of decay is characterized by a net loss of lignin and net mineralization of N (Prescott, 2005).

2.2.2.2.1 Factors affecting nutrient release

Plant litter decomposition has long been recognized as an essential process for organic matter turnover and nutrient fluxes in most ecosystems. The subsequent release of carbon and nutrients represents the primary source of nutrients for plants and microbes (Swift *et al.,* 1979; Berg and McClaugherty, 2008). These are key processes for the functioning of ecosystems and the delivery of ecosystem goods and services (Hättenschwiler and Gasser, 2005). The rate at which nutrients are released depends on several factors, as indicated by Seastedt (1984); the chemical composition of the litter, the structural nature of the nutrient in the litter matrix, the microbial demand for the nutrient, and the availability of exogenous nutrient sources. Rates of plant litter decomposition and nutrient mineralization are influenced mainly by three factors: (i) climate on a broad regional scale with warmer and more humid climate generally leading to faster decomposition, (ii) litter quality on a smaller scale with higher nitrogen (N) contents mostly enhancing decomposition and (iii) nature and abundance of decomposing organisms (Jonsson and Wardle, 2008).

Although the activity of soil organisms has been identified as a controlling factor (Lavelle *et al.,* 1993; Couteaux *et al.,* 1995), the rate of microbial activity should be considered as a mechanism by which the influences of climate and litter quality are realized (Prescott, 2005). Tree species can also alter decomposition rates indirectly through effects on environmental conditions. For example, tree species can induce changes in soil fertility, microclimate and faunal and microbial communities in the forest floor (Mitchell *et al.,* 2007; Aponte *et al.,* 2010, 2011), all of which influence the decomposition process (Hobbie, 1996; Sariyildiz and Anderson, 2003; Austin and Vivanco, 2006).

Decomposition rate is also determined by the chemical quality of the litter, which is largely a function of the relative proportions of major groups of C compounds in the litter (Prescott, 2005). These groups, in order of decreasing decomposability, are sugars, cellulose, lignin, and phenols (Minderman, 1968). Differences between tree species litter decomposition have commonly been related to distinct substrate quality with litter C:N and N:P ratios, lignin content, Ca and Mn concentrations emerging as the main rate-controlling factors (Melillo *et al.,* 1982; Cornelissen *et al.,* 2006; Hobbie *et al.,* 2006; Cornwell *et al.,* 2008; Güsewell and Gessner, 2009; Berg *et al.,* 2010).

As litter decomposition progresses through time, litter quality varies and the factors controlling litter mass loss might change (Berg and McClaugherty, 2008). Early decomposition is often determined by the availability of limiting elements such as N and P, whereas in late stages carbon loss has been related to elements required to decompose recalcitrant components such as lignin that accumulate in the remaining litter (Güsewell and Gessner, 2009; Berg *et al.,* 2010). Seneviratne (2000) suggested that N contents lower than 2% limit the decomposition of tropical litters. Some of the apparent effect of N may actually be the result of low levels of polyphenols that usually accompany high concentrations of N in litter (Haynes, 1986). Relationships between decay rates and litter P concentrations have also been reported at sites where P availability is low due to either edaphic factors or N deposition (Aerts and Caluwe, 1989; Vitousek *et al.,* 1994; Vesterdal, 1999).

Other attributes of litter, such as toughness, also influence the rate of decay. Perez-Harguindeguy *et al.* (2000) found that leaf toughness or tensile strength was a good predictor of decomposition rate in a broad range of species. In the same study, the C:N ratio was also found to be a good predictor of decomposition rate, due largely to the fact that higher C:N values are often associated with compounds showing higher C enrichment, particularly lignin. The generally faster decay of N-rich litters suggests that litter decay rates would increase if their N content were increased through N fertilization or deposition, or would decrease if the N content declined as a result of elevated atmospheric CO^2 levels. In contrast, rates of decay have not been consistently altered by changes in the C:N ratio of litter resulting from N additions (Cotrufo and Ineson, 1995; Prescott, 1995) or elevated CO^2 (Kemp *et al.,* 1994; Hirschel *et al.,* 1997; Finzi *et al.,* 2001). Thus, the completeness of decomposition is largely a function of the nature of the litter (Prescott, 2005).

Patterns of nutrient release from decomposing litter do not always follow those for mass or C losses (Prescott, 2005). While some nutrients (e.g., Mg^{2+}, Ca^{2+}, K^{+}, Na^{+}) are released as fast or faster than C, N and P are usually retained in the litter during the initial stages of decay (Swift *et al.*, 1979). This net immobilization may lead to an increase in tissue nutrient content, indicative of net import of N or P into the litter (Staaf, 1980). The tendency for N or P to accumulate or be released varies with species and with site of incubation (MacLean and Wein, 1978; Edmonds, 1980; Bartos and DeByle, 1981; Kelly and Beauchamp, 1987; Tripathi and Singh, 1992), but appears to be closely related to the initial concentrations of these nutrients in the litter.

2.2.2.3 Vegetation nutrient status

Several studies have shown that plant species differ in their capacity to modify soil properties (Gallardo and Merino, 1993; Vinton and Burke, 1995; Cornelissen *et al.*, 1999) since plant functional traits such as growth form, biomass allocation, tissue chemistry, and lifespan can significantly affect organic matter decomposition and nutrient dynamics (Hooper and Vitousek, 1998; Carrera *et al.*, 2009). Plant species composition affects ecosystem nutrient cycling through plant-nutrient uptake and use amount and chemical composition of the leaf litter, rhizosphere interactions and micro-environmental changes (Hättenschwiler *et al.*, 2005; Hättenschwiler and Gasser, 2005). Total nutrient contents are determined by the amount of biomass, its distribution into different plant parts (leaves, branches, bark, boles), and the nutrient concentrations in each part (Vitousek and Sanford, 1986).

The forest canopy has a large influence on nutrient cycling. The foliage and branches of the canopy are a major nutrient sink, which retains nutrients on site (Prescott, 2002). Although branches and foliage comprise only a small portion of total tree biomass, these tissues are relatively nutrient-rich, and so may contain up to half of the N, P, Mg, K and Ca immobilized in tree biomass (Alban *et al.*, 1978). Despite this low percentage of total biomass the amount of nutrients accumulated in leaves is of great qualitative importance because the nutrients are subject to internal annual cycles within the tree (deciduous species) and, also, some of them return to the soil in the form of leaf litter (Vitousek and Sanford, 1986). The most important aspect of the canopy in terms of its influence on nutrient cycling is its role as the source of leaf litter. Characteristics of the canopy determine the amount and composition of leaf litter produced, which largely determines the amount of nutrients to be recycled, the composition of the soil microbial and faunal communities and the resulting availability of nutrients (Prescott, 2002). The amount of nutrients stored in the leaves depends above all on the leaf biomass of the population (Regina *et al.,* 1999).

Trees dilute their overall initial nutrient capital by increasing organic matter storage at a faster rate than the storage of nutrients and allows trees to survive in infertile soils, provided they successfully become established (Lugo *et al.,* 2004). Increased nutrient retranslocation and recycling with age allows older forest stands to sustain a larger biomass pool with similar or lower soil nutrient uptake as younger stands. This behavior contributes to the function of forests as nutrient and carbon sinks. Sequestration of carbon and nutrients occurs in woody tissue with low nutrient concentration, while production of new tissue uses nutrients acquired by retranslocation and soil uptake (Lugo *et al.,* 2004).

Nutrient concentrations in individual tissues are more likely to reflect the influence of soil fertility. All leaves have the same basic function, and all utilize the same suite of nutrients in the process of fixing energy into organic forms (Vitousek and Sanford, 1986). Data on the extent to which plants on different sites accumulate nutrients in leaves can thus be useful in comparing nutrient status in different species and sites (Driessche, 1974). Nutrient concentrations in leaves (by weight) are sensitive to variations in the relative amounts of different tissues within leaves (Grubb, 1977); the presence of low-nutrient structural material within sclerophyllous leaves dilutes nutrient contents and yields lower concentrations. When a single species is found on two sites that differ in soil fertility, foliar nutrient concentrations are usually quite similar (Tanner, 1977), deviating only slightly in the direction of the mean difference between sites (Vitousek and Sanford, 1986).

When nutrient concentrations in leaves are correlated with nutrient concentrations in other plant parts, then foliar chemistry represents a useful indicator of overall nutrient status (Vitousek and Sanford, 1986). Grubb and Edwards (1982) and Tanner (1985) examined these correlations in detail within particular sites; the latter found significant correlations for nitrogen and phosphorus while the former did not. Vitousek and Sanford (1986) compared foliar and overall vegetation nutrient concentration of broader range of sites in tropical forests of the world, and found that they are clearly positively correlated.

The dynamics of nutrient cycling in restored stands will change depending on the species that occupy the site, their abundance, and dominance. A particular species can affect nutrient cycling in different ways depending on the process, its magnitude, timing, and efficiency (Lugo *et al.*, 2004).

2.2.3 Estimation of above ground biomass in restored sites

Carbon stock is typically derived from above-ground biomass by assuming that 50% of the biomass is made up by carbon. The most accurate method for the estimation of biomass is through cutting of trees and weighing of their parts. This destructive method is often used to validate others, less invasive and costly methods, such as the estimation of carbon stock using non-destructive in-situ measurements and remote sensing (Clark *et al.*, 2001; Wang *et al.*, 2003). But it is an extremely time consuming and destructive method, generally limited to small areas and small tree sample sizes (Ketterings *et al.*, 2001). For natural vegetation and restoration sites destructive method is not often recommended where cutting trees are strictly prohibited. Allometric equations for relating tree diameter at breast height (D) or other easily measurable variables to standing volume of wood or total biomass C, and nutrient stocks are commonly used for forest inventories and ecological studies (Ketterings *et al.*, 2001). These long term forest inventories are most useful in order to evaluate the magnitude of carbon fluxes between aboveground forest ecosystems and the atmosphere (Houghton, 2003; Grace, 2004).

The use of allometric regression models is a crucial step in estimating Above Ground Biomass (AGB), yet it is seldom directly tested (Crow, 1978; Cunia, 1987; Brown *et al.*, 1989; Houghton *et al.*, 2001; Chave *et al.*, 2001). Because 1 ha of tropical forest may shelter as many as 300 different tree species (Oliveira and Mori, 1999), one cannot use species-specific regression models, as in the temperate zone (Ter-Mikaelian and Korzukhin, 1997; Shepashenko *et al.*, 1998; Brown and Schroeder, 1999). Instead, mixed species tree biomass regression models must be used. Ketterings *et al.* (2001) proposed a protocol for forest biomass assessment based on the use of these allometric relationships which involve four steps: (1) choosing a suitable functional form for the allometric equation; (2) choosing suitable values for any adjustable parameters in the equation; (3) field measurements of the input variables such as tree diameter; and (4) using the allometric equation to give the above-ground biomass of individual trees and summation to get area estimates.

The allometric scaling theory postulates the existence of a universal power-law relationship between tree biomass and tree diameter with a fixed scaling exponent close to 8/3 (Enquist *et al.,* 1998; West *et al.,* 1999; Enquist and Niklas, 2001). This value was derived from naturally occurring fractal metabolic networks that branch to supply all parts of living organisms, such as the vascular system and the branching structure in trees (West *et al.,* 1997). Relying on the allometric scaling theory, several authors recently developed regional biomass allometric models assuming a power-law relationship between tree biomass and tree diameter (Ketterings *et al.,* 2001; Chojnacky, 2002; Zianis and Mencuccini, 2004; Pilli *et al.,* 2006; Navar, 2009) while discussing the existence of a truly universal value of 8/3 (2.667) for the scaling exponent. The simple power-law relationship has also been questioned for large trees (Niklas, 1995; Chave *et al.,* 2005) because of mechanical and physiological limits to an increase in tree height at large diameters. For this reason, using a power-law relationship might lead to overestimation of biomass for large trees (Vieilledent *et al.,* 2012).

To overcome this problem, polynomial models of degree two and three on diameter, viewed as a reasonable generalization of the power-law model, have been used (Brown *et al.,* 1989; Niklas, 1995; Chave *et al.,* 2005). Including tree height as an additional size covariate has generally been shown to lead to far better biomass estimates (Brown *et al.,* 1989; Chave *et al.,* 2005). Chave *et al.* (2005) also found that environmental variables such as precipitation and seasonality, which determine forest type (e.g., dry, moist, and wet tropical forest), were significant variables in predicting tree biomass. In addition, the importance of wood density as an intrinsic explicative variable was confirmed in several studies (Baker *et al.,* 2004, Chave *et al.,* 2005, 2009; Henry *et al.,* 2010).

Dawkins (1961) collected data from forests in Trinidad, Puerto Rico, and Honduras. He used 38 trees from 8 different species. He predicted that a single biomass equation which hold across these species. Later, Ogawa *et al.* (1965), contrasted results from four forests stands in Thailand, a dry monsoon forest, a mixed savannah monsoon forest, a savannah forest, and a tropical rain forest. They found that the variable D^2H was a suitable predictor of total tree AGB across this gradient and proposed a general equation. Brown *et al.* (1989) analysed data from five studies in the humid tropics (1500 – 4000mm rainfall per year). A total of 168 trees were cut and weighed and an allometric equation for predicting biomass was obtained. Despite the fact that a sample of 168 trees is not likely to be representative of the many different tree species and forest types present in the humid tropics, the biomass equation filled to these data is widely used (Anderson and Ingram, 1993). Two major research efforts sought to establish such generic empirical allometric models for tropical forests by using large pan-continental data sets. Brown *et al.* (1989) and Brown (1997) used data from Central and South America and south and Southeast Asia, and the resulting models were updated by Pearson *et al.* (2005).

2.3 IMPORTANCE OF THE STUDY

The ultimate goal of restoration is to create a self-supporting ecosystem that is resilient to perturbation without further assistance (Urbanska *et al.*, 1997; SER, 2004). It is necessary to evaluate the status of a restoration project for further utilization in other interventions. Various authors have suggested that restoration success could be based on vegetation characteristics (Walters, 2000; Wilkins *et al.*, 2003), species diversity (Aarde *et al.*, 1996; Reay and Norton, 1999; Passell, 2000; McCoy and Mushinsky, 2002), or ecosystem processes (Rhoades *et al.*, 1998). Other authors have promoted a more integrated approach that includes many variables to provide a better measure of restoration success (Hobbs and Norton, 1996; Neckles *et al.*, 2002; SER, 2004).

Ecological processes such as nutrient cycling and biological interactions are important because they provide information on the resilience of the restored ecosystem (Ruiz-Jaen and Mitchell, 2005). For example, nutrient cycling determines how much organic and inorganic components are available for organisms to persist in an ecosystem (Davidson *et al.*, 2004; Feldpausch *et al.*, 2004). Nutrient cycling is usually measured indirectly by estimating nutrient availability (Fuhlendorf *et al.*, 2002). This can be accomplished by evaluating the proper channel of nutrient flow through vegetation, litter and soil nutrient balance. A study conducted by Lugo *et al.* (2004) on biomass and nutrient dynamics of restored Neotropical forests of Puerto Rico suggested that the capacity to acquire nutrients from soil, return nutrients via litter-fall, accumulate nutrients in soil, and rate of decomposition are species-specific.

MATERIALS AND METHODS

3. MATERIALS AND METHODS

3.1 STUDY AREA

3.1.1 Location

Attappady is one of the two extensive east sloping plateaus on the Western Ghats of Kerala. Attappady lies within the geographical extremes of 10^0 55' N and 11^0 15' N latitude and 76^0 22' E and 76^0 46' E longitudes in the district of Palakkad, Kerala. It covers an area of 731 km^2. The watershed line of the Western Ghats forms the western boundary of Attappady (ESRG, 1989). The northern side of Attappady is demarcated by the southern face of the Nilgiri. The eastern part is undulating to flat and merges with the plains of Coimbatore. The southern and south eastern boundaries are at a height of 1500 m extending from Muthikulam. The study area belongs to eastern part of the Attappady where high intensity of forest clearing occurred, ranging from Agali and Palliyara in the south to Chavadiyur in the north. Patches of existing biomass with a canopy cover of over 40% having the potential of natural regeneration were treated as biomass conservation areas (BCA) and forest patches with less than 40% canopy cover was subjected to total restoration and earmarked as plantations (AHADS, 2011). Eco-restoration works have been completed on 11,837.91 ha of forestland (Table 1) includes 3,776.25 ha of plantation and 8,061.66 ha of natural regeneration area (BCA) (AHADS, 2011). About 3,500 ha are still remain as wastelands which is considered as non-eco-restored areas in the study. The study area comprises of ten plantations, five Biomass Conservation Areas (BCA) and five non-eco-restored areas in eastern Attappady.

3.1.2 Land use

Deforestation, implementation of development projects and migration of settlers from the plains have all contributed to a typical land use scenario in Attappady (KFRI, 1991). The presence of sub-zones with distinct climate characteristics makes the same more complex. Habitation and agriculture is becoming the most dominating landuse system followed and are concentrated in the central and eastern portions of Attappady. The north-west and southern areas are mostly vegetated and habitation and agriculture is sparse.

Table 1. Afforestation and Biomass conservation works at Attappady (AHADS, 2011)

Sl. No.	Year	Biomass Conservation Area (Ha)	Plantations (Ha)	Seedlings planted (nos.)	Casuality replacement (nos.)
1	2000-01	-	69.21	72785	-
2	2001-02	-	226.5	170874	15750
3	2002-03	792.2	573.67	425047	51074
4	2003-04	1347.81	750.89	438705	78796
5	2004-05	1334.3	703.78	344482	191656
6	2005-06	941.7	522.26	399500	215252
7	2006-07	1033.29	501.65	304000	290000
8	2007-08	1774.36	428.29	272630	279560
9	2008-09	838	-	-	235207
10	2009-10	-	-	-	125900
Total		**8061.66**	**3776.25**	**2428023**	**1483195**

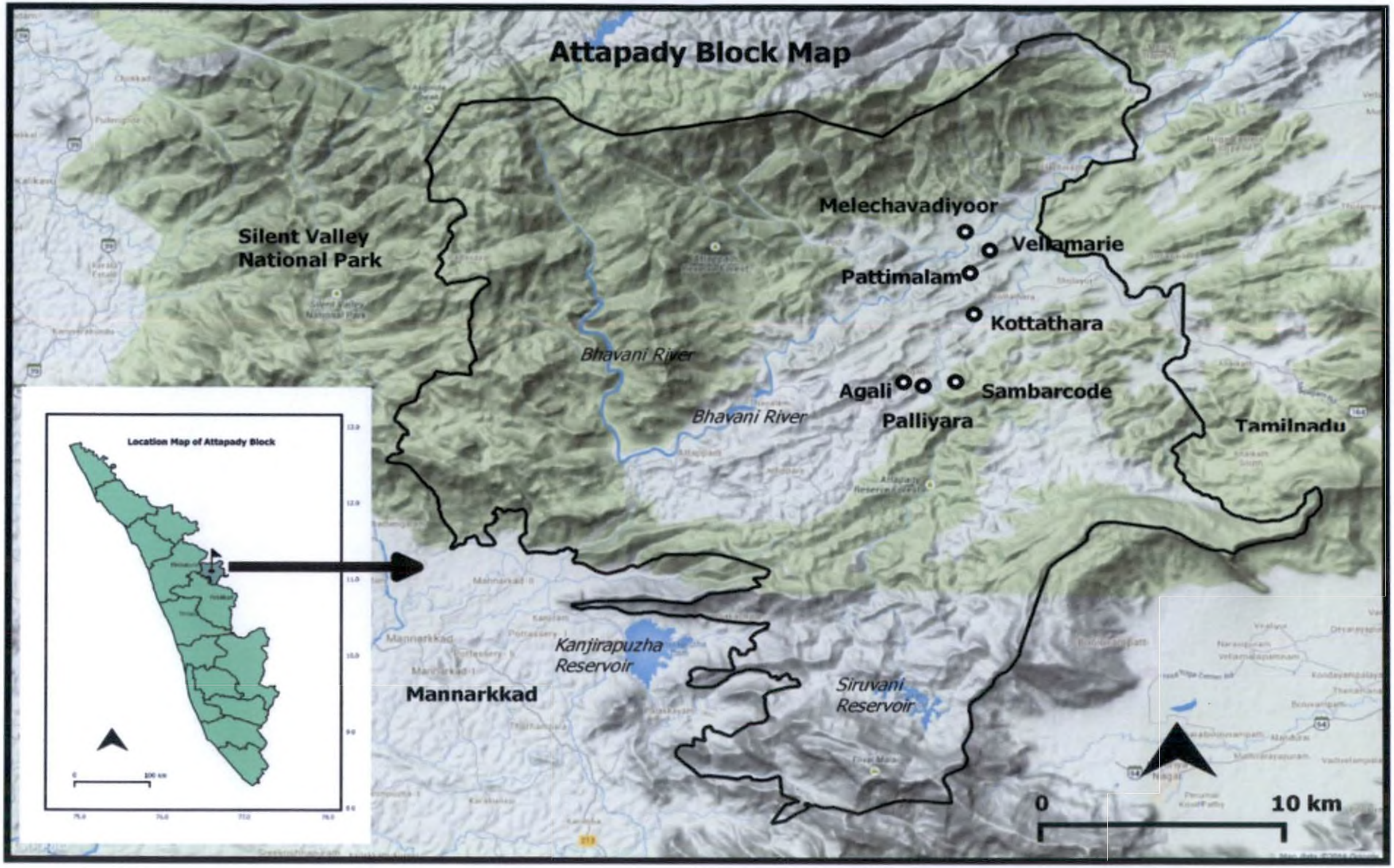


Fig. 1. Location Map of study area

3.1.3 Vegetation

The total forest cover of the area is 387 km^2 of which only 131 km^2 is dense. Degraded forests cover an area of 210 km^2 and are mostly the erstwhile private forests vested with the government in 1971 (KFRI, 1991). The central and eastern portions of the valley do not contain thick forests at all. Grasslands which occupy 46 km^2, include both high level (> 1500 m and climax) and low level (< 1500 m and pyrogenic) types. The important forest types found in Attappady area are classified by Basha (1977) and Zacharia (1981). This consists of eight forest types including; tropical wet evergreen forest, west-coast tropical semi-evergreen forest, South Indian moist deciduous forest, southern tropical dry deciduous forest, pioneer euphorbiaceous scrub, subtropical hill forest and southern montane temperate forest. Above 30% of the present Attappady forest cover belongs to southern tropical dry deciduous forest. They are understocked in most places due to destruction in the form of removal, fire and grazing (KFRI, 1991). South Indian moist deciduous forest is the dominant vegetation type in Attappady, which is largely concentrated in the eastern part. Tropical wet evergreen forests occupy humid areas and are found on hills and valleys between 300 m and 1100 m elevation. The major vegetation type in the eastern part is dry deciduous forest with frequent individual trees of the moist deciduous type.

3.1.4 Climate

Attappady is among the driest parts of Kerala Western Ghats (ESRG, 1989). The western part is humid and humidity decreases as one traverses from west to east. The average annual atmospheric temperature is always above 17°C. March-May is the hottest period. From November to December a cool dry winter is experienced. Rainfall varies from above 3000 mm in the western half to around 900 mm in the eastern boundary. The eastern sector of Attappady is the low rainfall zone. This area receives bulk of rainfall from the north-east monsoon. The dry season extends from six to nine months and the mean annual rainfall is below 800 mm.

3.1.5 Physiography

Attappady area is dominated by medium elevation zones (600 – 1200m). The low elevation part extends from the opening of the hills from Mannarkad on the western side and through the river valleys of Bhavani and Siruvani towards east. The high elevation areas are in the northern portion, i.e. Nilgiri slopes and the southern portion of the Siruvani hills. Two rivers control the drainage of Attappady. The Bhavani river originates from the Nilgiris and the Siruvani river descends from the southern portion of the Attappady at Muthikulam and flows south-south west to north-north east and join with Bhavani in the valley itself. Thus Attappady forms the drainage basin of one (Bhavani) of the three east flowing rivers in Kerala (KFRI, 1991).

3.1.6 Geology, Rock and Soil

Based on the information gathered by Vidyasagaran and Anil Kumar (2009) the parent material is the Archean crystalline and metamorphic rocks such as garnetiferous gneiss, biotite gneiss, amphibolite, crystalline limestones and granites under sub-humid to semi-arid climate and under evergreen, semi-evergreen, moist deciduous and dry deciduous types of vegetation. Soils under evergreen and semi-evergreen forest are brown to dark yellowish brown, while those under moist and dry deciduous forests are dark brown to dark greyish brown in colour. The surface horizons of these soils have the following general features: loam to sandy loam texture, slightly acid to neutral reaction, fairly high content of organic carbon except in dry deciduous forest area and fairly high cation exchange capacity values.

Peninsular gneisses occupy the southern part of the valley and megascopically they are greyish-white, coarse to medium grained, massive and foliated. Quartz – Biotite schist characterizes the shear zone along the Bhavani River. It occurs in a wide zone for about 10 km between Kottathara in the north and Varangambadi in the south. Pegmatite and Quartz are profuse in the Agali area and contain green coloured beryl. Nodular kanker occurs as small disseminations along strem beds near Agali and Kottathara (Vidyasagaran and Anil Kumar, 2009).

3.1.7 Human Habitation

Population in Attappady consists of tribals and non tribals and the latter constitute the settlers from Tamil Nadu and other parts of Kerala. The tribal inhabitants of Attappady are not aborginal population, who have all practically vanished as a result of ingression of population into the hills and annihilation of earliest residents (Nair, 1988). The tribals in Attappady were the early migrants who moved into the thick forests, aiming to escape from persecution in the low lands in the neighbouring states such as Karnataka and Tamil Nadu. The tribal communities identified in the study area are Kurumbas, Mudugas and Irulas who all belong to the broad group of Dravidians (KFRI, 1991).

3.2 METHODOLOGY

3.2.1 Floristic analysis

3.2.1.1 Sampling

The study was conducted in the eco-restored areas of eastern Attappady. Ten plantations and five biomass conservation areas (BCA) and five non-eco-restored areas were randomly selected for the study (Table 2). In each area a 50m x 50m sample plot was taken in such a way that each sample plot represents the respective study area. The whole study area mainly fall in two rainfall regimes. Agali, Sambarcode and Palliyara represents medium rainfall (1000 – 2000mm) areas and Kottathara, Pattimalam, Vellaimari and Chavadiyur represents low rainfall (<1000mm) areas. Vegetation samples (stem, leaves and branches) of all the species encountered during enumeration were collected from the sample plots in such a way that a single sample of a species forms the representative of that species in the whole study area.

Table 2. Sites selected for the study.

Sl. No.	Study sites	Status
1	Agali	Plantations
2	Sambarcode P1	
3	Sambarcode P2	
4	Vannanthura medu	
5	Kottathara	
6	Pattimalam P1	
7	Pattimalam P2	
8	Pattimalam P3	
9	Vellaimari	
10	Mele chavadiyur	
11	Sambarcode BCA	Biomass Conservation Areas
12	Kottathara BCA	
13	Palliyara BCA1	
14	Palliyara BCA2	
15	Palliyara BCA3	

3.2.1.2 Enumeration

All sample plots in the study area were enumerated for tree species. All the plants which have a GBH of and above10 cm and height greater than 1 m were designated as trees. GBH and height of all the tree species in the sample plots were measured and recorded.

3.2.1.3 Quantitative analysis

The vegetation (tree with GBH $\geq$ 10 cm) was quantitatively analyzed for their abundance, frequency, density and their relative values and important value index (Curtis and McIntosh, 1950). In order to determine the quantitative relationship between the species, the following parameters were determined.

Density (D) = No. of individuals/hectare

$$\text{Relative Density (RD)} = \frac{\text{No. of individuals of the species}}{\text{No. of individuals of all the species}} \times 100$$

$$\text{Abundance (A)} = \frac{\text{Total No. of individuals of the species}}{\text{No. of quadrats of occurrence}}$$

$$\text{Percentage Frequency (PF)} = \frac{\text{No. of quadrats of occurrence}}{\text{Total No. of quadrats studied}} \times 100$$

$$\text{Relative Frequency (RF)} = \frac{\text{PF of individual species}}{\text{Sum Percentage frequency of all species}} \times 100$$

$$\text{Basal Area (BA)} = \frac{GBH^2}{4\pi}$$

$$\text{Relative Basal Area (RBA)} = \frac{\text{Basal Area of the species}}{\text{Basal area of all the species}} \times 100$$

Important Value Index (IVI) = RD + RF + RBA

3.2.1.4 Floristic diversity

Species diversity is applied to represent the species richness, relative abundance or the variability in a community. Shannon – Weiner index and Simpson index were used as species diversity measurements (Magurann, 1988). The following indices were worked out:

a. ***Simpson index*****,** $D = 1 - \sum (n_i/N)^2$ (Simpson, 1949)

Where,

n_i = Number of individuals of the species

N = Total number of individuals in the plot

D = Diversity

b. Concentration of dominance, Cd = $\sum (n_i/N)^2$

***a. Shannon-Weiner's index*, H' = 3.3219(Log N-1/N $\sum$ n_i Log n_i)** (Shannon and Weiner, 1962)

Where, ni = Number of individuals of the species

N = Total number of individuals

b. *H max = 3.3219 log $_{10}$S*

Where, H max = the maximum dispersion taking into account the number of species present in the plot.

S = Total number of species

c. *Equitability (E) = H'/H max*

Equitability gives an idea of the real distribution as compared to the maximum dispersion taking into account the number of species present in the plot.

3.2.2 Soil Sampling

From each study area, surface soil was collected to a depth of 15 cm. The collected samples were packed in air tight containers and brought to the laboratory. The samples were air dried and passed through a two mm sieve. The sieved samples were then stored in a polythene bags for chemical analysis.

3.2.3 Litter Sampling

Three litter traps of size 70 X 70 X 70 cm each were placed at random (Fig 2-5) in each sample plot, including ten plantations and five biomass conservation areas. Litter traps were made of PVC pipes and net of 2 mm mesh size according to the guidelines of Litterfall monitoring protocol of CTFS Global forest carbon research initiative (Muller-Landau and Wright, 2010). Litter was collected from the traps every three month duration i.e. four times throughout the year of study. The collected litter from each litter traps were packed tight in polythene bags without losing the moisture and were carried to the laboratory for further analysis for the major nutrients including organic carbon, total nitrogen, total potassium and total phosphorus content. Fresh weight and dry weight of the samples were recorded before the analysis.

3.2.4 Vegetation Sampling

Vegetation samples including stem, leaves and branches were collected from all the tree species identified from the study area. The samples were packed tight without losing the moisture and were taken to the laboratory for further chemical analysis. Fresh weight and dry weight of the samples were taken before the analysis.


Plate 1a. Fixing litter trap in the study site

Plate 1b. Base of Litter trap


Plate 1c and 1d. Litter trap fixed in different study sites

3.2.5 Chemical Analysis

3.2.5.1 Soil

3.2.5.1.1 Organic carbon

Organic carbon content of the soil was determined by wet digestion method using 1 g soil (Walkley and Black, 1934). Soil organic matter was determined by multiplying the value of organic carbon by 1.724 (Van Bemmelen factor).

3.2.5.1.2 Total Nitrogen

Total nitrogen content of the soil was determined by macro Kjeldahl method using 0.5 g soil (Kjeldahl, 1883).

3.2.5.1.3 Available Potassium

Available potassium in the soil sample was extracted using 1N ammonium acetate and estimated using flame photometry (Jackson, 1958).

3.2.5.1.4 Available Phosphorous

Available phosphorus in the soil sample was extracted using Bray No.1 reagent (Bray and Kurtz, 1945) and estimated colorimetrically by reduced molybdate ascorbic acid blue colour method (Watanabe and Olsen, 1965) using a spectrophotometer.

3.2.5.1.5 Total Phosphorous

Total phosphorus in the soil sample was extracted by di-acid digestion, using a di-acid mixture of nitric acid and perchloric acid in the ratio 9:4 and then estimated colorimetrically by vanadomolybdate (blue colour) method (Bray and Kurtz, 1945) using a spectrophotometer.

3.2.5.1.6 Cation exchange capacity (CEC)

Cation exchange capacity of the soil sample was determined by displacing cations in 10 g soil sample with ammonium ions by leaching with neutral normal ammonium acetate. The excess of ammonium acetate was removed with alcohol and absorbed ammonium ions were then determined by displacing the adsorbed ammonium ions using a mild alkaline material followed by steam distillation in the Kjeldahl apparatus (Kjeldahl, 1883).

3.2.5.2 Litter and Vegetation

3.2.5.2.1 Total Carbon

Total carbon content in the litter and the vegetation samples were estimated by ash method. Ten grams of dry litter and vegetation samples were weighed and transferred to silica crucibles of known weight. After measuring the initial weight the crucibles were placed in the Muffle furnace for ignition. The Muffle furnace was set at a temperature of 600°C for 6 hours. After cooling the crucibles are taken out and final weight was measured.

$$Total\ Organic\ Matter\ (\%) = \frac{Initial\ wt. - Final\ wt.}{Wt.\ of\ sample\ taken} X\ 100$$

Total carbon was determined by dividing the TOM by 1.724 (Van Bemmelen factor).

3.2.5.2.2 Total Nitrogen

Total nitrogen of the litter and vegetation samples were estimated by Skalar method using a continuous flow analyzer. Litter samples were digested using a solution mixture of H_2SO_4 and Selenium powder with boric acid. Then the digest is taken to the continuous flow analyzer for estimation of total nitrogen.

3.2.5.2.3 Total Potassium

Total potassium content in the litter and vegetation samples were extracted using the digestion mixture (HNO_3 and $HClO_4$ in 9:4 ratio) and estimated using flame photometry (Jackson, 1958).

3.2.5.2.4 Total Phosphorus

Total phosphorus content of the litter and vegetation samples were extracted using the digestion mixture containing H_2SO_4, Selenium powder and boric acid and estimated by Skalar method using the continuous flow analyzer.

3.2.6 Estimation of Aboveground Biomass (AGB)

Among the various equations suggested, the most suited equation based on the nature of the study area was identified and AGB was determined by applying the enumerated data in to the equation. AGB of the tree species in the study area was estimated using Allometric equation proposed by Brown *et al.* (1989).

$$Y = 34.4703 - 8.0671\,(D) + 0.6589\,(D^2)$$

Where Y = AGB in Kg/tree

D = Diameter at breast height (DBH) of each tree species.

3.3 STATISTICAL ANALYSIS

Analysis of variance and t-test were used to analyze the data. Statistical software SPSS v.20 was used for the analysis.

RESULTS

4. RESULTS

The study on "Impact of eco-restoration on nutrient balance in eastern Attappady, Kerala" was carried out during the period of 2012-2014. The results obtained from this study are detailed below:-

4.1 Vegetation studies

4.1.1 Species composition and vegetation structure of trees in the study area

The species composition of seven study locations of Eastern Attappady comprised a total of 55 tree species (Table 3). A total of 1930 trees were identified and enumerated in 15 sample plots (2500 m^2 each) in seven different locations of eastern Attappady. The sample plots consisted of ten plantations and five Biomass Conservation Areas (BCA).

A total of 1930 trees were encountered in the study. Among the sample plots, five biomass conservation areas represent 40 percent (764 nos.) of the total of 1930 trees. Ten plantations together constitute the rest 60 percent (1166 nos.) of trees. The density of trees in eastern Attappady varied with location and status (Table 4). Palliyara BCA3 with 768 trees/ha had the highest density among the study areas (Fig 2). Kottathara BCA with 428 trees/ha represents the lowest among the BCA. Agali with 744 trees/ha represents the highest density among the plantations (Fig. 3). Vannathura medu with 356 trees/ha represents the lowest among the plantations.

The Abundance (A), Relative Density (RD), Relative Basal area (RBA) and Important Value Index (IVI) of all tree species (>10 cm GBH) in eastern Attappady is given in Table 5. *Santalum album* had the highest abundance of 32.2. The other seven tree species that recorded abundance greater than 10 were *Pterocarpus marsupium* (25), *Albizia amara* (20.31), *Leucaena leucocephala* (18.33), *Senna siamea* (13.44), *Prosopis juliflora* (13.33), *Chloroxylon swietenia* (13.09) and *Anogeissus latifolia* (11.14) (Fig. 4). Out of 1930 trees in the study area, 52.4 percent of the total relative density of all tree species in eastern Attappady was contributed by seven species together which include *Albizia amara* (13.68), *Leucaena leucocephala* (8.55), *Santalum album* (8.34), *Chloroxylon swietenia* (7.46), *Senna siamea* (6.27), *Anogeissus latifolia* (4.04) and *Azadirachta indica* (4.04) (Fig. 5).

Table 3. Species composition of study sites at eastern Attappady.

Sl. No.	Species	Family
1	*Acacia chundra*	Fabaceae
2	*Acacia ferruginea*	Fabaceae
3	*Acacia leucophloea*	Fabaceae
4	*Acacia planifrons*	Mimosoideae
5	*Ailanthus excels*	Simaroubaceae
6	*Albizia amara*	Fabaceae
7	*Albizia lebbeck*	Ceasalpinaceae
8	*Annona squamosal*	Annonaceae
9	*Anogeissus latifolia*	Combretaceae
10	*Azadirachta indica*	Meliaceae
11	*Bauhinia racemosa*	Ceasalpinaceae
12	*Briedelia retusa*	Phyllanthaceae
13	*Cassia fistula*	Fabaceae
14	*Cassine albens*	Celastraceae
15	*Cassine paniculata*	Celastraceae
16	*Chloroxylon swietenia*	Rutaceae
17	*Dalbergia lanceolaria*	Fabaceae
18	*Dalbergia latifolia*	Fabaceae
19	*Diospyros montana*	Ebenaceae
20	*Erythroxylum monogynum*	Erythoxylaceae
21	*Eucalyptus grandis*	Myrtaceae
22	*Eucalyptus tereticornis*	Myrtaceae
23	*Givotia moluccanum*	Euphorbiaceae
24	*Gmelina arborea*	Lamiaceae
25	*Grevillea robusta*	Proteaceae
26	*Grewia serrulata*	Tiliaceae
27	*Grewia tiliifolia*	Tiliaceae
28	*Helicteres isora*	Sterculiaceae
29	*Holoptelea integrifolia*	Ulmaceae
30	*Leucaena leucocephala*	Fabaceae
31	*Morinda tinctoria*	Rubiaceae
32	*Mundulea sericea*	Fabaceae
33	*Neolamarckia cadamba*	Rubiaceae
34	*Peltophorum pterocarpum*	Fabaceae
35	*Phyllanthus emblica*	Phyllanthaceae
36	*Pongamia pinnata*	Fabaceae
37	*Premna tomentosa*	Lamiaceae
38	*Prosopis juliflora*	Fabaceae

Sl. No.	Species	Family
39	*Pterocarpus marsupium*	Fabaceae
40	*Santalum album*	Santalaceae
41	*Schefflera wallichiana*	Araliaceae
42	*Senna siamea*	Fabaceae
43	*Simarouba glauca*	Simaroubaceae
44	*Sterculia colorata*	Malvaceae
45	*Stereospermum suaveolens*	Bignoniaceae
46	*Strychnos potatorum*	Longaniaceae
47	*Syzygium cumini*	Myrtaceae
48	*Tamarindus indica*	Fabaceae
49	*Tectona grandis*	Lamiaceae
50	*Terminalia bellirica*	Combretaceae
51	Unknown i	
52	Unknown ii	
53	Unknown iii	
54	*Wrightia tinctoria*	Apocynaceae
55	*Zizyphus mauritiana*	Rhamnaceae

Table 4. Tree density in plantations and Biomass Conservation Areas (BCA) of eastern Attappady.

Sl. No.	Study sites	Status	Tree density (trees/ha)
1.	Agali	Plantations	744
2.	Sambarcode P1		548
3.	Sambarcode P2		452
4.	Vannanthura Medu		356
5.	Kottathara		464
6.	Pattimalam P1		404
7.	Pattimalam P2		460
8.	Pattimalam P3		440
9.	Vellaimari		424
10.	Mele Chavadiyur		372
11.	Sambarcode BCA	Biomass conservation areas	688
12.	Kottathara BCA		428
13.	Palliyara BCA1		472
14.	Palliyara BCA2		700
15.	Palliyara BCA3		768

Table 5. Relative Density (RD), Abundance (A), Relative Basal Area (RBA) and Important Value Index (IVI) of trees in eastern Attappady.

Sl.No.	Species	RD (%)	A	RBA (%)	IVI
1	*Acacia chundra*	2.07	5.00	1.67	6.82
2	*Acacia ferruginea*	0.83	2.29	1.44	4.96
3	*Acacia leucophloea*	0.88	4.25	1.02	3.44
4	*Acacia planifrons*	0.05	1.00	0.09	0.53
5	*Ailanthus excelsa*	0.21	2.00	0.09	1.07
6	*Albizia amara*	13.68	20.31	17.85	36.53
7	*Albizia lebbeck*	0.31	3.00	0.43	1.51
8	*Annona squamosa*	0.21	4.00	0.08	0.67
9	*Anogeissus latifolia*	4.04	11.14	2.63	9.36
10	*Azadirachta indica*	4.04	7.09	3.98	12.25
11	*Bauhinia racemosa*	0.52	3.33	0.16	1.83
12	*Briedelia retusa*	0.57	2.75	0.49	2.59
13	*Cassia fistula*	0.41	2.67	0.15	1.72
14	*Cassine albens*	0.88	2.83	0.91	4.10
15	*Cassine paniculata*	2.75	10.60	1.95	6.61
16	*Chloroxylon swietenia*	7.46	13.09	7.85	19.54
17	*Dalbergia lanceolaria*	1.30	4.17	1.65	5.26
18	*Dalbergia latifolia*	0.62	4.00	0.84	2.61
19	*Diospyros montana*	1.40	2.70	0.70	5.94
20	*Erythroxylum monogynum*	0.62	4.00	0.31	2.09
21	*Eucalyptus grandis*	0.05	1.00	0.38	0.82
22	*Eucalyptus tereticornis*	0.52	10.00	1.81	2.71
23	*Givotia moluccanum*	0.41	2.67	9.21	10.78
24	*Gmelina arborea*	1.61	4.43	0.71	5.00
25	*Grevillea robusta*	1.19	4.60	0.42	3.53
26	*Grewia serrulata*	0.10	2.00	0.31	0.80
27	*Grewia tiliifolia*	1.50	5.80	0.66	4.09
28	*Helicteres isora*	0.26	5.00	0.08	0.72
29	*Holoptelea integrifolia*	1.04	2.86	0.88	4.61
30	*Leucaena leucocephala*	8.55	18.33	4.93	16.94
31	*Morinda tinctoria*	1.09	3.50	1.19	4.59
32	*Mundulea sericea*	3.47	8.38	0.80	7.34
33	*Neolamarckia cadamba*	0.36	2.33	1.40	2.91
34	*Peltophorum pterocarpum*	0.73	3.50	0.53	2.80
35	*Phyllanthus emblica*	2.80	9.00	0.82	5.93
36	*Pongamia pinnata*	0.36	2.33	0.10	1.62
37	*Premna tomentosa*	2.38	4.18	1.09	7.71

Sl.No.	Species	RD (%)	A	RBA (%)	IVI
38	*Prosopis juliflora*	2.07	13.33	2.98	6.21
39	*Pterocarpus marsupium*	3.89	25.00	4.13	9.17
40	*Santalum album*	8.34	32.20	3.80	14.07
41	*Schefflera wallichiana*	0.52	2.50	0.19	2.25
42	*Senna siamea*	6.27	13.44	5.27	15.00
43	*Simarouba glauca*	1.97	7.60	1.78	5.67
44	*Sterculia colorata*	0.31	3.00	3.53	4.61
45	*Stereospermum suaveolens*	0.41	2.67	0.51	2.08
46	*Strychnos potatorum*	0.47	2.25	0.41	2.42
47	*Syzygium cumini*	0.78	5.00	0.22	2.15
48	*Tamarimdus indica*	0.36	7.00	0.07	0.82
49	*Tectona grandis*	2.33	6.43	3.87	8.89
50	*Terminalia bellirica*	0.41	2.67	0.21	1.78
51	Unknown i	0.36	2.33	0.51	2.03
52	Unknown ii	0.05	1.00	0.00	0.44
53	Unknown iii	0.26	2.50	0.05	1.08
54	*Wrightia tinctoria*	1.24	4.80	2.56	5.72
55	*Zizyphus mauritiana*	0.67	2.60	0.32	2.92

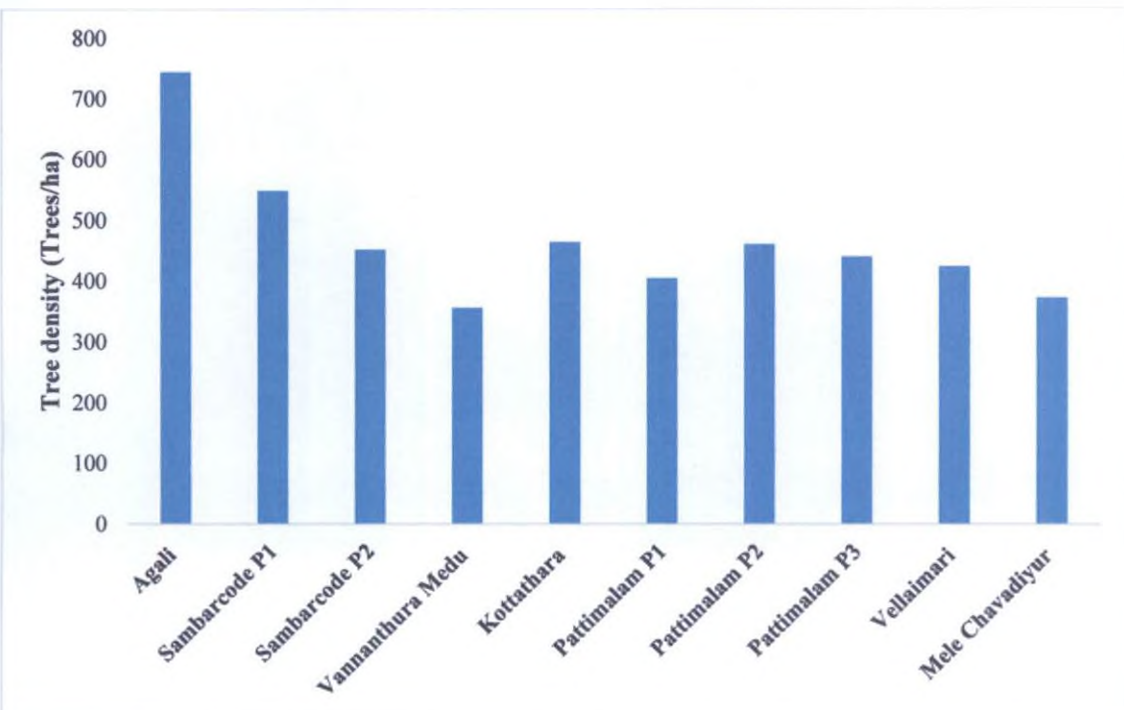


Fig. 2. Tree density in plantations of eastern Attappady.

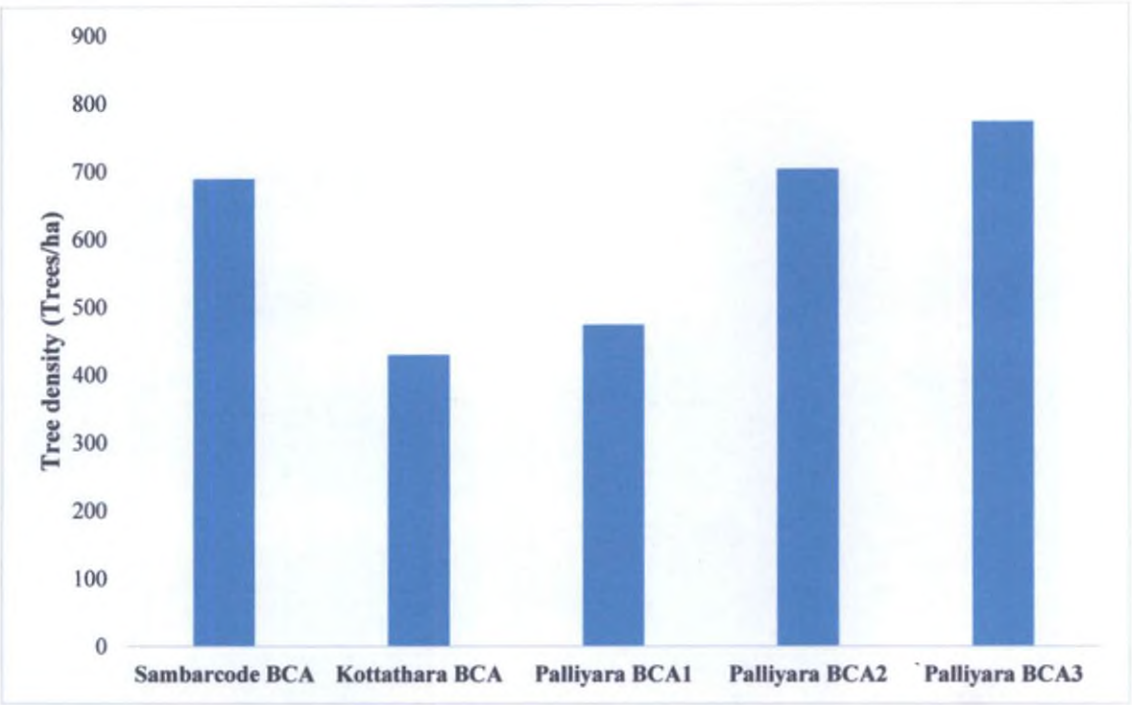


Fig. 3. Tree density in Biomass Conservation Areas (BCA) of eastern Attappady.

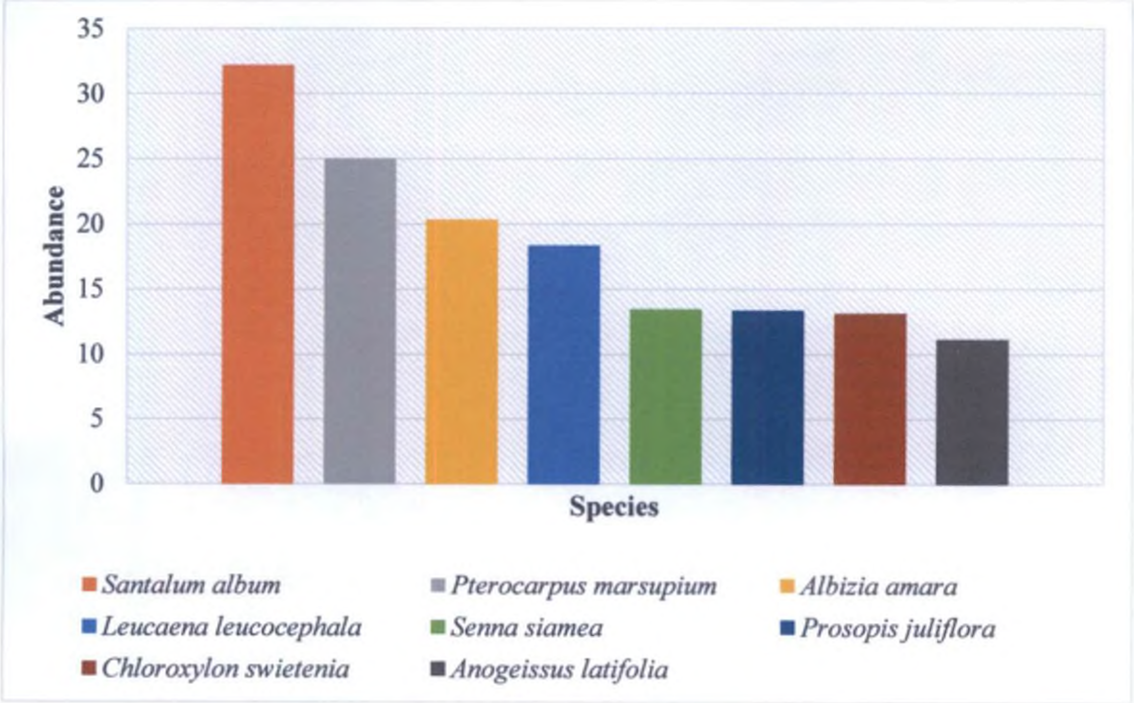


Fig. 4. Abundance (A) of most abundant tree species in eastern Attappady.

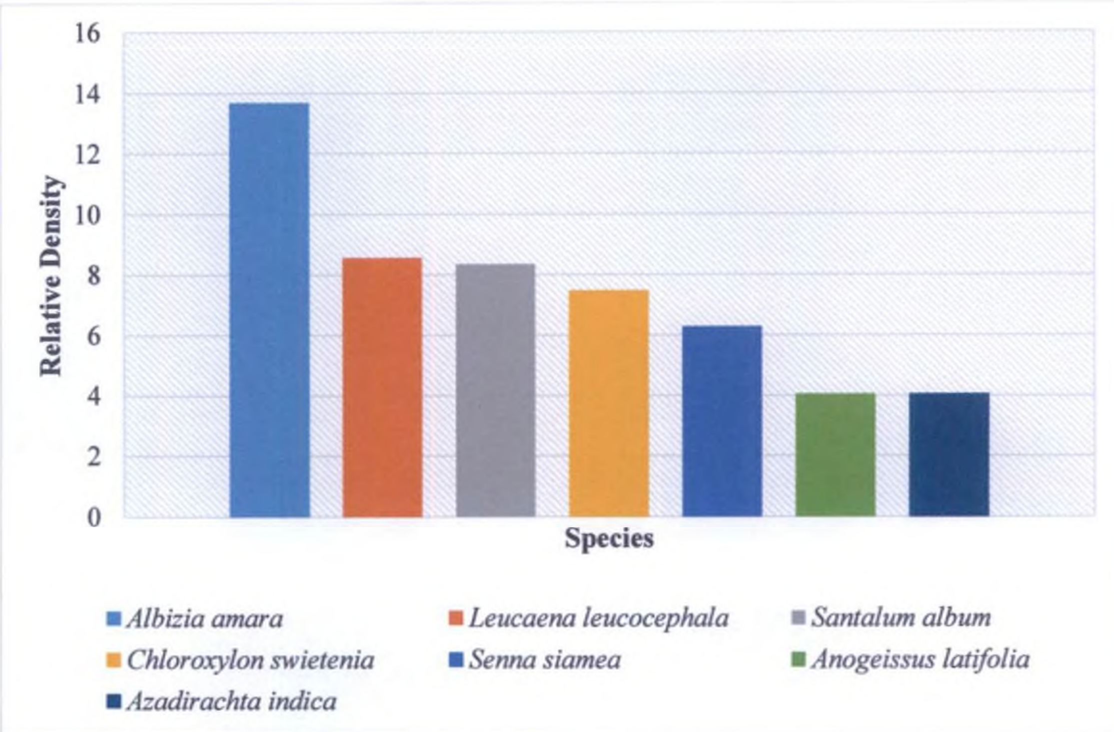
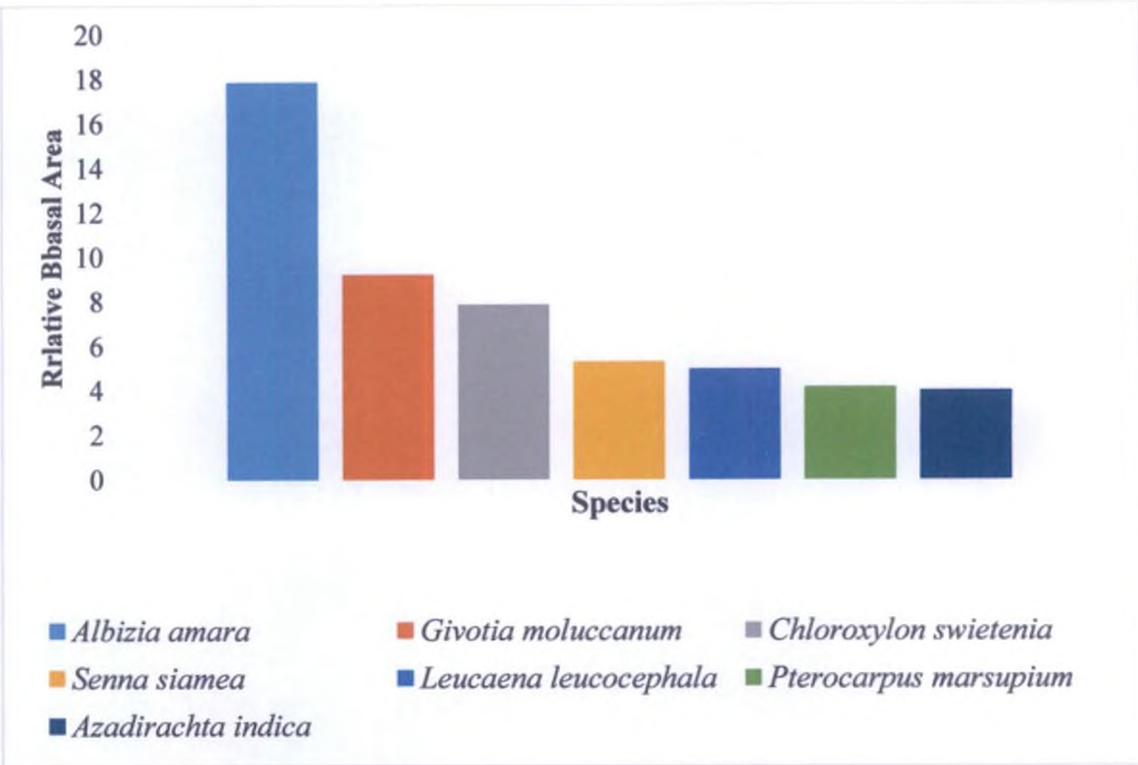


Fig. 5. Relative density (RD) of important tree species in eastern Attappady.

The 1930 trees of the 55 tree species in eastern Attappady, together account for 17.88 m^2 basal area. Seven species accounted for 53.2 percent of total basal area. These species were *Albizia amara* (17.84 %), *Givotia moluccanum* (9.2 %), *Chloroxylon swietenia* (7.85 %), *Senna siamea* (5.27 %), *Leucaena leucocephala* (4.93 %), *Pterocarpus marsupium* (4.13 %) and *Azadirachta indica* (3.97 %) (Fig. 6). Out of 17.88 m^2, 12.4 percent of total relative basal area of eastern Attappady is contributed by 32 tree species, and each individually accounts for less than 1 percent of the total.

Among the 55 tree species encountered in the study *Albizia amara* had the highest IVI with 36.53, which is followed by six species having IVI values greater than 10, viz., *Chloroxylon swietenia* (19.54), *Leucaena leucocephala* (16.94), *Senna siamea* (15), *Santalum album* (14.07), *Azadirachta indica* (12.25) and *Givotia moluccanum* (10.78). The seven tree species with the largest IVIs in the study area are given in Fig. 7.



.Fig. 6. Relative Basal Area (RBA) of important tree species in eastern Attappady.

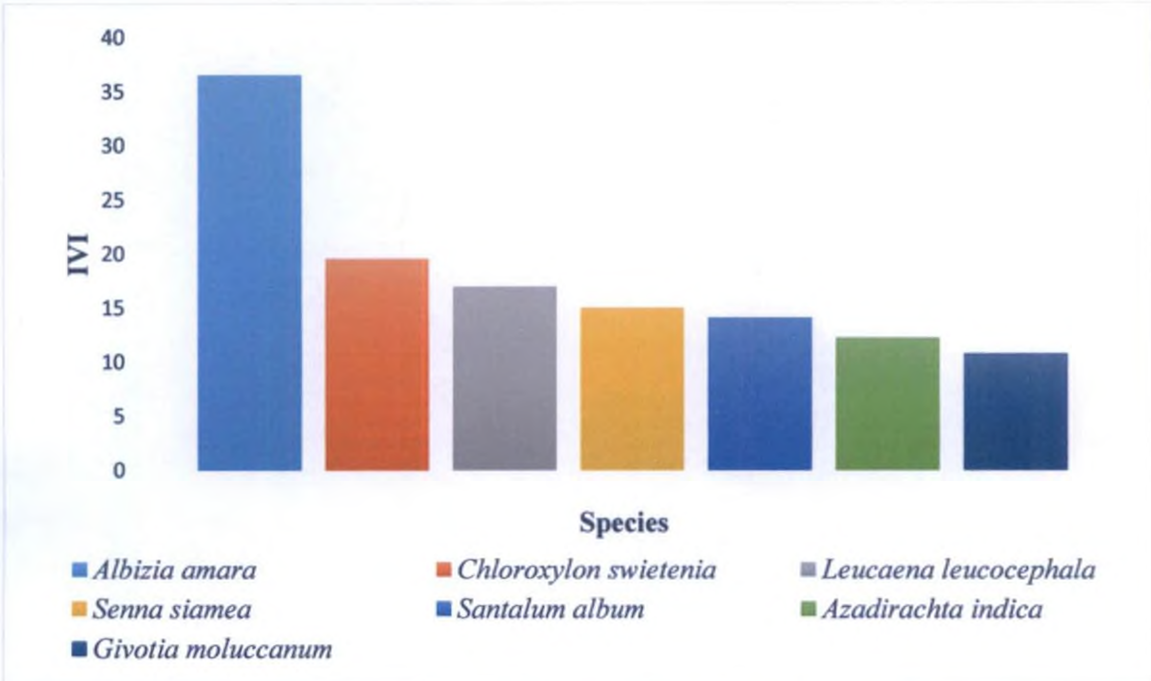


Fig. 7. Important Value Index (IVI) of prominent tree species in eastern Attappady.

4.1.2 Floristic diversity of vegetation of Eastern Attappady

The floristic diversity for all the trees in eastern Attappady were estimated. The Simpson index, Concentration of dominance (Cd), Shannon-Wiener index, H max and Equitability (E) for the trees of all the study sites, including 10 plantations and 5 BCA were calculated (Table 6 and 7). Pattimalam P3 had the highest value for Simpson index (0.933) with Cd value 0.067 among plantations. The Simpson index value for Sambarcode P1 and Sambarcode P2 were 0.906 and 0.9 and their Cd values were 0.094 and 0.1 respectively. Kottathara recorded the lowest value of 0.55 with Cd 0.45. Among the BCA, Sambarcode BCA had the highest value for Simpson index (0.88) with Cd value 0.12. Kottathara BCA recorded the lowest value (0.71) with Cd 0.29.

Among plantations, Agali and Kottathara plantations recorded the highest values for Shannon-Wiener index of 2.07 and 2.04 respectively with H max and Equitability of 4.09, 0.51 and 4.09, 0.5 respectively (Table 6). Pattimalam P3 recorded the lowest Shannon-Wiener index value of 1.14 with H max and E 4.58 and 0.25 respectively. Among the BCA, Palliyara BCA3 recorded the highest Shannon-Wiener index value of 1.87 with H max and Equitability 4.58 and 0.41 respectively (Table 7). Palliyara BCA1 had the lowest value of Shannon-Wiener index of 1.43 with H max and E 4.39 and 0.33 respectively among biomass conservation areas.

Table 6. Floristic diversity indices of plantations in eastern Attappady

Study sites	Cd	Simpson Index	Shannon-Wiener index	H max	Equitability (E)
Agali	0.24	0.76	2.07	4.09	0.51
Sambarcode P1	0.09	0.91	1.44	4.46	0.32
Sambarcode P2	0.10	0.90	1.33	4.46	0.30
Vannanthura Medu	0.20	0.80	1.60	3.81	0.42
Kottathara	0.45	0.55	2.04	4.09	0.50
Pattimalam P1	0.29	0.71	1.95	3.17	0.62
Pattimalam P2	0.17	0.83	1.71	3.46	0.50
Pattimalam P3	0.07	0.93	1.14	4.58	0.25
Vellaimari	0.13	0.87	1.49	3.70	0.40
Mele Chavadiyur	0.29	0.71	1.80	3.17	0.57

Table 7. Floristic diversity indices of Biomass conservation areas of eastern Attappady.

Study sites	Cd	Simpson Index	Shannon-Wiener index	H max	Equitability (E)
Sambarcode BCA	0.12	0.88	1.63	4.52	0.36
Kottathara BCA	0.29	0.71	1.82	3.58	0.51
Palliyara BCA1	0.13	0.87	1.43	4.39	0.33
Palliyara BCA2	0.15	0.85	1.78	4.39	0.40
Palliyara BCA3	0.16	0.84	1.87	4.58	0.41

4.2 Aboveground Biomass of vegetation in eastern Attappady

Aboveground biomass (AGB) of all the tree species (≥ 10 cm GBH) in eastern Attappady, including ten plantations and five BCAs were calculated (Table 8). An average of 20397.62 kg/ha of AGB were recorded from the total of 15 study areas. Among the study sites in eastern Attappady 49 percent of the total AGB were contributed by five BCAs and rest 51 percent by ten plantations. Pattimalam P3 recorded the highest AGB of 27742.42 kg/ha among the plantations (Fig. 8). Vannanthara medu ERA recorded the lowest among the plantations with 5757.55 kg/ha of AGB. Among the BCAs, Sambarcode BCA with 88729.75 kg/ha accounts for the highest and Kottathara BCA with 12554.64 kg/ha recorded the lowest AGB (Fig. 9).

Table 8. Aboveground biomass (AGB) of trees ($\geq$ 10 cm GBH) in plantations and biomass conservation areas of eastern Attappady.

Sl. No	Study sites	Status	AGB (kg/ha)
1.	Agali	Plantations	15718.29
2.	Sambarcode P1	„	14636.99
3.	Sambarcode P2	„	14002.43
4.	Vannanthura Medu	„	5757.55
5.	Kottathara	„	10501.86
6.	Pattimalam P1	„	17788.18
7.	Pattimalam P2	„	8344.19
8.	Pattimalam P3	„	27742.42
9.	Vellaimari	„	15248.16
10.	Mele Chavadiyur	„	26858.36
11.	Sambarcode BCA	Biomass conservation area	88729.75
12.	Kottathara BCA	„	12554.64
13.	Palliyara BCA1	„	14504.56
14.	Palliyara BCA2	„	14575.46
15.	Palliyara BCA3	„	19001.53

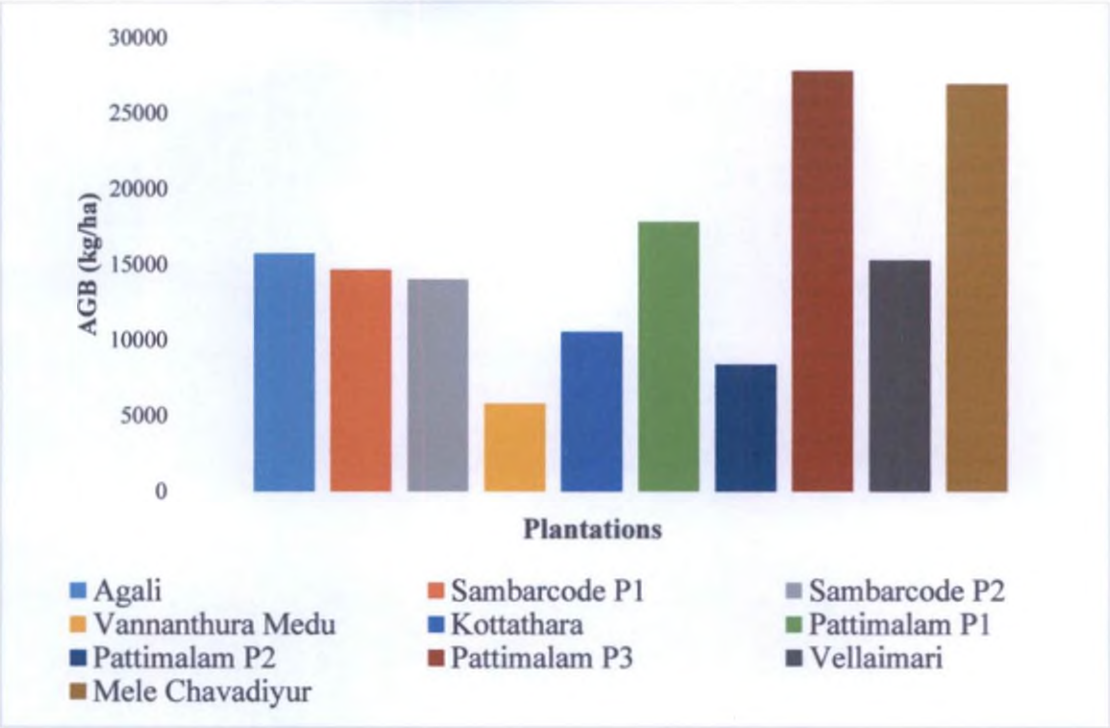


Fig. 8. Aboveground biomass (AGB) of trees (≥ 10 cm GBH) in plantations of eastern Attappady.

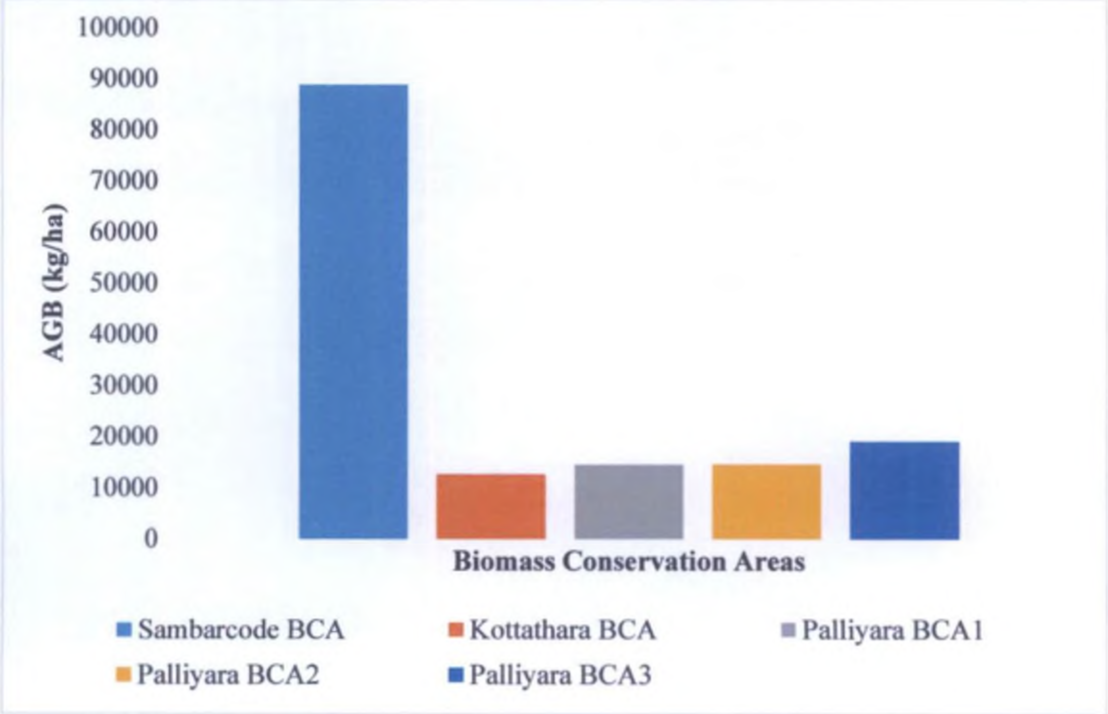


Fig. 9. Aboveground biomass (AGB) of trees (≥ 10 cm GBH) in BCA of eastern Attappady.

4.3 Nutrient status of vegetation of eastern Attappady

Nutrient stock of vegetation (trees with GBH ≥ 10 cm) of eastern Attappady were analyzed for total carbon, total nitrogen, total phosphorus and total potassium. Results are given in Table 9.

4.3.1 Total Carbon

The analysis showed that the total carbon in vegetation of study sites varied between plantations and BCAs. An average of 11104.56 kg/ha of total carbon was present in the whole study area. Ten plantations together accounts for an average of 8557.35 kg/ha of total carbon and the five BCA together accounts for an average of 16199 kg/ha of total carbon in eastern Attappady.

The total carbon was observed to be highest in the Pattimalam P3 (15177.3 kg/ha), which was followed by Mele Chavadiyur (14715.32 kg/ha). The lowest total carbon was in Vannanthara medu with 3139.22 kg/ha among plantations (Fig. 10). Among the biomass conservation areas, Sambarcode BCA exhibited high variation and had highest total carbon of 48164.96 kg/ha. Kottathara BCA was observed to have lowest total carbon among the BCAs with 6815.72 kg/ha (Fig. 11).

4.3.2 Total Nitrogen

The analysis for total nitrogen in vegetation of study sites showed that the total nitrogen varied between plantations and BCAs. The whole study area accounts for an average of 248.97 kg/ha of total nitrogen in eastern Attappady. The plantations together constituted an average of 196.56 kg/ha of total nitrogen and the BCAs together of an average of 353.8 kg/ha of total nitrogen.

Among the plantations total nitrogen followed the similar trend of total carbon, with the highest value recorded in the Pattimalam P3 with 316.8 kg/ha followed by Melechavadiyur with 315.25 kg/ha (Fig. 12). The lowest was in Vannanthura medu with 75.3 kg/ha of total nitrogen. Among the BCAs, Sambarcode BCA was observed to be the highest with 1031.86 kg/ha of total nitrogen and the lowest were from the Kottathara BCA with 156.99 kg/ha of TN (Fig. 13).

Table 9. Nutrient stock of vegetation (trees with GBH ≥ 10 cm) in plantations and biomass conservation areas of eastern Attappady.

Study sites	**Status**	**Total carbon (kg/ha)**	**Total Nitrogen (kg/ha)**	**Total Phosphorus (kg/ha)**	**Total Potassium (kg/ha)**
Agali	Plantations	8598.22	218.15	20.55	26.75
Sambarcode P1	,,	8015.28	181.70	19.86	22.35
Sambarcode P2	,,	7627.39	172.95	19.94	21.71
Vannanthura Medu	,,	3139.22	75.30	8.13	9.65
Kottathara	,,	5704.03	135.71	16.35	16.79
Pattimalam P1	,,	9739.84	252.50	22.63	34.31
Pattimalam P2	,,	4555.93	97.99	11.84	13.91
Pattimalam P3	,,	15177.30	316.80	35.14	48.54
Vellaimari	,,	8300.93	199.20	22.26	23.48
Mele Chavadiyur	,,	14715.32	315.25	35.32	33.81
Sambarcode BCA	BCA	48164.96	1031.86	115.47	185.92
Kottathara BCA	,,	6815.72	156.99	19.46	20.49
Palliyara BCA1	,,	7838.81	184.77	21.46	26.99
Palliyara BCA2	,,	7855.02	170.42	18.65	26.86
Palliyara BCA3	,,	10320.50	224.95	23.54	32.33

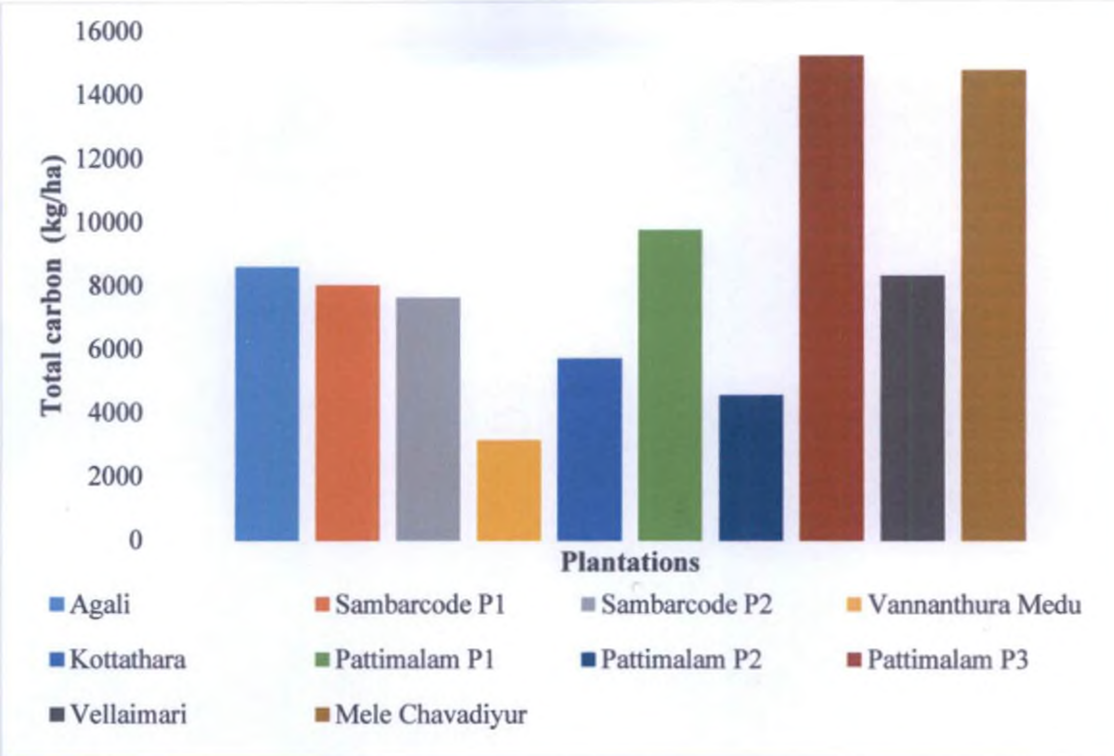


Fig. 10. Total carbon of vegetation (trees with GBH ≥ 10 cm) in the plantations of eastern Attappady.

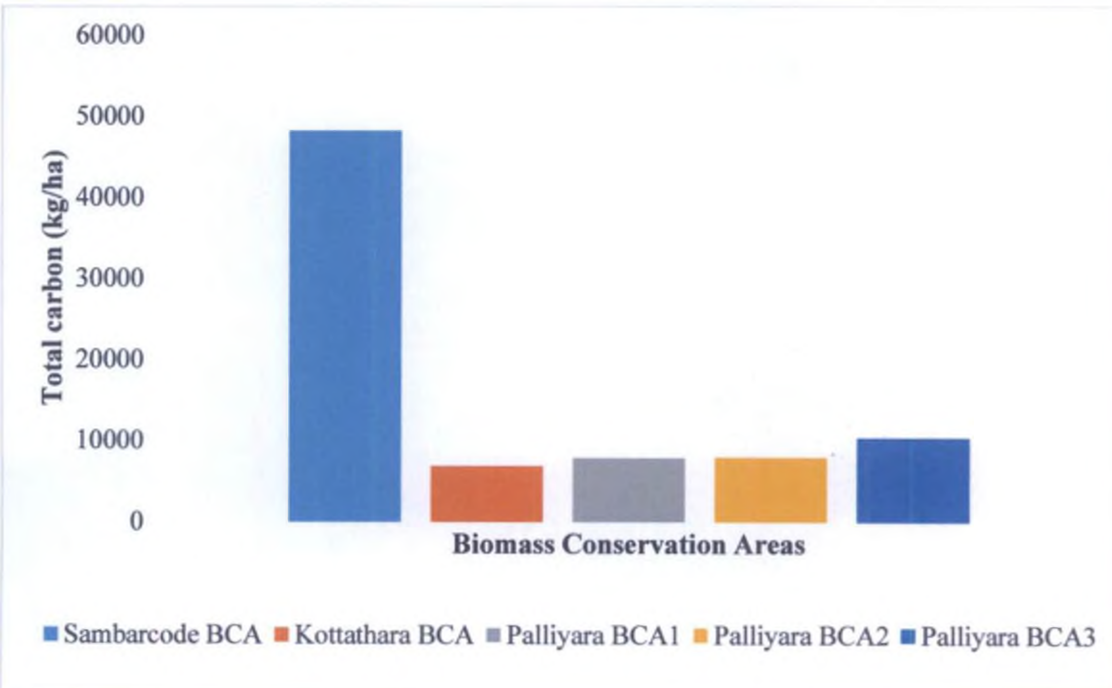


Fig. 11. Total carbon of vegetation (trees with GBH ≥ 10 cm) in the BCA of eastern Attappady.

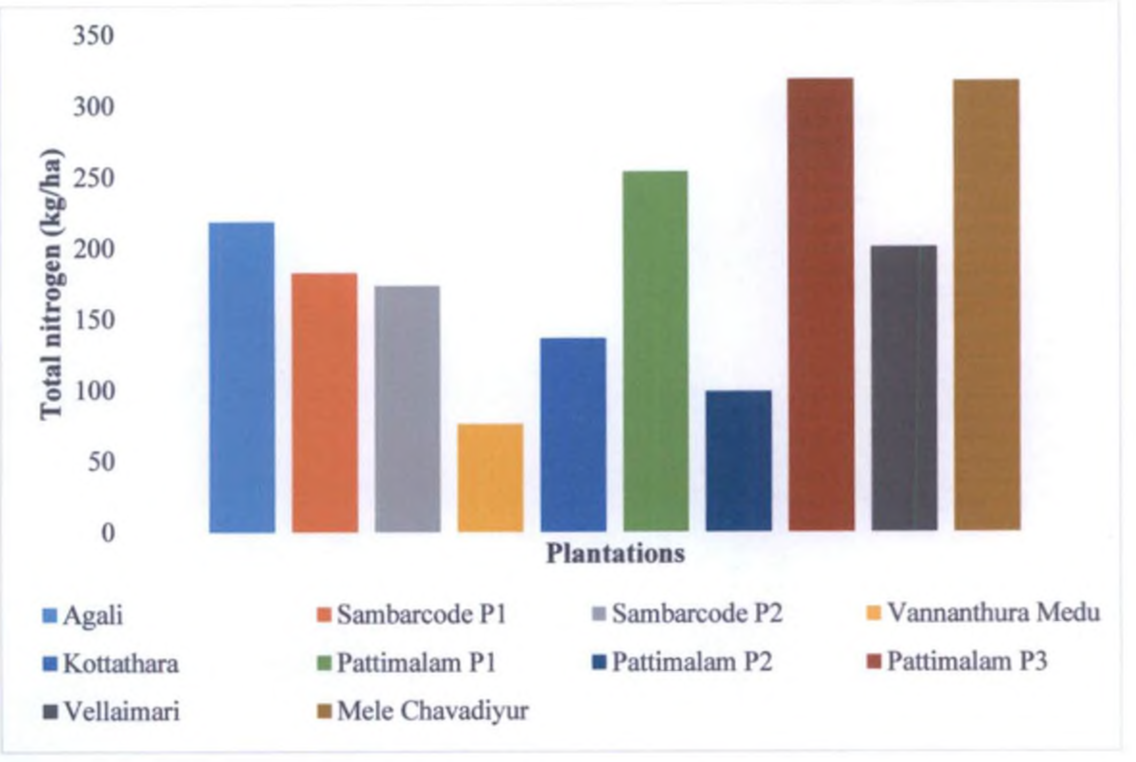


Fig. 12. Total nitrogen of vegetation (trees with GBH ≥ 10 cm) in the plantations of eastern Attappady.

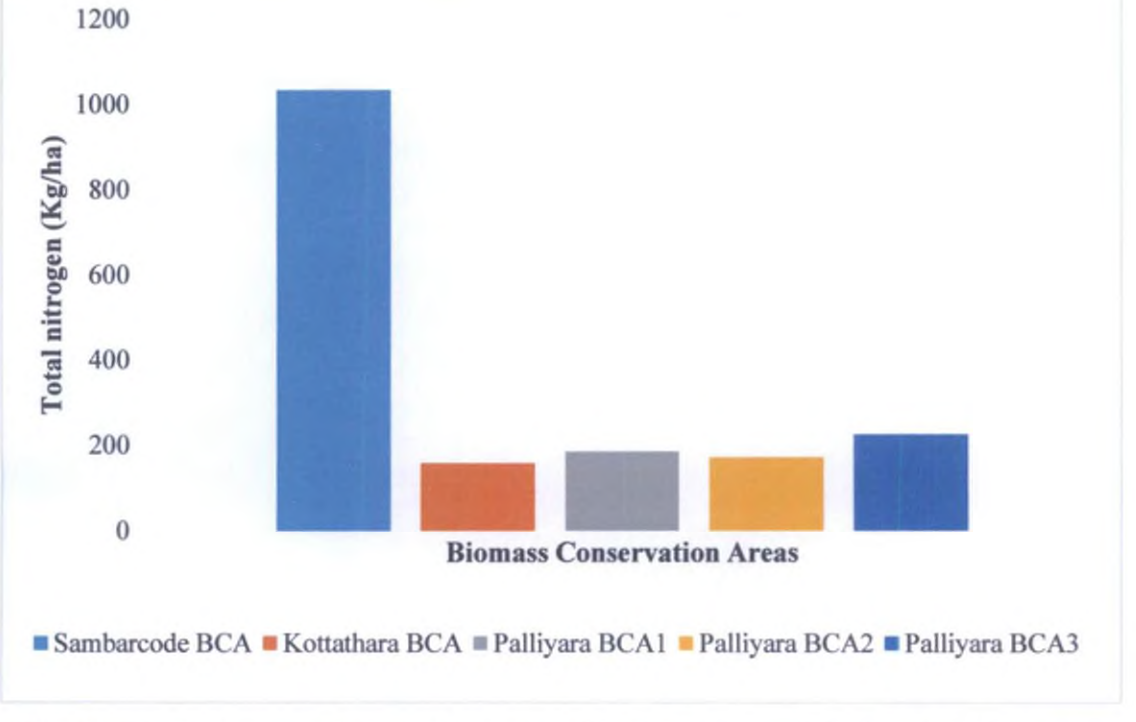


Fig. 13. Total nitrogen of vegetation (trees with GBH ≥ 10 cm) in the BCA of eastern Attappady.

4.3.3 Total Phosphorus

The analysis for total phosphorus in the vegetation (trees ≥ 10 cm GBH) among the study sites showed that an average of 27.37 kg/ha was present in eastern Attappady. The ten plantations accounted for an average of 21.2 kg/ha of total phosphorus and the five BCAs accounted for an average of 39.72 kg/ha of total phosphorus content in vegetation of eastern Attappady.

Among the plantations, total phosphorus was observed to be highest in Mele Chavadiyur with 35.32 kg/ha, which was followed by Pattimalam P3 (35.14 kg/ha). The lowest total phosphorus was recorded by Vannanthura medu with 8.13 kg/ha (Fig. 14). Among the biomass conservation areas, Sambarcode BCA recorded the highest total phosphorus stock with 115.47 kg/ha and the lowest was for Palliyara BCA2 with 18.65 kg/ha of total phosphorus (Fig. 15).

4.3.4 Total Potassium

The analysis for total potassium in the vegetation of study sites showed that total potassium varied between the plantations and biomass conservation areas. The whole study area accounted for an average of 36.26 kg/ha of total potassium in the vegetation of eastern Attappady. The ten plantations together constituted an average of 25.13 kg/ha of total potassium and the five biomass conservation areas accounted an average of 58.12 kg/ha of total potassium in the vegetation.

Among the plantations Pattimalam P3 recorded the highest total potassium in the vegetation with 48.54 kg/ha, which was followed by Pattimalam P1 and Mele Chavadiyur with 34.31 kg/ha and 33.81 kg/ha of total potassium content respectively (Fig. 16). Among the BCAs, total potassium was observed to be highest in the Sambarcode BCA with 185.92 kg/ha among biomass conservation areas. Kottathara BCA recorded the lowest total potassium stock in vegetation with 20.49 kg/ha (Fig. 17).

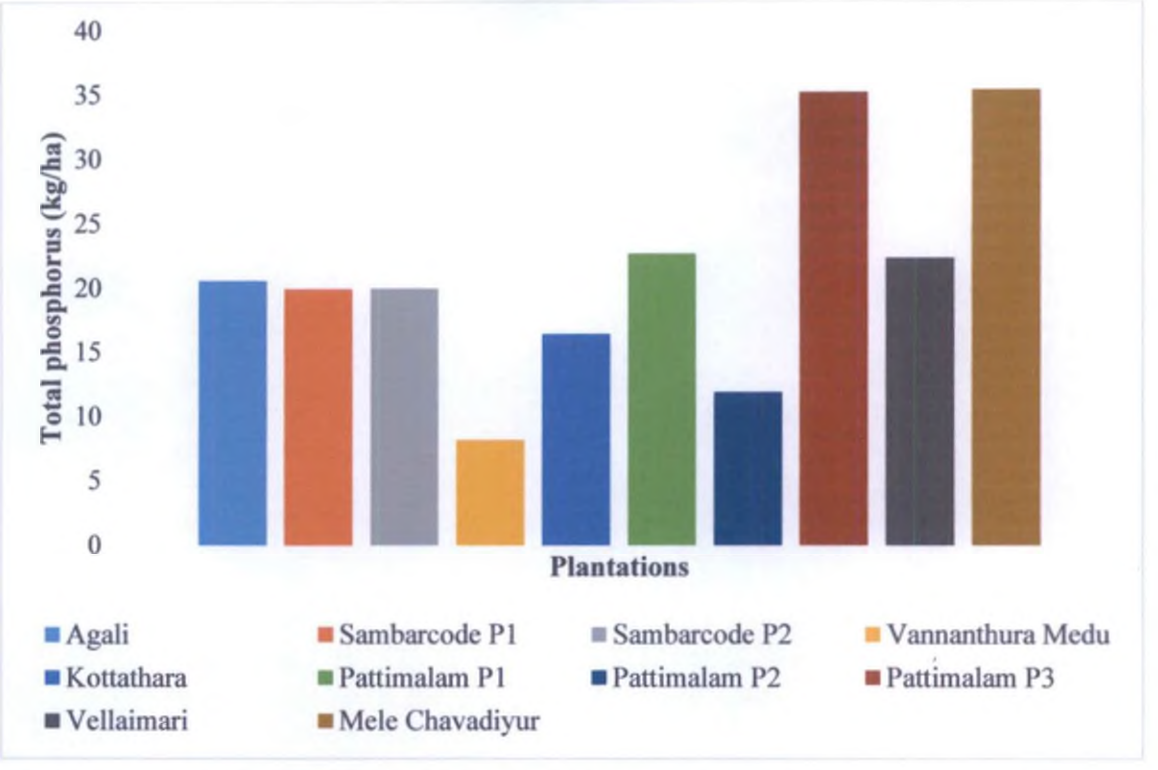


Fig. 14. Total phosphorus content of vegetation (trees with GBH ≥ 10 cm) in the plantations of eastern Attappady.

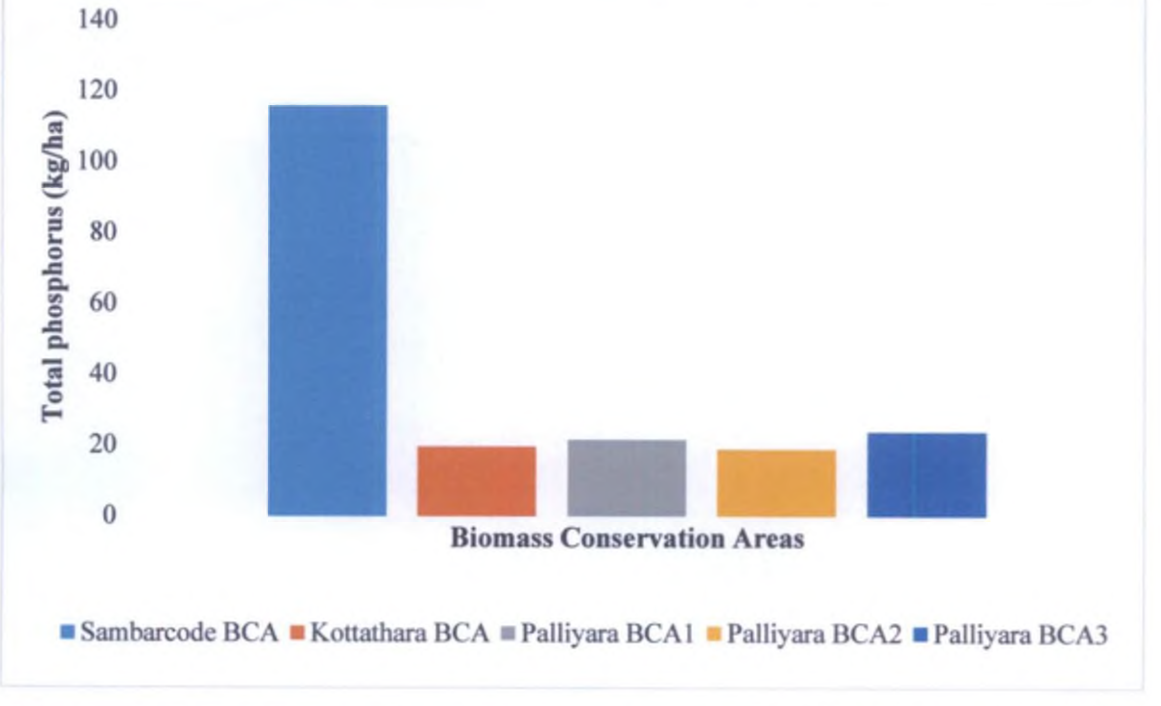


Fig. 15. Total phosphorus content of vegetation (trees with GBH ≥ 10 cm) in the BCA of eastern Attappady.

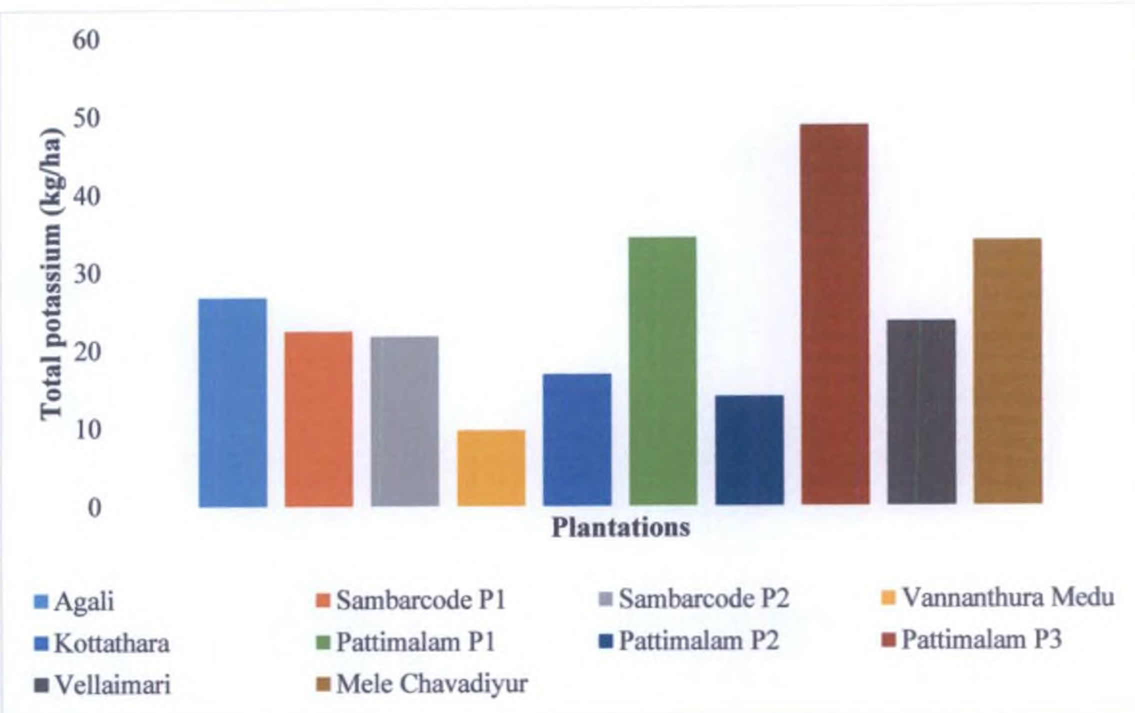


Fig. 16. Total potassium content of vegetation (trees with GBH ≥ 10 cm) in the plantations of eastern Attappady.

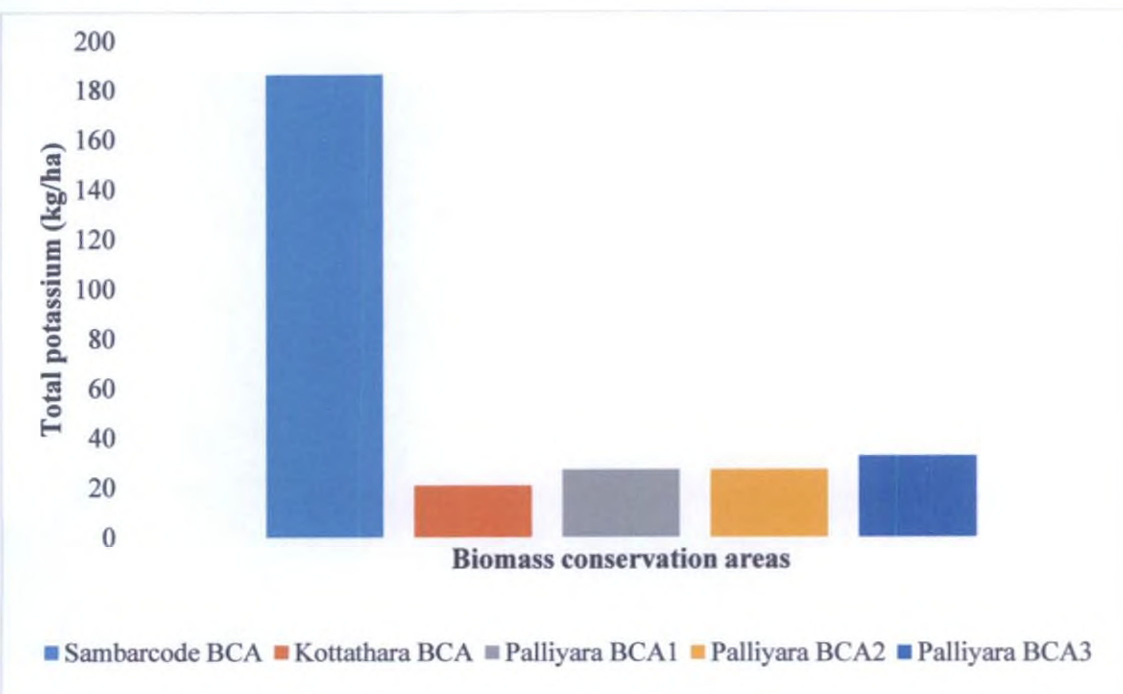


Fig. 17. Total potassium content of vegetation (trees with GBH ≥ 10 cm) in the BCA of eastern Attappady.

4.4 Litter studies

4.4.1 Nutrient content in litter samples of eastern Attappady

The litter samples from ten plantations and five biomass conservation areas in eastern Attappady were collected during periods, June – September, September – December, December – March and March – June. The litter samples were analyzed for variation in fresh weight, dry weight, total carbon, total nitrogen, total potassium and total phosphorus (Table 10).

4.4.1.1 Fresh weight

The analysis of variance showed that the fresh weight of litter samples varied between plantations and BCA with time period. The fresh weight of litter samples showed a seasonal variation during the four time period Jun – Sep, Sep – Dec, Dec – Mar and Mar –Jun (Table 9). The biomass conservation areas showed higher fresh weight for the litter samples throughout the four time period from Jun – Sep to Mar – Jun with an average of 1506.48 ± 756.28 kg/ha. The fresh weight of litter samples in plantations were comparatively lower throughout the four time period of the study with an average of 903.88 ± 556.63 kg/ha.

The fresh weight of litter samples was observed to be highest in the biomass conservation areas during the period of December – March (2098 ± 1187.1 kg/ha), which was followed by biomass conservation areas during the period of September – December (1990.4 ± 949.4 kg/ha). The fresh weight of litter samples in BCA for the period of June – September and March – June were 940.2 ± 294.7 kg/ha and 997.3 ± 308 kg/ha respectively. The fresh weight of litter samples were observed to be highest in the plantations during the period of December – March (1334.1 ± 593.1 kg/ha). The fresh weight of litter samples were observed to be lowest in the plantations during the period of March – June (451 ± 206.7 kg/ha) and the fresh weight of litter samples for the period of June – September and September – December were 740 ± 477.3 kg/ha and 1090.4 ± 949.4 kg/ha respectively.

The fresh weight of litter sample during the period of June – September were not significantly different between the plantations and biomass conservation areas. All the

Table 10. Seasonal variation in litter mass and its nutrient content of plantations and biomass conservation areas in eastern Attappady.

Parameters	Jun - Sep 2013			Sept - Dec 2013			Dec - Mar 2013/14			Mar - Jun 2014		
	Plantations	BCA	t-value	Plantations	BCA	t-value	Plantations	BCA	t-value	Plantations	BCA	t-value
Fresh weight (Kg/ha)	740 (477.3)	940.2 (294.7)	-1.484	1090.4 (949.4)	1990.4 (1235.3)	-2.708*	1334.1 (593.1)	2098 (1187.1)	-2.895*	451 (206.7)	997.3 (308)	-7.073*
Dry weight (Kg/ha)	406.7 (79)	625.9 (239)	-2.57*	770 (719.2)	1219 (632.9)	-2.051*	1061.8 (523.5)	1521 (916.1)	-2.146*	321 (193.1)	655.7 (239.8)	-5.054*
Total C (% of dry wt.)	51.73 (2.16)	52.67 (1.4)	-1.515	50.63 (3.51)	50.73 (2.19)	-0.101	50.33 (3.51)	51.4 (3.98)	-0.92	50.9 (3.91)	52.67 (1.88)	-1.652
Total N (% of dry wt.)	1.6 (0.68)	1.53 (0.52)	0.336	2.1 (0.99)	1.4 (0.63)	2.478*	1.57 (0.63)[a]	1.33 (0.49)[a]	1.262	1.73 (0.79)	1.6 (0.63)	0.571
Total K (% of dry wt.)	0.16 (0.15)	0.11 (0.05)		0.09 (0.10)	0.07 (0.04)		0.09 (0.07)	0.10 (0.05)		0.10 (0.06)	0.11 (0.06)	
Total P (% of dry wt.)	0.09 (0.10)	0.10 (0.11)		0.09 (0.09)	0.07 (0.05)		0.08 (0.10)	0.08 (0.06)		0.09 (0.06)	0.10 (0.06)	

"*" shows t-value of the variable which are significantly different.

Values in parenthesis indicate Standard deviation litter samples collected during the other three time period show significant difference for fresh weight.

4.4.1.2 Dry weight

The analysis of variance showed that the dry weight of litter samples varied between plantations and BCAs with time period. All the litter samples collected during the four time period from June – September to March – June show significant difference for dry weight. The biomass conservation areas showed higher dry weight for the litter samples throughout the four time period from Jun – Sep to Mar – Jun with an average of 1005.4 ± 506.95 kg/ha. The dry weight of litter samples in plantations were comparatively lower throughout the four time period of the study with an average of 639.88 ± 378.7 kg/ha.

The dry weight of litter samples was observed to be highest in the biomass conservation areas during the period of December – March (1521 ± 916.1 kg/ha), which was followed that during the period of September – December (1219 ± 632.9 kg/ha). The dry weight of litter samples in BCA for the period of June – September and March – June were 625.9 ± 239 kg/ha and 655.7 ± 239.8 kg/ha respectively. The dry weight of litter samples were observed to be highest in the plantations during the period of December – March (1061.8 ± 523.5 kg/ha). The dry weight of litter samples were observed to be lowest in the plantations during the period of March – June (321 ± 193.1 kg/ha) and the dry weight of litter samples for the period of June – September and September – December were 406.7 ± 79 kg/ha and 770 ± 719.2 kg/ha respectively.

4.4.1.3 Total Carbon

The analysis of variance for the total carbon of litter samples of plantations and biomass conservation areas in eastern Attappady did not show any significant difference. There was seasonal variation in the total carbon during the four time period of study from June – September to March – June. The total carbon content in litter samples was observed to be highest in the biomass conservation areas throughout the four time period of study with an average of 51.87 ± 2.36 percent of dry weight. The total carbon in the litter samples of plantations were observed to be lowest throughout the four time period from June – September to March – June with an average of 50.9 ± 3.27 percent of dry weight.

The total carbon content was observed to be the highest in the litter samples of biomass conservation areas collected during the period of June – September (52.67 ± 1.4 % of dry wt.) and March – June (52.67 ± 1.88 % of dry wt.). During September – December and December – March the total carbon content in the litter samples of biomass conservation areas were observed to be 50.73 ± 2.19 percent of dry weight and 51.4 ± 3.98 percent of dry weight respectively. The highest total carbon content in the litter samples of plantations were observed to be in the samples collected during the period of June – September (51.73 ± 2.16 % of dry wt.), and lowest in the samples collected during the period of December – March (50.33 ± 3.51 % of dry wt.). In the litter samples of plantations collected during the time period of September – December and March – June the total carbon was observed to be 50.63 ± 3.51 percent of dry weight and 50.9 ± 3.91 percent of dry weight respectively.

4.4.1.4 Total Nitrogen

The analysis of variance for total nitrogen of litter samples of plantations and biomass conservation areas in eastern Attappady did not show significant difference except for the litter samples collected during the period of September – December. The total nitrogen content in litter samples was observed to be highest in the plantations throughout the four time period of study with an average of 1.75 ± 0.77 percent of dry weight. The total nitrogen in the litter samples of biomass conservation areas were observed to be the lowest throughout the four time period from June – September to March – June with an average of 1.47 ± 0.57 percent of dry weight.

The total nitrogen content was observed to be the highest in the litter samples of plantations collected during the period of September - December (2.1 ± 0.99 % of dry wt.), followed by litter samples of plantations collected during the period of March – June (1.73 ± 0.79 % of dry wt.). For the time period of June - September and December – March the total nitrogen content in the litter samples of plantations were observed to be 1.6 ± 0.68 percent of dry weight and 1.57 ± 0.63 percent of dry weight respectively. The highest total nitrogen content in the litter samples of biomass conservation areas were recorded by the litter samples collected during the period of March – June (1.6 ± 0.63 %

of dry wt.) and the lowest was observed to be in the litter samples collected during December – March (1.33 ± 0.49 % of dry wt.). For the litter samples of biomass conservation areas collected during the time period of June – September and September – December the total nitrogen was observed to be 1.53 ± 0.52 percent of dry weight and 1.4 ± 0.63 percent of dry weight respectively.

4.4.1.5 Total Potassium

The analysis of variance for the total potassium content in litter samples of plantations and biomass conservation areas in eastern Attappady did not show significant difference with time period. The total potassium content in litter samples was observed to be highest in the plantations during the time period of June – September and September – December with 0.16 ± 0.15 percent of dry weight and 0.09 ± 0.10 percent of dry weight respectively. During the time period of December – March and March – June, the total potassium content in litter samples of eastern Attappady were observed to be highest in the biomass conservation areas with values 0.10 ± 0.05 percent of dry weight and 0.11 ± 0.06 percent of dry weight respectively.

Among the litter samples of plantations, the total potassium content were observed to be highest in the litter samples collected during the period of June - September (0.16 ± 0.15 % of dry wt.), followed by litter samples collected during the period of March – June (0.10 ± 0.06 % of dry wt.). For the time period of December – March the total potassium content in the litter samples of plantations were observed to be 0.09 ± 0.07 percent of dry weight. The highest total potassium content in the litter samples of biomass conservation areas were recorded by the litter samples collected during the period of June – September and March – June (0.11 ± 0.05 % of dry wt. and 0.11 ± 0.06 % of dry wt. respectively). Among the litter samples of biomass conservation areas collected during the time period of September – December, the total potassium was observed to be 0.07 ± 0.04 percent of dry weight.

4.4.1.6 Total Phosphorus

The analysis of variance for total phosphorus of litter samples of plantations and biomass conservation areas in eastern Attappady did not show significant difference with time period. During the period of June – September and March – June the total phosphorus content were observed to be highest in the biomass conservation areas with 0.10 ± 0.11 percent of dry weight and 0.10 ± 0.06 percent of dry weight respectively. During September – December the total phosphorus content in the litter samples were observed to be highest in plantations (0.09 ± 0.09 % of dry wt.). The litter samples of plantations and biomass conservation areas recorded similar total phosphorus content during the period of December – March (0.08 ± 0.10 % of dry wt. and 0.08 ± 0.06 % of dry wt. respectively).

The total phosphorus content in the litter samples of biomass conservation areas collected during the period of September – December were observed to be the lowest with 0.07 ± 0.05 percent of dry weight. For the litter samples of plantations collected during the time period of June – September and March – June the total phosphorus were 0.09 ± 0.10 percent of dry weight and 0.09 ± 0.06 percent of dry weight respectively.

4.5 Soil studies

4.5.1 Chemical properties of the soil of eastern Attappady

The chemical properties of soils in non-eco-restored areas, plantations and biomass conservation areas of eastern Attappady were analyzed for Organic carbon, Organic matter content, total nitrogen, available potassium, available phosphorus, total phosphorus and cation exchange capacity (CEC) (Table 11).

4.5.1.1 Organic carbon

The analysis of variance for comparing organic carbon in soil along the study sites show significant difference among them. The organic carbon content in the non-eco-restored areas, plantations and biomass conservation areas showed wide variation.

The highest carbon content was observed in the biomass conservation areas (1.43 ± 0.55 %) and the lowest was in the non-eco-restored areas (0.30 ± 0.07 %). The organic carbon content in the soils of plantations were observed to be 0.75 ± 0.21 percent.

Table 11. Chemical properties soil in non-eco-restored areas, plantations and biomass conservation areas of eastern Attappady.

Parameters	Non eco-restored areas	Plantations	BCA
Organic Carbon (%)	0.30 (0.07)^b	0.75 (0.21)^a	1.43 (0.55)^c
Organic Matter Content (%)	0.51 (0.12)^b	1.29 (0.36)^a	2.46 (0.95)^c
Total Nitrogen (%)	0.04 (0.01)^b	0.11 (0.04)^a	0.19 (0.06)^c
Available K (kg/ha)	162.49 (52.68)^a	208.44 (102.74)^a	306.20 (104.45)^b
Available P (kg/ha)	18.92 (6.84)^a	22.62 (13.11)^a	16.94 (6.02)^a
Total P (%)	0.09 (0.02)^a	0.07 (0.03)^a	0.07 (0.05)^a
CEC (Cmol(p+)kg^{-1})	7.69 (2.70)^b	15.24 (3.51)^a	22.34 (6.46)^c

*values with similar subscript along the row do not differ from each other.

Values in parenthesis indicate standard deviation

4.5.1.2 Organic matter content

The analysis of variance for comparing organic matter content in soil along the study sites showed significant difference among them. The organic matter content in the non-eco-restored areas, plantations and biomass conservation areas showed wide variation.

The highest organic matter content was observed in the biomass conservation areas (2.46 ± 0.95 %) and the lowest was in the non-eco-restored areas (0.51 ± 0.12 %). The organic matter content in the soils of plantations were observed to be 1.29 ± 0.36 percent.

4.5.1.3 Total Nitrogen

The analysis of variance for total nitrogen in soil showed significant difference among the study sites. The total nitrogen content in soils of non-eco-restored areas, plantations and biomass conservation areas showed variation among them.

The highest total nitrogen content was observed in the soils of biomass conservation areas (0.19 ± 0.06 %) and the lowest was observed in the soils of non-eco-restored areas (0.04 ± 0.01 %). The total nitrogen content in the soils of plantations were 0.11 ± 0.04 percent.

4.5.1.4 Available potassium

The analysis of variance for available potassium in soil among the study sites showed that the available potassium in plantations and non-eco-restored areas were not significantly different from each other but both were significantly different with that of biomass conservation areas.

The highest available potassium content was observed to be in the soils of biomass conservation areas (306.20 ± 104.45 kg/ha) and the lowest in the soils of non-eco-restored areas (162.49 ± 52.68 kg/ha). The available potassium content in the soils of plantations were observed to be 208.44 ± 102.74 kg/ha.

4.5.1.5 Available phosphorus

The analysis of variance for comparing available phosphorus along the study sites show that they were not significantly different among them. The available phosphorus content in the soils of non-eco-restored areas, plantations and biomass conservation areas had showed that there is no variation between them.

The available phosphorus content in the soils of plantations (22.62 ± 13.11 kg/ha) were observed to be slightly higher compared to the available phosphorus content in the soils of non-eco-restored areas and biomass conservation areas. The available phosphorus content in the soils of non-eco-restored areas and biomass conservation areas were 18.92 ± 6.84 kg/ha and 16.94 ± 6.02 kg/ha respectively.

4.5.1.6 Total phosphorus

The analysis of variance for comparing total phosphorus along the study sites show that they were not significantly different among them. The total phosphorus content in the soils of non-eco-restored areas, plantations and biomass conservation areas had showed that there is no variation between them.

The total phosphorus content in the soils of non-eco-restored areas (0.09 ± 0.02 %) were observed to be higher compared to the total phosphorus content in the soils of plantations and biomass conservation areas. The total phosphorus content in the soils of plantations and biomass conservation areas were 0.07 ± 0.03 percent and 0.07 ± 0.05 percent respectively.

4.5.1.7 Cation Exchange Capacity (CEC)

The analysis of variance for cation exchange capacity along the study sites showed significant difference among them. The CEC in soils of non-eco-restored areas, plantations and biomass conservation areas varied between them.

The highest CEC was observed in the soils of biomass conservation areas (22.34 ± 6.46 Cmol(p+)kg^{-1}) and the lowest was observed in the soils of non-eco-restored areas (7.69 ± 2.70 Cmol(p+)kg^{-1}). The cation exchange capacity in the soils of plantations were 15.24 ± 3.51 Cmol(p+)kg^{-1}.

4.6 Nutrient pool in eastern Attappady

4.6.1 Nutrient pool along the sample plots in eastern Attappady

4.6.1.1 Carbon pool

4.6.1.1.1 Carbon pool in Non-eco-restored areas

Since there is no vegetation and litter fall, the total carbon stock in non-eco-restored areas rely on the soil carbon pool. The carbon pool in the non-eco-restored areas show variation among the study sites. The total carbon stock of non-eco-restored areas are given in Table 12.

The total carbon stock (i.e. soil carbon pool) in sample plots of non-eco-restored areas were observed to be highest in NE1 (7458.3 kg/ha). The lowest carbon stock among the non-eco-restored areas were in NE3 (4258.8 kg/ha). The total carbon stock of other sample plots in non-eco-restored areas were NE2 (5443.2 kg/ha), NE4 (4377.6 kg/ha) and NE5 (5325.3 kg/ha) (Fig. 18).

Table 12. Carbon pool in the study sites of non-eco-restored, plantations and biomass conservation areas in eastern Attappady.

Status	Study sites	Total Carbon			
		Vegetation (kg/ha)	Litter (kg/ha/year)	Soil (kg/ha)	Total (kg/ha)
Non eco-restored areas	NE1	-	-	7458.3	7458.3
	NE2	-	-	5443.2	5443.2
	NE3	-	-	4258.8	4258.8
	NE4	-	-	4377.6	4377.6
	NE5	-	-	5325.3	5325.3
Plantations	Agali	8598.22	2735.47	10854.60	22188.29
	Sambarcode P1	8015.28	2295.09	12946.80	23257.17
	Sambarcode P2	7627.39	2563.49	16748.40	26939.28
	Vannanthura Medu	3139.22	1295.16	8301.30	12735.68
	Kottathara	5704.03	1639.17	12172.50	19515.71
	Pattimalam P1	9739.84	2112.75	15420.00	27272.58
	Pattimalam P2	4555.93	2384.33	14832.90	21773.16
	Pattimalam P3	15177.30	1555.24	16733.40	33465.94
	Vellaimari	8300.93	2256.34	11651.40	22208.66
	Mele Chavadiyur	14715.32	2899.33	15982.20	33596.85
Biomass conservation areas	Sambarcode BCA	48164.96	1715.80	26667.00	76547.77
	Kottathara BCA	6815.72	1478.15	10602.60	18896.47
	Palliyara BCA1	7838.81	6203.07	20370.60	34412.48
	Palliyara BCA2	7855.02	2788.12	34540.80	45183.94
	Palliyara BCA3	10320.50	3589.69	32885.10	46795.29

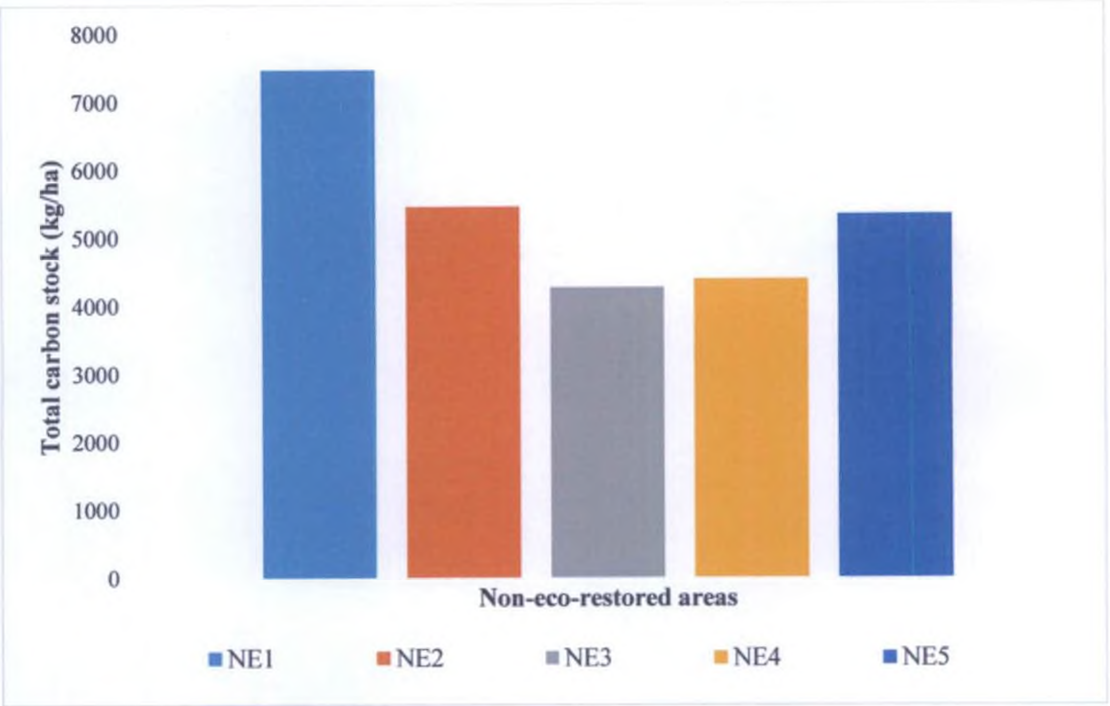


Fig. 18. Total carbon stock in Non-eco-restored areas of eastern Attappady.

4.6.1.1.2 Carbon pool among sample plots in plantations

The carbon pool among the vegetation, litter and soil in the plantations showed variation among the study sites. The carbon stock among the vegetation, litter and soil of plantations are given in Table 12.

The total carbon stock in the plantations were observed to be highest in Mele Chavadiyur (33596.85 kg/ha) followed by Pattimalam P3 (33465.94 kg/ha). The lowest total carbon stock among the plantations were in Vannanthura Medu (12735.68 kg/ha). The total carbon stock of other plantations were Agali (22188.29 kg/ha), Sambarcode P1 (23257.17 kg/ha), Sambarcode P2 (26939.28 kg/ha), Kottathara (19515.71 kg/ha), Pattimalam P1 (27272.58 kg/ha), Pattimalam P2 (21773.16 kg/ha) and Vellaimari (22208.66 kg/ha) (Fig. 19).

Among the plantations the highest carbon stock in vegetation were observed to be in Pattimalam P3 (15177.30 kg/ha) followed by Mele Chavadiyur (14715.32 kg/ha). The lowest carbon stock in vegetation of plantations were observed to be in Vannanthura

Medu with 3139.22 kg/ha. The carbon stock in vegetation of other plantations were Agali (8598.22 kg/ha), Sambarcode P1 (8015.28 kg/ha), Sambarcode P2 (7627.39 kg/ha), Kottathara (5704.03 kg/ha), Pattimalam P1 (9739.84 kg/ha), Pattimalam P2 (4555.93 kg/ha) and Vellaimari (8300.93 kg/ha).

The carbon stock in litter of plantations were observed to be highest in the Mele Chavadiyur (2899.33 kg/ha/year) followed by Agali (2735.47 kg/ha/year). The lowest carbon stock in litter of plantations were observed to be in Vannanthura Medu (1295.16 kg/ha/year). The carbon stock in litter of other plantations were, Sambarcode P1 (2295.09 kg/ha/year), Sambarcode P2 (2563.49 kg/ha/year), Kottathara (1639.17 kg/ha/year), Pattimalam P1 (2112.75 kg/ha/year), Pattimalam P2 (2384.33 kg/ha/year), Pattimalam P3 (1555.24 kg/ha/year) and Vellaimari (2256.34 kg/ha/year).

The carbon stock in soil of plantations were observed to be highest in the Sambarcode P2 (16748.40 kg/ha) followed by Pattimalam P3 (16733.40 kg/ha). The lowest carbon stock in soil of plantations were in Vannanthura Medu (8301.30 kg/ha). The carbon stock in soil of other plantations were, Agali (10854.6 kg/ha), Sambarcode P1 (12946.80 kg/ha), Kottathara (12172.50 kg/ha), Pattimalam P1 (15420.00 kg/ha), Pattimalam P2 (14832.90 kg/ha), Velleimari (11651.40 kg/ha) and Mele Chavadiyur (15982.20 kg/ha).

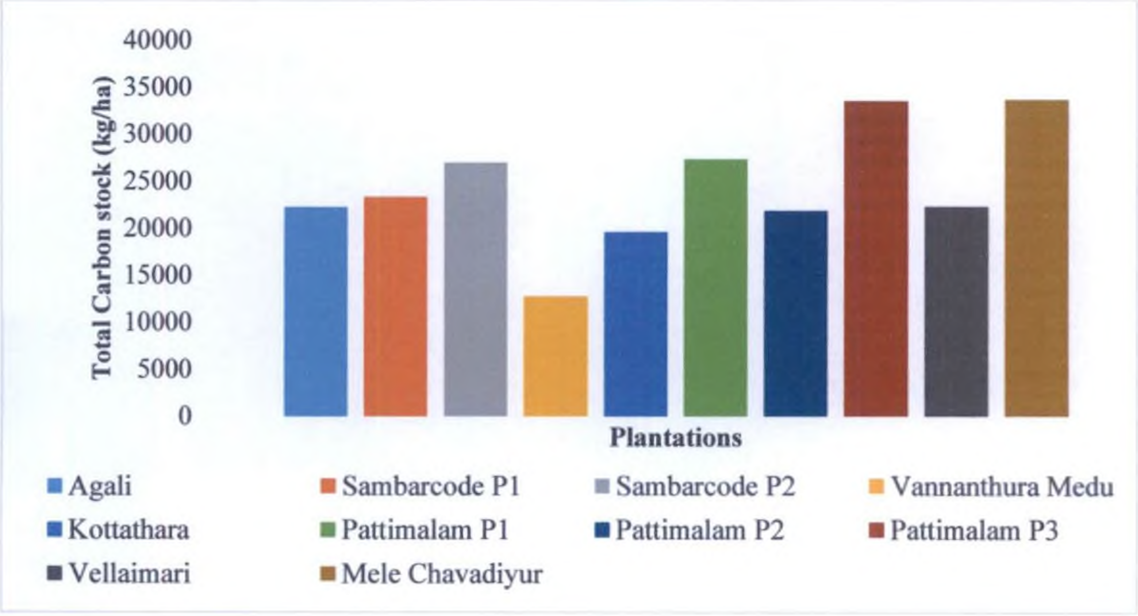


Fig. 19. Total carbon stock in plantations of eastern Attappady

4.6.1.1.3 Carbon pool in biomass conservation areas

The analysis of variance for carbon pool among the vegetation, litter and soil in the biomass conservation areas showed variation along the study sites.

The total carbon stock in the biomass conservation areas were observed to be highest in Sambarcode BCA (76547.77 kg/ha) followed by Palliyara BCA3 (46795.29 kg/ha). The lowest total carbon stock among the biomass conservation areas were in Kottathara BCA (18896.47 kg/ha). The total carbon stock of other biomass conservation areas were Palliyara BCA1 (34412.48 kg/ha) and Palliyara BCA2 (45183.94 kg/ha) (Fig. 20).

Among the biomass conservation areas the highest carbon stock in vegetation were observed to be in Sambarcode BCA (48164.96 kg/ha) followed by Palliyara BCA3 (10320.50 kg/ha). The lowest carbon stock in vegetation of biomass conservation areas were observed to be in Kottathara with 6815.72 kg/ha. The carbon stock in vegetation of other biomass conservation areas were Palliyara BCA1 (7838.81 kg/ha) and Palliyara BCA2 (7855.02 kg/ha).

The carbon stock in litter of biomass conservation areas were observed to be highest in the Palliyara BCA1 (6203.07 kg/ha/year) followed by Palliyara BCA3 (3589.69 kg/ha/year). The lowest carbon stock in litter of biomass conservation areas were observed to be in Kottathara BCA (1478.15 kg/ha/year). The carbon stock in litter of other biomass conservation areas were, Sambarcode BCA (1715.80 kg/ha/year) and Palliyara BCA2 (2788.12 kg/ha/year).

The carbon stock in soil of biomass conservation areas were observed to be highest in the Palliyara BCA2 (34540.80 kg/ha) followed by Palliyara BCA3 (32885.10 kg/ha). The lowest organic carbon stock in soil of biomass conservation areas were in Kottathara BCA (10602.60 kg/ha). The organic carbon stock in soil of other biomass conservation areas were, Sambarcode BCA (26667.00 kg/ha) and Palliyara BCA1 (20370.60 kg/ha).

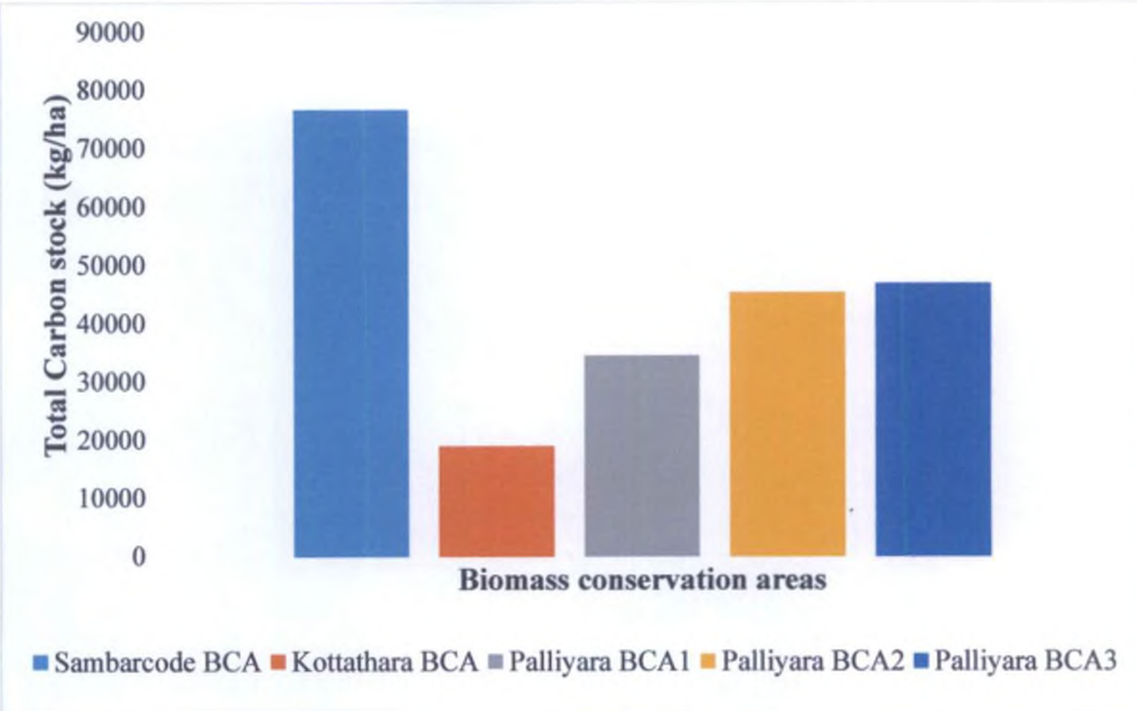


Fig. 20. Total carbon stock in biomass conservation areas of eastern Attappady.

4.6.1.2 Nitrogen pool

4.6.1.2.1 Nitrogen pool in Non-eco-restored areas

Since there is no vegetation and litter fall, the total nitrogen stock in non-eco-restored areas rely on the soil nitrogen pool. The nitrogen pool in the non-eco-restored areas show variation among the study sites. The total nitrogen stock of non-eco-restored areas are given in Table 13.

The total nitrogen stock (i.e. soil nitrogen pool) in study sites of non-eco-restored areas were observed to be highest in NE4 (1008 kg/ha). The lowest carbon stock among the non-eco-restored areas were in NE2 and NE3 (both 504 kg/ha). The total nitrogen stock of other study sites in non-eco-restored areas were NE1 (756 kg/ha) and NE5 (756 kg/ha) (Fig. 21).

Table 13. Nitrogen pool in the study sites of non-eco-restored, plantations and biomass conservation areas in eastern Attappady.

		Total nitrogen			
Status	Study sites	Vegetation (kg/ha)	Litter (kg/ha/year)	Soil (kg/ha)	Total (kg/ha)
Non eco-restored areas	NE1	-	-	756	756
	NE2	-	-	504	504
	NE3	-	-	504	504
	NE4	-	-	1008	1008
	NE5	-	-	756	756
Plantations	Agali	218.15	101.69	1512	1831.84
	Sambarcode P1	181.70	63.53	2184	2429.23
	Sambarcode P2	172.95	79.13	1764	2016.07
	Vannanthura Medu	75.30	45.92	2100	2221.22
	Kottathara	135.71	41.82	2184	2361.53
	Pattimalam P1	252.50	64.16	2268	2584.66
	Pattimalam P2	97.99	72.29	756	926.29
	Pattimalam P3	316.80	34.47	2016	2367.27
	Vellaimari	199.20	92.14	1344	1635.33
	Mele Chavadiyur	315.25	50.48	2016	2381.73
BCA	Sambarcode BCA	1031.86	54.77	4368	5454.63
	Kottathara BCA	156.99	47.61	1932	2136.59
	Palliyara BCA1	184.77	113.09	840	1137.87
	Palliyara BCA2	170.42	69.27	3612	3851.69
	Palliyara BCA3	224.95	82.76	4200	4507.71

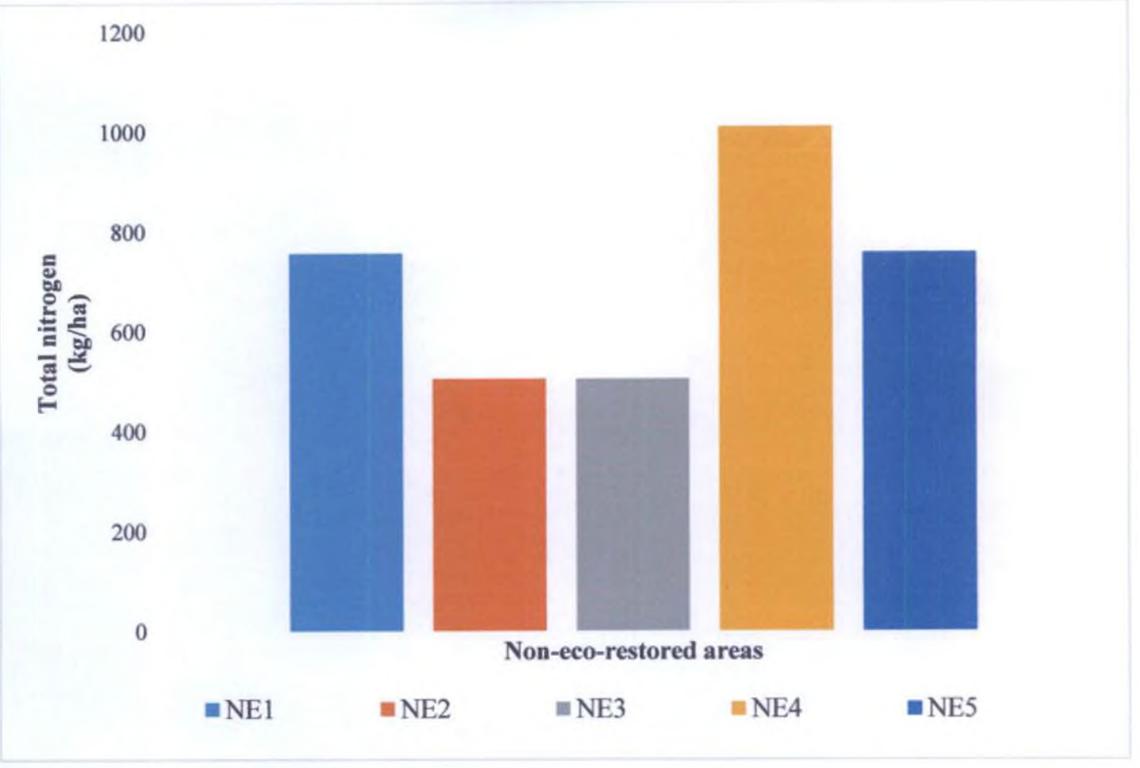


Fig. 21. Total nitrogen stock in non-eco-restored areas of eastern Attappady.

4.6.1.2.2 Nitrogen pool in plantations

The analysis of variance for nitrogen pool among the vegetation and soil in the plantations showed variation along the study sites. The nitrogen stock among the litter were not significantly different along the study sites. The nitrogen stock among the vegetation, litter and soil of plantations are given in Table 13.

The total nitrogen stock in the plantations were observed to be highest in Pattimalam P1 (2584.66 kg/ha) followed by Sambarcode P1 (2429.23 kg/ha). The lowest total nitrogen stock among the plantations were in Pattimalam P2 (926.29 kg/ha). The total nitrogen stock of other plantations were Agali (1831.84 kg/ha), Sambarcode P2 (2016.07 Kg/ha), Vannanthura Medu (2221.22 kg/ha), Kottathara (2361.53 kg/ha), Pattimalam P3 (2367.27 kg/ha), Vellaimari (1635.33 kg/ha) and Mele Chavadiyur (2381.73 kg/ha) (Fig. 22).

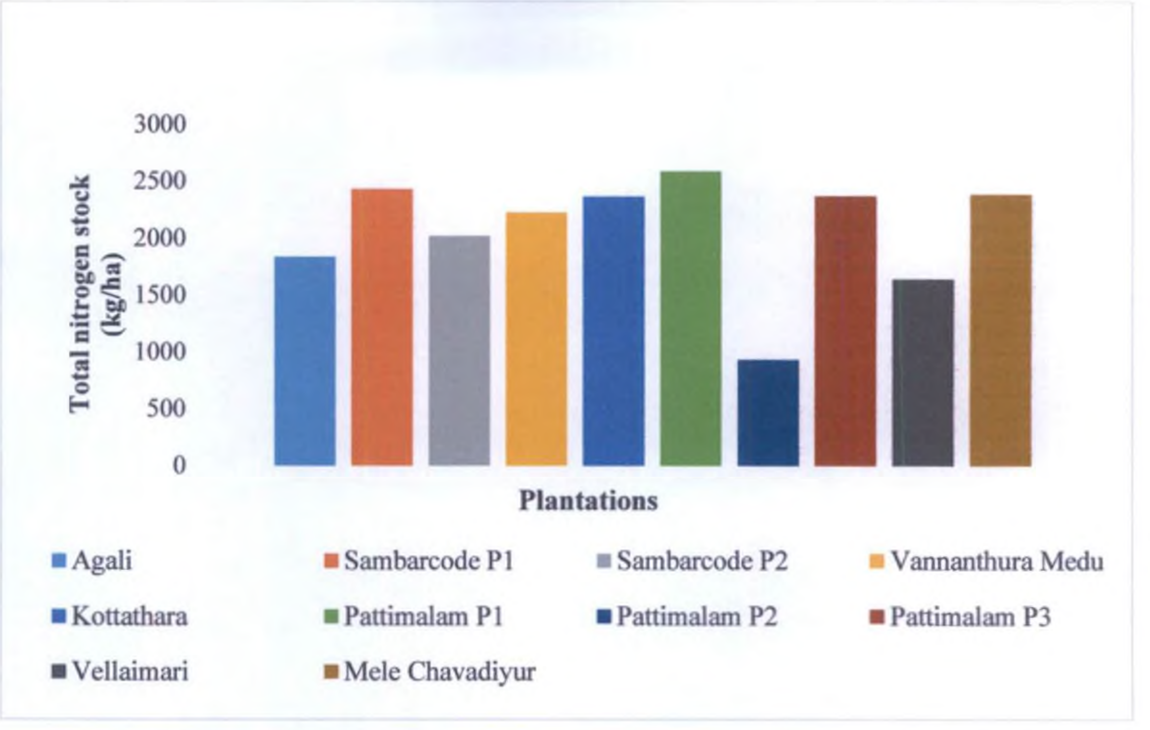


Fig. 22. Total nitrogen stock in plantations of eastern Attappady.

Among the plantations the highest nitrogen stock in vegetation were observed to be in Pattimalam P3 (316.80 kg/ha) followed by Mele Chavadiyur (315.25 kg/ha). The lowest nitrogen stock in vegetation of plantations were observed to be in Vannanthura Medu with 75.30 kg/ha. The nitrogen stock in vegetation of other plantations were Agali (218.15 kg/ha), Sambarcode P1 (181.70 kg/ha), Sambarcode P2 (172.95 kg/ha), Kottathara (135.71 kg/ha), Pattimalam P1 (252.50 kg/ha), Pattimalam P2 (97.99 kg/ha) and Vellaimari (199.20 kg/ha).

The nitrogen stock in litter of plantations were observed to be highest in the Agali (101.69 kg/ha/year) followed by Vellaimari (92.14 kg/ha/year). The lowest nitrogen stock in litter of plantations were observed to be in Pattimalam P3 (34.47 kg/ha/year). The nitrogen stock in litter of other plantations were, Sambarcode P1 (63.53 kg/ha/year), Sambarcode P2 (79.13 kg/ha/year), Vannanthura Medu (45.92 kg/ha/year), Kottathara (41.82 kg/ha/year), Pattimalam P1 (64.16 kg/ha/year), Pattimalam P2 (72.29 kg/ha/year) and Mele Chavadiyur (50.48 kg/ha/year).

The nitrogen stock in soil of plantations were observed to be highest in the Pattimalam P1 (2268 kg/ha) followed by Sambarcode P1 (2184 kg/ha) and Kottathara (2184 kg/ha). The lowest nitrogen stock in soil of plantations were in Pattimalam P2 (756 kg/ha). The nitrogen stock in soil of other plantations were, Agali (1512 kg/ha), Sambarcode P2 (1764 kg/ha), Pattimalam P3 (2016 kg/ha), Velleimari (1344 kg/ha) and Mele Chavediyur (2016 kg/ha).

4.6.1.2.3 Nitrogen pool in biomass conservation areas

The analysis of variance for nitrogen pool among the vegetation, litter and soil in the plantations showed variation along the study sites. The nitrogen stock among the litter were not significantly different along the study sites. The nitrogen stock among the vegetation, litter and soil of BCA are given in Table 13.

The total nitrogen stock in the biomass conservation areas were observed to be highest in Sambarcode BCA (5400.01 kg/ha) followed by Palliyara BCA3 (4425.18 kg/ha). The lowest total nitrogen stock among the biomass conservation areas were in Palliyara BCA1 (1025.08 kg/ha). The total nitrogen stock of other biomass conservation areas were Kottathara BCA (2089.12 kg/ha) and Palliyara BCA2 (3782.61 kg/ha) (Fig. 23).

Among the biomass conservation areas the highest nitrogen stock in vegetation were observed to be in Sambarcode BCA (1031.86 kg/ha) followed by Palliyara BCA3 (224.95 kg/ha). The lowest nitrogen stock in vegetation of biomass conservation areas were observed to be in Kottathara with 156.99 kg/ha. The nitrogen stock in vegetation of other biomass conservation areas were Palliyara BCA1 (184.77 kg/ha) and Palliyara BCA2 (170.42 kg/ha).

The nitrogen stock in litter of biomass conservation areas were observed to be highest in the Palliyara BCA1 (113.09 kg/ha/year) followed by Palliyara BCA3 (82.76 kg/ha/year). The lowest nitrogen stock in litter of biomass conservation areas were observed to be in Kottathara BCA (47.61 kg/ha/year). The nitrogen stock in litter of other biomass conservation areas were, Sambarcode BCA (54.77 kg/ha/year) and Palliyara BCA2 (69.27 kg/ha/year).

The nitrogen stock in soil of biomass conservation areas were observed to be highest in the Sambarcode BCA (4368 kg/ha) followed by Palliyara BCA3 (4200 kg/ha). The lowest nitrogen stock in soil of biomass conservation areas were in Palliyara BCA1 (840 kg/ha). The nitrogen stock in soil of other biomass conservation areas were, Kottathara BCA (1932 kg/ha) and Palliyara BCA2 (3612 kg/ha).

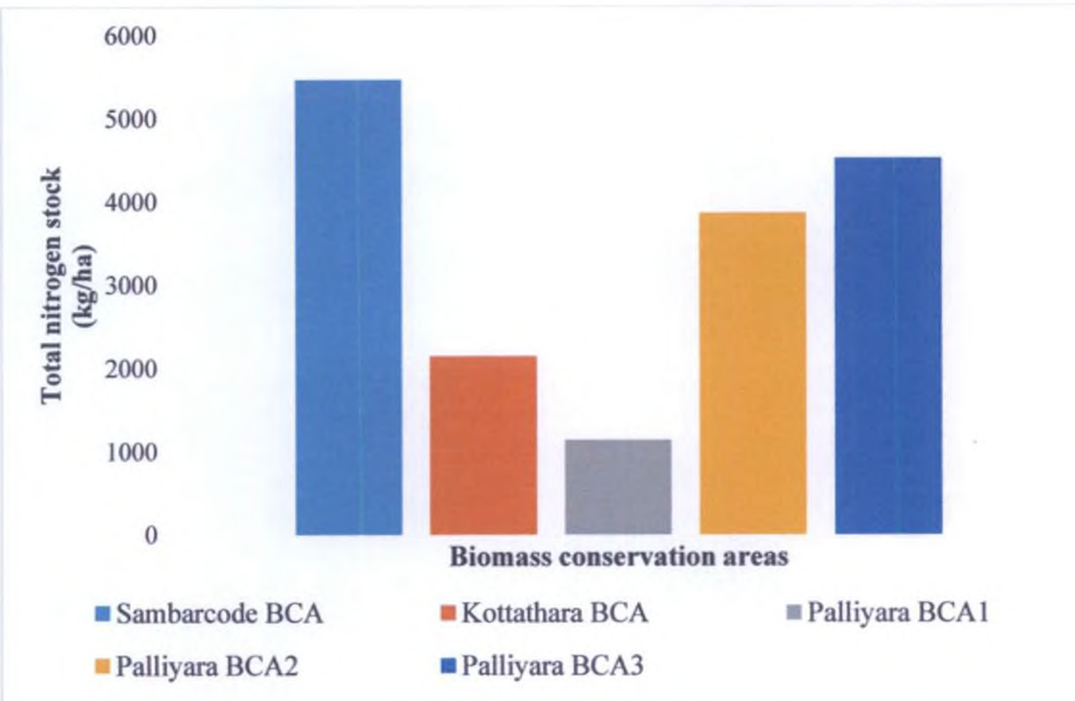


Fig. 23. Total nitrogen stock in biomass conservation areas of eastern Attappady.

4.6.1.3 Phosphorus pool

4.6.1.3.1 Phosphorus pool in Non-eco-restored areas

Since there is no vegetation and litter fall, the total phosphorus stock in non-eco-restored areas rely on the soil phosphorus pool. The phosphorus pool in the non-eco-restored areas show variation among the study sites. The total phosphorus stock of non-eco-restored areas are given in Table 14.

The total phosphorus stock (i.e. soil phosphorus pool) in sample plots of non-eco-restored areas were observed to be highest in NE2 (2235.60 kg/ha). The lowest stock

Table 14. Phosphorus pool in the sample plots of eco-restored and biomass conservation areas in eastern Attappady.

Status	Study sites	Total phosphorus			
		Vegetation (kg/ha)	Litter (kg/ha/year)	Soil (kg/ha)	Total (kg/ha)
Non eco-restored areas	NE1	-	-	1239.30	1239.30
	NE2	-	-	2235.60	2235.60
	NE3	-	-	1496.64	1496.64
	NE4	-	-	1402.82	1402.82
	NE5	-	-	1629.11	1629.11
Plantations	Agali	20.55	4.242	1726.88	1751.67
	Sambarcode P1	19.86	6.186	1756.91	1782.96
	Sambarcode P2	19.94	3.336	1713.71	1736.99
	Vannanthura Medu	8.13	2.111	1620.73	1630.98
	Kottathara	16.35	3.292	1083.49	1103.13
	Pattimalam P1	22.63	2.115	795.32	820.06
	Pattimalam P2	11.84	4.943	1213.14	1229.93
	Pattimalam P3	35.14	1.656	1448.44	1485.23
	Vellaimari	22.26	2.307	572.57	597.14
	Mele Chavadiyur	35.32	2.091	705.94	743.35
BCA	Sambarcode BCA	115.47	3.857	2545.71	2665.03
	Kottathara BCA	19.46	2.756	1284.75	1306.97
	Palliyara BCA1	21.46	5.149	469.80	496.41
	Palliyara BCA2	18.65	4.447	696.94	720.03
	Palliyara BCA3	23.54	4.644	720.45	748.64

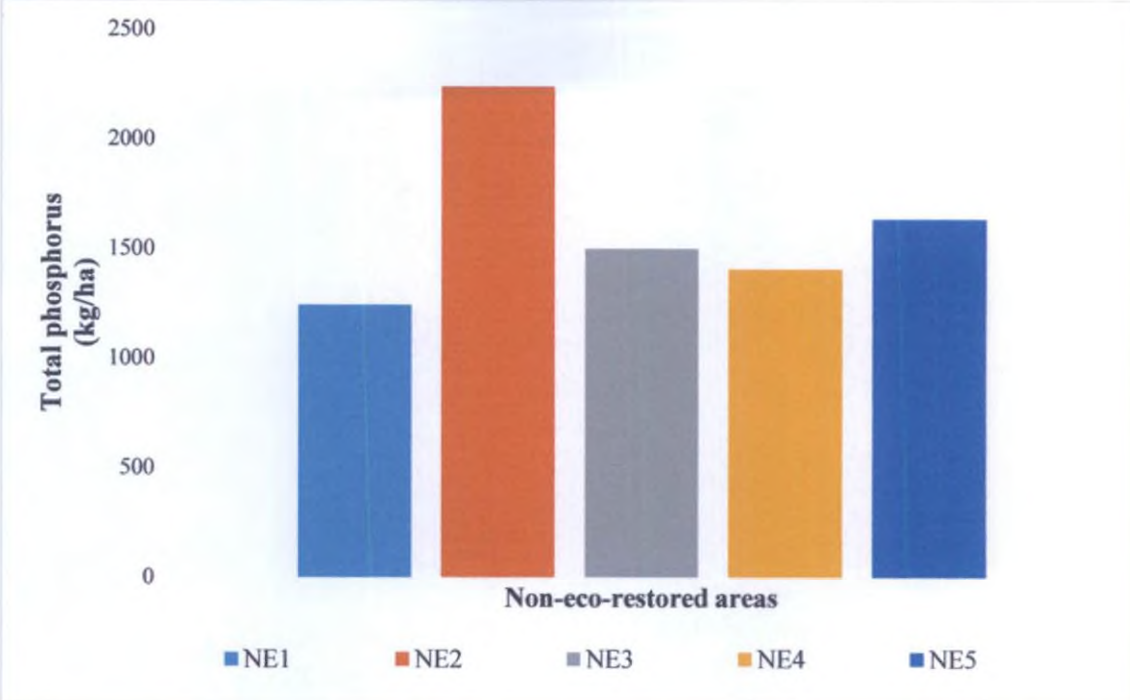


Fig. 24. Total phosphorus stock in non-eco-restored areas of eastern Attappady.

among the non-eco-restored areas were in NE1 (1239.30 kg/ha). The total phosphorus stock of other study sites in non-eco-restored areas were NE3 (1496.64 kg/ha), NE4 (1402.82 kg/ha) and NE5 (1629.11 kg/ha) (Fig. 24).

4.6.1.3.2 Phosphorus pool in plantations

The analysis of variance for phosphorus pool among the vegetation and soil in the plantations showed variation along the study sites. The phosphorus stock among the litter were not significantly different along the study sites. The phosphorus stock among the vegetation, litter and soil of plantations are given in Table 14.

The total phosphorus stock in the plantations were observed to be highest in Sambarcode P1 (1782.96 kg/ha) followed by Agali (1751.67 kg/ha). The lowest total phosphorus stock among the plantations were in Vellaimari (597.14 kg/ha). The total phosphorus stock of other plantations were Sambarcode P2 (1736.99 kg/ha), Vannanthura Medu (1630.98 kg/ha), Kottathara (1103.13 kg/ha), Pattimalam P1 (820.06 kg/ha), Pattimalam P2 (1229.93 kg/ha), Pattimalam P3 (1485.23 kg/ha) and Mele Chavadiyur (743.35 kg/ha) (Fig. 25).

Among the plantations the highest phosphorus stock in vegetation were observed to be in Mele Chavadiyur (35.32 kg/ha) followed by Pattimalam P3 (35.14 kg/ha). The lowest phosphorus stock in vegetation of plantations were observed to be in Vannanthura Medu with 8.13 kg/ha. The phosphorus stock in vegetation of other plantations were Agali (20.55 kg/ha), Sambarcode P1 (19.86 kg/ha), Sambarcode P2 (19.94 kg/ha), Kottathara (16.35 kg/ha), Pattimalam P1 (22.63 kg/ha), Pattimalam P2 (11.84 kg/ha) and Vellaimari (22.26 kg/ha).

The phosphorus stock in litter of plantations were observed to be highest in the Sambarcode P1 (6.186 kg/ha/year) followed by Pattimalam P2 (4.943 kg/ha/year). The lowest phosphorus stock in litter of plantations were observed to be in Pattimalam P3 (1.656 kg/ha/year). The phosphorus stock in litter of other plantations were, Agali (4.242 kg/ha/year), Sambarcode P2 (3.336 kg/ha/year), Vannanthura Medu (2.111 kg/ha/year), Kottathara (3.292 kg/ha/year), Pattimalam P1 (2.115 kg/ha/year), Vellaimari (2.307 kg/ha/year) and Mele Chavadiyur (2.091 kg/ha/year).

The phosphorus stock in soil of plantations were observed to be highest in the Sambarcode P1 (1756.91 kg/ha) followed by Agali (1726.88 kg/ha). The lowest phosphorus stock in soil of plantations were in Vellaimari (572.57 kg/ha). The phosphorus stock in soil of other plantations were, Sambarcode P2 (1713.71 kg/ha), Vannanthura Medu (1620.73 kg/ha), Kottathara (1083.49 kg/ha), Pattimalam P1 (795.32 kg/ha), Pattimalam P2 (1213.14 kg/ha), Pattimalam P3 (1448.44 kg/ha) and Mele Chavediyur (705.94 kg/ha).

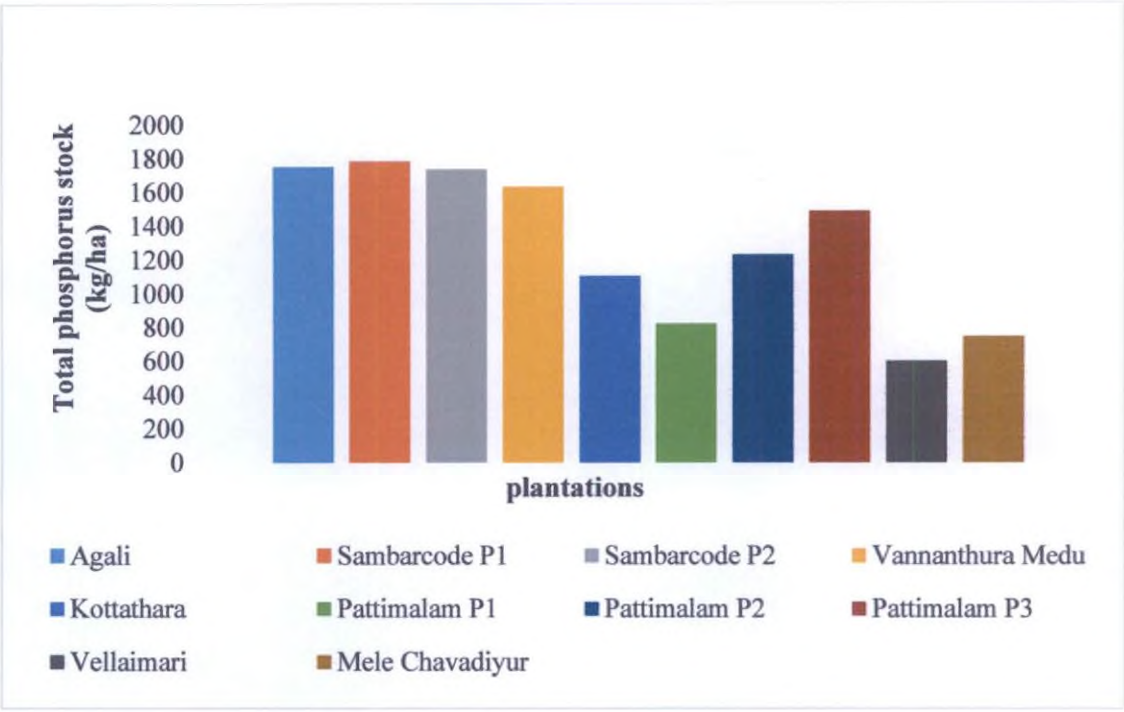


Fig 25. Total phosphorus stock in plantations of eastern Attappady.

4.6.1.3.3 Phosphorus pool in biomass conservation areas

The analysis of variance for phosphorus pool among the vegetation, litter and soil in the plantations showed variation along the study sites. The phosphorus stock among the litter were not significantly different along the study sites. The phosphorus stock among the vegetation, litter and soil of biomass conservation areas are given in Table 14.

The total phosphorus stock in the biomass conservation areas were observed to be highest in Sambarcode BCA (2661.18 kg/ha) followed by Kottathara BCA (1304.22 kg/ha). The lowest total phosphorus stock among the biomass conservation areas were in Palliyara BCA1 (491.27 kg/ha). The total phosphorus stock of other biomass conservation areas were Palliyara BCA2 (715.60 kg/ha) and Palliyara BCA3 (744.01 kg/ha) (Fig. 26).

Among the biomass conservation areas the highest phosphorus stock in vegetation were observed to be in Sambarcode BCA (115.47 kg/ha) followed by Palliyara BCA3 (23.54 kg/ha). The lowest phosphorus stock in vegetation of biomass conservation areas were observed to be in Palliyara BCA2 with 18.65 kg/ha. The phosphorus stock in vegetation of other biomass conservation areas were Kottathara (19.46 kg/ha) and Palliyara BCA1 (21.46 kg/ha).

The phosphorus stock in litter of biomass conservation areas were observed to be highest in the Palliyara BCA1 (5.149 kg/ha/year) followed by Palliyara BCA3 (4.644 kg/ha/year). The lowest phosphotus stock in litter of biomass conservation areas were observed to be in Kottathara BCA (2.756 kg/ha/year). The phosphorus stock in litter of other biomass conservation areas were, Sambarcode BCA (3.857 kg/ha/year) and Palliyara BCA2 (4.447 kg/ha/year).

The phosphorus stock in soil of biomass conservation areas were observed to be highest in the Sambarcode BCA (2545.71 Kg/ha) followed by Kottathara BCA (1284.75 kg/ha). The lowest phosphorus stock in soil of biomass conservation areas were in Palliyara BCA1 (469.80 kg/ha). The phosphorus stock in soil of other biomass conservation areas were, Palliyara BCA2 (696.94 kg/ha) and Palliyara BCA3 (720.45 kg/ha).

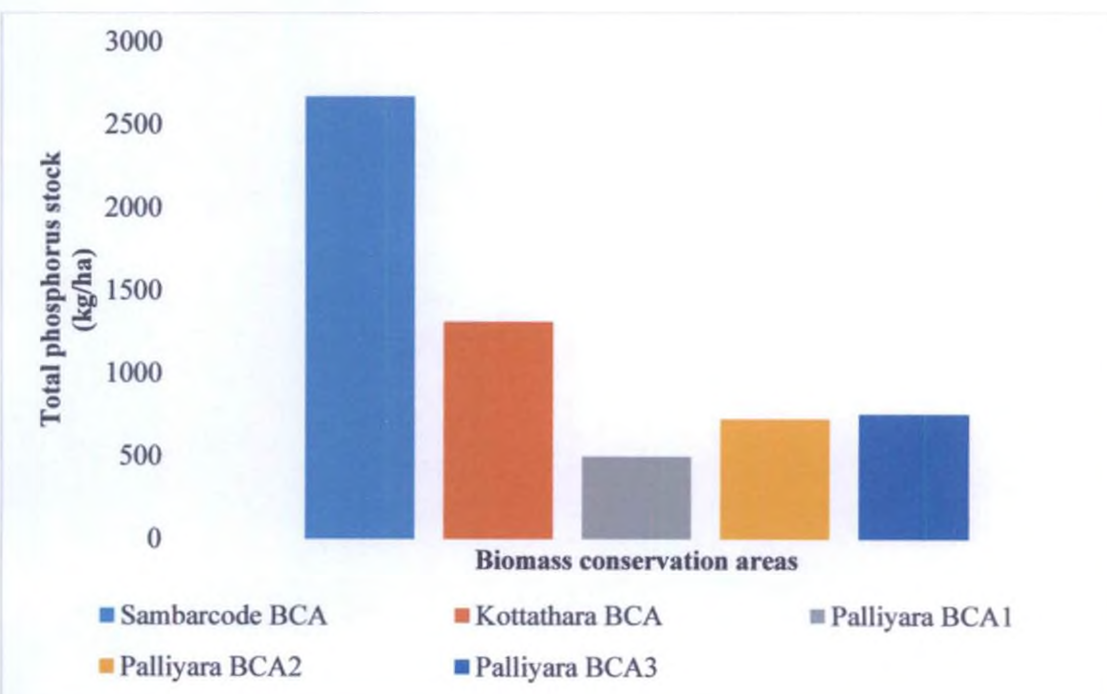


Fig. 26. Total phosphorus stock in biomass conservation areas of eastern Attappady.

4.6.1.4 Potassium pool

4.6.1.4.1 Potassium pool in non-eco-restored areas

Since there is no vegetation and litter fall, the total potassium stock in non-eco-restored areas rely on the soil potassium pool. The potassium pool in the non-eco-restored areas show variation among the study sites. The total potassium stock of non-eco-restored areas are given in Table 15.

The total potassium stock (i.e. soil potassium pool) in study sites of non-eco-restored areas were observed to be highest in NE1 (236.32 kg/ha). The lowest potassium stock among the non-eco-restored areas were in NE4 (97.78 kg/ha). The total potassium stock of other sample plots in non-eco-restored areas were NE2 (128.8 kg/ha), NE3 (171.36 kg/ha) and NE5 (178.19 kg/ha) (Fig. 27).

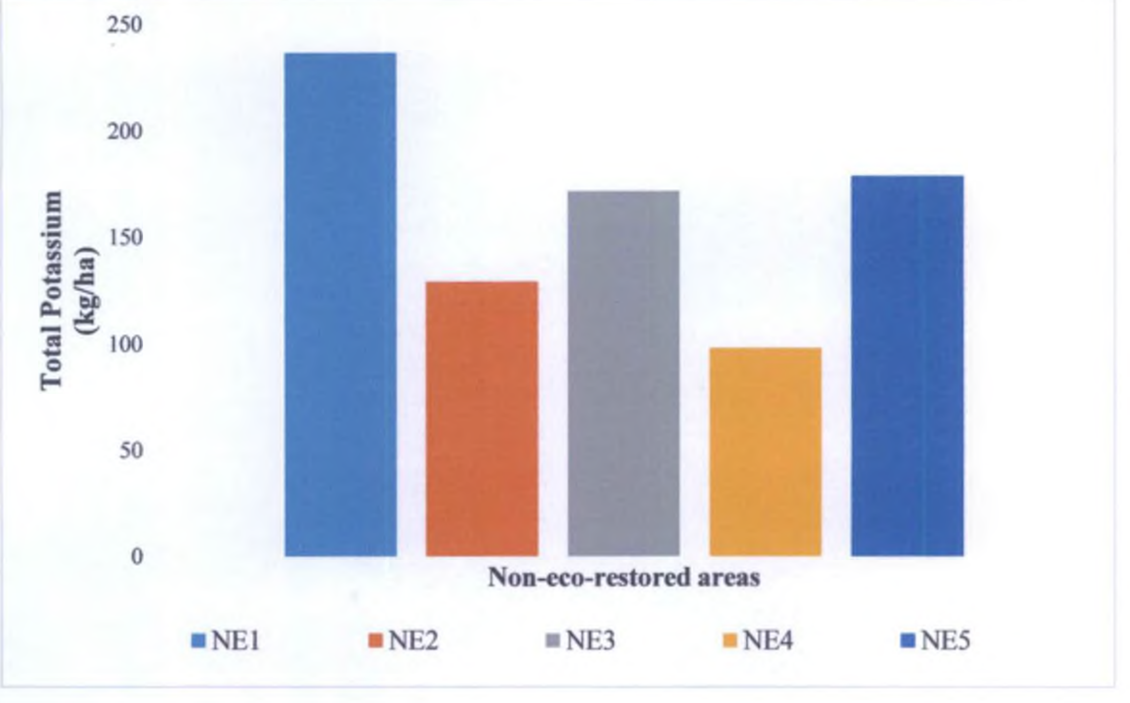


Fig. 27. Total potassium stock in non-eco-restored areas of eastern Attappady.

Table 15. Potassium pool in the sample plots of non-eco-restored, plantations and biomass conservation areas in eastern Attappady

Status	Study sites	Total potassium			
		Vegetation (kg/ha)	Litter (kg/ha/year)	Soil (kg/ha)	Total (kg/ha)
Non eco-restored areas	NE1	-	-	236.32	236.32
	NE2	-	-	128.8	128.8
	NE3	-	-	171.36	171.36
	NE4	-	-	97.78	97.78
	NE5	-	-	178.19	178.19
Plantations	Agali	26.75	5.904	97.59	130.25
	Sambarcode P1	22.35	4.603	186.67	213.62
	Sambarcode P2	21.71	4.110	237.74	263.55
	Vannanthura Medu	9.65	1.470	145.08	156.20
	Kottathara	16.79	3.920	307.29	328.00
	Pattimalam P1	34.31	4.321	246.92	285.55
	Pattimalam P2	13.91	5.159	252.34	271.41
	Pattimalam P3	48.54	2.896	245.21	296.64
	Vellaimari	23.48	4.426	112.49	140.39
	Mele Chavadiyur	33.81	3.348	282.35	319.51
BCA	Sambarcode BCA	185.92	4.740	402.19	592.86
	Kottathara BCA	20.49	3.182	258.46	282.13
	Palliyara BCA1	26.99	9.324	114.24	150.56
	Palliyara BCA2	26.86	3.972	341.75	372.59
	Palliyara BCA3	32.33	5.748	286.38	324.46

4.6.1.4.2 Potassium pool in plantations

The analysis of variance for potassium pool among the vegetation and soil in the plantations showed variation along the study sites. The potassium stock among the litter were not significantly different along the study sites. The potassium stock among the vegetation, litter and soil of plantations are given in Table 15.

The total potassium stock in the plantations were observed to be highest in Kottathara (328.00 kg/ha) followed by Mele Chavadiyur (319.51 kg/ha). The lowest total potassium stock among the plantations were in Agali (130.25 kg/ha). The total potassium stock of other plantations were Sambarcode P1 (213.62 kg/ha), Sambarcode P2 (263.55 kg/ha), Vannanthura Medu (156.20 kg/ha), Pattimalam P1 (285.55 kg/ha), Pattimalam P2 (271.41 kg/ha), Pattimalam P3 (296.64 kg/ha) and Vellaimari (140.39 kg/ha) (Fig. 28).

Among the plantations the highest potassium stock in vegetation were observed to be in Pattimalam P3 (48.54 kg/ha) followed by Pattimalam P1 (34.31 kg/ha). The lowest potassium stock in vegetation of plantations were observed to be in Vannanthura Medu with 9.65 kg/ha. The potassium stock in vegetation of other plantations were Agali (26.75 kg/ha), Sambarcode P1 (22.35 kg/ha), Sambarcode P2 (21.71 kg/ha), Kottathara (16.79 kg/ha), Pattimalam P2 (13.91 kg/ha), Vellaimari (23.48 kg/ha) and Mele Chavadiyur (33.81 kg/ha).

The potassium stock in litter of plantations were observed to be highest in the Agali (5.904 kg/ha/year) followed by Pattimalam P2 (5.159 kg/ha/year). The lowest potassium stock in litter of plantations were observed to be in Vannanthura Medu (1.470 kg/ha/year). The potassium stock in litter of other plantations were, Sambarcode P1 (4.603 kg/ha/year), Sambarcode P2 (4.110 kg/ha/year), Kottathara (3.920 kg/ha/year), Pattimalam P1 (4.321 kg/ha/year), Palliyara P3 (2.896 kg/ha), Vellaimari (4.426 kg/ha/year) and Mele Chavadiyur (3.348 kg/ha/year).

The potassium stock in soil of plantations were observed to be highest in the Kottathara (307.29 kg/ha) followed by Mele Chavadiyur (282.35 kg/ha). The lowest potassium stock in soil of plantations were in Agali (97.59 kg/ha). The potassium stock in soil of other plantations were, Sambarcode P1 (186.67 kg/ha), Sambarcode P2 (237.74

kg/ha), Vannanthura Medu (145.08 kg/ha), Pattimalam P1 (246.92 kg/ha), Pattimalam P2 (252.34 kg/ha), Pattimalam P3 (245.21 kg/ha) and Vallaimari (112.49 kg/ha).

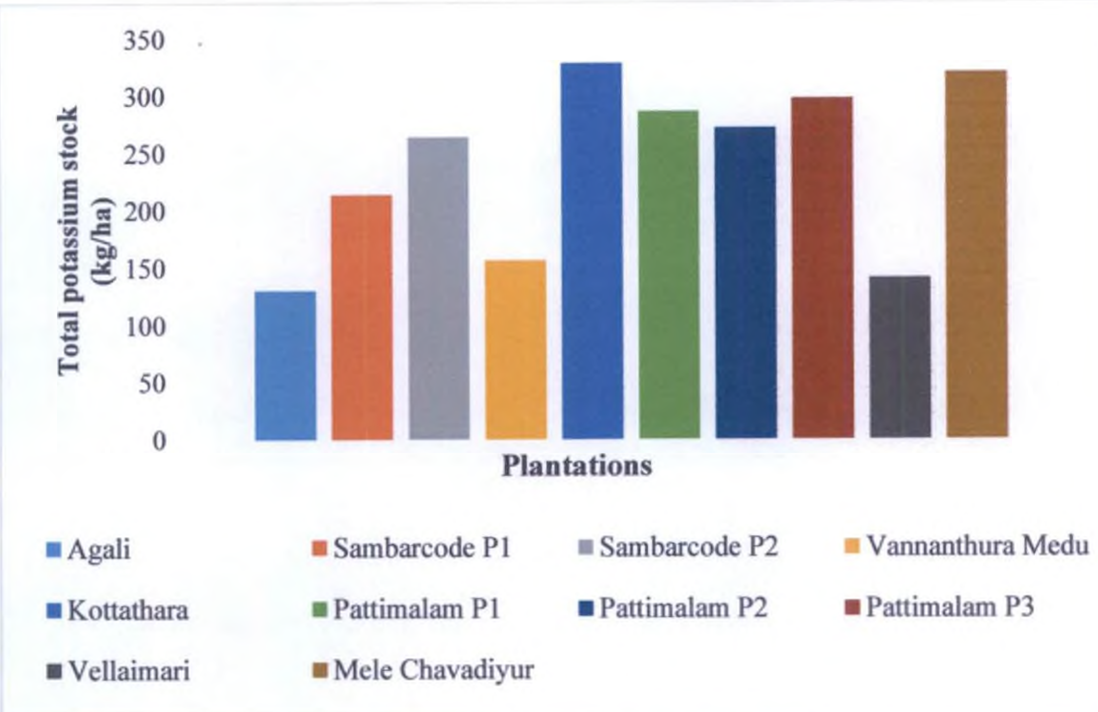


Fig. 28. Total potassium stock in plantations of eastern Attappady.

4.6.1.4.3 Potassium pool in biomass conservation areas

The analysis of variance for potassium pool among the vegetation, litter and soil in the plantations showed variation along the study sites. The potassium stock among the litter were not significantly different along the study sites. The potassium stock among the vegetation, litter and soil of biomass conservation areas are given in Table 15.

The total potassium stock in the biomass conservation areas were observed to be highest in Sambarcode BCA (592.86 kg/ha) followed by Palliyara BCA2 (372.59 kg/ha). The lowest total potassium stock among the biomass conservation areas were in Palliyara BCA1 (150.56 kg/ha). The total potassium stock of other biomass conservation areas were Kottathara BCA (282.13 kg/ha) and Palliyara BCA3 (324.46 kg/ha) (Fig. 29).

Among the biomass conservation areas the highest potassium stock in vegetation were observed to be in Sambarcode BCA (185.92 kg/ha) followed by Palliyara BCA3 (32.33 kg/ha). The lowest potassium stock in vegetation of biomass conservation areas were observed to be in Kottathara with 20.49 kg/ha. The potassium stock in vegetation of other biomass conservation areas were Palliyara BCA1 (26.99 kg/ha) and Palliyara BCA2 (26.86 kg/ha).

The potassium stock in litter of biomass conservation areas were observed to be highest in the Palliyara BCA1 (9.324 kg/ha/year) followed by Palliyara BCA3 (5.748 kg/ha/year). The lowest potassium stock in litter of biomass conservation areas were observed to be in Kottathara BCA (3.182 kg/ha/year). The potassium stock in litter of other biomass conservation areas were, Sambarcode BCA (4.740 kg/ha/year) and Palliyara BCA2 (3.972 kg/ha/year).

The potassium stock in soil of biomass conservation areas were observed to be highest in the Sambarcode BCA (402.19 kg/ha) followed by Palliyara BCA2 (341.75 kg/ha). The lowest potassium stock in soil of biomass conservation areas were in Palliyara BCA1 (114.24 kg/ha). The potassium stock in soil of other biomass conservation areas were, Kottathara BCA (258.46 kg/ha) and Palliyara BCA3 (286.38 kg/ha).

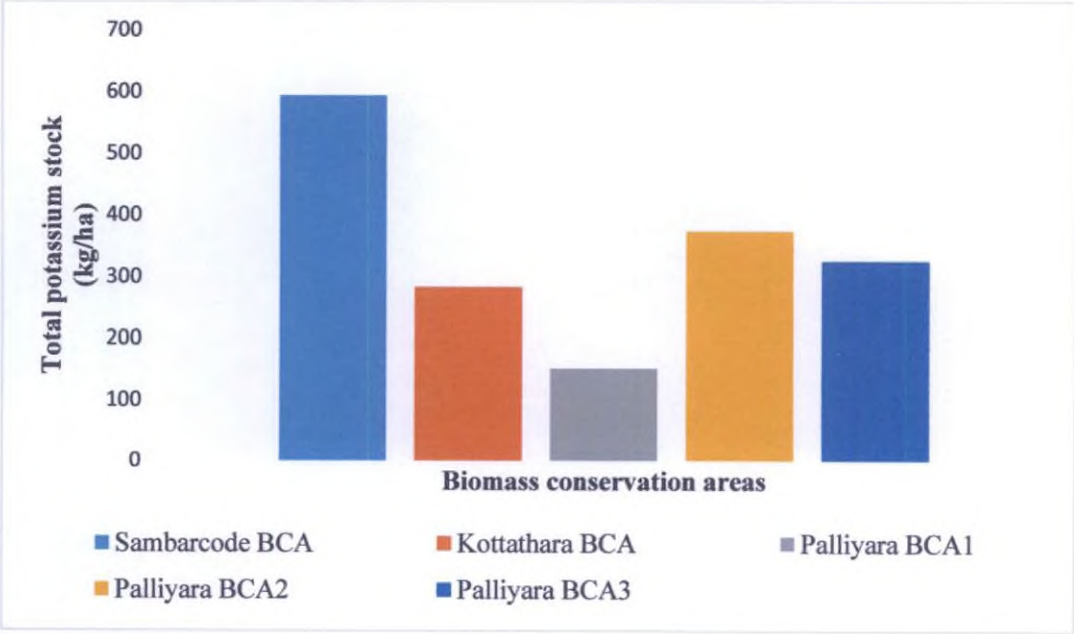


Fig. 29. Total potassium stock in biomass conservation areas of eastern Attappady.

4.6.2 Comparison of nutrient pool in eastern Attappady based on status

The nutrient pool along the non-eco-restored areas, plantations and biomass conservation areas in eastern Attappady were analyzed for carbon, nitrogen, phosphorus and potassium (Table 16).

4.6.2.1 Carbon pool

The analysis of variance for carbon pool among the vegetation, litter and soil along the non-eco-restored areas, plantations and biomass conservation areas show significant difference among them. The carbon stock in vegetation were observed to be highest in the biomass conservation areas (16199.2 ± 17915.97 kg/ha). The carbon stock in the vegetation of plantations were 8557.2 ± 3913.98 kg/ha and vegetation were absent in non-eco-restored areas. The carbon stock in litter were observed to be highest in the biomass conservation areas (3154.97 ± 1887.05 kg/ha/year) and the carbon stock in the litter of plantations were 2173.64 ± 529.25 kg/ha/year.

Carbon stock in the soil were observed to be highest in the soils of biomass conservation areas (25013.4 ± 9806.67 kg/ha). The carbon stock in the soils were lowest among the non-eco-restored areas (5372.64 ± 3199.5 kg/ha) and organic carbon in the soil of plantations were 13564.2 ± 2830.35 kg/ha.

Among the plantations, out of the total carbon stock of 24295.33 ± 6114.53 Kg/ha, 35 percent carbon is present in the vegetation, 9 percent in the litter and 56 percent in the soil (Fig. 30). Out of the total carbon stock in the biomass conservation areas (44367.19 ± 21625.63 Kg/ha), 37 percent organic carbon is present in the vegetation, 7 percent in the litter and 56 percent in the soil (Fig. 31). Among the non-eco-restored areas where vegetation is absent, the only source of carbon pool is the soil. The total carbon stock of non-eco-restored areas were 5372.64 ± 3199.5 kg/ha.

Table 16. Nutrient pool (major nutrients: C, N, P and K) in non-eco-restored, plantations and biomass conservation areas areas of eastern Attappady.

	Parameters	Non eco-restored areas	Plantations	BCA
Vegetation	Total organic carbon (kg/ha)	-	8557.2 (3913.98)[a]	16199.2 (17915.97)[b]
	Total N (kg/Ha)	-	196.6 (82.4)[a]	353.8 (379.98)[b]
	Total P (kg/Ha)	-	21.2 (8.65)[a]	39.6 (42.2)[b]
	Total K (kg/Ha)	-	25.2 (11.42)[a]	58.4 (71.46)[b]
Litter	Total C(Kg/ha)	-	2173.64 (529.25)[a]	3154.97 (1887.05)[b]
	Total N (Kg/Ha)	-	64.56 (69.35)[a]	73.50 (65.7)[a]
	Total P (Kg/Ha)	-	3.23 (2.65)[a]	4.17 (3.25)[a]
	Total K (Kg/Ha)	-	4.02 (3.28)[a]	5.39 (3.65)[a]
Soil	Organic Carbon (Kg/ha)	5372.64 (3199.5)[c]	13564.2 (2830.35)[a]	25013.4 (9806.67)[b]
	Total N (Kg/Ha)	705.60 (504)[c]	1814.4 (480.43)[a]	2990.4 (1540.43)[b]
	Total P (Kg/Ha)	1600.70 (996.3)[a]	1263.7 (455.26)[a]	1143.6 (839.54)[a]
	Available K (Kg/Ha)	162.49 (138.54)[a]	211.3 (71.97)[a]	280.4 (108.17)[a]
Total	Carbon (Kg/ha)	5372.64 (3199.5)[c]	24295.33 (6114.53)[a]	44367.19 (21625.63)[b]
	Nitrogen (Kg/ha)	705.60 (504)[c]	2075.52 (511.72)[a]	3417.7 (1770.68)[b]
	Phosphorus (Kg/ha)	1600.70 (996.3)[a]	1288.14 (452.52)[a]	1187.42 (878.75)[a]
	Potassium (Kg/ha)	162.49 (138.54)[a]	240.51 (75.12)[a]	344.52 (162.87)[a]

4.6.2.2 Nitrogen pool

The analysis of variance for nitrogen pool among the vegetation and soil along the non-eco-restored areas, plantations and biomass conservation areas show significant difference among them. Whereas the nitrogen stock in the litter along the plantations and biomass conservation areas did not show significant difference. The nitrogen stock in vegetation were observed to be highest in the biomass conservation areas (353.8 ± 379.98 kg/ha). The nitrogen stock in the vegetation of plantations were 196.6 ± 82.4 kg/ha and vegetation was absent in non-eco-restored areas. The nitrogen stock in litter was observed to be highest in the biomass conservation areas (73.5 ± 65.7 kg/ha/year) and the nitrogen stock in the litter of plantations were 64.56 ± 69.35 kg/ha/year.

Nitrogen stock in the soil was observed to be highest in the soils of biomass conservation areas (2990.4 ± 1540.43 kg/ha). The lowest nitrogen stock was in the soils of non-eco-restored areas (705.6 ± 504 kg/ha) and nitrogen stock in the soil of plantations was 1814.4 ± 480.43 kg/ha.

Among the plantations, out of the total nitrogen stock of 2075.52 ± 511.72 kg/ha, 10 percent nitrogen is present in the vegetation, 3 percent in the litter and 87 percent in the soil (Fig. 30). Out of the total nitrogen stock in the biomass conservation areas (3417.7 ± 1770.68 kg/ha) 10 percent nitrogen is present in the vegetation, 2 percent in the litter and 88 percent in the soil (Fig. 31). Among the non-eco-restored areas where vegetation is absent, the only source of nutrient pool is the soil. The total nitrogen stock of non-eco-restored areas were 705.6 ± 504 kg/ha.

4.6.2.3 Phosphorus pool

The analysis of variance for phosphorus pool among the vegetation, litter and soil along the non-eco-restored areas, plantations and biomass conservation areas did not show significant difference among them. The phosphorus stock in the vegetation was significantly different between the biomass conservation areas and plantations. The phosphorus stock in vegetation was observed to be highest in the biomass conservation areas (39.6 ± 42.2 kg/ha). The phosphorus stock in the vegetation of plantations were 21.2 ± 8.65 kg/ha and vegetation were absent in non-eco-restored areas. The phosphorus stock in litter were observed to be higher in the biomass conservation areas (4.17 ± 3.25 kg/ha/year) than in the plantations (3.23 ± 2.65 kg/ha/year).

Phosphorus stock in the soil was observed to be highest in the soils of non-eco-restored areas (1600.7 ± 996.3 kg/ha) followed by the plantations (1263.7 ± 455.26 kg/ha). The lowest phosphorus stock in the soils was among the biomass conservation areas (1143.6 ± 839.54 kg/ha).

Among the plantations, out of the total phosphorus stock of 1288.14 ± 452.52 kg/ha, 2 percent phosphorus is present in the vegetation and 98 percent in the soil whereas phosphorous stock is negligible in litter (Fig. 30). Out of the total phosphorus stock in the biomass conservation areas (1187.42 ± 878.75 kg/ha), 3 percent phosphorus is present in the vegetation, 1 percent in litter and 96 percent in the soil (Fig. 31). Among the non-eco-restored areas where vegetation is absent, the only source of phosphorus pool is the soil. The total phosphorus stock of non-eco-restored areas were 1600.7 ± 996.3 kg/ha.

4.6.2.4 Potassium pool

The analysis of variance for potassium pool among the vegetation, litter and soil along the non-eco-restored areas, plantations and biomass conservation areas did not show significant difference among them. The potassium stock in the vegetation were significantly different along the biomass conservation areas and plantations. The potassium stock in vegetation were observed to be highest in the biomass conservation areas (58.4 ± 71.46 kg/ha). The potassium stock in the vegetation of plantations were 25.2 ± 11.42 kg/ha and vegetation were absent in non-eco-restored areas. The potassium stock in litter were observed to be higher in the biomass conservation areas (5.39 ± 3.65 kg/ha/year) than in the plantations (4.02 ± 3.28 kg/ha/year).

Potassium stock in the soil were observed to be highest in the soils of biomass conservation areas (280.4 ± 108.17 kg/ha). The potassium stock in the soil were observed to be lowest among the non-eco-restored areas (162.49 ± 138.54 kg/ha) and the potassium stock in the soil of plantations were 211.3 ± 71.97 kg/ha.

Among the plantations, out of the total potassium stock of 240.51 ± 75.12 kg/ha, 10 percent potassium was present in the vegetation, 2 percent in litter and 88 percent in the soil (Fig. 30). Out of the total potassium stock in the biomass conservation areas (344.52 ± 162.87 kg/ha), 17 percent potassium was present in the vegetation, 2 percent in litter and 81 percent in the soil (Fig. 31). Among the non-eco-restored areas where vegetation is absent, the only source of potassium pool is the soil. The total potassium stock of non-eco-restored areas were 162.49 ± 138.54 kg/ha.

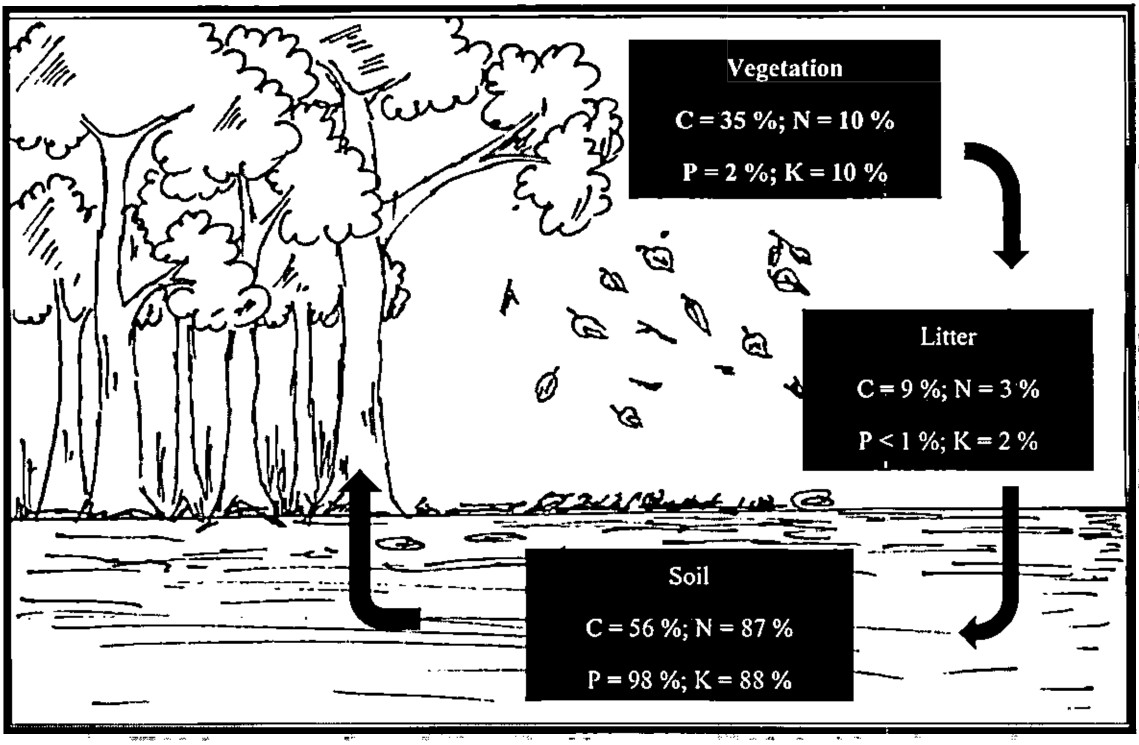


Fig. 30. Schematic representation of nutrient balance in plantations of eastern Attappady.

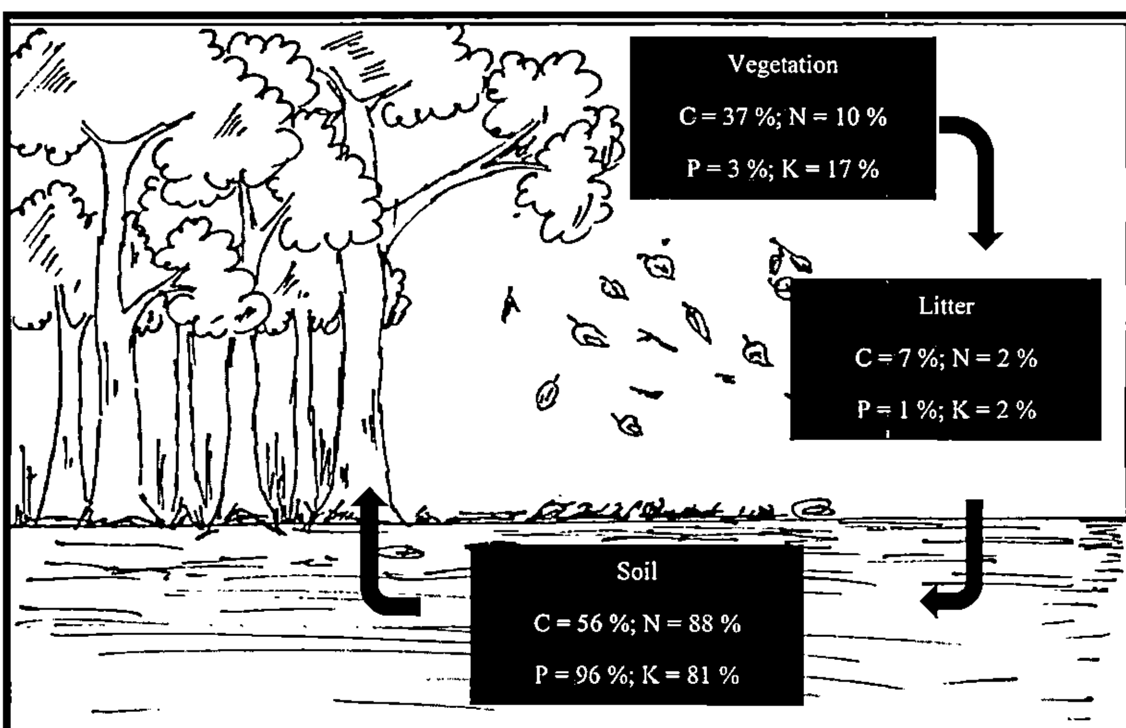


Fig. 31. Schematic representation of Nutrient balance in Biomass Conservation Areas (BCA) of eastern Attappady.

DISCUSSION

5. DISCUSSION

Assessing restoration success is an important phase in an ecological restoration intervention. A large number of qualitative and quantitative indicators have been either reported or proposed in the literature for the assessment of restoration success. Le *et al.* (2011) proposed four major potential indicators for measuring restoration success. These include indicators for measuring establishment success, forest growth success, environmental success and socio- economic success. Vegetation structure, species diversity, and ecosystem processes were suggested as indicators for measuring environmental success of restoration (Le *et al.,* 2012). The present study mainly emphasis on measuring the environmental success of ecological restoration.

The present study was done to investigate the impact of eco-restoration on nutrient balance in eastern Attappady. Nutrient content (major nutrients) of vegetation, litter and soil samples in plantations, biomass conservation areas and non-eco-restored areas of eastern Attappady were estimated. For eco-restoration, forest area identified as having more than 40 percent crown cover was designated as Biomass Conservation Areas (BCA) and given protection from grazing, fire wood collection and forest fires. The assumption is that with sufficient protection, areas with such remnant vegetation will recover in due course. The remnant vegetation often plays a critical role in forest recovery, promoting rapid increases in species richness, tree density and aboveground biomass (Guariguata *et al.,* 1995). Forest patches with less than 40% canopy cover was subjected to total restoration and earmarked as plantations (AHADS, 2011). Nutrient pool of major nutrients from ten plantations, five biomass conservation areas, and five non-eco-restored areas were calculated and compared to assess the impact of eco-restoration in eastern Attappady. The results obtained from the study are discussed in this chapter.

5.1 Vegetation studies

5.1.1 Species composition and vegetation structure of vegetation

The rainfall regime of Attappady has been classified into four regimes based on the rainfall and duration of dry season by KFRI (1990). Attappady mostly receives high rainfall, so the areas receiving high rainfall were designated as the first regime (Table 17)

(Appendix I). They are located on the western and southern sectors and receive bulk of the precipitation (70%) during the south-west monsoon (June - September). The northern and the southern part of this zone are forested, while the central portion in this zone has undergone severe land-use changes from forest to agro-forest, agriculture and monoculture cash crop plantations. The biotope of the first regime is evergreen forests. The second rainfall regime (<6 month dry season, 1000-2000 mm rainfall) is found close to the heavy rain fall area but towards south east. The third regime lies in the northern portion of the same tract, although receiving the same amount of rain fall, but has a dry season lasting more than six months in a year. The biotope changes from drier tracts of moist deciduous forests to dry deciduous forests. The fourth rainfall regime falls in the eastern sector of Attappady, which is the low rainfall zone (<1000 mm). This area receives bulk of rainfall mainly from the north-east monsoon. The biotope of this regime is dry deciduous forest with frequent individual trees of the moist deciduous type.

Table 17. Rainfall regime in Attappady area (KFRI, 1991)

Rainfall regime	Rainfall	Area	Location	Study sites
1st regime	High rainfall, > 2000 mm	334 Km^2	Western and southern Attappady	-
2nd regime	Medium rainfall, 1000 - 2000 mm (< 6 months dry season)	65 Km^2	South-east Attappady	-
3rd regime	Medium rainfall, 1000 - 2000 mm (> 6 months dry season)	154 Km^2	North-east Attappady	Agali Sambarcode P1 Sambarcode P2 Sambarcode BCA Palliyara BCA1 Palliyara BCA2 and Palliyara BCA2
4th regime	Low rainfall, < 1000 mm	178 Km^2	Eastern Attappady	Vannanthura Medu Kottathara Pattimalam P1 Pattimalam P2 Pattimalam P3 Vellaimari Mele Chavadiyur and Kottathara BCA

The study sites in the current study fall under the third and fourth rainfall regimes. The locations Agali, Sambarcode and Palliyara with plantations Agali, Sambarcode P1 and Sambarcode P2, and biomass conservation areas Sambarcode BCA, Palliyara BCA1, Palliyara BCA2 and Palliyara BCA2 falls under the third rainfall regime receiving the rainfall of 1000 mm to 2000 mm and period of dry season less than 6 months in an year. The locations Kottathara, Pattimalam, Vellaimari and Mele Chavadiyur with plantations Vannanthura Medu, Kottathara, Pattimalam P1, Pattimalam P2, Pattimalam P3, Vellaimari and Mele Chavadiyur and biomass conservation area Kottathara BCA falls under the fourth rainfall regime receiving rainfall of < 1000 mm and dry season lasts more than nine months.

The species composition of eastern Attappady was clearly depicted from the vegetation (trees with GBH ≥ 10 cm) density among the study sites. The vegetation (trees with GBH ≥ 10 cm) density revealed that plantations of location Agali (Agali), Sambarcode (Sambarcode P1) and biomass conservation areas of location Sambarcode (Sambarcode BCA) and Palliyara (Palliyara BCA 2 and Palliyara BCA3) were found to be higher compared to other plantations and biomass conservation areas (Table 18). These areas fall in the medium rainfall tracts of Attappady and hence can be attributed to the rainfall pattern present in this region. The sample plots Sambarcode ERA2 and Palliyara BCA1 even though situated in the wetter tract, proximity to human interferences and disturbances probably affected the vegetation density of these areas.

The other areas including Vannanthura medu, Kottathara, Pattimalam, Vellaimari and Mele Chavadiyur fall under the fourth rainfall regime which is drier and have comparatively less tree density among the plantations and biomass conservation areas. Even though all the plantations of eastern Attappady comprised of mostly similar species and differ only in their composition, the areas in the drier tract could not provide adequate growing situation for the vegetation prevailing in the area compared to plantations in the wetter tract. This can be explained with the low rainfall (< 1000 mm) received by the plantations in drier areas, where vegetation establishment is slower due to poor growth of vegetation and more causalities compared to plantations in wetter region. The poor performance of the biomass conservation area of drier tract (Kottathara BCA) can also be attributed to the rainfall and water availability. The process of eco-restoration is gradual in drier tracts (Murphy and Lugo, 1986). It may be explained that even though both plantations and biomass conservation areas grow similarly in the wet season, dry forests decrease in growth or even stop growing during the dry season. Above all in plantations Vannanthura medu, Kottathara, Pattimalam P1 and Mele Chavadiyur human disturbances are higher compared to other areas. This was evident from the damage caused to the litter traps in these areas and the stumps of cut trees observed during the field inspection.

Table 18. Vegetation (trees with GBH $\geq$ 10 cm) density in study sites of eastern Attappady with varying rainfall regime.

Rainfall regime	**Status**	**Sample plots**	**Density (trees/ha)**
3rd regime	Plantations	Agali	744
		Sambarcode P1	548
		Sambarcode P2	452
	BCA	Sambarcode BCA	688
		Palliyara BCA1	472
		Palliyara BCA2	700
		Palliyara BCA3	768
4th regime	Plantations	Vannanthura Medu	356
		Kottathara	464
		Pattimalam P1	404
		Pattimalam P2	460
		Pattimalam P3	440
		Vellaimari	424
		Mele Chavadiyur	372
	BCA	Kottathara BCA	428

The study revealed that significant differences were found among the study sites with respect to species composition and vegetation structure. *Albizia amara* with IVI value 36.53 was the dominant species among the study sites in eastern Attappady. *Chloroxylon sweitenia* (19.54), *Leucaena leucocephala* (16.94) and *Senna siamea* (15) were the other three important species which were dominant among the study sites in eastern Attappady (Table 19). Study conducted by Vidyasagaran and Anilkumar (2009) in plantations of Attappady also found that *Albizia amara*, *Chloroxylon sweitenia* and *Leucaena leucocephala* were predominant in eastern Attappady because they were planted extensively and their survival rate was higher. The reason for their extensive growth and high survival rate is that they are pioneer species suitable for this ecosystem. Pioneer tree species are light demanding, effective in producing large number of seeds, dispersing seeds over long distance and successful in germination of large number of seeds and well developed capacities to germinate in different ground vegetation layers and other difficult circumstances including exposed mineral soils (Otto, 2000). Hence it can be concluded that pioneer species that are early colonizers in exposed sites are a better choice in afforestation program where limited care is possible.

Table 19. Important value index (IVI) of prominent tree species in eastern Attappady.

Species	IVI
Albizia amara	36.53
Chloroxylon swietenia	19.54
Leucaena leucocephala	16.94
Senna siamea	15.00
Santalum album	14.07
Azadirachta indica	12.25
Givotia moluccana	10.78

5.1.2 Floristic diversity of vegetation of Eastern Attappady

Measures of species diversity provide information on habitat suitability and ecosystem resilience (Nichols and Nichols, 2003). Diversity is usually measured by determining the abundance and richness of species within trophic levels or functional groups within the forest (Benayas *et al.*, 2009). Floristic diversity studies in eastern

Attappady revealed that species richness was higher in biomass conservation areas compared to plantations. Species richness between plantations and biomass conservation areas varied significantly. When biomass conservation areas were compared with plantations, it was found that species richness (Simpson's diversity index) for biomass conservation areas were 0.83 while it was 0.79 for plantations (Table 20). Study conducted by Vidyasagaran and Anilkumar (2009) in the biomass conservation areas observed species richness of 0.88 in BCA of Attappady. However some of the sample plots among the plantations had higher species richness compared to biomass conservation areas. For example Pattimalam P3 had the highest species richness (Simpson index, 0.93) among the study areas which may be due to the area is subjected to lesser human disturbances. Simpson index obtained in the study varied from 0.55 to 0.93 in plantations. Species density was lower in areas nearer to habitations. For example Simpson index for the plantations Kottathara (0.55), Pattimalam P1 (0.71) and Mele Chavadiyur (0.71) which are nearer to human habitation were lower compared to other plantations (Fig. 32). Some of the biomass conservation areas also show lesser floristic diversity compared to plantations, this is due to constant disturbances from the nearby inhabitants. Study conducted by Sagar *et al.* (2003) on the tree species composition, dispersion along a disturbance gradient in a dry tropical forest region of Vindhyan hill ranges, India found similar results of decreasing species richness (Simpson index) with disturbance regime. Thus it can be assumed that the species diversity and vegetation structure also depends on human disturbance regime along with climate.

Table 20. Floristic diversity indices of plantations and biomass conservation areas of eastern Attappady.

Floristic diversity indices	**Plantations**	**Biomass conservation areas**
Cd	0.2	0.17
Simpson index	0.79	0.83
Shannon-Wiener index	1.66	1.71
H max	3.9	4.3
Equitability (E)	0.44	0.4

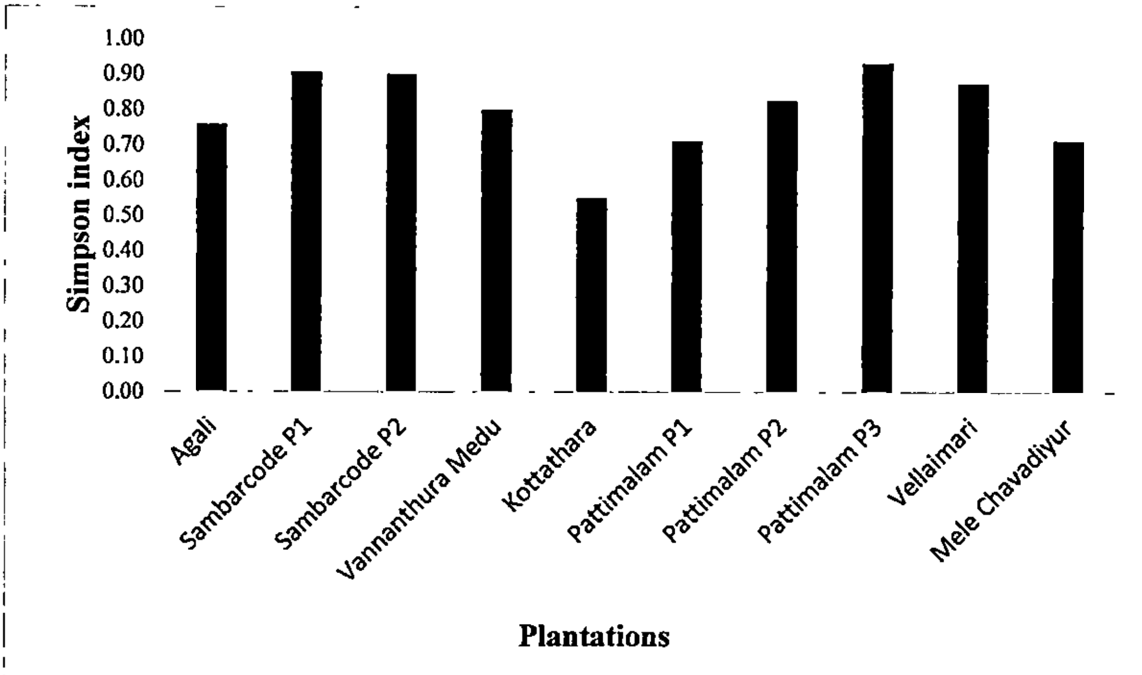


Fig 32. Species richness (Simpson's diversity index) of plantations in eastern Attappady.

5.2 Aboveground Biomass (AGB) of vegetation in eastern Attappady

Aboveground biomass of vegetation (trees with GBH ≥ 10 cm) in eastern Attappady show significant difference among plantations. Pattimalam P3 (27742.42 kg/ha) and Mele Chavadiyur (26858.36 kg/ha) show higher AGB compared to other plantations. The reason for their higher performance is due to the presence of trees representing higher girth class (Table 21). The AGB of study sites like Vannanthura medu (5757.55 kg/ha), Kottathara (10501.86 kg/ha) and Pattimalam P2 (8344.19 kg/ha) were low due to the trees representing lower girth class among the plantations.

The study revealed that significant difference were found in the AGB of vegetation (trees with GBH ≥ 10 cm) among the biomass conservation areas. Sambarcode BCA had higher AGB (88729.75 kg/ha) compared to other areas and the reason for this higher performance is that Sambarcode BCA had a habitat which is more or less similar to that of moist deciduous forest with trees representing higher girth class compared to other BCA (Table 21). Human disturbance is very low in Sambarcode BCA compared to other study sites. This is evident from the tree density (8 trees/ha representing girth class

Table 21. *Girth class distribution of trees in plantations and biomass conservation areas of eastern Attappady.*

Status	**Study sites**	**Tree Density (trees/ha)**						
		10 - 30 cm	**31 - 50 cm**	**51 - 70 cm**	**71 - 100 cm**	**101 - 150 cm**	**151 - 200 cm**	**201 - 250 cm**
Plantations	Agali	596	120	20	4	4	0	0
	Sambarcode P1	368	128	48	4	0	0	0
	Sambarcode P2	204	200	48	0	0	0	0
	Vannanthura Medu	284	72	0	0	0	0	0
	Kottathara	296	144	20	4	0	0	0
	Pattimalam P1	236	112	28	28	0	0	0
	Pattimalam P2	384	68	4	4	0	0	0
	Pattimalam P3	316	84	12	16	4	8	0
	Vellaimari	284	80	52	8	0	0	0
	Mele Chavadiyur	108	160	72	28	4	0	0
Biomass conservation areas	Sambarcode BCA	212	252	116	84	12	4	8
	Kottathara BCA	224	164	40	0	0	0	0
	Palliyara BCA1	284	140	44	4	0	0	0
	Palliyara BCA2	564	108	20	8	0	0	0
	Palliyara BCA3	572	156	28	8	4	0	0

201cm – 250 cm and 4 trees/ha representing girth class 151cm – 200 cm) representing higher girth class and the location which is far from habitation where wildlife is higher compared to other areas. Total AGB varies by geographical region, life zone, forest type, forest structure, and degree of disturbance (Brown *et al.,* 1989). BCA had a better aboveground biomass of vegetation (trees with GBH ≥ 10 cm) compared to plantations.

5.3 Nutrient status of vegetation of eastern Attappady

Total nutrient contents in vegetation are determined by the amount of biomass, its distribution into different plant parts (leaves, branches, bark, boles), and the nutrient concentrations in each part (Vitousek and Sanford, 1986). The nutrient status (C, N, P and K) of vegetation in eastern Attappady revealed that significant difference were found among biomass conservation areas and plantations. The nutrient content in vegetation of plantations and biomass conservation areas in eastern Attappady is attributed to the AGB of vegetation of respective area.

The nutrient concentration in different plant parts (mainly leaves, branches and stem) of vegetation (trees with GBH ≥ 10 cm) in easten Attappady did not show significant difference between biomass conservation areas and plantations. When a single species is found on two sites that differ in soil fertility, nutrient concentrations are usually quite similar (Tanner, 1977), deviating only slightly in the direction of the mean difference between sites (Vitousek and Sanford, 1986). The nutrient concentration of vegetation (trees with GBH ≥ 10 cm) in eastern Attappady show significant difference with respect to different plant parts and species (Table 22). N, P and K of leaves and branches were higher compared to the nutrient concentration of stem among different species in eastern Attappady. Nutrient concentrations in leaves correlated with nutrient concentrations in other plant parts, represents a useful indicator of overall nutrient status (Vitousek and Sanford, 1986). Grubb and Edwards (1982) and Tanner (1985) examined these correlations in detail within particular sites; the latter found significant correlations for nitrogen and phosphorus while the former did not. Vitousek and Sanford (1986) compared foliar and overall vegetation nutrient concentration of broader range of sites in tropical forests of the world, and found that they are clearly positively correlated.

Table 22. Nutrient concentration in different plant parts of ten important tree species of eastern Attappad

Species	Stem				Leaves and Branches			
	Total C (%)	Total N (%)	Total P (%)	Total K (%)	Total C (%)	Total N (%)	Total P (%)	Total K (%)
Albizia amara	56.15	0.62	0.06	0.08	52.44	1.88	0.26	0.22
Chloroxylon swietenia	56.38	0.68	0.05	0.04	54.99	1.74	0.25	0.22
Leucaena leucocephala	56.96	0.46	0.06	0.06	53.36	3.21	0.21	0.26
Senna siamea	56.03	0.49	0.10	0.10	53.36	1.90	0.23	0.27
Santalum album	54.87	0.65	0.06	0.08	54.41	2.18	0.21	0.26
Azadirachta indica	55.92	0.34	0.06	0.05	50.81	2.27	0.27	0.44
Givotia moluccana	55.57	0.61	0.05	0.10	54.06	1.60	0.17	0.28
Anogeissus latifolia	57.31	0.22	0.06	0.03	54.41	1.69	0.16	0.19
Pterocarpus marsupium	52.90	0.36	0.08	0.09	53.60	1.71	0.17	0.30
Tectona grandis	54.29	0.25	0.06	0.05	52.64	2.49	0.36	0.46

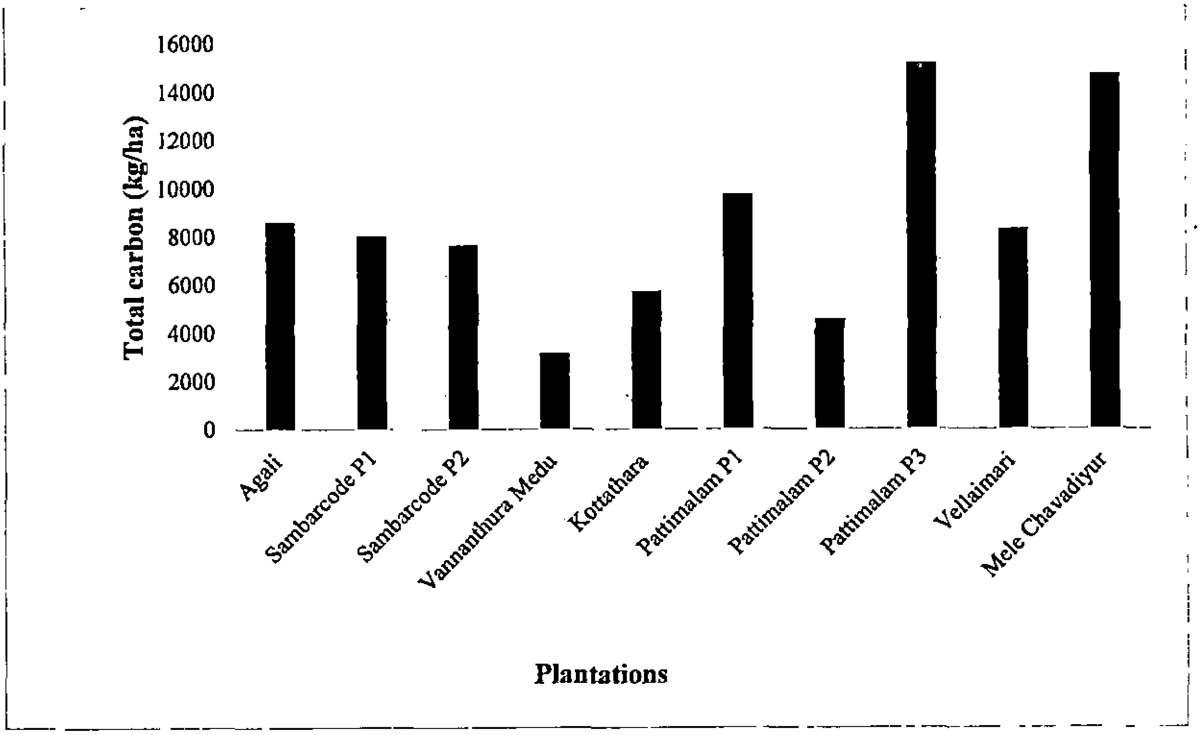


Fig. 33. Total carbon (kg/ha) in vegetation (trees with GBH ≥ 10 cm) of plantations in eastern Attappady.

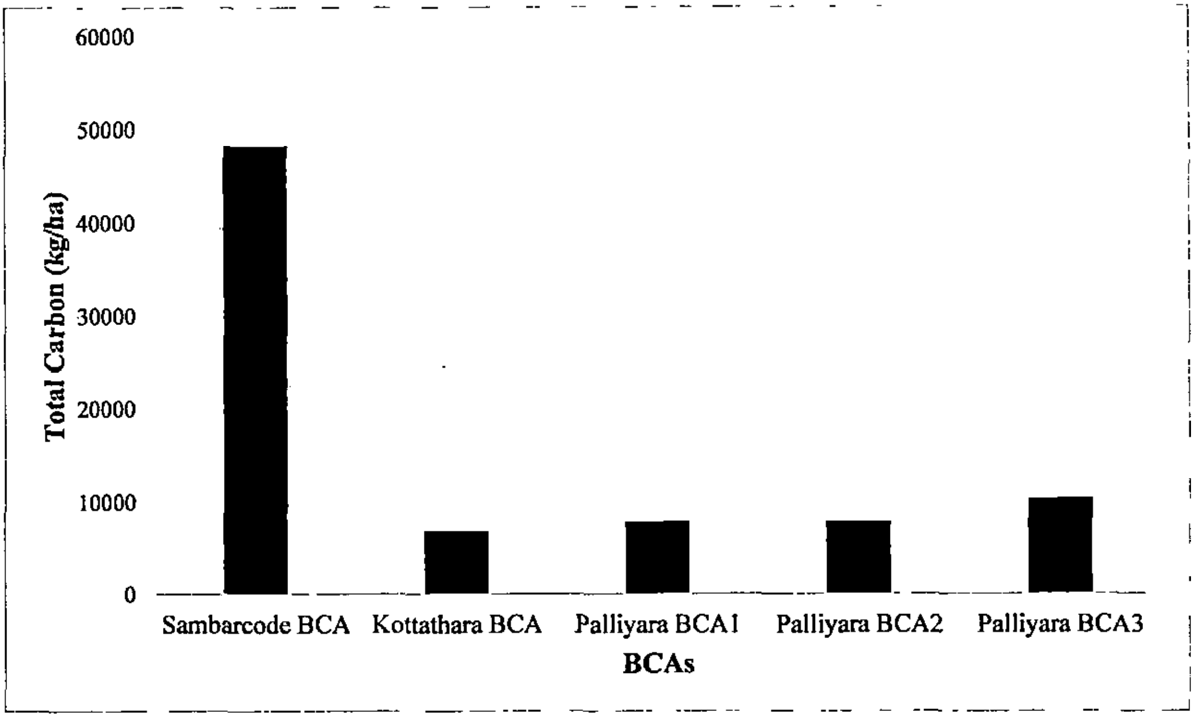


Fig. 34. Total carbon (Kg/ha) in vegetation (trees with GBH ≥ 10 cm) of biomass conservation areas in eastern Attappady.

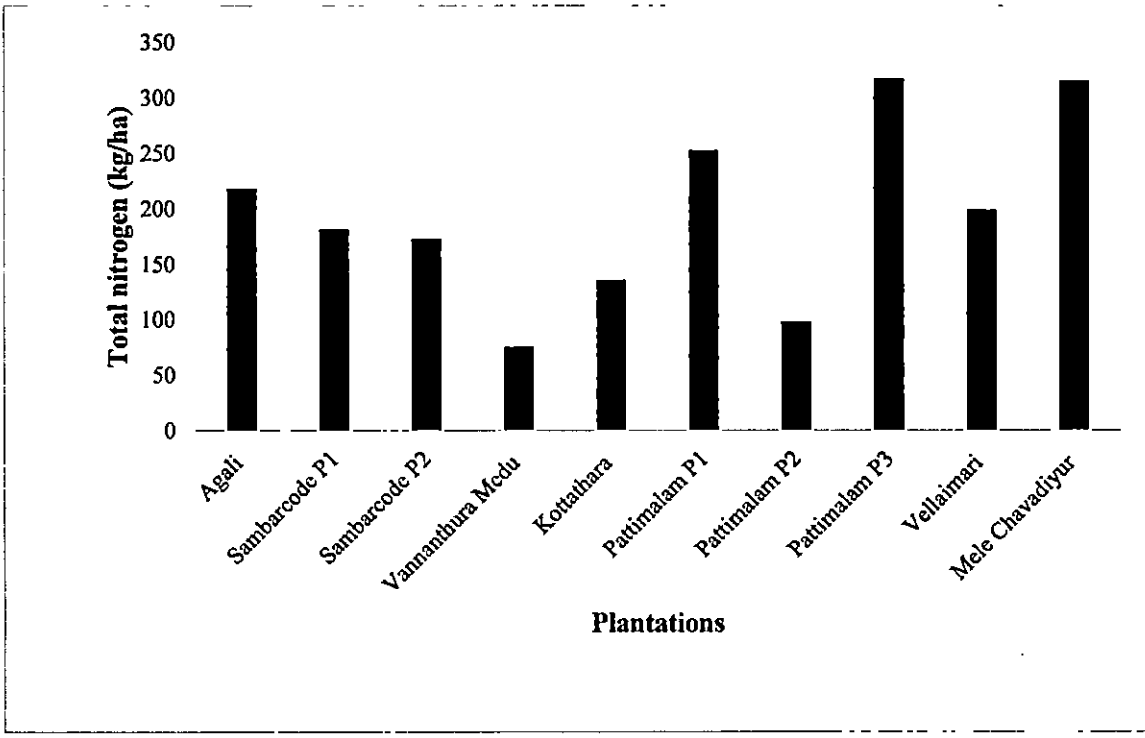


Fig. 35. Total nitrogen (kg/ha) in vegetation (trees with GBH ≥ 10 cm) of plantations in eastern Attappady.

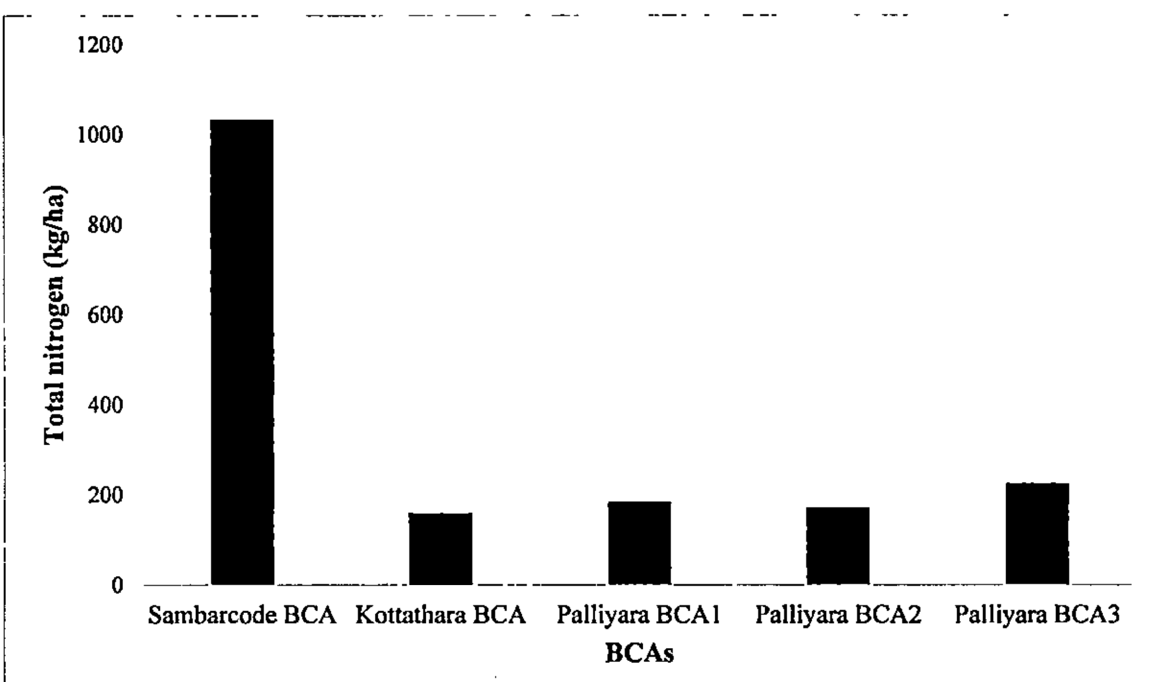


Fig. 36. Total nitrogen (kg/ha) in vegetation (trees with GBH ≥ 10 cm) of biomass conservation areas in eastern Attappady.

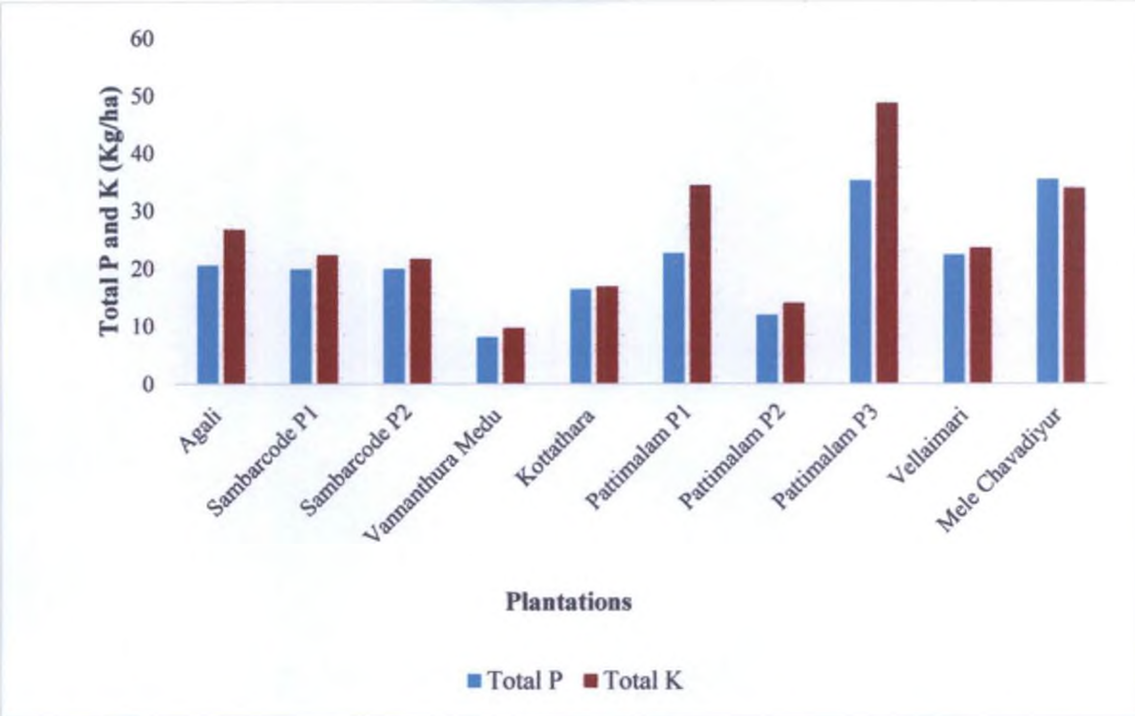


Fig. 37. Total P and K (kg/ha) in vegetation (trees with GBH ≥ 10 cm) of plantations in eastern Attappady.

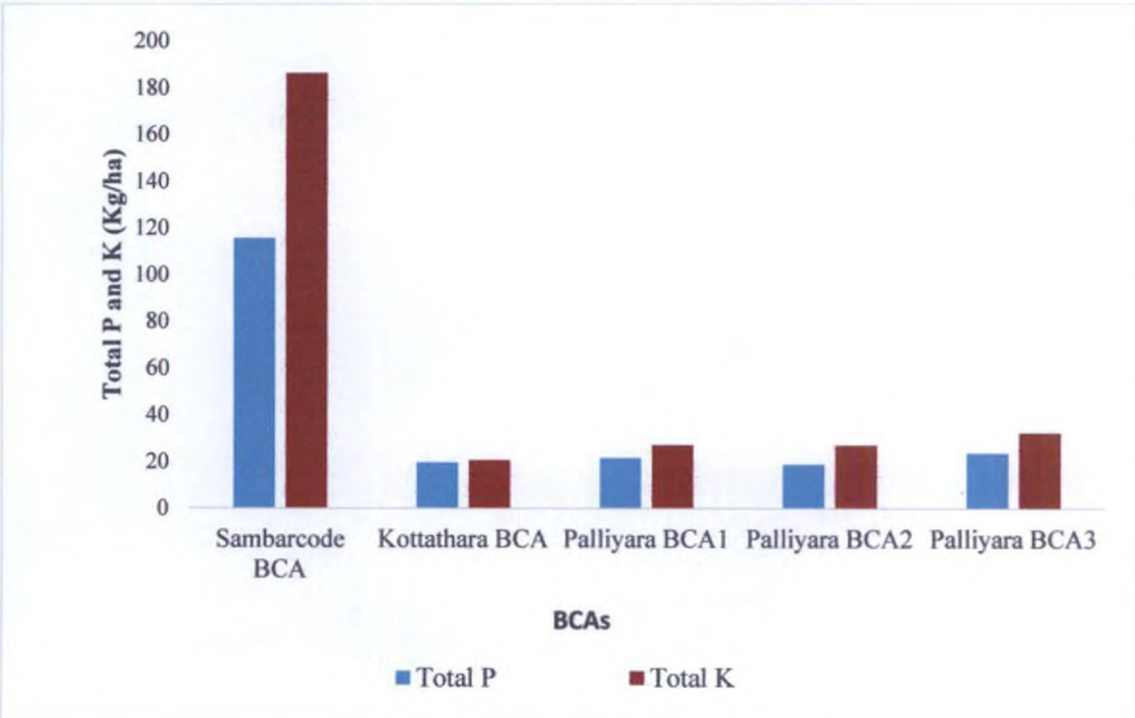


Fig. 38. Total P and K (kg/ha) in vegetation (trees with GBH ≥ 10 cm) of biomass conservation areas in eastern Attappady.

The study also showed that nutrient status of vegetation of plantations and BCA's were significantly different. Biomass conservation areas in general had higher nutrient stock compared to plantations. The carbon stock in vegetation of BCA's were 16199 kg/ha, which were higher compared to carbon stock in vegetation (8557.35 kg/ha) of plantations. Similarly nitrogen stock (353.8 kg/ha), potassium stock (58.52 kg/ha) and phosphorus stock (39.72 kg/ha) in vegetation of BCA's were higher compared to the N (196.56 kg/ha), K (25.13 kg/ha) and P (21.2 kg/ha) stock in vegetation of plantations (Fig. 39). It is already established that the dynamics of nutrient cycling in restored stands changes depending on the species that occupy the site, their abundance, and dominance (Lugo *et al.,* 2004). A particular species can affect nutrient cycling in different ways depending on the process, its magnitude, timing, and efficiency. Study conducted by Lugo *et al.* (2004) found nutrient accumulation in vegetation of rehabilitated forest stands to be lower than vegetation of naturally regenerated secondary forests and undisturbed mature stands. Since the vegetation was absent in the non-eco-restored areas, the nutrient stock in vegetation was nil for non-eco-restored areas.

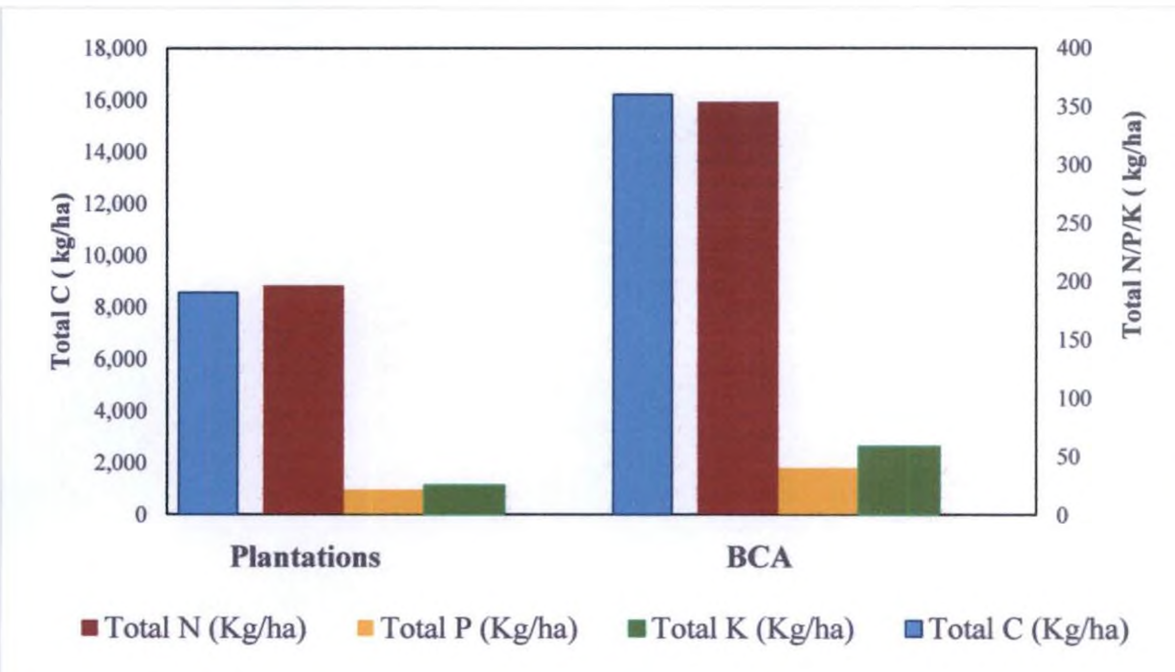


Fig. 39. Nutrient stock among the vegetation (trees with GBH $\geq$ 10 cm) of plantations and biomass conservation areas (BCA) at eastern Attappady.

5.4 Nutrient content in litter samples of eastern Attappady

The analysis of litter samples of plantations and BCA's in eastern Attappady revealed that there were significant difference among fresh weight and dry weight of litter samples along the plantations and biomass conservation areas collected during four periods (Fig. 40 and 41). Litter production varies with climate, season, substrate quality and type of vegetation (Vitousek *et al.,* 1994). Litter turnover from the biomass conservation areas (6.02 t/ha/year) were higher compared to plantations (3.61 t/ha/year). They also showed a seasonal variation throughout the time period. Litter production was highest during the period of December – March in both plantations and biomass conservation areas whereas it was lowest during March – June. These forests being deciduous the pattern is expected. However it is noted that the peak litterfall in plantations during December – March is less than the least litter fall in BCA's that occurred in March – June. Study conducted by Pande *et al.* (2002) in the tropical dry deciduous teak forest also found that litter production showed a seasonal variation as in the present study and were highest during the period of January – March.

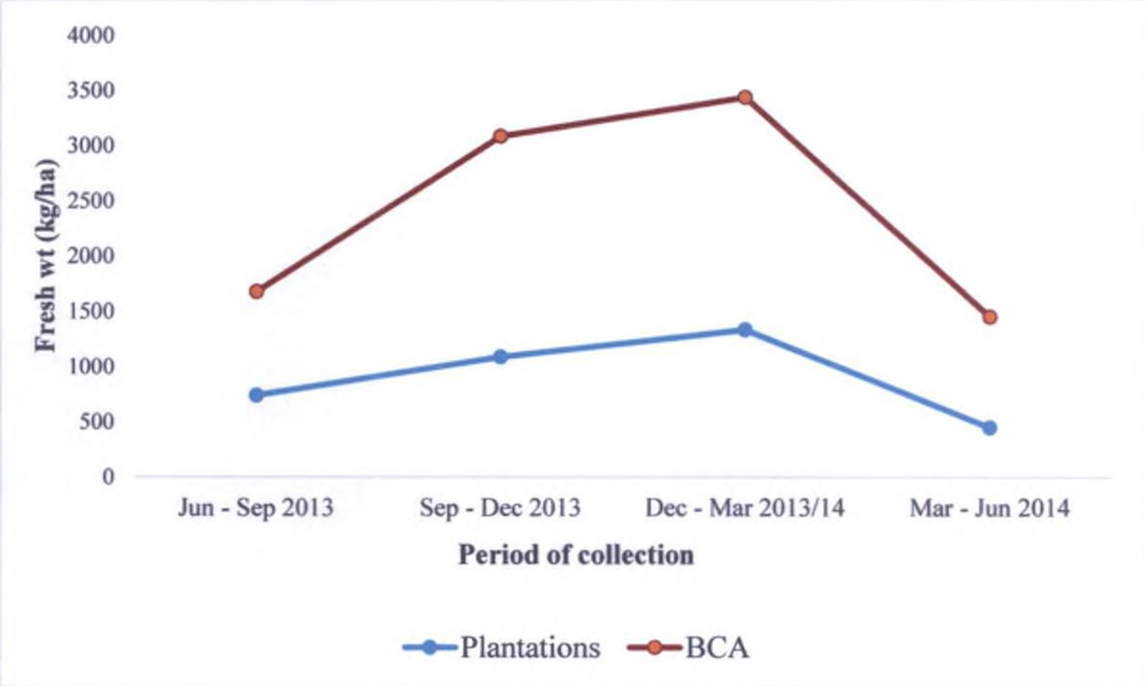


Fig. 40. Seasonal variation in litter production (fresh weight) in plantations and biomass conservation areas of eastern Attappady during the four periods.

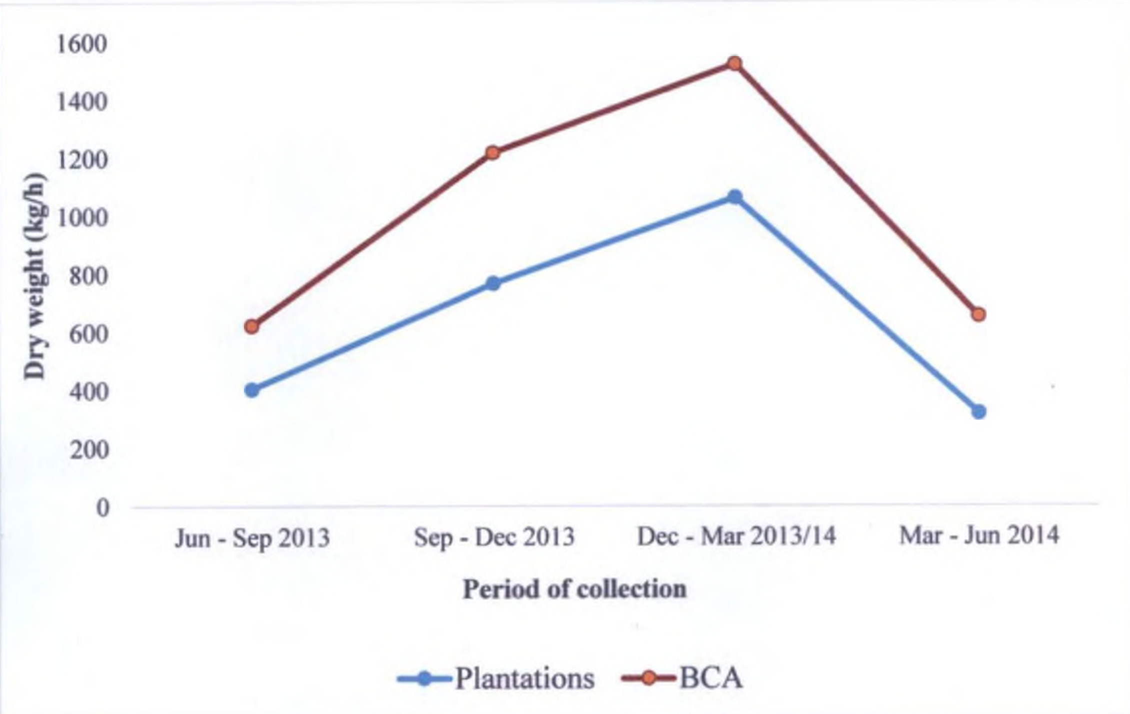


Fig. 41. Seasonal variation in dry weight of litter among the plantations and biomass conservation areas of eastern Attappady.

Several authors have defined litter quality in terms of initial N concentrations, the C/N ratio, initial lignin concentrations, and the lignin/N ratio. Litter quality affects not only the rates of mass loss, but also the patterns and rates of nutrient immobilization or release (Regina *et al.,* 1999).The present study revealed that there was significant difference in nitrogen content among litter samples of plantations and biomass conservation areas during the period of September – December. There were no significant difference in other litter nutrients (C, P and K) between plantations and biomass conservation areas of eastern Attappady. The total nutrient stock (C, N, P and K) were higher in litter samples of biomass conservation areas compared to litter samples of plantations. This might be due to high litter turnover rate in biomass conservation areas. Litter turnover rate is a deciding factor of nutrient stock (Sangha *et al.,* 2006). However the litter nutrient concentration was similar in both plantations and BCAs because nutrient concentration varies with components and not with sites. Study conducted by Rawat *et al.* (2009) found that litter nutrients were higher in protected areas where litter turnover rate was higher compared to unprotected areas.

The total nutrient stock in litter among plantations and biomass conservation areas show seasonal variation for total C, N, P and K (Fig. 42, 43 and 44). Total carbon were observed to be higher during the period of December – March in both plantations (2173.64 Kg/ha/year) and biomass conservation areas (3154.97 Kg/ha/year). This corresponds with higher litter during these periods. Total nitrogen in litter samples were higher during the period of September – December among the plantations (72.34 Kg/ha/year) and December – March among the biomass conservation areas (73.50 Kg/ha/year). Total phosphorus in litter samples were higher during the period of September – December among plantations (3.28 Kg/ha/year) and December – March (4.17 Kg/ha/year) among biomass conservation areas. Total potassium were higher during December – March among plantations (4.02 Kg/ha/year) and March – June among biomass conservation areas (11.23 Kg/ha/year). Study conducted by Pande *et al.* (2002) on litter production and nutrient return in tropical dry deciduous teak forests found similar pattern of seasonal variation among the litter nutrients.

The study clearly points out that BCA's are far superior in cycling of nutrients between vegetation and soil compared to plantations indicating that it might take a longer duration of time for plantations to achieve status of BCA.

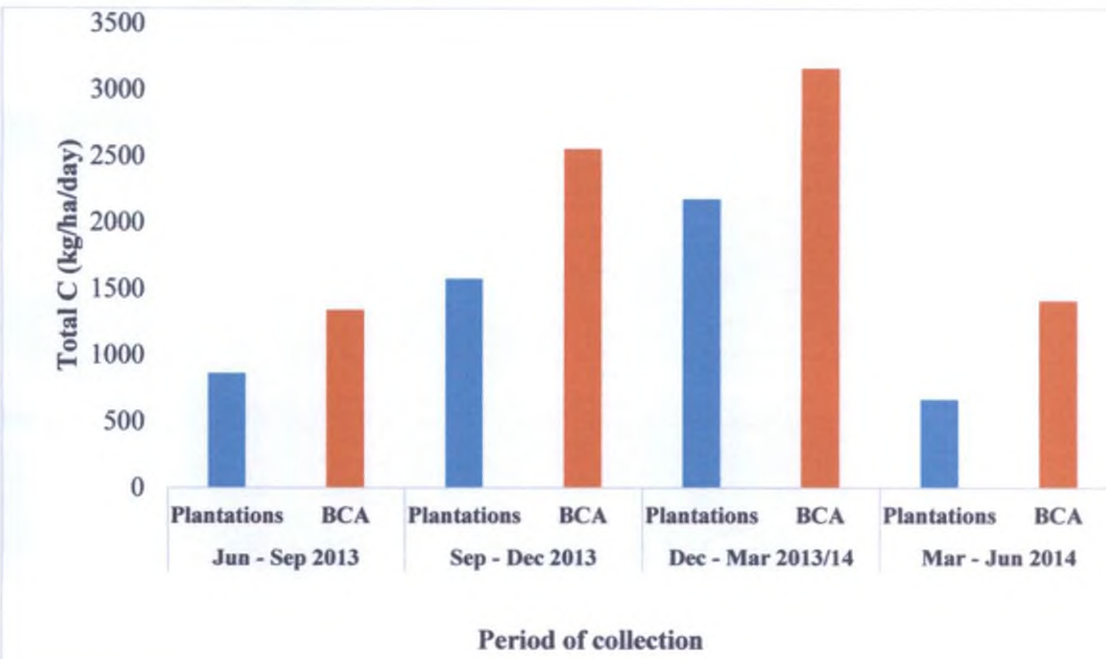


Fig. 42. Seasonal variation of total C in litter samples of plantations and biomass conservation areas of eastern Attappady.

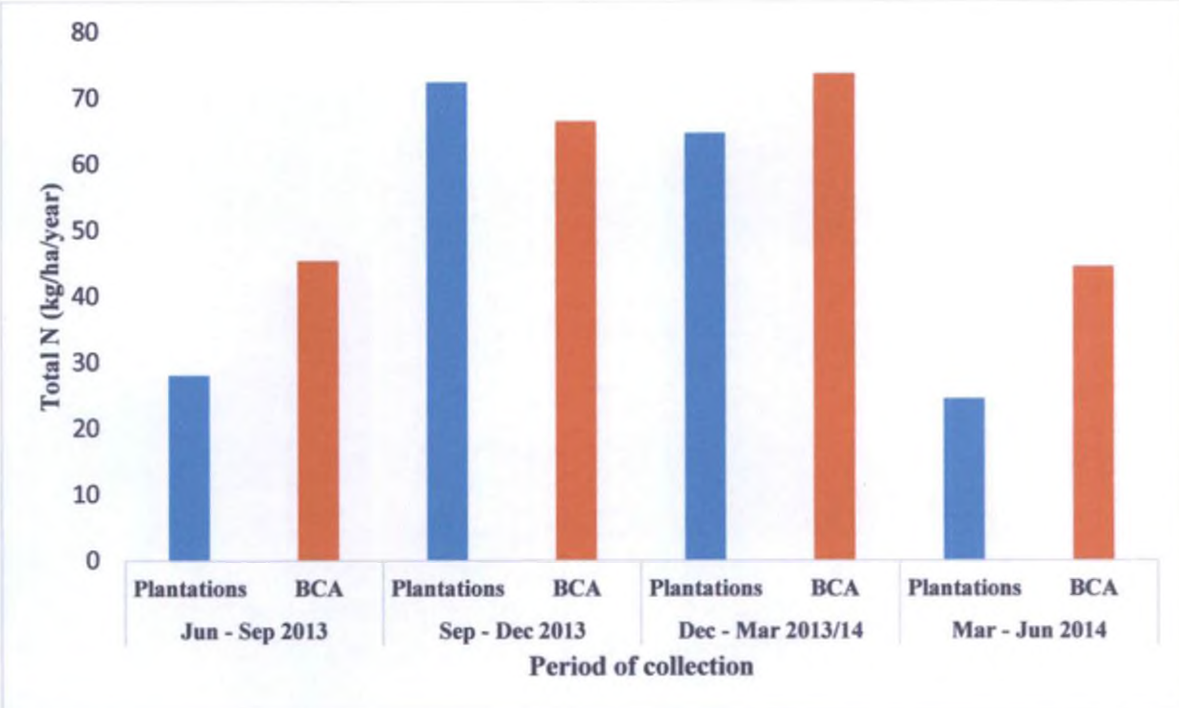


Fig. 43. Seasonal variation of total N in litter samples of plantations and biomass conservation areas of eastern Attappady.

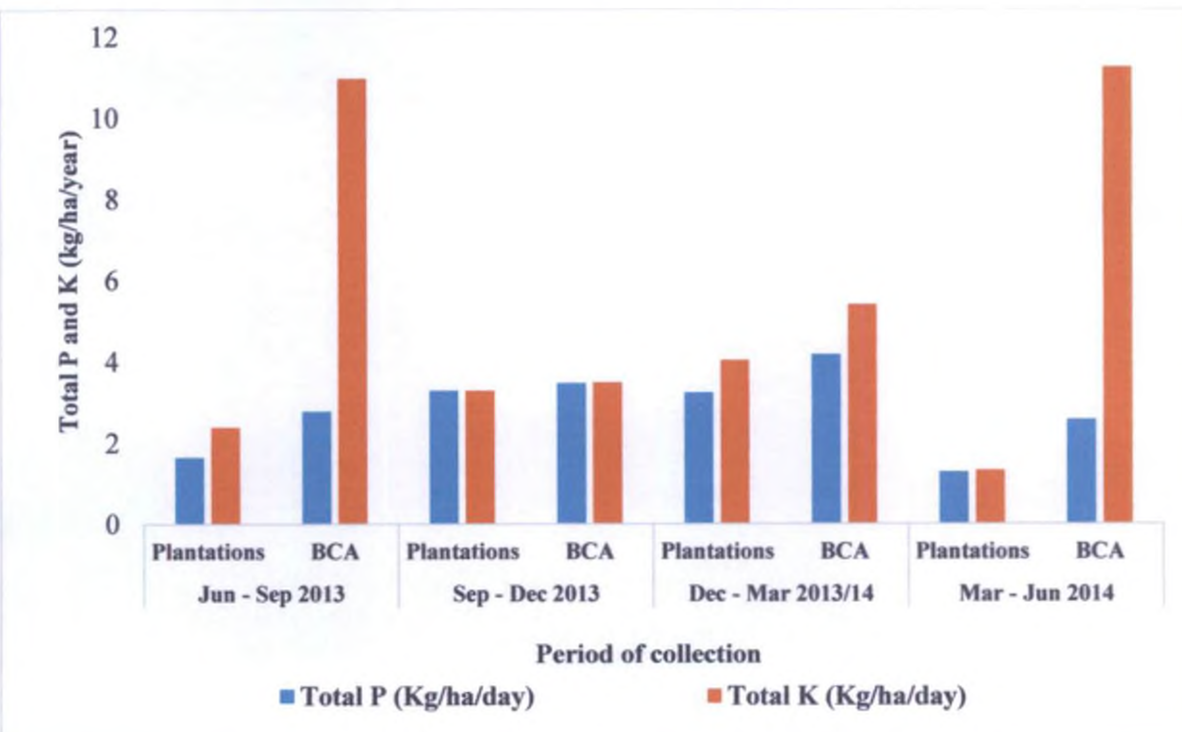


Fig. 44. Seasonal variation of total P and K in litter samples of plantations and biomass conservation areas of eastern Attappady.

5.5 Soil nutrients in eastern Attappady

Soil nutrient status in eastern Attappady showed significant differences for organic C, organic matter content, total N, available K and CEC along the non-eco-restored, plantations and biomass conservation areas. It was observed that organic C, organic matter content, total N, available K and CEC were higher in biomass conservation areas compared to non-eco-restored areas and plantations (Fig 45 to Fig 48). There was no significant difference for total and available phosphorus among the non-eco-restored areas, plantations and biomass conservation areas. Differences in vegetation structure and composition between the reference site and the restored plots are likely to contribute to the differences observed in some of the studied soil chemical properties (Cornwell *et al.*, 2008; Guo *et al.*, 2008).

The higher soil organic carbon among the biomass conservation areas (1.43 ± 0.55 %) clearly show that vegetation prevailing in the ecosystem influences the chemical properties of the soil to a greater extent. The selective absorption of nutrient elements by different tree species and their capacity to return them to the soil brings about changes in soil properties (Singh *et al.*, 1986). High litter turnover rate also favoured the organic carbon in soil of biomass conservation areas. Giardina *et al.* (2001) documented that high quality litter leads to the formation of high quality organic C and N in the mineral soil. Since the vegetation structure and species composition of BCAs are superior to non-eco-restored areas and plantations, the carbon sequestered among them was also higher. Similarly biomass conservation areas accounts for the highest organic matter content (2.46 ± 0.95 %) and total nitrogen (0.19 ± 0.06 %) compared to non-eco-restored areas (0.51 ± 0.12 % and 0.04 ± 0.01 %) and plantations (1.29 ± 0.36 % and 0.11 ± 0.04 %) in eastern Attappady. The availability of N depends to a large extent on the amount and properties of organic matter (Hann, 1977). The floristic analysis of the present study revealed that higher number of nitrogen fixing species like *Cassia fistula*, *Dalbergia* sp., *Pongamia pinnata*, *Pterocarpus marsupium* etc. among the BCAs compared to non-eco-restored areas and plantations increased the efficiency of nitrogen fixed in the soil of BCA.

The present study revealed that available K was higher among the biomass conservation areas (306.20 ± 104.45 kg/ha) compared to non-eco-restored areas (162.49

± 52.68 Kg/ha) and plantations (208.44 ± 102.74 Kg/ha). Basumatary and Bordoloi (1992) and Boruah and Nath (1992) reasoned that a layer of organic matter significantly improves the retention of K in the soils. Janssens *et al.* (1998) studied the relationship between plant biodiversity and different soil chemical factors in numerous sites and observed higher soil K content in sites with higher species diversity. It was observed that CEC was higher among the biomass conservation areas (22.34 ± 6.46 Cmol (p+) kg^{-1}) compared to non-eco-restored areas (7.69 ± 2.70 Cmol (p+) kg^{-1}) and plantations (15.24 ± 3.51 Cmol (p+) kg^{-1}) in eastern Attappady. This reflects the high humus in the soil of biomass conservation areas compared to non-eco-restored areas and plantations. High humus content in soil favours the life cycle of soil microbes which can improve the fertility of soil by higher dry matter decomposition. Foth (1990) suggests that soil texture and organic matter content influences the soil exchange capacity.

The present study revealed that total phosphorus in soil was observed to be higher among the non-eco-restored areas (0.09 ± 0.02 %) compared to plantations (0.07 ± 0.03 %) and biomass conservation areas (0.07 ± 0.05 %). This can be reasoned to the high immobile nature of phosphorus. Among the plantations and BCAs the phosphorus content in soil are absorbed by the prevailing vegetation which is absent among the non-eco-restored areas. Since vegetation was absent in non-eco-restored areas soil phosphorus remains accumulated. Compared to other nutrients cycling of phosphorus in an ecosystem is slower.

The study revealed that significant differences were found among non-eco-restored areas and plantations with respect to soil chemical properties. All the tested parameters including soil organic C, organic matter content, total N, available K, available P and CEC were found higher among the plantations compared to non-eco-restored areas. This show a positive sign towards the objective of eco-restoration project carried out in eastern Attappady.

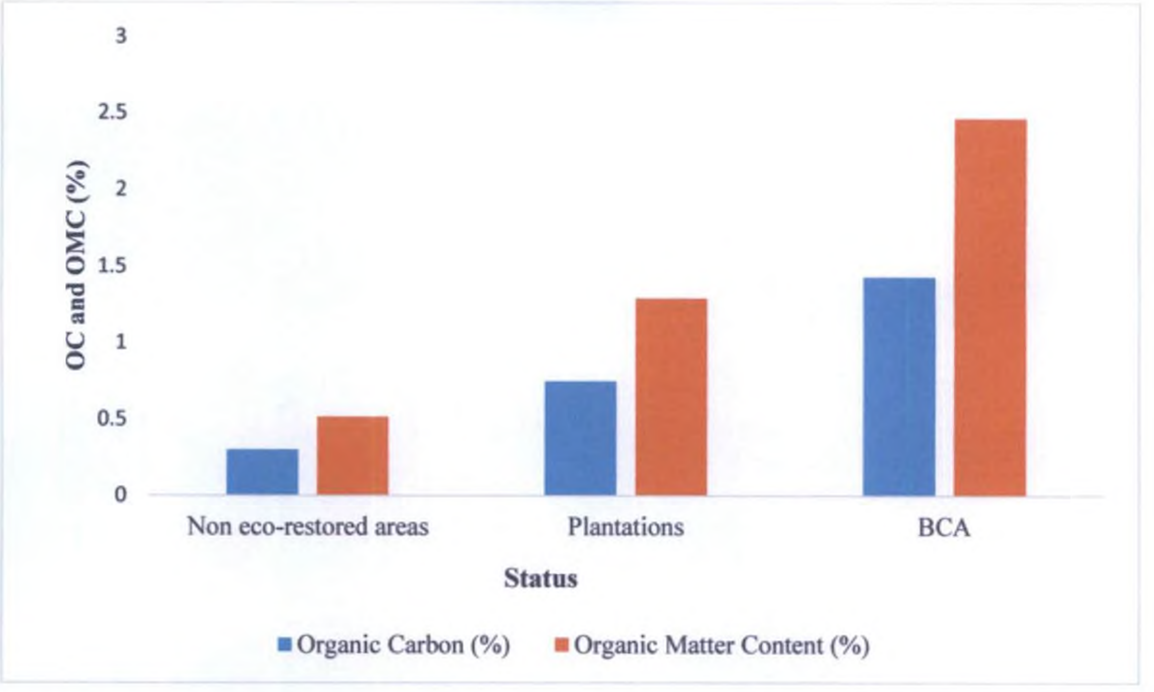


Fig. 45. Soil Organic carbon (SOC) and Organic Matter Content (OMC) among the non-eco-restored areas, plantations and biomass conservation areas (BCA) of eastern Attappady.

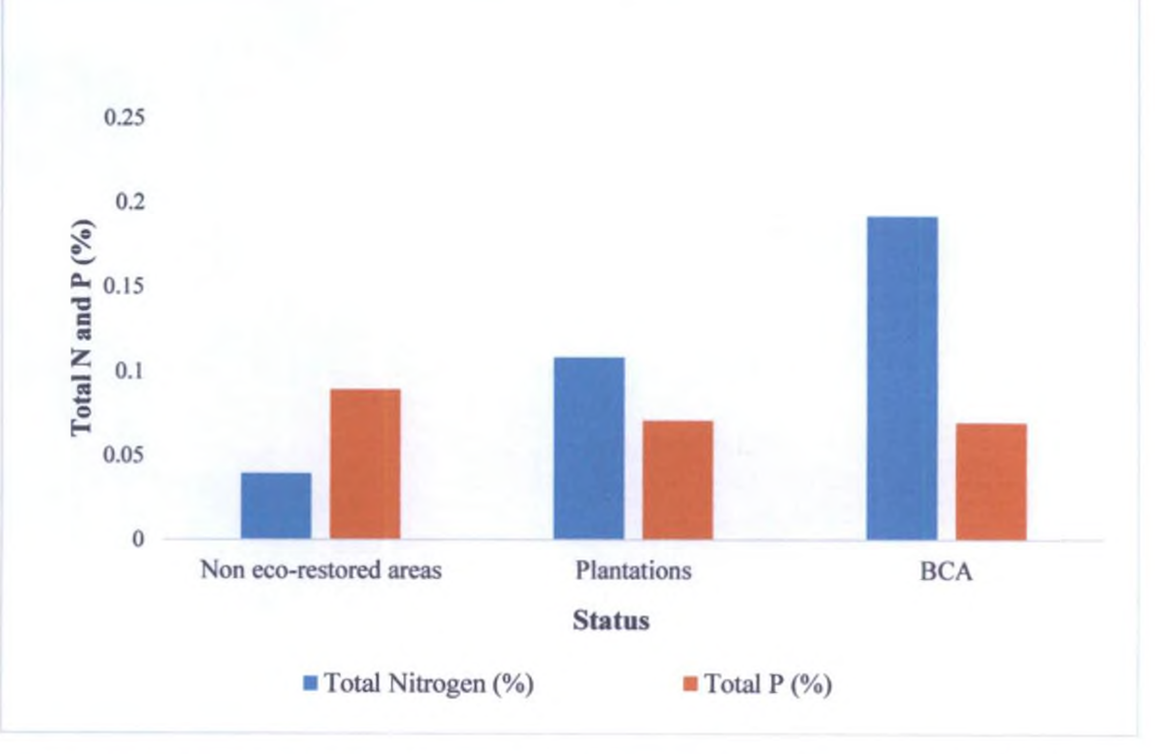


Fig. 46. Total N and P in soil among the non-eco-restored areas, plantations and biomass conservation areas (BCA) of eastern Attappady.

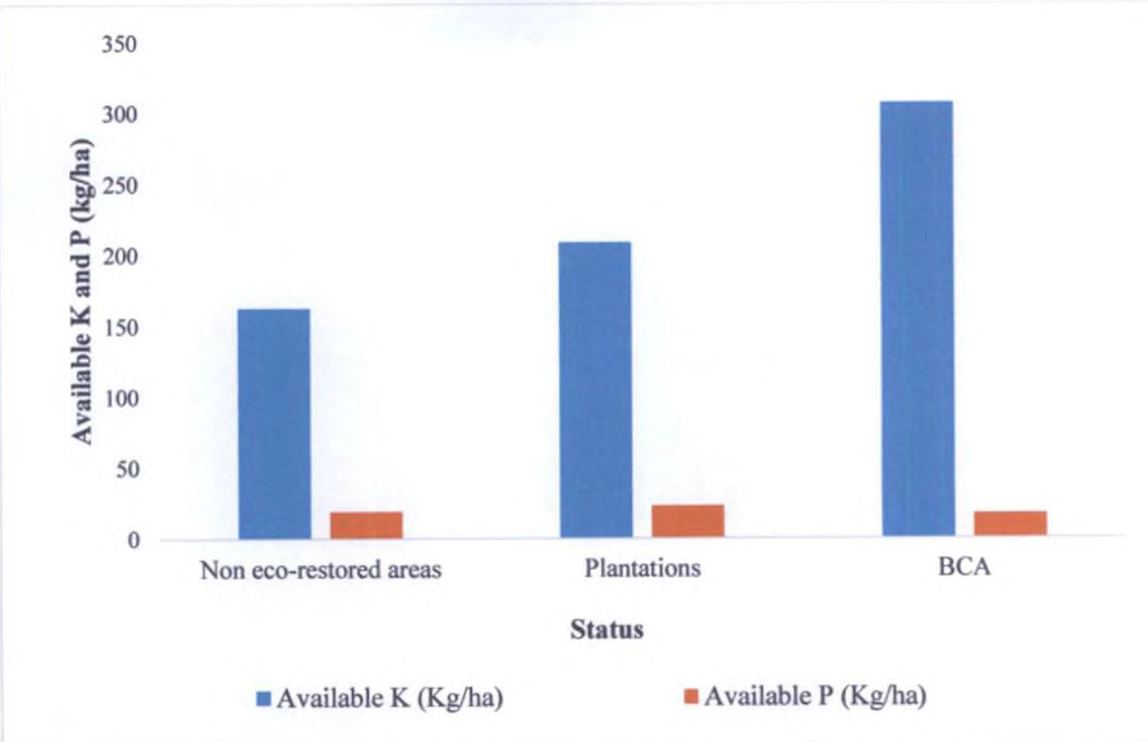


Fig 47. Available K and P in soil among the non-eco-restored areas, plantations and biomass conservation areas (BCA) of eastern Attappady.

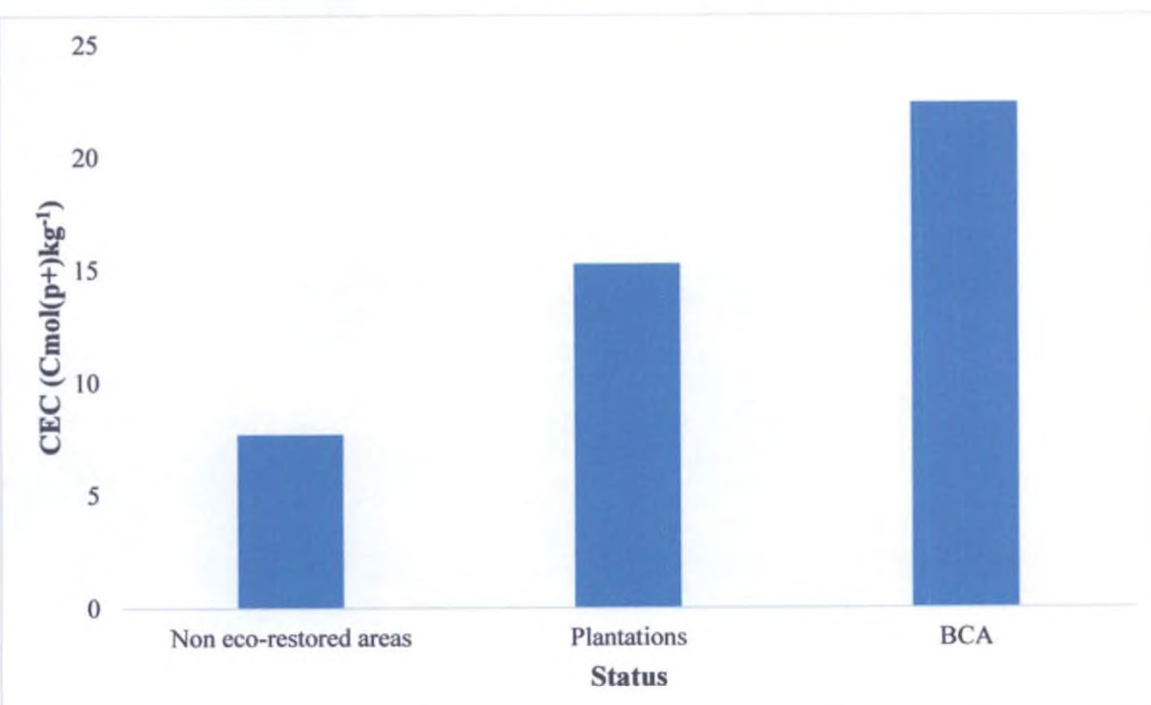


Fig 48. Cation exchange capacity (CEC) of soil among the non-eco-restored areas, plantations and biomass conservation areas (BCA) of eastern Attappady.

5.6 Total nutrient pool in eastern Attappady

Nutrient pool is the sum total of nutrients cycling in an ecosystem, flowing through vegetation, litter and soil. The results from the present study revealed that the nutrient pool in the non-eco-restored areas, plantations and biomass conservation areas of eastern Attappady show significant difference among them.

The present study revealed that total carbon pool were observed to be highest among the BCA's (44367.19 kg/ha) compared to the plantations (24295.33 kg/ha) and non-eco-restored areas (5372.64 kg/ha) (Fig 49). This corresponds with higher nutrient accumulation in vegetation (16199 kg/ha), litter (3154.97 kg/ha/year) and soil (25013.4 kg/ha) of biomass conservation areas where canopy cover over 40 % having the potential of natural regeneration are maintained. Among the plantations the total carbon pool constitutes, 8557.2 kg/ha (35 %) of C among vegetation, 2173.64 Kg/ha/year (9 %) C among litter and 13564.2 Kg/ha (56 %) C among soil. The total carbon pool of non-eco-restored areas were completely restricted to soil organic carbon (5372.64 kg/ha) where vegetation is absent. Since the carbon pool among BCAs were higher, vegetation structure, carbon sequestered in the soil, soil microbial activity and soil fertility were also superior among them. The carbon pool of the plantation indicates its potential to develop to a status of BCA in near future if proper management interventions are implemented.

The total nitrogen pool were higher among the BCAs (3417.7 ± 1770.68 kg/ha) compared to plantations (2075.52 ± 511.72 kg/ha) and non-eco-restored areas (705.6 ± 504 kg/ha) (Fig 49).This is due to the higher nitrogen accumulation in vegetation (353.8 ± 379.98 kg/ha), litter (73.50 ± 65.7 kg/ha/year) and soil (2990.4 ± 1540.43 kg/ha) of biomass conservation areas. Among the plantations the total nitrogen pool constitutes, 196.6 ± 82.4 kg/ha (10 %) of N among vegetation, 64.56 ± 69.35 kg/ha/year (3 %) N among litter and 1814.4 ± 480.43 kg/ha (87 %) N among soil. The total nitrogen pool of non-eco-restored areas were completely restricted to soil nitrogen (705.6 ± 504 kg/ha) where vegetation is absent. Since the nitrogen pool was higher among BCA's, nitrogen fixation was superior among them. The eco-restoration work was carried out by planting some nitrogen fixing trees like Acacias, *Pongamia pinnata, Pterocarpus marsupium* etc., this indicates the potential of the plantations to develop efficient nitrogen cycle if they are provided with amble management.

The total potassium pool were also higher among the BCAs (344.52 ± 162.87 kg/ha) compared to the plantations (240.51 ± 75.12 kg/ha) and non-eco-restored areas (162.49 ± 138.54 kg/ha) (Fig 49). This corresponds to higher potassium accumulation in vegetation (58.4 ± 71.46 kg/ha), litter (5.39 ± 3.65 kg/ha/year) and soil (280.4 ± 108.17 kg/ha) of BCAs. Among the plantations the total potassium pool constitutes 25.2 ± 11.42 kg/ha (10 %) K among vegetation, 4.02 ± 3.28 kg/ha/year (2 %) of K among litter and 211.3 ± 71.97 kg/ha (88 %) among soil. The total potassium pool of non-eco-restored areas were completely restricted soil potassium (162.49 ± 138.54 kg/ha) where vegetation is absent.

The present study revealed that total phosphorus pool unlike other nutrient pool were higher among the non-eco-restored areas (1600.7 ± 996.3 kg/ha) compared to plantations (1288.14 ± 452.52 kg/ha) and BCA's (1187.42 ± 878.75 kg/ha) (Fig 49). This is due to high phosphorous stock among the soil of non-eco-restored areas (1600.7 ± 996.3 kg/ha). The phosphorus stock among the soil of plantations (1263.7 ± 455.26 kg/ha) were higher than soil of BCAs (1143.6 ± 839.54 kg/ha). This is because phosphorus is a highly immobile element. In non-eco-restored areas where vegetation is absent, the phosphorus in soil remains unfixed and remains accumulated for a longer period. As phosphorus is an element which is insoluble in water and are not able to convert to gaseous state the cycle of this nutrient is very slow among the vegetated ecosystems.

The high nutrient stock in the soil, vegetation and litter of biomass conservation areas made more efficient nutrient pool among them compared to plantations and non-eco-restored areas. The nutrient pool in plantations show significant difference with that of non-eco-restored areas. It reflects an increasing potential of nutrient pool of plantations towards the status of biomass conservation areas. Hence, it can be assumed that in due course of time with sufficient management interventions, the nutrient balance would be similar in both the eco-restored areas and BCA.

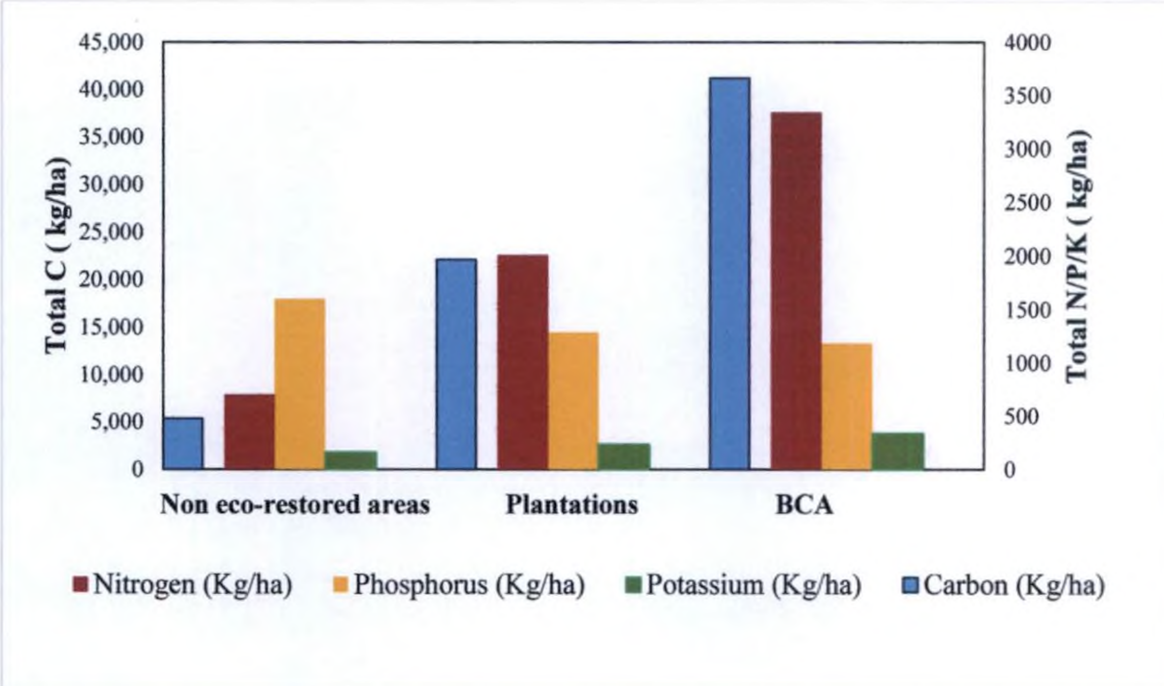


Fig 49. Comparison of nutrient pool among the plantations, Non eco-restored and Biomass conservation areas of eastern Attappady.

SUMMARY

6. SUMMARY

The objective of study was to find the impact of eco-restoration on nutrient balance in Eastern Attappady. Fifteen sites were randomly selected consisting of ten plantations and five Biomass Conservations Areas (BCA). From each site, aboveground vegetation (trees with GBH $\geq$ 10 cm) were enumerated and aboveground biomass were estimated. For the nutrient pool analysis vegetation, litter and soil samples were collected from each site and chemical analysis were done to estimate the nutrients. Salient features of the study are summarized below.

1. Altogether fifty five species were encountered in the study area. The density of trees in the study sites ranged from 356 trees/ha to 768 trees/ha.

2. *Albizia amara* with higher IVI value (36.53) was dominant in eastern Attappady which was followed by *Chloroxylon sweitenia* (19.54) and *Leucaena leucocephala* (16.94). These species were predominant because they are pioneer tree species.

3. The present study showed that vegetation structure and species composition of plantations and BCAs of study sites in medium rainfall areas like Agali, Sambarcode and Palliyara were significantly different from that of low rainfall areas like Kottathara, Pattimalam, Vellaimari and Mele chavadiyur. So it is assumed that the rainfall regime of the region is one of the main driving forces for this vegetation structure.

4. The poor performance of vegetation structure and species composition of study sites Sambarcode P2, Vannanthura medu and Kottathara BCA which were near to human habitation revealed that the human disturbance is also a determining factor of the vegetation structure in the study areas.

5. Floristic diversity studies revealed that species richness was higher in biomass conservation areas (Simpson index 0.83) compared to plantations (0.79).

6. Aboveground Biomass (AGB) of biomass conservation areas (avg. 29873.19 kg/ha) were higher compared to plantations (avg. 15659.84). Higher AGB of plantations Pattimalam P3 (27742.42 kg/ha), Mele chavadiyur (26858.36 kg/ha) and BCA Sambarcode BCA (88729.75 kg/ha) can be attributed to higher number of trees representing higher girth class.

7. Nutrient stock in vegetation of biomass conservation areas with higher total carbon (avg. 16199 kg/ha), total nitrogen (avg. 353.8 kg/ha), total phosphorus (avg. 39.72 kg/ha) and total potassium (avg. 58.12 kg/ha) were higher compared to total carbon (avg. 8557.35 kg/ha), total nitrogen (196.56 kg/ha), total phosphorus (avg. 21.2 kg/ha) and total potassium (avg. 25.13 kg/ha) of plantations.

8. The higher vegetation nutrient stock in vegetation of BCA can be attributed to the higher AGB among them compared to plantations.

9. Litter turnover from the biomass conservation areas (6.02 t/ha/year) were higher compared to plantations (3.61 t/ha/year). They also showed a seasonal variation throughout the four time period. Litter production was highest during the period of December – March in both plantations and biomass conservation areas whereas it was lowest during March – June.

10. The total nutrient stock in litter among plantations and biomass conservation areas show seasonal variation for total C, N, P and K.

11. Total carbon in litter samples were observed to be higher during the period of December – March in both plantations (2173.64 Kg/ha/year) and biomass conservation areas (3154.97 Kg/ha/year).

12. Total nitrogen in litter samples were higher during the period of September – December among the plantations (72.34 Kg/ha/year) and December – March among the biomass conservation areas (73.50 Kg/ha). Total phosphorus in litter

samples were higher during the period of September – December among plantations (3.28 Kg/ha/year) and December – March (4.17 Kg/ha/year) among biomass conservation areas. Total potassium were higher during December – March among plantations (4.02 Kg/ha/year) and March – June among biomass conservation areas (11.23 Kg/ha/year).

13. Soil nutrient status in eastern Attappady showed significant differences for organic C, organic matter content, total N, available K and CEC along the non-eco-restored, plantations and biomass conservation areas.

14. The higher soil organic carbon (1.43 ± 0.55 %), organic matter content (2.46 ± 0.95 %), total nitrogen (0.19 ± 0.06 %), available potassium (306.20 ± 104.45 kg/ha) and CEC (22.34 ± 6.46 Cmol (p+) kg^{-1}) among the biomass conservation areas clearly show that vegetation prevailing in the ecosystem influences the chemical properties of the soil to a greater extent.

15. Total P were higher among the soil of non-eco-restored areas (0.09 ± 0.02 %) compared to plantations and BCA. This can be attributed to the highly immobile nature of phosphorus. Among the plantations and BCA soil P get absorbed by the prevailing vegetation. In non-eco-restored areas soil P remains as such since vegetation cover was absent there.

16. The study revealed that significant differences were found among plantations and non-eco-restored areas with respect to soil chemical properties. All the tested parameters including soil organic C, organic matter content, total N, available K, available P and CEC were found higher among the plantations compared to non-eco-restored areas. This show a positive sign towards the objective of eco-restoration project carried out in eastern Attappady.

17. The present study revealed that the nutrient pool in the non-eco-restored areas, plantations and biomass conservation areas of eastern Attappady show significant difference among them.

18. The total carbon pool was observed to be highest among the BCAs (44367.19 ± 21625.63 Kg/ha) compared to the plantations (24295.33 ± 6114.53 Kg/ha) and non-eco-restored areas (5372.64 ± 3199.5 Kg/ha).

19. The total nitrogen pool was higher among the BCAs (3417.7 ± 1770.68 Kg/ha) compared to plantations (2075.52 ± 511.72 Kg/ha) and non-eco-restored areas (705.6 ± 504 Kg/ha)

20. The total potassium pool was also higher among the BCAs (344.52 ± 162.87 Kg/ha) compared to the plantations (240.51 ± 75.12 Kg/ha) and non-eco-restored areas (162.49 ± 138.54 Kg/ha).

21. The present study revealed that total phosphorus pool unlike other nutrient pool were higher among the non-eco-restored areas (1600.7 ± 996.3 Kg/ha) compared to plantations (1288.14 ± 452.52 Kg/ha) and BCA's (1187.42 ± 878.75 Kg/ha) (Fig 46). This is due to high phosphorous stock among the soil of non-eco-restored areas (1600.7 ± 996.3 Kg/ha).

22. The higher nutrient stock in the soil, vegetation and litter of biomass conservation areas indicates an efficient nutrient pool among them compared to plantations and non-eco-restored areas.

23. The nutrient pool in plantations show significant difference with that of non-eco-restored areas. The nutrient stock and flow of plantations have higher efficiency compared to non-eco-restored areas. It reflects an increasing potential of nutrient pool of plantations towards the status of biomass conservation areas in near future.

24. The nutrient flow among the plantations and BCA revealed that the rate of flow of nutrient in both the ecosystems were similar. The only difference among the nutrient flow were the quantity of nutrient flowing in BCA were higher compared to plantations

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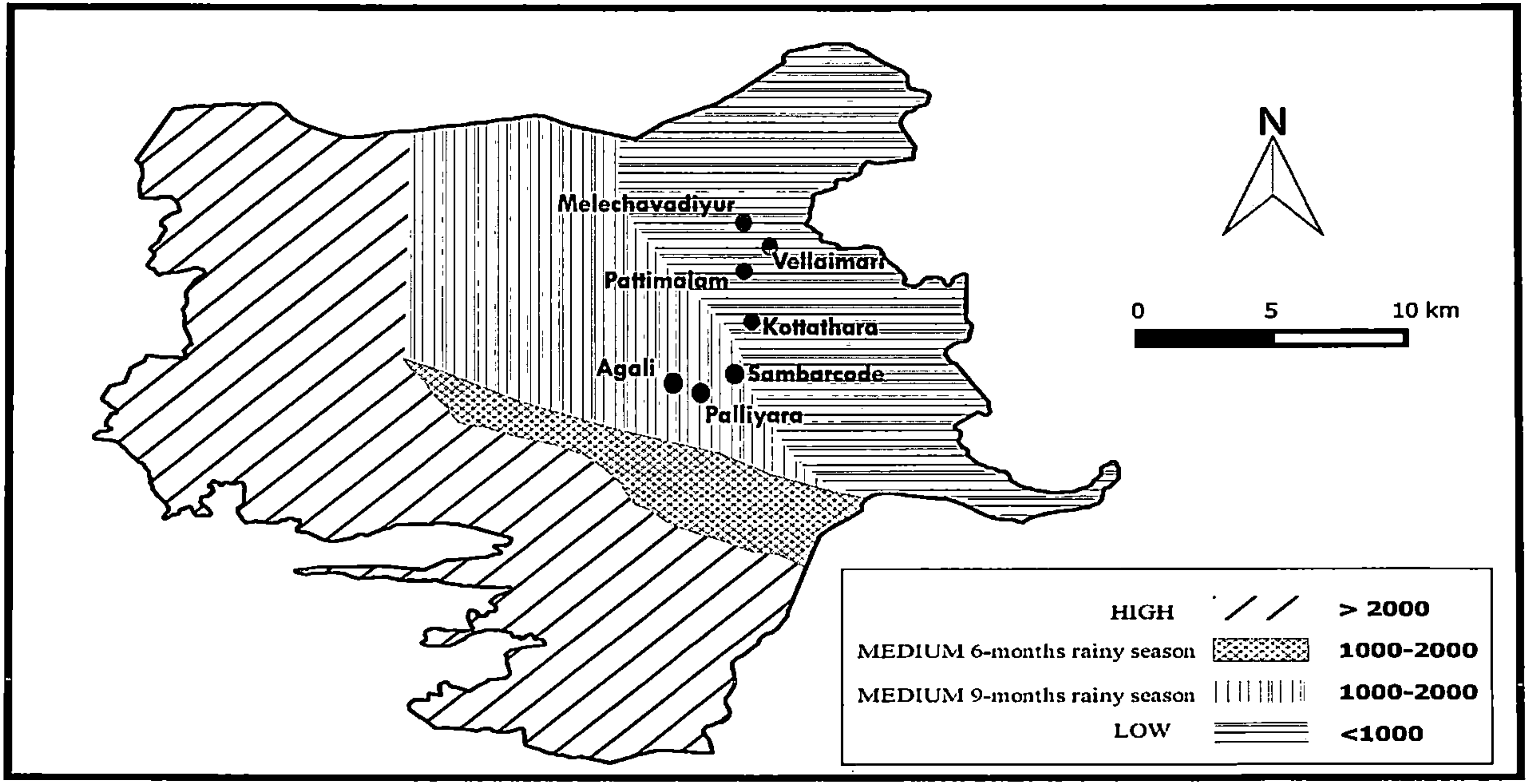
APPENDICES

Appendix 1.



Rainfall regime of Attappady area (KFRI, 1991)

IMPACT OF ECO-RESTORATION ON NUTRIENT BALANCE IN EASTERN ATTAPPADY, KERALA

By

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(2012-17-106)

ABSTRACT

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Faculty of Forestry

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DEPARTMENT OF TREE PHYSIOLOGY AND BREEDING

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9. ABSTRACT

A study on "Impact of Eco-restoration on nutrient balance in eastern Attappady, Kerala" was carried out with the objective of analyzing the nutrient stock and flow of the ecosystem for evaluating the impact of eco-restoration work in eastern Attappady. The study sample included ten plantations, five biomass conservation areas and five non-eco-restored areas spread over seven locations in eastern Attappady. At each study site, a 50 x 50 m^2 quadrat was enumerated for trees (GBH $\geq$ 10 cm) for analyzing the vegetation structure and species composition. Vegetation, soil and litter samples were collected from each sample plots for estimating the nutrient pool and its flow. Stem, leaves and branches were collected from all the tree species encountered during the study. Soil samples were collected up to a depth of 15 cm from all the sample plots and for litter sample collection, litter traps were placed in each sample plot and were collected four times throughout a year with an interval of three months. Organic C, Total N, Total P, Available P, Available K and CEC were estimated from soil. Carbon, N, P and K were estimated from vegetation and litter. Aboveground Biomass (AGB) of the study site was estimated using the universal allometric equation for tropical dry deciduous forests.

Rainfall regimes of the region were found to be the main driving forces for the vegetation structure. The vegetation of plantations and BCAs in the locations Agali, Sambarcode and Palliyara, which fall in the wetter region of the study area had higher tree density compared to drier tracts. Floristic diversity studies revealed that species richness were higher among the BCA's compared to plantations. The vegetation structure and species composition of plantations in the areas with medium rainfall was better than the BCA in drier tracts. The Aboveground Biomass (AGB) was observed to be higher among the BCAs compared to plantations. The higher AGB were correlated to higher density of larger girth class trees.

Nutrient stock in vegetation was proportional to the AGB of the area. The vegetation nutrients were higher among the BCAs compared to plantations due to higher AGB. Species composition and richness was a factor which determined the litter turnover of the ecosystem. Litter turnover was higher among the BCAs compared to plantations. Litter turnover rate was the major factor which determines the litter nutrient stock in the

area. Litter nutrient accumulation were higher among the BCAs compared to plantations in general. Soil nutrient stock was dependent on the above ground vegetation and its composition of the study area. Soil nutrients were higher among the BCA's compared to plantations and non-eco-restored areas except for phosphorous which was higher in soils of non-eco-restored areas since it got absorbed in vegetated areas.

The nutrient capital was higher among the BCAs compared to plantations and non-eco-restored areas. The total carbon stock of BCAs (44367.19 kg/ha) were found to be higher compared to plantations (24295.33 kg/ha) and non-eco-restored areas (5372.64 kg/ha) due to better vegetation structure and species composition among them. Nitrogen pool and potassium pool were also higher among the BCAs (3417.7 kg/ha and 344.52 kg/ha) compared to plantations (2075.52 kg/ha and 240.51 kg/ha) and non-eco-restored areas (705.6 kg/ha and 162.4 kg/ha). The only exception was in the phosphorous pool which was higher in non-eco-restored areas (1600.7 kg/ha). However, rate of nutrient flow in plantations and BCAs were similar. The study indicates that the nutrient flow pattern of plantation is similar to BCAs and if plantations are provided with adequate protection and management, it may attain the stock levels of BCA in due course.