BIOMASS PRODUCTION AND ROOT DISTRIBUTION PATTERN OF SELECTED FAST GROWING MULTI-PURPOSE TREE SPECIES

By

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THESIS

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DECLARATION

I hereby declare that the thesis entitled **Biomass production and root distribution pattern of selected fast growing multi-purpose tree species** is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or any other similar title of any other University or Society.

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CERTIFICATE

Certified that the thesis entitled **Biomass production and root distribution pattern of selected fast growing multi-purpose tree species** is a bonafied record of research work done by Mr. V. Jamaludheen under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship or associateship to him.

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JAMALUDHEEN, V.

Dedicated to

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Introduction

INTRODUCTION

Tropical forests are disappearing at an alarming rate. The global rates of deforestation is estimated to be of the order of about 17 million hectares every year (F.A.O., 1992). In the Indian context also, there is an acute problem of high population pressure, mounting rates of deforestation and the consequent shrinking of our forest resource base. With just two per cent of the world's geographical area and about 15 per cent of its human and livestock population, India faces a critical imbalance in its natural resource base. The Indian farmers are required not only to increase food output per unit of land area, but also to produce fodder and fuelwood on the farm itself. It is estimated that by the turn of this century, we may require about 250 million tonnes of food grains, 2085 million tonnes of green and dry fooder, 350 million tonnes of fuel wood and about 63 million m^3 of timber (NRCAF, 1991). The present production is incapable of meeting even 50 per cent of this projected demand. Agroforestry in general, and fast growing multipurpose trees in particular, are often regarded as renewable sources of fuelwood, fodder, green manure and the like. Furthermore, they are also capable of bridging the gap between supply and availability of timber products.

The term multipurpose tree (MPT) refers to all woody perennials that are deliberately grown on the farm to make more than one significant contributions to the production and/or service functions of land-use systems. Multipurpose tree production forms an important agroforestry activity that attempts to produce timber and other tree products from the same land management unit. Such systems are characterised by the yield of diverse products and/or multiple uses for the same or different tree products. MPTs have the potential to perform specific functions in the system besides sustainable production and/or reduction of inputs and increase of output without affecting the ecological stability of the system. Most MPTs grow quickly, and many are legumes that may fix atmosphereic nitrogen, thus improving soil fertility, others produce fruit or timber and grow well in combination with annual crops. Besides providing a wide range of services and products, several MPTs are adapted to difficult environmental conditions such as drought affected, saline/alkaline or acidic soils. Some others can cope with difficult management situations such as frequent lopping to provide fodder and fuel wood (ICRAF, 1992).

Although there are a large number of MPTs suitable for various agroforestry systems, product diversity, additional income and sustainability are important attributes in the choice of taxa for agroforestry interventions (ICRAF, 1993). Choice of MPTs also depends on adaptability to local climatic conditions; crown architecture, ease of propagation, potential for yielding poles, wood, food, fodder, medicinal products and high quality leaf litter, N fixation potential, resistance to drought and floods, deep thrusting tap root system, ease of management and higher demand and better value for products.

Short rotation tropical plantations that couple intensive management with rapid growth rates may,however, lead to especially high rates of nutrient removal in the harvested fibre, raising concerns about long-term site quality and sustainable production. The potential nutrient export, especially with whole - tree harvesting tend to deplete the nutrient capital of the site (Wang et al., 1991). Altering the rate of nutrient removal in products is probably one of the most important design criteria in planning for sustainable plantation.

Many of the fundamental questions relating to MPTs, right from the selection of species and their efficient management could be answered only with scientific investigations. However, research data on these aspects are scarce in the Kerala context. Hence a study was carried out to evaluate the growth rate, biomass production, nutrient export through harvest, root distribution pattern, soil fertility improvement, litter fall and litter decomposition dynamics of nine multipurpose tree species under the eco-climatic conditions of Central Kerala.

Review of Literature

REVIEW OF LITERATURE

2.1 Multipurpose agroforestry systems

Agroforestry aims at optimising the productive and protective aspects of land use systems. More specifically they attempt to meet the food, fuel, fodder and timber requirements of the society, besides soil conservation and environmental protection. Multipurpose tree production system is an important agroforestry activity which aims at the production of timber and other tree products. The term multipurpose tree (MPT) refers to all woody perennials that are deliberately grown so as to make more than one significant contribution to the production and\or service functions of land use systems. Implicit in this agroforestry intervention is the yield of multiple products. In addition to wood, the MPTs may also yield fruits, flowers, bark, roots, gums, honey, medicines etc., which may be eaten and\or utilised for other purposes (Singh, 1989). Thus, the benefits from MPTS would include food, water, energy, shelter and raw materials for processing (Chundawat and Gautam, 1993).

The National Commission on Agriculture (1976) has estimated that the country would face a deficit of about 100 million cu.m of wood for fuel purpose alone. To meet this alarming shortfall in fuelwood availability, approximately 3 million hectares of land would have to be afforested every year for a period of 10 years. Although the fuelwood shortage remains a serious concern of our planners, equally serious is the problem of fodder scarcity. It is estimated that only one third of the India's total fodder need requirement is satisfied locally (Singh, 1987)

Many indigenous multipurpose trees in different agroclimatic zones of India yield excellent fodder and fuelwood. Various authors have also recommended diverse types of MPTS for various agro-ecological zones of India (Shankaranarayan et al., 1987; Grewal and Abrol, 1986; Singh et al., 1988 and Verma, 1988).

In order to surmount the problem of shortage of firewood and industrial raw materials, farmers have also taken up cultivation of trees in a major way. Poplar (*Populus deltoides*), Subabul (*Leucaena leucocephala*) and *Casuarina equisetifolia* are prominent examples in this respect. Casuarina is grown in Andhra Pradesh, Tamil Nadu and Karnataka, on marginal lands which are usually poor and not suitable for profitable agriculture. Subabul (*Leucaena leucocephala*) is another important multipurpose tree yielding fodder and fuelwood and is grown in Maharashtra, Madhya Pradesh and Andhra Pradesh.

2.2.1 Biomass productivity of various tree taxa

The productive capacity of many MPTs exhibit substantial variability. For instance, the clear felling of

Casuarina (spacing 1m x 1m) at an age of 7 to 10 years yielded 120 tonnes ha^{-1} of firewood (Prakash an Hocking, 1986). Gurumurti *et al*. (1984) reported a net primary production (NPP) of 30 tonnes ha^{-1} year^{-1} for *Prosopis juliflora* and 38 tonnes ha^{-1} year^{-1} for *Leucaena leucocephala*. In a comparative study of biomass productivity of *Acacia auriculiformis* and *Casuarina equisetifolia* in a five year old plantation; Kushalapa (1987) found that *A. auriculiformis* gave a green biomass yield of 81.05 t ha^{-1} while for *C. equisetifolia* it was 68.9 t ha^{-1}. Wang *et al*. (1991) assessed the biomass accumulation rates of five tropical tree taxa (at 10m x 10m) in a 5.5 year old plantation in Puerto Rico. *Casuarina equisetifolia* recorded the highest dry matter accumulation of 36.2 tonnes ha^{-1} year^{-1}. The respective figures for *Albizia procera*, *Eucalyptus robusta*, *Leucaena leucocephala* var. K8 and *L. leucocephala* var. Puerto Rico were 22.5, 12.18, 8.5 and 6 tonnes ha^{-1} year^{-1}. In another study, Singh and Gupta (1993) found that biomass production in *Eucalyptus* hybrid (26.74 kg/plant), *Acacia auriculiformis* (6.49 kg/plant) at 7 years of age, and *Emblica officinalis* (13.49 kg/plant) at 9 years of age were higher compared to *Tectona grandis* (11.34 kg/plant) at 30 years of age.

In a coffee and cocoa production system interplanted with *Cordia alliodora* and\or *Erythrina poeppigiana* of Latin

America, it was estimated that the tree component alone gave about 10 tonnes ha^{-1} $year^{-1}$ of biomass (Russo and Budowski, 1986). In a hedge row intercropping system in Nigeria, Gliricidia sepium produced 3 - 4.5 tonnes ha^{-1} $year^{-1}$ (Yamoah et al., 1986).

2.2.1.1 Partitioning of biomass

The relative allocation of biomass or energy to various above ground parts is a decisive factor that reflects the success of an organism in an environment (Gadgil and Solbrig, 1972). The partitioning of dry matter between different components namely, leaf, reproductive parts, bole, branchwood and root is a matter of considerable importance in agroforestry too. This is important in a multipurpose tree production system, as some of these components are harvested, periodically or at a stretch, and some others are returned to the system. In this context, Maghembe et al. (1986) reported values ranging from 14.8 per cent (foliage) and 50.4 per cent (bole) in Leucaena leucocephala. Further they did not observe any significant difference between intercropped and monoculture situations.

Total dry matter recorded including roots of Acacia nilotica (5264 plants ha^{-1}) after 1-year and 5-years of age were 16 and 154 tonnes ha^{-1} respectively (Gurumurti et al., 1986). Of these the utilisable biomass (bole, bark, branch) was 10.9 and 110.1 t dry matter ha-1 respectively. Stemwood was 30 per cent and branches 35 per cent. Root biomass was 9 per cent at 1-year while it was 26 per cent at the 5-year stage.

Tree biomass production and its relative allocation to various components in a central Himalayan forest revealed striking variability. For example, in Shorea robusta, 61.3 per cent biomass was allocated to the bole, 10.5 per cent to the branches, 4.7 per cent to the twigs, 2.6 per cent to leaves and 20.5 per cent to the roots. While in a mixed oak forest the bole, branch, twig, leaf and the root contributions in the biomass were 43.9, 26.9, 10.5, 3.5 and 15.2 per cent respectively. (Rana et al.,1989)

Wang et al.(1991) studied the biomass partitioning in five tropical tree taxa in a 5.5 year old plantation in Puerto Rico. Casuarina equisetifolia accumulated 70.8 per cent biomass in its bole, 17.4 per cent in the branch and 10.9 per cent in the leaves. In Leucaena leucocephala var. Puerto Rico, the respective values were 72.7, 15.4 and 11.5 per cent and for var. K8, 78.7, 17.4 and 5.1 per cent respectively. From a four year old Acacia auriculiformis stand. Osman et al. (1992) found that the percentage of biomass allocation to the system was to the tune of 72-76 and that to the leaves was 9-12 per cent.

In four multi-purpose tree species, George (1993) observed that foliage had the least biomass yields (ranging from 5.2 per cent in Leucaena to 8.5 per cent in Casuarina) and the boles with the highest relative allocation of total biomass (ranging from 66.59 per cent for Leucaena to as much as 71.74 per cent for Casuarina).

2.2.2 Biomass Nutrient Export

A direct result of high biomass accumulation rate in many MPT species is a correspondingly high nutrient accumulation and export. Singh and Gupta (1993) recorded biomass production and nutrient distribution of different components in six tree species. Biomass was comparatively higher in the Eucalyptus hybrid, Acacia auriculiformis, Hardwickia binata and Emblica officinalis as compared to Tectona grandis and Dalbergia sissoo. Nutrient content, in general, was higher in leaves and lower in roots of all species.

Grove and Malajczuk (1985), from an age series of Eucalyptus diversicolor, concluded that average rates of nutrient accumulation in above ground biomass decreased with increasing stand age. Helmisaari and Siltala (1989) reported that in Pinus sylvestris, concentration of N, P and K increased in stemwood and inner bark towards the youngest tissues at the top.

Hopman et al. (1993) analysed the impact of harvesting on nutrients in a eucalypts ecosystem in south eastern Australia. Nutrient removals from wood generally represented only a small percentage of available soil reserves. Nutrient content of bark was higher compared to stemwood and therefore, export of nutrients, especially of Ca and Mg as a result of wood harvesting could be significantly reduced by on-site debarking.

The accumulation and distribution of nutrients in the plant body is affected by several factors such as age, species, soil conditions, spacing and climate (Ovington, 1968). For most of the nutrient elements, the order of nutrient content is reported as leaves> bark> small branches> stem plus large wood. However, for Ca it is as: bark> leaves> small branches> stem plus large wood (Lugo and Murphy, 1986)

Nutrient losses accompanying biomass harvest has been of great concern, especially, in the context of planting high yielding short rotation species followed by whole- tree harvesting (Jorgensen et al., 1975;Johnson, 1983).

2.3 Factors affecting productivity of MPTs

2.3.1 Choice of species

In agroforestry, it is necessary that the selected trees and shrubs have multiple uses so that each and every part (Singh, 1989) and/or product(s) of the trees can be fully utilised for domestic and/or industrial uses. Furthermore, multipurpose trees and shrubs protect the environment and may thus form integral components of many land use systems providing shade, shelter, wind protection, medicinal/ ornamental plants, soil fertility improvement and the like (Evans, 1983).

Adaptability to local climatic conditions, light open crown, ability to resprout quickly after pruning, coppiceability, capacity to produce poles, wood, food, fodder, medicinal and other products; nitrogen fixing ability, tolerance to environmental hazards like drought, flooding etc., deep thrusting tap root system, ease of establishment and management and production of quick decomposing litter to facilitate faster nutrient turnover, besides high demand and better value for the produce are the characteristics of MPTs suitable for agroforestry (Chundawat and Gautam, 1993).

2.3.1.1. Nitrogen Fixing Trees (NFTs)

Nitrogen fixing trees (NFTs) form a subset of MPTs that has the ability to fix atmospheric nitrogen symbiotically through the involvement of either rhizobia or actinomycetes. Nitrogen being a major essential element for plant growth and chemical sources of fertilizer N represent an energy intensive process, nitrogen fixing trees and shrubs have a special role in every sustainable land use system. Besides, NFTs such as leucaena and acacia have a deep tap root system enabling them to recover moisture and nutrients from deeper layers of the soil. Many NFTs also have small leaflets (e.g. sesbania, leucaena) which decompose rapidly and enable the nutrients to return quickly to the surface and thus maintain the productivity of surface soil. Kang et al. (1985) showed that alley cropping of L. leucocephala can support maize production levels of 2.0 tonnes/ha or approximately 80 per cent of the yield without addition of nitrogenous fertilisers. Inclusion of NFT such as Paraserianthes falcataria has been shown to improve the growth of eucalyptus in Hawaii (Debell et al., 1985).

Several NFTs have multiple uses and provide a combination of benefits. For instance, Leucaena leucocephala, Paraserianthes falcataria, Calliandra calothyrsus and Gliricidia sepium can provide fuelwood, fodder, timber, green manure besides serving as living fences.

NFTs have great potential in regreening the degraded sites and wastelands. Available evidence indicates that NFT can adapt themselves to wastelands and significantly improve the physical and chemical properties of the soil. A marked increase in soil N, cation exchange capacity, exchangeable Ca and K are the reported advantages in this context (Mac Dicken, 1981; FAO, 1988). NFTs mostly constitute a group of extremely fast growing species. Available information suggests that *Acacia mangium*, *Leucaena leucocephala* and *Paraserianthes falcataria* are quick growing and an annual yield of 30-90m^3 ha^{-1} has been obtained in many experimental plantations (FAO, 1988).

Despite the reported evidence of nitrogen fixation by NFTs, some authors doubt the significance of nitrogen fixation on the ground that these trees may exert a heavy demand on the soil N during their rapid juvenile growth phase (Wigston, 1985). The production of allelo-chemicals by trees have also been suggested as a possible problem in agroforestry. Nevertheless only anecdotal evidences are available in this respect, although some of the *Eucalyptus* species have been reported to produce toxins which can inhibit germination or growth of some annual herbs (Poore and Fries, 1985).

2.3.2 Marketability of the produce

While selecting species, besides growth rates, marketability and rate of returns are also very important. In some parts of India, *Eucalyptus tereticornis*, *Populus deltoides*, *Leucaena leucocephala* and *Casuarina equisetifolia* have become popular as these species could be harvested within a period of 8 to 10 years. Further they provide a handsome revenue often greater than that is possible under cash crops like sugar-cane and cotton (Saxena, 1990).

However, there is a potential danger in the form of flooded local markets. Mallik (1989) reported that in Haryana state due to increased production of eucalyptus wood, the market became glutted and prices have gone down. It is therefore, advisable to diversify the tree cropping pattern. However, research reports on these aspects are lacking.

2.3.3 Spacing/Tree density

Biomass productivity of MPTs is strongly dependent on density which in turn might decide the magnitude of intra-specific competition. Factors that decides the choice of spacing are rate of growth of species, growth form, weed growth and the object of management. When the purpose of plantation is to produce fuelwood, small timber and pulpwood closer spacing may be adapted. But wider spacing is necessary, when it is meant to produce structural timber, besides under intercropping situations.

The effects of spacing on biomass distribution and nutrient contents of *Tectona grandis* and *Terminalia superba* in South Western Nigeria was studied by Ola-Adams (1993). He found that stem, bark and leaf weight per hectare in *T. grandis* appeared to decrease with increasing spacing. There was significant difference with spacing for small branches and big roots also. In *T. superba* the total biomass, stem wood, stem bark and small root weight decreased with increasing spacing. However, the widest spacing showed a significant increase in stem wood biomass.

2.4 System Dynamics

Micro-site enrichment through improvement in the soil organic and mineral nutrient pool forms an important attribute of woody perennials in agroforestry and other tree based farming systems (Mac Dicken and Vergara, 1990; Kumar, 1994). Such soil enrichment may arise from stemflow, preferential tapping of atmospheric inputs, enhanced nutrient uptake from depth, deep rooted nature of tree roots and efficient nutrient cycling (Young, 1991). Several workers have reported enhanced nutrient and water availability under woody perennials. For instance, comparing soil properties under the canopy of individual Faidherbia albida trees with the sorrounding areas without trees, Felker (1978) reported a 50-60 per cent increase in soil organic matter and nitrogen under the canopy.

In the moist subhumid zone of Belize, tree-soil transects of broad leaf savanna showed considerable enrichments in nitrogen, phosphorus, potassium, calcium and other bases under trees (Kellman, 1980). In a sandy luvisol in the semi-arid zone of Northern Senegal, soil organic carbon, total nitrogen and the mineral nitrogen levels showed a progressive decrease from the tree trunk to the canopy margin under *Acacia senegal*, *Balanites aegyptica* and *Adansonia digitata* (Bernhard-Reversat, 1982).

It can not however, be concluded that the above advantages of agroforestry systems are available under all conditions. Considerable depletion of soil nutrients has been reported by short-rotation, fast-growing species e.g. eucalyptus, casuarina and others (Lundgren, 1978; Negi and Sharma, 1984; Singh, 1984).

The major pathways which contribute to the accretion of mineral elements in the surface soils of agroforestry systems are out lined below.

2.4.1 Nutrient cycling

Litter plays an important role in the recycling of nutrients and in the transfer of energy between plants and soil The significance of the detrital pathway to the over all ecosystem productivity and nutrient cycling has long been recognised and is reflected in the voluminous literature on this subject (see reviewes by: Bray and Gorham, 1964; Cole and Rapp, 1981; Waring and Schlesinger, 1985; Vogt *et al*., 1986). Litter fall, decomposition and turnover rates have been reported from diverse ecosystem: Van cleve and Norman (1978) from higher altitudinal forests of Alaska, Lam (1985) from Australian Eucalyptus forests, Das and Ramakrishnan (1985) from sub-tropical *Pinus kesiya* of north east India, Stohlgren (1988) in the sierren mixed coniferous forests, Harmon *et al*. (1990) from a picea/Tsuga forest and Kumar and Deepu (1992) for the moist deciduous forests of the peninsular India. Many of the published reports are however, from temperate and/or monocultural situations and only a few of the studies are concerned with tropical agroforestry. The available literature in this respect are reviewed hereunder.

2.4.1.1 Litter production rates

Litterfall represents a principal mechanism of nutrient recycling and redistribution. The amount of detritus or litter produced vary markedly among ecosystems and a number of factors appear to control this process.

Das and Ramakrishnan (1985) reported that for a *Pinus kesiya* stand of North-East India, the total litter production ranged from 6663 to 8984 kg ha^{-1} $year^{-1}$ while the needle litter ranged from 6383 to 6908 kg ha^{-1} $year^{-1}$. Annual litter production in warm temperate forests range from 5-7 t ha^{-1} $year^{-1}$ but can be as high as 18 t ha^{-1} $year^{-1}$ (Bray and Gorham, 1964). Litter production rates reported from tropical forest formation vary widely: 9.8 t ha^{-1} $year^{-1}$ (Fraken *et al*., 1979), 5.5 to 15.3 t ha^{-1} $year^{-1}$ for equatorial forests (Williams and Gray, 1974), 12.2 to 14.4 t ha^{-1} $year^{-1}$ for a tropical deciduous forest in peninsular India (Kumar and Deepu, 1992).

Venkataraman et al. (983) monitored the extent of litterfall in blue gum and black wattle plantations of Nilgiris. The dry weight of litter for the former was 1.9 t ha^{-1} $year^{-1}$ while it was only 0.96 t ha^{-1} $year^{-1}$ for the latter. Mean annual litter production from sites in Darjeeling was 4.8 t ha^{-1} $year^{-1}$ and the maximum litterfall (69 per cent) occurred during the pre-monsoon season (Nirmal et al., 1986). Litter production in an Acacia nilotica plantation was significantly higher than that of a Ecucalyptus tereticornis plantation of the same age and stocking rate (Gill et al., 1987). A mean annual litter production of 12.92 t ha^{-1} $year^{-1}$ was reported from an Acacia auriculiformis stand in Kerala (Kunhamu, 1991).

The total litterfall was highly variable among trees at five years of age. Acacia consistently recorded the highest litterfall throughout the year. Monthly litterfall, when averaged over the collection period was about 52.11 g m^{-2}, 19.2 g m^{-2}, 19.2 g m^{-2} and 16.0 g m^{-2} respectively for Acacia auriculoformis, Casuarina equisetifolia, Leucaena leucocephala and Ailanthus triphysa plots (George, 1993).

Litterfall acts as an important nutrient recharge mechanisms in many ecosystems. The amount of litterfall varies widely depending on factors such as latitude, altitude, species, stand density and age.

2.4.2.1 Seasonal variations in litterfall

Witkamp and Van Der Drift (1961) reported that for *Populus tremula* in Netherlands, the peak litterfall occurred during October which they attributed to prevailing wind conditions. Lonsdale (1988) analysed total litter fall from 389 forest sites throughout the world using multiple regression analyses considering latitude, altitude and precipitation as the predictor variables. Pokhriyal *et al*. (1989) made a detailed analysis of the leaf emergence and shedding behaviour in *Populus deltoides* at Dehradun and found that almost 90 per cent of the leaves were shed during October-December. In a study on litter production in young *Acacia nilotica* and *Eucalyptus tereticornis* in North India, Gill *et al*. (1987), found that winter season accounted for a larger proportion of the annual litter production. In the temperate regions of Northern hemisphere, the maximum litterfall in the deciduous stands was concentrated in autumn with a pronounced peak during October-November (Viro, 1955).

Madge (1965) reported that peak leaf fall occurred during the dry months from November to March in a mixed deciduous forests of Nigeria. For *Populus deltoides* plantations in India, Raisada and Shrivastava (1986) observed two peaks in May and October. Kumar and Deepu (1992) conducted detailed studies on litter dynamics of a moist deciduous ecosystem in the peninsular India and suggested that litterfall followed a monomodal distribution pattern with a peak during the dry period from November-December to March -April, perhaps due to the water stress induced abscission of the leaves and other parts.

George (1993) observed that the period between December and May accounted for bulk of the litterfall in four agroforestry tree species. Litter production remained markedly low during the south west monsoon season for all species.

To sum up, climatic factors play a vital role in deciding the pattern of variations in litterfall.

2.4.3 Litter decomposition

Decomposition of plant litter is the primary mechanism of nutrient cycling in agroforestry systems. The rates and pathways of litter decomposition are determined by quantitative and qualitative composition of the decomposer community, their physical environment and biochemical quality of the substrate (Swift et al., 1979).

Litter decomposition rates have been reported from a wide variety of litter types throughout the world. Cold temperate forests are characterised by slow decomposition and mineralisation of organic matter and nutrients (Jenny et al., 1949; Makrenko and Atkin, 1976). While in the warmer or more mesic regions, the forest floor accumulation of nutrients and organic matter are generally lower. It is estimated that needles of *Pinus silvestris* spent about six months in the L- layer of the soil profile and two years in the F1 and seven years in the F2 layer before being humified (Kendrick, 1959). In temperate forests the decomposition rates are comparatively higher for broad leaved species as compared to conifers (Bray and Gorham, 1964).

Deciduous tree litter usually decomposes more rapidly, but considerable variations occur between species. The complete disappearance of the original mass took place within five to eight months in six tropical deciduous tree species (Kumar and Deepu, 1992). Shankaran (1993) reported a weight loss of about 96 per cent in teak and 94 per cent in eucalypt, over a period of 18 months. The annual decomposition coefficient (k) for various *Pinus* species across a variety of habitats ranged between 0.23 to 0.78 (Das and Ramakrishnan, 1985) and for temperate hardwood species ranged from 0.008 to 0.470 (Melillo *et al*., 1982). In sierran mixed temperate forests, the annual decay rates were between 0.18 and 0.62 (Stohlgren, 1988). The time required for 95 per cent decay ranged from 11 to 27 years. In a study conducted in Colombia, the half-life of litter was found to be about 80 days for *Giliricidia sepium* and *Sesbania grandiflora*, 120 days for *Erythrina* sp. and *Cajanus cajan* and 170 days for *Cassia grandis* (Arias, 1988).

It is clear that litter of different species do not decompose at the same rate under similar environmental conditions. This is clearly due to difference in the structure and composition of their leaves and other parts (Meentemeyer, 1978).

2.4.3.1 Nutrient dynamics of senescing leaves

Nutrient contents of older leaves decline as a result of senescence related retranslocation. The changing litter nutrient concentrations decisively affect plant nutrition and within-stand nutrient cycling. In recent years, therefore, much emphasis has been placed on studies of nutrient retrieval from senescing leaves (Vitousek, 1984).

Das and Ramakrishnan (1985) reported a higher concentration of nitrogen and phosphorus in the needle litter of Pinus kesiya during May-July which is attributed to the lower retranslocation of these elements before abscission and due to addition of nutrients through precipitation. Contrary to this, potassium concentration during this period was low perhaps due to its higher degree of leachability. Gill et al. (1987) studied the nutrient cycling through litter production in young plantations of Acacia nilotica and Eucalyptus tereticornis. The recycling of N, P, K, Ca, Mg, S, Na, Fe and Mn closely followed the periodicity of litter production. Sharma and Pande (1989) found that foliar nutrient content was negatively correlated with the quantum of leaf fall in teak and sal.

2.4.3.2 Factors affecting litter decay

a. Resource quality

Many workers have reported a strong negative relationship between initial lignin/nitrogen ratios and the rate of decomposition of litter. Aber and Melillo (1982) found that highest nitrogen immobilisation occurred in litters with highest initial lignin content. Decomposition dynamics of litter was described by inverse linear relationships linking original mass (%) remaining and the nitrogen concentration in the residual material (Melillo *et al*., 1982). Stohlgren (1988) studied the litter dynamics of two sierran mixed conifer forests. He found that long term (3.6 years) foliage decomposition rates were best correlated with initial lignin/N and lignin concentration. But several workers failed to find a strong dependence of either lignin or lignin/nitrogen ratio on decay rate coefficients (Schlesinger and Hasey, 1981; Stohlgren, 1988; George, 1993).

b. Environmental factors

Van Der Drift (1963) studied the effect of moisture on decomposition of pine, oak and dog wood litter. In spring both the rate of decomposition and micro-arthropod population were greater because of moisture availability. A similar study in *Eucalyptus marginata* and *Eucalyptus* *diversicolor* also revealed that the decomposition was highest in autumn and spring and lowest in dry summer (O' connel, 1990). Studies in a deciduous broad leaved forest conclusively stated that soil moisture status has a greater effect on the rate of litter decomposition. Hutson and Veitch (1985) established a linear relationship between decomposition constant and mean annual rainfall within a range of 600 to 1800 mm $year^{-1}$

Temperature is yet another factor that determines the rate of litter decomposition. The combined effect of temperature and moisture is more pronounced than the effect of temperature alone. Jenny *et al*. (1949) reported a heavy weight loss in alfalfa leaves under high temperature and moisture in a tropical climate. Rate of decomposition in a warm tropical rain forest was found to be 8.2 t ha^{-1} $year^{-1}$ whereas the artic litter has a rate less than 1.2 t ha^{-1} $year^{-1}$ (Wanner, 1970).

2.4.3.3 Nutrient dynamics of decomposing litter

The concentration of N increased sharply over the one year decay period for *Pinus banksiana*, *Betula paperifera* *Populus tremuloides* and *Quercus ellipsodalis* (Bockheim *et al*., 1991) and six tropical species (Kumar and Deepu, 1992). But the concentration of P remained constant for about the first 250 days and then increased, while K concentration declined over the one year period.

However, several workers failed to get a distinct accumulation phase of N in the decomposing litter. Such a phase can be difficult to distinguish in field studies (Berg and Staaf, 1981) or indeed it may be absent. In some cases there is no change in absolute N content of litter (Anderson, 1973; Berg and Staaf, 1980) during decomposition while in others there is a consistant absolute release of N (Bocock, 1964; Berg and Staaf, 1980) particularly in litter with a high N content (Amato and Ladd, 1980). Once the release phase has started the pattern of N loss appears to follow that of weight loss (Wood, 1974). Staaf and Berg (1977) found that the release of N from scots pine needles was linearly related to weight loss.

2.4.4 Root distribution pattern

Agroforestry represent a complex land use system where the system components share the environmental resources. Knowledge of root distribution of tree species is, therefore, very crucial in selection of species, design of agroforestry system and its management (Dhyani et al., 1990). Information on tree-root distribution, especially of the multi-purpose species suitable for agroforestry are scarce.

In a ten year old plantation of *Eucalyptus globulus*, the roots reached a depth of 4.2 m and extended a distance of up to 11 m from the trunk (Davidson, 1985). In 5 and 15 years old *Eucalyptus camaldulensis* plantations, the roots reached up to a depth of 3 m with a lateral spread of 9 m and 20 m respectively (Ram Prasad *et al*., 1984). The lateral spread has been found to be affected by spacing of trees. Widely spaced trees possess roots with longer lateral spread.

Measurement of the quantities and spatial distribution of roots in the soil is made by excavating the root system (Bohm, 1979; Dhyani *et al*., 1990). But a more precise and informative method is the use of slowly diffusing radionucleides as ^{32}P so that the position of the label can be correlated with the root activity (Nye and Tinker, 1977; Vose, 1980).

Distribution pattern of active roots of cashew upto a lateral distance of 4 m from the tree and to a soil depth of 60 cm was studied by Wahid *et al*. (1989 a) employing ^{32}P soil-injection technique. They found that cashew tree is a surface feeder with about 50 per cent of the root activity confining to the top 15 cm of soil layer. About 72 % of the root activity was found within a radial distance of 2 m from the tree. Wahid *et al*. (1989 b) reported a similar result from *Theobroma cacao*. In view of the lateral spread of over 150 cm, they concluded that the roots of adjoining cocoa trees spaced 3 m apart are likely to overlap and compete for water and nutrients.

As regards to mixed species systems, Sankar *et al*. (1988) analysed the root activity pattern of black pepper vine and different support trees in relation to the root competition. It was found that 90 per cent of the root activity was confined to a radial distance of 30 cm from the vine. Pepper vines trained on erythrina had a larger lateral root spread than those trained on teak poles.

Trees and shrubs are known to use their extensive root systems to absorb substantial quantities of nutrients from lower soil horizons and enrich the top soil through leaf fall. However, the general apprehension of the farmers is that trees in association with crops may strongly compete for nutrients and moisture (Dhyani *et al*., 1990). The competition could be grouped into two main classes namely above-ground and below-ground competition. Underground root competition for moisture and nutrients is relatively more important in agroforestry system than above ground competition.

A knowledge of size of the resource pools, their accessibility to the system components and the concept of resource sharing between and among the components are important to design and manage agroforestry systems (Buck, 1986). An important factor in the effective resource sharing, both temporal and spatial, is the selection of tree/crop species with differential root system behaviour.

Materials and Methods

MATERIALS AND METHODS

3.1 Location

The study was conducted at the Livestock Research Station, Thiruvazhamkunnu, Palakkad district, Kerala (between 11° 2' 30'' and 11° 21' 50" N latitude, 76° 21' 50" E longitude and at an elevation of 60 m above mean sea level).

3.1.1 Climate

Thiruvazhamkunnu enjoys a warm humid climate having a mean annual rainfall of 2568.8 mm, the bulk of which is received during the south-west monsoon. The mean maximum temperature ranges from 28.1°C to 38.7°C and the mean minimum temperature varies from 19.5°C to 26.0°C (Fig. 1).

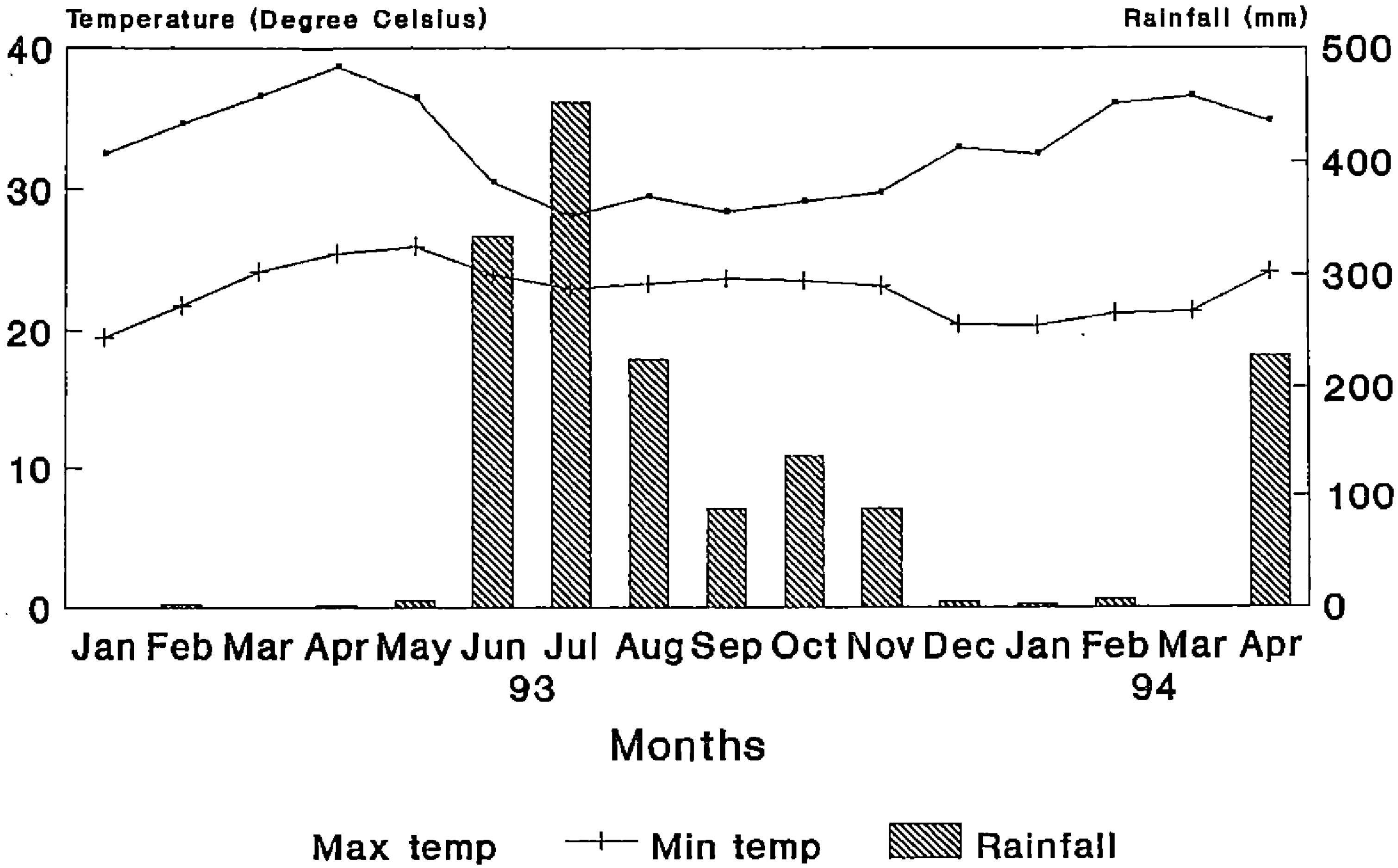
3.1.2 Soil

The soil of the experimental site was Oxisol having a pH of 6.7

3.2 Field experiment

A randomized block design experiment involving the following nine fast growing multi-purpose trees (*Acacia auriculiformis* A. Cunn. ex Benth., *Casuarina equisetifolia* J.R. & G Forst., *Leucaena leucocephala* (Lamk.) de Wit. var.

Fig. 1 Weather parameters for the experimental period



K 8, *Ailanthus triphysa* (Dennst.) Alston, *Emblica officinalis* Gaertn, *Artocarpus heterophyllus* Lamk., *Pterocarpus marsupium* Roxb., *Paraserianthes falcataria* (L.) Neilson and *Artocarpus hirsutus* Lamk.) initiated during June, 1985 was used for the present investigations (Plate I to IX). This experiment involved trees planted in plots of size 20m X 20m at 2m X 2m spacing and having three replications each.

3.2.1 Brief description of the nine fast growing multipurpose tree species

a. *Acacia auriculiformis* A. Cunn. ex. Benth.

Family : Mimosae

An evergreen tree with dense foliage and open spreading crown, native to Papua New Guinea, islands of the Torres Strait, and the northern areas of Australia. It was introduced to India and many other tropical countries in the recent past. Acacia possesses ability to grow on poor soils and in areas with extended dry seasons. The wood is used for fuel, pulp and charcoal purposes. It is having a calorific value of 4800-4900 kcal kg^{-1} (NAS, 1980).

b. *Casuarina equisetifolia* J.R. & G. Forst.

Family : Casuarinaceae

Casuarina is a native of Australia. It is a fast growing nitrogen fixing tree suitable for sand dune

Multi-purpose tree experimental plots at LRS, Thiruvazhamkunnu, Palakkad, Kerala.

Plate I *Acacia auriculiformis* *A*. *Cunn*. ex. Benth.

Plate II *Casuarina equisetifolia* J. R. & G. Forst.

Plate III _Leucaena_ _leucocephala_ (Lamk.) de Wit. var. k8

Plate IV _Ailanthus_ _triphysa_ (Dennst.) Alston

Plate V *Emblica officinalis* Gaertn.

Plate VI *Artocarpus heterophyllus* Lamk.

Plate VII *Pterocarpus marsupium* Roxb.

Plate VIII *Paraserianthes falcataria* (L.) Neilson

Plate IX *Artocarpus hirsutus* Lamk.

stabilization, wind breaks and fence posts. The leaves are actually reduced to small sheaths on the needle -like branchlets. These green branchlets perform the functions of leaves. The wood is used for pulp and fuel. Calorific value is 4950 kcal kg^{-1} (NAS, 1980).

c. Leucaena leucocephala. (Lamk.) de Wit. var. K 8.

Family : Mimosae

A fast growing nitrogen fixing tree native to southern Mexico occurring either as a tall, slender tree that may grow up to 20 m. The foliage is a good source of forage. Drought tolerance and hardiness make it a promising candidate tree for forage purposes throughout the dry tropics. Nitrogen fixation potential of this species give figures in the range 100 to 300 kg ha^{-1} $year^{-1}$ (NAS, 1980). The wood has a caloric value of 4200-4600 kcal kg^{-1}.

d. Ailanthus triphysa (Dennst.) Alston

Family : Simaroubaceae

It is a deciduous tree with tall cylindrical trunk, indigenous to the Indian sub-continent. It is extensively grown in the homesteads of Kerala (Kumar, 1994) and is one of the best species for match industry (NAS, 1980).

e. *Emblica officinalis* Gaertn.

Family : Euphorbiaceae

This tree is found both wild and cultivated throughout the central and southern India. *Emblica* is a medium sized, deciduous tree growing to a height of 25-33 m. The red, close-grained dense wood makes good fuel and excellent charcoal. The caloric value is about 5200 kcal kg^{-1}. Wood is durable even under water, and is used for agricultural impliments. *Emblica* fruit is one of the richest known natural sources of Vitamin C. The foliage and fruits are relished by livestock. Branch loppings are used as good green manure, particularly for neutralising excessive soil alkalinity (NAS, 1980).

f. *Artocarpus heterophyllus* Lamk.

Family : Moraceae

Jack is a large evergreen tree, 10-15 m in height, indigenous to the evergreen forests of the Western Ghats and cultivated throughout the hotter parts of India. Jack fruit is one of the most popular fuits of South India. It enjoys special favour in homegardens on the west coast and is used as one of the shade trees in coffee, areca and cardamom plantations. Owing to its numerous culinary uses and its availability in plenty during the monsoon season, it is popularly known as "Poor man's food". The wood is moderately hard, polishes well and does not warp and split.

It seasons well and is not attacked by white ants or fungi. It is largely used for carpentry boxes and furniture and occasionally for cabinet work. Bark contains tannin and is reported to be used in dyeing and tanning. The leaves are used as fodder and seem to be particularly relished by goats (Anon., 1985).

g. **Pterocarpus marsupium Roxb.**

Family : Fabaceae

A moderate to large sized deciduous tree with a straight clean bole found commonly in hilly regions throughout the Deccan peninsula. The normal rainfall in its natural habitat ranges from 75 to 200 cm. It coppices fairly well, but is found to pollard better. It yields one of the most important timbers in peninsular India. The timber is mainly used for building purposes, as doors, window frames, rafters, beams and posts. It is used as fuel. Calorific value of sap wood is 4904 kcal kg^{-1} and that of heartwood is 5141 kcal kg^{-1}. The bark is used as an astringent and for tooth ache. The flowers are said to be used for the treatment of fever. The leaves make an excellent fodder and are valuable as manure in arecanut plantations (Anon, 1985).

h. <u>Paraserianthes</u> <u>falcataria</u> **(L.) Neilson**

Family : Mimosae

One of the fastest-growing trees in the world. This species is native to eastern islands of the Moluccas and to Papua New Guinea. The growth of this species is so rapid that the plant has been termed a miracle tree. It may reach 7m height in little more than a year, 21 m in 4 years, and 30 m in 9 to 10 years (NAS, 1980). It has a light to medium hardwood. The wood can be used for making matches, match boxes, catamarams, packing cases and as a source of pulpwood. It makes good charcoal and has a calorific value ranging from 2865 to 3357 kcal kg^{-1}. It is widely used as a shade tree for cattle and for cocoa, coffee, banana and tea plantations.

i. <u>Artocarpus</u> <u>hirsutus</u> **Lamk.**

Family : Moraceae

The tree is commonly found in the evergreen forests of Western Ghats from the Konkan south-wards and is fairly commonm in North Kanara and Coorg in Karnataka and south-wards through South Kanara to Kerala. The tree can tolerate shade, but thrives best with a fair amount of light. It copices well and produces root suckers. This plant is useful as an under wood in teak plantations. The wood is almost as strong as teak and has the advantage of lightness (Anon, 1985). Its calorific value is 5223 kcal kg^{-1}. The dry leaves and juice together with zedoary and camphor are used as application to swellings.

3.3 Tree allometric observations

Total height and diameter at breast hieght of ten randomly selected trees from each plots were measured at six monthly intervals (April 1993 and October 1993). The data pertaining to the tree growth were statistically analysed following the analysis of variance technique.

3.4 Litter collection

Litter collections were made using specially designed circular litter traps (Hughes et al.,1987). For each trap, four 210 cm long galvanised (2 to 3 mm) iron wire was used. A tripod was made using three galvanised wires. The remaining one was made into a hoop of 55 cm diameter by overlapping the ends of the wire and tying them firmly. This hoop was tied horizontally on the tripod. A plastic grain bag was placed inside the hoop with tapering end downwards. Each trap had a collection area of 0.24 m^2 and about 15 litres capacity. Ten such traps per species were randomly placed in the inter spaces of trees on February 1st, 1993.

Litter collections were made from each trap at monthly intertvals for a one-year period from 1st February, 1993 to

31st January, 1994. Leaf litter was sorted into twigs, foliage and reproductive parts.

The samples were oven dried at 70°C until constant weights and the mean litter fall (species-wise) on unit area basis was computed for each month. Chemical analyses were carried out for total nitrogen (micro-kjeldhal method), phosphorus (vanado-molybdo phosphoric yellow colour method) and potassium (flame photometry) following Jackson (1958). The nutrient inputs into the system through litterfall was ascertained by multiplying the total mass of litter by the estimated nutrient concentrations and the data generated was statistically analysed following the analysis of variance technique.

3.4.1 Litter decomposition

Standard litter bag technique was employed for characterising litter decomposing dynamics. Freshly fallen leaves of *Acacia*, *Casuarina*, *Leucaena*, *Ailanthus*, *Emblica*, *A. heterophyllus*, *Pterocarpus*, *Paraserianthes* and *A. hirsutus* were collected and dried under shade for approximately 48 hours. Twenty gram samples were placed in litter bags of 20 cm X 20 cm size made of 4 mm nylon wire mesh. Representative litter samples of each species were collected in triplicate to estimate the fresh to dry matter ratio at the time of transferring the samples into the litter bags. The bags were then placed in the litter layer of the soil in the plot on April 1, 1993. (96 samples per species and altogether of 864 litter bags: 9 species X 12 months X 8 replicates).

At monthly intervals, starting from Ist April, 1993 to March 31st 1994, residual mass from the litter bags were retrieved by carefully removing the accumulated soil and litter over the bags and returning the bags to the laboratory. After removing the extraneous materials like large arthropods, fine roots and soil and washing in running water, the residual litter in the bags were oven dried.

The contents of the bags were analysed for oven dry mass, nitrogen, phosphorus and potassium following Jackson (1958). Apart from this, the initial lignin content was assessed by the Van Soest (1966) method for estimating acid detergent fibre and lignin. For lignin assay, one gram of leaf samples (two replicates per species) were weighed out, which 100 ml cold acid detergent solution (prepared by adding 20 g of cetyl trimethyl ammonium bromide (CTAB) to one litre of one normal H_2SO_4) was added. This was refluxed for 60 minutes on a refluxing rack. The sample was then filtered and washed. The filtrate was dried over night and then weighed to determine the acid detergent fibre per cent. Seventy two per cent H_2SO_4 was poured in to this dried sample and intermittently stirred at half hourly intervals for three hours. After filtering this solution, the sample was dried overnight and weighed, which was kept in a muffle furnace for about three hours at 600°C and weighed at the end of this period. The difference in weight between the sample before being kept in the muffle furnace to that after wards, gave the lignin content of the sample.

Acid detergent lignin (%) =

$$\frac{(\text{Wt. of crucible + lignin}) - (\text{Wt. of crucible + Ash}) \times 100}{\text{Wt. of sample}}$$

3.4.2 Nutrients remaining in the litter

Nutrient content of the decomposing leaf was calculated using the follwing equation:

$$\%\ \text{nutrient remaining} = (C/Co) \times (DM/DM_o) \times 10^2$$

Where C is the concentration of element in the leaf litter at the time of sampling; Co is the concentration of the initial litter kept for decomposition; DM is the mass of dry matter at the time of sampling, and DM_o is the dry matter of initial litter kept for decomposition (Bockheim _et al._, 1991).

3.4.2.1 Decay rate coefficients

The model for constant potential weight loss (Olson, 1963) represented by the equation:

$$X/X^{\circ} = e^{-kt}$$

Where X is the weight remaining at time t, X° is the original mass, e is the base of the natural logartham, k is the decay rate coefficient and t is the time, was fitted on the data on mass disappearance. Half lives (t 0.5) of the decomposing litter were estimated from the k-values using the equation.

$$t_{0.5} = \ln(0.5)/-k$$
$$= -0.693/-k$$

3.5 Estimation of Tree Biomass

For biomass estimation, all trees forming alternate diagonal rows in the stand was destructively sampled during April, 1994. Number of trees harvested per species ranged from 17-32. The trees were felled at the ground level using a mechanical chain saw (Poulan/Pro, USA).

After recording the total height and girth at breast height of the felled trees, the above ground portions were separated into stem wood (main shoot, if the main shoot is forked below the BH level then such branches were also treated as stem wood); Branch wood (all branches differentiating above BH level from the stem) and foliage. Fresh weights of all the tree components were recorded immediately after felling using appropriate spring scales (to either nearest 0.1 kg or 10 mg).

For quantifying the coarse root component, three randomly selected trees from each species were completely excavated and all roots > 5 mm in diameter were collected and their length and weight recorded.

3.5.1 Sampling of tree biomass fractions

Leaf samples (ca 0.5 kg each) were randomly collected (in triplicate) from the felled trees for chemical analyses and moisture estimation. Stem disks approximately 2 cm in thickness were cut at the breast height level and at the base of crown from the three randomly selected trees for chemical analysis and moisture estimation. Branch wood samples were also collected in triplicate (ca 0.5 kg each) from the selected trees. Root samples for chemical analyses and moisture estimation were collected from the excavated trees (three replicates per species).

The samples were immediately transfered to the laboratory in double sealed polythene bags. After recording the fresh weights, these were dried to constant weights at 60°C to 70°C. The samples were ground to pass through a 2 mm mesh. Three sub-samples were then drawn from the composite samples for phyto-chemical analysis.

Representative leaf samples (ca 0.5 kg) were collected from the felled trees for estimating the total leaf area (three samples per species). These samples were transported to vellanikkara in a refrigerated container. The leaf area was measured using a 'Li Cor Model 3100' area meter (Li Cor. Lincoln, Neberaska). Total leaf area for a species was calculated by multiplying the fresh foliage weight with leaf area-weight factor.

Statistical analysis was carried out on the biomass data. Allometric equations were developed to predict total above ground biomass of nine tree species. Equations of the following form were used.

1. $B = a\ (DBH^2.\ H)^b$

B = total above grounq biomass, H = total height, DBH = Diameter at breast height, a and b are coefficients. (Rana _et al._, 1989). The power function was fitted by linear regression of log-log transformed data using

$\ln B = a + b \ln DBH^2$ (Rana _et al._, 1989)

2. $B = aDBH^b$ (Dudley and Fownes, 1992)

B = total above ground biomass, H = Total height, DBH = Diameter at breast height, a and b are coefficients.

3. $B = a\ (DBH)^b\ (H)^c$ (Dudley and Fownes, 1992)

B = total above ground biomass, H = total height, DBH = Diameter at breast height

a, b, and c are coefficients

3.6.1 Characterisation of root distribution pattern by destructive sampling

Three randomly selected trees per species were excavated following the method of Bohm (1979) by digging along the course followed by the roots. Pick-axe, spade and small tools were used for digging the soil. Length of tap root, maximum lateral spread and biomass (dry weight) of roots having diameter > 5 mm were recorded.

3.6.2 Characterisation of root distribution pattern by radioisotope technique

Root distribution pattern of *Artocarpus hirstus* perhaps the most commonlly scattered tree found on Kerala homesteads (Kumar *et al*., 1994) was characterised by radiotracer technique involving ^{32}P soil injection. The experimental variables included combinations of three lateral distances (75 cm, 150 cm and 225 cm) from the tree and three depths (30 cm, 60 cm and 90 cm).

Selection of experimental units for ^{32}P application was done on the basis of uniformity of growth and maximum distance as far as possible between the experimental units, so as to ensure minimum interference to adjacent units. Each unit was replicated thrice. The experimental units for radioisotope application were laid out in a randomised block design with two factors-lateral distance and depth-each at three levels.

Eight equally spaced holes were dug to the required depth and at a particular radius along a circle around the tree i.e. equal to the lateral distance as per the treatments protocol using a soil auger of 2 cm diameter. The holes were plugged with PVC access tubes protruding 10 cm above the soil surface. The open end of each tube was covered with a polythene cap to prevent entry of rain water. ^{32}P solution at the rate of 1.0 mCi. at a carrier level of 1000 ppm P was dispensed into the access tube at the rate of 4 ml per hole on November 23, 1993, using a device fabricated for the purpose (Wahid et al., 1988). After dispensing, the access tube was washed down with a jet of about 15 ml water to clean the residual activity remaining in the tube. The carrier in the ^{32}P solution was used to minimise the chances of soil fixation of the radioisotope.

3.6.2.1 Leaf sampling and radioassay

Newly formed, young leaves from the experimental units were sampled for radioassy. Samping was done at 15, 30 and 45 days after application of ^{32}P. The leaf samples were dried at 70°C and radioassayed for ^{32}P content by the

Cerenkov counting technique (Wahid et al., 1985) at the Radiotracer Laboratory, Kerala Agricultural University, Vellanikkara. The method consisted of wet digestion of one gram of plant sample using diacid mixture (HNO_3 and $HClO_4$ in 2:1 ratio) and the digest was transferred to a counting vial. The final volume of the content in the vial was made to 20 ml. The vials were counted in a liquid scintillation counter (Wallac 1409 Pharmacia , Finland) by Cerenkov counting technique. During the course of experiment, the counting efficiency remained constant at 32 per cent and hence the count rates were not converted to dpm but were expressed as cpm values.

The cpm values were corrected for back ground as well as for decay. Then $\log_{10}$ transformation was done on the data and the analysis of variance was performed. Assuming that recovery of radioactivity in the foliage is a reflection of the density of active roots, the root activity percentage at a particular lateral distance and depth was calculated using the formula:

$$\left.\begin{array}{l}\text{\% root activity at}\\ \text{a particular lateral}\\ \text{distance and depth}\end{array}\right\} = \frac{\text{Count rate (cpm g}^{-1}\text{) for that lateral distance and depth}}{\text{Total cpm for all treatments}} \times 100$$

3.7 Phytochemical Analyses

Triplicate samples of each tissue fraction were analysed for nitrogen, phosphorus and potassium. Total nitrogen was estimated following the micro-kjeldahl method after the samples were ground to pass through a 2 mm sieve. Phosphorus and potassium contents of the litter samples were determined after digesting the sample in triple acid mixture (HNO_3, H_2SO_4 and $HClO_4$ in the ratio 10:1:3). Phosphorus was estimated following the Vanado-molybdo phosphoric yellow colour method and potassium by flame photometry (Jackson, 1958).

3.8 Soil chemical analyses

Soil samples were collected from the interspaces between two rows of trees at three points from the top 15 cm layer in different treatments and was air dried and ground to pass through a 2 mm sieve. For each treatment, three replicates were used for chemical analyses as follows:

Soil pH was determied using an aqueous suspension of soils (soil and water in the ratio 1:2) using an 'Elico' pH meter, organic carbon by the Walkley and Black method. Total nitrogen was determined on oven dry basis (micro-kjeldhal method), available P was extracted folllowing the Bray method (number -I) and phosphorus content was then colorimetrically assayed (chloromolybdic acid blue colour method). The reducing agent was stannous chloride. Available potassium was estimated flame photometrically using one N neutral ammonium acetate solution as the extractant (Jackson, 1958).

Results

RESULTS

4.1 Tree growth characteristics

4.1.1 Height and diameter

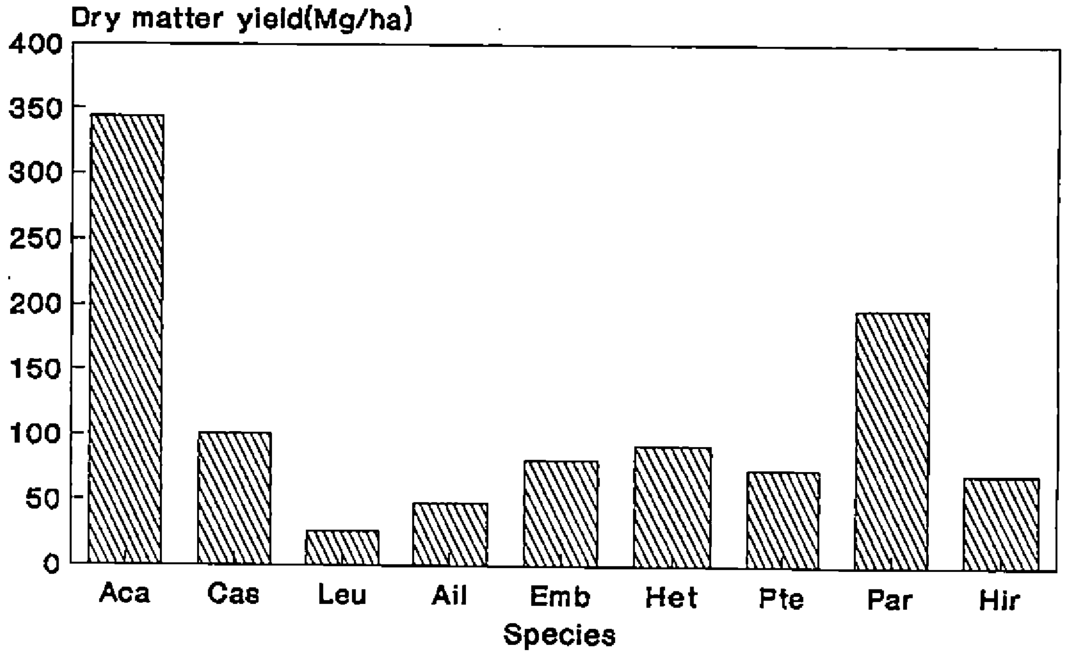
There was marked variations in the growth rates of the nine multipurpose trees (MPTs) at eight years of age (Table 1). *Acacia* recorded the maximum height of 18.1 m, closely followed by *Paraserianthes* (14.6 m) and *Casuarina* (13.8 m). *Ailanthus* recorded the lowest height of 4.1 m. With regard to radial growth, the selected MPTs decreased in the order: *Paraserianthes* > *Acacia* > *Artocarpus heterophyllus* > *Casuarina* > *Emblica* > *Artocarpus hirsutus* > *Ailanthus* > *Leucaena* > *Pterocarpus*.

Allometry of the trees felled for biomass estimation (Table 2) also indicated a similar trend with *Acacia* and *Paraserianthes* being superior to the rest of the species in respect of the total height and diameter at breast height. Highest leaf area was recorded by *Acacia* (99.6 m^2 $tree^{-1}$) followed by *Casuarina*, *A. hirsutus*, *A. heterophyllus* and *Paraserianthes*.

4.1.2 Biomass accumulation

Biomass yield was highest for *Acacia* (344.2 Mg ha^{-1}) followed by *Paraserianthes* and *Casuarina* (Table 3; Fig. 2 and Appendix II). Mean annual increment was markedly high

Fig.2 Total dry matter yield of nine MPT species at eight years of age



Aca- *Acacia*	Cas- *Casuarina*	Leu- *Leucaena*
Ail- *Ailanthus*	Emb- *Emblica*	Het- *A. heterophyllus*
Pte- *Pterocarpus*	Par- *Paraserianthus*	Hir- *A. hirsutus*

Table 1. Growth characteristics of eight year old fast growing multi-purpose trees.

Species	Mean tree height (m)		Mean tree 7DBH (cm)	
	Apr '93	Oct '93	Apr '93	Oct '93
Acacia auriculiformis	17.21	18.08	13.31	13.93
Casuarina equisetifolia	13.53	13.77	8.38	9.55
Leucaena leucocephala	8.35	8.36	7.09	7.46
Ailanthus triphysa	4.05	4.14	7.09	7.59
Emblica officinalis	6.72	6.92	7.76	8.46
Artocarpus heterophyllus	6.40	6.74	8.90	9.65
Pterocarpus marsupium	6.17	6.37	5.92	6.86
Paraserianthes falcataria	14.03	14.57	16.66	17.79
Artocarpus hirsutus	5.21	5.50	7.18	7.75
P	<0.01	<0.01	<0.01	<0.01
SEM(±)	1.331	1.394	1.608	1.651
CD (0.05)	3.99	4.18	4.82	4.95

Table 2. Allometric data for eight year old destructively sampled fast growing multi-purpose trees

Species	Height (m)	DBH (cm)	Leaf area[&] (m^2 $tree^{-1}$)
Acacia auriculiformis	17.84	13.63	99.63
Casuarina equisetifolia	12.13	7.50	45.87
Leucaena leucocephala	6.30	4.88	17.75
Ailanthus triphysa	5.00	8.42	30.90
Emblica officinalis	7.38	7.32	43.23
Artocarpus heterophyllus	8.73	9.24	63.94
Pterocarpus marsupium	8.76	8.85	40.76
Paraserianthes falcataria	14.57	13.29	59.44
Artocarpus hirsutus	6.48	8.12	78.51
P	<0.01	<0.01	<0.01
F ratio	49.925	14.200	7.32

& Leaf area refers to one side area only

Table 3. Mean dry matter yield (kg tree^{-1} and Mg ha^{-1}) of nine fast growing multi-purpose trees at eight years of age.

Species	No. of trees felled (n)	Biomass components: Bole kg per tree	Bole Mg per ha	Branch kg per tree	Branch Mg per ha	Root [&] kg per tree	Root [&] Mg per ha	Foliage kg per tree	Foliage Mg per ha	Total kg per tree	Total Mg per ha	M.A.I. Mg per ha per year
Acacia auriculiformis	31	109.97 (74.06)	274.93	17.02 (16.50)	42.55	7.09 (3.54)	17.73	3.58 (1.85)	8.95	137.67 (85.49)	344.18	43.02
Casuarina equisetifolia	26	29.30 (34.51)	73.25	6.65 (10.35)	16.63	2.24 (0.64)	5.60	2.28 (2.76)	5.70	40.47 (46.43)	101.18	12.65
Leucaena leucocephala	18	6.11 (5.14)	15.28	2.50 (2.81)	6.25	1.29 (0.85)	3.23	0.51 (0.37)	1.28	10.41 (8.13)	26.03	3.25
Ailanthus triphysa	30	11.51 (7.35)	28.78	3.07 (2.91)	7.68	2.96 (0.28)	7.40	1.63 (1.40)	4.08	19.16 (11.07)	47.90	5.99
Emblica officinalis	17	18.48 (14.23)	46.20	7.29 (8.15)	18.23	5.05 (5.80)	12.63	1.77 (1.82)	4.43	32.59 (23.63)	81.48	10.19
Artocarpus heterophyllus	32	21.75 (14.74)	54.38	7.94 (7.75)	19.85	4.05 (2.86)	10.13	3.11 (2.54)	7.78	36.85 (23.57)	92.13	11.52
Pterocarpus marsupium	30	21.04 (17.23)	52.60	4.03 (4.85)	10.08	2.92 (2.91)	7.30	1.37 (1.23)	3.43	29.36 (22.50)	73.40	9.18
Paraserianthes falcataria	19	56.47 (44.65)	141.18	14.90 (18.95)	37.25	5.51 (3.84)	13.78	2.02 (1.44)	5.05	78.89 (61.25)	197.23	24.65
Artocarpus hirsutus	28	12.86 (12.31)	32.15	5.93 (6.33)	14.83	4.46 (1.04)	11.15	4.78 (4.36)	11.95	28.02 (22.32)	70.05	8.76
P		<0.01		<0.01		NS		<0.01		<0.01		
F ratio		26.63		6.61		—		7.88		24.22		

& n for root component is 3 for all the species

Figures in paranthesis indicates the standard deviation for Acacia (43.02 Mg ha^{-1} yr^{-1}; Table 3). Clearly the most important component of biomass yield in all species was the bole (range: 45.1% in A. hirsutus to 79.9% in Acacia). The contribution of branches ranged from 12.4 % (Acacia) to 24.0% (Leucaena). Percentage contribution of root was generally low (range: 5.2% for Acacia to 15.9% for A. hirsutus). Foliage invariably had the least biomass yield for all species (Fig. 3). A. hirsutus, however, had a relatively higher proportion of biomass compared to other species (Fig. 3).

4.1.2.1 Tree allometric relationships

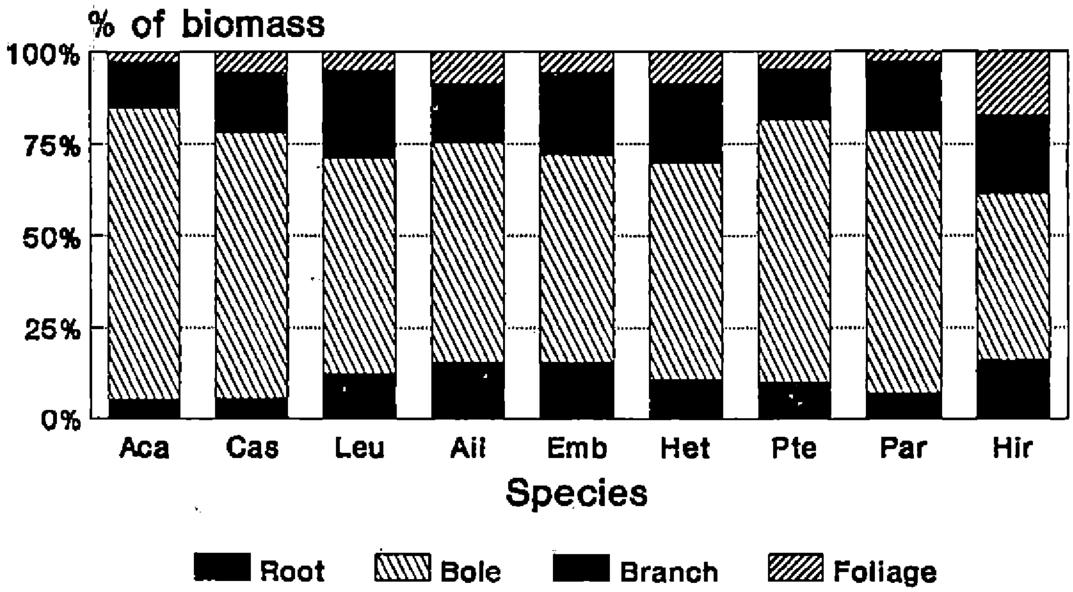
Biomass equations for different species linking total above ground biomass to growth parameters such as height (H) and/or diameter at breast height (DBH) are presented in Table 4. In general r^2 values were very high (>0.90) for all species except Ailanthus and Emblica. However, the r^2 values did not differ quite substantially among the different models tried suggesting that all the equations had a reasonably good fit. For Ailanthus, r^2 values were generally lower and the model $\ln B = a + b \ln DBH + c \ln H$ gave the best fit.

4.2. Tissue nutrient concentration

4.2.1 Nitrogen

Nitrogen concentration of different biomass fractions showed substantial variability (Table 5 and Appendix III).

Fig.3 Relative proportion of biomass accumulated in various organs of nine MPT species



Aca- Acacia   Cas- Casuarina   Leu- Leucaena

Ail- Ailanthus   Emb- Emblica   Het- A. heterophyllus

Pte- Pterocarpus   Par- Paraserianthus   Hir- A. hirsutus

Tabe 4. Allometric relationships relating oven dry above ground tree biomass (kg tree^{-1}) with DBH (cm) and/or total tree height (H) in m.

Species	Model[&]	a	b	c	S.E.E.	r^2	n
Acacia auriculiformis	1	-2.087	0.840		0.174	0.952	31
	2	-1.298	2.307		0.186	0.945	
	3	-2.024	1.734	0.769	0.177	0.950	
Casuarina equisetifolia	1	-2.693	0.904		0.143	0.988	26
	2	-2.255	2.710		0.139	0.989	
	3	-2.482	2.290	0.431	0.119	0.992	
Leucaena leucocephala	1	-3.727	1.123		0.320	0.910	18
	2	-3.223	3.228		0.355	0.889	
	3	-3.656	2.456	0.902	0.328	0.905	
Ailanthus triphysa	1	-1.522	0.711		0.331	0.780	30
	2	-1.221	1.817		0.382	0.707	
	3	-1.660	0.554	1.940	0.296	0.825	
Emblica officinalis	1	-2.700	0.969		0.281	0.901	17
	2	-1.542	2.330		0.321	0.870	
	3	-2.736	1.919	1.004	0.290	0.894	
Artocarpus heterophyllus	1	-2.921	0.936		0.351	0.917	32
	2	-1.737	2.259		0.361	0.912	
	3	-2.744	1.932	0.792	0.356	0.914	
Pterocarpus marsupium	1	-3.147	0.945		0.308	0.956	30
	2	-3.055	2.792		0.316	0.953	
	3	-3.125	2.247	0.577	0.308	0.956	
Paraserianthes falcataria	1	-3.763	0.989		0.181	0.977	19
	2	-2.923	2.682		0.182	0.977	
	3	-3.366	2.324	0.509	0.181	0.978	
Artocarpus hirsutus	1	-3.694	1.065		0.451	0.901	28
	2	-3.054	2.786		0.441	0.906	
	3	-3.288	2.574	0.360	0.445	0.904	

& Model 1 $\ln B = a + b \ln DBH^2 H$

2 $\ln B = a + b \ln DBH$

3 $\ln B = a + b \ln DBH + c \ln H$ where

B = Above ground biomass, DBH=Diameter at breast height, H=Total Height.

Table 5. Tissue nitrogen concentration (%) of nine fast growing multi-purpose tree species

Species	Biomass components			
	Bole	Branch	Root	Foliage
Acacia auriculiformis	0.163	0.677	0.537	2.473
Casuarina equisetifolia	0.140	0.303	0.280	1.587
Leucaena leucocephala	0.233	0.350	0.513	4.737
Ailanthus triphysa	0.327	0.653	0.513	2.847
Emblica officinalis	0.187	0.233	0.210	2.403
Artocarpus heterophyllus	0.140	0.373	0.350	2.147
Pterocarpus marsupium	0.280	0.583	0.350	2.893
Paraserianthes falcataria	0.233	0.373	0.233	3.057
Artocarpus hirsutus	0.210	0.233	0.467	1.727
P	<0.01	<0.01	<0.01	<0.01
SEM (±)	0.0183	0.0258	0.0183	0.0365
CD (0.05)	0.0543	0.0766	0.0543	0.1085

In general, N content of the above ground portions decreased in the order: foliage > branch > roots > bole. However, for Leucaena and A. hirsutus, the concentration of N in roots was higher than that of the branches. As regards to foliage N content, Leucaena had the highest N (4.74%) followed by Paraserianthes (3.06%), while Casuarina had the lowest (1.59%).

4.2.2 Phosphorus

There was significant difference in the P content of different biomass fractions (Table 6 and Appendix IV). P concentration of the above ground parts was decreased in the order: foliage > branch ≈ roots > bole. P content of the bole was maximum in Ailanthus (0.027%) and least in Pterocarpus and Paraserianthes. As regards to foliage P content, Pterocarpus (0.138%) and A. hirsutus (0.132%) had the maximum concentration while Casuarina (0.067%) and Leucaena (0.060%) recorded the two lowest P levels.

4.2.3 Potassium

The concentration of K in different biomass fractions showed marked variability. As in the case of N and P, concentration of K in the above ground portions followed the order: foliage > branch ≈ roots > bole (Table 7 and Appendix V). However, for Paraserianthes, K concentration of roots was the lowest of all tissue types. The concentrations

Table 6. Tissue phosphorus concentration (%) of nine fast growing multi-purpose tree species

Species	Biomass components			
	Bole	Branch	Root	Foliage
Acacia auriculiformis	0.007	0.013	0.007	0.077
Casuarina equisetifolia	0.005	0.012	0.012	0.067
Leucaena leucocephala	0.013	0.015	0.018	0.060
Ailanthus triphysa	0.027	0.040	0.032	0.125
Emblica officinalis	0.017	0.020	0.042	0.128
Artocarpus heterophyllus	0.008	0.022	0.038	0.110
Pterocarpus marsupium	0.005	0.017	0.017	0.138
Paraserianthes falcataria	0.005	0.012	0.007	0.092
Artocarpus hirsutus	0.013	0.068	0.057	0.132
P	<0.01	<0.01	<0.01	<0.01
SEM (±)	0.0013	0.0017	0.0070	0.0025
CD (0.05)	0.0040	0.0052	0.0209	0.0076

Table 7. Tissue potassium concentration (%) of nine fast growing multi-purpose tree species

Species	Biomass components			
	Bole	Branch	Root	Foliage
Acacia auriculiformis	0.083	0.217	0.200	0.725
Casuarina equisetifolia	0.050	0.075	0.580	0.458
Leucaena leucocephala	0.100	0.208	0.158	0.408
Ailanthus triphysa	0.142	0.208	0.342	0.683
Emblica officinalis	0.208	0.383	0.233	0.817
Artocarpus heterophyllus	0.233	0.333	0.392	1.258
Pterocarpus marsupium	0.233	0.458	0.500	2.433
Paraserianthes falcataria	0.117	0.192	0.083	0.858
Artocarpus hirsutus	0.283	0.875	0.583	1.683
P	<0.01	<0.01	<0.01	<0.01
SEM (±)	0.0086	0.0086	0.0096	0.0105
CD (0.05)	0.0256	0.0256	0.0286	0.0312

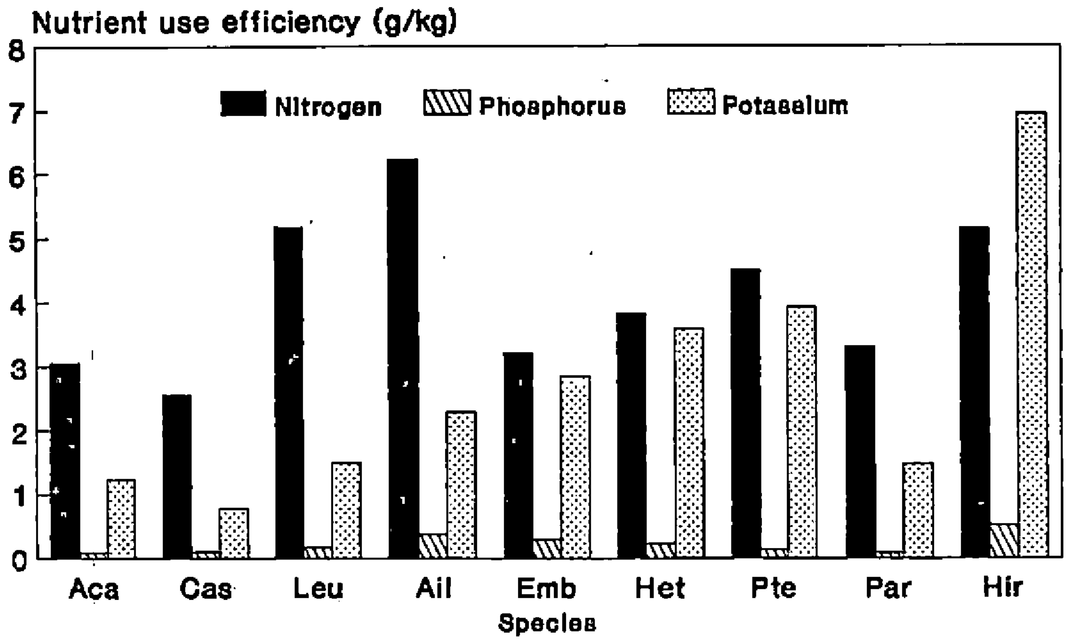
of K in bole, branches and roots were maximum in A. hirsutus. As regards to foliage, the highest K content was recorded by Pterocarpus (2.43%), followed by A. hirsutus (1.68%) and A. heterophyllus (1.26%) while Casuarina (0.46%) and Leucaena (0.41%) recorded the lowest two values.

4.2.4 Nutrient accumulation and nutrient use efficiency

4.2.4.1 Nitrogen

Nitrogen accumulation of different tree taxa showed significant variations ($P<0.01$). Different biomass fractions also exhibited substantial variability in this respect. Acacia showed significantly higher nitrogen accumulation for total biomass as well as for all the tissue types (Table 8 and Appendix VI). Leucaena recorded the lowest level of N accumulation regardless of the tissue fractions. As regards to N use efficiency, Casuarina recorded the lowest nitrogen to biomass ratio indicating its higher N use efficiency while Ailanthus was the least efficient, followed by Leucaena (Table 9; Fig. 4 and Appendix VII). Foliar N use efficiency was significantly higher for A. hirsutus closely followed by Casuarina. Leucaena recorded the highest nitrogen to biomass ratio indicating its low efficiency. For all species studied, boles invariably represented the lowest nitrogen to biomass ratio and foliage the highest.

Fig.4 Nutrient use efficiency of nine MPT species for N, P and K



Aca- Acacia   Cas- Casuarina   Leu- Leucaena

Ail- Ailanthus   Emb- Emblica   Het- A. heterophyllus

Pte- Pterocarpus   Par- Paraserianthus   Hir- A. hirsutus

Table 8. Nitrogen accumulation in different organs of nine multi-purpose tree species at eight years of age.

Species	Biomass components									
	Bole		Branch		Root		Foliage		Total	
	g $tree^{-1}$	kg ha^{-1}	g $tree^{-1}$	kg ha^{-1}	g $tree^{-1}$	kg ha^{-1}	g $tree^{-1}$	kg ha^{-1}	g $tree^{-1}$	kg ha^{-1}
Acacia auriculiformis	179.62	449.05	115.17	287.93	38.05	95.13	88.55	221.38	421.38	1053.45
Casuarina equisetifolia	41.02	102.55	20.17	50.43	6.27	15.68	36.18	90.45	103.64	259.10
Leucaena leucocephala	14.26	35.65	8.75	21.88	6.62	16.55	24.16	60.40	53.70	134.25
Ailanthus triphysa	37.60	94.00	20.06	50.15	15.19	37.98	46.40	116.00	119.25	298.13
Emblica officinalis	34.50	56.25	17.01	42.53	10.61	26.53	42.54	106.35	104.66	261.65
Artocarpus heterophyllus	30.45	76.13	29.64	74.10	14.17	35.43	66.76	166.90	141.03	352.58
Pterocarpus marsupium	58.91	147.28	23.51	58.78	10.22	25.55	37.64	94.10	132.28	330.70
Paraserianthes falcataria	131.77	329.43	55.63	139.08	12.86	32.15	61.74	154.35	261.99	654.98
Artocarpus hirsutus	27.01	67.52	13.83	34.58	20.81	52.03	82.53	206.33	144.19	360.48
P	<0.01		<0.01		<0.01		<0.01		<0.01	
SEM (±)	9.775		2.132		0.819		0.735		9.200	
CD (0.05)	29.039		6.335		2.433		2.183		27.331	

Table 9. Nitrogen use efficiency of nine multi-purpose tree species

Species	N use efficiency of different components (g N per kg biomass)				
	Bole	Branch	Root	Foliage	Total
Acacia auriculiformis	1.633	6.767	5.366	24.734	3.061
Casuarina equisetifolia	1.400	3.034	2.799	15.867	2.561
Leucaena leucocephala	2.333	3.500	5.132	47.366	5.167
Ailanthus triphysa	3.267	6.533	5.133	28.466	6.224
Emblica officinalis	1.867	2.333	2.101	24.036	3.211
Artocarpus heterophyllus	1.400	3.733	3.499	21.467	3.827
Pterocarpus marsupium	2.800	5.833	3.500	28.934	4.505
Paraserianthes falcataria	2.333	3.733	2.333	30.566	3.321
Artocarpus hirsutus	2.100	2.332	4.666	7.266	5.146
P	<0.01	<0.01	<0.01	<0.01	<0.01
SEM (±)	0.1742	0.2582	0.1742	0.3564	0.1265
CD (0.05)	0.5174	0.7671	0.5174	1.0587	0.3757

4.2.4.2 Phosphorus

Phosphorus accumulation pattern of different species exhibited considerable variations (Table 10 and Appendix VIII). Total P accumulation was highest for A. hirsutus (36.5 kg ha^{-1}) and it decreased in the order: Acacia > Emblica > A. heterophyllus > Ailanthus > Paraserianthes > Pterocarpus > Casuarina > Leucaena. A. hirsutus also recorded the highest phosphorus to biomass ratio for whole tree, while the most efficient species in this respect was Paraserianthes. Acacia and Casuarina also recorded markedly higher P use efficiency (Table 11 and Appendix IX). With respect to foliage P use efficiency, Leucaena was the most efficient and Pterocarpus the least.

4.2.4.3 Potassium

As regard to K accumulation also,there was significant difference between species (Table 12 and Appendix X). A. hirsutus had the highest K accumulation while the least was in Leucaena. Casuarina was the most efficient as far as whole tree K use efficiency was concerned, and A. hirsutus the least efficient (Table 13 and Appendix XI).

4.3 Soil chemical characteristics

Physico-chemical properties of the soil from different stands (taxa) tested showed significant variations (P <

Table 10. Phosphorus accumulation in different organs of nine multi-purpose tree species at eight years of age.

Species	Biomass components									
	Bole		Branch		Root		Foliage		Total	
	g $tree^{-1}$	kg ha^{-1}	g $tree^{-1}$	kg ha^{-1}	g $tree^{-1}$	kg ha^{-1}	g $tree^{-1}$	kg ha^{-1}	g $tree^{-1}$	kg ha
Acacia auriculiformis	7.33	18.33	2.30	5.75	0.47	1.18	2.75	6.88	12.82	32.[illegible]
Casuarina equisetifolia	1.47	3.68	0.78	1.95	0.26	0.65	1.52	3.80	4.02	10.[illegible]
Leucaena leucocephala	0.81	2.03	0.38	0.95	0.24	0.60	0.31	0.78	1.73	3.[illegible]
Ailanthus triphysa	3.07	7.68	1.23	3.08	0.94	2.35	2.04	5.10	7.27	18.[illegible]
Emblica officinalis	3.08	7.70	2.07	5.18	2.10	5.25	2.27	5.68	9.52	23.[illegible]
Artocarpus heterophyllus	1.81	4.53	1.72	4.30	1.55	3.88	3.11	7.78	8.20	20.[illegible]
Pterocarpus marsupium	1.05	2.63	0.67	1.68	0.49	1.23	1.90	4.75	4.11	10.[illegible]
Paraserianthes falcataria	2.82	7.05	1.74	4.35	0.37	0.75	1.85	4.63	6.78	16.[illegible]
Artocarpus hirsutus	1.72	4.30	4.05	10.13	2.53	6.33	6.29	15.73	14.59	36.[illegible]
P	<0.01		<0.01		<0.01		<0.01		<0.01	
SEM (±)	0.6393		0.1517		0.0707		0.0548		0.7589	
CD (0.05)	1.8991		0.4505		0.2101		0.1628		2.2546	

Table 11. Phosphorus use efficiency of nine multi-purpose tree species

Species	P use efficiency of different components (g P per kg biomass)				
	Bole	Branch	Root	Foliage	Total
Acacia auriculiformis	0.067	0.133	0.067	0.767	0.093
Casuarina equisetifolia	0.050	0.117	0.117	0.667	0.100
Leucaena leucocephala	0.133	0.150	0.183	0.601	0.167
Ailanthus triphysa	0.267	0.400	0.317	1.250	0.379
Emblica officinalis	0.167	0.283	0.417	1.283	0.292
Artocarpus heterophyllus	0.083	0.217	0.383	1.000	0.222
Pterocarpus marsupium	0.050	0.167	0.167	1.383	0.140
Paraserianthes falcataria	0.050	0.117	0.067	0.917	0.086
Artocarpus hirsutus	0.133	0.683	0.567	1.317	0.521
P	<0.01	<0.01	<0.01	<0.01	<0.01
SEM (±)	0.0183	0.0183	0.0183	0.0258	0.0096
CD (0.05)	0.0543	0.0543	0.0543	0.0766	0.0286

Table 12. Potassium accumulation in different organs of nine multi-purpose tree species at eight years of age.

Species	Biomass components									
	Bole		Branch		Root		Foliage		Total	
	g $tree^{-1}$	kg ha^{-1}	g $tree^{-1}$	kg ha^{-1}	g $tree^{-1}$	kg ha^{-1}	g $tree^{-1}$	kg ha^{-1}	g $tree^{-1}$	kg ha^{-1}
Acacia auriculiformis	91.64	229.10	36.88	92.20	14.18	35.45	25.96	64.90	168.65	421.63
Casuarina equisetifolia	14.65	36.63	4.99	12.48	1.31	3.28	10.45	26.13	31.40	78.50
Leucaena leucocephala	6.11	15.28	5.21	13.03	2.04	5.10	2.08	5.20	15.44	38.60
Ailanthus triphysa	16.31	40.78	6.40	16.00	10.11	25.28	11.14	27.85	43.95	109.88
Emblica officinalis	38.50	96.25	27.95	69.88	11.78	29.45	14.46	36.15	72.68	181.70
Artocarpus heterophyllus	50.75	126.88	26.47	66.18	15.86	39.65	39.13	97.83	132.21	330.53
Pterocarpus marsupium	49.09	122.73	18.47	46.18	14.60	36.50	33.34	83.35	115.50	288.75
Paraserianthes falcataria	65.88	164.70	28.56	71.40	4.59	11.48	17.34	43.25	116.37	290.93
Artocarpus hirsutus	36.44	91.30	51.89	129.73	26.02	65.05	80.46	201.15	194.80	487.00
P	<0.01		<0.01		<0.01		<0.01		<0.01	
SEM (±)	3.6571		0.7685		0.4680		0.2620		3.4437	
CD (0.05)	10.8646		2.2832		1.3902		0.7785		10.2306	

Table 13. Potassium use efficiency of nine multi-purpose tree species

Species	K use efficiency of different components (g K per kg biomass)				
	Bole	Branch	Root	Foliage	Total
Acacia auriculiformis	0.833	2.167	2.000	7.250	1.225
Casuarina equisetifolia	0.500	0.750	0.583	4.583	0.776
Leucaena leucocephala	1.000	2.083	1.583	4.083	1.483
Ailanthus triphysa	1.417	2.083	3.417	6.833	2.294
Emblica officinalis	2.083	3.833	2.333	8.167	2.844
Artocarpus heterophyllus	2.333	3.333	3.917	12.583	3.588
Pterocarpus marsupium	2.333	4.583	5.000	24.333	3.934
Paraserianthes falcataria	1.167	1.917	0.833	8.583	1.475
Artocarpus hirsutus	2.833	8.750	5.833	16.833	6.952
P	<0.01	<0.01	<0.01	<0.01	<0.01
SEM (±)	0.0876	0.0876	0.1000	0.1033	0.0548
CD (0.05)	0.2602	0.2602	0.2971	0.3068	0.1628

Table 14. Soil chemical properties (0-15 cm soil layer) under different multi-purpose tree blocks

Species	pH	OC(%)	N(%)	P (ppm)	K (ppm)
Acacia auriculiformis	6.7	1.677	0.154	11.07	53.08
Casuarina equisetifolia	6.8	1.148	0.112	12.93	23.83
Leucaena leucocephala	6.7	1.866	0.168	8.07	21.45
Ailanthus triphysa	6.7	1.526	0.117	9.93	23.83
Emblica officinalis	6.7	1.463	0.117	12.73	19.07
Artocarpus heterophyllus	6.7	1.412	0.093	9.33	23.83
Pterocarpus marsupium	6.6	1.337	0.121	12.00	19.07
Paraserianthes falcataria	6.6	1.387	0.126	10.47	48.32
Artocarpus hirsutus	6.7	1.400	0.103	8.67	45.93
P	NS	<0.01	<0.01	<0.01	<0.01
SEM (±)	0.055	0.006	0.007	0.855	4.700
CD (0.05)	--	0.018	0.022	2.540	13.962

Table 15. Mean weights (g m^{-2}) of litter in stands of nine fast growing multi-purpose tree species

Months	Total dry weights of litter (g m^{-2})								
	Aca	Cas	Leu	Ail	Emb	Het	Pte	Par	Hir
Feb - 93	65.49 (5.16)	42.44 (6.59)	40.97 (8.05)	2.71 (0.59)	24.44 (4.71)	51.75 (8.31)	71.77 (20.95)	42.99 (4.69)	40.72 (10.40)
Mar - 93	90.37 (7.12)	42.98 (6.68)	35.89 (7.05)	10.69 (2.34)	34.91 (6.73)	32.40 (5.20)	54.20 (15.82)	92.12 (10.04)	29.13 (7.44)
Apr - 93	81.16 (6.39)	50.65 (7.87)	43.34 (8.51)	15.84 (3.45)	39.85 (7.69)	61.78 (9.92)	5.97 (1.74)	79.03 (8.62)	29.56 (7.55)
May - 93	28.27 (2.23)	25.05 (3.89)	43.69 (8.58)	11.89 (2.60)	24.90 (4.80)	24.12 (3.87)	5.08 (1.48)	43.13 (4.70)	27.76 (7.09)
Jun - 93	48.66 (3.83)	35.05 (5.45)	67.77 (13.31)	17.81 (3.90)	34.75 (6.70)	43.59 (6.70)	11.23 (3.28)	72.27 (7.88)	31.52 (8.05)
Jul - 93	63.31 (4.99)	44.06 (6.85)	54.02 (10.61)	34.50 (7.55)	38.39 (7.41)	48.38 (7.77)	22.27 (6.50)	56.26 (6.13)	26.68 (6.81)
Aug - 93	55.03 (4.34)	42.47 (6.60)	31.50 (6.19)	35.92 (7.87)	58.81 (11.35)	34.41 (5.52)	11.89 (3.47)	71.22 (7.76)	31.00 (7.92)
Sep - 93	91.67 (7.22)	45.25 (7.03)	18.06 (3.55)	42.02 (9.20)	61.49 (11.86)	54.58 (8.76)	17.55 (5.12)	91.52 (9.98)	41.14 (10.50)
Oct - 93	59.78 (4.71)	69.48 (10.80)	69.68 (13.69)	21.98 (4.81)	50.63 (9.77)	48.98 (7.86)	26.15 (7.63)	63.37 (6.91)	49.13 (12.54)
Nov - 93	159.69 (12.58)	73.50 (11.42)	25.78 (5.06)	74.98 (16.42)	56.50 (10.90)	73.37 (11.78)	37.78 (11.03)	96.29 (10.50)	34.07 (8.70)
Dec - 93	333.20 (26.25)	113.09 (17.57)	36.22 (7.12)	171.63 (37.58)	67.73 (13.07)	75.80 (12.17)	33.77 (9.86)	121.00 (13.19)	25.56 (6.53)
Jan - 94	192.86 (15.19)	59.61 (9.26)	42.06 (8.26)	16.71 (3.66)	25.96 (5.01)	73.82 (11.85)	45.00 (13.13)	88.14 (9.61)	25.39 (6.48)
Total	1269.41	643.62	509.01	456.66	518.35	622.96	342.65	917.34	391.65

	Species	Month	Speices X Month
P	<0.01	<0.01	<0.01
SEM (+)	2.3322	2.6930	8.0790
CD (0.05)	6.4635	7.4635	22.3904

Figures in paranthesis indicate percentage of annual litter fall

Aca - Acacia auriculiformis, Cas - Casuarina equisetifolia, Leu - Leucaena leucocephala, Ail - Ailanthus triphysa, Emb - Emblica officinalis, Het - Artocarpus heterophyllus, Pte - Pterocarpus marsupium, Par - Paraserianthes falcataria, Hir - Artocarpus hirsutus

Ailanthus < Leucaena < Emblica < A. heterophyllus < Casuarina < Paraserianthes < Acacia. The observed differences were also highly significant (P<0.01) with respect to monthly litter fall rates for different taxa. Acacia consistently recorded the highest amount of litter fall throughout the year.

4.4.1 Seasonal variation in litter fall

Monthly litter fall varied significantly between tree species (Table 15; Fig.5 and Appendix XIII). Peak detritus fall occurred during the month of December for Acacia, Casuarina, Ailanthus, Emblica, A. heterophyllus and Paraserianthes. However, Leucaena and A. hirsutus had peak falls during October and the peak month of detritus fall in Pterocarpus was February.

4.4.2 Littter fractions

For all species, foliage formed the main chunk of the total litter fall (Appendix I). Variation in foliage component of litter, by and large, followed the pattern of total litterfall. Twig fractions, however, followed no consistant pattern. But twigs formed an important component of litter throughout the year in all species except A. heterophyllus and A. hirsutus. The contribution of twigs to total litter ranged from 0.77% (A. hirsutus) to 27.4% (Paraserianthes). Reproductive components were not recorded by the traps kept under Emblica and Pterocarpus. For other species it ranged from 0.5% (A. heterophyllus) to 21.3% (Acacia).

4.4.3 Seasonal variability in litter nutrient concentration

The concentration of macro elements in the composite litter sample showed considerable variations throughout the year (Tables 16-18 and Appendix XIV).

4.4.3.1 Nitrogen

Significant differences were observed in the N content of the litter between species and months. For all species, N content of the foliage fraction was lower than that of fresh foliage prior to abscission (Table 5). Species, month and the interaction effects (month X species) were significant in this respect (Table 16). Peak values of N were recorded during June -July in Acacia, Casuarina and Pterocarpus and during October-November in Emblica and Paraserianthes. In Leucaena and A. heterophyllus, a higher N content was recorded during the August-January period (Fig 6). Although no distinctive pattern of variation in N content of litter was discernible, Ailanthus and A. hirsutus recorded the maximum N content in February.

Fig.6 Seasonal variations in litter N concentration of nine MPT species

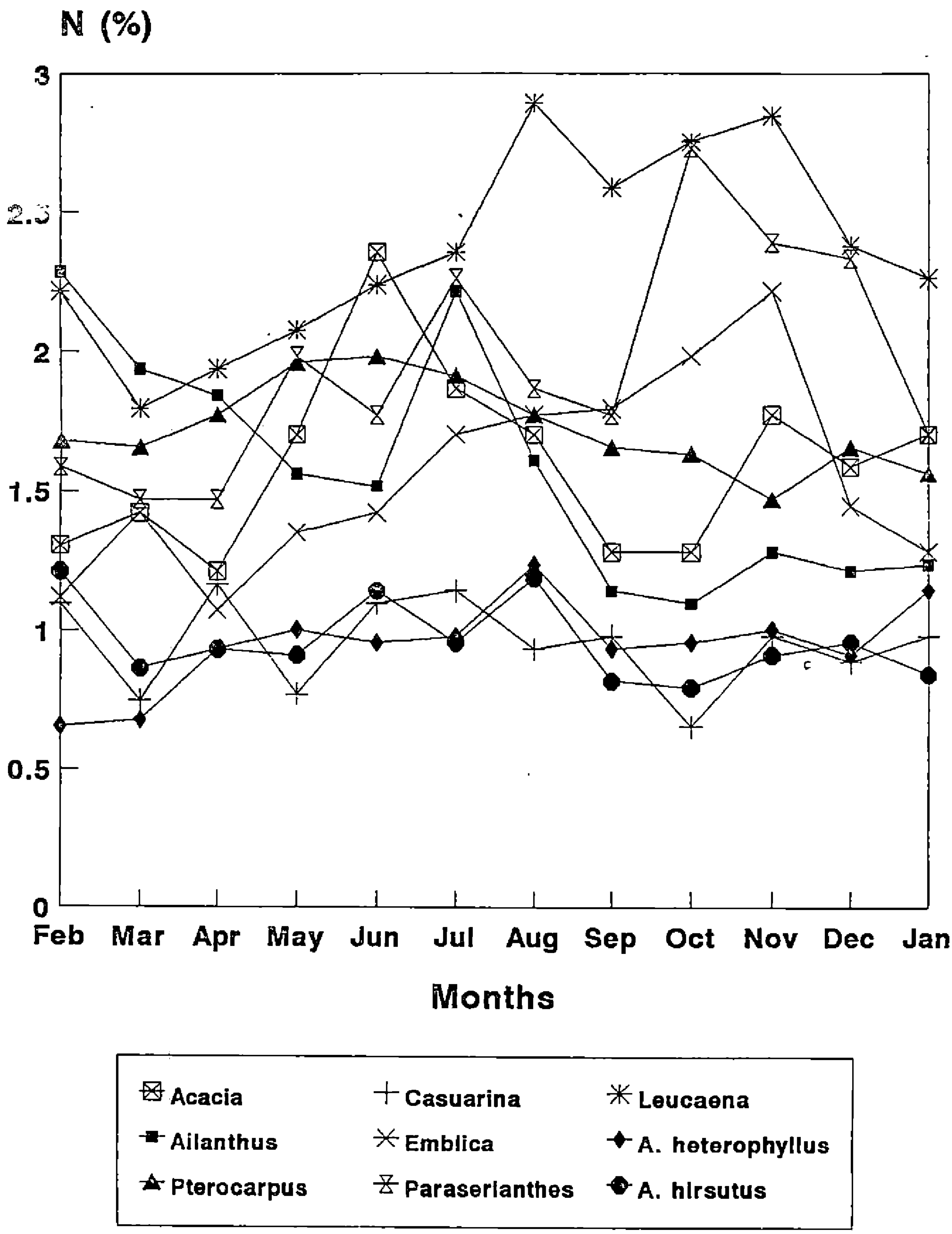


Table 16. Seasonal variation in litter (composite) nitrogen concentration (%) of nine multi-purpose tree species.

Months	Aca	Cas	Leu	Ail	Emb	Het	Pte	Par	Hir
Feb-93	1.307	1.097	2.217	2.287	1.120	0.653	1.680	1.587	1.213
Mar-93	1.423	0.747	1.797	1.937	1.423	0.677	1.657	1.470	0.863
Apr-93	1.213	1.167	1.937	1.843	1.073	0.933	1.773	1.470	0.933
May-93	1.703	0.770	2.077	1.563	1.353	1.003	1.960	1.983	0.910
Jun-93	2.357	1.097	2.240	1.517	1.423	0.957	1.983	1.773	1.143
Jul-93	1.867	1.143	2.357	2.217	1.703	0.980	1.913	2.263	0.957
Aug-93	1.703	0.933	2.893	1.610	1.773	1.237	1.773	1.867	1.190
Sep-93	1.283	0.980	2.590	1.143	1.797	0.933	1.657	1.773	0.817
Oct-93	1.283	0.653	2.753	1.097	1.983	0.957	1.633	2.730	0.793
Nov-93	1.773	0.980	2.847	1.283	2.217	1.003	1.470	2.380	0.910
Dec-93	1.587	0.887	2.380	1.213	1.447	0.910	1.657	2.333	0.957
Jan-94	1.703	0.980	2.263	1.237	1.283	1.143	1.563	1.703	0.840
Overall mean	1.600	0.953	2.362	1.579	1.550	0.949	1.727	1.944	0.961

	Species	Month	Speices X Month
P	<0.01	<0.01	<0.01
SEM (±)	0.0164	0.0189	0.0568
CD (0.05)	0.0454	0.0523	0.1574

Aca- *Acacia auriculiformis*, Cas- *Casuarina equisetifolia*, Leu- *Leucaena leucocephala*, Ail- *Ailanthus triphysa*, Emb- *Emblica officinalis* , Het- *Artocarpus heterophyllus*, Pte- *Pterocarpus marsupium*, Par- *Paraserianthus falcataria*, Hir- *Artocarpus hirsutus*

4.4.3.2 Phosphorus

With respect to litter P content, species, month and their interaction effects were significant (Table 17). In all species except *Leucaena*, P content of litter was lower than that of fresh foliage prior to abscission (Table 6). Surprisingly *Leucaena* litter recorded markedly higher P levels (0.118 %) than corresponding foliar levels (0.06 %). No clear trend was discernible with respect to the peak values of P for majority of the species (Fig.7).

4.4.3.3 Potassium

Significant differences were observed with respect to species and months (Table 18) for litter K content. Unlike N and P content, the reduction in K content in fallen leaves compared to that of foliage prior to abscission was very dramatic (Table 7). Peak values of litter K was recorded in December for *Casuarina*, *Paraserianthes* and *A. heterophyllus*; during March for *Ailanthus* and *A. hirsutus*; during April for *Leucaena* and *Pterocarpus*; during October for *Emblica* and during January for *Acacia*. In general, the south-west monsoon period (June-September) was characterised by relatively lower detrital K contents (Fig 8) and potassium concentration in litter was found to increase by the end of the rainy season (October onwards).

Fig.7 Seasonal variations in litter P concentration of nine MPT species

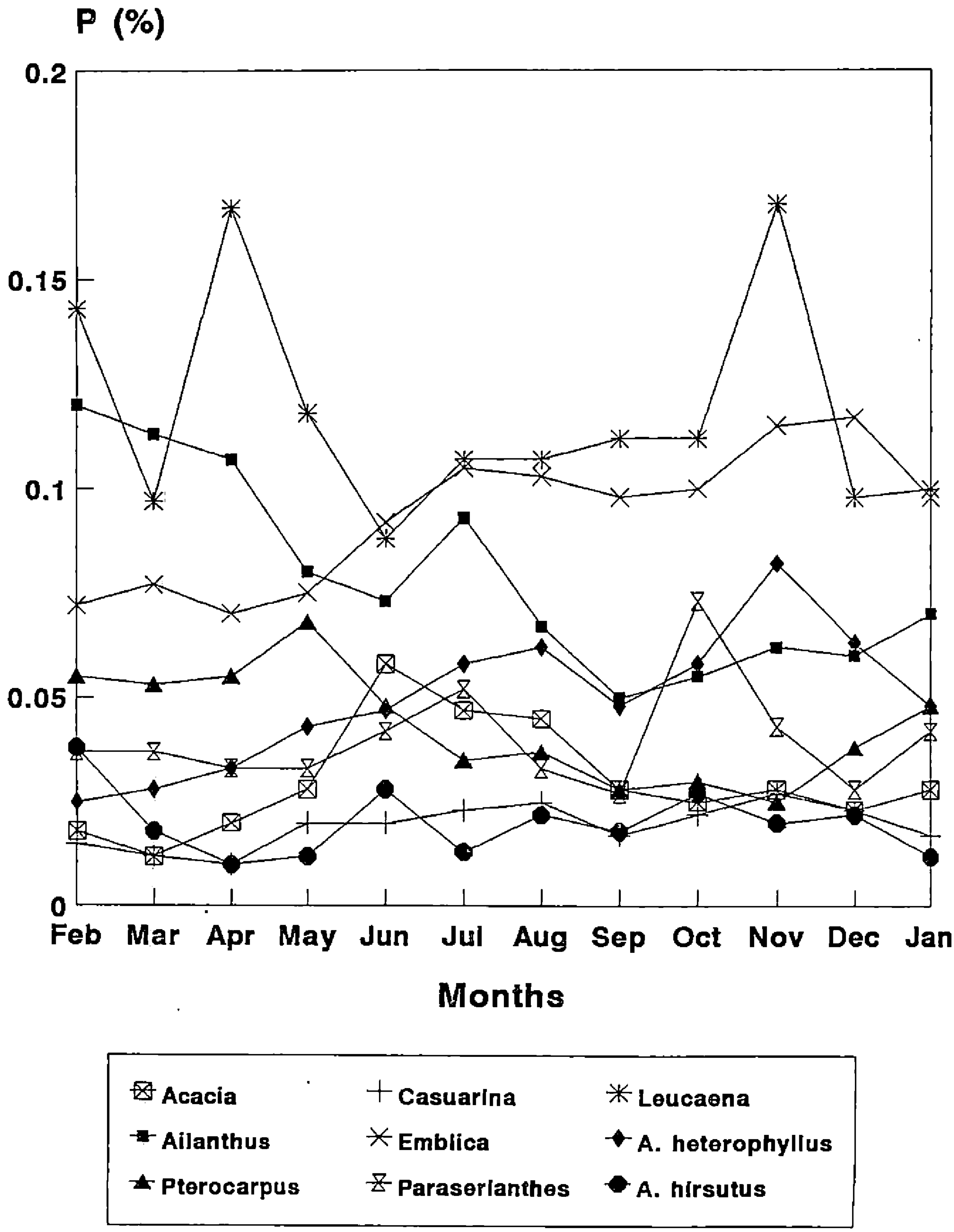


Fig.8 Seasonal variations in litter K concentration of nine MPT species

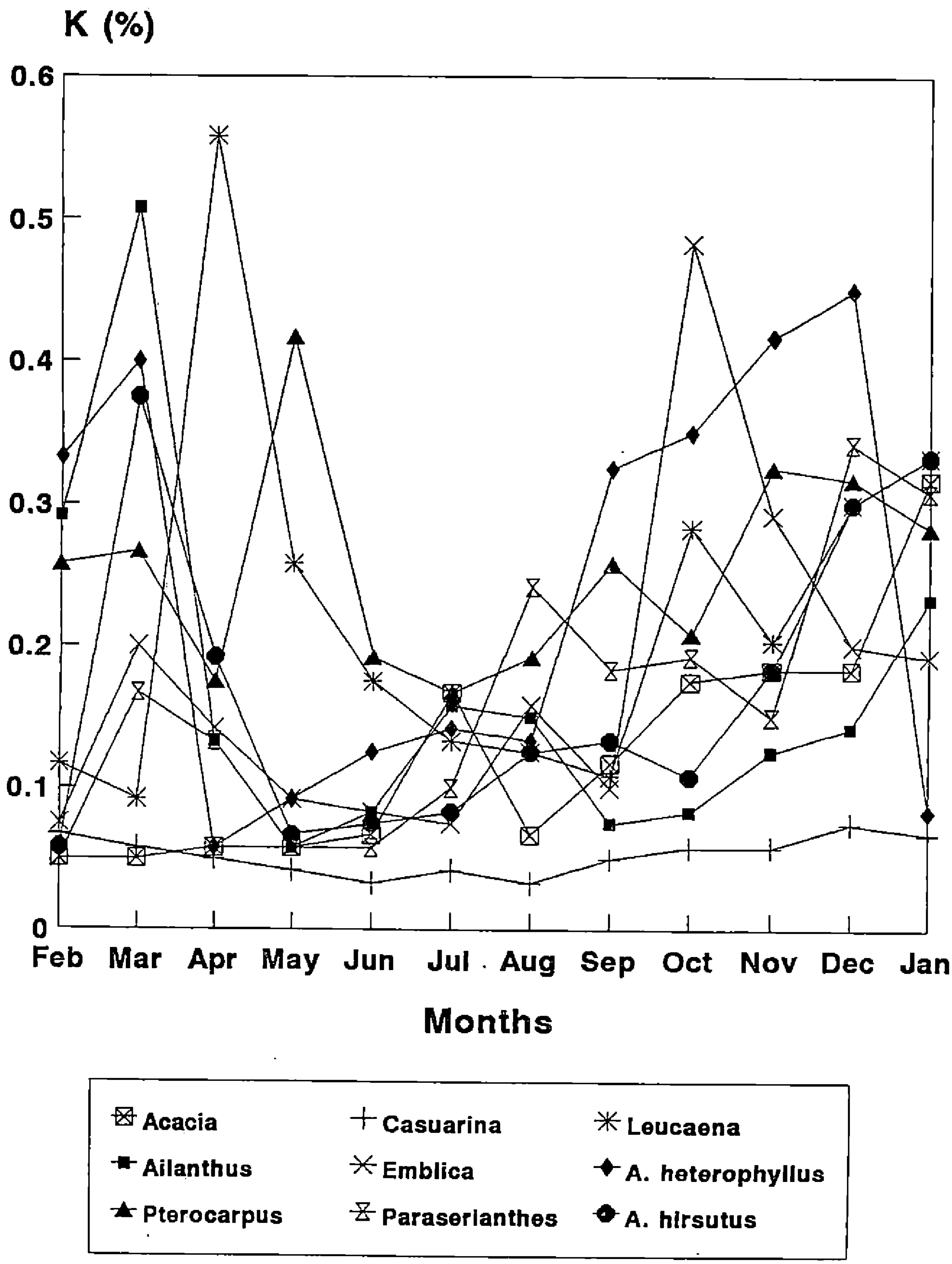


Table 17. Seasonal variation in litter (composite) phosphorus concentration (%) of nine multi-purpose tree species.

Months	Aca	Cas	Leu	Ail	Emb	Het	Pte	Par	Hir
Feb-93	0.018	0.015	0.143	0.120	0.072	0.025	0.055	0.037	0.038
Mar-93	0.012	0.012	0.097	0.113	0.077	0.028	0.053	0.037	0.018
Apr-93	0.020	0.010	0.167	0.107	0.070	0.033	0.055	0.033	0.010
May-93	0.028	0.020	0.118	0.080	0.075	0.043	0.068	0.033	0.012
Jun-93	0.058	0.020	0.088	0.073	0.092	0.047	0.048	0.042	0.028
Jul-93	0.047	0.023	0.107	0.093	0.105	0.058	0.035	0.052	0.013
Aug-93	0.045	0.025	0.107	0.067	0.103	0.062	0.037	0.033	0.022
Sep-93	0.028	0.017	0.112	0.050	0.098	0.048	0.028	0.027	0.018
Oct-93	0.025	0.022	0.112	0.055	0.100	0.058	0.030	0.073	0.027
Nov-93	0.028	0.027	0.168	0.062	0.115	0.082	0.025	0.043	0.020
Dec-93	0.023	0.023	0.098	0.060	0.117	0.063	0.038	0.028	0.022
Jan-94	0.028	0.017	0.100	0.070	0.098	0.048	0.048	0.042	0.012
Over all mean	0.030	0.019	0.118	0.079	0.093	0.050	0.043	0.040	0.020

	Species	Month	Speices X Month
P	<0.01	<0.01	<0.01
SEM (+)	0.0008	0.0009	0.0027
CD (0.05)	0.0023	0.0025	0.0075

Aca- *Acacia auriculiformis*, Cas- *Casuarina equisetifolia*, Leu- *Leucaena leucocephala*, Ail- *Ailanthus triphysa*, Emb- *Emblica officinalis* , Het- *Artocarpus heterophyllus*, Pte- *Pterocarpus marsupium*, Par- *Paraserianthus falcataria*, Hir- *Artocarpus hirsutus*

Table 18. Seasonal variation in litter (composite) potassium concentration (%) of nine multi-purpose tree species.

Months	Aca	Cas	Leu	Ail	Emb	Het	Pte	Par	Hir
Feb-93	0.050	0.067	0.117	0.292	0.075	0.333	0.258	0.050	0.058
Mar-93	0.050	0.058	0.092	0.508	0.200	0.400	0.267	0.167	0.375
Apr-93	0.058	0.050	0.558	0.133	0.142	0.058	1.175	0.133	0.192
May-93	0.058	0.042	0.258	0.058	0.092	0.092	0.417	0.058	0.067
Jun-93	0.067	0.033	0.175	0.083	0.083	0.125	0.192	0.058	0.075
Jul-93	0.167	0.042	0.133	0.158	0.075	0.142	0.167	0.100	0.083
Aug-93	0.067	0.033	0.125	0.150	0.158	0.133	0.192	0.242	0.125
Sep-93	0.117	0.050	0.108	0.075	0.100	0.325	0.258	0.183	0.133
Oct-93	0.175	0.058	0.283	0.083	0.483	0.350	0.208	0.192	0.108
Nov-93	0.183	0.058	0.203	0.125	0.292	0.417	0.325	0.150	0.183
Dec-93	0.183	0.075	0.300	0.142	0.200	0.450	0.317	0.342	0.300
Jan-94	0.317	0.067	0.333	0.233	0.192	0.083	0.283	0.308	0.333
Overall mean	0.124	0.053	0.224	0.170	0.174	0.242	0.338	0.163	0.169

	Species	Month	Speices X Month
P	<0.01	<0.01	<0.01
SEM (+)	0.0025	0.0029	0.0086
CD (0.05)	0.0069	0.0081	0.0239

Aca- *Acacia auriculiformis*, Cas- *Casuarina equisetifolia*, Leu- *Leucaena leucocephala*, Ail- *Ailanthus triphysa*, Emb- *Emblica officinalis* , Het- *Artocarpus heterophyllus*, Pte- *Pterocarpus marsupium*, Par- *Paraserianthus falcataria*, Hir- *Artocarpus hirsutus*

4.5 Litter decomposition

The mean mass loss of decomposing litter for nine multipurpose tree species are furnished in Table 19 and Fig. 9. Out of the nine species investigated, litter samples of only three species decomposed completely during the experimental period (i.e. 9, 10 and 11 months for Leucaena, Ailanthus and Paraserianthes respectively). By and large mass loss of litter followed -ve exponential pattern, regardless of species. The mass remained at the end of 12-month (% of initial mass) period was: Acacia - 9.1%, Casuarina - 14.9%, Emblica - 5.7%, A. heterophyllus - 1.4%, Pterocarpus - 1.5% and A. hirsutus - 1.6%. The highest decomposition rate was observed for Ailanthus and Leucaena and the least for Acacia and Casuarina (Table 20). Time taken to reach half of the initial quantity also varied from 2.2 (Ailanthus) to 4.2 months (Acacia).

The initial lignin content, initial nitrogen content and lignin to nitrogen ratio are given in Table 21. Initial lignin content was highest in A. hirsutus (31.4%) while Emblica (4.9%) had the least value. The lignin to nitrogen ratio was highest for A. hirsutus (18.2) closely followed by Casuarina (16.9). Emblica (2.1), Ailanthus (2.8) and Leucaena (5.1) recorded much lower values.

Fig.9 Relative proportion of biomass remaining in the litter bags at various time intervals for nine MPT species

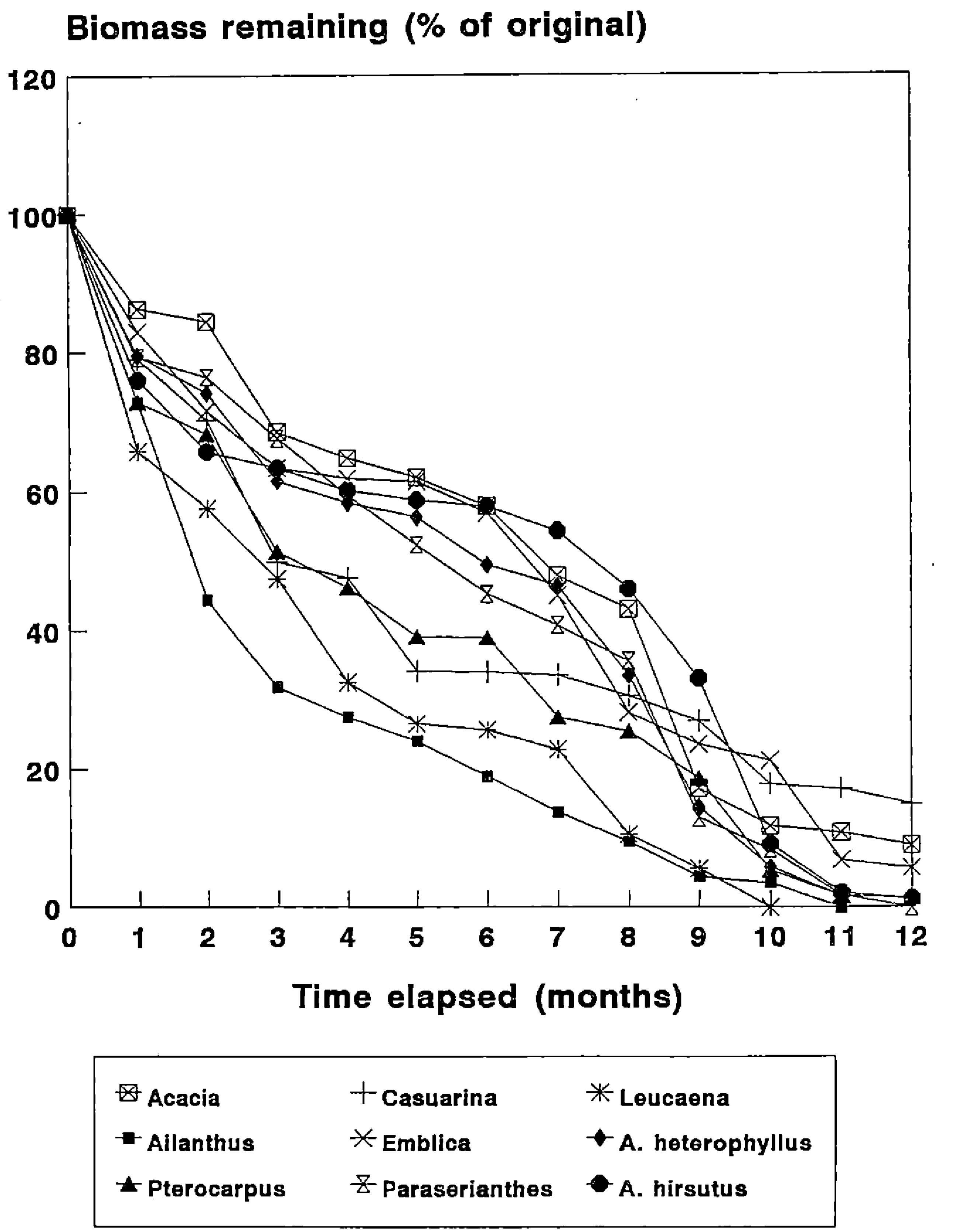


Table 19. Biomass and nutrients remaining in litter bags of nine fast growing multi-purpose tree species.

(1) Speices	(2) Time (Month)	(3) Litter mass remaining (g)	(4) Litter nutrient concentration			(5) Relative preportion of nutrient remaining			(6) Relative changes in the nutrient concentration of litter		
			N(%)	P(%)	K(%)	N(%)	P(%)	K(%)	N(%)	P(%)	K(%)
Acacia auriculiformis	0	17.76	2.473	0.072	0.708	100.000	100.000	100.000	100.000	100.000	100.000
	1	15.34	2.940	0.077	0.667	102.685	92.372	81.372	118.884	106.944	94.290
	2	15.01	2.823	0.073	0.192	96.478	85.690	29.290	114.153	101.389	27.119
	3	12.17	2.730	0.068	0.133	75.646	64.718	12.872	110.392	94.444	18.785
	4	11.51	2.683	0.062	0.108	70.313	55.808	9.886	108.492	86.111	15.254
	5	11.02	2.193	0.062	0.100	55.025	53.432	8.764	88.678	86.111	14.124
	6	10.29	2.077	0.058	0.133	48.661	46.673	10.884	83.987	80.556	18.785
	7	8.50	1.050	0.047	0.125	20.321	31.242	8.450	42.459	65.278	17.655
	8	7.65	0.980	0.053	0.108	17.068	31.704	6.570	39.628	73.611	15.254
	9	3.05	0.933	0.057	0.092	6.478	13.593	2.231	37.727	79.167	12.994
	10	2.09	0.887	0.055	0.075	4.222	8.991	1.247	35.867	76.387	10.593
	11	1.92	0.887	0.052	0.067	3.877	7.807	1.023	35.867	72.222	9.463
	12	1.60	0.770	0.048	0.058	3.366	7.207	0.886	31.136	66.667	8.192
Casuarina equisetifolia	0	18.21	1.587	0.063	0.383	100.000	100.000	100.000	100.000	100.000	100.000
	1	14.40	2.053	0.068	0.367	102.297	85.353	75.773	129.364	107.937	95.822
	2	12.79	1.843	0.062	0.242	81.565	69.121	44.378	116.131	98.413	63.185
	3	9.09	1.797	0.060	0.150	56.523	47.540	19.549	113.232	95.238	39.164
	4	8.67	1.517	0.067	0.142	45.510	50.633	17.652	95.389	106.349	37.076
	5	6.21	1.073	0.067	0.133	23.057	36.267	11.842	67.612	106.349	34.726
	6	6.20	1.027	0.052	0.125	22.032	28.102	11.111	64.713	82.540	32.637
	7	6.10	0.957	0.045	0.108	20.199	23.927	9.445	60.302	71.429	28.198
	8	5.55	0.933	0.048	0.092	17.919	23.223	7.322	58.790	76.190	24.021
	9	4.91	0.910	0.052	0.075	15.459	22.253	5.279	57.341	82.540	19.582
	10	3.24	0.910	0.048	0.067	10.201	13.554	3.112	57.341	76.190	17.493
	11	3.13	0.840	0.045	0.067	9.099	12.279	3.007	52.930	71.429	17.493
	12	2.72	0.817	0.040	0.050	7.691	9.486	1.950	51.481	63.492	13.055
Leucaena leucocephala	0	18.07	3.337	0.125	1.392	100.00	100.000	100.000	100.000	100.000	100.000
	1	11.89	4.130	0.127	1.367	81.436	66.852	64.618	123.764	101.600	98.204
	2	10.41	4.083	0.107	0.575	70.487	49.313	23.796	122.355	85.600	41.307
	3	8.58	3.943	0.098	0.192	56.104	37.225	6.547	118.160	78.400	13.793
	4	5.88	2.007	0.085	0.167	19.570	22.127	3.903	60.144	68.000	11.997
	5	4.81	0.980	0.055	0.150	7.817	11.712	2.868	29.368	44.000	10.776
	6	4.64	0.933	0.052	0.142	7.179	10.682	2.619	27.959	41.600	10.201
	7	4.13	0.770	0.043	0.133	5.274	7.862	2.182	23.075	34.400	9.555
	8	1.91	0.770	0.047	0.092	2.439	3.974	0.699	23.075	37.600	6.609
	9	1.01	0.747	0.047	0.067	1.251	2.102	0.269	22.385	37.600	4.813

Ailanthus triphysa	0	18.60	2.847	0.152	1.150	100.000	100.00	100.000	100.000	100.000	100.000
	1	13.54	3.803	0.157	1.092	97.240	75.190	69.124	133.579	103.289	94.957
	2	8.26	2.077	0.103	0.267	32.398	30.092	10.310	72.954	67.763	23.217
	3	5.92	1.937	0.097	0.183	21.654	20.311	5.064	68.037	63.816	15.913
	4	5.13	0.840	0.048	0.167	8.137	8.709	4.005	29.505	31.579	14.522
	5	4.48	0.583	0.042	0.150	4.932	6.655	3.141	20.478	27.632	13.043
	6	3.53	0.443	0.035	0.133	2.952	4.369	2.194	15.560	23.026	11.565
	7	2.56	0.303	0.035	0.100	1.464	3.169	1.196	10.643	23.026	8.696
	8	1.77	0.280	0.032	0.083	0.936	2.004	0.687	9.835	21.053	7.217
	9	0.83	0.233	0.028	0.067	0.365	0.822	0.260	8.184	18.421	5.826
	10	0.66	0.187	0.027	0.058	0.233	0.631	0.179	6.568	17.763	5.043
Emblica officinalis	0	18.18	2.357	0.125	0.800	100.000	100.000	100.000	100.000	100.000	100.000
	1	15.09	2.543	0.123	0.867	89.552	81.674	79.579	107.891	98.400	95.825
	2	13.02	2.450	0.118	0.642	74.043	67.606	57.472	103.946	94.400	80.250
	3	11.53	2.007	0.088	0.208	54.003	44.648	16.489	85.181	70.400	26.000
	4	11.26	1.797	0.073	0.117	47.220	36.170	8.835	76.241	58.400	14.265
	5	11.18	1.423	0.037	0.092	37.126	18.202	7.072	60.373	29.600	11.500
	6	10.35	1.307	0.063	0.083	31.569	28.693	5.906	55.452	50.400	10.375
	7	8.19	1.167	0.052	0.075	22.305	18.740	4.223	49.512	41.600	9.375
	8	5.12	1.097	0.057	0.067	13.106	12.841	2.358	46.542	45.600	8.375
	9	4.29	1.073	0.055	0.058	10.744	10.384	1.711	45.724	44.000	7.250
	10	3.86	1.050	0.052	0.050	9.458	8.832	1.327	44.548	41.600	6.250
	11	1.24	1.003	0.047	0.042	2.902	2.564	0.358	42.554	37.600	5.250
	12	1.04	0.933	0.045	0.025	2.264	2.059	0.179	39.584	36.000	3.125
Artocarpus heterophyllus	0	18.14	2.147	0.075	0.392	100.000	100.000	100.000	100.000	100.000	100.000
	1	14.91	2.567	0.070	0.350	95.125	74.155	71.037	119.562	93.333	89.286
	2	13.89	2.053	0.072	0.333	70.875	71.155	62.964	95.622	96.000	84.949
	3	11.54	1.913	0.073	0.192	54.868	59.93	30.161	89.101	97.333	48.980
	4	10.95	0.933	0.042	0.158	25.391	32.721	23.551	43.456	56.000	40.306
	5	10.56	0.677	0.033	0.142	17.768	24.794	20.412	31.532	44.000	36.224
	6	9.26	0.633	0.053	0.133	15.028	34.918	16.765	30.415	70.667	33.929
	7	8.71	0.583	0.055	0.125	12.620	34.082	14.817	27.154	73.333	31.888
	8	6.26	0.583	0.057	0.108	9.609	25.384	9.202	27.154	76.000	27.551
	9	2.72	0.537	0.058	0.083	3.629	11.221	3.072	25.012	77.333	21.551
	10	1.09	0.513	0.058	0.067	1.391	4.501	0.995	23.894	77.333	17.092
	11	0.31	0.467	0.057	0.033	0.359	1.254	0.139	21.751	76.000	8.418
	12	0.26	0.420	0.057	0.025	0.272	1.056	0.089	19.562	76.000	6.378
Pterocarpus marsupium	0	18.56	2.567	0.108	0.233	100.000	100.000	100.000	100.000	100.000	100.000
	1	13.52	2.847	0.107	0.183	80.790	72.170	57.213	110.908	99.074	78.541
	2	12.68	2.777	0.098	0.117	73.908	61.993	34.306	108.181	90.741	50.215
	3	9.54	2.217	0.058	0.110	44.392	27.604	22.060	86.365	53.704	42.918
	4	8.57	1.237	0.052	0.058	22.251	22.232	11.493	48.189	48.148	24.892
	5	7.25	0.887	0.018	0.050	13.419	6.510	8.382	34.354	16.667	21.459
	6	7.22	0.793	0.043	0.033	12.017	15.488	5.509	30.892	39.815	14.163
	7	5.10	0.747	0.035	0.033	7.996	8.904	3.891	29.100	32.407	14.163
	8	4.73	0.700	0.042	0.022	6.948	9.909	2.406	27.269	38.889	9.442
	9	3.46	0.653	0.048	0.017	4.742	8.284	1.360	25.438	44.444	7.296
	10	0.99	0.607	0.050	0.013	1.260	2.468	0.297	23.646	46.296	5.579
	11	0.32	0.560	0.053	0.013	0.375	0.844	0.096	21.815	49.074	5.579
	12	0.27	0.513	0.052	0.008	0.290	0.698	0.050	19.984	48.148	3.433

Paraserianthes falcataria	0	18.09	3.057	0.127	0.142	100.000	100.000	100.000	100.000	100.000	100.000
	1	14.35	3.477	0.115	0.108	90.224	71.830	60.332	113.739	90.739	76.056
	2	13.83	3.337	0.110	0.053	83.453	65.857	44.686	109.159	86.114	58.451
	3	12.24	3.080	0.087	0.067	68.170	46.351	31.924	100.752	68.504	47.183
	4	10.76	2.707	0.077	0.058	52.670	36.062	24.294	88.551	60.630	40.845
	5	9.47	2.053	6.057	0.050	35.156	23.495	18.432	67.157	44.882	35.211
	6	8.19	1.843	0.050	0.048	27.294	17.823	15.304	60.288	39.370	33.803
	7	7.37	1.027	0.042	0.046	13.686	13.473	13.198	33.595	33.071	32.394
	8	6.43	1.027	0.045	0.050	11.940	12.593	12.514	33.595	35.433	35.211
	9	2.34	0.957	0.048	0.050	4.051	4.891	4.556	31.305	37.795	35.211
	10	1.52	0.910	0.053	0.033	2.501	3.503	1.952	29.768	41.732	23.239
	11	0.33	0.863	0.053	0.025	0.514	0.760	0.320	28.320	41.732	17.606
Artocarpus hirsutus	0	18.54	1.727	0.123	0.150	100.000	100.000	100.000	100.000	100.000	100.000
	1	14.11	2.543	0.130	0.133	112.066	80.437	67.480	147.250	105.691	88.667
	2	12.19	2.217	0.088	0.042	84.405	47.040	18.410	128.373	71.545	28.000
	3	11.76	1.960	0.072	0.042	71.987	37.130	17.760	113.492	58.537	28.000
	4	11.15	1.890	0.062	0.033	65.816	30.314	13.230	109.438	50.407	22.000
	5	10.90	1.587	0.073	0.033	54.025	34.893	12.934	91.893	59.350	22.000
	6	10.74	1.470	0.065	0.025	49.308	30.613	9.655	85.119	52.846	16.667
	7	10.08	0.910	0.047	0.025	28.648	20.774	9.061	52.693	38.211	16.667
	8	8.52	0.863	0.048	0.025	22.96	17.932	7.658	49.971	39.024	16.667
	9	6.12	0.817	0.053	0.022	15.616	14.224	4.842	47.307	43.089	14.667
	10	1.69	0.793	0.048	0.017	4.188	3.559	1.034	45.918	39.024	11.333
	11	0.39	0.723	0.053	0.013	0.879	0.905	0.182	41.865	43.089	8.667
	12	0.29	0.677	0.057	0.008	0.486	0.575	0.066	39.201	46.341	5.333

	Residual mass			N%			P%			K %		
	Species	Month	Species X Month	Species	Month	Species X Month	Species	Month	Species X Month	Species	Month	Species X Month
P	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
SEM(±)	0.2436	0.2296	0.6889	0.0117	0.0111	0.0332	0.0007	0.0006	0.0019	0.0031	0.0029	0.0087
CD (0.05)	0.6752	0.6363	1.9092	0.0324	0.0308	0.0921	0.0020	0.0017	0.0052	0.0086	0.0072	0.0242

ANOVA was performed for residual biomass and its nutrient content at 7 month stage.

Table 20. Decay rate coefficient (k) and half life of decomposing litter for nine fast growing multi-purpose tree species

Species	k (per months)	R^2	S.E.E.	Half life (t 0.5) months	n
Acacia auriculiformis	0.1644	0.865	0.4674	4.2	93
Casuarina equisetifolia	0.1729	0.902	0.4155	4.0	95
Leucaena leucocephala	0.2935	0.897	0.5607	2.4	72
Ailanthus triphysa	0.3148	0.925	0.5214	2.2	73
Emblica officinalis	0.1799	0.892	0.4531	3.9	94
Artocarpus heterophyllus	0.2221	0.842	0.6567	3.1	86
Pterocarpus marsupium	0.2480	0.869	0.6535	2.8	86
Paraserianthes falcataria	0.2020	0.812	0.6129	3.4	81
Artocarpus hirsutus	0.2065	0.740	0.8455	3.4	88

Table 21. Initial lignin content, initial nitrogen content and lignin / nitrogen ratio for nine fast growing multi-purpose tree species.

Species	Initial lignin (%)	Initial N(%)	Lignin / Nitrogen ratio
Acacia auriculiformis	16.50	2.47	6.68
Casuarina equisetifolia	26.84	1.59	16.88
Leucaena leucocephala	17.00	3.34	5.09
Ailanthus triphysa	7.94	2.85	2.79
Emblica officinalis	4.97	2.36	2.11
Artocarpus heterophyllus	17.92	2.15	8.33
Pterocarpus marsupium	22.35	2.57	8.70
Paraserianthes falcataria	28.09	3.06	9.18
Artocarpus hirsutus	31.42	1.73	18.16

4.5.1 Nutrient dynamics of decomposing litter mass

Nitrogen concentration of the decomposing litter declined after an initial increase (Fig. 10). Initial concentration was highest for Leucaena (3.33%) and lowest for Casuarina (1.58%; Table 19 and Appendix XV). The per cent increase over the initial concentration after one month was 18.9% in Acacia, 29.4 % in Casuarina, 23. 8% in Leucaena, 33. 6% in Ailanthus, 7.9 % in Emblica, 19.6% in A. heterophyllus, 10.9% in Pterocarpus, 13.7% in Paraserianthes and 47.2% A. hirsutus. The relative proportion of N remaining was highest for Casuarina (7.69%) at the end of the one year period of decomposition.

Phosphorus concentration of the residual litter mass exhibited a modest initial increase and then declined in Acacia, Casuarina, Leucaena, Ailanthus and A. hirsutus (Fig. 11). Emblica, A. heterophyllus, Pterocarpus and Paraserianthes were however, characterised by a steady decline. Paraserianthes litter recorded the highest (0.13%) initial P content and Casuarina (0.06%) the least.

Potassium concentration of residual mass declined rapidly for all species. It followed a characteristic negative exponential relationship (Fig. 12). There was no pronounced species influence on this parameter. Highest initial concentration was for Leucaena (1.39%) and lowest for Paraserianthes (0.14%).

Fig. 10 Changes in N content of the residual litter mass over time for nine MPT species

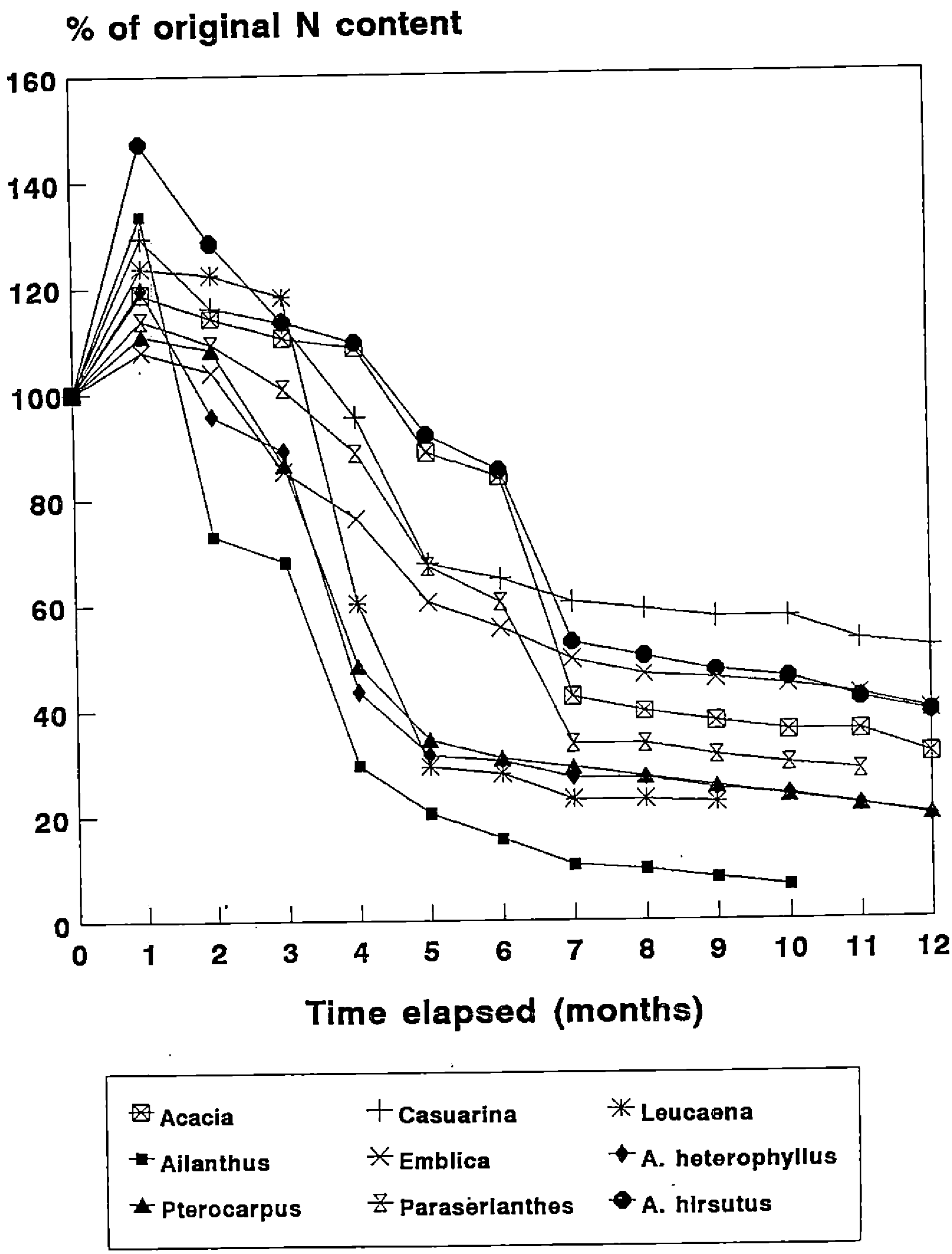


Fig.11 Changes in the P content of the residual litter mass over time for nine MPT species

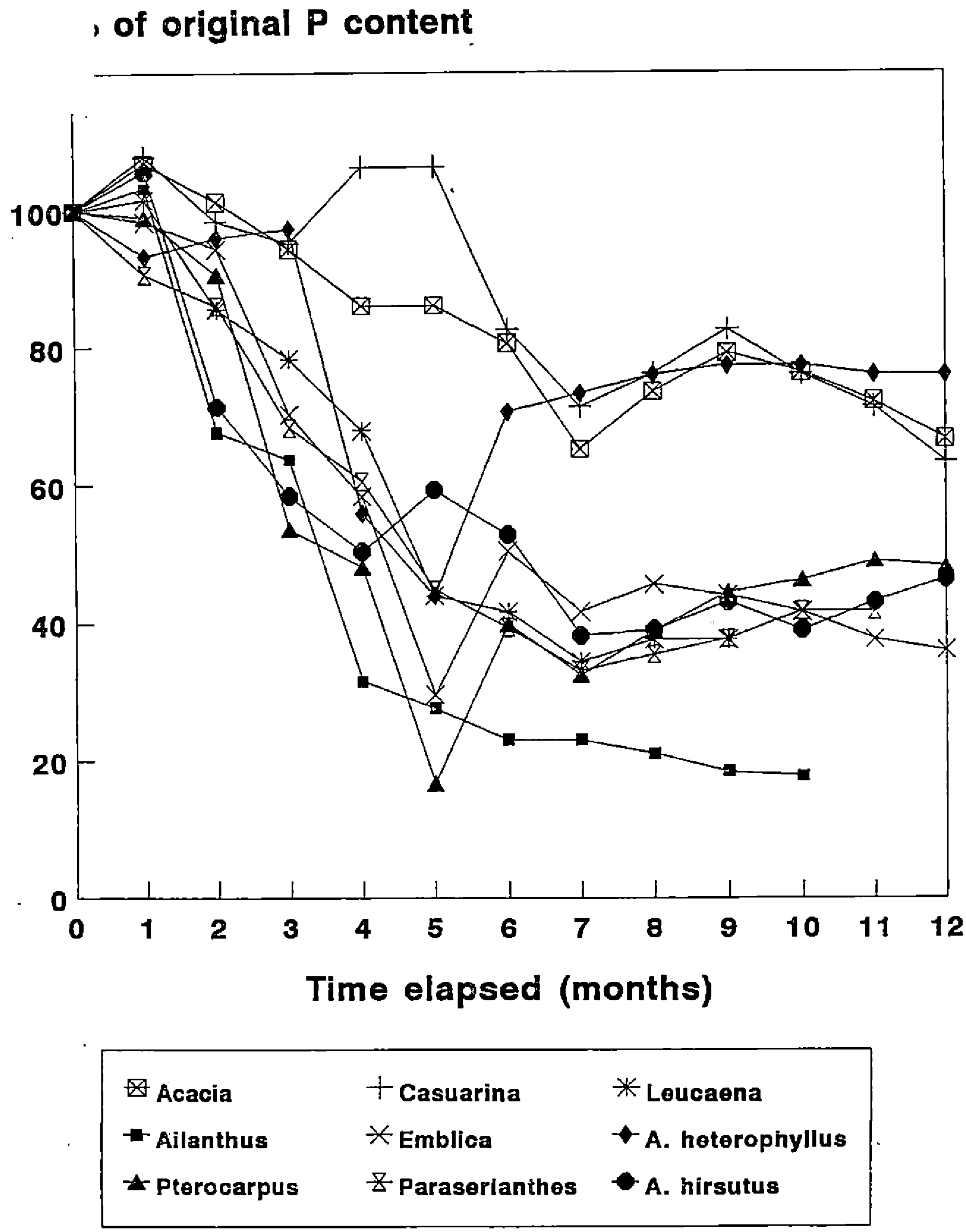
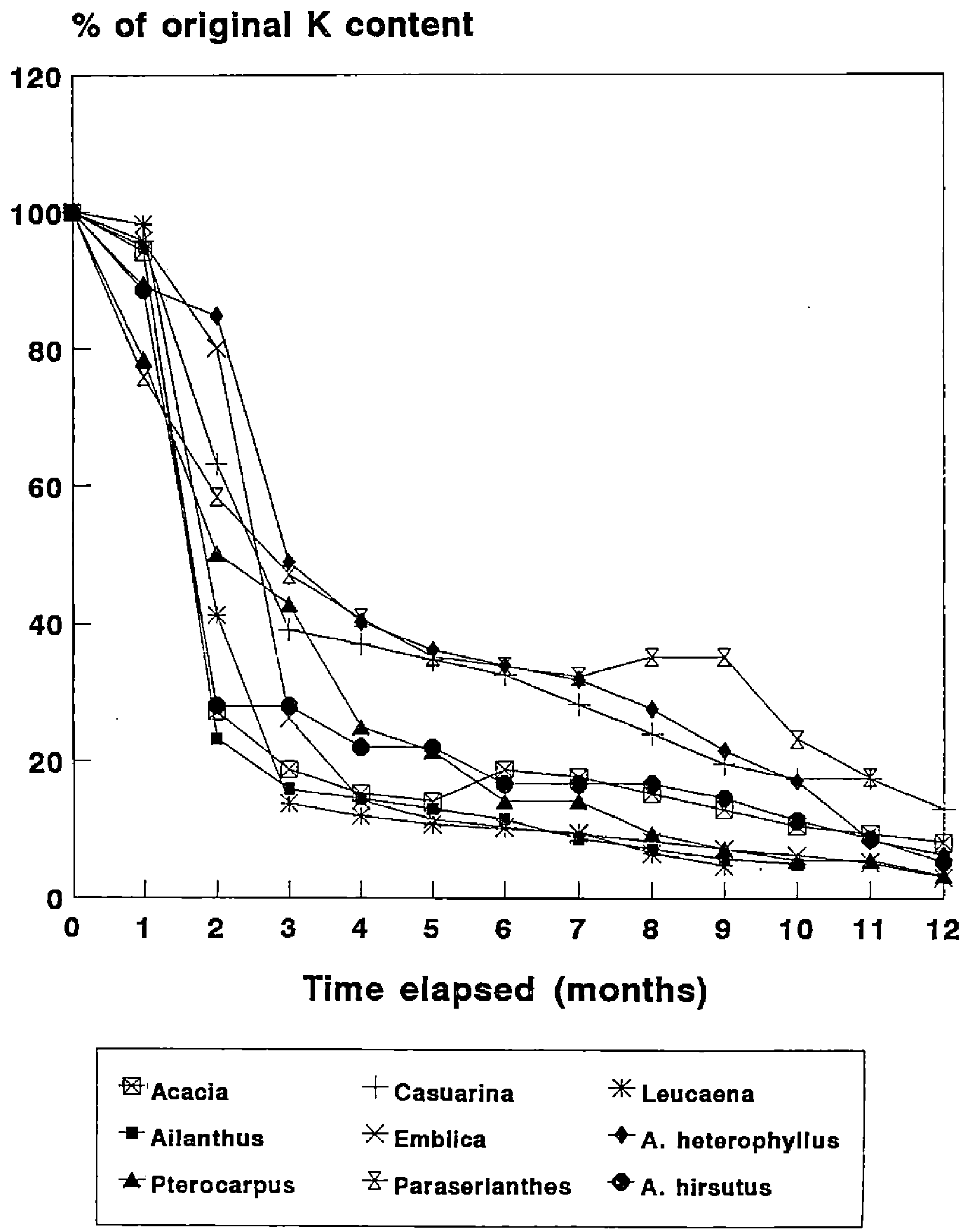


Fig.12 Changes in the K content of the residual litter mass over time for nine MPT species



4.6 Root distribution pattern

Length of tap root, maximum lateral spread and root dry weight of nine multipurpose tree species estimated following the direct excavation method are given in Table 22. Length of tap root ranged from 60.3 cm (Casuarina) to 153.3 cm (Emblica). However, this parameter did not show any statistically significant differences. Maximum lateral spread, however, was significantly different among the species (Appendix XVI). The highest lateral spread was recorded by A. heterophyllus (304.7 cm) closely followed by while Emblica (206.7 cm) and Paraserianthes (201.0 cm) while the lowest lateral spread was recorded for Ailanthus (76.0 cm). All the remaining five species studied were intermediate and statistically at par in this respect. The difference in mean root dry weight again was not statistically significant. It varied from 1.29 kg tree^{-1} (Leucaena) to 7.09 kg tree $^{-1}$ (Acacia).

4.6.1 Recovery of soil applied ^{32}P in the foliages of Artocarpus hirsutus as a function of lateral distance and depth of application.

The recovery of ^{32}P applied at different lateral distance was significant at 15 ($P<0.05$), 30 and 45 days ($P<0.01$) after application (Table 23A and Appendix XVII). In general, ^{32}P recovery declined as the lateral distances of application increased. Recovery of soil applied

Table 22. Root growth data of eight year old destructively sampled trees.

Species	Length of tap root (cm)	Maximum lateral spread (cm)	Root biomass (dry weight) (kg)
Acacia auriculiformis	106.0	136.7	7.09
Casuarina equisetifolia	60.3	96.7	2.24
Leucaena leucocephala	84.3	107.7	1.29
Ailanthus triphysa	115.3	76.0	2.96
Emblica officinalis	153.3	206.7	5.05
Artocarpus heterophyllus	120.0	304.7	4.05
Pterocarpus marsupium	95.3	121.7	2.92
Paraserianthes falcataria	101.3	201.0	5.51
Artocarpus hirsutus	90.0	173.3	4.46
P	NS	<0.01	NS
SEM (±)	20.174	36.960	1.720
CD (0.05)	--	109.801	--

Table 23A. Radioactivity recovered (log cpm g^{-1}) from the leaves of <u>Artocarpus hirsutus</u> grown under multi-purpose tree production system, as a function of lateral distances, depth and days after application of ^{32}P.

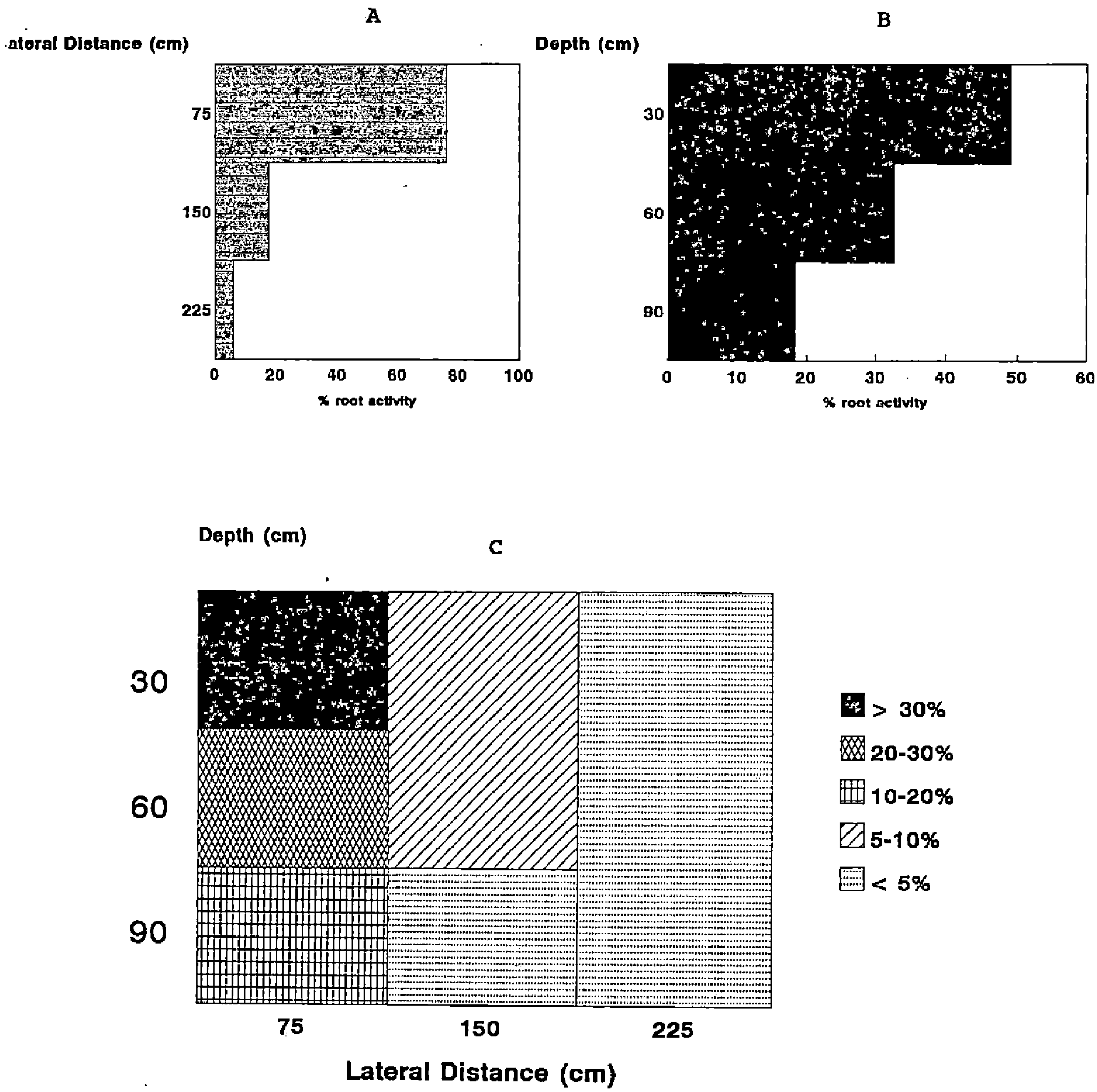
Days after application	15	30	45
Lateral distances (cm)			
75	1.400 (25.12)	1.959 (90.99)	1.994 (98.63)
150	0.942 (8.75)	1.180 (15.14)	1.336 (21.68)
225	0.684 (4.83)	0.645 (4.42)	0.640 (4.37)
P	<0.05	<0.01	<0.01
SEM (±)	0.1601	0.2419	0.1937
CD (0.05)	0.4799	0.7251	0.5806
Depth (cm)			
30	1.520 (33.11)	1.971 (93.54)	1.573 (37.41)
60	0.458 (2.87)	0.900 (7.94)	1.266 (18.45)
90	1.048 (11.17)	0.913 (8.18)	1.131 (13.52)
P	<0.01	<0.01	NS
SEM (±)	0.1601	0.2419	0.1937
CD (0.05)	0.4799	0.7251	--

Retransformed values given in parenthesis

Table 23B. Root activity (%) of *Artocarpus hirsutus* grown in multi-purpose tree production system as a function of lateral distance and/or depth at 45 days after application.

	Lateral distance (cm)			
	75	150	225	Total
Depth (cm)				
30	39.5	7.8	1.7	49.0
60	23.0	8.6	1.1	32.7
90	13.7	1.3	3.3	18.3
Total	76.2	17.7	6.1	

Fig 13. Root activity (%) of Artocarpus hirsutus as a function of lateral distance (A) and depth (B) (Combined effects in C), at 45 days after application of phosphorus-32



radiophosphorus was maximum at 75 cm lateral distance at 15 days after application. This was statistically superior to 150 cm and 225 cm treatments. Both at 30 and 45 days after application, a similar trend was discernible. At 45 days after application, the root activity percentage was 76.2%, 17.7% and 6.1% at 75, 150 and 225 cm respectively (Table 23 B and Fig. 13 A).

Recovery of ^{32}P at 30 cm depth was significantly higher than that of 60 cm and 90 cm treatments at 15 days and 30 days after application, while the recovery at 45 days after application as a function of soil depth was not significant. In general, recovery of applied ^{32}p declined as depth of application increased. The respective values of root activity percentages for 30, 60 and 90 cm depths were 49%, 32.7% and 18.3% (Fig. 13 B).

Fig. 13C depicts the root distribution pattern of <u>A. hirsutus</u> as a function of depth and lateral distance. The combination of lowest lateral distance (75cm) and depth (30cm) represented >30% root activity. The root activity per cent at lateral distance of 225cm, regardless of the depth treatments, was meagre (<5%).

Discussion

DISCUSSION

5.1. Biomass productivity and allometry of tree growth

The data on tree growth characteristics and dry matter production (Table 2 and 3; Fig. 2) revealed that *Acacia* was the top ranking species not only in respect of biomass yield but also in terms of height and radial growth. It recorded a Mean Annual Increment (MAI) of 43.02 Mg ha^{-1} $year^{-1}$ at eight years of age. The high biomass yield and growth rates of *Acacia* can be attributed to its wider adaptability, nitrogen fixing ability (Chundawat and Gautam, 1993), lower transpirational loss of water (Kallarackal and Soman, 1992) and the consequent lower probability of being subjected to an episode of water stress. This is of special significance in view of the monomodal rainfall distribution characteristic of the experimental site (Fig. 1). Besides *Acacia* also recorded the highest leaf area and foliar biomass compared to other species (Table 2) implying a higher potential for photosynthetic carbon fixation. Similar high growth rate and volume production of *Acacia* stands were reported by Mathew *et al*. (1992) and Osman *et al*. (1992). George (1993) also reported a significantly higher value for biomass production for *Acacia* compared to *Casuarina*, *Leucaena* and *Ailanthus* under the same ecoclimatic condition of the present study. The respective values were 182.82 Mg ha^{-1}, 32.61 Mg ha^{-1}, 81.91 Mg ha^{-1} and 26.57 Mg ha^{-1} at five years of age.

Furthermore, none of the species except _Acacia_, crossed the Leith's (1976) above ground net primary productivity (NPP) values for natural vegetation in the humid tropics with short dry period (23 Mg ha^{-1} yr^{-1} of dry matter). Lugo _et al_. (1988) suggested a range of 16 to 29.8 Mg ha^{-1} yr^{-1} of dry matter for above ground NPP for tropical trees. In the present study, _Acacia_ recorded an above ground NPP of 40.8 Mg ha^{-1} yr^{-1} of dry matter, which is substantially greater than the previously reported values. _Paraserianthes_, however, recorded a value very close (22.9 Mg ha^{-1} yr^{-1}) to Leith's (1976) reported values for above ground NPP. All other species have fallen well below this figure.

Allometric relationships attempted in the present study (Table 4) linking above ground tree biomass with DBH and/or total height gave reasonably good predictions and would help in estimating the biomass yield of a particular stand of tree. Previously Dudley and Fownes (1992) and George (1993) have also attempted developing such relationships for _Acacia_ and a few other speices. Nevertheless, this is the first attempt to develop allometric relationships for predicting biomass yields with respect to tree taxa such as _Emblica_, _Artocarpus heterophyllus_, _Pterocarpus_, _Paraserianthes_ and _Artocarpus hirsutus_.

5.2. Nutrient removal and nutrient use efficiency

Nutrient removal at harvest from the site is a function of both nutrient concentrations of the different tissue fractions and biomass yield. Nutrient concentrations were found to vary markedly among the species studied (Table 5-7). Although no consistant pattern of variation existed with respect, to taxa, mineral elements and tissue types, broadly foliage registered the highest N, P and K contents. Furthermore, N fixing leguminous trees had markedly higher foliar N levels. For instance, Leucaena had the highest foliar N concentration followed by Paraserianthes and Pterocarpus. Surprisingly Casuarina, an actinorhizal tree had the lowest foliar N concentration. Previously reported values (Wang et al., 1991) of N concentration for Leucaena (3.25%) and Casuarina (1.56%) was very close to that obtained in the present study (Table 5). With regard to foliar P concentration, a divergent pattern was discernible with Leucaena recording the lowest concentration and Casuarina recording the second lowest concentration. The two highest foliar P concentrations were for Pterocarpus and A. hirsutus.

Interestingly, foliar K concentrations followed more or less a similar pattern as that of foliar P. Leucaena and Casuarina had the lowest foliar K content and Pterocarpus and *A. hirsutus* with the two highest K levels (Table 7). Wang *et al*.(1991), however, reported 3-4 times higher foliar K in *Leucaena* over *Casuarina*.

Because of wide variations in elemental concentrations among species and also among tissue types, nutrient accumulation did not yield a one-to-one correspondence with biomass yield. *Acacia* had the highest N accumulation (1053 kg ha^{-1} ; Table 8) despite having relatively low levels of N in various tissue fractions. This may be due to the heavy above-ground biomass accumulation observed in this species. About 43% of total N, is also tied up in the bole fraction and another 27% in the branches. Therefore, during the harvesting operation, if the branches and bole alone are removed, leaving the foliage and other tissue fractions at the site itself, nutrient loss from the site could be substantially reduced. The relative proportion of N tied up in various tissue fractions however is substantially different among the species. For instance in *Paraserianthes*, more than 50% of N is tied up in the bole fraction. The diverse nutrient removal rates at harvest is attributed to differential nutrient concentrations among various types of harvested tissues (Tables 5-7) and the high variability in the relative abundance of tissue types (Table 3). *A. hirsutus* registered the highest P (Table 10) and K (Table 12) accumulation.

Nutrient accumulation and export from site has become an important consideration in the context of short rotation, high yield plantation systems where nutrients removed at frequent harvests may exceed the natural rates of nutrient input such as mineral weathering, atmospheric inputs and biological fixation. Heavy nutrient drain may have an adverse impact on the long term site quality and sustained production also (Wang et al. 1991). Small additional biomass yields are almost always accompanied by a many fold increase in nutrient removal. Hence a slight reduction in the tree parts that are removed from the site would definitely alter the rate of nutrient export from site. It points to the fact that the fast growing trees such as Acacia and Paraserianthes can result in marked loss of nutrients from the site especially when whole tree harvesting is resorted to. Moreover, the bole fractions did not account for more than 50% of total nutrient export except in the case of Paraserianthes.

Sustainable production without adversely affecting the site quality is perhaps a key consideration in all Short Rotation Intensive Cultural (SRIC) systems. Such systems are however, characterised by frequent removal of parts in the form of pruning, lopping etc. or whole tree harvest which, in turn, may have the potential of high nutrient depletion (Wang et al., 1991). Repeated biomass harvest can also lead to high rates of nutrient export from the site in

SRIC system. In this context, nutrient use efficiency provides a good measure to evaluate large differences in nutrient 'costs' of biomass production. Species selection that take in to consideration of nutrient use efficiency, therefore, is a potential tool available to the agroforester to alter the 'nutrient costs' associated with SRIC system. Within a species, a further alteration in nutrient rates at harvest can be achieved by adjusting the types of tissues removed from site.

No clear pattern of N accumulation by leguminos and non leguminous trees was observed in the present study. But the N use for leguminous foliage was clearly higher than that required for non leguminous foliage production (Table 11). According to Wang et al. (1991) such a comparison among species for nitrogen use efficiency may not be completely meaningful as symbiotic nitrogen fixing might have involved in deciding the N to biomass ratio.

Variations in nutrient use efficiency also did not follow the same pattern for all nutrients. *Casuarina* was the most efficient for N (2.56 g kg^{-1}) and *Ailanthus* the least efficient (6.22 g N kg^{-1}). The most efficient species for P and K were *Paraserianthes* and *Casuarina* respectively while *A. hirsutus* was the least efficient for both these nutrients. Since the amount of symbiotically fixed nitrogen and soil nitrogen pool was not partitioned, it is difficult to make species selection solely based on nitrogen use efficiency. However, if P and K use efficiency used as the criteria; Acacia, Casuarina and Paraserianthes are better options. Even with a higher efficiency for all major nutrients, Casuarina ranked only next to Acacia and Paraserianthes in terms of biomass production, which may have a limitation in the context of overall productivity. But Casuarina offer high potential for reducing N depletion through biomass removal.

5.3 Soil properties under multipurpose tree production system

Micro-site enrichment through improvement in the soil organic matter and mineral nutrient pool forms an important attribute of woody perennials in agroforestry and other tree based farming systems (Mac Dicken and Vergara, 1990; Kumar, 1994). Trees in managed land use system are capable of bringing about favourable changes in the soil physico-chemical properties. Although fast growing trees in general tend to remove large quantities of nutrients at harvest, all woody perennials by and large, tend to enrich the soil during the long years of occupancy through various processes of natural cycling, nutrient pumping and so on (Nair, 1983). In the present study also, marked variations in the soil chemical properties have been noticed between the plots under different tree species (Table 14).

Although the observed variations in soil pH were not significant, there was an overall trend of soil pH values approaching neutrality in all stands. This becomes explicit when the presently reported values are viewed in conjunction with previously reported values for Thiruvazhamkunnu soil (pH 5.1; George, 1993)

The soil organic matter status was significantly high in Leucaena and Acacia plots. Variations among species in the organic matter status can be attributed to the changes in rates of litterfall (Table 15), litter decay (Table 19) and variations in litter nutrient contents (Table 16-18). The comparatively higher N status of N - fixing tree plots (Table 14) may probably due to release of fixed N in to rhizosphere (Huxley, 1985). Casuarina, Emblica and Pterocarpus plots were having significantly higher P. Strangely enough, Leucaena plots had the lowest soil P. Soil K was almost uniform and was statistically at par for most of the species except a markedly higher level in Acacia, Paraserianthes and A. hirsutus plots.

5.4 Nutrient recycling in multipurpose tree production system

Nutrients absorbed by the tree roots are returned to the soil surface through th litter route. Furthermore, the decomposing litter release the nutrients at a rather slow rate and functions like a "slow release fertilizer material". Thus litter fall and its subsequent decay are the basic mechanisms involved in regulating the nutrient losses from th site and thus maintaining the sustainability of land by conserving nutrients on site.

5.4.1 Litter fall

Litter plays an important role in the cycling of nutrients and in the transfer of energy between plants and soil, functioning as the substrate for nutrient cycling in the upper most layers of the soil profile. Litterfall in the eight year old stands of nine multipurpose trees exhibited marked seasonal variations (Fig. 5). In the present study, the amount of detritus produced ranged from 3.42 Mg ha^{-1} yr^{-1} (Pterocarpus) to 12.69 Mg ha^{-1} yr^{-1} (Acacia). For acacia, this was close to the earlier reported value (12.93 Mg ha^{-1} yr^{-1}; Kunhamu, 1991). However, rates of detritus fall for all species studied except Acacia, was less than that obtained for moist deciduous forests of Thrissur (12.18 to 14.43 Mg ha^{-1} yr^{-1}; Kumar and Deepu, 1992). This may be due to lower age, stocking level and difference in species composition.

In general, litterfall followed a unimodal distribution pattern with a distinct peak during November to January period and the period of lean fall was during May to August. Such variations have been reported by many workers

(Kumar and Deepu, 1992; Kunhamu, 1991 and George, 1993). One of the direct effects of dry season to trees is the water stress, when the moisture availability is limited, besides the temperature also shoots up. Thus the periodicity of litterfall, in general, could be viewed as an effect of tree water stress.

Foliage constituted the main component of litterfall in all species (Appendix I). Similar results were reported by Kumar and Deepu (1992).

5.4.1.1 Seasonal variability in litter nutrient concentration.

Litter concentration of mineral elements was substantially lower than that of the fresh foliage. The lower nutrient content of the foliage fraction of litter, in comparison to fresh foliage, can be explained by the retranslocation of mineral nutrients from aging foliage to younger leaves and/or other tissues prior to abscission (Jorgensen and Wells, 1986; Helmisaari, 1992).

Based on the N content of the litter (Fig. 6) the nine species studied could be broadly divided into two classes: High (>1.5%) and low (<1.5%) detrital N content species. Leucaena, Paraserianthes, Pterocarpus, Acacia, Ailanthus and Emblica forming examples of the first category. With the exception of Emblica and Ailanthus all the high N containing species were members of the family leguminosae.

Examples of the low N containing species included Casuarina, A. heterophyllus and A. hirsutus. Although such differences are visible round the year, generally they have become amplified during the wet period, July-December.

As regards to litter P, it did not follow a consistent pattern in the present study (Fig. 7). Khiewtam and Ramakrishnan (1993) however, reported uniformly low values for N, P and K for litter samples during the wet season. The relatively low N status of litter during the dry season can be explained based on the seasonal variation in retranslocation efficiency. The retranslocation mechanism is more efficient during the summer, possibly because of water stress induced nutrient deficiencies which tend to reduce the nutrient losses from the plant system. On the contrary, when soil moisture availability is adequate and temperature regimes are favourable (two main factors influencing nutrient release from litter decomposition, and the size of the soil nutrient pool), the efficiency of internal nutrient cycling is generally retarded. Sharma and Pande (1989) also reported that retranslocation of nutrients is more efficient during the dry months.

Contrary to nitrogen and phosphorus, potassium concentration of the litter were generally low (Fig. 8) during the rainy season (June-August) which may be due to the increased leaching of this element though stem flow and throughfall. Das and Ramakrishnan (1985) also observed increased surface wash from intact foliage and that loss of K from litter collected in traps was higher during rainy season. Litter dynamics accounted for bulk of the nutrient inputs to the system (Table 24).

5.4.2. Litter decay

Litter decomposition is the primary mechanism of nutrient recharge in natural ecosystem. It plays a vital role in maintaining the soil fertility. In intensive cultural systems like multipurpose tree production system and other agroforestry systems where sustainability is a major consideration, nutrient cycling is of paramount importance. The rate and pathways of litter decomposition is primarily depended on the biochemical quality of the substrate, prevailing temperature, moisture availability and the quantitative and qualitative composition of the decomposer community.

Chemical composition is an intrinsic property of the litter that decides its turnover rates. Species with higher initial N status generally has a faster rate of decomposition (Singh and Gupta, 1977 and Meentemeyer, 1978) and may exhibit low N immobilisation rates. In the present study also, time taken for the complete disappearance of decomposing mass was found to be related with initial N content. The time taken for complete disappearance of

Table 24. Nutrient accretion (N, P and K) to the soil through litterfall.

Species	N	P	K
		(kg ha^{-1} yr^{-1})	
Acacia auriculiformis	203.0	3.8	15.7
Casuarina equisetifolia	61.4	1.2	3.4
Leucaena leucocephala	120.2	6.0	11.4
Ailanthus triphysa	72.2	3.6	7.8
Emblica officinalis	80.3	4.8	9.0
Artocarpus heterophyllus	59.1	3.1	15.0
Pterocarpus marsupium	59.2	1.5	11.6
Paraserianthes falcataria	178.3	3.7	15.1
Artocarpus hirsutus	37.7	0.8	6.6

the original litter mass ranged from nine months to 12 months or more. Leucaena with the highest initial N content decomposed completely in the shortest period (Fig. 9 and Table 22). In this context, Constantinides and Fownes (1994) suggested that initial N as the best determinant of the N dynamics of litter. Initial lignin or initial lignin/nitrogen ratio (as sugested by Melillo, 1982) could not be directly related to decay rate coefficient in the present study. Several workers have failed to find a strong dependence on either lignin or lignin/ nitrogen ratio on decay rate coefficients (Stohlgren, 1988; Kumar and Deepu, 1992 and George, 1993).

The time course of the mass disappearance of litter indicates that weight loss of litter was highest during the summer season suggesting a favourable effect of temperature. William and Gray (1974) also suggested the favourable effect of temperature, relative humidity and soil moisture availability on litter decay rates. Witkamp and Van Der Drift (1961) and Singh and Gupta (1977) also reported that both rainfall and temperature are strong determinants of decay rates. In addition, nutrient inputs through stemflow and throughfall during the wet season also may favour the decomposer community (Young, 1991). The slow decay rate towards the later stages may be explained by chances of quick loss of simpler components and the accumulation of more recalcitrant compounds in the residual litter mass.

5.4.2.1 Nutrient dynamics of decomposing litter

During the course of decomposition, N followed a triphasic pattern of release. N concentration in the residual mass increased initially followed by a rapid decline and finally reached a slow decline phase (Table 19; Fig. 10). Similar observations were made by Bockheim et al. (1991) and George (1993).

Phosphorus concentration also showed a slight initial accumulation followed by a final release phase in Acacia, Casuarina, Leucaena, Ailanthus and A. hirsutus (Fig. 11). In other species studied, a rather slow decrease in P concentration was discernible. Phosphorus is seen to be readily immoblised (Bockheim et al, 1991).

Potassium is not structurally bound like N or P. Potassium being a monovalent ion is weakly bound and is highly water soluble (Bocock, 1963 and Gosz et al., 1973). The leaching process is an important mechanism of K loss. This would explain the decline of the K levels in residual litter mass as decomposition advanced (Fig. 12).

5.5 Root distribution pattern

Rooting pattern of different tree taxa were found to (Table 22) vary considerably. One of the most important factors that decides the development of roots is the genetic factors. Length of tap root ranged from 60.3 cm (*Casuarina*) to 153. 3 cm (*Emblica*). Lateral spread ranged from 76.0 cm (*Ailanthus*) to 304.7 cm (*A. heterophyllus*).

Below ground competition for moisture and nutrients and space is relatively more important in agroforestry systems. The roots of most of the agricultural crops are limited to the upper 50 cm of the surface layer. Ideally agroforestry trees shall have deep root systems. The data on root distribution indicate that *A. heterophyllus*, *Emblica* and *Paraserianthes* are unsuitable for intensive mixing and close planting in agroforestry as they posses shallow and spreading root system. *Ailanthus*, however recorded the lowest lateral spread and at the same time possessing a deeper tap root in the excavation studies. Hence it may be suggested as one of the most preferred tree species for the intensive mixing in agroforestry.

Excavation method however, does not take in to account the physiologically active fine roots, which are generally recognised as the organs responsible for absorption of water and nutrients. Besides, this method also requires a very high input in time and labour. Nonetheless, most of the root studies reported in the literature (Singh et al., 1989 and Dhyani et al., 1990) concerning agroforestry systems are based on the excavation method. Methods involving radioactive isotopes have gained significance in ecological root research considering the limitations of excavation approach. ^{32}P is the most commonly used isotope for plant root studies (IAEA, 1976). It has half life of 14.2 days. It is mobile enough in plants to become rather uniformly distributed throughout the root system in a short time and is relatively less expensive.

5.5.1 Root activity studies of *Artocarpus hirsutus* using ^{32}P

Artocarpus hirsutus is an important component of the home gardens of Kerala (Kumar et al., 1994). It is generally grown as a scattered tree on farm lands or as a boarder tree, often in association with various field and other tree crops. However, no research data are available characterising the competitive influence of this species. Hence an attempt was made to characterise the root activity pattern of stand-grown trees of this species using ^{32}P.

The data furnished in Table 23A conclusively suggest that ^{32}P activity by the trees was markedly higher when applied at 75 cm lateral distance than at 150 cm and 225 cm. This was true at all the three periods of sampling i.e. 15, 30 and 45 days after application. This pronounced decline in root activity as a function of increasing distances from the base of the tree trunk clearly points to the fact that the active roots responsible for water and nutrient uptake are concentrated more towards the base of the tree than away from it. It is interesting to note that > 75 per cent of the root activity was in the 75 cm lateral distance (Fig.13A). A similar trend in root activity, with regard to the lateral distance from the tree, was reported in cocoa (Wahid et al., 1989a) and Casuarina (George, 1993), although Wahid et al., (1989b) and George, (1993) did not observe any significant decrease in root activity with lateral distance for cashew and Leucaena respectively.

As regards the vertcal spread of the roots, significant differences were observed. Root activity was significantly high at 30 cm depth (Table 23 A). A higher root activity at the surface soil layer compared to lower depths was reported by Wahid et al. (1989b) and George (1994). However, a higher recovery of ^{32}P occured at 90 cm than at 60 cm depth at 15 days after application. Moreover, at 30 days after application recovery of ^{32}P from both these treatments (60 cm and 90 cm) were statistically at par suggesting the occurrence of a rather uniform distribution of active roots in this region.

The pronounced decline in root activity with increasing lateral distance and soil depth observed (Fig. 13C) in the present study corroborates the observations of Jonsson et *al*. (1988) who studied the fine root dynamics of five Tanzanian tree species, root architecture analysis of 12 trees in North Indian species by Toky and Bisht (1992) and studies using ^{32}P by Wahid *et al*. (1989 a).

Stratification of the root system of different species is a fairly desirable feature of any agroforestry system (Payne, 1985). Together with minimising the competitive effect, the trees would act as a trap for nutrients that leached out from the reach of non woody crops (Johnson *et al*., 1988).

Summary and Conclusions

SUMMARY AND CONCLUSIONS

The term agroforestry includes a wide range of traditional land use systems which integrate woody perennials, herbaceous crops and/or livestock on the same land management unit. Multipurpose tree production is an important agroforestry activity that aims at the production of timber and other tree products. The term multipurpose trees (MPTs) refers to all woody perennials that are deliberately grown so as to make more than one significant contributions to the production and/or service functions of land use systems. As they are capable of meeting the felt needs of the society in terms of fuel wood, fodder and timber from outside the natural forests, they also have the potential to ease the severe anthropogenic pressure on natural forests. MPTs have been an integral component of many traditional farming systems. The woody perennial components require care right from the selection of species and its subsequent management. Information on various attributes of such trees, except some growth data, are lacking. In this context, a randomised block design experiment involving nine fast growing multipurpose tree species (*Acacia auriculiformis* A. Cunn. ex. Benth, *Casuarina equisetifolia* J.R. & G. Forst., *Leucaena leucocephala*. (Lamk.) de Wit. var. K-8, *Ailanthus triphysa* (Dennst.) Alston, *Emblica officinalis* Gaertn., Artocarpus heterophyllus Lamk., Pterocarpus marsupium Roxb., Paraserianthes falcataria (L.) Neilson and Artocarpus hirsutus Lamk.) was initiated during June, 1985 at the Livestock Research Station, Thiruvazhamkunnu with the objectives of quantifying the relative productivity of these trees, besides, elucidating the nutrient export from short rotation intensive cultural systems involving these taxa and also characterising the root distribution pattern of important MPTs.

The Salient results are summarised below:

1. Acacia auriculiformis was the top ranking species in respect of biomass yield. It also recorded the highest leaf area. Biomass of remaining species decreased in the order: Paraserianthes > Casuarina > A. heterophyllus > Emblica > Pterocarpus > A. hirsutus > Ailanthus > Leucaena. Acacia had a net primary production of 43.02 Mg ha^{-1} yr^{-1} of dry matter and was clearly greater than most reported values. Acacia and Paraserianthes were superior to rest of species in respect of total height and diameter at breast height.

2. Allometric relationships attempted linking above ground tree biomass with DBH and/or total height gave reasonably good fit and would help in predicting biomass yield.

3. Relative allocation of various fractions to total biomass varied markedly among the species. Clearly, the most important component in respect of total biomass accumulation for all species was the bole while foliage had the least biomass yield.

4. The nutrient concentration of various biomass components also varied. In general, foliage registered the highest N, P and K contents. Furthermore, leguminous trees had markedly higher foliar N levels. For instance, Leucaena had the highest foliar N concentration followed by Paraserianthes and Pterocarpus. Regarding foliar P and K concentrations, Leucaena and Casuarina recorded the lowest content while Pterocarpus and A. hirsutus were the toppers in respect of both these nutrients. A one-to-one correspondence between nutrient accumulation and biomass yield was, however, lacking because of wide variations in elemental concentrations among species and also amnong tissue types.

5. Regarding nutrient export from site, a slight reduction in the tree parts that are removed from the site would definitely alter the rate of nutrient export. Bole fractions, in general, did not account for more than 50 % of total nutrient export. Hence

returning leaves and small twigs to the site at the time of harvest may be a worthwhile option in this respect.

6. Large differences in whole-tree nutrient use efficiency were seen among the nine multipurpose tree species. For N, Casuarina was the most efficient and Ailanthus the least. The most efficient species for P and K were Paraserianthes and Casuarina respectively while A. hirsutus was the least efficient for both these nutrients. Casuarina offer high potentail for reducing N depletion through biomass harvest.

7. As regards to soil nutrient levels, nitrogen fixing trees generally had a higher N status. Casuarina, Emblica and Pterocarpus plots were having significantly higher P. Soil potassium levels were more or less uniform but for Acacia, Parasrianthes and A. hirsutus plots, which registered markedly higher levels.

8. The amount of litterfall ranged from 3.42 Mg ha^{-1} yr^{-1} (Pterocarpus) to 12.69 Mg ha^{-1} yr^{-1} (Acacia). Litterfall also exhibited marked seasonal variations. It followed a unimodal distribution pattern with a distinct peak during the November to January period and the period of lean fall was during May to August.

9. The lower nutrient content of litter in comparison to fresh foliage highlights the retranslocation of mineral nutrients from senescing leaves to younger leaves and/or other tissues prior to abscission.

10. Based on the N content of litter, the nine species studied could be broadly grouped into two classes: High (>1.5%) and low (<1.5%) detrital N content species. Leucaena, Paraserianthes, Pterocarpus, Acacia, Ailanthus and Emblica forming examples of the first category. With the exception of Emblica and Ailanthus all the high N containing species were legumes. Low N containing species included Casuarina, A. heterophyllus and A. hirsutus.

11. Seasonal changes in the macronutrient status of litter was obvious. The wet period (June - August) was characterised by increased concentration of N in litter for most of the species. Litter P did not follow a consistent pattern with respect to seasonality. However, K concentration of litter was generally low during the rainy season.

12. Decomposition studies indicated that mass disappearance of litter samples followed a negative exponential relationship. Regarding interspecific variations, high N species such as Leucaena,

Ailanthus and Paraserianthes were quick decomposers while Acacia, despite being a high N species, and Casuarina were slow decomposers.

13. Time taken for complete disappearance of decomposing mass was found to be generally related to the initial N content. Leucaena with the highest initial N content decomposed completely in the shortest period.

14. Litter dynamics accounted for bulk of the nutrient inputs to the system. The nitrogen accretion to the soil through litterfall ranged from 59.1 kg ha^{-1} yr^{-1} (A. heterophyllus) to 203.0 kg ha^{-1} yr^{-1} (Acacia); phosphorus values ranged between 0.8 kg ha^{-1} yr^{-1} (A. hirsutus) to 6.0 kg ha^{-1} yr^{-1} (Leucaena) and potassium accretion ranged from 3.4 kg ha^{-1} yr^{-1} (Casuarina) to 15.7 kg ha^{-1} yr^{-1} (Acaica).

15. Marked interspecific variations existed with regard to maximum lateral spread of roots. A. heterophyllus, Emblica and Paraserianthes are perhaps unsuitable for intensive mixing and close planting in agroforestry as they posses shallow and highly spreading root system. On the other hand, Ailanthus is a better candidate tree for Agroforestry as it possesses relatively lower lateral spread and at the same time having a deep tap root system.

16. The recovery pattern of ^{32}P in <u>Artocarpus hirsutus</u> indicated that > 75% of fine roots responsible for water and nutrient absorption are concentrated in the 75 cm radius around the base of the tree. Recovery of applied ^{32}P declined as depth of application increased. At all stages of sampling, 30 cm depth treatment recorded maximum root activity. The combination of lowest lateral distance (75 cm) and depth (30 cm) accounted for > 30% of the root activity. The root activity per cent at the farthest point of application (lateral distance: 225 cm) at all three depth treatments was only modest (< 5%).

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BIOMASS PRODUCTION AND ROOT DISTRIBUTION PATTERN OF SELECTED FAST GROWING MULTI-PURPOSE TREE SPECIES

By

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ABSTRACT OF A THESIS

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ABSTRACT

A randomized block design experiment involving nine fast growing multi-purpose trees (Acacia auriculiformis A. Cunn. ex Benth., Casuarina equisetifolia J.R. & G Forst., Leucaena leucocephala (Lamk.) de Wit. var. K 8, Ailanthus triphysa (Dennst.) Alston, Emblica officinalis Gaertn, Artocarpus heterophyllus Lamk., Pterocarpus marsupium Roxb., Paraserianthes falcataria (L.) Neilson and Artocarpus hirsutus Lamk.) initiated during June, 1985 was used for the present investigations. The objectives of the study included quantifying the biomass production potential of nine selected fast growing multi-purpose tree species grown under short rotation intensive cultural systems; characterisisng the root distribution pattern of these trees and also elucidating the extent of nutrient loss through harvest, besides characterising litter dynamics.

Acacia and Paraserianthes recorded the highest growth rates in terms of height, radial growth and biomass yield. Biomass production decreased in the order: Acacia > Paraserianthes > Casuarina > A. heterophullus > Emblica Pterocarpus > A. hisrsutus > Ailanthus > Leucaena. The most important component of total biomass undoubtedly, was the bole while foliage contributed least to biomass yield. Nevertheless foliage, in general registered the highest N,

P and K contents. Among the species, Leucaena had the highest N concentration followed by Paraserianthes and Pterocarpus. For P and K concentrations, Pterocarpus and A. hirsutus registered the highest concentration. A one-to-one correspondence between nutrient accumulation and biomass yield was however, lacking because of wide variations in elemental concentrations among species and also among tissue types. Bole fractions, in general, did not account for more than 50 % of total nutrient export from site. Altering the rate of nutrient removal in products is one of the most important design criteria in planning for sustainable plantation. N-fixing tree plots generallly had a higher soil N status. Casuarina, Emblica and Pterocarpus plots were having higher P levels. Acacia, Paraserianthes and A. hisrsutus plots registered markedly higher K level.

The amount of litterfall was maximum for Acacia and the minimum for Pterocarpus. Litterfall also followed a unimodal distribution pattern with a distinct peak during the November-January period and the period of lean fall was during May-August. Litter dynamics accounted for bulk of the nutrient inputs into the system. The retranslocation of mineral nutrients from senescing leaves to younger leaves and/or other tissues prior to abscission was obvious. Leucaena, Paraserianthes, Pterocarpus, Acacia, Alinathus and Emblica formed examples of high (>1.5%) detrital N content. Generally the wet period (June-August) was characterised by increased concentration of N in litter. Litter P did not follow a consistent pattern with respect to seasons. However, a characteristic decline in litter K concentration was noticed during the rainy season. Mass disappearance of litter samples followed a negative expontential relationship. Leucaena litter, having the higest initial N content, decomposed compeletely in the shortest period (9 months).

Root system studies suggest that A. hetrophyllus, Emblica and Paraserianthes are perhaps unsuitable for intensive mixing and close planting in agroforestry as they possess shallow and highly spreading root system. Ailanthus is perhaps a better candidate species for the above purpose as it possess relatively lower lateral root spread and at the same time having a deep tap root system. Root activity paatern of Artocarpus hisrsutus revealed that more than 75% of fine roots responsible for water nutrient absorption is concentrated in the 75 cm radius around the base of the tree. Recovery of ^{32}P declined as depth of application increased. The combination of lowest lateral distance (75 cm) and depth (30 cm) accounted for more than 30% root activity.

Appendices

Appendix - I

Mean weights (g m^{-2}) of different fractions of litter in nine fast growing multi-purpose trees

Foliage

Months	Aca	Cas	Leu	Ail	Emb	Het	Pte	Par	Hir
Feb. 93	55.84	40.42	30.75	2.44	21.30	51.75	61.82	27.60	39.59
Mar. 93	64.45	40.23	20.32	9.36	28.21	29.99	45.36	65.43	25.97
Apr. 93	57.61	46.04	27.95	14.41	36.65	60.07	4.35	58.58	27.24
May. 93	17.41	22.36	34.65	10.23	21.57	22.69	3.57	30.90	26.06
Jun. 93	23.98	23.37	37.05	14.55	29.18	42.48	7.61	49.80	28.91
Jul. 93	52.11	33.72	46.75	28.34	32.45	44.83	13.97	41.45	26.21
Aug. 93	47.96	22.01	25.43	18.62	39.54	33.19	10.20	49.08	28.38
Sep. 93	86.56	38.65	15.63	37.53	43.48	54.58	16.90	65.12	41.14
Oct. 93	53.62	63.18	45.10	20.13	32.76	48.98	24.91	53.14	49.13
Nov. 93	118.45	61.75	17.10	67.49	42.44	63.02	33.88	67.25	33.42
Dec. 93	199.67	104.63	29.49	41.77	50.56	75.33	30.34	81.84	25.56
Jan. 94	127.14	54.55	28.20	11.88	15.64	72.77	40.28	54.66	25.39

Twig

Months	Aca	Cas	Leu	Ail	Emb	Het	Pte	Par	Hir
Feb. 93	0.85	0.71	10.21	0.27	3.14	—	9.96	14.44	0.81
Mar. 93	9.80	1.50	15.58	1.33	6.69	—	8.84	23.80	0.16
Apr. 93	3.47	3.13	7.17	1.43	3.20	0.20	1.62	19.66	—
May. 93	3.46	1.50	6.91	1.66	3.33	0.35	1.50	12.03	0.15
Jun. 93	6.94	1.36	20.15	3.26	5.57	—	3.62	22.46	—
Jul. 93	10.60	3.17	7.29	1.72	5.95	3.55	8.30	14.81	0.48
Aug. 93	1.99	0.81	6.07	2.04	19.28	1.22	1.69	22.13	0.75
Sep. 93	1.07	2.93	2.43	4.49	18.01	—	0.65	26.40	—
Oct. 93	1.17	0.16	24.58	1.85	17.88	—	1.23	10.23	—
Nov. 93	14.31	0.55	8.69	7.48	14.06	10.36	3.90	29.04	0.65
Dec. 93	30.80	1.87	6.29	29.66	17.17	0.46	3.43	31.10	—
Jan. 94	24.48	2.06	13.87	4.82	10.32	1.05	4.72	25.62	—

Reproductive part

Months	Aca	Cas	Leu	Ail	Emb	Het	Pte	Par	Hir
Feb. 93	8.80	1.31	—	—	—	—	—	0.95	0.32
Mar. 93	16.11	1.25	—	—	—	2.41	—	2.88	3.00
Apr. 93	20.09	1.48	8.22	—	—	1.50	—	0.80	2.32
May. 93	7.40	1.19	2.13	—	—	1.08	—	0.21	1.55
Jun. 93	17.75	10.31	10.58	—	—	1.11	—	—	2.61
Jul. 93	0.60	7.17	—	4.45	—	—	—	—	—
Aug. 93	5.08	19.65	—	15.26	—	—	—	—	1.88
Sep. 93	3.99	3.66	—	—	—	—	—	—	—
Oct. 93	4.99	6.14	—	—	—	—	—	—	—
Nov. 93	26.93	11.20	—	—	—	—	—	—	—
Dec. 93	102.73	6.59	0.44	—	—	—	—	8.06	—
Jan. 94	41.24	3.00	—	—	—	—	—	7.86	—

Aca- Acacia auriculiformis, Cas- Casuarina equisetifolia, Leu- Leucaena leucocephala,
Ail- Ailanthus triphysa, Emb- Emblica officinalis , Het- Artocarpus heterophyllus,
Pte- Pterocarpus marsupium, Par- Paraserianthus falcataria, Hir- Artocarpus hirsutus

Appendix II

Abstracts of ANOVA tables for dry matter yield (kg $tree^{-1}$) of nine fast growing multi-purpose trees at eight years of age.

Source	df	Mean square			
		Biomass components			
		Bole	Branch	Foliage	Total
Between species	8	30578.90**	666.34**	42.561**	43601.23**
Within species	222	1148.26	100.82	5.404	1800.06

Appendix III

Abstracts of ANOVA tables for tissue nitrogen concentration (%) of nine fast growing multi-purpose tree species.

Source	df	Mean square			
		Biomass components			
		Bole	Branch	Root	Foliage
Between species	8	0.012**	0.090**	0.049**	2.605**
Within species	18	0.001	0.002	0.001	0.004

Appendix IV

Abstracts of ANOVA tables for tissue phosphorus concentration (%) of nine fast growing multi-purpose tree species.

Source	df	Mean square			
		Biomass components			
		Bole	Branch	Root	Foliage
Between species	8	0.00016**	0.001**	0.001*	0.003**
Within species	18	0.000006	0.000009	0.0002	0.00002

* Significant at 5 % level
** Significant at 1 % level

Appendix V

Abstracts of ANOVA tables for tissue potassium concentration (%) of nine fast growing multi-purpose tree species.

Source	df	Mean square			
		Biomass components			
		Bole	Branch	Root	Foliage
Between species	8	0.020**	0.166**	0.100**	1.294**
Within species	18	0.0002	0.0002	0.0003	0.0003

Appendix VI

Abstracts of ANOVA tables for nitrogen accumulation (g $tree^{-1}$) in different organs of nine multi-purpose trees at eight years of age.

Source	df	Mean square				
		Biomass components				
		Bole	Branch	Root	Foliage	Total
Between species	8	9375.65**	3338.72**	284.54**	1437.49**	37157.34**
Within species	18	286.63	13.64	2.01	1.62	253.91

Appendix VII

Abstracts of ANOVA tables for nitrogen use efficiency of nine multi-purpose tree species

Source	df	Mean square				
		Biomass components				
		Bole	Branch	Root	Foliage	Total
Between species	8	1.202**	8.984**	4.860**	260.46**	4.434**
Within species	18	0.091	0.200	0.091	0.38	0.048

* Significant at 5 % level

** Significant at 1 % level

Appendix VIII

Abstracts of ANOVA tables for phosphorus accumulation (g $tree^{-1}$) in different organs of nine multi-purpose trees at eight years of age.

Source	df	Mean square				
		Biomass components				
		Bole	Branch	Root	Foliage	Total
Between species	8	11.68**	3.698**	2.224**	8.109**	52.601**
Within species	18	1.23	0.069	0.015	0.009	1.728

Appendix IX

Abstracts of ANOVA tables for phosphorus use efficiency of nine multi-purpose tree species

Source	df	Mean square				
		Biomass components				
		Bole	Branch	Root	Foliage	Total
Between species	8	0.016**	0.104**	0.092**	0.269**	0.067**
Within species	18	0.001	0.001	0.001	0.002	0.0003

Appendix X

Abstracts of ANOVA tables for potassium accumulation (g $tree^{-1}$) in different organs of nine multi-purpose trees at eight years of age.

Source	df	Mean square				
		Biomass components				
		Bole	Branch	Root	Foliage	Total
Between species	8	2209.80**	761.85**	183.24**	1663.349**	11356.87**
Within species	18	40.12	1.77	0.657	0.206	35.58

* Significant at 5 % level
** Significant at 1 % level

Appendix XI

Abstracts of ANOVA tables for potassium use efficiency of nine multi-purpose tree species

Source	df	Mean square				
		Biomass components				
		Bole	Branch	Root	Foliage	Total
Between species	8	1.953**	16.609**	10.042**	129.356**	11.035**
Within species	18	0.023	0.023	0.030	0.032	0.009

Appendix XII

Abstracts of ANOVA tables for soil chemical properties (0-15 cm soil layer) under different multi-purpose tree blocks.

Source	df	Mean square				
		Biomass components				
		pH	OC(%)	N(%)	P(ppm)	K(ppm)
Between species	8	0.010	0.127**	0.002**	9.147**	577.726**
Within species	18	0.009	0.0001	0.0002	2.194	66.270

Appendix XIII

Abstracts of ANOVA tables for seasonal variations in litterfall of nine fast growing multi-purpose tree species.

Source	df	Mean square
		Litterfall (g m^{-2})
Species	8	71685.15**
Month	11	39551.01**
Interaction	88	9782.05**
Error	972	652.690

* Significant at 5 % level
** Significant at 1 % level

Appendix XIV

Abstracts of ANAVA tables for seasonal variations in litter (composite) nutrient concentrations (%) of nine multi-purpose tree species

Source	df	Mean square		
		N(%)	P(%)	K(%)
Species	8	8.568**	0.043**	0.227**
Month	11	0.402**	0.001**	0.102**
Interaction	88	0.242**	0.001**	0.052**
Error	216	0.010	0.00002	0.0002

Appendix XV

Abstracts of ANOVA tables for nutrients remaining in the litter bags of nine fast growing multi-purpose tree species.

Source	df	Mean square		
		N(%)	P(%)	K(%)
Species	8	4.67**	0.003**	0.561**
Month	7	16.78**	0.019**	1.201**
Interaction	56	0.62**	0.001**	0.118**
Error	144	0.003	0.00001	0.0002

* Significant at 5 % level
** Significant at 1 % level

Appendix XVI

Abstracts of ANOVA tables for root growth data of eight year old destructively sampled trees.

Source	df	Mean square		
		Length of tap root(cm)	Max. Lateral spread (cm)	Root biomass (kg)
Between species	8	2018.58	15284.07**	9.673
Within species	18	1221.00	4098.15	8.875

Appendix XVII

Abstracts of ANOVA tables for radioactivity recovered (log cpm g^{-1}) from the leaves of <u>Artocarpus hirsutus</u> grown under multi-purpose tree production system, as a function of lateral distances and depth and days after application of ^{32}P.

Source	df	Mean square		
		Days after application of ^{32}P		
		15	30	45
Lateral distance (cm)	2	2.366*	3.926**	4.123**
Depth (cm)	2	5.092**	3.400**	0.461
Interaction	4	3.977	0.529	0.122
Error	16	3.690	0.526	0.338

* Significant at 5 % level
** Significant at 1 % level