BIOMASS PRODUCTION AND RESOURCE PARTITIONING IN SILVI-PASTORAL SYSTEMS

By

SUMAN JACOB GEORGE

THESIS

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DECLARATION

I hereby declare that the thesis entitled Biomass **Production and Resource Partitioning in Silvi-pastoral Systems** 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.

Vellanikkara,
28.10.1993.

Suman Jacob George

CERTIFICATE

Certified that the thesis entitled **Biomass Production and Resource Partitioning in Silvi-pastoral Systems** is a bonafide record of research work done by Mr. Suman Jacob George, 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.

Vellanikkara,
28.10.1993.

Dr. B. Mohankumar
Chairman
Advisory committee
Associate Professor
College of Forestry
Vellanikkara, Thrissur

CERTIFICATE

We, the undersigned, members of the Advisory Committee of **Mr. Suman Jacob George**, a candidate for the degree of Master of Science in Forestry, agree that the thesis entitled **Biomass Production and Resource Partitioning in Silvi-pastoral Systems** may be submitted by Suman Jacob George in partial fulfilment of the requirement for the degree.

Vellanikkara,
23.10.1993.

CHAIRMAN: **Dr. B. Mohankumar**
Associate Professor
College of Forestry

MEMBERS: **Dr. C.C. Abraham**
Associate Dean
College of Horticulture

Dr. P.A. Wahid
Professor
Radiotracer Laboratory

Dr. K. V. Suresh Babu
Assistant Professor
College of Horticulture

(V. M. SRINIVASAN)
External Examiner

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Dedicated to
My Loving Parents

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Introduction

INTRODUCTION

Declining availability of various forest products such as fuelwood, fodder and timber on the one hand, and rising rates of deforestation on the other, are two fundamental problems that the tropical world is confronted with. The global rate of deforestation is estimated to be of the order of about 11 million hectares every year (FAO, 1983). Broadly, agroforestry type of land-use systems which integrate woody perennials, herbaceous crops and/or livestock on the same unit of land tend to optimize productivity and also strive to offset the severe anthropogenic pressures on natural forests by providing these resources from outside the natural forests.

Silvopastoralism refers to land use systems in which pasture and livestock production are integrated with woody perennials on the same land management unit. Although opinions differ, it broadly covers grazing systems and 'cut and carry' fodder practices. These land use systems are generally characterised by higher productivity on account of the vertical stratification of the shoot and root systems of different components

(Payne, 1985). The ability of crop combinations to use available light more efficiently is well documented in the literature (Ewel et al., 1982). In addition, trees in managed species mixtures have a great potential to bring 'micro-site enrichment' through processes such as efficient cycling of plant nutrients and nutrient pumping (Haines and DeBell, 1979; Huxley, 1985 and Nair, 1984). Nitrogen-fixing trees have the additional potential of bringing in substantial quantities of atmospheric nitrogen into the combined form. Crude protein content of the forage also was found to be higher under nitrogen-fixing trees (Deccarett and Blydenstein, 1968). Mitigation of extremities in temperature and rainfall, physical amelioration of soil, lesser weed proliferation, better extractability of available nutrients through changes brought in soil micro-floral spectra are some of the other advantages of integrating tree crops with annuals (Budowski, 1981).

Interference of trees, however, is a major constraint in the integration of trees with field crops. As tree matures and canopy is formed, intensity of light at the ground level decreases, thereby affecting the understorey forage productivity (Mathew et al., 1992). Another adverse factor is the possible inter-specific competition for nutrients (Buck, 1986) and water (Budowski, 1981). The potential nutrient export, especially with whole-tree harvesting tend to deplete the nutrient capital of the site (Wang et al., 1991)

Proper selection of tree and field crop components, which ensures maximum compatibility among the various components of the system can, to some extent, mitigate these adverse effects. Ideally in such systems, the tree components should exploit the lower layers of the soil profile without exerting any allelopathic influence on the associated crops, fixing atmospheric nitrogen, facilitating light infiltration through the canopy, besides, that the root systems of the field crops should exploit the top layers which the tree roots do not normally scavenge. However, precise quantitative information on the resource sharing aspects of silvopastoral systems involving tropical species and the above and below ground interactions in such situations are lacking. In this context the present study was taken up with the following objectives:

1. Quantification of the biomass production potential of selected forage species grown in association with tree components after canopy closure.

2. Compare the productivity of different tree components grown in silvopastoral system.

3. Charaterisation of the micro-site enrichment and nutrient cycling aspects of silvopastoral systems; analyse the partitioning of solar radiation among the different components of the systems and elucidate influences regarding the nature of root interactions in silvopastoral system.

Review of Literature

REVIEW OF LITERATURE

2.1 Integrating Livestock/Crop Production systems

Agroforestry systems tend to integrate various crop, livestock and tree production systems on the same land management unit. Animal agroforestry is proposed as a generic name for land use systems which include animals (for production and /or performance) as one of the components (Torres, 1982). It has been suggested that these systems can be called silvopastoral systems when they include tree or shrubs in pastures or animals, while the agrosilvopastural systems are the ones which contain herbaceous food crops also.

Broadly, three major integrated livestock/crop production systems are often distinguished: viz grazing and/or browsing in natural forests; grazing or harvesting of forage under planted trees or the 'cut-and-carry system' and browsing or harvesting of tree forage or protein banks (Payne, 1985). Major advantages cited in favour of the cattle/tree crop system include the ability to simulate the canopy structure of the tropical rainforest ecosystem, although to a limited extent, utilization of solar energy more efficiently due to vertical stratification of the aboveground components and protecting the soil from erosion. The vertical stratification of the root system also enhances 'microsite enrichment' besides providing a closed nutrient cycle (Payne, 1985).

According to Budowski (1980) such integrated systems abound in the humid tropical zones of Mexico, Central America. Combe (1979) described a system of silvopasture in the highlands of Costa Rica wherein under a canopy of Alnus acuminata, Pennisetum clandestinum is planted and rotationally grazed. Besides, Pennisetum pupureum and Axonopus scoparius are also grown under trees and are cut for feeding the cattle.

Barker and Nyberg (1968) surveyed the coconut based production systems of Philippines and found that on 22 per cent of such holdings, cattle grazing is practiced. Hill (1969), recommended the use of Brachiaria mutica, Brachiaria ruziziensis and Panicum maximum for the cattle/coconut systems of Papua New Guinea. Brachiaria miliformis, B. brizantha, and Panicum maximum are suitable for growing under coconuts and that they are adapted to relatively low light intensities (Eriksen and Whitney, 1977). Several workers have described integrated tree and forage production systems characterising of the tropical and sub-tropical regions of Indian sub-continent (Raut and Gill, 1987; Mathew et al., 1982).

2.2 Productivity of Silvopastural systems

The agroforestry systems are characterized by high productivity and they are extremely dynamic with available resources and environmental conditions changing over time. A basic yet useful approach is to look at the resource pools of light, nutrients and water and how the plants will utilize them in the horizontal, vertical and time dimensions (Buck,1986).

Management can affect biomass production and the allocation of these resources by controlling inter-crop and intra crop competition.

2.2 Understorey herbage yield

In a series of intercropping experiments with Leucaena leucocephala, Sesbania sesban and Desmanthes virgatus with (hybrid napier and Guniea grass) at Jhansi, U.P., Gill and Patel (1985) reported fodder yields to be the highest under Leucaena leucocephala. Herbage yield of 80-150 t ha^{-1} $year^{-1}$ was obtained from Panicum maximum intercropped with Leucaena leucocephala (Mohatkar, 1987). Similarly, intercropping studies of Panicum maximum with

Leucaena leucocephala in India yielded highest forage biomass (120 t ha^{-1} of green fodder) and was significantly greater than four other forage legumes (Raut and Gill, 1987). Mathew, *et al*. (1992) observed that under the eco-climatic condition of Kerala, *Pennisetum purpureum*, *Panicum maximum*, *Brachiaria ruziziensis*, and *Euchlaena maxicana* grown in association with *Casuarina equisetifoilia* and *Ailanthus malabarica* recorded comparatively higher fodder yield even after canopy formation.

2.2.2 Tree Biomass Production

Mishra *et al*. (1986) reported a net primary production (N.P.P.) of 38,000 kg ha^{-1} $year^{-1}$ from *Leucaena* plantations in a sub-humid region of India. *Prosopis juliflora* gave an N.P.P. of 30,000 kg ha^{-1} $year^{-1}$ (Gurumurthi *et al*., 1984). In a comparative study of biomass of *Acacia auriculiformis* and *Casuarina equisetifolia* from a five-year-old plantation at 1m x 1 m spacing it was 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}. But at 1.5 m x 1.5 m *C. equisetifolia* gave a higher biomass (Kushalapa, 1987). Biomass accumulation rates of five tropical tree taxa in a 5.5 year-old plantation in Peurto Rico, at 10 m x 10 m, were assessed by Wang et al. (1991). Casuarina equisetifolia recorded the highest dry matter accumulation of 36.2 Mg ha^{-1} year^{-1}. Albizia procera, Eucalyptus robusta, Leucaena leucocephala var K8, Leucaena leucocephala var Puerto Rico had a N.P.P. of 22.5, 12.18, 8.5 and 6 respectively.

For a spatial mixed system there are several examples of the plantation/crop associated with shade trees. For instance in a coffee and cocoa production system interplanted with Cordia alliodora and/or Erythrina poeppigiana of Latin America, it is estimated that the tree component alone produce about 10,000 kg ha^{-1} year^{-1}of biomass (Russo and Budowski, 1986; Alpizar et al., 1988). In a hedge row intercropping system in Nigeria, Gliricidia sepium produced 3000-4500 kg ha^{-1} year^{-1} (Yamoah, 1986; Bahiru-Duguma et al., 1988) and for Leucaena leucocephala it was 6770 kg ha^{-1} year^{-1} (Kang et al., 1985). The tree rows were spaced at 4 m interval.

In an integrated tree crop system the total biomass supported by an area is tremendously boosted compared to the monoculture situation of either of these.

2.2.2.1 Partitioning of biomass among the tree components

The success of an organism in an environment can be predicted by looking at its relative allocation of biomass or energy (Gadgil and Solbrig, 1972). The partitioning of dry matter production between the four components: leaf, reproductive parts, wood and root is a matter of considerable importance in agroforestry, since some of these components will be harvested and others returned to the system.

Total biomass measured including roots of _Acacia_ _nilotica_ (5264 plants ha^{-1}) after 12-month and 60-month periods were 16.0 and 154.0 t ha^{-1} dry matter respectively (Gurumurthi _et_ _al_., 1986); of these utilizable 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 19 per cent at 12 months interval while it was 26 per cent at the 60-month stage.

The tree biomass and its relative allocation to various components of different trees in a central Himalayan forest revealed striking variability in phytomass allocation among species. For _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 in leaves and 20.5 per cent in the roots, in a mature sal forest. While in a chir pine-sal/mixed broadleaved forest the bole, branch, twig, leaf and the root component were 43.9,26.9,10.5,3.5 and 15.2 per cent respectively. While for *Quercus incana* in a mixed oak forest it was 43.9,26.9,10.5,3.5 and 15.2 per cent respectively (Rana *et al*., 1989).

In an intercropping experiment involving *Leucaena leucocephala* with beans and maize, no significant difference were found in the biomass allocation between the intercrop and monoculture situations. Leaf component was around 14.8 per cent while branches 34.7 per cent and bole 50.4 per cent (Maghembe *et al*., 1986).

In the analysis of Wang *et al*. (1991) found that biomass partitioning for five tropical tree taxa in a 5.5 year-old plantation in Peurto Rico, *Casuarina equisetifolia* accumulated 70.8 per cent biomass in its bole, 17.4 per cent in its branch and 10.9 per cent its leaves. For *Leucaena leucocephala* var K8 it was 78.7, 17.4 and 5.1 per cent respectively. The corresponding values for *Leucaena leucocephala* var Puerto Rico were 72.7,15.4 and 11.5 per cent.

In a four year old Acacia auriculiformis stand had 72-76 per cent of the biomass was allocated to the stem and 9-12 per cent to the leaves (Osman et al., 1992).

2.2.3 Biomass Nutrient Export

A direct result of high biomass accumulation rate is that the nutrient accumulation rates are also correspondingly high. Comparing the nutrient use efficiency and biomass production of five tropical trees Wang et al. (1991) have shown that Casuarina equisetifolia with the highest growth rate had the highest nutrient efficiency for N, P, K and Mg and Leucaena leucocephala var K8 had the least efficiency for N, K, Ca and Mg. For most nutrients stem wood and large branches were the most important nutrient sinks, followed by small branch, bark and then leaves. According to Hopman et al. (1993) who analysed the impact of harvesting on nutrients in a eucalypts ecosystem in south eastern Australia, nutrient removals from wood generally represented only a small per centage of available soil reserves. Nutrient content of bark was higher compared to stemwood and therefore, export of nutrients (Ca and Mn in particular) as a result of harvesting was significantly reduced by on-site debarking.

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

Nutrient losses accompanying biomass harvest has been of great concern in the recent years, especially, in the context of planting high-yield species followed by whole-tree harvesting (Bormann and Likens, 1967; Jorgensen <u>et</u> <u>al</u>., 1975; Kimmins, 1977; Johnson, 1983).

2.3 Factors Affecting Productivity of Silvopastoral Systems

2.3.1 Tree characteristics

Trees in managed species mixtures have a great potential to bring about 'micro-site enrichment' through processes such as efficient cycling of plant nutrients and nutrient pumping (Huxley, 1985) and consequently increased biomass productivity of the components of the system. Nitrogen fixing trees have the additional potential of bringing in substantial quantities of atmospheric nitrogen into combined form and it is inferred that a significant portion of the nitrogen fixed is also released into the rhizosphere (LaRue and Patterson, 1981). Trees tend also to moderate the influence of leaching through addition of bases to the soil surface. The production of allelo-chemical substances by trees, however, have been suggested as a possible problem in agroforestry. But evidences are mostly anecdotal, in this context, 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).

Canopy structure and orientation of the plant canopy in space plays an important role in intercepting the incoming solar radiation. Terjeing and Louise (1972) experimented with tree shapes simulated by sphere, cylinders and cones of equal surface area. Cones intercepted the largest amount of radiation, especially, at higher altitudes. In another study, Norman and Jarvis (1974), evaluating the influence of canopy structure on interception of radiation, concluded that the path length of light through the crown, silhouette area and canopy volume did not significantly affect shading capacities in five stands of tree species studied.

2.3.2 Spacing/tree density

Tree densities will have varying effects on each individual crop component and total system yield. Maize yields did not vary significantly under varying densities of leucaena provided the trees are routinely pruned to a height of 20 cm (CIAT, 1977). Ola-adams (1993) investigated the effects of spacing on biomass distribution and nutrient contents of Tectona grandis and Terminalia superba in south western Nigeria and found that stem bark and leaf weight per hectare in Tectona grandis appeared to decrease with increasing spacing. There was a significant difference with spacing for small branches and big roots also. In Terminalia the total biomass, stemwood, stembark and small root weight decreased with increasing spacing. The widest spacing showed a significant increase in stemwood biomass.

2.3.3 Stage of stand development

Lewis et al. (1984) reported a reduction in forage yield with increasing tree canopy under a Pinus elliolotii stand compared to the open. Evaluating the performance of wheat under a three-year-old Populus deltoides stand. Ralhan et al. (1992) observed yield reduction .of 23.3 per cent compared to the first year.

Mathew et al. (1992) reported that growth and yield of fodder species was significantly affected by the tree components only after canopy formation.

2.3.4 Tree management practices

After assessing the influence of canopy lopping of Leucaena on the sorghum intercrop, Hocking and Rao (1990), suggested that pollarding Leucaena at the time of under-sowing sorghum registered an sorghum grain yield equivalent to 46 per cent of the pure sorghum crop. Palled et al. (1989) found that increasing stubble height of Leucaena reduced the grain and stover yield of sorghum.

2.3.5 Shade tolerance

Among the factors affecting forage yield .degree of tolerance of the forage crop is of crucial importance. In south eastern United States Pinus elliotii and P. taeda are major tree species used in conjunction with shade tolerant forage species such as Paspalum notatum, grown as summer forage and Trifolium subterranem as winter forage. Mean forage yield under the canopy was 2800 kg ha^{-1} and in the outside it was 3300 kg ha^{-1} (Johnson and Davis, 1983).

2.4 System Dynamics

Implicit in the role of agroforestry in maintaining soil fertility, is the fundamental proposition that trees improve soils. Such soil enrichment has been attributed to stemflow, preferential trapping of atmospheric inputs, enhanced nutrient uptake from depth, deep rooting nature of trees 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 Acacia albida trees with the surrounding areas without tree canopy, Felker (1978) reported a 50-60 per cent increase in organic matter and nitrogen under the canopy together with increased water-holding capacity.

In northern Nigeria maize and sorghum grown in pot culture using 'soils under trees' grew two to three times faster than in soil without trees. Soil fertility decreased in the order Azadiracta indica > Prosopis juliflora > Eucalyptus camaldulensis > control (Verinumbe, 1987). In the moist sub-humid 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). On 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 trunk to the canopy margin under *Acacia senegal*, *Balanites eagyptiaca* and *Adansonia digitata* (Bernhard-Reversat, 1982). In Maxcala, Mexico trees intercropped with maize influenced soil properties upto six to 10 m radius, under *Premus capuli* and *Juniperus* sp. Nitrogen was 1.5 to 3.0 times higher under trees, available phosphorus was 4.0 to 7.0, potassium 1.5 to 3.0 times higher, calcium, magnesium, carbon and cation exchange capacity showed an increasing trend (Altieri *et al*.,1987).

To sum up, overwhelming evidence exists on the ameliorative role of trees on the soil it supports. The accessibility of trees to deeper soil horizons helps the component herbaceous crops to get nutrients out of their reach.

Other major pathways which contributes to the accretion of mineral elements in the surface soils of agroforestry systems are outlined below.

2.4.1 Nutrient cycling

Litter plays a fundamental role in the cycling of nutrients and in the transfer of energy between plants and soil, functioning as fuel for the nutrient cycles in the upper-most layers of the soil (Medwecka-Kornas, 1970). The importance of the detrital pathway to the overall ecosystem productivity and nutrient cycling has long been recognized and is reflected in the voluminous literature on this subject matter (see reviews by: Bray and Gorham, 1964; Cole and Rapp, 1981; Waring and Schlesinger, 1985 and Vogt et al., 1986). Litter fall, decomposition and turnover rates have been reported from diverse ecosystems: Van Cleve and Norman (1978) from higher altitudinal forests of Alaska, Lamb (1985) from Australian eucalpts forests, Das and Ramakrishnan (1985) from subtropical Pinus kesyia of north east India, Stohlgren (1988a) in the Sierran mixed coniferous forests, Harmon et al. (1990) from a picea/tsuga forest, Kumar and Deepu (1992) for the moist deciduous forests of the peninsular India. A vast majority of the works cited are however, from temperate and/or monoculture stands and only a fewer number of studies are reported from tropical forests in general and agroforestry systems in particular. The available literature in this respect are reviewed underneath.

2.4.2.1 Litter production rates

Litter represents an input-output mechanism for mineral nutrients and organic matter. The amount of detritus or litter produced vary markedly among ecosystems and a number of factors appear to control this parameter.

Bray and Gorham (1964) have shown that an inverse relationship exists between the total amount of litter production per year and the latitude of the locality. Das and Ramkrishnan (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}, lower than the values projected by Bray and Gorham (1964). For a secondary successional stand, on a well-drained uplands of the East Gulf Coastal Plain of Mississippi, Hinseley _et al_. (1991) suggested that foliage litter mass was in conformity with the Bray and Gorham's hypothesised values. Nevertheless, the proportion of reproductive parts were lower than the values reported by Cromack and Monk (1975), Gizzard _et al_. (1976) and Rolfe (1975).

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). Values reported for tropical forest formation vary widely 9.8 t ha^{-1} year^{-1} (Klinge, 1977; Fraken _et al_., 1979; Luizao and Shubart, 1987), 5.5-15.3 t ha^{-1} year^{-1} for equatorial forests (William and Gray 1974), 12.2-14.4 t ha^{-1} year^{-1} for a tropical deciduous forest in peninsular India (Kumar and Deepu, 1992).

Venkataraman et al. (1983) monitored the extent of litter fall in Eucalyptus globulus and Acacia mearnsii plantation of Nilgiris. For blue gum the amount of dry weight of litter was 1.9 t ha^{-1} year^{-1} and for black wattle it was 0.96 t ha^{-1} year^{-1}. 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, 1986). Maximum litter fall in spruce and silver fir plantations varied from 5.2-5.17 t ha^{-1} year^{-1} in different experimental plots (Virendra Singh et al. 1987). Litter dynamics in an Acacia auriculiformis stand in Kerala was around 12.92 t ha^{-1} year^{-1} (Kunhamu, 1991).

Depending on an array of factors such as latitude, altitude, stand density, species etc. the amount of litterfall varies widely but it remains as the primary source of nutrient recharge into any ecosystem.

2.4.2.2 Seasonal variations in litterfall

Lonsdale (1988) analysed the total litter fall from 389 forest sites throughout the world using multiple regression analyses considering latitude, altitude as predictor variables. Witkamp and van der Drift (1961) reported that for Populus tremula, in Netherlands, there was only one peak in litterfall during October, which they attributed to prevailing wind conditions. Whereas for Populus deltoides plantation (in India) two peaks in May and October (Raizada and Shrivastava, 1986) were observed.

Increased leaf fall due to drought condition have been reported by Pool (1913). Pokhriyal et al. (1989) made a detailed analysis of the leaf emergence and shedding behavior in Populus deltoides at Dehradun and found out 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. This was unlike deciduous plantations (Gosh et al., 1982; Kikuzawa et al., 1984), which yielded maximum litter during summer months. While in the deciduous stands in the temperate regions of Northern hemisphere the maximum litter fall normally is concentrated in the autumn with a pronounced peak during October-November (Viro, 1955; Andersson, 1970). 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 mono-modal 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.

In short, chronosequencial variations in litterfall can be attributed to the climatic variations.

2.4.2.3 Litter decomposition

Litter decomposition is an important 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 the biochemical quality of the substrate (Swift *et al.*, 1979).

Litter disappearance rates have been determined for a wide variety of litter types throughout the world. Cold temperate forests were characterised by slow decomposition and mineralisation of organic matter and nutrients (Jenny *et al.*, 1948; 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). But decomposition rates were markedly higher for tropical forests, ranging from 0.45 to 1.5 per cent per day (Laudelout and Mayer, 1954). In temperate forests the rates are comparatively higher for broadleaved species as compared to conifers (Bray and Gorham 1964).

Deciduous tree litter usually decompose more rapidly, but considerable variations occur between different species. The time required for the complete disappearance of the original biomass ranged from five to eight months (Kumar and Deepu, 1992). Sankaran (1993) reported a weight loss of 96 per cent teak and 94 per cent for eucalypt, over a period of 18 months. The annual decomposition coefficient (k) for various Pinus species across a variety of habitats ranged between 0.228-0.78 (Das and Ramakrishnan, 1985) and for temperate hardwood species it lay between 0.008 and 0.47 (Melillo *et al.*, 1982). Annual decay rates were between 0.18 and 0.62 for Sierran mixed temperate forests (Stohlgren, 1988a) and the time required for 95 per cent decay ranged from 11 to 27 years.

Heterogeneity in decomposition rates among various agroforestry systems have been reported. Usmansyah (1980) observed that the weight loss in *Albizia falcataria* leaves after 16 weeks was highest in the forest gardens (57.5 per cent), medium in home gardens (46.5 per cent) and lowest in annual dryland cropping (37.5 per cent). The rate of decomposition of prunings were reported to be: *Leucaena leucocephala* > *Gliricidia sepium* > *Cassia siamea* > *Flemingia congesta* (Yamoah, 1986; Wilson, *et al*., 1986). In a study conducted in Colombia, the half-life of litter was found to be about 60 days for *Albizia carbonaria*, 80 days for *Gliricidia sepium* and *Sesbania grandiflora* and 120 days for *Erythrina* sp. and *Cajanus cajan* and 170 days for *Cassia grandis*. These rates were found to be directly proportional to rainfall (Arias, 1988).

2.4.2.4 Nutrient dynamics of senescing leaves

Metabolically active leaves continue to derive nutrients till maturity. Thereafter, nutrient contents often decline to a minimum as a result of senescence-caused retranslocation (Stachurski and Zimka, 1975; Charley and Richard, 1983). 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 senesceing leaves (Vitousek, 1984).

Das and Ramakrishnan (1985) observed increased concentrations of nitrogen and phosphorus were observed during May-July in the needle litter of Pinus kesiya which was attributed to lower retraslocatian of these nutrients before abscission and due to addition of nutrients through precipitation. Contrary to this potassium had lower concentration during May-July which was attributed to its higher degree of leachability. Nutrients inputs through litter fall exhibited seasonal variations under Acacia nilotica and Eucalyptus tereticornis. Amounts of nitrogen, phosphorus, sulphur, calcium, magnesium, potassium and sodium closely followed the trend of the variations in seasonal litter fall, indicating maximum recycling during winter season and the amounts of recycled nutrients particularly N,P,K,Ca,Mg,S were much higher in acacia than for eucalypts (Gill et al., 1987). Seasonal variation of N, P and K were reported to be more than Ca and Mg (Sharma and Pande, 1989). The variation in nutrient concentration of deciduous plantation (Sal and teak) leaf litter were more than evergreen, except for N in pine and was found to be negatively correlated with the magnitude of leaf fall.

Compared to leaf litter the twig litter has been reported to contain lower nutrient concentrations and was attributed to the differences in non-photosynthetic to photosynthetic-tissue ratio and tissue longevity compared to leaves (Sharma and Pande,1989). Low nutrient concentration in perennial tissues have also been reported by Gosz *et al*. (1973) and Atiwill *et al*. (1978).

2.4.2.5 Factors affecting litter decay

2.4.2.5.1 Resource quality

Several workers have found a strong negative relationships between initial lignin/nitrogen ratios and the mass disappearance rates of litter (Aber and Melillo, 1982; Taylor *et al*., 1989). Aber and Melillo (1982) studied the nitrogen immobilization rates and found that highest nitrogen immobilization occurred in litters with highest lignin and nitrogen contents. Carbon-nitrogen ratio of the litter has been reported to be a good predictor of decomposition rates (Meentemeyer, 1978; Taylor, *et al*., 1989).

Initial low N concentrations resulted in high maximum litter accumulation, low levels of P in forest litter also resulted in a slower rate of nutrient release (Gholz et al., 1985). Stohlgren, (1988b) found that the species with the lowest initial concentration of N,P,K,Ca,Mg and Mn retained the greatest proportion of nutrients after six years, in a Sierran mixed conifer forest.

2.4.2.5.2 Environmental factors

In terrestrial ecosystems leaf litter decay is regulated by an array of factors besides the biochemical quality of the litter. Environmental conditions such as temperature and moisture supply can play a vital role in deciding decay rates (Singh and Gupta, 1977; Pastor and Post, 1977).

2.4.3 Nutrient dynamics of decomposing litter

The concentration of N increased sharply over the one year period for Pinus banksiana, Betula papyrifera, Populus tremuloides and Quercus ellipsoidalis, (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. Many studies have reported that K and Mg as the most readily released nutrients and that N as the most slowly released macronutrient (Gosz et al., 1973; Staaf, 1980).

Studies on leaf decomposition have shown the reduction of carbon as the reason for the apparent increase in concentration of many of the elements. For N, however, microbial fixation of atmospheric nitrogen, through fall, stem flow, and translocation of N are also important (Bocock, 1963).

2.4.4 Root interactions

Root system studies concerning fine root dynamics, root biomass and root architecture of trees are scattered. Besides, the real issue of the degree of competition for nutrients between roots of trees and adjacent herbaceous crops has not been dwelled deep into. Measurement of the quantities and spatial distribution of roots in the soil is made by excavating the root system (Bohm, 1979). But a more precise and informative method is the use of slowly diffusing radioneuclides as ^{32}P so that the position of the label can be correlated with root activity (Nye and Tinker, 1977; Vose, 1980). Literature on root activity of agroforestry systems is very fragmentry.

Sankar (1988) analysed root activity patterns of black pepper vine and various support trees in relation to the root competition. It was found that 90 per cent of root activity was confined to a radial distance of 30 cm from the vine. Pepper vines trained on Erythrina sp. had a larger lateral root spread than those trained on teak poles. No other published reports are available concerning tree-crop root interactions.

2.4.5 Canopy influence on solar spectral characteristics

Plant canopies effect both quality and quantity of light. Under a canopy, the photon fluence rate gets attenuated to varying degrees (Hart, 1988). Light on absorption by photosynthetic pigments undergoes alteration in the red : infra red ratio (Hart, 1988). The spectral environment in a canopy is further complicated by sunflecks, where light enters through gap in the canopy (Holmes, 1984). Whitmore and Wang (1959) observed that roughly half the total energy in a low land tropical rainforest in Singapore are due to sunflecks.

Alterations in the composition of short-wave radiations penetrating plant canopy indicates minimal changes in spectral components during noon and maximum changes during sun rise and sun set (Daynard, 1969). Comparing four forest types and two shrub vegetation types, in The Netherlands, Stoutjesdijk (1972) observed that leaf canopies transmitted very little radiation in the photosynthetically active wavelength and a larger amount of longer wavelength. Stoner _et al._ (1978) who modelled irradiance within vegetation in _Betula alba_ canopies for Northern latitudes showed that photosynthetically active radiation profiles was influenced by foliage area, foliage reflectance and foliage angle.

Spectral energy distribution patterns of photosynthetically active wavelength during foliage development (from April to June) under a canopy of mixed oaks (_Quercus alba_ and _Q. rubra_)/ yellow poplar (_Liridendron tulipfera_) in Ohio, using the spectroradiometric technique showed that energy incident on the canopy was highest at 550 nm and lowest at 400 nm. Radiation beneath the canopy was reduced by 98 per cent, when leaves were fully developed (Floyd _et al._, 1978). When incident radiation were predominantly direct beam a bimodal distribution of photosynthetically active radiation was observed for a 15-year-old loblolly pine plantation. However, for diffused incident radiation the photosynthetically active radiation profile was unimodal

(Sinclair and Knoerr, 1982). Increased light infiltration into the understorey due to the cladophyllous canopy of Casuarina equisetifoilia was attributed as reason for increased herbage yield of the four fodder crops grown underneath (Mathew, et al., 1992).

2.4.5.1 Canopy influence on attenuation of solar irradiation

Plant foliage, apart from bringing qualitative changes to the solar spectrum, plays an important part in the quantitative reduction of the incoming radiation. Hoffer (1963) tried to relate certain stand density parameters of lodgepole pine (Pinus contorta) with incoming radiation and net radiation. The best relation for both was found when canopy coverage and basal area per acre were used as independent variables. Vezina (1965) also attributed stand basal area as an important parameter for judging solar radiation availability below forest stands. Solar radiation beneath stands of basal area 228,189 and 125 ft^2 $acre^{-1}$ were six, eight and 10 per cent respectively of the open. Variation in the amount of solar radiation in the open did not effect the mean percentage of solar radiation in the stand. Light measurements, at a height of one meter, under a 100-140 year old stand of Pinetum polytrichosum, P. equisetoso-sphagnosum, and P. fruitioso-sphagnosum, showed a reduction of two to six percent light infiltration during summer compared to winter. Differences between solar radiation under canopy and in the open decreased with increasing cloud cover (Izotov, 1966; Brasseur and Sloover, 1973).

Photometric evaluation of the radiation regime under a forest canopy in Sakhalin, Russia, showed that maximum photosynthetically active radiations were from noon to 15 hours local solar time under stand of fir, birch, spruce and larch of different densities and ages. Under dense canopy (density index:1.0-0.8) photosynthetically active radiation under a spruce/fir stand was only 1.1 to 3.8 per centage of the open. In a spruce stand of density 0.6 photosynthetically active radiation increased six to seven fold. Photosynthetically active radiation under the canopy of birch stand was five times more than that under spruce/fir stand of equal density (Klinstov, 1976). Solar radiation under a Cryptomeria japonica stand managed on group selection system was 40 to 50 per cent higher than an unmanaged stand (Fujimoto, 1973).

Seasonal variation of solar radiation in a 140-year-old stand of Fagus sylvatica, a 56-year-old plantation of Picea abies and the open were studied by (Brasseur and Sloover, 1973). Spruce canopy intercepted 95 per cent of the incoming sunlight during autumn and 97.5 per cent during foliated condition. For beech stand the respective values were 91 per cent and 99 per cent.

Relative light intensity under a *Fagus sylvatica* stand was 11 to 20 per cent to that in the open during spring and two to three per cent in summer (Draskovits, 1975). In a tropical dry evergreen forest of Thailand, Yoda *et al.* (1983) noted that the relative illuminance decreased linearly with height. The curve could be split into three segments. The first segment represented the 20 to 31 m layer, which intercepted about 90 per cent of the incident light, while second layer with fewer leaves intercepted negligible amount of light.

Solar radiation and relative transmission within the canopy tended to reach maximum when the sun reached its maximum altitude (Fujimoto, 1973).

2.4.5.2 Effect of light interception in intercropped situation

Hazara (1985) showed that photosynthetically active radiation under the canopies of *Albizia lebbeck*, *A. tortolis* and *Leucaena leucocephala* were 80, 66 and 58 per cent respectively. Sankar and Muthuswamy (1986) studied the dry matter production and recovery of dry ginger under arecanut plantation in relation to light intensity. The recovery of dry matter was high under a six- year-old stand than under a two-year-old stand and monoculture of ginger. As part of the investigation on the use of shade tolerant species as a component of silvopastural system in Central America, 25 different species/cultivars were sown in the open and under cover of *Pinus caribaea* var *houndurensis*. Mean light intensity under the canopy was 18 per cent of full sunlight. *Centrosema*, *Desmodium* and *Flemingia congesta* were good performers (Bazil, 1987). A model for estimating the optimum tree density for maximum herbage production showed that woody plants with a light, high canopy was seen favouring certain grasses. It was hypothesised that for maximum herbage production tree should be distributed in such a way so that the shadow of one of the tree does not shade the base of another at maximum shadow length (Obot, 1988).

2.4.6 Resource partitioning

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 farmer is that trees in association with crops compete strongly for nutrients and moisture.

An important factor in the effective resource sharing of nutrients and water in the rhizosphere is the selection of crop species with differential root system behaviour, both spatially and temporally. The root distribution and resource use in the rizosphere can be influenced by the genetic characteristics of the plant species, the localized soil conditions and management. Water and nutrient demands in the rhizosphere can be partitioned temporarily by timing the harvest of crop components in a manner that avoids competitive resource sharing (Buck, 1986). A knowledge of the size of the resource pools, their accessibility to the crop components, and the concepts of resource sharing between and among the components are important to design and manage agroforestry systems.

Materials and Methods

MATERIALS AND METHODS

3.1 Study site

The study was conducted at the Livestock Research Station, Thiruvazhamkunnu, Palakkad district, Kerala (between 11°21'30" and 11°21'50"E latitude, 76°21'50" longitude and at an elevation of 60-70 m above mean sea level. The silvopastoral experiment in which the present study was conducted was laid out during June, 1988, as part of the ongoing All India Coordinated Research Project on Agroforestry.

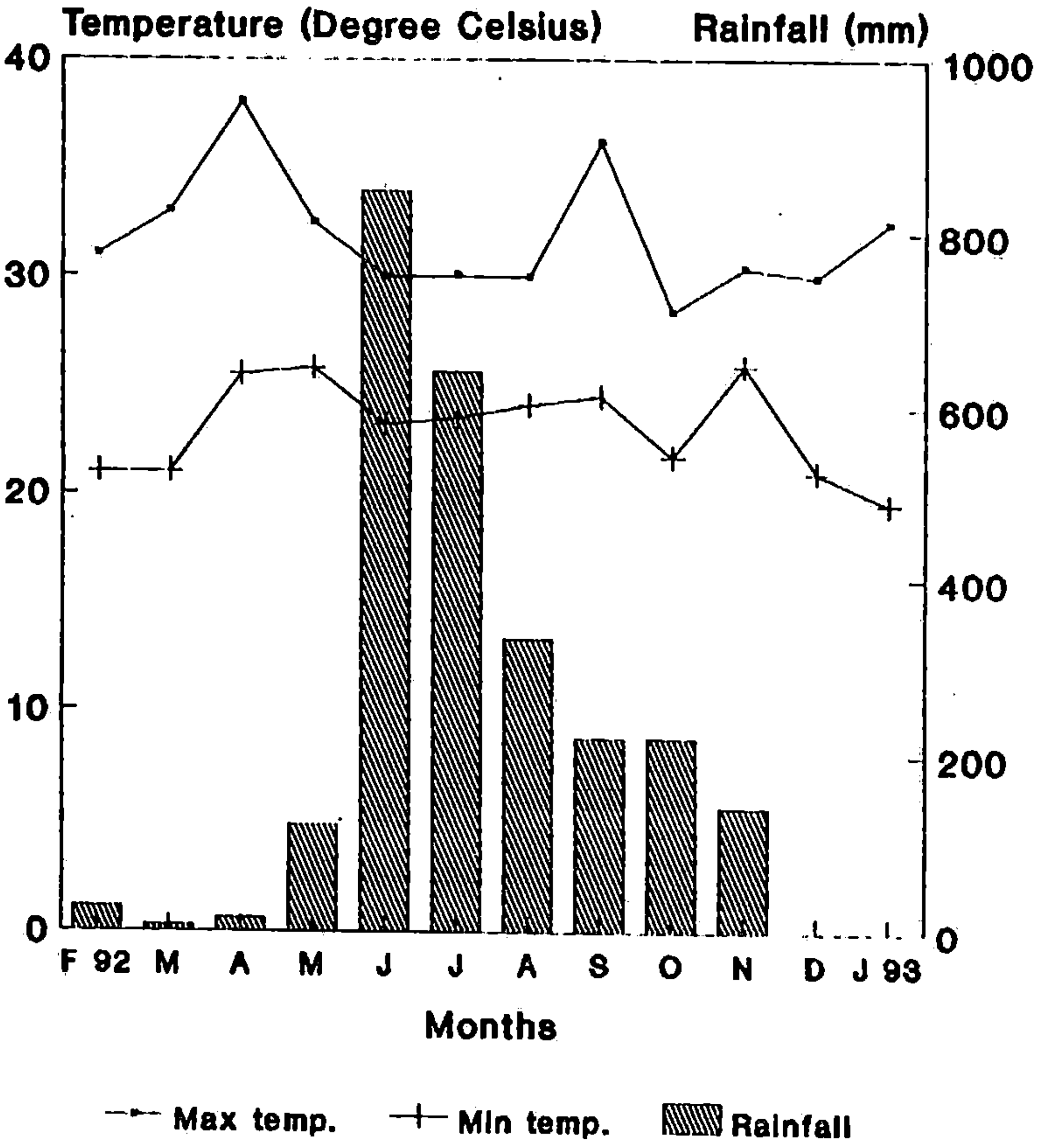
3.1.1 Climate

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 season (Fig.1) The mean maximum temperature at the nearby Dhoni farm ranges from 28.4°C (October) to 38.0°C (April). The mean minimum temperature varies from 19.5°C (January) to 25.9°C (November) (Fig.1).

3.1.2 Soil

The soil of the experimental site was oxisol having a pH of 5.1.

Fig. 1 Weather parameters for the experimental period (February 1992 to January 1993)



3.2 Field experiment

A randomised block design experiment involving factorial combinations of four fodder species: Pennisetum purpureum Schumach. (hybrid napier), Brachiaria ruziziensis Germain & Everard. (congo signal), Panicum maximum Jacq. (guniea grass) and Zea mexicana (Schrad.) Reeves & Mangelsd. (teosinte) and four tree species (Leucaena leucocephala (Lam.) de Wit., Casuarina equisetifolia J.R. & G. Forst., Acacia auriculiformis A. Cunn. ex Benth. and Ailanthus triphysa (Dennst.) Alston.), initiated in June 1988 (Fig.2 and Plate I, II) was used for the present investigations. In order to quantify the magnitude of forage yield loss due to the overstorey trees, additional plots comprising of the four forage species, (three replicates) were established in the area adjoining to the original experimental plot.

In the original experiment, trees were planted in plots of 6 m x 6 m in two rows, 4 m apart. Each row consisted of six trees spaced at 1m distance constituting 12 trees per plot. All plots were demarcated by 50 cm wide bunds on all sides. The fodder species were planted in the alleys of trees, since 1988. A spacing of 60 cm x 30 cm was followed in the case of Pennisetum purpureum and Brachiaria ruzizensis, while for Panicum maximum and Zea mexicana the

Plates I & II Silvopastoral experimental plots at Thiruvazhamkunnu, Palakkad, Kerala

spacing followed were 40 cm x 20 cm and 30 cm x 15 cm respectively (KAU, 1992).

3.2.1 Fast growing trees

a) Leucaena leucocephala (Lam.) de Wit.

A fast growing nitrogen fixing tree native to Central America and Mexico occurring both as a branched shrub and a tall single trunked tree growing to a height of 5 m to 20 m in 4 to 5 years. The leaves are feathery and permit high amount of sunlight to reach the ground. The foliage is an excellent source of cattle feed and green manure. Acetylene reduction method and difference method which have been used to evaluate nitrogen fixation potential of this species gave figures in the range of 100 to 500 kg ha^{-1} $year^{-1}$ (NAS, 1980). The wood has a calorific value of 19492 KJ kg^{-1} (Prakash and Hocking, 1986).

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

A native of Australia, Casuarina is fast growing nitrogen fixing tree suitable for sand dune stabilization, wind breaks and fence posts. The jointed branchlets are green and perform the functions of leaves. The wood is used for pulp and fuel. Calorific value of heart wood is 20585 KJ kg^{-1}(NAS, 1980).

c) *Acacia auriculiformis* A. Cunn. ex Benth.

An evergreen tree with dense foliage and open spreading crown, native to Papua New Guniea and northern areas of Australia. It was introduced to India and many other tropical countries in the recent past. The most outstanding feature of this species is its ability to grow on marginal soils and to fix atmospheric nitrogen. The wood is used for fuel, pulp and charcoal. The calorific value of heart wood is estimated to be 20450 KJ kg^{-1} (NAS, 1980).

d) *Ailanthus triphysa* (Dennst.) Alston.

A deciduous tree with a tall cylindrical trunk attaining a height of about 30 m, indigenous to the Indian sub-continent. It is extensively grown in the homesteads of Kerala and is one of the best match wood species (NAS, 1980).

3.2.2 Fodder species

a) *Pennisetum purpureum* Schumach.

A tropical grass from Africa characterized by robust growth and requiring a warm humid climate. It grows to a height of 3 to 3.8 m and can be grown under rainfed or irrigated conditions. Seed setting is generally very poor and hence propagated by cuttings (Skerman and Riveros, 1990).

b) Panicum maximum Jacq.

A drought tolerant, shade bearing, erect, perennial grass, native to tropical and sub-tropical Africa, sometimes grown as an intercrop in coconut plantations. The crop grows to a height of 1.8 to 2.7 m with dark green leaves, flowers profusely but seed setting poor. It may be used for making hay and silage and contains about 5 to 8 per cent crude protein (Skerman and Riveros, 1990).

c) Brachiaria ruziziensis Germain & Everard

An East African introduction highly suitable for soil conservation and grows to height of 1 m. This perennial grass requires a warm humid climate and is grown as an intercrop in coconut gardens. It contains 10 to 14 per cent crude protein and is relished by cattle. It is ideal for hay making and silage. Seed setting is comparatively high (Skerman and Riveros, 1990).

d) Zea mexicana (Schrad.) Reeves & Mangelsd

Zea, the progenitor of cultivated maize has originated in the Central American tropics. This seed propagated annual is considered an ideal fodder crop and is used for silage making (Skerman and Riveros, 1990).

3.3 Forage Planting

As part of the plot preparation exercise for planting fodder grasses, the lateral branches of trees were pruned during June, 1992, leaving the leader intact. The pruned materials were subdivided into logs (diameter >2 cm), branches and leaves and their weights recorded using spring scales. Representative samples (three replicates) were collected to ascertain the fresh to dry matter ratio from each fractions. The leaves were then incorporated into the respective plots from where the prunings were obtained (on an average 1970.3 kg ha^{-1}, 237.2 kg ha^{-1}, 548.6 kg ha^{-1} and 1117.5 kg ha^{-1} respectively for acacia, casuarina, leucaena and ailanthus, respectively; Appendix II).

The grass stubbles of the previous crops were removed and the plots hoed and levelled during June 1992. Fertilizers were applied uniformly at the rate of 200 kg N ha^{-1}, 50 kg P_2O_5 ha^{-1} and 50 kg K_2O ha^{-1}, in two equal split doses on 14th June, 1992 (basal dressing) and 15th August, 1992 (top dressing; KAU, 1992). Two slips of hybrid napier, congo signal and guniea grass were planted per hole at the spacing mentioned in Section 2.0 on 15th June, 1992 throughout the plot. In the case of teosinte, two seeds per plot were dibbled at the recommended spacing (KAU, 1992). The plots were weeded and gap filled on 1-7-1992 and 15-7-1992.

3.3.1 Harvesting forage crops

The fodder species except teosinte were cut at an interval of approximately 45 days. In total four harvests were made during the experimental period (16-8-92, 3-11-92, 31-12-92 and 26-4-93). Teosinte, however, was harvested only once on 31st December, 1992. For estimating the fodder biomass three representative random quadrats of 1 x 1 m dimension were harvested from the alleys of each plot and fresh weights of the harvested material recorded in the field. Besides, three replicates samples per species (approximately 0.5 kg each) were collected to ascertain the fresh to dry matter ratio.

3.4 Biometric observations of fodder species

Three random hills were destructively sampled on 31st December, 1992, from each plot and the following measurements made:

1. Mean plant height
2. Mean number of tillers per hill

3. Mean number of leaves per tiller
4. Mean dry matter weight per tiller.

3.4.1 Tree allometric observations

Total tree height and diameter at breast height were enumerated on three randomly selected trees from each plots at six monthly intervals (September 1992 and March 1993). The crown diameters of same three trees were also measured during March 1993 by projecting the edges of the crown and measuring the distance between the widest points in any two directions and calculating their arithmetic mean.

The experimental data pertaining to forage crops and trees were statistically analysed following the analysis of variance technique, using MSTATC statistical software.

3.5 Litter collection

The litter collections were made using specially designed traps (Hughes et al., 1987). Each trap was made of four 210 cm long galvanised (2 to 3 mm) iron wire frames. A hoop of 55 cm diameter was made by overlapping the ends of the wire and tying them firmly. A tripod was made using the remaining three galvanized wires. The 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 liters capacity. Nineteen such traps were randomly placed in the alleys of trees so that each of the four tree species had more or less equal number of (4 or 5) traps on January 31st, 1992.

Litter collections were made from each traps at monthly intervals for a one-year period from 1st February, 1992 to 31st January, 1993. The leaf litter was sorted initially into target species litter and neighborhood tree litter. Target tree litter was further fractionated into leaves, twigs, branches, reproductive parts and residual mass (that fraction whose category/origin could not be ascertained).

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

3.5.1 Litter decomposition

Standard litter bag technique was employed for characterising litter decomposition dynamics. Freshly fallen leaves of leucaena, casuarina, acacia, and ailanthus were collected. The collected samples were 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 samples into the litter bags. The bags were then placed in the litter layer of the soil in the plot adjoining to the experimental area. A total of 120 samples for each species were placed (four species with 10 replicates each for 12 months).

At monthly intervals, starting from 1st February, 1992 to January, 31st 1993, residual mass from the litter bags were retrieved by carefully removing the accumulated soil and litter over the bags and returning them to the laboratory, after removing the extraneous materials like large anthropods, fine roots and soil and washing in running water.

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 also assesed by the Van Soest (1966) method for estimation of acid detergent fiber and lignin. For lignin assay, one gram of leaf samples (two replicates each for a species) were weighed, to which 100 ml cold acid-detergent solution (prepared by adding 20 g of cetyl trimethylammonium bromide (CTAB) to one liter of one normal H_2SO_4) and 2 ml of decahydro naphthalene (decalin) were added to the sample. This was refluxed for 60 minutes on a refluxing rack. The sample was then filtered and washed with acetone. The filtrate was dried overnight and then weighed to determine the acid detergent fiber per cent. Seventy two per cent H_2SO_4 was poured into this dried sample and intermittently stirred at half hourly intervals. After filtering this solution, the sample was dried overnight and weighed, which was kept in a muffle furnace for three hours at 600°C and weighed at the end of this period. The weight difference between the sample before being kept in the muffle furnace to that afterwards, gave the lignin content of the sample.

3.5.2 Nutrients remaining in the litter

Nutrient content of the decomposing leaf was determined by the equation

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

were 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 DMo is the dry matter initial litter kept for decomposition (Bockheim et al., 1991).

3.5.2.1 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 logarithm, k is the decay rate coefficient and t is time, was fitted on the data on mass disappearance. Half lives ($t_{0.5}$) of decomposing litter were estimated from the k-values using the equation

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

$$= -0.693/-k \quad \text{(Bockheim et al., 1991)}$$

In addition to the exponential decay model characterized by Olson's (1963) equation, linear, quadratic and cubic functions were also fitted on mass disappearance data.

3.6 Solar radiation measurements

Light measurements were made from selected plots of each species during the period from 13th April, 1993 to 2nd May, 1993. Integrated values (at hourly intervals from 6 a.m. to 6 p.m.) of the photosynthetically active radiations (P.A.R.) in the open and under the canopy at 50 cm, 1.50 cm, 2.50 cm and 3.50 cm heights were recorded using a Point Quantum Sensor and a Line Quantum Sensor respectively, having a data logger attachment (Li Corp., Lincoln, Nebraska, U.S.A.).

3.7 Soil temperature and Climatic parameters

Five soil thermometers were installed (15 cm depth) under the canopy of the four tree species and one in the open grass plots (grass monocultures) and temperature recorded on a daily basis.

3.8 Characterization of root interaction with radioisotope technique

To assess the nature of root interactions among the components of the silvopastoral system radiotracer technique involving ^{32}P soil injection was employed (Plate-III). The experimental variables included combinations of two lateral distances (15 cm and 50 cm) from the tree and two depths (15 cm and 50 cm), besides the tree-grass combinations (20 numbers) mentioned in section 2.0.

Selection of trees (experimental units) for ^{32}P application was done on the basis of uniformity of growth and maximum distance as far as possible between two experimental units, so as to ensure minimum interference to adjacent units (Fig. 2). Each unit was replicated thrice. A particular tree-grass combination thus had a total of 12 such experimental units. The experimental units for radioisotope application were laid out in a completely randomized factorial design.

Six equally spaced holes were dug to the required depth and lateral distance as per the treatments protocol using a soil auger of 2.5 cm diameter for ^{32}P application. The holes in a row were spaced at 25 cm apart (Fig. 3). 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 plastic cap to prevent entry of rain water. ^{32}P solution at the rate of 1.25 mCi at carrier level of

Fig. 3 Layout plan for isotope application

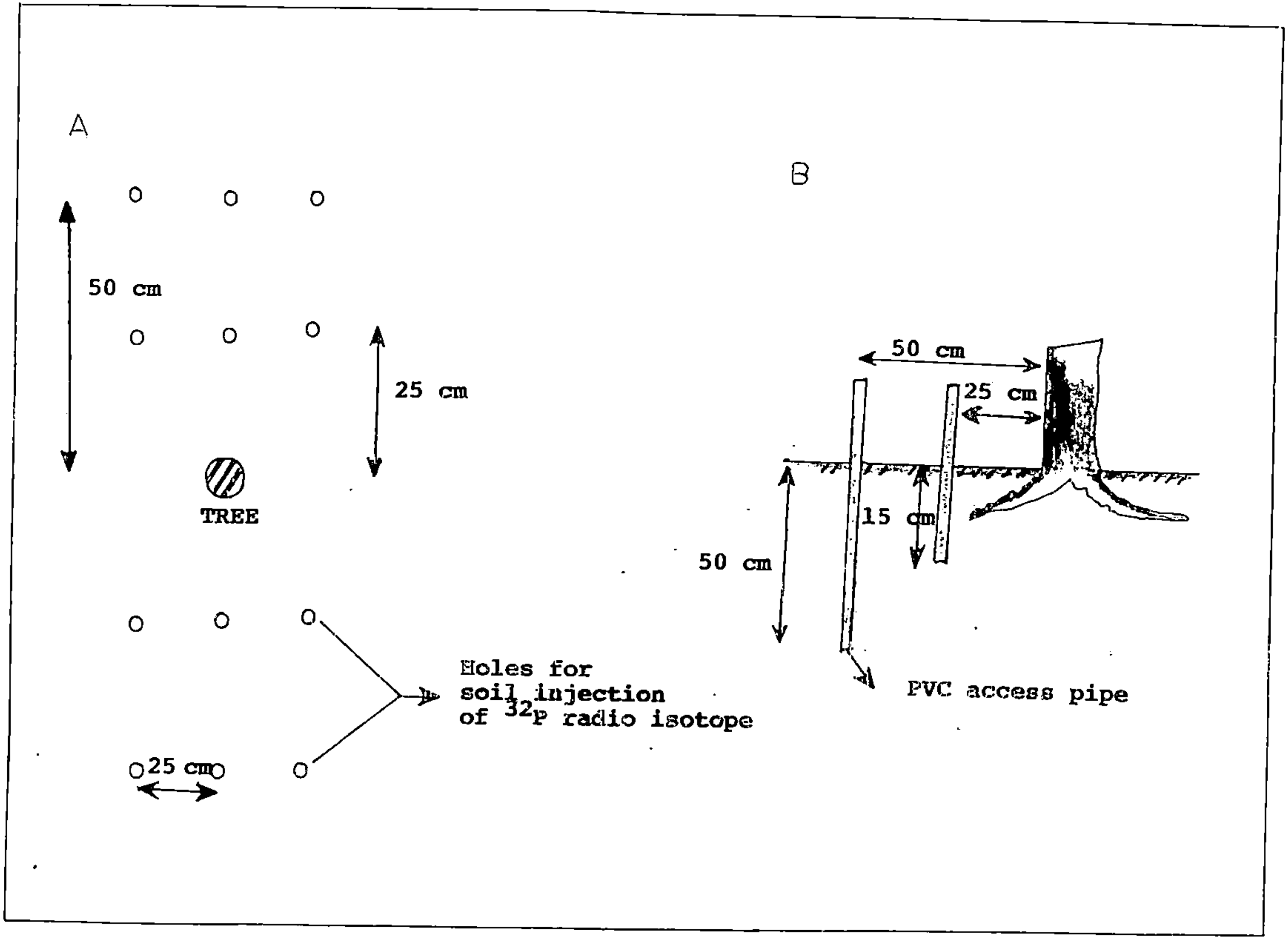


Plate III Soil injection of ^{32}P radioisotope for assessing the tree-grass root interactions

1000 ppm P was dispensed into the access tube at the rate of 4 ml per hole on October 17, 1992, using a 'Lumac Dispensette' suitable for repeated delivery of fixed volumes. The whole dispensette was kept in a sealed apparatus ensuring the highest radiation shielding. The shielding materials used in the construction had very low Bremsstrahlung (Wahid et al.,1988).After dispensing, the residual activity remaining inside the access tube was washed down with a jet of about 15 ml water. The inclusion of carrier in the ^{32}P solution was to minimise the soil fixation of the radiolabel.

3.8.1 Leaf sampling and radioassay

Leaves from the treated trees and the grasses coming inside the limits of the experimental units, were sampled for radioassay. The first sampling was on November 2, 1992 and the second sampling on November 18, 1992, that is, 15 and 30 days after application of ^{32}P. The leaf samples were dried at 75° and radioassayed for ^{32}P content by Cerenkov counting technique (Wahid et al., 1985) at the Radioisotope Laboratory of 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 the ratio of 2:1) and the digest was transferred to a counting vial. The final contents in the vial was about

20 ml. The vials were counted in a liquid scintillation counter (Wallac 1409) Pharmacia Corp., Finland) by the Cerenkov counting technique employing a built-in computer programme for tritium counting. During the period of the experiment the Cerenkov counting efficiency remained constant at 32 per cent and hence the count rates were not converted to dpm but are expressed as cpm values.

Prior to statistical analyses, the cpm values were corrected for background as well as for decay and subjected to $\log_{10}$ transformation and analysis of variance was performed individually for different multipurpose tree species and forage crops. Assuming that the 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:

Per centage root activity at a particular lateral distance and depth = (Count rate (cpm g^{-1}) for that particular lateral distance and depth/ Total cpm for all the treatments) x 100.

3.9 Estimation of Tree Biomass

For biomass estimation all trees in eight 6m x 6m plots (two for each species) were felled almost at ground level using a 'Poulan' mechanised chain saw. The number of trees per species ranged from 15 to 22. The following observations were made on the felled trees.

1. Total height
2. Height upto first crown forming branch
3. Crown diameter
4. Girth at breast height

The felled trees were then partitioned into :

1. Stem wood (main shoot, if the main shoot forked below the BH level then such branches were also treated as stem wood).

2. Branch wood (all branches differentiating from the trunk) above breast height level.

3. Foliage

4. Coarse roots (all roots upto 5 mm in diameter) - For quantifying the coarse root component, three trees from each species were completely excavated and all roots greater than 5 mm in diameter were collected.

Fresh weights of all the above ground components were recorded tree-wise using appropriate spring scales (to either nearest 0.1 kg or 10 mg).

3.9.1 Sampling tree biomass fractions for moisture estimation, chemical analyses and leaf ares determination

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 width were cut at the breast height level and at the base of the crown from a randomly selected tree in each row of felled trees for chemical analyses and moisture estimation. Branch wood samples were 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 numbers) for each species.

The samples transported to the laboratory in double sealed polythene bags, after pre-weighing were dried to constant weights at 60-70°C. Species-wise composite samples were made from the different components after oven drying. The samples were ground to pass through a 2 mm mesh. Three sub-samples were then drawn from the composite samples for phyto-chemical analyses.

Representative leaf samples (ca. 500 g) collected from the felled trees for estimating the total leaf area (three samples per species). These samples were transported to Vellanikkara in an insulated container wherein low temperature was maintained with ice cubes. The leaf area was measured using a 'Li Cor Model 3100' area meter (LiCor, Lincoln, Neberaska). Total leaf area for a species was calculated by multiplying this with the total fresh foliage weights.

Statistical analyses was carried out on the biomass data. Allometric equations were developed to predict total aboveground biomass of the four tree species. Equations of the following form were used :

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

   B=total aboveground 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 the

   $ln=B=c+b \ ln \ DBH^2H$ (Rana *et al*., 1989.

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

   B=total aboveground 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 aboveground biomass H=total height DBH=Diameter at breast height a, b and c are coefficients.

3.10 Phytochemical Analyses

Triplicate samples of each tissue fractions 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 estimated after digesting the sample in a triple acid mixture (HNO_3), H_2SO_4 and $HClO_4$ in the ratio 10:1:3). Phosphorus was determined following the vanado-molybdo phosphoric yellow colour method and potassium by flame photometry (Jackson, 1958).

3.11 Soil chemical analyses

Soil samples were collected from the interspaces between the two rows of trees at three points in the 15 cm layer in different treatments and was air dried and ground to pass through a 2 mm sieve. Two sub-samples were made from each treatment for chemical analyses. Moisture content of the soil was ascertained by drying to constant weights at 105°C.

Soil pH was determined 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 an oven dry basis (micro-Kjeldhal method), available P was extracted following the Bray method (number I) and phosphorus content was then colourimetrically 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 Tree height and Diameter

The four multi-purpose tree species grown in silvopastoral system exhibited marked variations in their growth rates at five years of age (Table 1 and Appendix III). Acacia recorded the maximum height of 9.38 m, and was about 280 per cent greater than ailanthus which, in turn, recorded the lowest value. The height increment was 1.99, 1.21, 2.86 and 0.74 m yr^{-1} for acacia, casuarina, leucaena and ailanthus respectively during the period from March, 1992 to March, 1993. Surprisingly, the indigenous tree ailanthus had the lowest radial growth rate while acacia and leucaena showed substantial radial growth rates (11.1 and 9.5 cm respectively) and were significantly superior to both casuarina and ailanthus (5.6 and 4.8 cm respectively). The difference between casuarina and ailanthus was not, however, statistically significant. Crown diameters of acacia, casuarina and leucaena did not differ significantly but were markedly superior to ailanthus.

Allometry of the trees felled for biomass

Table 1. Growth characteristics of the five-year-old multipurpose fast growing trees grown in silvopastoral system during March, 1992 to March, 1993.

Tree-fodder combinations	Mean tree height (m) Sep 92	Mar 93	Mean tree D.B.H. (cm) Sep 92	Mar 93	Mean crown diameter (m) Mar 93
Acacia auriculiformis					
Pennisetum purpureum	8.750	9.553	8.345	11.594	2.524
Panicum maximum	8.097	9.287	8.015	10.805	3.872
Brachiaria ruziziensis	8.183	9.317	7.943	10.812	3.082
Zea mexicana	8.510	9.373	7.180	11.140	3.059
Overall mean	8.385	9.382	7.871	11.090	3.134
Casuarina equisetifolia					
Pennisetum purpureum	6.333	7.593	5.096	5.628	3.634
Panicum maximum	6.683	6.927	4.877	5.673	2.543
Brachiaria ruziziensis	6.233	6.595	4.673	5.906	2.476
Zea mexicana	6.000	6.553	4.714	5.077	3.141
Overall mean	6.313	6.917	4.840	5.571	2.948
Leucaena leucocephala					
Pennisetum purpureum	6.167	6.977	5.823	9.119	2.701
Panicum maximum	5.800	7.533	7.523	9.667	3.821
Brachiaria ruziziensis	6.517	7.833	6.480	9.657	3.821
Zea mexicana	5.933	6.977	6.227	9.584	2.937
Overall mean	6.104	7.535	6.514	9.507	3.320
Ailanthus triphysa					
Pennisetum purpureum	3.250	3.783	4.525	4.763	1.459
Panicum maximum	3.067	3.500	4.687	5.555	1.824
Brachiaria ruziziensis	2.833	3.003	4.184	4.637	1.629
Zea mexicana	2.600	2.933	3.830	4.252	1.605
Overall mean	2.937	3.305	4.307	4.802	1.629
Tree means					
P	<0.01	<0.01	<0.01	<0.01	<0.01
SEM (±)	0.1377	0.2430	0.1944	0.2816	0.2992
CD (0.05)	0.3963	0.7004	0.5595	0.8125	0.8611
Fodder means					
P	<0.01	<0.01	<0.01	<0.01	<0.01
SEM (±)	0.1377	0.2430	0.1944	0.2816	0.2992
CD (0.05)	N.S.	N.S.	N.S.	N.S.	N.S.
Tree-fodder interaction					
P	<0.01	<0.01	<0.01	<0.01	<0.01
SEM (±)	0.2754	0.4861	0.3899	0.5632	0.5984
CD (0.05)	N.S.	N.S.	N.S.	N.S.	N.S.

Table 2. Allometric data for five-year-old, destructively sampled fast growing multipurpose trees in a silvopastoral system

Sl. No.	Species	Height (m)	DBH (cm)	Crown Diameter (cm)	Leaf area (m^2 $tree^{-1}$)
1.	*Acacia auriculiformis*	10.914	9.283	4.281	58.083
2.	*Casuarina equisetifolia*	8.235	5.537	2.998	0.192&
3.	*Leucaena leucocephala*	9.054	6.697	3.005	7.079
4.	*Ailanthus triphysa*	4.182	5.636	1.663	4.232
p		<0.01	<0.01	<0.01	<0.01
Treatment comparisons CD (0.05)					
1- 2		1.4314	1.5465	1.8405	21.1387
1- 3		1.3563	1.4410	1.7513	20.0606
1- 4		1.3711	1.4557	1.8104	20.0899
2- 3		1.4839	1.5985	1.8935	21.8755
2- 4		1.4974	1.6115	1.9482	21.9024
3- 4		1.4258	1.5105	1.8642	20.8638

& Projected leaf area (one side of the needle) estimation (Table 2 and Appendix V also showed that acacia was significantly superior to other species in respect of total height and diameter at breast height (D.B.H.). Acacia recorded significantly higher total leaf area compared to other three species.

4.1.2 Biomass accumulation

Biomass accumulation was highest for acacia (182.82 Mg ha^{-1}) compared to other three species ($p < 0.01$, Table 3 and Appendix IV). All the biomass components also exhibited this trend. By and large, foliage had the least biomass yields (5.2 to 8.5 % of the total biomass) and tree boles the highest relative allocation of the total biomass (ranging from 66.59 % for leucaena to as much as 71.74 % in casuarina) in all species (Table 2, Fig. 4 and Appendix VI). Interestingly below ground portion did not exhibit any marked variability among species, although leucaena and ailanthus showed comparatively higher biomass accumulation rates in the root.

4.1.2.1 Tree allometric relationships

Among the various power equations tried relating the biomass with stand parameters such as height (H) and/or DBH, the equations which yielded the best fit are presented in Table 4. All trees except ailanthus gave good results

Fig. 4 Biomass accumulation in various organs of four MPT species

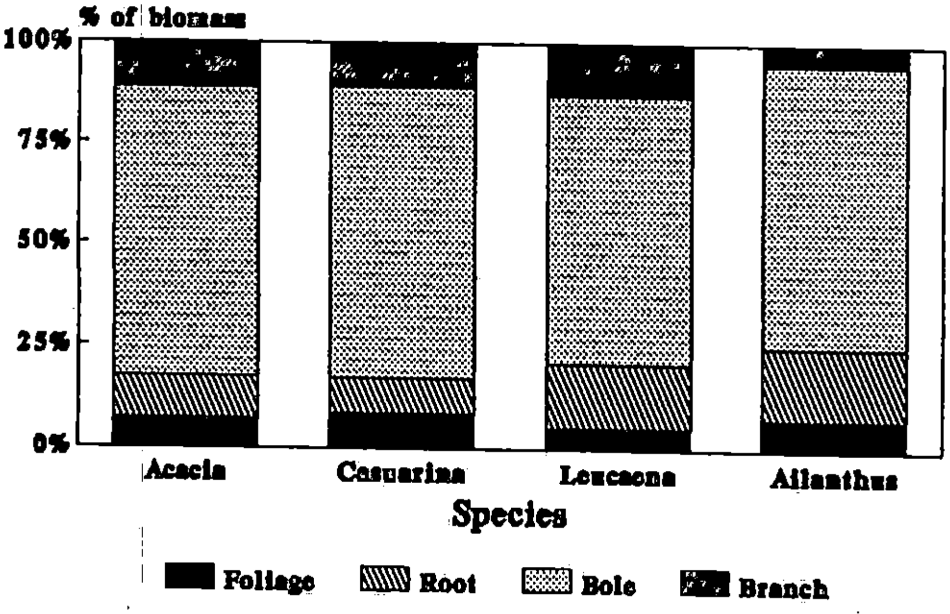


Fig. 5 Nutrient use efficiency of four MPT species for N, P and K

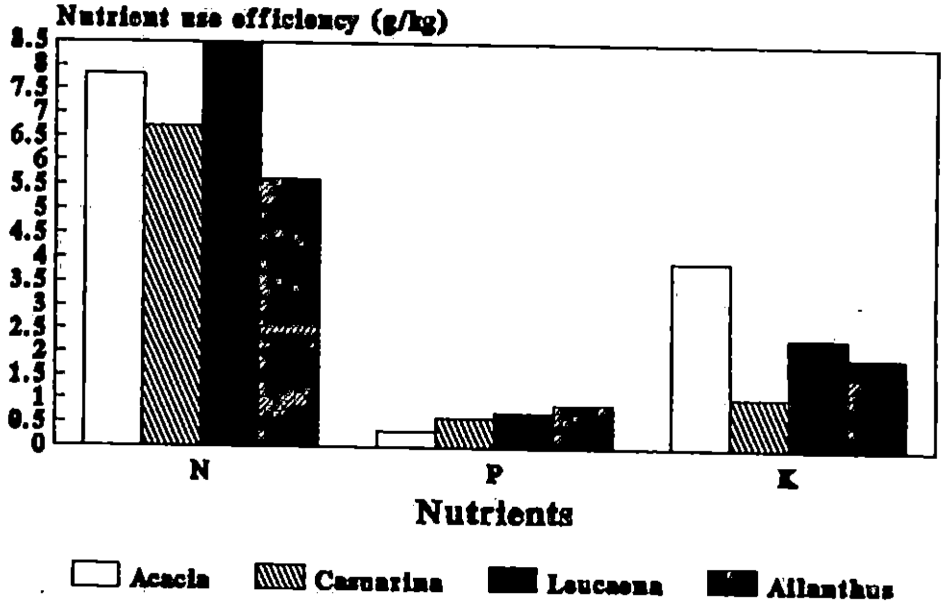


Table 3. Mean dry matter yield (kg tree^{-1} and Mg ha^{-1}) of four multipurpose fast growing trees grown in silvopastoral system at five years of age.

Sl. No.	Species	No. of trees felled (n)	Biomass components									
			Foliage		Branch		Bole		Root[&]		Total	
			kg per tree	Mg per ha	kg per tree	Mg per ha	kg per tree	Mg per ha	kg per tree	Mg per ha	kg per tree	Mg per ha
1	*Acacia auriculiformis*	21	4.43 (7.62)	12.91	7.00 (11.16)	20.40	44.70 (71.40)	130.54	6.50 (10.37)	18.90	62.68	182.82
2	*Casuarina equisetifolia*	15	1.34 (8.56)	2.79	1.71 (10.94)	3.75	11.26 (71.94)	23.45	1.34 (8.56)	2.79	15.65	32.61
3	*Leucaena leucocephala*	19	1.62 (5.22)	4.28	3.99 (12.84)	10.52	20.67 (66.59)	54.55	4.79 (15.43)	12.64	31.04	81.91
4	*Ailanthus triphysa*	20	0.71 (7.45)	1.98	0.46 (4.77)	1.27	6.70 (70.07)	18.62	1.69 (17.69)	4.70	9.57	26.57
p			<0.01		<0.01		<0.01		N.S.		<0.01	
Treatment comparisons CD (0.05)												
1- 2			1.2039		1.9683		12.8342		-		15.4979	
1- 3			1.2960		1.8497		12.0166		-		14.5161	
1- 4			1.1153		1.8210		11.8585		-		14.3291	
2- 3			1.2301		2.0077		13.1087		-		15.8376	
2- 4			1.2169		1.9813		12.9640		-		15.6664	
3- 4			1.1435		1.8636		12.1550		-		14.6961	

& n for root component is 3 for all the species
Figures in parenthesis indicates relative proportion of total biomass (%)

Table 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	Equation	a	b	c	S.E.E.	r^2	n
Acacia auriculiformis	$\ln B = a + b \ln DBH + c \ln H$	-2.244	1.907	0.772	0.297	0.9038	21
Casuarina equisetifolia	$\ln B = a + b \ln DBH + c \ln H$	-2.943	0.837	1.794	0.368	0.9238	15
Leucaena leucocephala	$\ln B = a + b \ln DBH + c \ln H$	-4.236	1.014	2.318	0.342	0.9548	19
Ailanthus triphysa	$\ln B = a + b \ln DBH$	-7.895	2.623		2.508	0.6711	20

with the log linear relationship of the form ln B= a + b ln DBH + c ln H while for ailanthus the equation of the form: ln B = a + b ln DBH gave better results (B=biomass and a,b,c are constants).

4.1.3 Tissue nutrient concentration

The concentrations of N, P and K in different biomass fractions showed significant differences except for bole P content. The concentration of N, P and K in the above ground portions decreased in the order: leaves > branches > bole (Table 5 and AppendixVI). The tissue nutrient concentration in roots was next only to the foliage in all the four species for N and P. Potassium levels, however, did not exhibit any consistent trend in this context.

As regard to foliage N content, leucaena foliage had the highest N content compared to the remaining three species (4.05 %) while casuarina had the lowest (1.56 %) and ailanthus and acacia were intermediates. As regards to the root N content, ailanthus and leucaena were statistically at par, while both acacia and casuarina had perceptibly higher levels of N. Acacia showed substantially lower values of P for all the biomass components. No clear cut trend could be observed in the case of K content of the different tissue fractions. Leucaena showed the highest K content in its

Table 5. Tissue nutrient concentration (%) of four multipurpose fast growing species

Species	Biomass components			
	Foliage	Branch	Bole	Root
Nitrogen (%)				
Acacia auriculiformis	2.319	0.931	0.518	1.143
Casuarina equisetifolia	1.866	0.764	0.441	1.288
Leucaena leucocephala	4.051	1.139	0.594	0.592
Ailanthus triphysa	2.760	0.505	0.338	0.549
p	<0.01	<0.01	<0.05	<0.01
SEM	0.22	0.04	0.02	0.10
CD (0.05)	0.7343	0.0668	0.1335	0.3338
Phosphorus (%)				
Acacia auriculiformis	0.081	0.035	0.031	0.045
Casuarina equisetifolia	0.153	0.123	0.043	0.108
Leucaena leucocephala	0.171	0.086	0.057	0.085
Ailanthus triphysa	0.123	0.125	0.076	0.110
p	<0.01	<0.01	N.S.	<0.01
SEM	0.01	0.01	0.01	0.01
CD	0.0334	0.0334	0.0334	0.0334
Potassium (%)				
Acacia auriculiformis	1.082	0.384	0.264	0.253
Casuarina equisetifolia	0.470	0.119	0.053	0.128
Leucaena leucocephala	1.392	0.348	0.134	0.178
Ailanthus triphysa	0.477	0.376	0.162	0.163
p	<0.01	<0.05	<0.01	<0.01
SEM	0.07	0.06	0.03	0.04
CD	0.2336	0.2002	0.1001	0.1335

leaves, while acacia showed significantly high K concentrations for root and bole fractions.

4.1.3.1 Nutrient accumulation and nutrient use efficiency

A one to one relationship was lacking between accumulation of biomass and nutrient accumulation (Table 6 and Appendix VII). Nutrient use efficiency of various macro-elements also exhibited profound variability among the tree species and biomass components (Table 7; Fig. 5 and Appendix VIII). Considering the whole tree biomass, leucaena showed significantly higher nutrient to biomass ratio for N followed by acacia. The same trend was discernible for other biomass fractions also except roots. For roots acacia and casuarina had significantly higher values of N use efficiency. In contrast for P, ailanthus showed the highest efficiency values (0.90) and acacia the lowest (0.36). Nevertheless, acacia had highest values of root K use efficiency. The differences were statistically significant in this respect also.

4.2 Understorey herbage yield

As regards to productivity of the four individual forage species, both green fodder and dry matter yield differed significantly ($p<0.01$; Table 8; Fig. 6 and Appendix IX). Acacia and leucaena had a marked negative

Table 6. Nutrient accumulation in different tree organs of species planted in silvopastoral system at 5-years of age

Species	Biomass components									
	Foliage		Branch		Bole		Root		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}
Nitrogen										
Acacia auriculiformis	102.77	299.74	65.33	190.54	230.95	673.60	74.10	216.61	489.50	1427.71
Casuarina equisetifolia	25.02	52.12	13.11	27.31	49.54	103.21	17.28	36.00	104.95	218.64
Leucaena leucocephala	65.66	173.27	45.35	119.67	122.64	323.63	28.42	75.00	262.08	691.60
Ailanthus triphysa	19.60	54.44	2.32	6.44	22.55	62.64	9.30	25.83	53.77	149.36
p	<0.01		<0.01		<0.01		<0.01		<0.01	
SEM	3.97		1.14		14.94		6.90		15.79	
CD (0.05)	12.9469		3.7177		48.7220		22.5021		51.49	
Phosphorus										
Acacia auriculiformis	3.54	10.32	2.80	8.17	13.41	39.11	2.82	8.22	22.57	65.83
Casuarina equisetifolia	2.01	4.19	2.05	4.27	4.50	9.37	1.43	2.99	9.99	20.81
Leucaena leucocephala	2.75	7.26	3.32	8.76	12.40	32.72	3.99	10.53	22.47	59.29
Ailanthus triphysa	0.85	2.36	0.58	1.61	5.36	14.89	1.86	5.17	8.65	24.03
p	<0.01		<0.01		<0.05		<0.01		<0.01	
SEM	0.16		0.20		1.94		0.37		2.3	
CD (0.05)	0.5218		0.6522		2.3409		3.2612		7.5007	
Potassium										
Acacia auriculiformis	47.99	139.97	27.07	78.95	116.96	341.13	55.25	161.14	246.53	719.04
Casuarina equisetifolia	6.34	13.10	1.99	4.14	6.70	13.96	1.70	3.54	16.73	34.85
Leucaena leucocephala	22.57	59.53	13.83	36.49	28.25	74.55	8.62	22.74	73.27	193.35
Ailanthus triphysa	3.36	9.44	1.74	4.83	10.72	29.78	2.76	7.67	18.65	51.80
p	<0.01		<0.01		<0.05		<0.01		<0.01	
SEM	1.78		3.20		11.21		2.26		11.57	
CD (0.05)	5.8049		10.4358		36.5578		7.3702		37.7318	

Table 7. Nutrient use efficiency of the four multipurpose tree species

Species	Nutrient use efficiency of different components (g nutrient per kg of biomass)				
	Foliage	Branch	Bole	Root	Total
Nitrogen					
Acacia auriculiformis	23.20	9.33	5.17	11.40	7.81
Casuarina equisetifolia	18.67	7.67	36.97	12.90	6.71
Leucaena leucocephala	40.53	11.38	5.93	5.93	8.44
Ailanthus triphysa	27.60	5.04	3.37	5.50	5.62
p	<0.01	<0.01	<0.01	<0.01	<0.01
SEM	2.16	0.23	1.72	0.97	0.33
CD (0.05)	7.0441	0.7501	5.6092	3.1633	1.2148
Phosphorus					
Acacia auriculiformis	0.80	0.40	0.30	0.43	0.36
Casuarina equisetifolia	1.50	1.20	0.40	1.07	0.64
Leucaena leucocephala	1.70	0.83	0.60	0.83	0.72
Ailanthus triphysa	1.20	1.27	0.80	1.10	0.90
p	<0.01	<0.01	<0.01	<0.01	<0.01
SEM	0.07	0.07	0.12	0.09	0.10
CD (0.05)	0.2283	0.2283	0.3913	0.2935	0.3261
Potassium					
Acacia auriculiformis	10.83	3.87	2.60	8.50	3.93
Casuarina equisetifolia	4.73	1.17	0.59	1.27	1.07
Leucaena leucocephala	13.93	3.47	1.37	1.80	2.36
Ailanthus triphysa	4.73	3.80	1.60	1.63	1.95
p	<0.01	<0.05	<0.01	<0.01	<0.05
SEM	0.66	0.60	0.26	0.36	0.19
CD (0.05)	2.1524	1.9567	0.8479	1.1740	0.6196

Fig.6 Yield of different forage crops grown in association with four MTP species

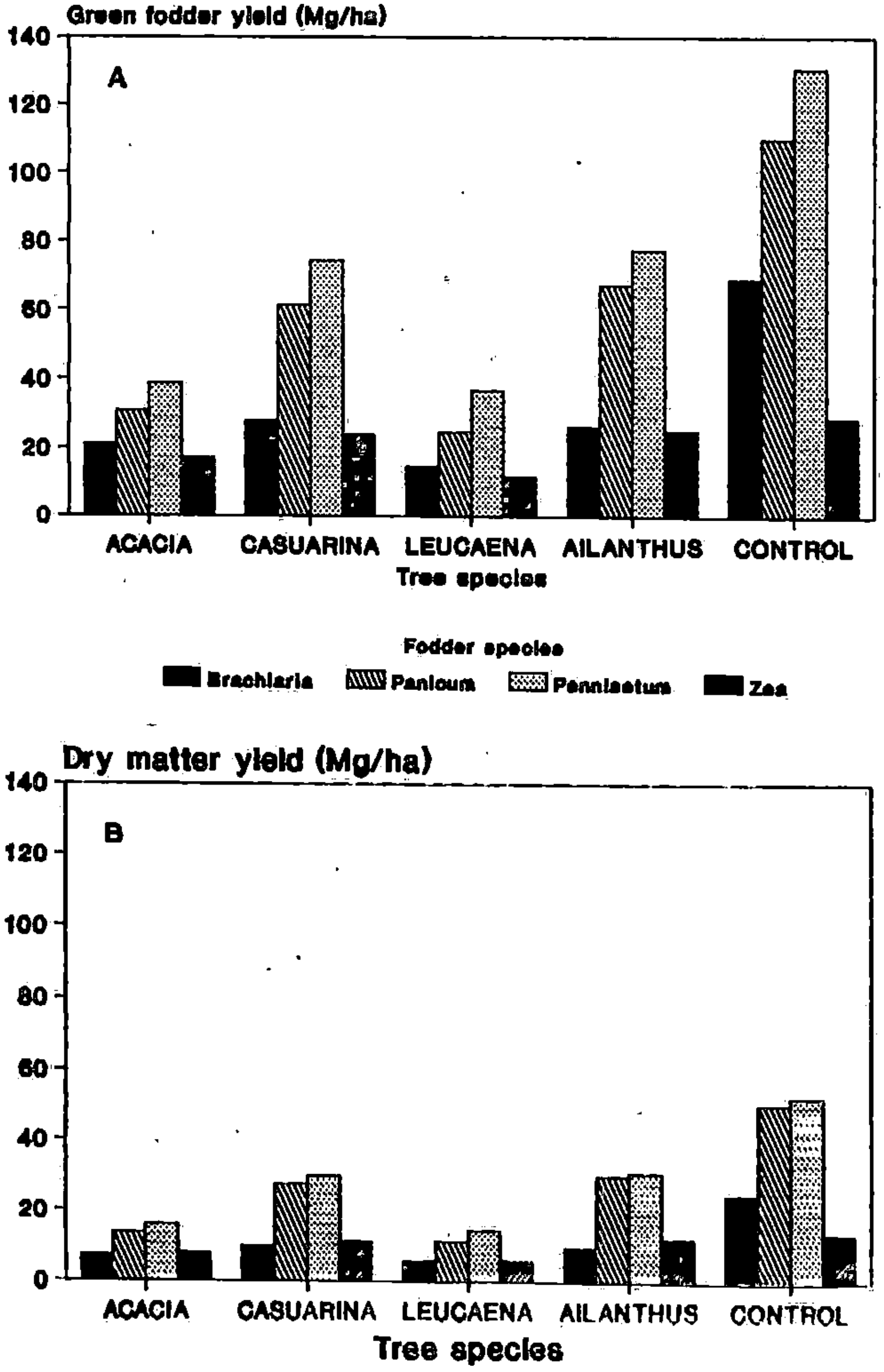


Table 8. Forage yields of diffferent fodder crops grown in association with four multipurpose tree species (mean of four harvests for all species except *Zea mexicana*, which was harvested only once)

Tree-fodder combinations	Mean green fodder yield (Mg ha^{-1})	Mean dry matter yield (Mg ha^{-1})
Acacia auriculiformis		
Pennisetum purpureum	38.8	16.0
Panicum maximum	30.8	13.7
Brachiaria ruziziensis	20.8	7.3
Zea mexicana	17.0	7.7
Casuarina equisetifolia		
Pennisetum purpureum	74.3	29.7
Panicum maximum	60.9	27.3
Brachiaria ruziziensis	28.0	9.7
Zea mexicana	23.9	11.0
Leucaena leucocephala		
Pennisetum purpureum	36.6	14.6
Panicum maximum	24.4	11.0
Brachiaria ruziziensis	14.5	5.3
Zea mexicana	11.4	5.7
Ailanthus triphysa		
Pennisetum purpureum	77.0	30.7
Panicum maximum	66.3	29.7
Brachiaria ruziziensis	26.0	9.3
Zea mexicana	25.0	11.7
Control (Tree-less)		
Pennisetum purpureum	130.4	52.0
Panicum maximum	109.9	49.7
Brachiaria ruziziensis	68.8	24.0
Zea mexicana	28.6	13.0
Fodder means		
Pennisetum purpureum	71.4	28.6
Panicum maximum	58.5	26.3
Brachiaria ruziziensis	31.6	11.1
Zea mexicana	21.2	9.8
Tree means		
p	<0.01	<0.01
SEM (±)	2.326	0.928
CD (0.05)	6.649	2.652
Fodder means		
p	<0.01	<0.01
SEM (±)	2.080	0.830
CD (0.05)	5.947	2.372
Tree-fodder interaction		
p	<0.01	<0.01
SEM (±)	4.653	1.856
CD (0.05)	13.299	5.304

effect on understorey herbage yields. Biomass production in the tree-less controls were significantly higher than that of other treatments of fodder species except teosinte. The productivity levels under ailanthus and casuarina were, however, statistically at par. On the whole, productivity decreased in the order: hybrid napier> guniea grass> congo signal> teosinte for both fresh fodder yield and on dry weight basis (71.43, 58.48, 31.61 and 21.18 Mg ha^{-1}) and dry weight yields (28.6, 26.27, 11.13 and 9.8 Mg ha^{-1}). The interaction effects were also highly significant. The combinations involving casuarina and ailanthus were generally better performers than other combinations both in terms of fresh weight and dry weight of fodder.

4.2.1 Fodder growth and yield attributes

The mean height of fodder grasses was significantly influenced by the different tree canopies (Table 9 and Appendix X). The highest mean height was registered in control plots (fodder species devoid of overstorey). Acacia overstorey had the most depressing effect in this context. Besides, leucaena also exhibited retarded understorey herbage growth. Congo signal and teosinte were characterised by considerably lower height under acacia and leucaena canopies compared to the tree-less

Table 9. Fodder growth and yield attributes of the forage crops grown in association with multipurpose tree species.

Tree-fodder combinations	Mean plant height (cm)	Mean number of tillers per hill	Mean number of leaves per tiller	Mean dry weight per tiller (g)
Acacia auriculiformis				
Pennisetum purpureum	162.3	36.0	7.3	2.9
Panicum maximum	138.8	37.7	5.1	1.1
Brachiaria ruziziensis	63.4	94.2	4.8	0.9
Zea mexicana	176.3	0.7	2.2	3.5
Casuarina equisetifolia				
Pennisetum purpureum	236.6	47.1	8.4	5.3
Panicum maximum	146.6	72.8	5.0	1.7
Brachiaria ruziziensis	103.7	91.5	6.5	1.3
Zea mexicana	304.4	1.0	5.1	6.2
Leucaena leucocephala				
Pennisetum purpureum	151.9	26.6	6.8	6.0
Panicum maximum	119.1	28.9	5.1	1.5
Brachiaria ruziziensis	60.5	104.6	5.3	1.0
Zea mexicana	238.9	0.2	2.8	2.3
Ailanthus triphysa				
Pennisetum purpureum	219.4	36.3	9.1	6.6
Panicum maximum	149.3	68.4	5.4	1.6
Brachiaria ruziziensis	108.2	112.9	5.8	1.2
Zea mexicana	305.7	1.0	2.2	5.3
Control (Tree-less)				
Pennisetum purpureum	277.3	36.8	10.8	6.4
Panicum maximum	170.7	79.7	5.1	1.9
Brachiaria ruziziensis	113.3	116.7	5.4	1.5
Zea mexicana	352.3	1.0	5.4	7.4
Forage means				
Pennisetum purpureum	209.5	34.5	8.5	5.4
Panicum maximum	144.9	57.5	5.1	1.5
Brachiaria ruziziensis	89.8	94.2	5.6	1.2
Zea mexicana	275.5	0.7	3.5	5.1
Tree means				
P	<0.01	<0.01	<0.01	<0.01
SEM (±)	8.474	0.847	0.074	0.073
CD (0.05)	24.218	2.705	0.212	0.208
Fodder means				
P	<0.01	<0.01	<0.01	<0.01
SEM (±)	7.579	0.846	0.066	0.065
CD (0.05)	21.650	2.420	0.189	0.186
Tree-fodder interaction				
P	<0.05	<0.01	<0.01	<0.01
SEM (±)	7.579	1.893	0.148	0.146
CD (0.05)	48.437	5.411	0.423	0.417

treatment. Similarly guniea grass under leucaena and hybrid napier under casuarina overstorey also registered reduced plant heights.

Mean number of tillers per hill and mean number of leaves per tiller were also significantly influenced by overstorey trees. Tree-less controls invariably registered the highest number of tillers per hill. Except in the case of congo signal, casuarina stands did not have any deleterious effect on the expression of tiller production potential of different forage crops (Table 9).

A similar trend was discernible in the case of number of leaves per tiller. There was a marked increase in the number of leaves per tiller for hybrid napier and teosinte in the open followed by its combination with ailanthus, casuarina, leucaena and acacia. However, guniea grass did not exhibit much variability in this respect and congo signal recorder the highest number of leaves per tiller under ailanthus canopy. As regards to dry weight per tiller, ailanthus again registered the highest dry weight followed by the control, leucaena, casuarina and acacia. Ailanthus and control values were, nevertheless, statistically at par. The depressing effect of acacia overstorey on the dry matter per tiller yield on all the forage crops was quite evident.

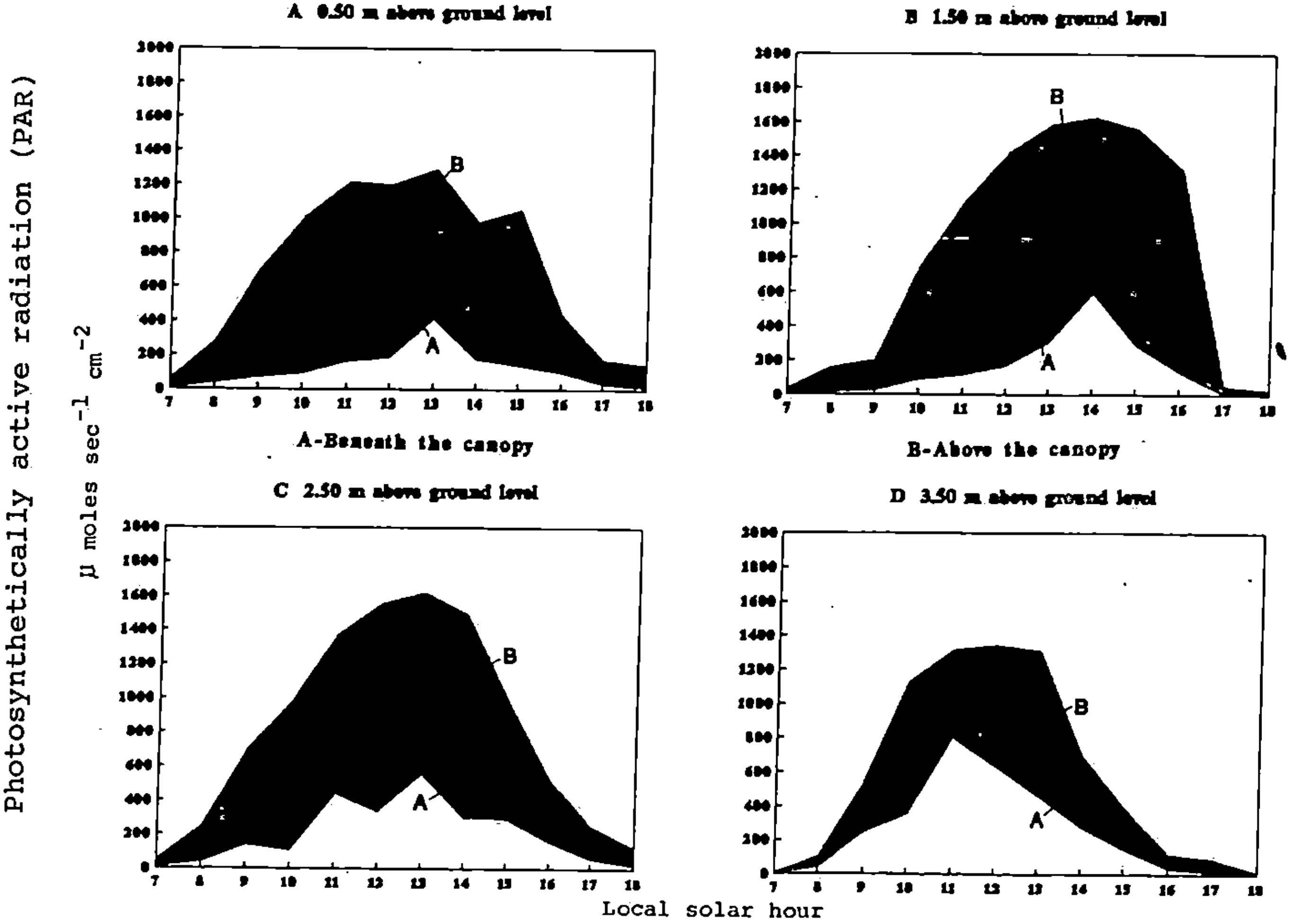
4.3 Canopy light interception

Large proportion of the incoming solar radiations in the photosynthetically active region (PAR) was intercepted by the acacia canopy (Table 10 and Fig. 7). The attenuation of light at various levels for acacia was most drastic (41.92 % of the open at 3.50 m and only 16.68 % at 0.50m above the ground level). Leucaena and casuarina facilitated relatively higher levels of light infiltration (50.2 % and 50.8 %, respectively of the open), (Table 10, Fig. 8 and 10). The photon flux density (PFD) at various levels was highest in the ailanthus stand. Although, the mean interception for ailanthus between 6.00 A.M. and 6.00 P.M.was 58.9 %, ailanthus crown intercepted the least PAR when the sun was overhead (Table 10, Fig. 9). In general, PFD levels increased as the height of measurement above ground level increased.

4.4 Soil temperature under tree canopies

Soil temperature under different multipurpose tree stands (0 - 15 cm depth) were generally lower than the open grasslands for most part of the year except November-December and April-May (Table 11 and Fig. 11). In

Fig. 7 Relative proportion of photosynthetically active radiation (PAR) intercepted at different heights above ground level (shaded region) in a 5-year-old stand of acacia. Each data point corresponds to the hourly integrated values of PAR. The data were recorded during the period from April 13, 1993 to April 16, 1993.


A 0.50 m above ground level

B 1.50 m above ground level

A-Beneath the canopy

B-Above the canopy

C 2.50 m above ground level

D 3.50 m above ground level

Fig. 8 Relative proportion of photosysnthetically active radiation (PAR) intercepted at different heights above ground level (shaded region) in a 5-year-old stand of casuarina. Each data point corresponds to the hourly integrated values of PAR. The data were recorded during the period from April 17, 1993 to April 20, 1993.

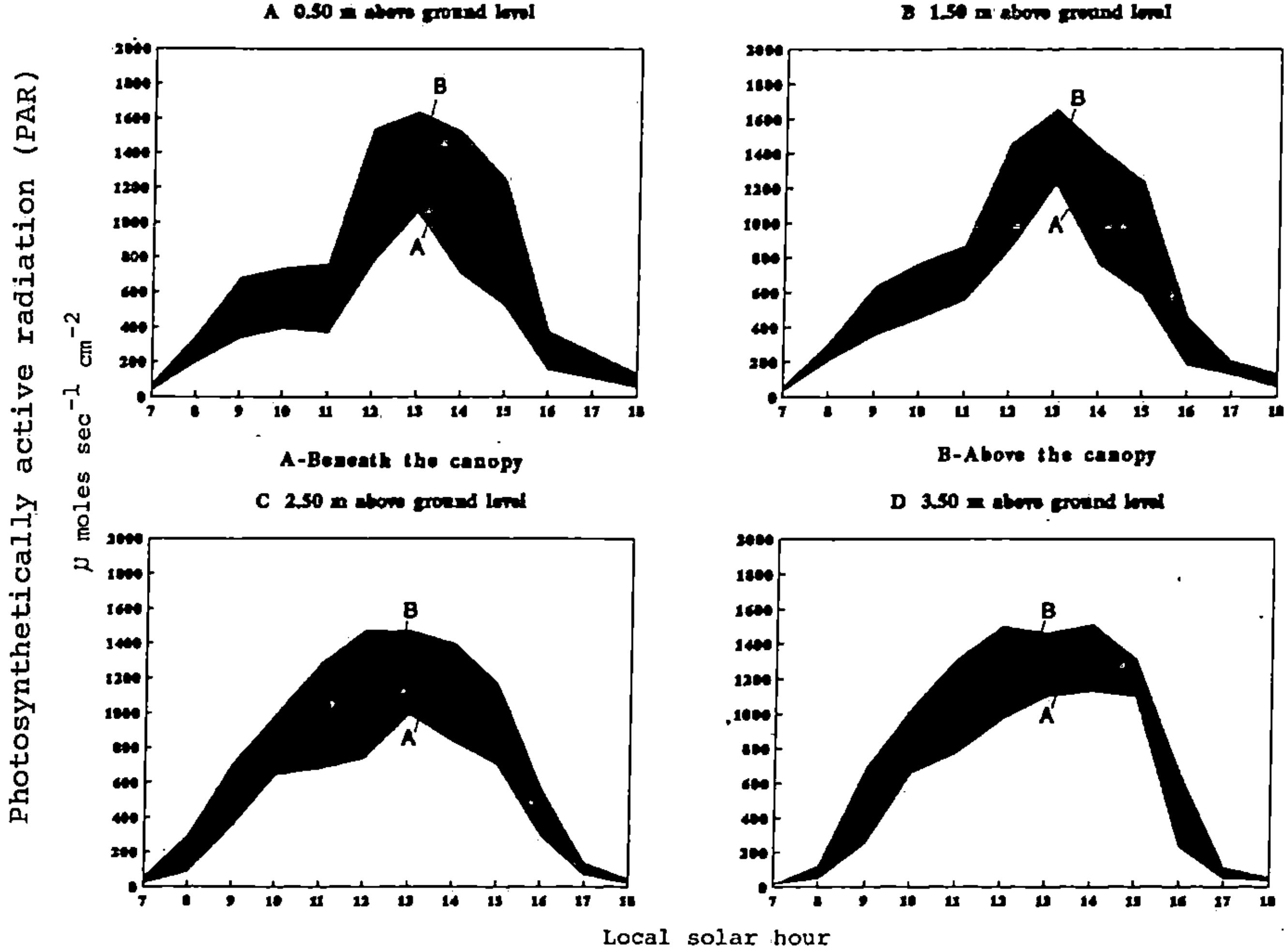
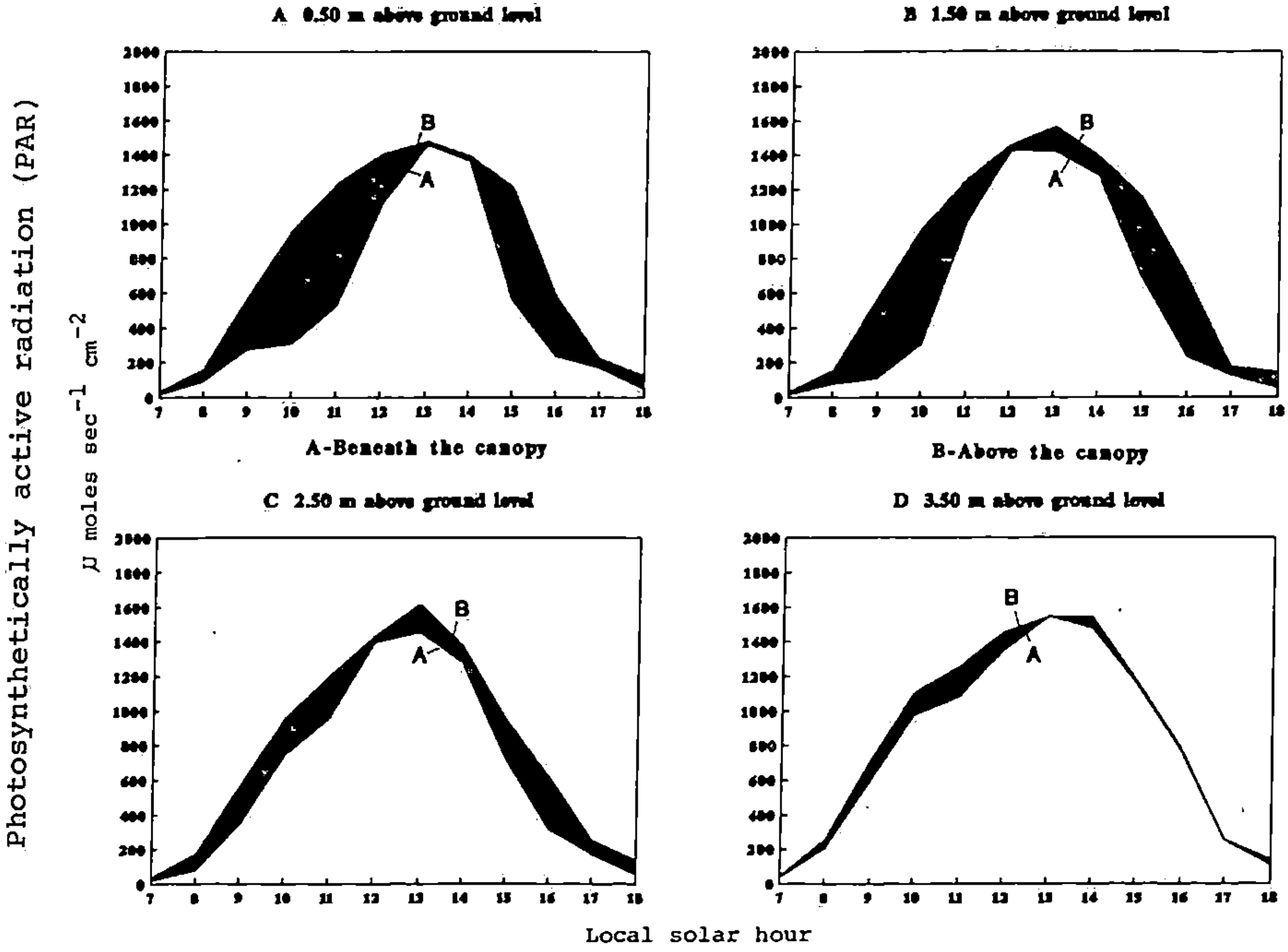


Fig. 9 Relative proportion of photosynthetically active radiation (PAR) intercepted at different heights above ground level (shaded region) in a 5-year-old stand of ailanthus. Each data point corresponds to the hourly integrated values of PAR. The data were recorded during the period from April 21, 1993 to April 24, 1993.



A 0.50 m above ground level

B 1.50 m above ground level

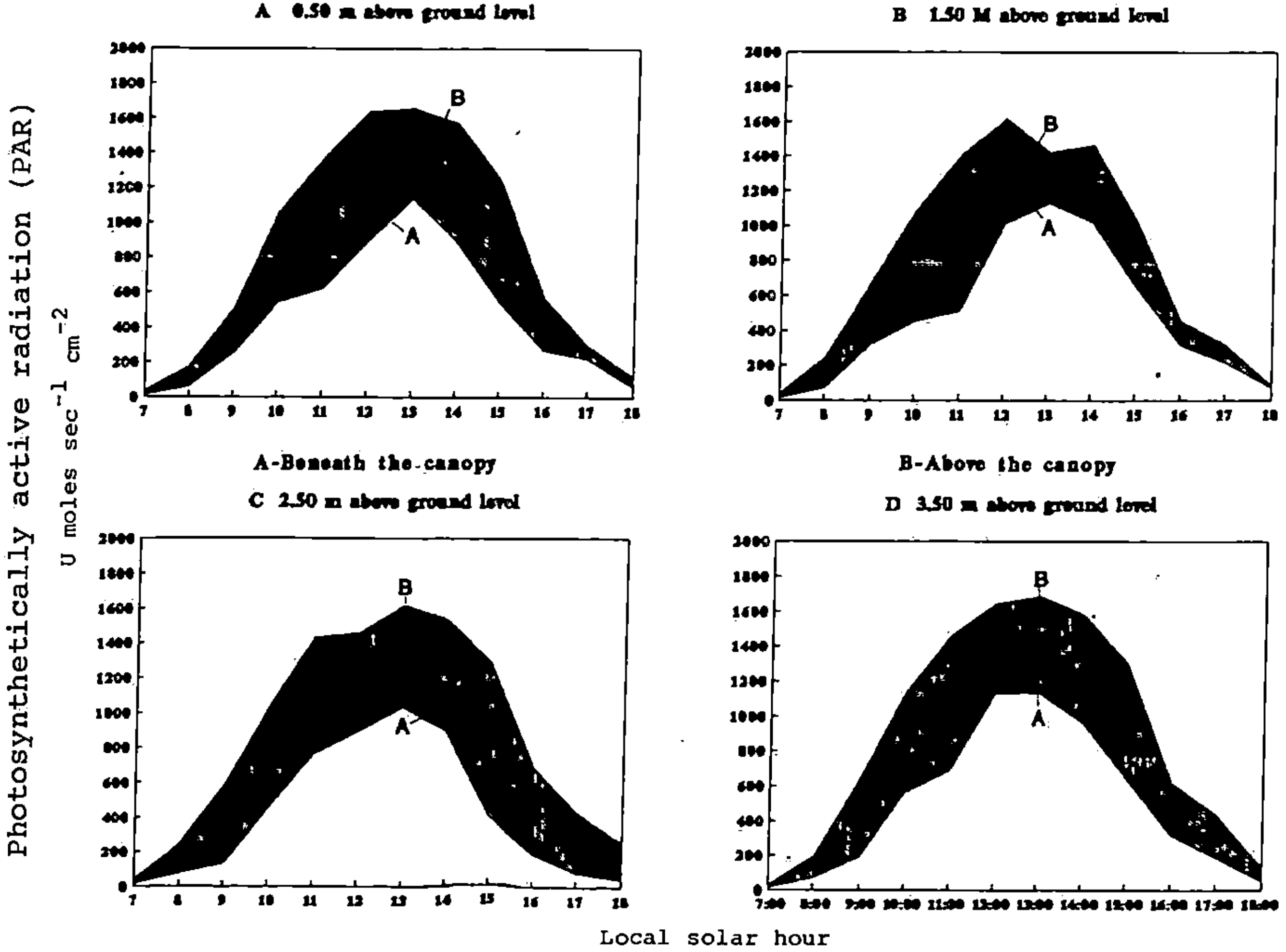
C 2.50 m above ground level

D 3.50 m above ground level

A-Beneath the canopy

B-Above the canopy

Fig. 10 Relative proportion of photosynthetically active radiation (PAR) intercepted at different heights above ground level (shaded region) in a 5-year-old stand of leucaena. Each data point corresponds to the hourly integrated values of PAR. The data were recorded during the period from April 29, 1993 to May 2, 1993.



A 0.50 m above ground level

B 1.50 M above ground level

A-Beneath the canopy

B-Above the canopy

C 2.50 m above ground level

D 3.50 m above ground level

Table 10. Integrated values of photon flux density (µ moles sec^{-1} cm^{-2}) at hourly intervals of the photosynthetically active radiation (P.A.R.) in the open and under the canopy at different heights above the ground level for the period from 13th April, 1993 to 2nd May, 1993) under four multipurpose tree species.

Species	Local solar hour	Photon flux density (µ moles sec^{-1} cm^{-2})							
		Heights above ground level (m)							
		0.50		1.50		2.50		3.50	
		L.Q.	Q.S	L.Q.	Q.S	L.Q.	Q.S	L.Q.	Q.S
<u>Acacia auriculiformis</u>	7.00	8.2	54.6	6.0	36.7	9.5	50.6	4.5	7.0
	8.00	43.8	276.4	19.6	156.3	42.4	246.9	43.1	100.6
	9.00	71.9	699.0	28.5	199.6	144.2	692.8	246.6	526.1
	10.00	96.8	1010.0	90.9	748.8	110.8	982.0	356.5	1130.0
	11.00	165.9	1213.0	116.7	1135.0	444.5	1375.0	808.2	1319.0
	12.00	186.6	1195.6	168.8	1423.0	339.5	1553.0	638.5	1343.0
	13.00	417.1	1289.0	312.4	1589.0	564.0	1621.0	464.1	1310.0
	14.00	180.5	974.0	602.2	1626.0	305.2	1490.0	281.0	699.7
	15.00	141.1	1052.0	291.3	1555.0	298.7	991.4	148.5	390.6
	16.00	103.4	434.0	135.0	1319.0	161.9	521.9	39.8	118.7
	17.00	35.2	170.8	9.1	49.9	63.5	255.3	15.6	89.5
	18.00	16.3	143.2	10.2	23.5	26.3	125.6	6.3	14.5
<u>Casuarina equisetifolia</u>	7.00	42.1	68.4	39.0	56.2	24.8	57.5	22.8	12.1
	8.00	200.2	342.9	213.3	306.0	90.8	291.5	53.4	122.1
	9.00	340.2	680.2	356.2	632.0	358.8	706.6	256.9	678.5
	10.00	396.4	734.6	453.0	765.3	649.0	988.6	559.9	859.0
	11.00	373.1	759.0	563.0	869.0	684.0	1285.0	778.1	1312.0
	12.00	771.0	1537.0	856.0	1456.0	742.9	1471.0	869.5	1197.0
	13.00	1066.0	1639.0	1230.0	1653.0	997.1	1470.0	1103.0	1359.0
	14.00	712.5	1520.0	765.0	1426.0	839.7	1398.0	1230.3	1508.0
	15.00	529.2	1242.0	589.0	1235.0	706.6	1168.0	1102.0	1313.0
	16.00	160.4	376.2	186.0	456.0	300.4	572.2	235.0	652.0
	17.00	112.6	254.4	132.0	205.0	72.6	139.5	52.9	110.7
	18.00	60.0	133.7	59.6	132.2	23.6	45.5	42.3	56.3

Q.S.-Point quantum sensor L.Q. -Line quantum sensor

Contd.

Table 10 (Contd.)

Species	Local solar hour	Photon flux density (µ moles sec^{-1} cm^{-2})							
		Heights above ground level (m)							
		0.50		1.50		2.50		3.50	
		L.Q.	Q.S	L.Q.	Q.S	L.Q.	Q.S	L.Q.	Q.S.
Ailanthus triphysa	7.00	17.1	33.2	17.2	31.6	20.2	36.3	40.6	50.7
	8.00	94.1	160.3	79.2	156.8	79.9	174.8	208.4	256.2
	9.00	277.7	577.7	109.9	572.3	348.2	568.5	598.2	712.8
	10.00	218.1	967.4	306.0	975.9	749.2	959.5	980.1	1105.0
	11.00	532.4	1239.0	1017.0	1258.0	780.0	1204.0	1081.9	1255.0
	12.00	1116.0	1404.0	1426.0	1456.0	1398.0	1433.0	1349.0	1455.0
	13.00	1461.0	1479.0	1422.0	1564.0	1458.0	1619.0	1546.0	1542.0
	14.00	1366.0	1395.0	1282.0	1393.0	1279.0	1377.0	1477.0	1540.0
	15.00	564.2	1214.0	690.0	1157.0	730.0	956.0	1162.1	1179.2
	16.00	239.0	584.0	237.7	686.6	318.2	621.6	770.2	779.6
	17.00	172.1	224.7	127.8	177.7	174.7	253.5	258.7	256.2
	18.00	54.2	126.8	56.2	145.2	56.2	138.2	110.0	142.0
Leucaena leucocephala	7.00	13.6	35.9	17.2	37.5	16.9	40.6	16.9	33.2
	8.00	62.9	172.6	72.7	242.9	79.8	244.2	72.3	194.9
	9.00	252.3	502.1	322.0	670.4	135.1	584.0	194.8	642.8
	10.00	546.4	1059.0	455.4	1086.0	453.0	1031.0	563.0	1130.0
	11.00	323.4	1174.0	512.1	1408.0	765.0	1431.0	689.0	1460.0
	12.00	893.1	1636.0	1018.0	1617.0	896.0	1458.0	1132.0	1645.0
	13.00	1139.0	1655.0	1130.0	1423.0	1035.0	1615.0	1134.0	1686.0
	14.00	893.6	1571.0	1023.0	1463.0	896.0	1532.0	965.0	1577.0
	15.00	543.5	1241.0	653.0	1030.0	407.2	1301.0	644.8	1300.0
	16.00	270.7	570.0	321.0	456.0	190.8	688.9	318.2	617.0
	17.00	223.7	298.7	220.0	320.0	82.3	430.2	192.4	436.2
	18.00	61.9	118.5	78.0	86.0	45.0	256.8	57.0	135.0

Q.S.-Point quantum sensor   L.Q. -Line quantum sensor

Fig. 11 Soil temperature (0-15 cm) under different tree canopies and in the open grasslands

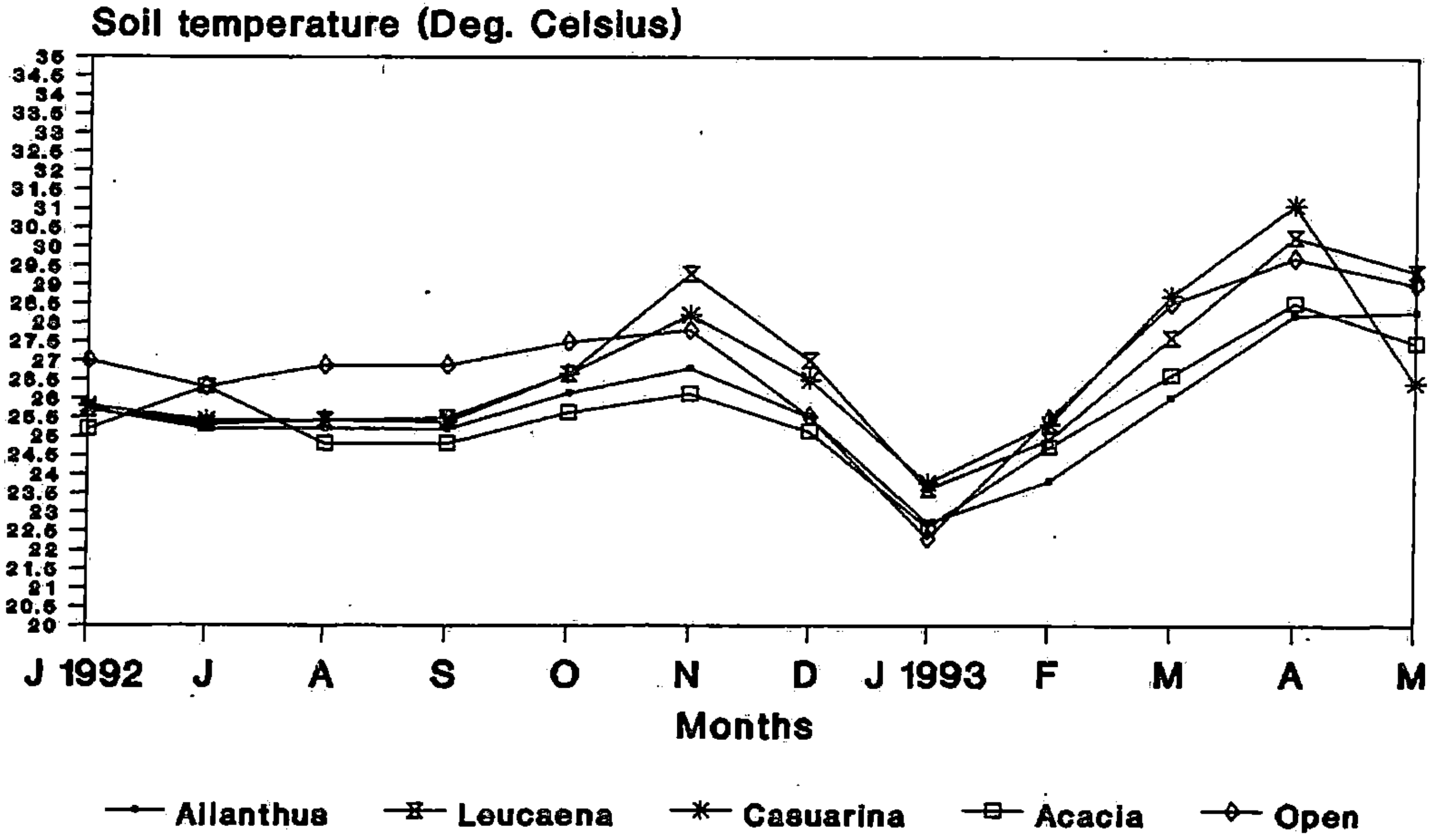


Table 11. Soil temperature variations in the 0-15 cm soil layer under different tree canopies and in the open grasslands

Month	Tree species				Open grass-land
	Ailanthus	Leucaena	Casuarina	Acacia	
Jun'92	25.7	25.7	25.8	25.2	27.0
Jul	25.2	25.3	25.4	26.3	26.3
Aug	25.2	25.4	25.4	24.8	26.8
Sep	25.2	25.5	25.4	24.8	26.8
Oct	26.1	25.5	25.4	25.6	27.5
Nov	26.8	29.3	26.6	26.1	27.8
Dec	25.5	27.0	28.2	25.1	25.5
Jan'93	22.7	23.6	26.5	22.6	22.3
Feb	23.8	24.9	23.7	24.7	25.4
Mar	26.0	27.6	25.3	26.6	28.5
Apr	28.2	30.2	28.7	28.5	29.7
May	28.3	29.3	31.1	27.4	29.0
Mean	25.7	26.7	26.5	25.6	26.9

this context acacia stand gave the lowest mean value (25.64°C). Top layer of the soil under ailanthus, leucaena and casuarina recorded 25.72, 26.70 and 26.5°C respectively. Soil temperature in the tree-less plot was 26.89°C. Surprisingly, leucaena registered the highest values for soil temperature during November-December and March-April.

4.5 Soil chemical characteristics under tree canopies

Soil pH (0-15 cm layer) under acacia was significantly lower (4.94) than that of tree-less control (5.15), ailanthus (5.12) and casuarina (5.17). Both acacia and leucaena (5.07) had similar soil pH (Table 12 and Appendix XI). Soil organic carbon status in the acacia stand was significantly higher (4.2 %) than that of the remaining treatments. Leucaena plots recorded the second highest organic carbon level (3.4 %). The tree-less control and ailanthus were however, statistically at par (2.1 % and 1.9 %, respectively). Fodder means and fodder-tree interactions were not significant in this respect (Table 12 and Appendix XI).

Regarding macro-elements in the surface (0-15 cm) layer of the soil, all the three N-fixing species had markedly higher nitrogen content (0.224%, 0.212 % and 0.262 % for acacia, casuarina and leucaena, respectively).

Table 12. Soil chemical properties (0-15 cm soil layer) under different tree-grass plots

Tree-fodder combinations	pH	OC (%)	N (%)	P (ppm)	K (ppm)
Acacia auriculiformis					
Pennisetum purpureum	5.0	3.997	0.238	17.877	63.340
Panicum maximum	5.1	4.326	0.212	15.343	61.560
Brachiaria ruziziensis	4.8	4.251	0.194	15.523	70.490
Zea mexicana	4.8	4.328	0.253	18.983	78.317
Overall mean	4.9	4.226	0.224	16.932	68.427
Casuarina equisetifolia					
Pennisetum purpureum	5.0	2.964	0.169	17.933	58.823
Panicum maximum	5.3	3.108	0.236	20.800	53.853
Brachiaria ruziziensis	5.2	3.121	0.244	22.353	55.963
Zea mexicana	5.2	3.054	0.198	19.083	54.610
Overall mean	5.2	3.062	0.212	20.043	57.328
Leucaena leucocephala					
Pennisetum purpureum	5.0	3.120	0.235	19.103	64.593
Panicum maximum	5.1	3.402	0.258	16.587	58.257
Brachiaria ruziziensis	5.0	3.622	0.261	14.233	61.740
Zea mexicana	5.2	3.643	0.295	19.317	54.610
Overall mean	5.1	3.447	0.262	17.310	59.800
Ailanthus triphysa					
Pennisetum purpureum	5.3	2.002	0.164	15.340	42.090
Panicum maximum	5.1	1.841	0.219	12.097	46.807
Brachiaria ruziziensis	4.9	2.926	0.295	13.337	50.927
Zea mexicana	5.2	1.621	0.156	13.980	49.763
Overall mean	5.1	2.097	0.190	13.688	47.397
Control (Tree-less)					
Pennisetum purpureum	5.1	1.687	0.147	12.280	33.540
Panicum maximum	5.0	1.763	0.148	11.583	35.673
Brachiaria ruziziensis	5.2	1.640	0.147	10.647	38.303
Zea mexicana	5.3	2.735	0.173	10.501	39.917
Overall means	5.1	1.956	0.154	11.253	36.656
Tree means					
p	<0.01	<0.01	<0.01	<0.01	<0.01
SEM (±)	0.0276	0.0957	0.0137	0.8936	1.9236
CD (0.05)	0.0788	0.2735	0.0391	1.8034	3.8820
Fodder means					
p	<0.05	<0.05	N.S.	N.S.	N.S.
SEM (±)	0.0247	0.0856	0.0122	0.7993	1.7205
CD (0.05)	0.0788	0.2446			
Tree-fodder interaction					
p	<0.01	<0.01	N.S.	N.S.	N.S.
SEM (±)	0.0553	0.1914	0.0273	1.7872	3.8472
CD (0.05)	0.1580	0.5470			

The soil N status of the tree-less control was at par with that of ailanthus (0.154 % and 0.190 %, respectively). Soil phosphorus status was considerably higher in the 'tree plots' in comparison to the tree-less plots. Casuarina recorded the highest soil P status and was significantly superior to all other treatments (20.0 ppm). Besides, acacia (16.9 ppm) and leucaena (17.3 ppm) exhibited markedly higher soil P status compared to ailanthus and tree-less control (13.7 and 11.2 ppm respectively). The soil K values were significantly higher for all the treatments compared to the tree-less control (68.4, 53.3, 59.8, 47.4 and 36.8 ppm for acacia, casuarina, leucaena, ailanthus and tree-less control respectively).

4.6 Root interactions

4.6.1 Recovery of soil applied ^{32}P in tree foliage as a function of depth and lateral distance of application

The difference in recovery of ^{32}P between the lateral distances was significant for acacia at 30 days of application, casuarina both at 15 and 30 days after application and ailanthus at 15 days after application (Table 13A and Appendix XII). In general, recovery declined as the lateral distances of ^{32}P application increased. The magnitude of reduction in ^{32}P was largely

Table 13A. Radioactivity recovered (log cpm g^{-1}) from the leaves of the mutipurpose tree species grown under silvopastoral system, as a function of depth, lateral distances and days after application of ^{32}P

	Radioactivity recovered (log cpm g^{-1}) in the leaves of							
	Acacia		Casuarina		Leucaena		Ailanthus	
Days after ^{32}P application	15	30	15	30	15	30	15	30
Lateral Distance (cm)								
25	2.021 (104.9)	2.352 (224.9)	1.487 (30.69)	1.892 (77.98)	1.916 (82.41)	2.405 (254.1)	1.684 (48.3)	1.907 (80.7)
50	1.977 (94.8)	2.224 (167.5)	1.180 (15.13)	1.541 (34.75)	1.880 (150.7)	2.388 (385.5)	1.255 (18.0)	1.889 (77.4)
p	N.S.	<0.05	<0.01	<0.01	N.S.	N.S.	<0.01	N.S.
SEM(±)	0.0497	0.0385	0.0680	0.0643	0.0667	0.0683	0.0703	0.0823
CD(0.05)		0.1095	0.1935	0.1829			0.2003	0.1829
Depth (cm)								
15	2.162 (145.2)	2.483 (304.1)	1.780 (60.25)	1.910 (81.28)	2.178 (150.7)	2.586 (385.5)	1.913 (81.8)	2.235 (171.8)
50	1.836 (68.5)	2.093 (123.9)	0.886 (7.69)	1.523 (33.34)	1.618 (41.5)	2.207 (161.1)	1.027 (10.6)	1.561 (36.4)
p	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
SEM(±)	0.0497	0.0385	0.0680	0.0643	0.0667	0.0683	0.0703	0.0823
CD(0.05)	0.1414	0.1095	0.1935	0.1829	0.1898	0.1943	0.2003	0.1829

Retransformed values given in parentheses

Table 13B. Root activity (%) of the tree components of the silvopastoral system

	Acacia	Casuarina	Leucaena	Ailanthus
Lateral Distance (cm)				
25	55.1	55.8	50.2	52.8
50	44.9	44.2	49.8	47.2
Depth (cm)				
15	70.6	69.5	64.9	81.8
50	29.4	30.5	35.1	18.2

inconsequential for both acacia and leucaena, whereas, for casuarina it was substantially different both at 15 and 30 days after application. The root activity percentages ranged from 55.8 to 50.2 % at 25 cm lateral distance for casuarina and leucaena respectively (Table 13B).

The recovery of ^{32}P declined markedly as the depth of ^{32}P application increased from 15 to 50 cm (Table 13 and Appendix XII). Implicit in the low recovery at 50 cm depth regardless of the tree species is the lower root activity in this zone (Table 13A). Furthermore, recovery of ^{32}P increased during the time interval from 15 to 30 days after application, for both depths of application. The root activity percentages ranged from 81.8 to 64.9 % in the upper depth zone for ailanthus and leucaena respectively (Table 13B).

4.6.2 Recovery of ^{32}P by tree components as influenced by the associated forage crops

Radioactivity recovered by tree species grown in association with different forage crops generally increased between 15 and 30 days after application (Table 14 and Appendix XIII). However, the differences were not significant initially in any of the tree species investigated, except casuarina. Over time, the forage

Table 14. Radioactivity recovered (log cpm g^{-1}) in the leaves of tree species grown in association with four forage crops at 15 and 30 days after ^{32}P application

Days after ^{32}P	Acacia		Casuarina		Leucaena		Ailanthus	
application ->	15	30	15	30	15	30	15	30
Congo signal	1.929	2.324	1.482	1.666	1.919	2.611	1.545	2.092
	(84.9)	(210.9)	(30.3)	(46.3)	(83.0)	(408.3)	(35.1)	(123.6)
Guinea grass	1.977	2.249	1.360	1.981	1.918	2.318	1.433	1.606
	(94.8)	(177.4)	(22.9)	(95.7)	(82.8)	(208.0)	(27.1)	(40.4)
Hybrid napier	1.965	2.265	1.204	1.948	1.793	2.328	1.366	1.848
	(92.2)	(162.5)	(16.0)	(88.7)	(62.1)	(212.8)	(23.2)	(70.5)
Teosinte	1.971	2.211	1.098	1.948	1.990	2.562	1.685	1.997
	(93.5)	(162.5)	(12.5)	(88.7)	(97.7)	(364.7)	(48.4)	(99.3)
Control	2.155	2.392	1.523	1.305	1.871	2.163	1.318	1.947
	(142.9)	(246.6)	(33.3)	(20.2)	(74.3)	(145.5)	(20.8)	(88.5)
P	N.S.	N.S.	<0.05	<0.01	N.S.	<0.05	N.S.	<0.05
SEM (±)	0.0785	0.0608	0.1075	0.1017	0.1054	0.1301	0.1122	0.1301
CD (0.05)			0.3072	0.2907		0.3720		0.3720

Retransformed values given in parentheses

crops began to exert marked influence on the amount of ^{32}P absorbed by all the tree species except acacia. Nevertheless, no consistent pattern could be observed in this regard.

^{32}P activity of casuarina leaves was highest in the guinea grass plots followed by hybrid napier and congo signal. Control plots had the least value at 30 days after application. For ailanthus ^{32}P recovery decreased in the order: congo signal > teosinte > control > hybrid napier > guniea grass and for leucaena: congo signal > teosinte > guniea grass > hybrid napier > control. In general, forage crops such as teosinte and congo signal and to a lesser extent guniea grass had a stimulatory effect on ^{32}P uptake by trees such as ailanthus and leucaena, although the difference were not significant for all combinations except guniea grass - ailanthus and leucaena monoculture. However, recovery of ^{32}P by casuarina grown in combination with teosinte was substantially lower than that of casuarina monoculture at 15 days after application. On the other hand at 30 days after application casuarina monoculture recorded substantially lower ^{32}P activity.

4.6.3 Recovery of ^{32}P by forage crops as affected by tree components growing in association

The tree components of the silvopastoral system exerted a marked influence on the amount of ^{32}P absorbed by all the four forage crops at both stages of observation except in the case of hybrid napier at 15 days after application (Table 15 and Appendix XIII). In general, tree-less controls registered an order of magnitude higher values of foliar ^{32}P activity for all forage crops with the exception of hybrid napier at 30 days after application and guniea grass at 15 days after application. This was, however, followed by ailanthus and/or casuarina in most of the cases. Acacia and leucaena combinations invariably registered lower recoveries of applied ^{32}P.

The recovery of ^{32}P by congo signal both at 15 and 30 days after application was significantly lower than the control when grown under ailanthus, casuarina and leucaena, although, at 15 days after application, acacia - congo signal monoculture ^{32}P recovery was higher (Table 15 and Appendix XIII At 30 days after application, congo signal ^{32}P counts under casuarina, ailanthus, acacia and the control were significantly greater than the leucaena combinations.

While ^{32}P recovery in guniea grass differed significantly among intercropped situations at the two dates of sampling (Table 15 and Appendix XIII), guniea grass under acacia showed significantly lower values compared to those grown under other tree species 15 days

Table 15. Radioactivity recovered (log cpm g^{-1}) in the leaves of forage species grown in association with four multipurpose fast growing tree species at 15 and 30 days after ^{32}P application

Days after ^{32}P application ->	Congo signal 15	Congo signal 30	Guinea grass 15	Guinea grass 30	Hybrid napier 15	Hybrid napier 30	Teosinte 15	Teosinte 30
Acacia	3.188 (1541.7)	3.300 (1995.3)	2.993 (984.0)	3.327 (2123.2)	3.280 (1905.5)	3.623 (4197.6)	2.324 (210.9)	2.708 (510.5)
Casuarina	2.884 (765.6)	3.419 (2624.2)	3.762 (5781.0)	3.314 (2060.6)	3.409 (2564.5)	4.266 (18450.1)	2.187 (153.8)	2.545 (350.7)
Leucaena	2.845 (699.8)	2.716 (520.0)	3.204 (1599.5)	3.280 (1905.4)	3.082 (1207.8)	3.635 (4315.2)	1.900 (79.4)	2.693 (493.2)
Ailanthus	2.920 (831.8)	3.325 (2113.5)	3.389 (2449.1)	3.357 (2275.1)	3.422 (2642.4)	3.500 (3162.3)	2.251 (178.2)	2.927 (845.3)
Control	3.210 (1621.8)	4.071 (11776.1)	3.730 (5370.3)	3.990 (9772.3)	3.531 (3396.2)	3.944 (8790.2)	2.904 (801.7)	3.619 (4159.1)
p	<0.01	<0.01	<0.01	<0.01	N.S.	<0.01	<0.01	<0.01
SEM (±)	0.0856	0.1231	0.0796	0.1354	0.1181	0.1083	0.1099	0.1541
CD (0.05)	0.2446	0.3518	0.2275	0.3870		0.3095	0.3141	0.4404

Retransformed values given in parentheses

after application. At 30 days after application hybrid napier in the tree-less plots and in association with casuarina registered significantly higher values compared to the remaining forage combinations tree forage combinations. Teosinte in the tree-less control was significantly higher count rates at both sampling intervals (Table 15 and Appendix XIII). Furthermore, compared to other combinations involving forage species except casuarina, teosinte under leucaena had markedly lower count rates at 15 days after application.

4.7 Litter fall

Average annual litter production in the five-year-old stand was highest for acacia (6.22 Mg ha^{-1} yr^{-1}; Table 16; Fig. 12 and Appendix XI V), followed by casuarina (2.48 Mg ha^{-1} yr^{-1}), leucaena (2.3 Mg ha^{-1} yr^{-1}) and ailanthus (1.92 Mg ha^{-1} yr^{-1}). Moreover, acacia consistently recorded the highest amount of litterfall throughout the year. The observed differences were highly significant ($p<0.01$) with respect to monthly litterfall rates for different species. Furthermore, in all the experimental plots, the bulk of the detritus collected in the traps were of the target species, the contribution from the neighborhood tree species (adjoining plots) were of the order of 1.8 % for

Fig.12 Seasonal variations in the litter fall of four 5-year-old stands of four MPT species.

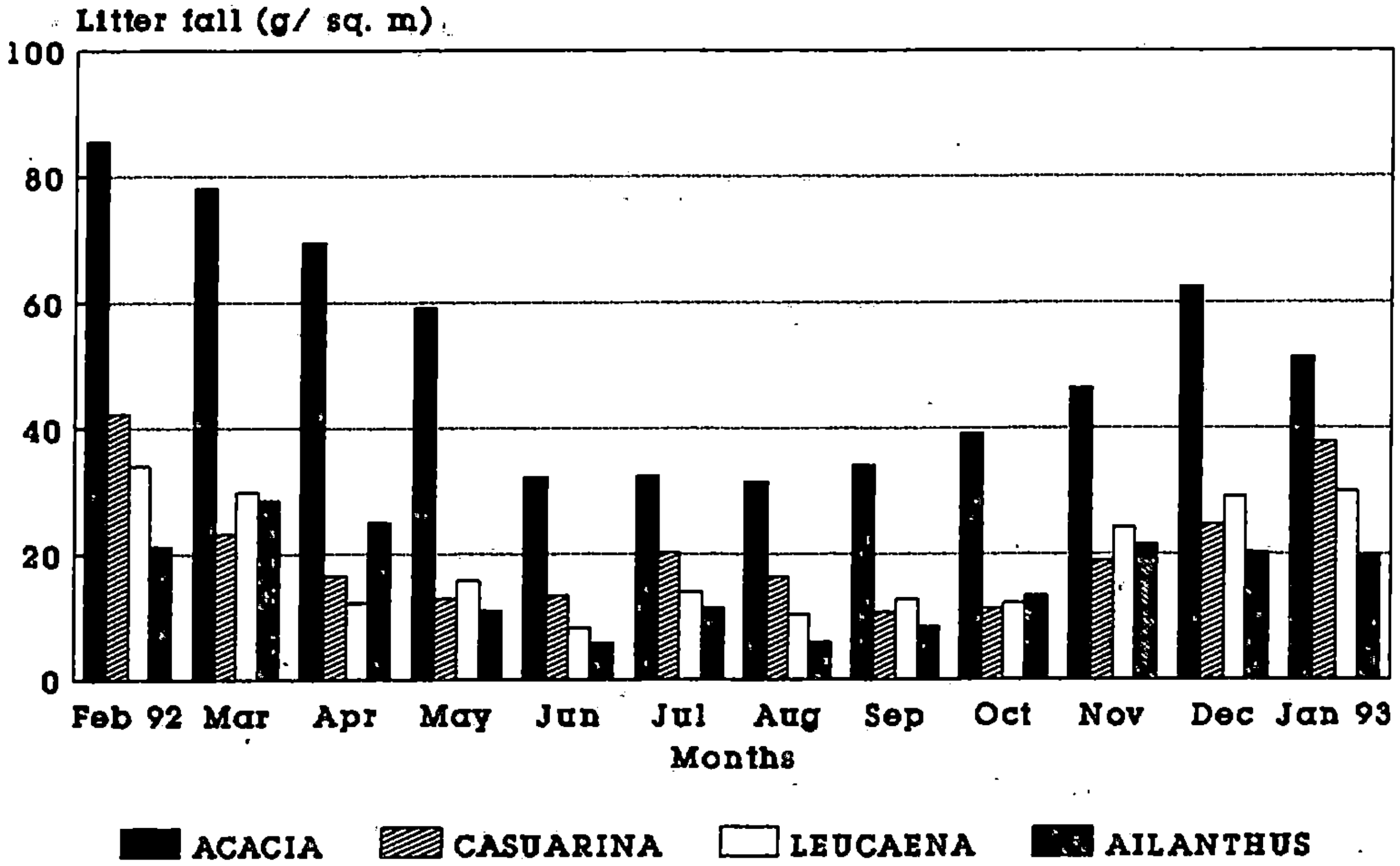


Table 16. Mean weights (g m^{-2}) of target species litter, neigbourhood tree litter and the total litterfall in stands of four multipurpose fast growing tree species

Months	Total dry weight (g m^{-2}) (Target species) Aca	Cas	Leu	Ail	Total dry weight (g m^{-2}) of neighbourhood species Aca	Cas	Leu	Ail	Grand total of target and neigbourhood Aca	Cas	Leu	Ail
Feb 92	85.5 (13.9)	38.0 (18.7)	28.3 (15.3)	21.9 (13.3)	-	2.3	4.3	-	85.5	40.3	32.6	21.2
Mar	76.7 (12.6)	19.7 (09.7)	23.5 (12.7)	21.2 (13.3)	2.8	2.6	7.6	7.3	79.5	22.3	31.1	28.5
Apr	66.8 (10.9)	14.8 (07.3)	8.8 (04.7)	23.9 (15.1)	1.4	2.9	3.4	1.0	70.1	17.7	12.2	24.9
May	59.3 (09.6)	13.1 (06.4)	14.1 (07.6)	9.6 (06.0)	-	-	1.7	1.4	59.3	13.1	15.8	11.0
Jun	32.2 (05.2)	11.8 (05.8)	6.4 (03.5)	3.7 (02.3)	-	1.8	1.8	2.1	32.2	13.6	8.2	5.8
Jul	32.4 (05.3)	16.0 (07.9)	14.0 (07.6)	6.4 (04.0)	-	3.1	-	5.1	32.4	19.1	14.0	11.6
Aug	31.4 (05.1)	12.5 (06.2)	10.4 (05.6)	4.1 (02.6)	-	3.1	-	1.8	31.4	15.6	10.4	5.9
Sep	34.2 (05.7)	10.9 (05.3)	11.1 (06.0)	7.0 (04.4)	-	2.9	1.7	1.4	34.2	13.8	12.8	8.4
Oct	38.4 (06.2)	9.3 (04.6)	8.8 (04.7)	11.8 (07.4)	1.4	-	3.4	1.5	39.2	9.3	12.2	13.3
Nov	45.1 (07.3)	15.8 (07.8)	16.5 (08.9)	16.7 (10.5)	2.8	1.1	7.7	4.8	47.9	16.9	24.2	21.5
Dec	61.0 (09.9)	12.7 (06.3)	19.3 (10.5)	13.4 (08.4)	2.8	1.1	7.7	6.8	63.8	13.8	27.0	20.2
Jan 93	51.2 (08.3)	28.4 (14.0)	23.5 (12.7)	19.8 (12.4)	-	6.7	6.4	-	51.2	35.1	29.9	19.8
Total	582.8	203.0	184.7	159.5	11.2	27.6	45.7	33.2	627.3	230.6	230.4	192.1

Figures in parantheses indicate percentage of annual litterfall
Aca-Acacia, Leu-Leucaena, Cas-Casuarina and Ail-Ailanthus

Species		
p	<0.01	<0.01
SEM (±)	1.0139	0.9988
CD (0.05)	1.9872	1.9576
Month		
p	<0.01	<0.01
SEM (±)	1.7561	1.7300
CD (0.05)	3.4419	3.3908
Species x Month		
p	<0.01	<0.01
SEM (±)	3.5122	3.4601
CD (0.05)	6.8839	6.7818

acacia, 17.3 % for ailanthus, 12.0 % for casuarina and 19.8 % for leucaena (Table 16; Fig. 12 and Appendix XIV).

4.7.1 Seasonal variation in litterfall

Seasonal variation in litterfall were very pronounced. In general it followed a monomodal distribution pattern with a distinctive peak during December-February. Furthermore, the December to May period accounted for bulk of the litter input (acacia-72.48 %, ailanthus-68.5 % casuarina-62.4 % and leucaena-63.5 %). Litter production remained markedly low during the South-West monsoon season for all species.

4.7.2 Litter fractions

Table 16, 17; Fig 13 and Appendix XIV clearly show that foliage biomass constituted the major chunk of the litter in all four stands (acacia-70.8 %, ailanthus-99.6 % casuarina-96.3 % and leucaena-83.4 %). Variations in foliage component of litter, by and large, followed the pattern of total litter fall (Fig 12). Twig fraction however, slightly increased during the rains. Interestingly, ailanthus did not record any twig component in its biomass. However, acacia recorded twig fall throughout the year, with an increase during the rainy season (7.6 % of the total litterfall). Reproductive components were not recorded by the

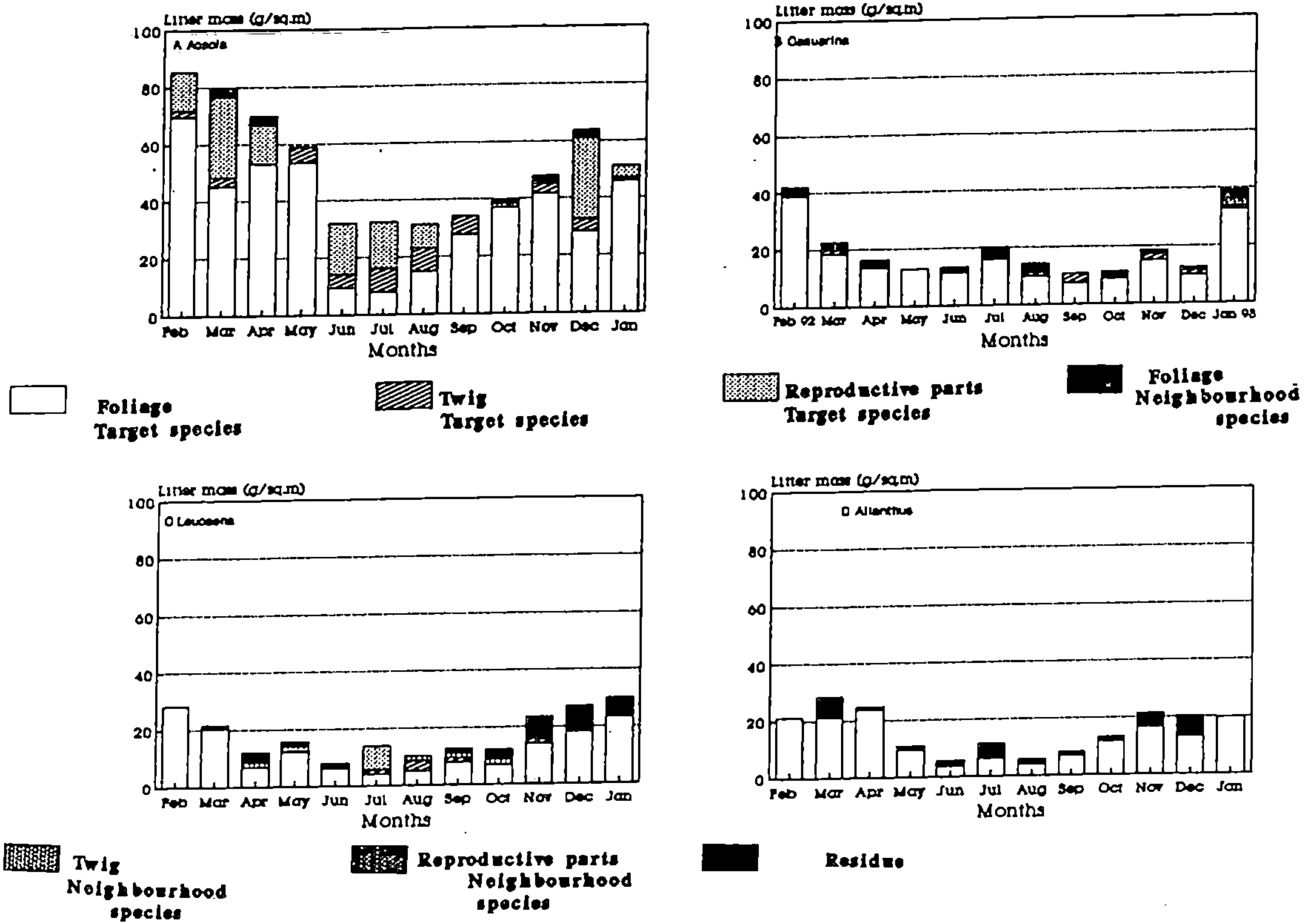


Fig. 13 Total litter production in stands of four MPT stands and the contribution of different litter fractions.

Table 17. Mean weights in (g m^{-2}) of different fractions of target and neigbourhood species in the stands of four multipurpose fast growing species

	Target species												Neighbourhood species											
	Foliage weight				Twig weight				Reproductive part				Foliage weight				Twig weight				Reproductive parts			
Months	Aca	Cas	Leu	Ail	Aca	Cas	Leu	Ail	Aca	Cas	Leu	Ail	Aca	Cas	Leu	Ail	Aca	Cas	Leu	Ail	Aca	Cas	Leu	Ail
Feb 92	69.7	38.9	28.3	21.2	2.1	-	-	-	13.6	-	-	-	-	1.9	4.3	-	-	1.4	-	-	-	-	-	-
Mar	45.1	18.5	20.4	21.2	3.3	1.5	1.2	-	28.3	-	1.0	-	1.4	1.4	7.6	7.3	1.4	-	-	-	-	1.2	-	-
Apr	53.1	13.5	6.9	23.9	-	-	-	-	13.7	-	1.8	-	0.7	2.9	3.4	1.0	0.7	-	-	-	-	-	-	-
May	53.4	12.9	12.1	9.6	5.5	-	0.5	-	-	-	1.6	-	-	-	1.7	1.4	-	-	-	-	-	-	-	-
Jun	9.6	11.6	6.4	3.7	4.6	-	-	-	17.8	-	-	-	-	1.8	1.8	2.1	-	-	-	-	-	-	-	-
Jul	8.0	16.1	4.0	6.4	8.2	1.0	1.7	-	16.2	-	8.3	-	-	3.1	-	5.1	-	-	-	-	-	-	-	-
Aug	15.1	9.9	5.1	4.1	7.9	1.5	3.6	-	8.4	-	1.7	-	-	2.9	-	1.8	-	-	-	-	-	-	-	-
Sep	27.8	7.5	8.0	7.0	6.4	3.2	1.5	-	-	-	1.6	-	-	-	1.7	1.4	-	-	-	-	-	-	-	-
Oct	37.1	8.9	7.0	11.8	-	-	-	-	1.3	-	1.9	-	0.7	2.4	3.4	1.5	0.7	-	-	-	-	-	-	-
Nov	41.8	15.2	14.1	16.7	3.3	2.3	1.8	-	-	-	-	-	1.4	1.1	7.7	4.8	1.4	-	-	-	-	-	-	-
Dec	28.4	10.0	18.2	13.4	4.3	1.5	1.2	-	28.3	-	-	-	1.4	1.1	7.7	6.8	1.4	-	-	-	-	-	-	-
Jan 93	45.9	32.6	23.5	19.8	1.1	-	-	-	4.2	-	-	-	-	1.2	6.4	-	-	2.7	-	-	-	2.8	-	-

Composite total of Acacia includes 1.9 g of residual mass for the month of April
Aca-Acacia, Leu-Leucaena, Cas-Casuarina and Ail-Ailanthus

Species	
p	<0.01
SEM (±)	0.8254
CD (0.05)	1.6178
Month	
p	<0.01
SEM (±)	1.4296
CD (0.05)	2.8020
Species x Month	
p	<0.01
SEM (±)	2.8592
CD (0.05)	5.6040

traps kept under the stands of ailanthus and casuarina. The December to March period showed a spurt in the quantum of reproductive components for acacia. But for leucaena an increase in the reproductive components in the litter were observed during August.

4.7.3 Seasonal variability in litter nutrient concentration

The concentration of macro elements in the composite litter sample showed considerable variation throughout the year (Table 18; Figs 14,15,16; and Appendix X V). The nutrient content of foliage fraction of litter was generally lower than that before abscission (ref. Table 5). Species, month and the interaction effects (month x species) were significant in this respect (Table 18 and Appendix X V). The peak values of N were recorded during June in acacia and casuarina while it was during September for leucaena and August for ailanthus. The lowest concentration of N was recorded during March and November for acacia and casuarina respectively, while it was during December for leucaena and February for ailanthus. Peak P concentration was observed during May, July, August and May-June in acacia, casuarina, leucaena and ailanthus respectively and lowest P concentration was observed during December for acacia, leucaena and ailanthus respectively and February for casuarina. Potassium

Fig. 14 Seasonal variations of litter N content of four MPT species

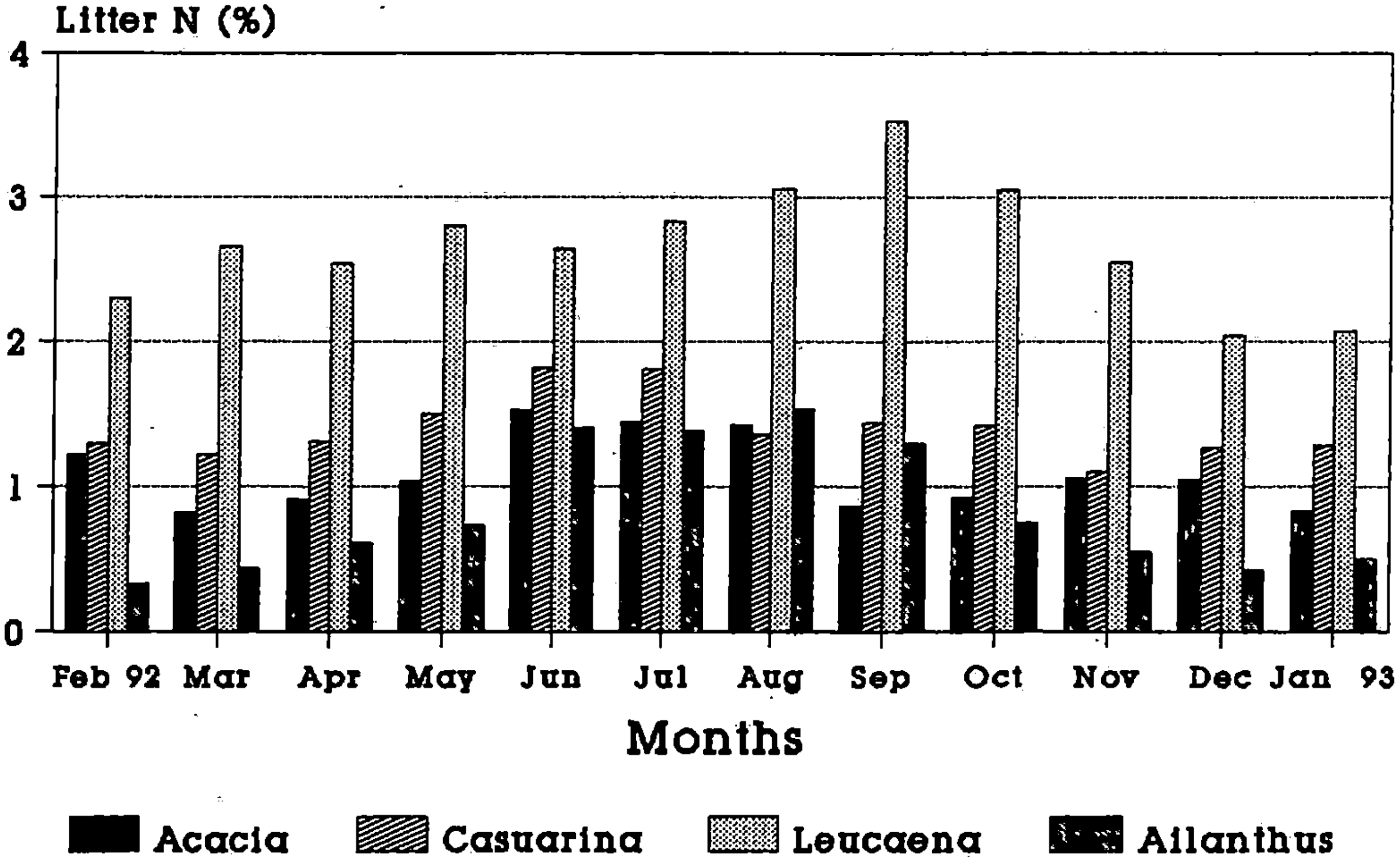


Fig. 15 Seasonal variations in litter P content of four MPT species

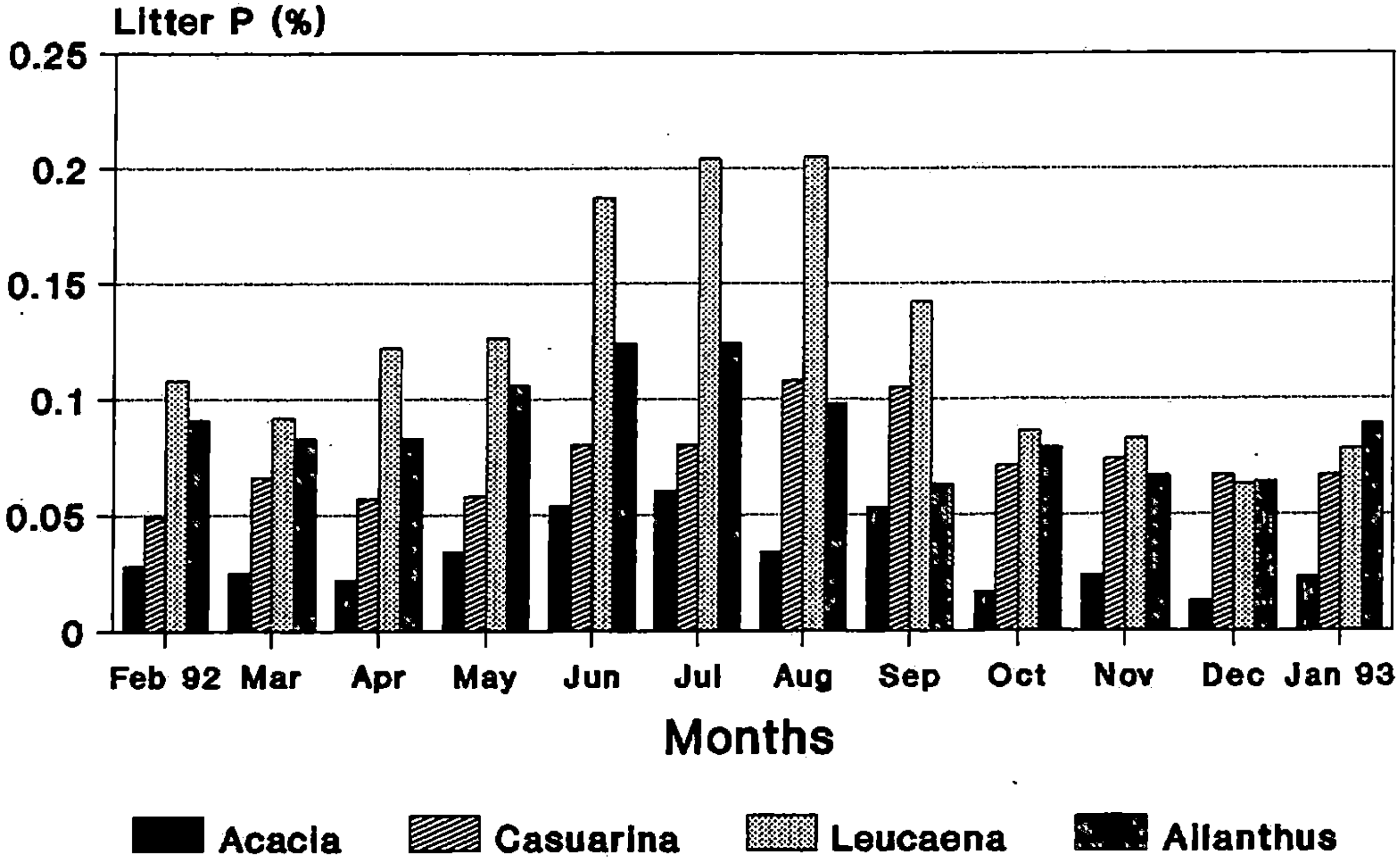


Fig. 16 Seasonal variations of litter K content in four MPT species

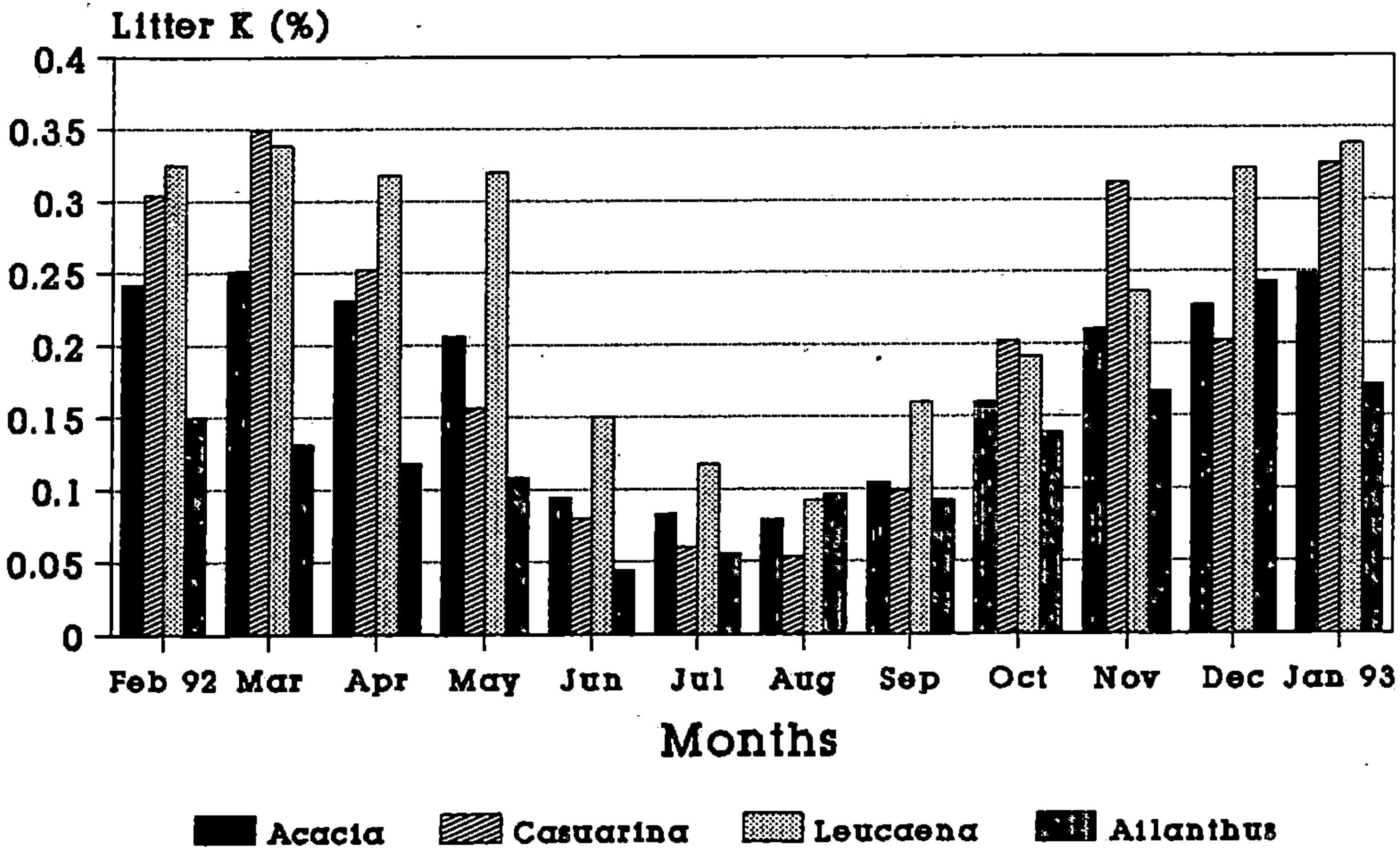


Table 18. Seasonal variations in litter (composite) nutrient concentrations of four multipurpose tree species.

	Nitrogen (%)				Phosphorus (%)				Potassium (%)			
Months	Aca	Cas	Leu	Ail	Aca	Cas	Leu	Ail	Aca	Cas	Leu	Ail
Feb 92	1.217	1.295	2.294	0.328	0.028	0.049	0.108	0.091	0.242	0.304	0.325	0.150
Mar	0.824	1.216	2.657	0.436	0.025	0.066	0.092	0.083	0.251	0.349	0.339	0.131
Apr	0.911	1.311	2.537	0.609	0.022	0.057	0.122	0.083	0.231	0.252	0.318	0.118
May	1.040	1.500	2.798	0.733	0.034	0.058	0.126	0.106	0.206	0.156	0.320	0.108
Jun	1.530	1.817	2.640	1.401	0.054	0.080	0.187	0.124	0.094	0.080	0.150	0.044
Jul	1.451	1.807	2.827	1.384	0.060	0.080	0.204	0.124	0.083	0.060	0.117	0.055
Aug	1.427	1.358	3.055	1.531	0.034	0.108	0.205	0.098	0.079	0.053	0.092	0.096
Sep	0.860	1.441	3.525	1.295	0.053	0.105	0.142	0.063	0.105	0.099	0.160	0.092
Oct	0.925	1.417	3.049	0.748	0.017	0.071	0.086	0.079	0.160	0.202	0.191	0.139
Nov	1.058	1.100	2.549	0.547	0.024	0.074	0.083	0.067	0.210	0.312	0.236	0.167
Dec	1.049	1.264	2.040	0.425	0.013	0.067	0.063	0.064	0.227	0.202	0.322	0.243
Jan 93	0.830	1.278	2.072	0.499	0.023	0.067	0.078	0.089	0.248	0.325	0.339	0.171
Overall mean	1.093	1.400	2.670	0.824	0.044	0.074	0.132	0.089	0.133	0.200	0.253	0.126

Aca-Acacia, Leu-Leucaena, Cas-Casuarina and Ail-Ailanthus

	Nitrogen	Phosphorus	Potassium
Species			
p	<0.01	<0.01	<0.01
SEM (±)	0.0143	0.0054	0.0061
CD (0.05)	0.0284	0.0107	<0.0121
Month			
p	<0.01	<0.01	<0.01
SEM (±)	0.0248	0.0093	0.0106
CD (0.05)	0.0492	0.0184	0.0210
Species x Month			
p	<0.01	<0.01	<0.01
SEM (±)	0.0495	0.0187	0.0212
CD (0.05)	0.0982	0.0371	0.0421

concentration of acacia, casuarina and leucaena litter was highest during June while for ailanthus it was during December. Potassium, however, had lowest values during March, for acacia and casuarina and March and January leucaena while for ailanthus it was during June. Nitrogen and phosphorus concentration showed a gradual increase with the advancement of rainy season followed by a decrease in concentration during the dry season. Potassium concentration showed a reverse trend.

4.8 Litter decomposition

The mean mass loss of the decomposing litter of four multipurpose fast growing tree species are given in Table 19 and Fig. 17. Of the four tree species litter studied only casuarina and leucaena litter decomposed completely during the experimental period (in a period of six and seven months respectively). At the end of the 12-month period acacia retained about 0.38 % of the initial mass while ailanthus retained, as much as, 9.4 % of the initial mass. The decomposition rate coefficients show that casuarina has a k-value of 0.665, leucaena: 0.510, acacia: 0.416 and ailanthus: 0.143 (Table 20). The time taken to reach half of the initial quantity was 1.0, 1.3, 1.7 and 4.8 months, respectively for casuarina, leucaena, acacia and ailanthus. Fig. 18 depicts the curve fitted using the Olson's equation

Fig. 17 Relative proportion of biomass remaining in litter bags at various time intervals for four MPT species

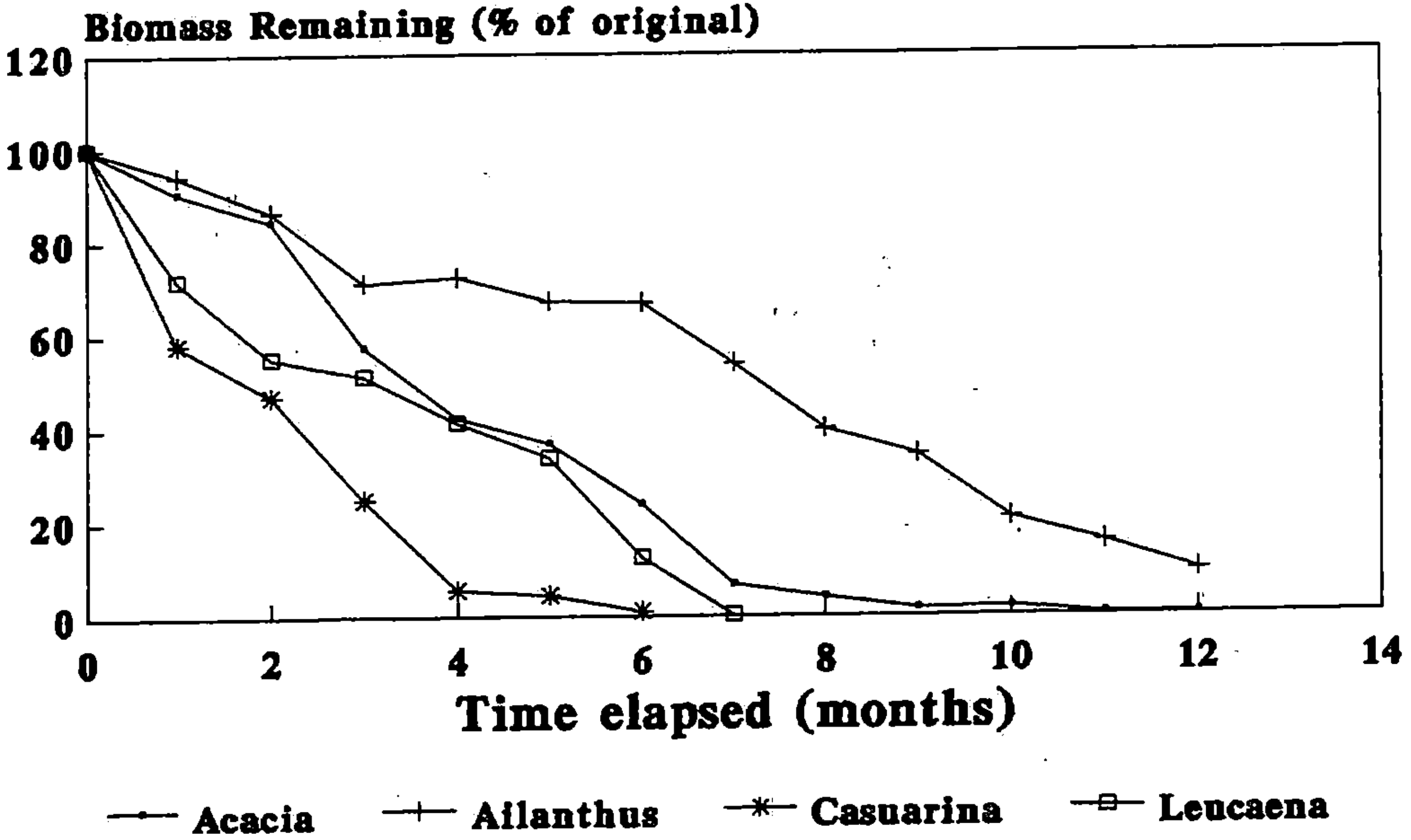


Fig. 18 Litter decay models of four multipurpose tree species

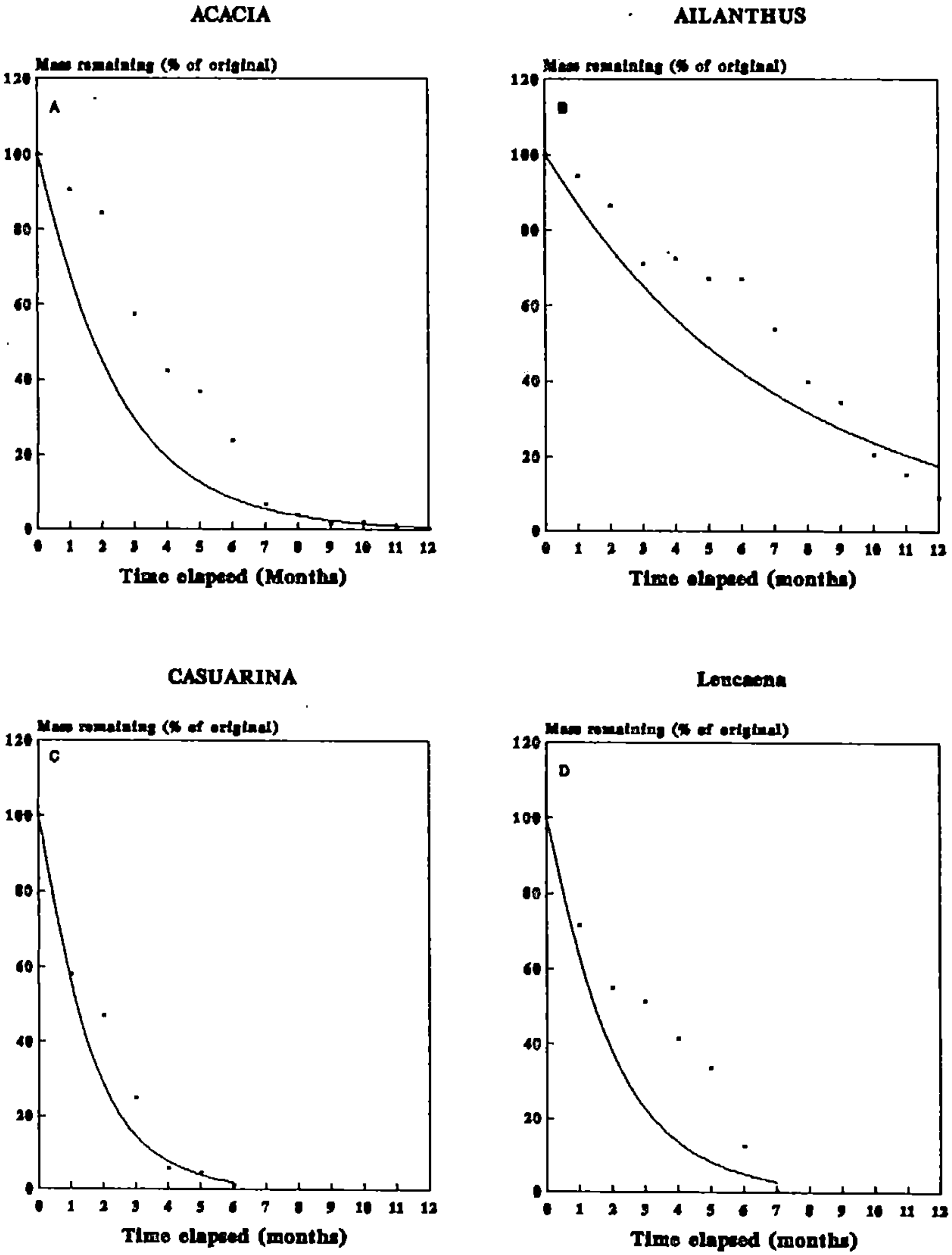


Fig. 19 Litter nutrient contents and their relative proportion in the residual mass of the decomposing litter for four MPT species.

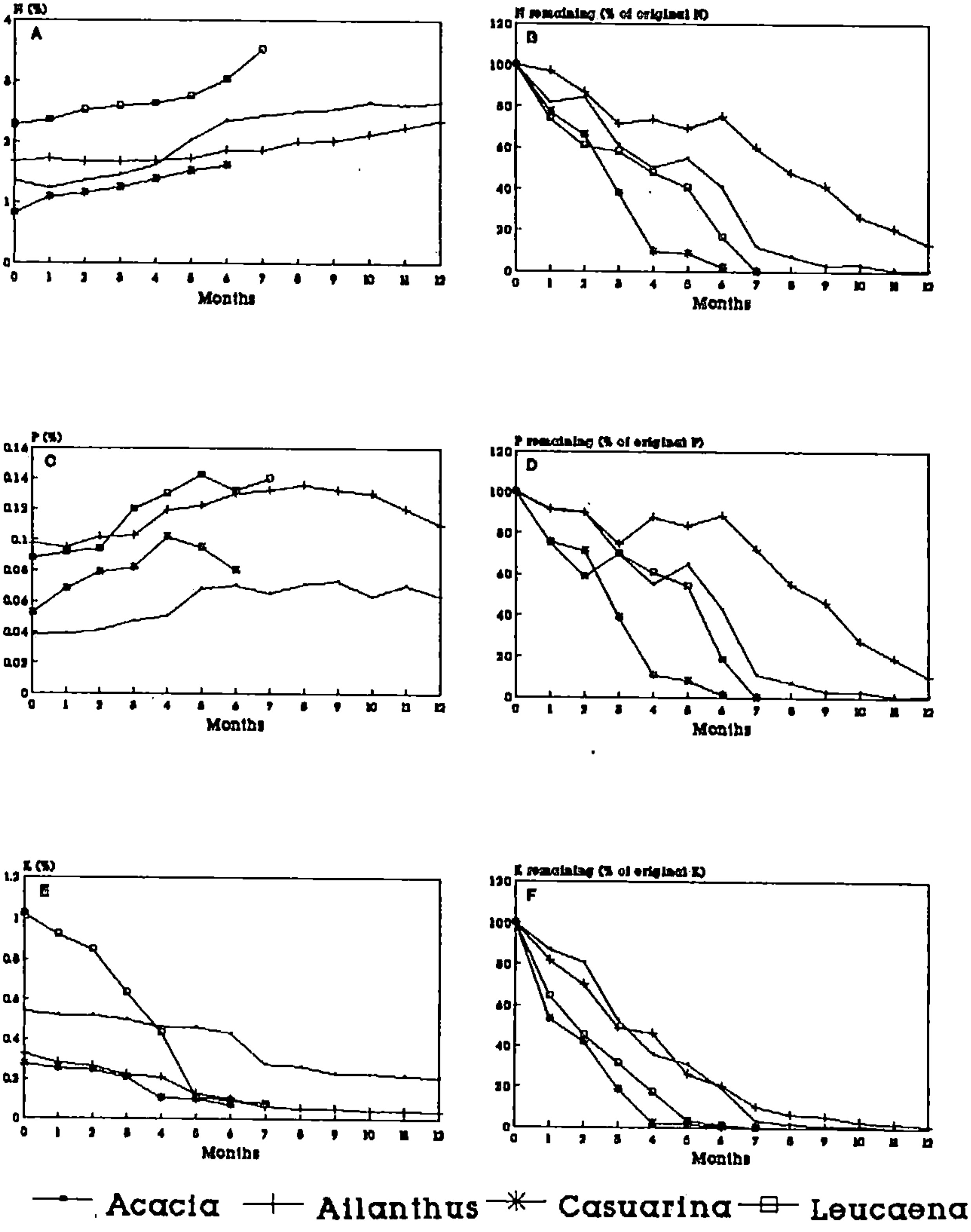


Table 19. Biomass and nutrients remaining in litterbags of four multi-purpose fast growing tree species.

Species	Time	Litter mass remaining	Litter nutrient concentration			Relative proportion of nutrient remaining			Relative changes in the nutrient concentration of the litter		
			N (%)	P (%)	K (%)	N (%)	P (%)	K (%)	N (%)	P (%)	K (%)
Acacia auriculiformis	0	19.258	1.365	0.039	0.542	100.000	100.000	100.000	100.000	100.000	100.000
	1	17.425	1.235	0.039	0.521	81.862	92.124	86.974	90.476	101.818	96.125
	2	16.225	1.368	0.041	0.520	84.433	90.156	80.828	100.220	107.013	95.941
	3	11.050	1.452	0.047	0.498	61.036	70.047	52.721	106.374	122.078	91.882
	4	8.150	1.623	0.050	0.462	50.319	55.181	36.074	118.901	130.390	85.240
	5	7.085	2.035	0.068	0.462	54.850	64.981	31.361	149.084	176.623	85.240
	6	4.589	2.352	0.070	0.430	41.058	43.324	18.913	172.308	181.818	79.373
	7	1.287	2.435	0.065	0.276	11.923	11.285	3.404	178.388	168.831	50.923
	8	0.770	2.503	0.071	0.264	7.335	7.376	1.948	183.370	184.416	48.708
	9	0.327	2.532	0.073	0.232	3.154	3.224	0.728	185.495	189.610	42.804
	10	0.350	2.653	0.063	0.228	3.531	2.973	0.764	194.359	163.636	42.066
	11	0.062	2.602	0.070	0.221	0.613	0.586	0.131	190.623	182.338	40.830
	12	0.075	2.653	0.063	0.210	0.757	0.639	0.151	194.359	164.156	38.819
Ailanthus triphysa	0	19.100	1.670	0.098	0.326	100.000	100.000	100.000	100.000	100.000	100.000
	1	17.988	1.720	0.095	0.283	96.997	91.295	81.755	102.994	96.939	86.810
	2	16.498	1.680	0.102	0.264	86.895	89.904	69.950	100.599	104.082	80.982
	3	13.579	1.680	0.103	0.224	71.522	74.723	48.851	100.599	105.102	68.712
	4	13.806	1.700	0.119	0.209	73.581	87.771	46.340	101.796	121.429	64.110
	5	12.819	1.720	0.122	0.128	69.123	83.550	26.351	102.994	124.490	39.264
	6	12.761	1.875	0.130	0.099	75.014	88.629	20.290	112.275	132.653	30.368
	7	10.272	1.855	0.132	0.062	59.735	72.435	10.244	111.078	134.694	19.049
	8	7.590	2.012	0.136	0.053	47.873	55.143	6.472	120.479	138.776	16.288
	9	6.567	2.021	0.132	0.051	41.605	46.307	5.378	121.018	134.694	15.644
	10	3.964	2.123	0.130	0.043	26.385	27.532	2.719	127.126	132.653	13.098
	11	2.973	2.240	0.120	0.041	20.877	19.058	1.943	134.132	122.449	12.485
	12	1.800	2.350	0.110	0.036	13.259	10.576	1.041	140.719	112.245	11.043

Contd.

Table 19 (Contd.)

Species	Time	Litter mass remaining	Litter nutrient concentration			Relative proportion of nutrient remaining			Relative changes in the nutrient concentration of the litter		
			N (%)	P (%)	K (%)	N (%)	P (%)	K (%)	N (%)	P (%)	K (%)
Casuarina equisetifolia	0	18.941	0.820	0.052	0.276	100.000	100.000	100.000	100.000	100.000	100.000
	1	10.987	1.095	0.068	0.253	77.456	75.851	53.212	133.537	130.769	91.739
	2	8.874	1.160	0.079	0.249	66.279	71.180	42.303	141.463	151.923	90.290
	3	4.693	1.256	0.082	0.210	37.947	39.068	18.868	153.171	157.692	76.159
	4	1.065	1.390	0.102	0.102	9.530	11.028	2.078	169.512	196.154	36.957
	5	0.862	1.520	0.095	0.098	8.439	8.317	1.617	185.366	182.692	35.507
	6	0.198	1.620	0.080	0.072	2.061	1.605	0.272	197.561	153.846	26.087
Leucaena leucocephala	0	19.136	2.280	0.088	1.024	100.000	100.000	100.000	100.000	100.000	100.000
	1	13.712	2.360	0.092	0.923	74.170	74.913	64.588	103.509	104.545	90.137
	2	10.528	2.520	0.094	0.846	60.807	58.766	45.452	110.526	106.818	82.617
	3	9.799	2.590	0.120	0.632	58.167	69.825	31.603	113.596	136.364	61.719
	4	7.895	2.645	0.130	0.432	47.864	60.951	17.406	116.009	147.727	42.188
	5	6.445	2.756	0.142	0.111	40.713	54.349	3.639	120.877	161.364	10.806
	6	2.387	3.025	0.132	0.094	16.553	18.714	1.145	132.675	150.000	9.180
	7	0.025	3.529	0.140	0.078	0.205	0.211	0.010	154.781	159.091	7.617

Table 20. Decay rate coefficient and half life of decomposing litter for four multipurpose fast growing tree species.

Species	k	r^2	S.E.E.	Half life ($t_{0.5}$) (months)	n
Acacia auriculiformis	0.4159	0.874	0.7266	1.6	13
Casuarina equisetifolia	0.6658	0.908	0.4758	1.0	7
Leucaena leucocephala	0.5099	0.502	1.5658	1.3	8
Ailanthus triphysa	0.1430	0.806	0.3253	4.8	13

Table 21. Initial lignin content, initial nitrogen content and lignin : nitrogen ratio for four multipurpose fast growing tree species.

Species	Initial Lignin (%)	Initial N (%)	Lignin : Nitrogen ratio
Acacia auriculiformis	22.23	1.36	16.28
Casuarina equisetifolia	15.69	0.82	19.13
Leucaena leucocephala	15.70	2.28	6.88
Ailanthus triphysa	9.60	1.67	3.35

for the four species relating time elapsed to the mass remaining.

The initial lignin concentration given in Table 21 show that ailanthus surprisingly, had the lowest concentration of lignin (9.6 %). acacia had the highest concentration of 22.2 %. Casuarina and leucaena were comparable in this respect (15.7 %). The lignin to initial nitrogen was highest for casuarina.

4.8.1 Nutrient dynamics of residual decomposing mass

4.8.1.1 Nitrogen

The nitrogen content of the decomposing litter increased during the one-year decomposing period for all the species (Table 19 and Fig. 19). The initial concentration was highest for leucaena (2.280 %) and lowest for casuarina (0.820 %). The per cent increase over the initial concentration was 94.3, 40.7, 97.6 and 54.8 for acacia, ailanthus, casuarina and leucaena respectively. The total amount of nutrient in the residual mass was highest for ailanthus (13.2 %) and lowest for leucaena (0.205 %).

The cubic model gave a better fit than other models in describing the changes in relative nutrient

Fig. 20 Changes in N content of the residual litter mass over time in four MPT species

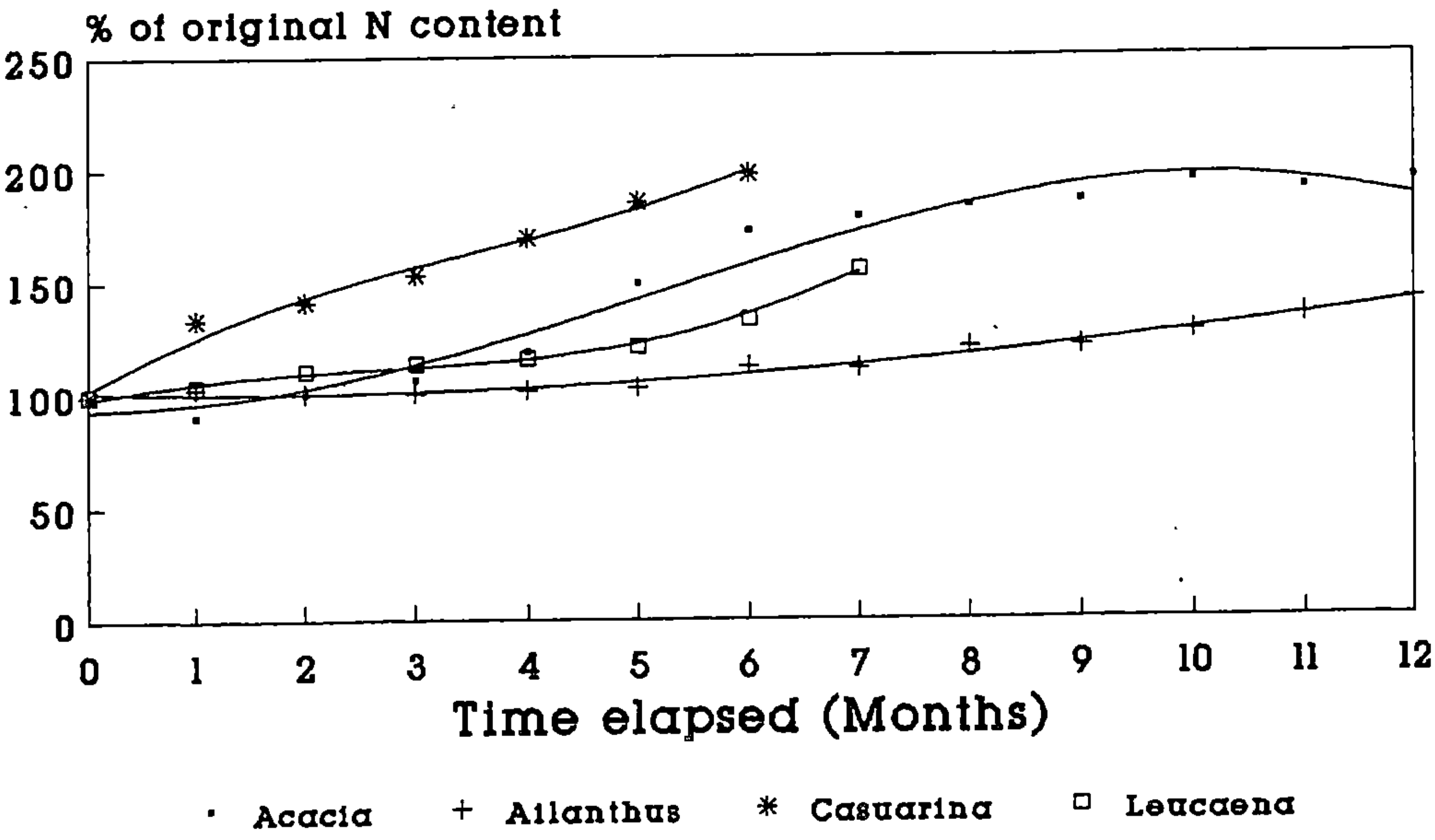


Fig. 21 Changes in P content of the residual litter mass over time for four MPT species

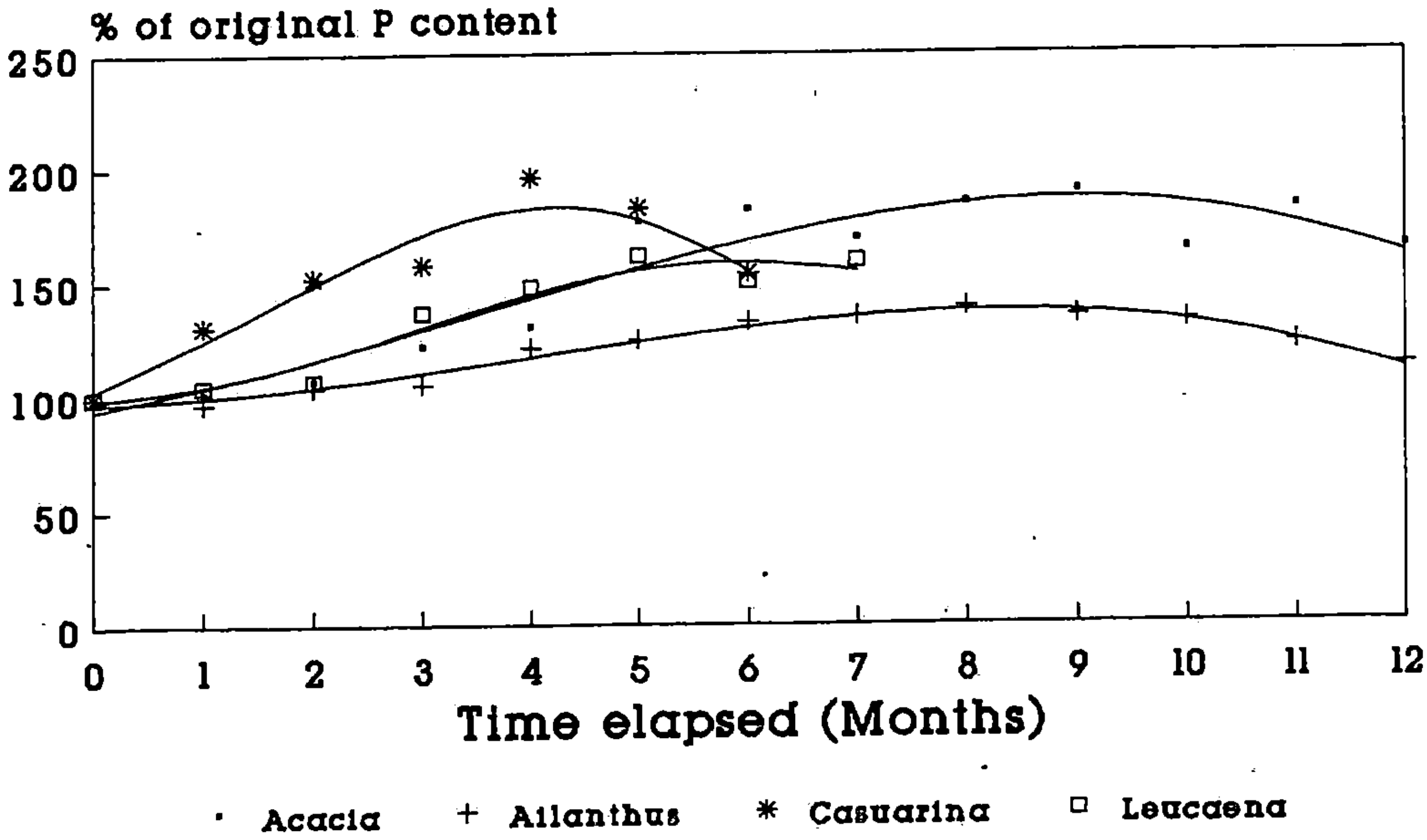


Fig. 22 Changes in K content of the residual litter mass over time in four MPT species

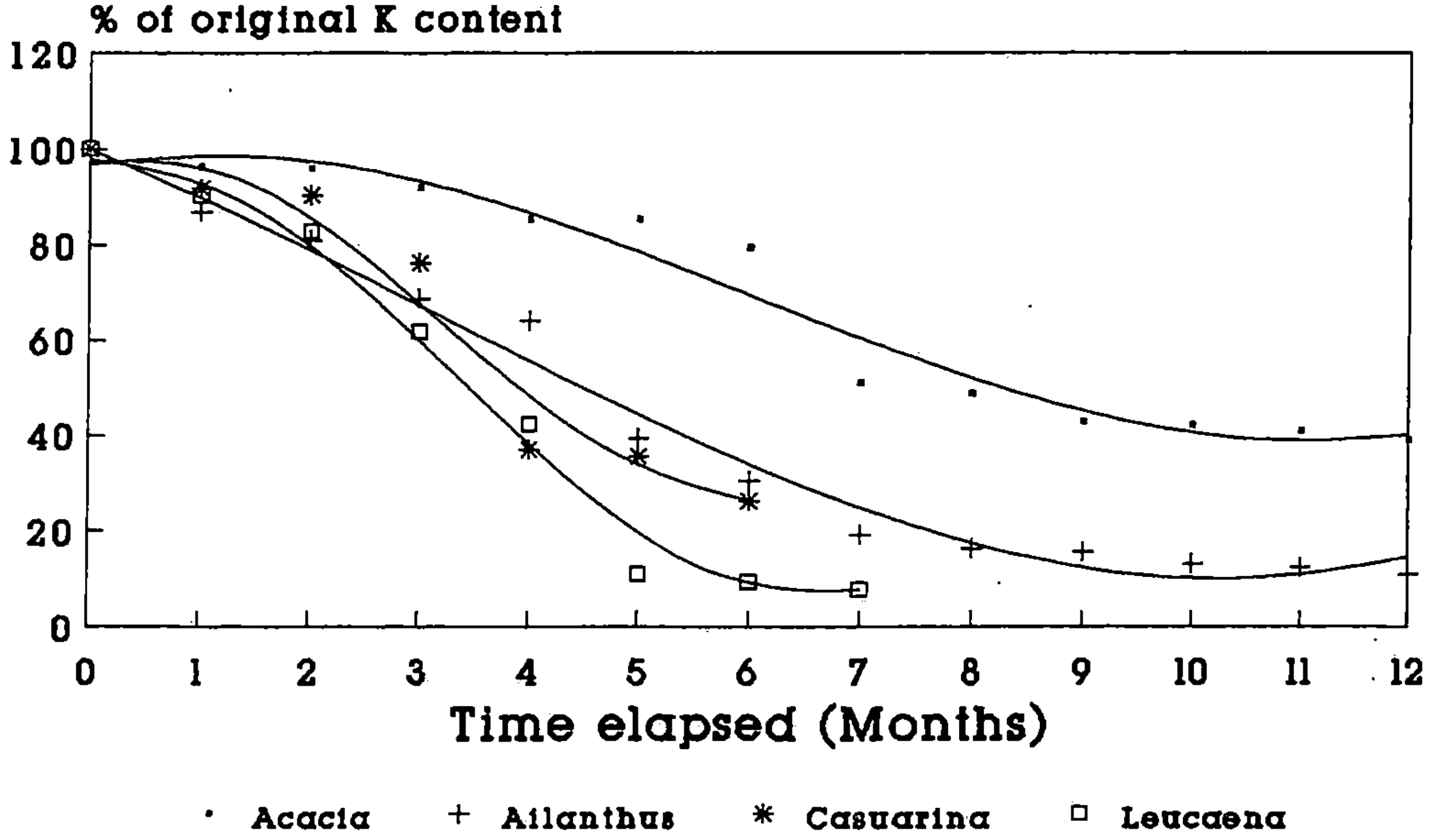


Table 22. Relationships between time elapsed and relative nutrient concentration of residual decomposing mass in four multi-purpose fast growing species.

Species	Nutrient	Equation	R^2	S.E.E.	n
<u>Acacia auriculiformis</u>	N	$90.44+10.10465x$	0.900	13.67	13
		$79.52+16.06485x-0.49668x^2$	0.924	12.50	13
		$93.52-1.54971x+3.323343x^2-0.21222x^3$	0.969	8.40	13
	P	$108.33+7.23562x$	0.678	20.28	13
		$83.45+20.80854x-1.13107x^2$	0.860	14.02	13
		$93.47+8.20138x+1.60301x^2-0.15189x^3$	0.894	12.87	13
	K	$105.79-6.11907x$	0.916	7.51	13
		$105.15-5.77325x-0.02881x^2$	0.917	7.81	13
		$96.78+4.76782x-2.31483x^2+0.12700x^3$	0.961	5.65	13
<u>Ailanthus triphysa</u>	N	$93.32+3.36711x$	0.883	4.99	13
		$100.73-0.67291x+0.33667x^2$	0.980	2.17	13
		$101.45-1.58525x+0.53452x^2-0.01099x^3$	0.981	2.23	13
	P	$105.21+2.466920x$	0.460	11.65	13
		$89.04+11.28667x-0.73497x^2$	0.842	6.41	13
		$97.42+0.74929x+1.55023x^2-0.12695x^3$	0.969	2.96	13
	K	$90.79-7.97781x$	0.907	10.40	13
		$105.22-15.85600x+0.65652x^2$	0.974	5.71	13
		$100.05-9.35232x-0.75393x^2+0.078358x^3$	0.984	4.72	13

Contd.

Table 22 (Contd.)

Species	Nutrient	Equation	R^2	S.E.E.	n
Casuarina equisetifolia	N	$108.90+15.15679x$	0.972	6.02	7
		$105.46+19.28571x-0.68815x^2$	0.979	5.95	7
		$102.51+29.10956x-5.10888x^2+0.491192x^3$	0.986	5.46	7
	P	$120.12+11.05769x$	0.564	23.01	7
		$95.97+40.04120x-4.83058x^2$	0.887	13.10	7
		$103.02+16.53693x-5.74637x^2-0.67863\ x^3$	0.936	11.38	7
	K	$106.77-13.8405x$	0.913	10.10	7
		$103.44-\ 9.8447x-0.665970x^2$	0.919	10.87	7
		$97.50+\ 9.9620x-9.579020x^2+\ 0.9903\ x^3$	0.955	9.33	7
Leucaena leucocephala	N	$95.55+\ 6.69956x$	0.864	7.03	8
		$102.94-\ 0.69261x+1.05602x^2$	0.950	4.67	8
		$98.75+10.27534x-3.13174x^2+0.398834x^3$	0.993	1.92	8
	P	$99.24+\ 9.71320x$	0.864	10.19	8
		$92.71+16.24729x-0.93344x^2$	0.896	9.77	8
		$98.79+\ 0.30663x-5.15299x^2-0.57966x^3$	0.939	8.33	8
	K	$104.13-15.3146x$	0.950	9.30	8
		$106.33-17.5161x+0.314505x^2$	0.951	10.02	8
		$97.87+\ 4.6630x-8.153900x^2+0.806514^3$	0.988	5.39	8

concentration of decomposing litter over time for all the four species (Table 22 and Fig. 20). The r^2 values were 0.969, 0.981, 0.986 and 0.993, respectively for acacia, ailanthus, casuarina and leucaena.

4.8.1.2 Phosphorus

Phosphorus concentration of the residual litter mass (Table 19 and Fig. 19) exhibited an initial increase and after reaching a plateau it finally decreased. The highest initial concentration was 0.098 % for ailanthus and the lowest was for acacia (0.039 %). For acacia the relative P content increased to 89.6 % after a period of 9-months followed by decrease to 4.1 per cent at the end of the 12-month period. Ailanthus concentration peaked after seven months which was followed by a decrease. Casuarina and leucaena reached peak concentration after 4 and 5 months respectively.

In the case of P too the cubic model gave the best fitting equation linking relative P content with the time elapsed (Table 22 and Fig. 21). The r^2 ranged from 0.894 to 0.969.

4.8.1.3 Potassium

Potassium concentration of the decomposing litter declined during the one-year period for all the four species (Table 19 and Fig. 19). Acacia registered the highest initial concentration (0.542 %) and leucaena the lowest (0.088 %). The decline of K content was of the order of 61.2 % and 88.9 % the nutrient concentration to the initial concentration for acacia and ailanthus respectively at the end of the 12-month period.

The cubic model gave a better fitting relationship between relative K content and the time elapsed (Table 22 and Fig. 22). The r^2 ranged from 0.955 to 0.988.

Discussion

DISCUSSION

5.1 Understorey herbage yield

The productivity of forage crops grown in association with fast growing multipurpose tree species were generally lower than their respective monoculutral plots. Furthermore, fodder productivity was strongly dependent on the characteristics of the tree component growing in association. For instance, five-year-old acacia and leucaena trees generally tended to depress and growth and yield of the understorey forage crops very substantially (Table 8 and Fig. 6). Casuarina and ailanthus, however, did not exert any marked adverse effect on the productivity of understorey species. Moreover, all important growth and yield parameters in respect of the forage crops such as plant height, number of tillers per hill, number of leaves per tiller and dry weight of tillers (Table 9) consistently recorded higher values when grown in association with casuarina and ailanthus albeit tree-less controls registered the highest values in this respect.

Regarding productivity of individual forage crops, hybrid napier recorded the highest forage yield levels under all combinations including the monoculture. Forage yield declined in the order hybrid napier > guniea grass > congo signal > teosinte, in the open. Nevertheless, under the various tree-crop combinations it generally followed the order: hybrid napier > guniea grass > teosinte > congo signal. Interspecific variations in biomass yield can be explained based on genotype x environment interaction (Leding, 1983).

5.1.1 Factors affecting understorey herabage yield

5.1.1.1 Understorey light availability

The life forms of silvopastoral ecosystem are interdependent because they depend on the same resource pool of light, water and nutrients. Hence competition for light and nutrients may be a cardinal factor responsible for the inferior performance of the herbaceous components of the silvopastoral systems (Table 8). During early stages of tree establishment however, the perennial grasses have an advantage over the young tree seedling (Byington and Child, 1981). At five years of age, it appears that the trees and forage interact to compete for factors essential for growth. In this connection Mathew et al. (1992) reported that the growth and yield of fodder crops were influenced by the tree components only after tree canopy closure and that trees with dense, spreading crowns, generally retarded understorey herbage productition.

In the present study both acacia and leucaena were characterised by larger canopy coverage (Table 1) resulting in a greater interception of incoming light by tree crowns. In silvopastoral systems the amount of light available at ground level for forage crops depends upon the species, the spacing and the age of the tree crop (Payne, 1985; Mathew _et al_., 1992). Crown characteristics _per se_ are, however, far more important than the quantitative spread of the crown. Although, canopy spread of acacia, leucaena and casuarina were not significantly different (Table 1), the attenuation of the incoming solar radiation presented an altogether different picture. Acacia with a dense crown structure intercepted more light than all other species (Fig. 7). Ailanthus due to the combination of its small crown and trunk intercepted the least (Fig. 9). Casuarina, with its needle like cladophyls actually facilitated greater light penetration into the understorey at all levels (Fig. 8). Leucaena, a fast growing N-fixer, however, exhibited relatively lower fodder growth and yield _albeit_ light availability in the understorey was comparable to that of casuarina (Fig.10). In general, fodder production followed a declining trend with increasing interception of the incoming solar radiation by tree crowns except leucaena.

Biomass production in the understorey is a function of the photosynthetically active radiation (PAR) falling on the ground (Hazara and Tripathi, 1986). The present study highlights the fact that sub-optimal PAR levels would substantially reduce understorey fodder production and hence the understorey and overstorey components should be carefully managed to optimize production. Canopy manipulation such as pruning the lateral branches pollarding etc. can improve understorey light availability regardless of stand age of trees, especially after canopy closure.

Although forage yield decreased as the understorey light availability declined, a direct relationship between the understorey PAR level and the forage yield was lacking as for hybrid napier grown under acacia had an yield reduction of 3.3 times compared to the open but received 16.7 per cent of PAR (0.50 m above ground level) while yield reduction of hybrid napier under leucaena was 3.5 times when it received 30.2 per cent PAR under its canopy.

It is often conceptualised that the available solar energy is more efficiently used in silvopastoral systems due to the vertical stratification of the vegetative components. Besides they tend to mimic the vertically stratified rainforest ecosystem (Payne, 1985). The present study clearly indicates that understorey light availability in a stand, though a function of the crown characteristics, is by and large uniform beneath crowns at different heights above the ground level. Presumably they simulate a two-tiered system where the trees occupy the top strata and the forage crops the bottom layer. Fundamental advantage of this system is the partitioning of incoming solar radiation between the two strata and consequently higher efficiency of light utilization in comparison to monocultural situations.

5.1.1.2 Tolerance

Monocultures of the forage crops invariably resulted in significantly higher biomass yields (Table 8). In general, the relative yield loss in association with leucaena (lowest recorded yields) was highest for hybrid napier followed by guniea grass, congo signal and teosinte, indirectly suggesting that teosinte perhaps is a better choice for silvopastoral systems. Nonetheless, overall productivity of teosinte was very low, especially with reference to hybrid napier and guniea grass. The variations in the magnitude of yield loss in the grass-tree combinations in comparison to grass monocultures can be attributed to the varying degrees of shade tolerance these forage crops possess. Tolerance is the ability of plants to subsist under reduced light, nutrients and/or water (Daniel et al.,1979.Although forage plants differ with respect to their ability to tolerate shade (Eriksen and Whitney, 1977; Byington and Child, 1981), the general effect of reduced light intensity is reduction in yield levels (Table 8 and 10). The preference of brachiaria genus, reportedly a shade bearer (Bor, 1960; Coconut Research Institute, 1966) in association with various tree species was surprisingly inferior to all other forage crops tested. Hence proper testing and selection of appropriate shade tolerant forage species/cultivar are of utmost importance in the management of silvopastoral systems which integrate trees and livestock on the same management unit, especially after the tree components attain canopy closure.

5.1.1.3 Below ground competition

A desirable feature of the silvopastoral system, true for other agroforestry system also, is presumably the vertical stratification of the root systems of different species (Payne, 1985), so that trees then would compete less with the crops and that the tree roots would act as a trap for nutrients leached out of the top soil (Jonsson _et_ _al_., 1988)

The data presented in Table 13A, however, clearly suggest that ^{32}P recovery by the trees was markedly high when applied at 15 cm depth than the 50 cm deep placement, regardless of the species. It appears that 65 to 80 per cent of the fine roots responsible for water and nutrient absorption are concentrated in the 0-15 cm layer of the soil profile (Table 13B). Regarding the lateral spread of fine roots, only casuarina and leucaena exhibited a consistent trend. There were perceptible variations in ^{32}P recovery of casuarina between the 25 cm and 50 cm lateral distance treatments, implying that casuarina root activity was higher towards the base of the tree trunk (25 cm radial distance). As regards to leucaena, ^{32}P applied at the two lateral distances were statistically at par suggesting that root spread and activity would be more or less uniform in the entire 50 cm radial distance from the base of the stem. For ailanthus and acacia the difference between the lateral distances of ^{32}P soil injection significant at 15 or 30 days after application. In both cases, however, ^{32}P recovery was higher when applied at closer distances.

The pronounced decline in root activity with increasing soil depth and increasing lateral distance except for leucaena, which had its roots evenly distributed upto 50 cm radial distance observed in the present study was corroborated by Johnsson et al. (1988) who studied the fine root dynamics of five Tanzanian tree species, root architecture analysis of 12 tree in North Indian species by Toky and Bisht (1992) and ^{32}P studies by Wahid et al. (1989). However, there are interspecific variations in root distribution patterns especially, with the below ground biomass accumulation (Table 3). Furthermore, the root architecture, depth of root penetration, their lateral spread and area of greater concentration differed among tree species (Eis, 1974; Savill, 1976; Sankar et al., 1988; Toky and Bist, 1992 and Dhyani et al., 1990). In addition, Toky and Bisht (1992) observed variations between species and also within the same species with regard to root distribution.

The ^{32}P studies have also indicated that treeless controls of forage crops were consistently more efficient in terms of ^{32}P absorption and were superior to all tree-grass combinations except casuarina-guniea grass at 15 days after application and casuarina-hybrid napier at 30 days after application (Table 15). The relatively low ^{32}P recovery in tree-grass combinations indicates that the root zones of the trees and grass components of the system overlap substantially. Implicit in the surface concentration of feeder roots is thus a high degree of competition between the tree and grass components. Nevertheless, the magnitude of this interspecific competition would be relatively lower in the casuarina plots. Hence casuarina has distinct advantage as a component of the silvopastoral system. The reduction in understorey herbage production of tree-grass system can therefore be partly explained by the below ground root interaction.

The above contention, however, is not entirely correct as the nutrient use efficiency (amount taken vis a vis present in the soil: both applied as well as native) increases as rooting density (number of roots per unit volume of soil) increases (Barber, 1962). Consequentially the nutrient loss from such a integrated land-use system would be negligible. In this context, Nair (1983) has described that most of the tropical land-use systems exhibit varying degrees of 'leakiness' and in that context inclusion of trees in these land management systems can to some extent plug these leaks. Increased rooting density is a definite possibility in species-mixture of this sort (Nair, 1983). Besides there may be also nutrient accretion due to various biological process associated with trees. Hence below ground competition for nutrients *per se* cannot explain the yield reduction in tree grass combinations, except possibly in the case of leucaena where despite a relatively higher understorey PAR level, forage productivity remained low.

The forage crops grown in association with the four tree species actually did not exhibit any consistent pattern with respect to ^{32}P recovery by trees (Table, 14). Surprisingly, ^{32}P recovery was least in the tree-monoculture (for casuarina at 30 days after application, ailanthus and leucaena at 15 days after application). The low recovery in the ^{32}P probably suggests that presence of an associated crop tend to stimulate nutrient absorption by the trees. However, no such favorable effects were visible in the tree-association involving acacia.

The obvious conclusion, therefore, would be that trees and forage crops are complementary to each other, *albeit* differences among species. Hence the general apprehension that trees will compete strongly for nutrients diameter at breast height and mean crown diameter and is probably one of the most promising multipurpose tree species (Table 2). By and large, growth rates and the magnitude of biomass productivity are dependent on the amount of light captured in photosynthesis, which in turn, is a function of the leaf area development (Humpherey, 1978). Acacia recorded the highest leaf area besides crown diameter compared to the other three species (Table 2), constituting more green surface for photosynthesis. Osman _et_ _al_. (1992) also reported high growth rates and volume production in acacia.

The above ground net primary productivity (NPP) for all species except acacia did not exceed the baseline figures for natural vegetation under the corresponding climate of humid tropics with short dry spell (23,000 kg ha^{-1} y^{-1} of dry matter; Leith, 1976). Lugo _et_ _al_. (1988) also found that above ground net primary productivity for tropical species ranged between 16,000 to 29,800 kg ha^{-1} yr^{-1} of dry matter. In the present study, acacia had an above ground NPP of 32, 784 by ha^{-1} yr^{-1} of dry matter (inclusive of the below ground component it came to 36, 564 kg ha^{-1} yr^{-1} dry matter). Other three species were below the 20,000 kg ha^{-1} yr^{-1} dry matter mark. If the forage component of the silvopastural system (Table 8) also was added to is somewhat unfounded. The main limiting factor under such situations would then be light rather than water and nutrients per se, although below ground competition may be significant in some situations. Understorey herbage productivity can be improved by proper selection of trees and forage crops and also managing them in a careful manner. As far as trees are concerned, light, compact crowns which facilitate light penetration to the understorey, having N-fixing potential, deep non-spreading type of root-system, and in short, complementary resource sharing habits would be desirable. Regarding forage crops, they should be tolerant to shade.

5.2 Allometry of tree growth and biomass productivity

Allometric relationships developed in the present study (Table 4) linking tree biomass with DBH and tree height gave reasonably good predictions and would help in estimating the biomass yield of a particular stand of trees without the expense of developing one. In the past, no efforts were made in this direction, although for some of the species equations developed elsewhere are available (Dudley and Fownes, 1992).

The data on tree growth and yield revealed that acacia had the highest biomass yield, height, the tree above ground NPP figures, then a combination like acacia and hybrid napier gave a very impressive figure of 48, 784 by ha^{-1} yr^{-1} of dry matter. Nevertheless, for grass monocultures, the NPP ranged from 13,000 to 52,000 kg ha^{-1} yr^{-1}, emphasising the dependence of total biomass productivity of silvopastoral system on the nature of the components. Therefore, selection of both the trees and grass components are of paramount importance, because the magnitude of competition between the trees and the associated crops depend on the nature of the trees included in the system. Regarding the attributes of the forage crops, shade tolerance is the primary aspect. Therefore, if the tree and forage components are selected considering these parameters such system will maintain high levels of productivity for a long period of time.

5.1.2 Nutrient accumulation and efficiency of the tree species in silvopastoral system

Nutrient concentrations were found to be fairly variable among the species studied and did not exhibit any consistent pattern (Table 5). Generally, leucaena had the highest concentrations for most elements and tissue types and leaves were the most 'costly' tissues to build. Casuarina and/or ailanthus invariably registered the lowest nutrient concentrations with the exception of P, for which acacia recorded the lowest elemental concentration in all tissue types. Similar observations were recorded by Wang et al. (1991) for leucaena and casuarina in the Lajas Valley of Peurto Rica. However, the observed nutrient levels in the present study for both casuarina and leucaena were generally higher than the values reported by Wang et al. (1991), which can be attributed to the relatively high site nutrient levels (Table 12).

The high biomass accumulation rates (Table 3), concomitantly resulted in the high nutrient accumulation rates of acacia (1427 kg N, 66 kg P and 719 kg K per hectare; Table 6). The nutrient accumulation for all other tree species studied were profoundly less than acacia. The annual rate of removal of nitrogen in respect of casuarina (36.5 kg N ha^{-1}) and ailanthus (24.7 kg ha^{-1}) were also much lower than that of annual crop systems such as maize (63 kg ha^{-1}) and sorghum (135 kg N ha^{-1}; Jorgensen and Wells, 1986). Wang et al. (1991) who analysed nutrient removal by casuarina and two strains of leucaena in Peurto Rica found that casuarina recorded almost 3.5 times higher nutrient export for N while the corresponding values for Leucaena leucocephala K8 were roughly 1/3 of the nitrogen removal reported in the present study. The most important reason for this pronounced variation in the above ground nutrient export through whole tree harvesting can be the large differences in biomass accumulation rates between the two sites.

Incidentally, the export of nutrients from the site through processes associated with biomass harvest has been great concern in recent years (Kimmin, 1977; Jorgensen and Wells, 1986 and Hopman _et_ _al_., 1993) and such heavy nutrient removal, has an important bearing on the long term site quality and sustainable production (Wang _et_ _al_, 1991). Hence selection of the tree taxa and the parts to be removed from the site would perhaps alter the rate of nutrient export from the site. It highlights the fact that a fast growing tree taxa such as _Acacia_ _auriculiformis_ can result in tremendous loss of nutrients from the site especially if whole tree harvesting is resorted to in silvopastoral systems and other short rotation intensive cultural (SRIC) systems too. The nutrient export from the site through whole tree harvesting was substantially high for both acacia and leucaena (1427.71 and 691.6 kg N ha^{-1}; Table 6). Differing nutrient concentration among types of harvested tissues (leaves, stem etc.) and the high variability in the relative abundance of tissue types in a species (Table 3 and 6) resulted in correspondingly diverse nutrient removal rates at harvest. However, due to the wide variation in nutrient concentration among species and among tissues within species, accumulation of nutrients did not correspond to a one-to-one pattern with overall biomass accumulation. Wang et al. (1991) also reported corroborative results. He found that taxa with the highest nutrient concentration did not have the greatest nutrient accumulation, which is largely applicable to the present study as well.

Implicit in the concept of silvopastoralism is sustainable production without any long term site degradation. Most of the SRIC systems are, however, characterised by repeated harvests which in turn may result in high nutrient drain that exceeds the natural rate of nutrient inputs (Wang, et al., 1991). The SRIC systems thus can lead to high rates of nutrient export from the site through repeated biomass harvests at frequent intervals. Nutrient use efficiency is an important concept in this context which enable us to evaluate the large differences in nutrient 'cost' as a result of species selection and harvest procedures in silvopastoral systems. Large differences in whole-tree nutrient use efficiency were seen among the four species studied (Table 7). The three N-fixers are seen to use more N than the non-N fixing species. According to Wang et al. (1991) such a comparison among species for nitrogen nutrient use efficiency may not be completely meaningful as symbiotic nitrogen-fixing may be involved in the growth of all species except ailanthus. Hence to understand the true harvest drain in case of nitrogen fixing species, he suggested that net nitrogen loss (N-harvested minus N-fixed) over the course of a rotation should be estimated.

Furthermore, efficiency pattern (Table 7) also did not extend from one nutrient to another. For instance ailanthus was the most efficient for N (5.62 g Kg^{-1}) and leucaena the least efficient (8.44 g kg^{-1}) for this element, while acacia and ailanthus respectively were the most efficient and least efficient in respect of P and casuarina the most K efficient and acacia the least K efficient species. Ideally in a silvopastoral system the tree components should not only be fast growing but should remove less nutrients (more efficiency means less nutrients per unit biomass), which in turn will perhaps entail less competition with the herbaceous components for nutrients. Since the amount of symbiotically fixed nitrogen and soil pool of nitrogen cannot be partitioned in this analysis, it is difficult to screen the species based on nutrient use efficiency alone. However, P and K use efficiency, if used as the sole criteria, casuarina clearly is a better option. Although nutrients are used more efficiently in casuarina the biomass accumulation is relatively low, which may be a constraint in the context of overall productivity. Nevertheless, the potential for altering nutrient drain through biomass removals through species selection is high.

Within a species nutrient export can be further modulated by regulating the magnitude and type of tissue removal. By resorting to whole-tree removal a substantial amount of nutrient nutrients would be exported from the site. However, by restricting the biomass removal at harvest to only stemwood and main branches, the nutrient costs can be substantially brought down.

5.3 Long term soil changes under silvopastoral system

Sustainability is the ultimate objective in the design of all agroforestry types of land-use systems. Apart from moderating the soil temperature in a limited manner (Table 11 Fig. 11) trees in managed land use system could bring about several favourable changes in the soil physico-chemical properties (Table 12). Although rapidly growing trees in general tend to export more 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, after five years of tree growth, marked variations in several of the soil physico-chemical properties have been noticed between the ´tree-plots' and ´tree-less' plots on the one hand and among the tree species themselves on the other. Acacia and leucaena have caused a significant lowering of the soil pH compared to the tree-less control, ailanthus and casuarina (Table 12). Perhaps this reduction in soil pH can be linked to the litter dynamics. The soil organic matter status was in the order acacia > leucaena > ailanthus = tree-less control (Table 12). Enhanced carbon fixation in photosynthesis and its transfer via the litter route and root decay are plausible explanations for the increase in soil organic matter status (Young, 1991). Inter-specific variations in this context can be explained by changes in rates of litterfall, residence time of litter and variations in nutrient litter contents. Not only the tree aspects were significant with respect to changes in soil organic matter status, the forage plants also influenced these parameters decisively. Regarding the forage species investigated, the high yielding hybrid napier consistently retarded the soil organic matter and the magnitude of the reduction could be directly correlated to the yield level.

Nevertheless, the organic matter status of the tree-grass combinations were considerably greater than the control plots. This in turn underscores the need for evolving tree-crop combinations which can sustain soil productivity. The higher N content seen below N-fixing trees may probably be through release of nitrogen fixed by these species into the rhizosphere (current nitrogen transfer; LaRue and Patterson, 1981 and Huxley, 1985; Mouilly and Margollis, 1992). The enhanced P and K may be, to a lesser extent, by abstraction of these elements released by rock weathering particularly from the B/C and C soil horizons (Young, 1991).

5.4 Nutrient recycling in silvopastoral systems

Most of the tropical land-use systems exhibit varying degrees of 'leakiness' according to Nair (1983). Integration of trees and herbaceous crops on the same land management unit has the potential of conserving mineral nutrients on site, by reducing hydrological outputs (Vitousek and Reiners, 1975). Nutrients absorbed by the tree roots are returned to the soil surface through the litter route. Furthermore, the decomposing litter release the nutrients at a rather slow rate. Thus litterfall and its subsequent decay are two fundamental mechanisms involved in moderating the nutrient losses from the site and also ensuring sustainability of the land use system by conserving nutrients on site. However, there are only very few reports characterising the nutrient cycling aspects of silvopastoral systems.

5.4.1 Litterfall

The amount of detritus produced ranged from 6.2 Mg ha^{-1} yr^{-1} (acacia) to 1.92 Mg ha^{-1} yr^{-1} (ailanthus). The annual litterfall rates for all the four species were less than that obtained for moist deciduous forests of Thrissur, reported by Kumar and Deepu (1992 ; 12.18 to 14.43 Mg ha^{-1} yr^{-1}) and that of <u>Acacia auriculiformis</u> stand at Pullazhi, Thrissur (12.93 Mg ha^{-1}; Kunhamu, 1992). The relatively lower values for litterfall can be explained by the relatively smaller dimensions and age of trees coupled with periodical pruning of lateral branches of trees at the commencement of experiment. In general, the magnitude of litterfall is expected to increase till canopy closure and thereafter parallel net primary productivity according to Waring and Schlesinger (1985). For the present stand also the quantum of litter fall is expected to increase as the trees expand their sizes.

The annual addition of detritus through litterfall in the five-year-old stands of the four multipurpose trees also exhibited profound seasonality. Leaf shedding was heavy during the dry period (November to April). May to August was a lean period as far as litterfall was concerned. Such seasonal variations in litterfall has been reported by several workers (Kumar and Deepu, 1992; Sharma and Pande, 1989; Stohlgren, 1988a). Foliage constituted the main component of litterfall in all species (Table 17 and Fig 13). Corroboratory results were obtained by Kumar and Deepu (1992). Tree water stress is the cardinal aspect of the dry seasons, where the moisture availability is limited and the temperature shoots up. Moore (1980) reported that water stress triggers *de novo* synthesis of abscissic acid in the foliage of plants, which in turn, can stimulate senescence of leaves and other plant parts. Hence changes in the endogenous hormonal balance can be a plausible explanation for the peak litterfall during summer months.

5.4.2 Seasonal variability in litter nutrient concentration

The lower nutrient content in the foliage fraction of litter (Table 18 and Fig.14 and 15) in comparison to the fresh foliage (Table 5), can be explained by the retranslocation of mineral nutrients from aging foliage and other tree tissues (Jorgensen and Wells , 1986; Miller *et al*., 1979; Strachurski and Zimka, 1975; Helmissari, 1992). According to Helmissari (1990), there are two phases in the retranslocation of nutrients and carbohydrates from older leaves: first, retranslocation may occur during the actively growing phase to the growing tissues and secondly, from senescing leaves and other components. During the more important second phase of translocation the cell structure disintegrates and most of the mobile nutrients are transported from the yellowing foliage. Macro-molecules are broken down to smaller molecules, example protein to amino acid that are easily transported (Thomas and Stoddart, 1990). Presumably a substantial portion of the N, P and K and the other minerals contained in the tree foliage as well as other parts are translocated to the growing shoots before the foliage and other organs are shed in litterfall process. For reasons not clearly known, the retranslocation efficiency *per se* was highest for ailanthus and the least in casuarina. Several authors (Strachurski and Zimka, 1975; Miller *et al.*, 1979) have suggested that retranslocation efficiency is determined by soil nutrient availability. However, Nambiar and Fife (1987) have observed that growth rate of trees, rather than the availability of nutrients in the soil (Miller *et al*. 1979) is the main mechanism controlling retranslocation efficiency. Nonetheless the observed interspecific variations in retranslocation efficiency could not be completely explained based on either of these hypotheses.

The data on seasonal variability in litter nutrient contents (Table 18, Fig. 14-16) for all nutrients indicate relatively lower contents of nitrogen and phosphorus during the dry period (March-April). This may be due to an efficient retranslocation mechanism operating to re-capture nutrients from senescing organs prior to fall during the summer season when the soil moisture availability is generally low and as a consequence the plant might be experiencing nutrient stress. Favourable conditions such as soil moisture and temperature, two cardinal factors found triggering litter decomposition and subsequent nutrient release perhaps might be responsible for reducing the pace of internal nutrient cycling. So, when nutrient availability is low translocation mechanism tends to be more efficient. Das and Ramakrishnan (1985), Sharma and Pande (1989) also reported that efficient retranslocation of nutrients are taking place in the dry months.

In contrast nitrogen and phosphorus concentrations of the detritus increased during the rainy season (Table 18 and Fig. 14, 15). Miller et al. (1979) concluded that retranslocation efficiency may be lower when soil nutrient availability increases. Comparatively good rainfall and associated higher litter decay rates enable the release of mineral nutrients tied up in the litter and the efficient recycling of nutrients constitute the principal reason for the reduced retranslocation efficiency and the consequent higher nutrient contents during this period. Contrary to the pattern of seasonal variations shown by phosphorus and nitrogen, potassium contents of the litter were generally low during the rainy season which may be due to the increased leaching of this element as surface wash from foliage and loss from the litter collected in traps (Das and Ramakrishnan, 1985).

5.4.2 Litter decay

Decomposition of litter is the primary mechanism of nutrient release in natural ecosystems. It can play a vital role to sustain soil fertility in land-use systems which integrate woody perennials along with other associated life forms on the same management unit. Furthermore, in silvopastoral systems and other agroforestry systems where intensive cultivation of the area in between the tree components is performed, it results in heavy removal of soil nutrients. A portion of this nutrient removal can be compensated by the nutrient released through the decomposing litter. The rate at which litter on the soil surface decomposes is primarily dependent on the biochemical quality of litter, prevailing temperature, moisture availability and other biotic factors.

Chemical composition is an intrinsic property of litter which determines the rate of turnover of organically bound nutrients. Tropical species in general are characterised by faster rate of decomposition (Kumar and Deepu, 1992) and presumably the nutrient turnover rates of the tropics including the managed land use systems which integrate herbaceous crops with woody perennials on the same land management unit are higher. Species with higher initial N content generally has a faster rate of decomposition (Singh and Gupta, 1977; Meentemeyer, 1978). Slow rate of decomposition due to presence of polyphenols and volatile terpenes in leaves (de Moral and Muller, 1969) which are known to reduce decay rate by inhibiting microbial enzyme action (Benoit and Starley, 1968). However initial N, lignin or initial lignin/nitrogen ratio (Melillo, 1982) could not be directly related to decay rate constant in the present study. Several workers failed to find strong dependence on either lignin or lignin/nitrogen ratio on decay rate coefficients (Schlesinger and Hasey, 1981; Stohlgren, 1988b).

The time-course of the mass disappearance of litter (12 months) indicates the loss in weight litter was highest during the south-west monsoon season (Table 19 and Fig. 17 and 18) vindicating the fact that high relative humidity, and optimal temperature tend to stimulate activity of soil microflora (William and Gray, 1974). Witkamp and Van der Drift (1961) and Singh and Gupta (1977) also suggested that among the climatic variables rainfall and temperature are of paramount importance in the control of litter decay. Madge (1965) also viewed soil moisture as a limiting factor for the breakdown of angiosperm tree litter in tropical forests. Additionally, nutrient inputs through stem flow and through fall also influence the decomposer communities directly.

5.4.3.1 Nutrient Release Pattern

As the litter decomposition proceeds the concentration of nitrogen in the residual mass increases (Table 19 and Fig.20-22). As litter samples decay the absolute mass decreased as of the rate of mass loss was far greater than the concentration increase (Coldwell and deLong, 1950). During decomposition carbon is oxidised causing an apparent increase in N concentration (Lousier and Parkinson, 1976). P also showed an accumulation followed by a final-release

Table 23. Nutrient accretion (N, P and K) to the soil through litterfall

Species	N	P	K
		(kg ha^{-1} yr^{-1})	
Acacia auriculiformis	68.0	2.7	8.3
Casuarina equisetifolia	34.7	1.8	5.0
Leucaena leucocephala	61.4	3.0	5.8
Ailanthus triphysa	15.8	1.7	2.4

phase. Phosphorus is seen to be readily immobilized as in the case of N (Bockheim _et al_., 1991). Potassium is not structurally bound in organic compounds like N or P. Potassium being a monovalent ion is weakly bound to adsorption sites and is highly water soluble (Bocock, 1963, Attwill, 1968 and Gosz _et al_., 1973). The leaching process is an important mechanism of K loss as retention of this cation is governed by the nature of the exchange complex. This would probably explain the decline of K level in residual litter mass as decomposition advances.

In summary, through the process associated with litter dynamics of trees the amount of nutrients added (Table 23) may compensate to a great extent the nutrient removal through tree harvesting.

Summary & 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. Silvopastoralism is an integral component of agroforestry. Besides sustainable production, buffering the natural forests from severe anthropogenic pressures, by providing the felt needs of the society such as: fuelwood, fodder and timber from outside the natural forests, and long term site improvement are characteristic features of agroforestry. Proper selection of the tree and field crop components are, however, of paramount significance for the success of agroforestry. Studies of such system on productivity is only anecdotal. In this context, a randomised block design experiment involving factorial combinations of four fodder species: *Pennisetum purpureum* (hybrid napier), *Brachiaria ruziziensis* (congo signal), *Panicum maximum* (guniea grass) and *Zea mexicana* (teosinte) and four tree species (*Leucaena leucocephala*, *Casuarina equisetifolia*, *Acacia auriculiformis* and *Ailanthus triphysa* (including their respective monocultures) was conducted at the Livestock Research Station, Thiruvazhamkunnu with the objective of quantifying the productivity of fodder crops grown in association with quick growing multipurpose tree species, besides evaluating the medium and long-term effects of tree farming on soil properties and characterising the partitioning of above and below ground site resources in silvopastoral systems.

The salient results are summarised below:

1. Productivity of forage crops grown in association with five-year-old fast growing multipurpose tree species was generally low. Implicit in this lower productivity of mixed-species cultural system is competition for the various above ground and below ground resources. Furthermore, fodder productivity was strongly dependent on the characteristics of the tree components.
2. Crown characteristics of the tree components were strong determinants of the understorey light availability (PAR). The attenuation of incoming solar radiation was highest for acacia perhaps due to its dense crown structure and least for ailanthus due to its compact crown and/or small relative size. Needle-like cladophyls of casuarina facilitated greater light penetration into the understorey. Hence competition for light was perhaps the most important reason for the low understorey herbage yield associated with acacia.

However, competition for light was negligible in the casuarina plots which may possibly explain the high yield levels recorded under that tree.

3. As regards to the productivity of individual forage crops, hybrid napier recorded the highest yield levels under all combinations including monoculture. It generally followed the order: hybrid napier > guinea grass > teosinte > congo signal in association with trees. The results thus underscore the need for selection of appropriate shade tolerant forage species/cultivar for mixed tree-fodder production systems.

4. Understorey herbage yield declined with increased interception of the incoming solar radiation by the tree crowns although not in direct proportion. Though ability of the mixed crop systems to use high light levels more efficiently, is widely perceived as an advantage of agroforestry, unless the herbaceous components are properly selected for compatibility and for shade tolerance, it may perhaps jeopardise the productivity of the herbaceous components in species mixtures. Canopy manipulation, to some extent, can decrease the interspecific competition for light.

5. The recovery pattern of ^{32}P isotope injected into the soil indicate that 65 to 85 per cent of the fine roots responsible for water and nutrient absorption are concentrated in the 0-15 cms layer of the soil profile. A pronounced decline in the root activity with increasing soil depth was discernible for all species, indicating that the multipurpose tree species studied are surface feeders. Implicit in the surface concentration of feeder roots is thus a high degree of of competition for the below ground resources such as water and nutrients. All the species except leucaena had ^{32}P recovery higher when the tracer was applied at closer distances. For leucaena, however, the feeder roots were more or less uniformly distributed upto 50 cm distance from the tree. Confining the root to the base of the trunk would be a desirable feature and such trees would normally less competition with the associated field crops.

6. The ^{32}P recovery pattern of the forage crops suggest indicated that tree-less controls were consistently more efficient in terms of nutrient uptake (^{32}P) than the tree-grass combinations. However, ^{32}P recovery of the tree monocultures were generally lower than the respective species mixtures, indicating a stimulatory

effect on the nutrient absorption of trees by the associated field crops. Increased rooting density in mixed species systems also would reduce the potential nutrient outputs and may improve nutrient efficiency.

7. Allometric relationships linking tree biomass to tree heights and diameter at breast height were developed by destructively sampling of the trees in one of the experimental blocks.

8. Regarding biomass productivity of individual trees, acacia topped the list with regard to yield and the growth attributes such as height, DBH, crown diameter and leaf area. Biomass of the remaining tree species decreased in the order: leucaena > casuarina > ailanthus. Acacia had an above ground net primary productivity of 32,784 kg ha^{-1} yr^{-1} of dry matter and was clearly greater than most reported values. Nevertheless, for grass monocultures, the net primary productivity was even higher, and it ranged from 13000 to 52000 kg ha^{-1} yr^{-1} dry matter.

9. The relatively long occupancy of woody perennials (five years in the present case) on the site improved the soil physico-chemical properties through enhanced nutrient cycling, N-fixation, nutrient pumping and/or amelioration

of the soil physical properties. Soil pH was significantly lower under are acacia and leucaena stands compared to the tree-less controls, ailanthus and casuarina. The organic matter status decreased in the order: acacia > leucaena > casuarina > ailanthus = tree - less control. A higher soil N content was seen below the N-fixing trees. Phosphorus and potassium levels were also higher in plots with tree components. The net effect of these improvements would be sustained production with lesser amount of inputs, particularly chemical nutrients.

10. Although there were medium and/or long term improvements in matters related to soil physico-chemical properties timber extraction can be a potential disadvantage in this respect as it can export large amounts of biomass and nutrients from the site. The high degree of variability in tissue nutrient levels observed among the multipurpose tree species and their tissue types, however, indicate the potential for altering the nutrient export from the system and have implications on sustainable production. Generally leucaena had the highest concentration for most elements. Tissue Nutrient concentration (N and P) followed the order leaf > roots> branch > bole. A one to one

correspondence was, however, lacking between the pattern of biomass accumulation and nutrient accumulation. The harvest of woody biomass may represent only a small percentage of the total site of nutrient capital. The foliage and small branches if left behind, containing a large proportion of the nutrient pool in vegetation due to higher nutrient concentration these tissues than in the bole, would thus deter any potential site depredation possibilities. The highest nutrient removal was observed in the case of acacia (1427 kg N ha^{-1}, 60 kg P ha^{-1} and 719 kg K ha^{-1}) when whole-tree harvest was resorted to. Hence selection of trees and tissue types have an important bearing in maintaining long term site productivity and sustainability.

11. Large differences in whole-tree nutrient use efficiency were seen among the four multipurpose tree species. The N-fixing tree species namely: acacia, leucaena and casuarina, used more N than the non-N fixer - ailanthus. Furthermore, nutrient use efficiency pattern did not extend from one nutrient to another for a species. If P and K are efficiency were the sole criteria for species selection, casuarina clearly is a better option.

12. The rate of litterfall ranged from 1.92 Mg $ha^{-1}yr^{-1}$ (ailanthus) to 6.2 Mg ha^{-1} yr^{-1} (acacia). The relatively lower magnitude of detritus production can be attributed to the smaller size of trees and the recurrent pruning of their lateral branches.

13. Lower nutrient content in the foliage fraction of litter in comparison to the fresh foliage implied the operation of an efficient retranslocation mechanism to capture nutrients from the senescing foliage and other tree tissues during summer. Consequently, lower contents of nitrogen and phosphorus in the litter were recorded during the dry period (March-April).

14. Decay rate studies indicated that mass disappearance rates of litter samples followed a negative exponential relationship. Regarding the inter-specific variations with regard to litter decomposition rates, casuarina and leucaena litter decomposed at a faster rate than acacia and leucaena.

15. Although widely accepted as valid, initial N, lignin or initial lignin/nitrogen ratio could not be directly related to decay rate coefficients in the present study.

16. Litter dynamics accounted for bulk of the nutrient inputs to the system. The nitrogen accretion to the soil through litterfall ranged from 68.0 kg ha^{-1} (acacia) to 15.8 kg ha^{-1} (ailanthus); phosphorus values ranged between 3.0 kg ha^{-1} (leucaena) to 1.7 kg ha^{-1} (ailanthus) and potassium accretion ranged between 8.3 kg ha^{-1} (acacia) to 2.4 kg ha^{-1} (ailanthus)

17. With its moderately fast growth, N fixation ability, needle-like cladophyls which intercept relatively lesser amounts of incoming solar radiation, high nutrient turnover rates and compact root system, casuarina appear to be a very good candidate for silvopastoral systems.

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* Originals not seen.

Appendices

Appendix I

Weather parameters for the experimental period (February, 1992 to January, 1993) recorded at nearby Dhoni farm

Months	Temperature		Rainfall (mm)
	Maximum (°C)	Minimum (°C)	
Feb 1992	31.0	21.0	28.0
Mar	33.0	21.0	6.0
Apr	38.0	25.5	14.5
May	32.5	25.8	120.2
Jun	30.0	23.2	848.4
Jul	30.1	23.5	640.3
Aug	30.0	24.1	332.0
Sep	36.2	24.5	219.1
Oct	28.4	21.7	220.0
Nov	30.4	25.9	140.3
Dec	30.0	21.0	0.0
Jan 1993	32.5	19.5	0.0
Mean	31.8	23.3	214.1
Total rainfall (mm)			2568.8

Appendix II

Mean weights of prunned materials from the four multipurpose tree species grown in association with forage crops in silvopastoral system.

Tree grass combinations	Pruning residue categories (kg ha^{-1})		
	Foliage	Branch	Logs
Acacia auriculiformis			
Pennisetum purpureum	1953.6	1288.6	2648.0
Panicum maximum	1694.0	2115.8	2319.4
Brachiaria ruziziensis	2085.2	1288.6	2648.0
Zea mexicana	2148.0	1611.4	3935.3
Overall mean	1970.3	1587.2	2843.6
Casuarina equisetifolia			
Pennisetum purpureum	180.5	759.2	-
Panicum maximum	217.5	685.3	-
Brachiaria ruziziensis	263.9	986.4	-
Zea mexicana	286.9	1013.9	-
Overall mean	237.2	861.1	-
Leucaena leucocephala			
Pennisetum purpureum	518.6	1518.6	750.0
Panicum maximum	472.2	1351.9	1036.9
Brachiaria ruziziensis	722.2	1259.2	2157.0
Zea mexicana	481.4	1675.8	1638.9
Overall mean	548.6	1451.4	1395.8
Ailanthus triphysa			
Pennisetum purpureum	1018.6	509.2	230.5
Panicum maximum	1120.3	324.2	277.8
Brachiaria ruziziensis	990.8	463.6	777.0
Zea mexicana	1370.3	847.2	1018.1
Overall mean	1125.0	536.3	576.2

*All branches above 2 cm diameter was considered as logs

Appendix III

Abstracts of ANOVA tables for growth characteristics of the five-year-old multipurpose fast growing trees grown in silvopastoral system during March, 1992 to March, 1993.

Source	df	Mean Square				
		Mean tree height (m)		Mean tree D.B.H. (cm)		Mean crown diameter (m)
		Sep 92	Mar 93	Sep 92	Mar 93	Mar 93
Tree	3	7.071**	60.635**	31.688**	110.722**	7.071**
Fodder	3	0.412	0.268	1.273	0.348	0.412
Interaction	9	0.836	0.260	0.525	0.512	0.836
Error	32	1.074	0.228	0.454	0.951	1.074

* - Significant at 5 % level

**- Significant at 1 % level

Appendix IV

Abstracts of ANOVA tables for dry matter yield (kg tree^{-1}) of four multipurpose tree species in silvopastoral system at five years of age.

Source	d.f.	Mean Square				
		Biomass components				
		Foliage	Branch	Bole	Root	Total
Between species	3	55.051^{**}	164.436^{**}	5772.582^{**}	18.570	19654.696^{**}
Within species	71	3.179	8.534	361.150	9.790	495.475

* - Significant at 5 % level

**- Significant at 1 % level

Appendix V

Abstracts of ANOVA tables for allometric data of five-year-old, destructively sampled multipurpose tree species in a silvopastoral system.

Source	d.f.	Mean Square			
		Height (m)	DBH (cm)	Crown diameter (cm)	Leaf area (m^2 tree^{-1})
Between species	3	552.117^{**}	189.368^{**}	77.480^{*}	27101.456^{**}
Within species	71	420.865	467.469	679.895	1142.984

* - Significant at 5 % level

**- Significant at 1 % level

Appendix VI

Abstracts of ANOVA tables for tissue nutrient concentration (%) of four multipurpose tree species.

1.Nitrogen

Source	d.f.	Mean Square			
		Biomass components			
		Foliage	Branch	Bole	Root
Between species	3	2.658**	0.215**	0.108*	1.282**
Within species	8	1.118	0.002	0.043	0.219

2.Phosphorus

Source	d.f.	Mean Square			
		Biomass components			
		Foliage	Branch	Bole	Root
Between species	3	0.014**	0.005**	0.001	0.008**
Within species	8	0.001	0.001	0.001	0.002

3.Potassium

Source	d.f.	Mean Square			
		Biomass components			
		Foliage	Branch	Bole	Root
Between species	3	1.894**	0.048*	0.023**	1.095**
Within species	8	0.107	0.011	0.002	0.031

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

Appendix VII

Abstracts of ANOVA tables for nutrient accumulation in different tree organs of species planted in silvopastoral system at 5-years of age.

1.Nitrogen

Source	d.f.	Mean Square				
		Biomass components				
		Foliage	Branch	Bole	Root	Total
Between species	3	4536.837**	2526.465**	26038.825**	2516.920**	115039.780**
Within species	8	47.218	3.889	669.647	111.107	748.114

2.Phosphorus

Source	d.f.	Mean Square				
		Biomass components				
		Foliage	Branch	Bole	Root	Total
Between species	3	3.983**	4.258**	64.474*	3.873**	175.055**
Within species	8	0.075	0.122	11.327	0.418	15.928

3.Potassium

Source	d.f.	Mean Square				
		Biomass components				
		Foliage	Branch	Bole	Root	Total
Between species	3	1253.588**	432.807*	8347.433**	1970.230**	36131.323**
Within species	8	9.536	30.716	377.258	15.268	401.755

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

Appendix VIII

Abstracts of ANOVA tables for nutrient use efficiency in different tree organs of species planted in silvopastoral system at 5-years of age.

1.Nitrogen

Source	d.f.	Mean Square				
		Biomass components				
		Foliage	Branch	Bole	Root	Total
Between species	3	266.396**	21.512**	778.582**	42.607**	4.656**
Within species	8	14.059	0.154	8.880	2.796	0.331

2.Phosphorus

Source	d.f.	Mean Square				
		Biomass components				
		Foliage	Branch	Bole	Root	Total
Between species	3	0.460**	0.476**	0.147	36.202**	0.154*
Within species	8	0.015	0.017	0.040	0.389	0.027

3.Potassium

Source	d.f.	Mean Square				
		Biomass components				
		Foliage	Branch	Bole	Root	Total
Between species	3	189.982**	4.943*	3.277**	36.202**	5.378**
Within species	8	10.567	1.090	0.196	3.113	0.910

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

Appendix IX

Abstracts of ANOVA tables for green forage yield and oven dry forage yield of different forage crops grown in association with multipurpose tree species.

Source	d.f.	Mean Square	
		Green fodder yield (Mg ha^{-1})	Dry matter yield (Mg ha^{-1})
Tree	4	7319.130**	1216.317**
Fodder	3	8125.623**	1457.394**
Interaction	12	675.098**	123.006**
Error	40	64.947	10.333

Appendix X

Abstracts of ANOVA tables for fodder growth and yield attributes of forage crops grown in association with multipurpose tree species.

Source	d.f.	Mean Square			
		Mean plant height (cm)	Mean number of tillers per hill	Mean number of tillers per leaves	Mean dry weight per tiller (g)
Tree	4	18930.964**	1072.573**	7.446**	11.111**
Fodder	3	96817.275*	23151.077**	64.018**	77.293**
Interaction	12	2146.929*	811.022**	2.913**	4.550**
Error	40	861.632	10.752	0.066	0.064

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

Appendix XI

Abstracts of ANOVA tables for soil chemical properties (0 to 15 cms) of soil level under different tree grass plots.

Source	d.f.	Mean Square				
		pH	OC%	N	P	K
Tree	4	0.099**	0.801**	0.019**	140.058**	1770.840**
Fodder	3	0.037*	0.421*	0.004	7.129	96.221
Interaction	12	0.051**	0.412**	0.002	9.640	58.181
Error	40	0.009	0.110	0.002	9.582	44.404

* - Significant at 5 % level

**- Significant at 1 % level

Appendix XII

Abstracts of ANOVA tables for radioactivity recovered in the leaves of four multipurpose tree species grown in association with four fodder crops following soil-application of ^{32}P (log cpm g^{-1}) at 15 and 30 days after application.

Source	d.f.	Mean Square							
		Acacia		Casuarina		Leucaena		Ailanthus	
		Days after ^{32}P application							
		15	30	15	30	15	30	15	30
Tree-Grass combinations**	4	0.095	0.060	0.393*	0.943**	0.063	0.418*	0.261	0.412
Lateral distance	1	0.029	0.247*	1.420**	1.854**	0.020	0.004	2.754**	0.005
Tree-Grass combination x Lateral distance	4	0.174	0.028	0.483*	0.115	0.020	0.399*	0.106	0.033
Depth	1	1.597**	2.272**	11.985**	2.254**	4.714**	2.157**	11.775**	6.808**
Tree-Grass combinations x Depth	4	0.169	0.110	0.150	0.428*	0.058	0.242*	0.251	0.038
Lateral distance x Depth	1	1.554**	0.109	1.996**	0.550*	0.030	0.013	0.132	0.191
Tree-Grass combinations x Lateral distance x Depth	4	0.171	0.013	0.458*	0.050	0.049	0.107	0.331	0.122
Error	40	0.074	0.044	0.139	0.124	0.133	0.140	0.148	0.203

* - Significant at 5 % level
**- Significant at 1 % level
** - Tree-grass combinations imply combinations of all four forage crops with a particular tree and the respective monoculture.

Appendix XIII

Abstracts of ANOVA tables for radioactivity recovered in the leaves of four multipurpose tree species grown in association with four fodder crops following soil-application of ^{32}P (log cpm g^{-1}) at 15 and 30 days after application.

Source	d.f.	Mean Square							
		Congo signal		Guniea grass		Hybrid napier		Teosinte	
		Days after ^{32}P application							
		15	30	15	30	15	30	15	30
Grass-Tree combinations&	4	1.472**	2.785**	1.329**	1.089**	0.354**	1.158**	1.620**	2.168**
Lateral distance	1	1.277**	0.008	0.257	3.015**	0.846*	0.053	3.087**	0.105
Grass-Tree combinations x Lateral distance	4	1.074	0.365	0.068	0.894**	0.491*	0.370*	0.405	0.044
Depth	1	16.292**	15.126**	24.524**	21.008**	7.247**	4.013**	17.754**	9.409**
Grass-Tree combinations x Depth	4	3.619**	0.365	3.958	0.745*	0.080	0.489*	0.230	0.406
Lateral distance x Depth	1	0.359	0.280	0.645	1.072	0.002*	0.299	0.325	0.051
Grass x Tree combinations x Lateral distance x Depth	4	0.336	0.241	2.535	0.582	0.125	0.260	0.304	0.109
Error	40	3.519	0.182	3.043	0.220	0.167	0.141	0.145	0.285

* - Significant at 5 % level

**- Significant at 1 % level

& - Grass-Tree combinations imply combinations of all four MPT species with a particular forage species and the respective tree-less control.

Appendix XIV

Abstracts of ANOVA tables for seasonal variations in target species foliage litter, total target species litter and total composite litter (target and neighborhood species) of four multipurpose tree species.

Source	d.f.	Mean Square		
		Target species foliage litter	Total target species litter	Total composite species litter
Species	3	7510.933**	15817.763**	19597.051**
Month	11	1889.423**	2682.905**	1689.281**
Interaction	33	26.491**	334.283**	298.848**
Error	180	40.875	61.676	59.860

There were 12 missing values, 12 has been subtracted from the d.f. of the final error term.

Appendix XV

Abstracts of ANOVA tables for seasonal variations in litter (composite) nutrient concentration of four multipurpose tree species.

Source	d.f.	Mean Square		
		N(%)	P(%)	K(%)
Species	3	24.019**	0.048**	0.129**
Month	11	0.892**	0.009**	0.058**
Interaction	33	0.197**	0.003**	0.010**
Error	96	0.007	0.001	0.001

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

BIOMASS PRODUCTION AND RESOURCE PARTITIONING IN SILVI-PASTORAL SYSTEMS

By

SUMAN JACOB GEORGE

ABSRACT OF A THESIS

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ABSTRACT

A randomised block design experiment involving factorial combinations of four fodder species: Pennisetum purpureum (hybrid napier), Brachiaria ruziziensis (congo signal), Panicum maximum (guniea grass) and Zea mexicana (Teosinte) and four tree species (Leucaena leucocephala, Casuarina equisetifolia, Acacia auriculiformis and Ailanthus triphysa, initiated in June 1988 was used for the present investigations. The study was pursued with the objective of quantifing the biomass production potential of selected forage species grown in association with tree components after canopy closure; comparing the productivity of different tree components grown in silvopastoral systems; characterising the micro-site enrichment and nutrient cycling aspects of silvopastoral systems; analyse the partitioning of solar radiation among the different components of the system and elucidate influences regarding the nature of root interactions in silvopastoral systems.

The tree attributes such as biomass, height, DBH and crown diameter were in the order acacia > leucaena > casuarina > ailanthus and the fodder biomasses were in the order hybrid napier > guniea grass > congo signal > teosinte. The concentration of N,P and K in the above ground portion decreased in the order: leaves > branches > bole. The N-fixing trees, in

general, had lower nutrient-use effeciencies. Amount of photosynthetically active radiation interception by the tree canopy was a cardinal factor effecting the herbage yield a direct correspondence was lacking. All the three N-fixing species had markedly higher soil nitrogen status. Soil organic matter, K and P were also higher under the tree canopy. Recovery pattern of ^{32}P isotope injected in the soil revealed that 65 to 85 per cent of the fine roots responsible for water and nutrient absorption were concentrated in the 0-15 cms layer of the soil profile. However, ^{32}P recovery from the tree monocultures was generally low suggesting stimulatory effect of nutrient absorption by trees in presence of an associated field crop. The rate of litterfall amount of detritus produced ranged from 1.92 Mg ha^{-1}yr^{-1}(ailanthus) to 6.2 Mg ha^{-1} yr^{-1} (acacia). Relatively lower contents of nitrogen and phosphorus in the litter recorded during the dry period (March-April). Regarding the inter-specific variations with regards to litter decomposition rates, casuarina and leucaena litter decomposed at a faster rate than acacia and leucaena. The nitrogen and phosphorus contents of the decomposing litter increased during the one-year decay period for all the species. Although widely accepted and valid initial N, lignin or initial lignin/nitrogen could not be directly related to decay rate coefficients in the present study.