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LITTER DYNAMICS OF SELECTED MULTIPURPOSE TREE SPECIES USED AS PEPPER STANDARDS

By

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THESIS

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the requirement for the degree

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VELLANIKARA, THRISSUR

2005

Dedicated to

my wife, parents, sister

and for all those who love me.

DECLARATION

I hereby declare that the thesis entitled **"Litter Dynamics of Selected Multipurpose Tree Species Used as Pepper Standards"** 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 titles, of any other university or society.
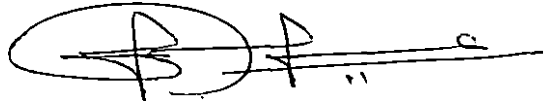
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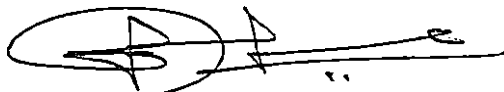
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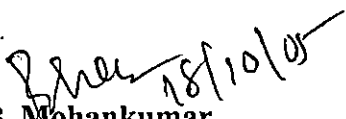
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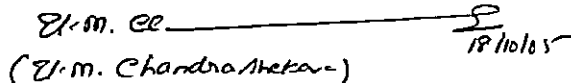(Member)

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EXTERNAL EXAMINER

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INTRODUCTION

INTRODUCTION

The last two decades had witnessed a rapid development in the farming system characterized by relatively inexpensive levels of the input, possessing high efficiency of the internal resource use and more sustainable production (Budelman, 1989). These developments could provide pragmatic solutions to the problems faced by the intensive farming systems based on the higher inputs of inorganic and pesticidal chemicals and the consequent degradation of the soil and ecosystem. The efficiency enjoyed by the natural systems in terms of the nutrient cycling and the soil physico-chemical attributes, needs to be incorporated into our system such that they act as potential interface between natural and agroecosystems. In this context, agroforestry systems and practices that effectively integrate trees with agricultural crops assumes greater importance particularly in the sensitive soils of the tropics. The main attributes that have been identified as contributing to the sustainability of these systems are biophysical advantages such as efficient nutrient cycling offered by multispecies composition, conservation of bio-cultural diversity, product diversification as well as nonmarket values of products and services, and social and cultural values including the opportunity for gender equality in managing the systems (Kumar and Nair, 2004).

Traditional pepper cultivation in Kerala forms a prominent agroforestry system where, the tree component forms an integral part of the production system. Historically, black pepper has a distinctive place in the economy of state like Kerala, which continues to be one of the major suppliers of this item in our country. Farmer's preference on the pepper standards is highly diverse. *Erythrina indica* is mostly preferred for block planting. Pepper is also trailed on tree species such as *Garuga pinnata, Gliricidia maculata, Grevillea robusta* and also grown in home gardens on trees like jack and mango. As many as 27 species were found to be serving as good pepper live standards (Salam *et al.*, 1991). Earlier investigations at Thiruvazhamkunnu have revealed that black pepper growth and yield characteristics vary considerably with the support trees. The study has also showed that the exotic species like *Acacia auriculiformis* and indigenous species like *Artocarpus heterophyllus* are promising candidates for trailing black pepper.

In pepper based intensive production systems, the functional role of the support trees as agents of soil and site productivity improvement has not been characterized

properly. Site enrichment by efficient nutrient turnover through litterfall and litter decomposition, form the most characteristic feature of any such systems, which mimic natural systems. Tree roots often serve as efficient nutrient pumps by way of drawing nourishment from deeper soil and thereby enrich the top soil. The safety net mechanisms by tree roots exert considerable control over nutrient leaching from these systems.

Diverse opinion exists regarding the long term sustainability of the tree-based production system particularly those involving fast growing multipurpose tree species. The fourteen-year-old black pepper support tree system under consideration has been under close monitoring with regard to pepper yield and tree growth characteristics since its establishment in 1988. However, detailed investigation on the productive capacity of this system has not been addressed so far. Hence, the present study was undertaken to characterize the litter yield, litter decomposition and nutrient flux associated with seven multipurpose tree species functioning as pepper standards in a fourteen-year-old experimental field. Also, attempts have been made to study the effect of biogeochemical process on the soil characteristics and pepper productivity.

REVIEW OF LITERATURE

REVIEW OF LITERATURE

The sustenance of any ecosystem is made possible by the interplay of biotic and abiotic factors of which edaphic factors are of prime importance in agro and forest ecosystem. Production of leaf litter by trees and shrubs and its subsequent decomposition accompanied by their nutrient release ultimately form the basis of a stable ecosystem. Besides maintaining fertility status of the soil, tree litter improves the chemical and physical properties of the soil. Short rotation plantations in the tropics are not only a source of timber and pulp, but also serve to take pressure off natural forests (Reddy, 2002). The low input agroforestry systems by the way of leaf litter incorporation offer a strong base for low cost sustainable agricultural production (Budelman, 1989). They also helps in rainfall interception and avoiding splash erosion.

Literally hundreds, if not thousands of studies were carried out on litterfall and litter decomposition especially after the classic work of Bray and Gorham (1964) in the natural ecosystems of the major climatic zones around the world. While most of the earlier workers concentrated on the forest stand in the temperate zones of Northern hemisphere, studies on managed mixed systems involving tree species are by far, scarce. Litter dynamics studies in the tropics is limited and more particularly with respect to the cash crop based agroecosystems. Attempt is therefore, made to review the information based on pepper based agroecosytems.

2.1 LITTER PRODUCTION

Litterfall and decomposition are two primary mechanisms by which the forest ecosystems maintain and even improve their nutrient reserve. The extent of litterfall has considerable effect on improving the nutrient status of the soil (Chapin, 1980). The litter on the forest floor acts as input-output system for nutrients (Das and Ramakrishnan, 1985). The fall and decomposition of litter usually represents a major pathway for matter and energy flow in terrestrial ecosystems. Bray (1964) estimated that at least 90% of the canopy leaves in temperate forest eventually contribute their organic matter and nutrients to the litter bank on the forest floor. Litter production and decomposition have been widely studied during the half century, with most studies

focusing on the role of the litter on the carbon balance (Odum, 1960; Olson, 1963; Golley, 1965) and the cycling of the nutrients (Furniss and Ferrari, 1982; Boerner, 1983; Holland and Coleman, 1987). Most of the litter dynamics studies have been confined to the forest and other natural systems. However, the contributions of litter in agroforestry systems involving tree components are by far scarce. Only few attempts have been made to quantify the underlying effects of litter on agroecosystems of black pepper standards and that too, on a comparative basis.

2.1.1 Factors affecting litterfall

Diverse opinions exist regarding the factors that regulate litter production. Litterfall is determined largely by the physiological and anatomical characters of the main tree species in the forest canopy (Reich *et al.*, 1992; Aerts, 1996). Many authors reported that species composition, basal area, age structure (Stohlgren, 1988), altitude (Reiners and Long, 1987), latitude (Bray and Gorham, 1964)) and season (Luizao and Schubart, 1987) are the factors that strongly influence the litterfall dynamics in natural forests. Furthermore, patterns of leaf fall in forests may be affected by environmental factors, including windstorms, seasonal droughts during summer and by the shortening of day-length during autumn (Cuevas and Medina 1986, Williams and Tolome 1996, Enright 1999). Lonsdale (1988) analyzed the total litterfall from 389 forest sites throughout the world using the multiple regression technique using latitude, altitude, and precipitation as predictor variables. It can be seen that a variety of known and unknown factors may be involved in this complex biological process.

2.1.1.1 *Location*

Tropics are characterized by higher rates of litterfall and rapid organic matter turnover than the temperate regions, both in natural forests as well as the managed land use systems. It has been reported that, in general, a tropical forest produces about five tons of dry organic matter per hectare per year, whereas a temperate forest produces about one ton of dry organic matter per hectare per year (Golley, 1983). Annual litterfall ranged from 12.2 to 14.4 Mg ha^{-1} yr^{-1} for the tropical moist deciduous forests in the western ghats of Kerala (Kumar and Deepu, 1992). Mean annual litterfall for the evergreen forest formation of Attappadi in Western Ghats was 8.5 Mg ha^{-1} yr^{-1}, which however was lower than that of the deciduous forest formation in the same locality (Pascal, 1988). But a recent study conducted by Vidyasagaran *et al.*,

(2002), in Niligiri hills of western ghats revealed litter production to the tune of 2132 kg ha^{-1} yr^{-1}.

Litterfall studies in the forest plantations in Indian subcontinent showed striking variation with tree species. Total annual litter production in a 13 year old *Populus deltoides* plantation at Dehra Dun was to the tune of 3.1 Mg ha^{-1} yr^{-1} (Raizada and Srivastava, 1986). The sal plantations reported litter production of 5.9 Mg ha^{-1} yr^{-1} (Puri 1953) and teak plantations, 5.3 Mg ha^{-1} yr^{-1} (Singh 1962). *Acacia auriculiformis* in plantation conditions at Western Ghats reported annual litterfall of 17.5 Mg ha^{-1} yr^{-1} (Swamy and Proctor, 1997). Litterfall plays an important role in agroforestry systems in cultivated lands (Agarwal, 1980).

The total litter production in the major climatic zones from alpine to equatorial forest showed an increasing trend (Bray and Gorham, 1964). They conducted extensive studies on the litterfall in the major forest ecosystem along the latitudinal gradient and found that annual litter production in warm temperate forests ranged from 5 -7 Mg ha^{-1} yr^{-1} but can be as high as 18 Mg ha^{-1} yr^{-1}. In the Mediterranean climatic zone, litter production of beech was in the range of 4682 kg ha^{-1} yr^{-1} (Santaregina and Tarazona, 2001).

2.1.1.2. *Seasonal variation in litterfall*

Seasonbound unimodal and bimodal pattern of litterfall for different tree species has been reported by Sharma and Ambasht (1987). Monthly litterfall in *Acacia* plantations in Kerala showed a unimodal pattern with its peak during December- January wherein the litterfall ranged between 280-2600 kg ha^{-1} yr^{-1} and the highest litterfall was recorded during January (Sankaran *et al.*, 1993). Kumar and Deepu (1992) reported that litterfall pattern followed a monomodal distribution with a distinct peak during the dry period from Nov- Dec to Mar- Apr in the moist deciduous forests of peninsular India. Raizda and Srivsatava (1986) found that maximum litterfall for *populus deltoides* occurred in October (1931 kg ha^{-1}) and second peak was observed at (May 440.7 kg ha^{-1}). Madge (1965) working in the mixed deciduous forest of Nigeria found that maximum litterfall occurred during the dry season and that the litterfall fluctuated little during the wet season. Shanmughavel and Francis (1999) in a 9 year old teak plantation at Tamilnadu reported peak litter production to be in the early summer (Feb-Mar). In a subhumid tropical forest of N-E.India,

litterfall was found to be unimodal with the peak during spring and trough during the rainy season (Arunachlam *et al*, 1998). The study at *Acacia auriculiformis* plantations in the Western Ghats reported that litterfall was seasonal with the peak during the wet season (Swamy and proctor, 1997).

2.1.1.3 *Site characteristics*

Soil fertility and soil water retention determines litterfall in the same climatic range (Facelli and Pickett, 1991). Cintron and Lugo (1990) found that, mean annual litterfall reflected the change of forest physiogamy from scrub to tall deciduous due to edaphic variations within the forest, which affect the water holding capacity of the soil. Scott (1955) held the view that annual litterfall is closely correlated with general productivity of the site. It has long been recognized that seasonal changes in the physiogamy of tropical forests are caused primarily by seasonal variation in rainfall which, in conjunction with soil moisture availability, is the principal determinant of tree water status (Schimper, 1890).

2.1.1.4 *Species composition of forest*

The effect of species composition on litter input pathway was demonstrated by Pande *et al.*, (1986) based on studies made on *Shorea robusta*, *Pinus roxburghii*, *Tectona grandis* and *Eucalyptus terticornis*. These trees were raised under identical edaphic and climatic conditions but showed widely varying litter production values showing that species composition has inevitable role in the regulation of litter production in an area. George and Kumar (1998) related the interspecific variation in litterfall to the crown diameter of trees and found that trees with large crown diameter *e.g. Acacia sp.* gave highest litterfall compared to that of trees with low crown diameter like *Ailanthus* sp. Also, Gill *et al.*, (1987) reported that litterfall in *Acacia nilotica* (2537-5746 kg ha^{-1} yr^{-1}) stands were significantly higher than the *Eucalyptus terticornis*.

2.1.1.5 *Litterfall patterns in agro-ecosystems*

Kunhamu *et al.*, (1994) studied litterfall characteristics of *Acacia auriculiformis* for a period of nine months and reported an increase in the monthly litter production during the dry season and low production in the wet season. George

and Kumar (1998) in a silvopastoral system reported litter production of *Ailanthus triphysa, Casuarina equisetifolia* and *Acacia auriculiformis* to be 1.92, 2.30, 6.20 Mg ha^{-1} yr^{-1} respectively. Vajranabhaiah *et al.*, (1996) studied the litter production in ten year old plantations of *Acacia auriculiformis, Casuarina equisetifolia and Grevillea robusta* and found that their respective annual litter production was 5.1 Mg ha^{-1} yr^{-1}, 3.0 Mg ha^{-1} yr^{-1} and 7.8 Mg ha^{-1} yr^{-1}.

2.1.2 Nutrient return through litterfall

Litter constituting dead leaves, twigs, bark and fruits transfer considerable quantity of nutrients to the soil. The amount of the nutrients in the fallen litter is of significance as it plays a major role in the nutrient cycling (Venkataraman *et al.*, 1983). In a study on litterfall pattern of blue gum in the Nilgiris, they found that annual addition of the litter amounted to 1935 kg ha^{-1}, constituting 31 kg nitrogen, 0.8 kg phosphorus, 4.3 kg potassium, on per hectare basis besides fixing 1548 kg of organic matter. However, George and Varghese (1990) reported that nutrient return through the litterfall of *Eucalyptus globulus* (blue gum) was 58, 46, and 40 kg ha^{-1} for N, P and K respectively. Vogt *et al.*, (1986) reported return of nitrogen from litterfall and fine root turnover as 90 and 70 kg ha^{-1}yr^{-1} respectively while George (1986) observed return of N, P, K and Ca as 29.8, 1.63, 15.0 and 40.2 kg ha^{-1}yr^{-1} from *Eucalyptus* hybrid litter. Chakraborthy and Chakraborthy (1989) conducted studies on the changes in the soil properties under the *Acacia auriculiformis* plantation in Tripura and concluded that the soil N, K and organic carbon status improved to a considerable extent. Studies by Adams and Atiwill (1984) on the nutrient dynamics in the *Acacia* spp. revealed that considerable amount of N, K and Ca immobilized in its biomass and found abundance of nitrogen in biomass due to its nitrogen fixing ability. Arunachalam *et al.*, (1998) observed that N concentration was maximum at autumn and minimum during the rainy season, whereas seasonal variation of P was found to be narrow.

Relatively, lower values of N return associated with fresh litter of evergreen forests can be expected on the basis of the extremely slow N cycle and strong N limitation documented by previous studies (Hedin *et al.*, 1995; Perez *et al.*, 1998; Perakis and Hedin 2001). The general view is that conifer-dominated forests are more N-use efficient than angiosperm-dominated forests (Vitousek, 1982; Yin, 1994).

Accordingly, a positive feedback mechanism appears to control the internal N cycle in forest ecosystems, as suggested by Gosz (1981) and Vitousek (1982). According to this hypothesis, lower N flux in fresh litter and higher C: N ratios in litterfall should slow down N mineralization rates in soils, leading to a more efficient internal N cycle.

2.1.3 Management practices

Parrota (1999) found that mixed species stands had usually higher litterfall rates than monospecific stands, despite variations on account of species composition. Since litterfall rates generally parallel the trend in biomass productivity, higher litter yield is probable in mixed species stands than sole stands (Binkley *et al.*, 1992). Study on the litter and biomass production from planted and natural fallows on degraded soils in South West Nigeria by Salako and Tian (2001) revealed no difference between annual litterfalls of planted and natural fallows with mean of 10.0 Mg ha^{-1} yr^{-1} and 13.6 Mg ha^{-1} yr^{-1} respectively. It was observed that pruning operation yielded less litter, albeit temporarily and altered leaf fall periodicity (George and Kumar, 1998).

2.2   LITTER DECOMPOSITION

2.2.1 Decomposition studies in forest ecosystems

There are various ways in which the nutrients are added and maintained in a forest ecosystem. The predominant mechanisms that govern a stable nutrient input are litterfall and litter decomposition. Litter dynamics is very important in the nutrition budgeting of tropical forest ecosystems where vegetation depends on the recycling of the nutrients contained in the plant detritus (Singh, 1968; Cole and Johnson, 1978; Pritchett and Fisher, 1987). Litter decomposition is the primary mechanism by which organic matter and nutrients are returned to the soil for the reabsorption of plants (Aber and Mellilo, 1980). In the recent years, much emphasis has been made on determining the nutrient flux associated with the litterfall and decomposition (Scot, 1955; Gessel and Turner 1974). Nutrients are released from the decomposing organic matter by a variety of physical and biological processes (Ebermayer, 1976). Vast tracts of biomes were subjected to the study of the decomposition and invariably all have revealed the importance of litter decomposition as a process that maintain and

improve the nutrient status of the soil. The amount, composition and subsequent decomposition of litter are of major importance in studies of nutrient cycling and primary production (Ovington, 1962).

2.2.2 Rate of decomposition

Litter decomposition and its effect on soil have been well studied across the world. The rate of decomposition regulates the energy flow, primary production and nutrient cycling of the forest ecosystems (Waring and Schlesinger, 1985). Studies on shola forest of Niligiris revealed that 77% of original biomass was lost within one year period (Vidyasagaran *et al.*, 2002). Kunhamu *et al.*, (1994) studied the decomposition dynamics of the *Acacia auriculiformis* and reported that 90% of the litter decomposed within six months. Singh *et al.*, (1993) observed a typical biphasic pattern of the biomass decomposition of the four species (teak, sal, eucalyptus and poplar) for a period of one year.

Observed mass loss in some mixtures is as much as 65% more extensive than expected from decomposition from the single species litter (Gartner and Cardon, 2004). Under the same climatic and soil conditions at Ibadan, Nigeria, the rate of decomposition of prunings of various agroforestry species was in the order, *Leucaena leucocephala* which recorded maximum followed *by Gliricidia sepium, Cassia siamea* and *Flemingia congesta* (Yamoah *et al.*, 1986).

2.2.3 Effect of site variations on decay rate

Sankaran *et al.*, (1993) studied the decay rates of the leaf litter of *Acacia auriculiformis* and observed significant difference between sites. A faster rate of decomposition was noticed in the fertile sites compared to the degraded one. It was seen that decomposition was slightly faster in the open area when compared to the closed areas. George and Kumar (1998) and Kunhamu and Gopikumar (1994) observed significant difference in the half life periods of different species when the decomposition study was conducted in home garden. However, Gopikumar *et al.*, (2001) reported similarity in litter decomposition rates in open areas and home gardens indicating poor influence of filed conditions on decomposition rate. Site

enrichment through the complementary effects of the tree species has been studied for many mixed species systems (Kang *et al.*, 1985; Kumar *et al.*, 2001).

2.2.4 Species variation on decay rate

Reports indicate that the litter of different species does not decompose at the same rate even under the similar environmental conditions (Alexander, 1977). In the home garden in Kerala there were significant differences in the decomposition of the various tree species viz., *Schelechira oleosa, Pongammia pinata, Macaranga peltata, Terminalia paniculata, Bridelia retusa and Acacia mangium* (Kunhamu, and Gopikumar 1994; Gopikumar *et al.*, 2001). Biochemical quality of the litter varies from species to species and explains the variation in decomposition rate.

2.2.5 Decomposition studies in agroecosystems

Tree species used in agroforestry vary widely in their quality and rates of decomposition (Wilson *et al.*, 1986). Yufdi and Hayani (1991) conducted a study in Indonesia about the use of *Gliricidia sepium* leaves in composts in the pepper nursery. Pepper cuttings rooted in sand were transferred to soil/leaf media (10:0, 9:1, 8:2, 7:3, 6:4 and 5:5) and development was assessed at 4 months. The best results were obtained with the 7:3 soil/leaf medium. Kang *et al.*, (1985) showed the effect of trees on the yield of associated crop in an alley cropping system involving *Leucaena leucocephala* and maize. Maize production was considerably increased (2.0 Mg ha^{-1}) without addition of the nitrogenous fertilizers. Kumar *et al.*, (2001) studied soil fertility changes in a mixed system involving four fodder grass species and four MPT's viz. *Acacia auriculiformis, Ailanthus triphysa, Casuarina equisetifolia* and *Leucaena leucocephala.* All tree-grass combinations showed an increasing initial trend in understorey herbage production. Pruning MPT's after crown closure generally improved productivity. During the post-rotation phase, MPT's plots were characterised by higher soil nutrient capital.

2.2.6   Factors affecting the biomass decomposition

2.2.6.1 *Substrate quality.*

Litter decomposition is mainly governed by the chemical and physical characteristic of the litter Johansson *et al.*, (1995) and it was found that in a long climatic interval, the substrate quality dominated over the climate. The contents of lignin, nitrogen, cellulose, and secondary compounds (particularly phenolic acids) are the most conspicuous variables which decide decomposition (Horner *et al.*, 1988; Meentemeyer, 1978). There appears to be a general opinion that climate rules decomposition on a regional scale where as litter chemical composition dominates the process on a local scale (Berg, 2000).

2.2.6.1.1 *Water soluble substances*

Water soluble organic material present in the leaf biomass provide readily available energy source for decomposers and therefore said to be highly influential during the initial stages of decomposition (Melin, 1930). The initial rapid mass loss phase usually observed in litter decomposition study is mainly due to the solubilization and subsequent leaching of simple organic substances (Boyd, 1970). Water soaking causes leaching of labile materials (Robertson, 1988) and promotes leaf conditioning by microbes both of which will increase decomposition rate (Tam *et al.*, 1990; Chale, 1993). The decomposition rates were positively correlated with concentration of water soluble substances and nitrogen and negatively with those of lignin (Berg and Landmark, 1987).

2.2.6.1.2 *Initial nitrogen*

Initial nitrogen content of the decomposing litter has a profound influence on the rate of the litter decomposition. Generally there is a positive relationship between the rate of the decomposition and the initial nitrogen content of the leaf litter (Jamaludheen and Kumar, 1999). Berg and Soderstrom (1979) found that increase of nitrogen in decomposing litter was correlated with increase in fungal biomass. The initial nitrogen content is of importance in nutrient poor ecosystems, wherein exogenous supply of nitrogen for the decomposing microorganisms is less (Melillo *et al.*, 1982). Kumar and Deepu (1992) observed an increase in nitrogen concentration

but a decrease in absolute amount of nitrogen in the leaf litters of *Casuarina, Acacia and Leucaena.* For non-leguminous litter, initial N and lignin percent or the ratio of lignin: N, correlated well with decomposition rates (Constantinides and Fownes, 1994). Under conditions where nitrogen limits the microbial growth, the rate of mass loss is determined by the nitrogen and lignin (Brendse *et al.*, 1987). (Berg and Staaf, 1987) found that with an increase in the total nitrogen concentration, the concentration of both "lignin-bound" and "non-lignin-bound" nitrogen increased proportionally. Thus, there exists a positive linear relationship between nitrogen concentration and rate of mass loss. Initial nitrogen is inversely related to the rate of N immobilization (Aber and Melillo, 1982).

2.2.6.1.3 *Carbon: Nitrogen ratio (C: N)*

The process of decomposition is highly influenced by the C: N ratio of the plant residues. The proportion of N that becomes available for plant growth depends on the ratio of total N to total C (Rosswall 1982). Litter components with high initial nitrogen content and low C: N ratio is known to decompose rapidly (Singh and Guptha, 1977). The decrease in organic carbon content as decomposition proceeds may be due to faster degradation of soil organic carbon as a result of enhanced microbial activity (Flaig, 1984). Fog (1988) stated that plant components with high C: N ratio does not provide sufficient nitrogen to the rapidly proceeding microbial activity. However, it was proved that C: N ratio of 20:1 or narrower will be enough to supply nitrogen for the decomposers and to release nitrogen for plant use (Alexander, 1977). The dynamics of carbon and nitrogen in the substrate are determined by the uptake of carbon and nitrogen by microorganisms and by the return of both elements to the substrate as dead microbial biomass (Brendse *et al.*, 1987). A lower initial C: N ratio can enhance the rate of decomposition (Rao *et al.*, 1994). In forest ecosystems, C: N ratios of litter affect soil processes, such as the rates of decomposition and net N mineralization of organic matter and the availability of nutrients in soil (Scott and Binkley 1997; Fassnacht and Gower 1999; Ferrari 1999). A study to find the seasonality on litter decomposition at Mediterranean water courses showed that the leaf decay is both quantitatively and qualitatively affected by the inorganic nutrient levels and temperature in the ambient environment regardless of the initial C: N ratio (Menendez *et al.*, 2003).

2.2.6.1.4 *Lignin*

Cromack and Monk (1975) have shown that lignin content of a substrate is an excellent index to be used for determining the rate of decomposition. Barry *et al.* (1989) stated that slow rate of decomposition in the latter phase of the litter decomposition is lignin controlled while the initial rapid mass loss phase is controlled by nitrogen present in the soluble carbon compounds. Minderman (1968) states that slowly decomposing litter components, such as lignin, tend to dominate the shape of the long term decomposition curve once the more labile components are removed. Lignin in litter is usually recalcitrant to enzyme degradation, therefore, higher the proportion of this constituent in a given litter, lower is the relative amount of more readily available carbon compounds (Kumar, 2001). The intimate association of lignin with cellulose fibres results in making of a large fraction of carbohydrate which otherwise would be accessible to the leaf associated microorganisms (Gessner and Chaunet, 1994). Hence, lignin content in leaf litter is viewed an inverse index for the availability of carbon to decomposers. (Melillo *et al.*, 1982) suggested that the initial lignin concentration was highly correlated (r^2 = 0.93) with the slope of inverse relationship with the decomposition rate. Available reports indicate that, among all the factors, the litter quality especially the initial lignin and initial lignin: nitrogen ratios of the litter samples decide the decay pattern to a greater extent.

2.2.6.1.5 *Lignin: Nitrogen ratio*

A study by (Melillo *et al.*, 1982) in six hardwood species in Hubbard Brook forest of USA found that various initial litter quality parameters were correlated to that of decay constant k. Among them, the rates of decay were correlated (r^2 = 0.89) with the initial lignin: initial nitrogen content of the leaf samples, both had an inverse relationship. However, this relationship holds good only in case of species with a narrow initial lignin: initial N ratio. They also found a negative hyperbolic relationship between decomposition rate and initial lignin: nitrogen ratio. Kumar and Deepu (1992) found that high lignin: nitrogen ratio was associated with the lower rate of mineralization. A negative correlation was found to be existing between rate of

decomposition and initial lignin: nitrogen ratio (Edmonds, 1987). This relation was found to be more conformable than taking initial lignin content alone.

2.2.7 Effect of environmental factors on decomposition

Rate of decomposition of leaf litter of the various tree species are found to be influenced by environmental factors that include rainfall, temperature, physical and chemical properties of the soil, relative abundance of the macro and micro organisms etc. They all operate at different scales of space and time in a hierarchical fashion with high level factors dominating those acting at lower levels. Climatic factors dominate this hierarchy, followed by soil physical properties, chemical properties of the resources and biological regulations through interaction between macro and micro-organisms (Lavelle *et al.*, 1993).

2.2.7.1 *Climate*

Pascal (1988) reported a low rate of decomposition throughout the dry period in Attapadi forests of Kerala. The decay rate was found to be doubled with the first pre- monsoon showers. Sankaran *et al.*, (1993) reported that the maximum weight loss in *Acacia* leaf litter occurred in September to November during the north east monsoon period in Kerala. Yearly environmental variations affect decomposition rates within a given system. Changes in temperature and moisture availability have been related to decomposition rates (Agbim, 1987; Woodwele and Dykeman, 1996). (Mackey and Smail, 1996) under subtropical condition revealed that the decay rate for both leaves and twigs were faster in summer than in winter. A linear relationship between mean annual rainfall and decay constant was established by Hutson and Veitch (1985). Guptha and Singh (1977) found high rate of disappearance of litter (36.25-52.85%) during months of highest rainfall (July-October).

2.2.7.2 *Soil environment*

Soil moisture and soil temperatures are reported to be the prominent factors controlling the rate of decay under natural conditions (Singh and Gupta, 1977; Moore, 1986). Gopikumar *et al.*, (2001) found that the influence of litter decomposition on soil pH was not significant, but the addition of leaf litter brought out changes in total

nitrogen, available phosphorus and exchangeable potassium. The microenvironment surrounding the litter affects the decomposition rate (Furniss and Ferrari, 1982). George and Kumar (1998) in a silvopastoral system observed that tree growth over five years had apparently improved the soil organic C, N, P and K content. Litter decomposition is regulated mainly by temperature and water regimes, soil fertility may be subsidiary (Staaf, 1987). Madge (1965) found a positive influence of soil moisture in controlling the activities of the soil organisms particularly of arthropods. Microbial activity increases exponentially with increasing temperatures upto a threshold and as a result, high temperature result in rapid decomposition (Waring and Schlesinger, 1985). Olson (1963) reported the presence of low content of carbon in highly productive tropical forest whereas high content in the cool temperate forest. In the tropics, with their higher temperatures, decomposers and shredder populations will be active throughout the year, but in temperate regions, most activity will occur during summer. Isaac and Nair (2002) in an agroforestry system observed the effect of *Artocarpus hirsuta* on the improvement of soil physico-chemical properties. They observed that due to litter decomposition, the soil pH, Organic C, N, P and K was bound to increase which inturn increased the site fertility. Bulk density of the soil was significantly lowered in both the open as well as the shaded sites. Also water holding capacity of the soil was found to be increased. The effect of rainfall and throughfall on tree growth as well as nutrient cycling was also an important aspect. Throughfall was found to be one of the most important factors deciding the K cycling and the small scale pattern of the nutrient input to the soil (Schroth *et al.*, 2001).

2.2.8   Biotic factors

There are many macro and micro fauna which help in decomposition of litter. The microbial activity is favored during the summer due to high moisture and temperature thus accelerating the rate of decomposition (Witkamp and Van der Dritt, 1961). The soil fauna plays a major role in decomposition that include fragmenting the litter on surface, physical mixing of the litter within the soil profile, adjustment of the soil physical properties to levels more conducive for organic matter decomposition. Bocock (1964) found that litter decomposition by earth worms and millipedes was rapid during the initial five months of decomposition. A greater earth worm activity (Anderson and Swift, 1983), higher bacterial cell counts and fungal

hyphal lengths (Swift *et al.*, 1979) are frequently reported in the tropical soils compared to those in temperate and boreal forests. Gong (1982) reported that more than 98.5% of leaf litter mass decomposed within 4 or 5 weeks when study was conducted in tropical ecosystem in Malaysia.

2.2.9   Seasonal variation in decomposition

The influence of the season on the progress of the decomposition has been referred in many tropical conditions. Pande (1999) showed that in tropical plantations higher decomposition rate is observed during the rainy months and lower rate during the winter. The decomposition of litter was faster particularly during the south-west monsoon season which is in agreement with findings of Pascal (1988) and Sankaran (1993). Sujatha *et al.*, (2003) observed that in leaf litter decomposition rate was highest in July and was strongly and positively correlated with the rainfall and soil moisture. Singh *et al.*, (1999) and Dutta *et al.*, (2001) established that the mean relative decomposition rates of leaf litter material were maximum in the rainy season and minimum during the summer season. But in study conducted at sacred groves of Kerala (Rajendraprasad *et al.*, 2000) showed that litter decomposition was least during the rainy season and high during the dry season and also for the period with the interrupted rains.

2.3   NUTRIENT RELEASE PATTERN

The decomposition dynamics of most of tree litter involve a rapid initial rate of decomposition followed by a subsequent lower rate of advancement. Berg (1986) divided decomposition into two parts (i) decomposition of liable fraction (hydrosolubles, non lignified cellulose and hemicellulose components) of the litter containing easily degradable compounds such as sugars, starches and proteins which can be rapidly utilized by decomposers which characterize "rapid release phase". This phase is controlled by nutrients like nitrogen, phosphorous and sulphur. (ii) decomposition of lignified carbohydrates (more recalcitrant materials such as cellulose, fats, waxes and tannins) which are chemically bound to lignin represents the slow release phase. The rapid phase of decomposition is governed by the metabolization of readily digestible water soluble compounds such as simple sugars,

proteins, amino acids and polysaccharides (Rangaswamy and Bagyaraj, 1993). During the later phase, the compounds resistant to the biodegradation process were found to be metabolized (Brady, 1984).

Jamaludheen and Kumar (1999) reported that the nitrogen release from decomposing litter followed a three phase release pattern for *Acacia, Casuarina* and *Artocarpus*. In this phase, concentration of nitrogen of the decomposing litter declines rapidly after a brief initial increase and was followed by a final slower release phase. They also found that other MPT's followed a biphasic pattern, characterized by an initial rapid and a subsequent slow release phase. Phosphorous and potassium remaining in the residual litter mass exhibited an initial rapid release followed by slower release. Berg and Staaf (1987) also described a triphasic model for nutrient release from decomposing litter. A comparative study between *Acacia auriculiformis and Acacia mangium* was carried out by Mishra *et al.*, (1994) who revealed that soil nitrogen fixation by *Acacia mangium* was superior to that of *Acacia auriculiformis*.

2.4 STUDIES ON BLACK PEPPER STANDARDS AND PEPPER YIELD

Alvim (1988) evaluated the combinations involving *Gliricidia sepium* with cacao and pepper in Bahia, Brazil and showed that *Gliricidia sepium* produced more biomass and nutrients than *Leucaena leucocephala* over this period. Much higher pepper yields were obtained with the dead posts than with the live, with *Leucaena* the best live post. Seibert (1988) comparing the growth of pepper on dead ironwood poles and on living poles of *Gliricidia sepium* and *Erythrina lithosperma*. The living poles were established from cuttings. No significant differences in pepper growth were found between the three treatments over 7 months.

Sankar *et al.*, (1988) observed that the nutrient uptake decreased in the pepper vines trailed on live trees and concluded that soil pH is important in the uptake of nutrients in pepper based systems. The yield variability in a black pepper plantation was examined in relation to the soil fertility in the root zone by Mathew *et al.*, (1995). The results indicated that soil pH should be maintained around neutral to obtain yield responses from nitrogen fertilizer application. Korikanthimath and Ankegowda (1999) studied the yield of *Piper nigrum*, grown as a mixed crop with robusta coffee, on four shade tree species viz. *Erythrina lithosperma, Ficus glomerata, Grevillea robusta* and *Terminalia bellerica*. Yield was significantly higher in vines trained on *Terminalia sp.*

(37.5 kg vine-green berries) than the other species. Data indicated that the total surface area available for support and the distribution of light through the canopy were important factors affecting the yield. Thomas *et al.*, (1996) studied the yield and growth characters of pepper in relation to the seven fast growing tree standards raised from cuttings at Livestock Research Station Thiruvazhamkunnu. Considerable variation in pepper yield was observed for different support tree species. Maximum yield in terms of vine height, number of leaves, number of nodes, leaf area index, number of spikes and black pepper yield were obtained when vines were trained on *Garuga pinnata* whereas training vines on *Gliricidia sepium* gave the lowest yield. Ramadasan (1987) trained vines of the *Piper nigrum.* (cv. Panniyur-1) on coconut palms intercropped with cocoa in Kerala. There was more than 50% reduction in yield due to shading compared with vines raised on non-living standards.

MATERIALS AND METHODS

MATERIALS AND METHODS

3.1 STUDY SITE

The present study was conducted at the Livestock Research Station Thiruvazhamkunnu, during the period from August 2002 to August 2003. The experimental area constitutes a black pepper stand raised during 1988, as part of the All India Coordinated Research Project (AICRP) on Agroforestry. This station is situated about 20 Km away from Mannarkkad town, Palakkad district, Kerala, and lies between 11^0 $21'$ $30''$ N and 11^0 $21'$ $50''$ N latitude, 76^0 $21'$ $50''$ longitude at an elevation of 60-70 m above mean sea level.

The area constituting the black pepper stand experience a warm humid tropical climate with total mean rain fall ranging of 3124 mm during 2002-2003 period mainly contributed by South-West monsoons. The area experienced heavy rainfall during the late June till August. The mean annual maximum temperature ranges between 29.4^0C (August) and 36.3^0C (February) and the mean minimum temperature varied between 17.5^0C (December) and 24.3^0C (May) during August 2002 to August 2003. The soil of the experimental area is oxisol with average soil pH of 5.1. The soil is formed mainly from granite and gneissic parent material. The general topography is undulating with small hills and valleys.

3.1.1 Experimental setup

The present study on litter dynamics of black pepper standards was super-imposed on a pre-existing field trial on evaluation of support trees for black pepper cultivation. The species selected for the study were *Acacia auriculiformis, Ailanthus triphysa, Artocarpus heterophyllus, Casuarina equisetifolia, Ceiba pentandra, Grevillea robusta and Macaranga peltata.* The trial was laid out in a randomized complete block design having three replications each. The support tree seedlings were planted at 3×3 m spacing in plots of size 12×12m. All species maintained healthy growth except *Ceiba pentandra*, where most of the trees were subjected to windfall or termite attack and hence it was excluded from the study.

3.1.1.1 *Cultural practices*

The black pepper standards were maintained as per the silvicultural practices recommended by Kerala Agricultural University. Manual weeding was carried out twice a year. Manurial practices were limited to the basal application of farm yard manure with virtually no addition of inorganic fertilizers and plant protection chemicals. Lopping was carried out once in a year just before the onset of monsoons and the lopped materials were incorporated in the respective plots. Ripe pepper was harvested during the month of January and corresponding yield was recorded.

3.2 FIELD EXPERIMENT

The study involved characterization of litter nutrient dynamics associated with pepper production systems involving six multipurpose tree species. This constitutes quantification of litterfall and litter decomposition over one year period. A brief description of the selected pepper support trees are given below.

1. *Acacia auriculiformis* (A. Cunn.) ex Benth. (Family: Fabaceae)

Commonly called as Australian wattle, extensive natural stands of *Acacia auriculiformis* are found in Australia, southwestern Papua New Guinea and Indonesia. It has been planted widely in tropical Asia, especially in China and India. It is predominantly found in the seasonally dry tropical lowlands in the humid and sub-humid zones. *A. auriculiformis* is an evergreen tree that grows to 15-30 m tall, with a trunk upto 50 cm in diameter. It has dense foliage with an open, spreading crown. Roots are shallow and spreading and flowers are creamy yellow. Fruit is a pod. Recommended rotation is 12-15 years for timber in plantations. This tree is used as fuel wood. *A. auriculiformis* is known for its ability to grow on marginal soils and to fix atmospheric nitrogen.

2. *Ailanthus triphysa* (Dennst.) Alston (Family: Simaroubaceae)

Commonly called as white palle and locally known as 'matty' or 'perumaram'. It is a light demanding tree found in the wet evergreen climax forests of the Western Ghats, from Konkan, North Kanara and Karnataka southwards to Travancore at an altitude of 60-1500 m. *Ailanthus triphysa* is a tree with cylindrical bole, usually attaining a height of 30 m and diameter of 1.2 m. It has grey bark. Leaves are pinnate, and are reddish brown in colour. Flowers are white and polygamous. It prefers well

drained light/sandy soil. Flowering usually occurs between February and March and fruiting in April. Usually this tree is propagated by direct sowing. Rotation period is usually 10 years. Wood is used for making boats, matches, fishing floats and weaponry accessories. The plant roots, leaves, bark and gum exudates are used as medicines in India. The tree is often planted for aesthetic purposes as well as used as live stakes for supporting black pepper vines.

3. *Artocarpus heterophyllus* (Linn.) (Family: Moraceae)

This tree is commonly called as jack and locally called as 'Plavu'. It is usually seen in homegardens of west coast and also used as shade trees in cardamom, pepper, areca and coffee plantations in South India. It prefers deep, rich and well drained soils. Jack is a large evergreen tree of 25-30 m height. The leaves are green and fleshy, leathery, simple and alternate. Fruit is multiple sorosis. The outer pericarp is prized cattle feed and latex from the bark contains resins. The timber is used for furniture. The fruits which are rich in vitamin A and C are made into syrup, jam and jelly.

4. *Casuarina equisetifolia* J.R. & G. Forst (Family: Casuarinaceae)

This tree is commonly called as beefwood tree and locally as 'Chula'. *Casuarina equisetifolia* is an evergreen tree, with a finely branched crown. Crown shape is initially conical but tends to be flattened with age. Trunk is straight, cylindrical, occasionally with buttresses. Bark is light greyish-brown, rough and the branchlets are deciduous, drooping, needle-like, but with prominent angular ribs. *Casuarina equisetifolia* is mainly wind pollinated. Root nodules containing actinorhizal symbiont Frankia enable *Casuarina equisetifolia* to fix atmospheric nitrogen. Since it is salt tolerant and grows in sand, it is used to control erosion along coastlines, estuaries, riverbanks and waterways.

5. *Grevillea robusta* (A. Cunn.) ex R. Br. (Family: Proteaceae)

This tree is commonly called as silver oak and it occurs naturally in Australia. *Grevillea robusta* is a deciduous tree 12-25 m tall with conical crown. Bole is straight, and the bark is fissured, dark grey to dark brown. Leaves are alternate, pinnately compound. It has been introduced into warm, temperate, subtropical highland regions around the world and is widely planted in India, Sri Lanka and many countries in Africa. In temperate areas, it can survive moderate winter frosts. In its natural range, the species is semi-deciduous, shedding most of its leaves in the dry season, and can

stand up to 6 months of drought. It establishes well in riverine habitats, on alluvial soils that are free of water logging. *Grevillea robusta* can be propagated through seed and cuttings. It is also characterized by root suckering, hence it is a good candidate for management under coppice rotation and it responds well to pollarding, lopping and pruning. The timber has great economic potential especially due to the prominent silver grain on its radial surface. Tree yields gum having some industrial applications. It is a well known shade tree in coffee and tea plantations. It also provides abundant quantities of leaf mulch.

6. *Macaranga peltata* (Roxb) M.-A (Family: Euphorbiaceae)

This tree is locally called as 'Vatta'. It is a small to medium sized tree distributed throughout India, especially in the hilly tracts. Bark is dark grey and leaves are peltate. The tree reproduces freely and comes up plentiful in old clearings. It is resistant to severe pruning and puts forth flushing growth within two to three months. The loppings are extensively applied as green manure in the paddy fields along the west coast. The leaves are rich in nitrogen and potassium. The wood is light weight and suitable for match, paper and pulp industries.

3.2.1 Litterfall quantification

Litter production from the pepper standards were monitored for a period of one year using specially designed litter traps described by Hughes *et al.,* (1987).

Specifications of the litter trap

Collection area	: 0.24 m^2
Capacity	: 20 litres.
Height above the ground	: 0.75m
No. of traps per plot	: 5
No. of traps per tree species	: 15
Total no. of traps in the plots	: 90
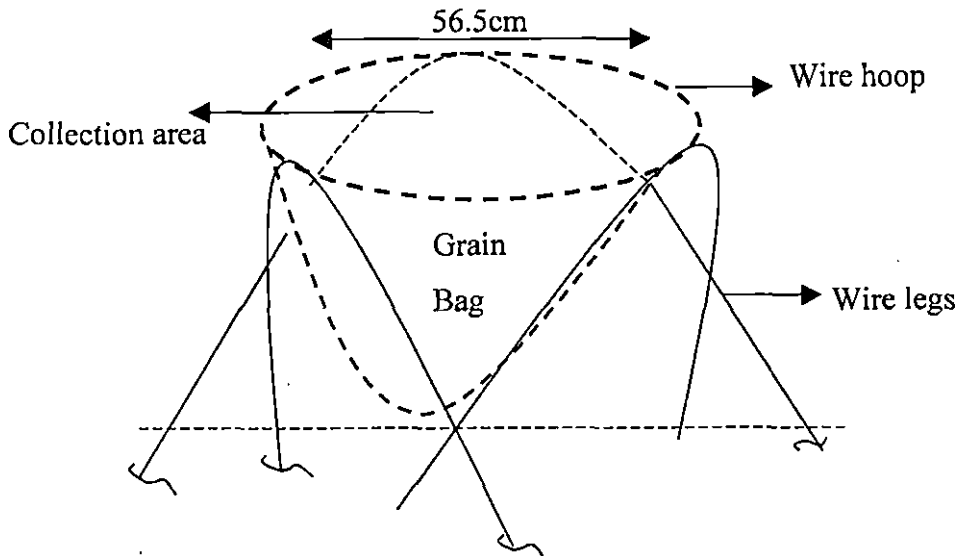
Fig. 1 A pictorial representation of litter trap

For each trap, four 210 cm long galvanized (2-3mm) iron wire were used. A tripod was made using the three galvanized wires. The remaining one was made into a hoop of diameter 55.2 cm by overlapping the ends of wire. This hoop was tied horizontally over the tripod. Gunny bags were placed inside the wire hoop with the tapering end downwards. It was then fixed in the soil with the galvanized wire piercing the soil five cm deep. Five litter traps were placed randomly in each plot. Due care was taken to avoid placing the traps on plot edges to minimize the chance of mixing up of the litter of other species. Litter collection was done from each trap at monthly intervals extending over a period of one year starting from September 2002 to August 2003. Only the leaf portion was collected and the other floral parts were not accounted for the present study. The litter samples so collected were taken to the laboratory and oven dried at 70^0 C until constant weights and the mean monthly litterfall on unit area basis (gm^{-2}) was calculated species wise. Monthly litter samples were analyzed for major nutrient viz. N, P, K to asses the nutrient turnover through litterfall.

3.2.2 Leaf biomass decomposition

Litter decomposition was studied in the experimental plots consisting of the pepper standards using the standard litterbag technique described by Bocock and Gilbert (1957). Fresh litter corresponding to each supports tree species were collected

randomly from the respective experimental plots and dried under shade for approximately 48 hours. The moisture content of the litter was estimated prior to the placement in the litter bags. Fifty gram air dried litter samples were placed in the litter bags.

Specifications of the litterbag

Size	: 30 × 30 cm
Nylon wire mesh size	: 2 × 2 mm
No. of bags per plot	: 48
Total no. of bags in the plots	: 864

The bags were placed in the plots during the month of August 2002. In each plot 48 bags were placed in 12 successive rows with four bags in each row. Bags were placed on the surface of the soil with a thin layer of soil covering. The bags were tied to bamboo pegs and tagged using the aluminium foil for easy detection during retrieval. Four litter bags from each randomly selected row were retrieved from each plot at monthly intervals for a period of one year starting from September 2002 to August 2003. The litter bags retrieved at each sampling was freed of extraneous materials by gentle washing in a smooth spray of water and the detritus oven dried at 70^0 C for constant weights.

3.2.3 Chemical analyses

Monthly collected litter samples corresponding to each support tree species were grounded in Willeys mill. Fresh litter samples collected before soil incorporation, were also powdered. The monthly retrieved detritus were made free of extraneous materials and powdered. Finely ground litterfall samples as well as the decomposed detritus were analyzed for major nutrient elements viz. N, P, K. The standard methods adopted for chemical analysis are given below.

3.2.3.1 *Organic Carbon*

The organic carbon was estimated following a method suggested by Walkley and Black (1934). 0.1 g of sample was taken in a 500 ml flask and added with 10ml of

$K_2Cr_2O_7$. This was swirled gently to mix the reagent with soil. Twenty ml of conc. H_2SO_4 was added along the walls of the conical flask. The acid was mixed with soil by rotating the flask gently and was left on asbestos for 30 minute to allow oxidation. Two hundred ml of water was then added along with one ml of phenathroline indicator. The contents of the flask were titrated with $FeSO_4$ solution. $FeSO_4$ was added freely from burette until the content of the flask turned dull green. Further addition was drop by drop until it changed to chocolate red and blank determination was carried out.

3.2.3.2 *Nitrogen*

Powdered plant material was weighed (0.5 g) and digested in the microkjeldhal digestion (Pelican microkjeldhal unit) assembly by using 10 ml of conc. H_2So_4 and 0.2 to 0.3 g of catalytic mixture ($CuSo_4$ and Na_2SO_4). The digest was allowed to cool to room temperature and transferred to the distillation assembly of MicroKjeldhal. Ammonia was distilled by using 10 ml of 40% NaOH. Liberated ammonia was collected in 4% boric acid with mixed indicator. The liberated ammonia was titrated against standard acid.

3.2.3.3 *Phosphorus*

One gram of the leaf sample was digested with triple acid mixture and a known aliquot was used to determine the phosphorus content using the Vanadomolybedo phosphoric yellow colour method (Jackson, 1958). The colour was read in the UV spectrometer at a wave length of 410 nm.

3.2.3.4 *Potassium*

One gram of the leaf sample was digested with triple acid mixture. Potassium content was determined by using flame photometry as described by Jackson (1958). The standard stock solutions of potassium (100, 10, 5, 2, 1 and 0 ppm) were prepared. The plant digest was diluted so that the final concentration lies between 0-10 ppm. The samples were then read in the flame photometer at 548 nm wave length using the filter for potassium.

3.2.3.5 *Lignin*

The method suggested by Van Soest (1963) for the estimation of acid detergent fibre and lignin was followed. For lignin assay, one gram of leaf sample was weighed to which hundred ml of cold acid detergent solution (prepared by adding twenty gram cetyl trimethyl ammonium bromide to one litre of 1 N H_2SO_4) and two ml of decaline were added which was then refluxed for 60 minutes. The sample was then filtered, washed with acetone, dried overnight and then weighed to determine the acid detergent fibre. H_2SO_4 (72%) was poured into this dried samples and intermittently stirred. After filtering, the sample was dried overnight and weighed. This was then kept in a muffle furnace for 3 hr at 600^0 C and reweighed. The difference in weight was used for the estimation of lignin.

Acid detergent lignin %= ((wt of crucible + lignin) - (weight of crucible + ash) / wt of sample)*100

3.2.4 Soil analysis

The soil sampling were made at three monthly intervals over a period of one year (August-2002, December-2002, April-2003 and August-2003).The soil samples were collected from five parts on each plot and from the adjacent open areas after making a V-shaped cut and collected sub-sample were thoroughly mixed following the quartering method. The samples brought to the laboratory were cleaned of roots and other extraneous materials, air dried and ground to pass through a 2mm sieve.

3.2.4.1 *Soil nutrient analyses*

Composite soil samples collected from each plot and adjacent open area were also analyzed for organic-carbon, nitrogen, phosphorus and potassium using the procedures as mentioned in the case of plant samples.

3.2.4.2 *Soil moisture content and soil pH*

Representative soil samples from the experimental areas and adjacent open areas were taken at three monthly intervals and analysed for soil moisture and pH. The soil samples were collected in double sealed cover and brought to the laboratory. Soil

moisture content was estimated on dry weight basis from the fresh weight and oven dry weight (dried at $105^O C$ for 48 hrs) of the soil samples. Soil pH was determined using a 1:2 mixture of soil and distilled water with Elico (L1 613) pH meter.

3.2.4.3 *Soil bulk density*

Soil samples were collected from all the experimental plots and also from the open areas to estimate the soil bulk density. A metal tube of diameter 5.5 cm and height 142.44 cm with known volume (**v**) was driven into 10 and 15 cm depth of the soil and the samples collected were weighed for fresh weight (w_1) and ovendried at $105^O C$ for 48 hrs to constant weight (w_2). The bulk density was then determined and calculated for each plot.

$$Bulk\ density = w_2 - w_1\ /\ v$$

3.2.5 Lopping of pepper support trees

Annual branch lopping of pepper support trees were carried out during August 2004 and lopping out turn was recorded for branches and leaves separately for each plot. The lopped materials were then incorporated in the respective plots. The leaf samples were also subjected to N, P, and K analysis.

3.2.6 Pepper growth attributes

Observations on pepper yield (wet weight and dry weight of berries), length of spike, and number of berries per spike were recorded for each support tree and the plot averages were worked out. The number of laterals in 0.25 m^2 metal frame at chest height was also recorded on monthly basis.

3.2.7 Rainfall interception by trees

To study the influence of the support trees on rainfall interception patterns, 5 litre collection bottles with funnels having collection surface area of 707 cm^2 (15cm diameter) were installed in all plots (five per plot) in June-2003 to capture the

throughfall. The bottles were placed randomly in each tree plots. Bottles were also placed in the open areas so as to determine rainfall interception by the trees.

3.2.8 Statistical analysis

The data relating to monthly litterfall, litter decomposition, pepper yield, rainfall interception and soil parameters were subjected to statistical analysis using the standard method suggested by Panse and Sukhatme (1978). MSTAT and SPSS were the softwares used for this purpose. The litter decay rate coefficients were worked following the constant potential weight loss model suggested by Olson (1963).

$$x / x^0 = e^{-kt.}$$

Where x= weight remaining at time 't' ; x^0= original mass; e= base of natural logarithm; k= the decay rate coefficient; t= time

Half lives [t $_{(0.5)}$] of decomposing litter were estimated from the k-values using the equation suggested by Bockheim *et al.*, (1991).

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

Regression equations were developed to predict mass loss with time separately for different support trees. Different functional models were tried and those with higher R^2 values were selected. For the estimation of the nutrients remaining in the decomposing leaf biomass over time, a method suggested by William (1992) was used. Second order hyperbolic function, modified Hoerl function and parabolic function were some of the functions used to fit the regression equation relating the nutrient mineralization with time. Seventy two regressions model were used to characterize the nutrient mineralization over time.

RESULTS

RESULTS

Litter production and litter decomposition patterns associated with a pepper production system involving six support tree species were studied for a period of one year. The species selected for study include, *Casuarina equisetifolia* J.R. & G. Forst, *Macaranga peltata* (Roxb) M.-A, *Ailanthus triphysa* (Dennst.) Alston, *Artocarpus heterophyllus* (Linn), *Acacia auriculiformis* (A. Cunn.) ex Benth and *Grevillea robusta* (A. Cunn.) ex R. Br.

4.1 LITTER FALL QUANTIFICATION

Litter production was monitored for the six pepper support trees species for a period of one year (Table 1). The annual litter production values (Fig-2) for the given tree species is as follows; *Artocarpus* (4653.63 kg ha^{-1}), *Macaranga* (4550.88 kg ha^{-1}), *Grevillea* (3036.04 kg ha^{-1}), *Casuarina* (2934.96 kg ha^{-1}), *Acacia* (2879.21 kg ha^{-1}) and *Ailanthus* (2221.25 kg ha^{-1}). *Artocarpus* and *Macaranga* were the toppers in terms of the annual litter yield while *Ailanthus* registered the lowest value.

4.1.1 Monthly variation in the litterfall among the black pepper standards

The litter production did not show significant variation between species from August till the end of December (Table 1 and Fig. 3). However, *Artocarpus heterophyllus* (470.50 kg ha^{-1}) recorded highest litter production while *Ailanthus triphysa* (180.71 kg ha^{-1}) recorded the lowest during the first month (September) of observation. The month of December characterized the period of peak litterfall for all the species. During this month, maximum litterfall was registered by *Ailanthus* (813.92 kg ha^{-1}).

Table 1. Monthly litterfall among the black pepper support trees, kg ha^{-1}

Months	Casuarina	Macaranga	Ailanthus	Artocarpus	Acacia	Grevillea	F-value	C.D
September	395.92	238.38	180.71	470.50	401.46	306.04	ns	-
October	342.33	282.00	232.42	334.96	296.71	272.88	ns	-
November	234.33	417.96	489.96	383.04	258.63	372.79	ns	-
December	362.67	787.08	813.92	623.33	325.88	641.29	ns	-
January	199.96^c	519.13^a	88.21^d	571.46^a	197.58^c	377.38^b	20.07*	61.17
February	130.46^b	462.71^a	70.33^b	389.38^a	138.50^b	171.63^b	40.78*	111.1
March	201.04^c	437.00^a	71.17^e	346.88^b	136.88^d	167.96^{cd}	20.51*	42.90
April	217.46^b	306.21^a	25.04^d	290.25^a	117.71^c	91.88^c	7.54*	58.51
May	127.96^{bc}	333.04^a	45.96^d	149.38^{bc}	175.08^b	84.08^{cd}	4.99*	62.94
June	330.54^b	478.54^a	71.67^c	465.71^a	297.63^b	111.88^c	15.23*	62.01
July	129.29^c	114.71^c	28.38^d	269.54^a	220.04^b	146.58^c	5.78*	49.51
August	263.00^c	174.13^d	103.54^e	359.21^a	313.13^b	291.67^b	31.89*	23.68
Total	2934.96	4550.88	2221.25	4653.63	2879.21	3036.04		

ns- Non significant   * - Significant at 5% level
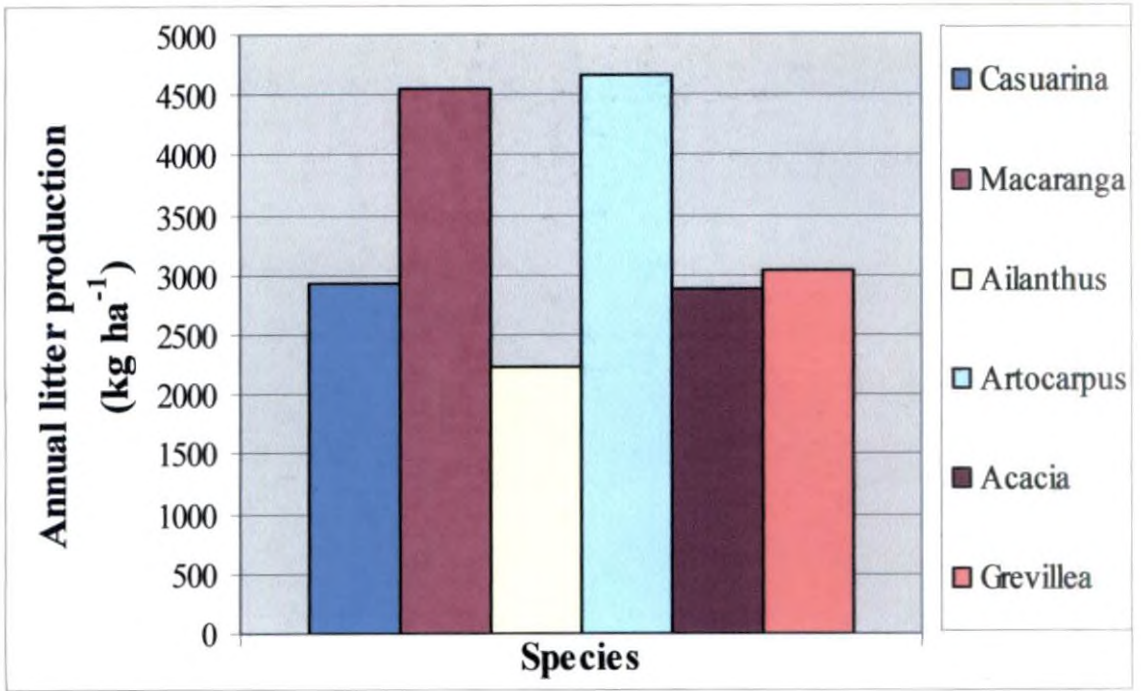
Fig. 2 Annual litter production of the black pepper standards
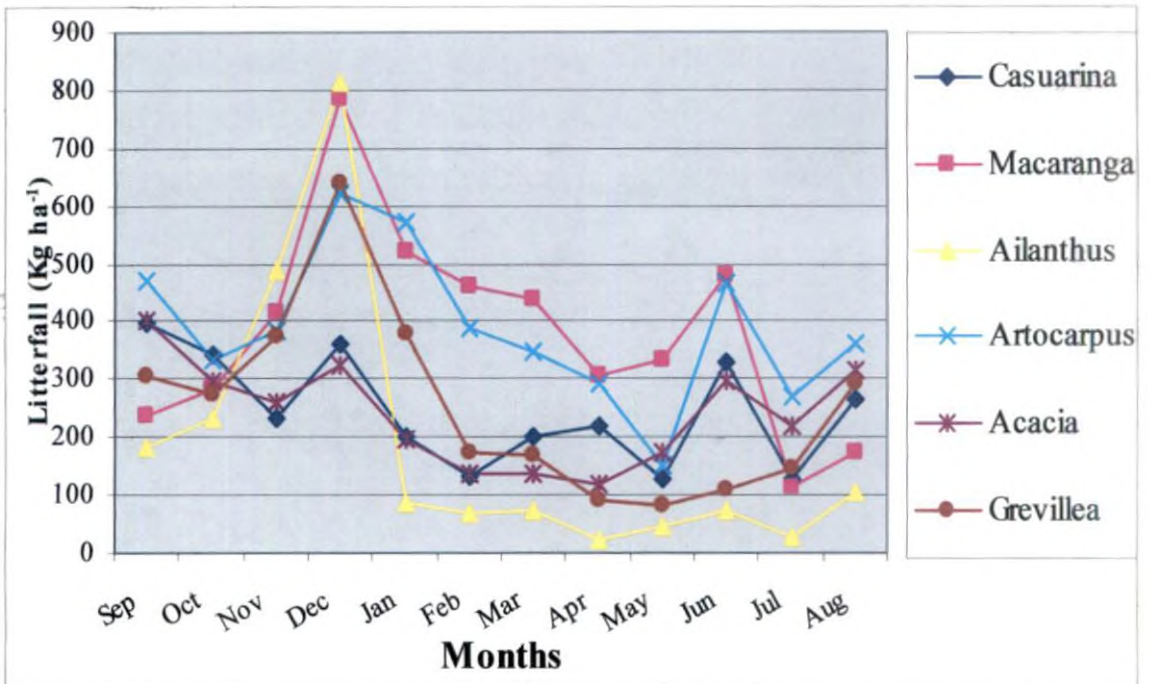
Fig. 3 Seasonal variation in the litterfall among the black pepper standards

Significant variation in monthly litterfall was observed among species from January onwards. After heavy litterfall in December, January reported a steep decline for all species with *Ailanthus* (88.21 kg ha^{-1}) showing drastic reduction in the litterfall. *Artocarpus* and *Macaranga* gave better litter yield during these periods which were on par. February followed the same trend. April- May represented lean months with regard to the litter yield for most of the species. For instance, *Ailanthus* (25.04 kg ha^{-1}) recorded the lowest litterfall during April. Similarly, lowest litter production was reported by *Grevillea* (84.08), *Casuarina* (127.96 kg ha^{-1}) and *Artocarpus* (149.38 kg ha^{-1}) during the month of May. Fluctuation in the litter yield was observed for the remaining three months of observation. The month of June showed an increase in production for all the species with major share from *Macaranga* (478.54), *Artocarpus* (465.71) and *Casuarina* (330.54). During the twelfth month of observation (August-2004), *Artocarpus* (359.21 kg ha^{-1}) showed the highest production followed by *Acacia* (313.13 kg ha^{-1}) and *Grevillea* (291.67 kg ha^{-1}). *Macaranga* (174.13 kg ha^{-1}) and *Ailanthus* (103.54 kg ha^{-1}) represented the lowest litter yield during this period.

4.1.2 Seasonal variation in litter production

The percentage of litterfall was maximum for the dry period (Dec-May) for all the species studied (Table 2 and 3). Major share of annual litter yield for *Ailanthus* (72.24%), *Macaranga* (71.70%) and *Grevillea* (62.81%) were contributed during summer. The period (June-Nov), characterized by relatively high rainfall, contributed lower litterfall particularly for *Macaranga, Ailanthus* and *Grevillea*. Total litter yield for *Casuarina* and *Acacia* during the summer and rainy season didn't showed considerable variation. Attempts to relate litterfall pattern with season reveals a steady increase from the initial study month of September onwards with a distinct peak for December for all the tree species. For instance, the litter production during December was as much as 36% of the total annual production for *Ailanthus* followed by the 21.1% for *Grevillea*, 17.3% for *Macaranga*.

Table 2. Monthly litter production of black pepper standards expressed as % of the total annual litterfall

Months	Casuarina (%)	Macaranga (%)	Ailanthus (%)	Artocarpus (%)	Acacia (%)	Grevillea (%)
September	13.49	5.24	8.14	10.11	13.94	10.08
October	11.66	6.20	10.46	7.20	10.31	8.99
November	7.98	9.18	22.06	8.23	8.98	12.28
December	12.36	17.30	36.64	13.39	11.32	21.12
January	6.81	11.41	3.97	12.28	6.86	12.43
February	4.45	10.17	3.17	8.37	4.81	5.65
March	6.85	9.60	3.20	7.45	4.75	5.53
April	7.41	6.73	1.13	6.24	4.09	3.03
May	4.36	7.32	2.07	3.21	6.08	2.77
June	11.26	10.52	3.23	10.01	10.34	3.69
July	4.41	2.52	1.28	5.79	7.64	4.83
August	8.96	3.83	4.66	7.72	10.88	9.61

Table 3. Proportionate litter production among black pepper standards corresponding to dry and wet period, %

Period	Casuarina (%)	Macaranga (%)	Ailanthus (%)	Artocarpus (%)	Acacia (%)	Grevillea (%)
Dry period (Dec- May)	50.22	71.70	72.24	59.17	46.90	62.81
Wet period (June- Nov)	49.78	28.30	27.76	40.83	53.10	37.19

Species variation in the litterfall pattern indicates that, *Ailanthus* followed monomodal distribution with a distinct peak at December. The same is the case with *Acacia* and *Grevillea* except a slight increase in June. For *Casuarina, Macaranga* and *Artocarpus* a bimodal pattern is evident. *Macaranga* and *Artocarpus* can be judged as the best performers in terms of annual litter production and least value was for *Ailanthus*.

4.1.3 Litter nutrient content and return through the litterfall
4.1.3.1 *Nitrogen*

Nitrogen content in the monthly fallen litter for different tree species are shown in the Table 4 and Figure 4. The nitrogen content in the monthly litterfall showed significant variation between species except for the months of February, March, April and June. Data for the initial months of study showed that nitrogen percentage in litter was maximum for the *Acacia* (1.85%) followed by *Casuarina* (1.81%). The lowest value was reported for *Artocarpus* (1.35%). *Casuarina* continued higher litter N content till December. Similar trend was followed by *Ailanthus* and *Grevillea*. No appreciable variation in N content for *Macaranga* has been observed throughout the period.

Acacia maintained higher N content during July and August followed by *Casuarina* and *Ailanthus*. Variation in N content over time among the species also showed considerable difference (Fig. 4). In general, *Casuarina* and *Acacia* litter showed higher N content almost throughout study with peak values corresponding to November and August respectively. No significant change in N content for the litter corresponding to *Macaranga* and *Artocarpus* were observed. *Ailanthus* reported higher values in December and August. For *Grevillea* also, the highest N content was reported during December. Litter nitrogen content in general, showed marginal increase during September to December followed by gradual decline till the month of May. Interestingly, the rainy months (June to August) were characterized by an increase in litter N content for all the support trees under study. Table 5 shows the monthly addition of N through litter route for the different species. The annual return of nitrogen by way of litterfall in kg ha^{-1}; this was maximum for *Macaranga* (68.13) followed by *Artocarpus* (65.75), *Casuarina* (53.25), *Acacia* (49.73), *Grevillea* (48.40) and *Ailanthus* (39.25).

Table 4. Nitrogen content in the monthly litterfall corresponding to various black pepper support trees, %

Months	Casuarina	Macaranga	Ailanthus	Artocarpus	Acacia	Grevillea	F-value	CD
Sep	1.81_{cd}^{BCD}	1.44_{ab}	1.61_{bc}^{ABC}	1.35_a	1.85_d^{DE}	1.49_{ab}^{DE}	8.03**	0.22
Oct	1.90_c^{E}	1.53_{ab}	1.71_{bc}^{BCDE}	1.32_a	1.87_c^{DE}	1.52_{ab}^{DE}	10.30**	0.22
Nov	1.99_c^{E}	1.60_{ab}	1.68_b^{ABCD}	1.37_a	1.77_{bc}^{CDE}	1.71_b^{GH}	5.79**	0.26
Dec	1.95_c^{E}	1.54_{ab}	1.91_c^{DE}	1.34_a	1.69_{abc}^{BCD}	1.78_{bc}^{H}	4.03**	0.34
Jan	1.87_c^{CD}	1.43_{ab}	1.81_c^{CDE}	1.21_a	1.57_{bc}^{ABCD}	1.59_{bc}^{EF}	5.25**	0.33
Feb	1.88^{D}	1.52	1.60^{ABC}	1.39	1.36^{A}	1.48^{CD}	2.29ns	0.38
Mar	1.77^{BCD}	1.35	1.50^{AB}	1.34	1.42^{AB}	1.51^{DE}	2.02ns	0.34
Apr	1.64^{ABC}	1.25	1.47^{AB}	1.42	1.34^{A}	1.34^{B}	1.56ns	0.33
May	1.52_{bc}^{A}	1.37_{ab}	1.44_{bc}^{A}	1.62_c	1.52_{bc}^{ABC}	1.18_a^{A}	4.01*	0.24
Jun	1.60^{AB}	1.62	1.70^{ABCDE}	1.58	1.73^{CDE}	1.39^{BC}	1.75ns	0.28
Jul	1.85_b^{CD}	1.72_{ab}	1.83_b^{CDE}	1.59_a	1.86_b^{DE}	1.53_a^{DE}	3.37*	0.24
Aug	1.88_{bc}^{E}	1.77_{ab}	1.95_c^{E}	1.74_{ab}	2.01_c^{E}	1.64_a^{FG}	7.61**	0.15
F-value	3.50**	2.00ns	3.52*	1.66ns	4.59**	24.57**		
CD	0.23	0.32	0.26	0.35	0.30	0.10		

ns – Non significant; * - Significant at 5% level; ** - Significant at 1% level
Within a row, means having same letter as subscript are homogeneous
Within a column, means having same letter as superscript are homogeneous

Table 5. Monthly nitrogen addition to the soil through litterfall among black pepper standards, kg ha^{-1}

Months	Casuarina	Macaranga	Ailanthus	Artocarpus	Acacia	Grevillea	F-value	CD
September	7.17 ^{C}	3.43 ^{AB}	2.90 ^{AB}	6.37 ^{BCD}	7.42 ^{F}	4.57 ^{CDE}	3.02ns	3.44
October	6.49 ^{BC}	4.32 ^{ABC}	3.97 ^{B}	4.41 ^{AB}	5.54 ^{EF}	4.15 ^{BCDE}	1.24ns	2.76
November	4.66 ^{ABC}	6.67 ^{CD}	8.23 ^{C}	5.26 ^{ABC}	4.59 ^{CDE}	6.37 ^{E}	1.01ns	4.17
December	7.08 ^{C}	12.12 ^{E}	15.57 ^{D}	8.32 ^{D}	5.50 ^{EF}	11.43 ^{F}	2.94ns	6.85
January	3.73$_{ab}$ ^{ABC}	7.42$_{c}$ ^{D}	1.60$_{a}$ ^{AB}	6.93$_{c}$ ^{BCD}	3.10$_{a}$ ^{ABCD}	5.99$_{bc}$ ^{E}	8.25**	2.48
February	2.45$_{b}$ ^{AB}	7.04$_{c}$ ^{CD}	1.12$_{a}$ ^{AB}	5.42$_{c}$ ^{BC}	1.89$_{ab}$ ^{AB}	2.53$_{ab}$ ^{AB}	16.86**	1.73
March	3.56$_{bc}$ ^{AB}	5.92$_{d}$ ^{BCD}	1.07$_{a}$ ^{AB}	4.66$_{cd}$ ^{ABC}	1.94$_{ab}$ ^{AB}	2.54$_{ab}$ ^{ABCD}	8.42**	2.05
April	3.57$_{b}$ ^{AB}	3.83$_{b}$ ^{AB}	0.37$_{a}$ ^{A}	4.12$_{b}$ ^{AB}	1.58$_{a}$ ^{A}	1.24$_{a}$ ^{A}	7.59**	1.75
May	1.95$_{ab}$ ^{A}	4.57$_{c}$ ^{ABC}	0.66$_{a}$ ^{A}	2.41$_{abc}$ ^{A}	2.66$_{bc}$ ^{ABC}	0.99$_{ab}$ ^{A}	4.18*	2.14
June	5.28$_{b}$ ^{BC}	7.77$_{b}$ ^{D}	1.22$_{a}$ ^{AB}	7.34$_{b}$ ^{CD}	5.14$_{b}$ ^{DEF}	1.56$_{a}$ ^{AC}	8.48**	3.02
July	2.39$_{b}$ ^{A}	1.97$_{b}$ ^{A}	0.52$_{a}$ ^{A}	4.29$_{c}$ ^{AB}	4.09$_{c}$ ^{BCDE}	2.24$_{b}$ ^{AB}	13.43**	1.23
August	4.93$_{b}$ ^{ABC}	3.09$_{a}$ ^{AB}	2.02$_{a}$ ^{AB}	6.24$_{c}$ ^{BCD}	6.28$_{c}$ ^{EF}	4.79$_{b}$ ^{DE}	23.45**	1.09
Total	53.25	68.13	39.25	65.75	49.73	48.40		
F-value	2.45*	8.05**	16.52**	2.88*	5.67**	10.78**		
CD	1.51	1.20	1.37	1.17	0.97	1.38		

ns – Non significant; * - Significant at 5% level; ** - Significant at 1% level
Within a row, means having same letter as subscript are homogeneous
Within a column, means having same letter as superscript are homogeneous
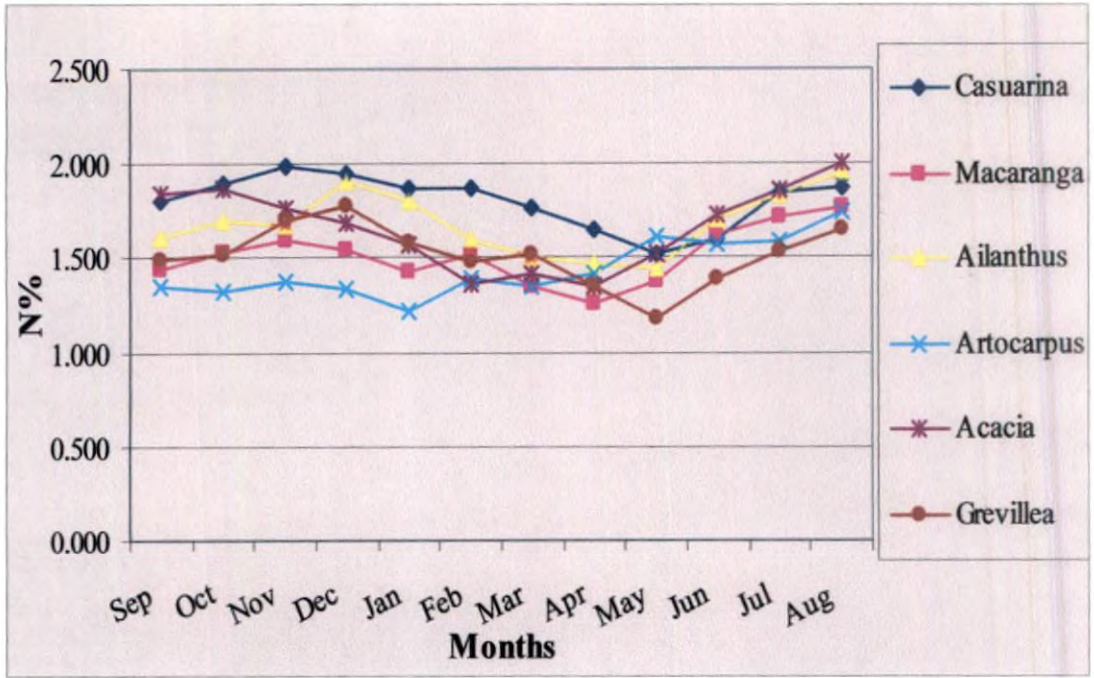
Fig. 4 Changes in the litter N content in the monthly litterfall among black pepper
standards
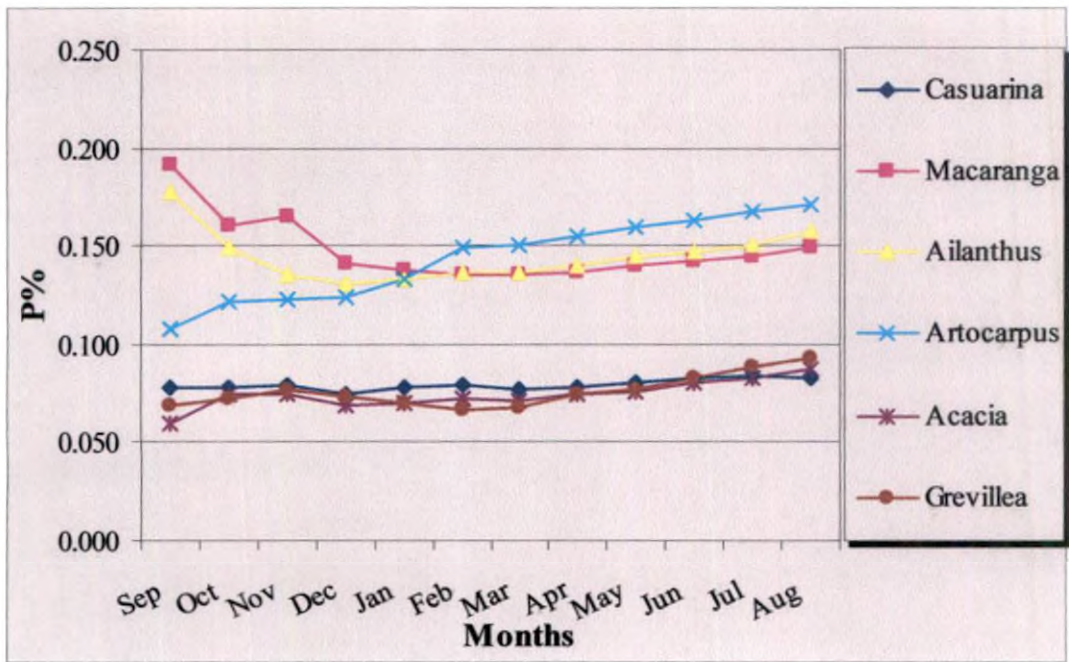
Fig. 5 Changes in the litter P content in the monthly litterfall among black pepper
standards

Table 6. Phosphorus content in the litter corresponding to various black pepper support trees, %

Months	Casuarina	Macaranga	Ailanthus	Artocarpus	Acacia	Grevillea	F-value	CD
Sep	0.08_c	0.19_f	0.18_e	$0.11_d{}^A$	$0.06_a{}^A$	$0.07_b{}^{AB}$	1027.64**	0.01
Oct	0.08_a	0.16_c	0.15_c	$0.12_b{}^{AB}$	$0.07_a{}^{AB}$	$0.07_a{}^{ABC}$	19.76**	0.03
Nov	0.08_a	0.17_c	0.14_b	$0.12_b{}^{AB}$	$0.08_a{}^{ABC}$	$0.08_a{}^{CD}$	19.76**	0.03
Dec	0.07_a	0.14_b	0.13_b	$0.12_b{}^{AB}$	$0.07_a{}^A$	$0.07_a{}^{ABC}$	22.64**	0.02
Jan	0.08_a	0.14_b	0.13_b	$0.13_b{}^{BC}$	$0.07_a{}^A$	$0.07_a{}^{ABC}$	22.19**	0.02
Feb	0.08_a	0.14_b	0.14_b	$0.15_b{}^{CD}$	$0.07_a{}^{AB}$	$0.07_a{}^A$	18.48**	0.03
Mar	0.08_a	0.14_b	0.14_b	$0.15_b{}^{CD}$	$0.07_a{}^{AB}$	$0.07_a{}^{AB}$	20.70**	0.03
Apr	0.08_a	0.14_b	0.14_b	$0.16_b{}^{DE}$	$0.07_a{}^{AB}$	$0.07_a{}^{BC}$	17.56**	0.03
May	0.08_a	0.14_b	0.15_b	$0.16_b{}^{DE}$	$0.08_a{}^B$	$0.08_a{}^{CD}$	19.14**	0.03
Jun	0.08_a	0.14_b	0.15_b	$0.16_b{}^{DE}$	$0.08_a{}^{CD}$	$0.09_a{}^{DE}$	17.07**	0.03
Jul	0.08_a	0.15_b	0.15_b	$0.17_b{}^E$	$0.08_a{}^{DE}$	$0.09_a{}^{EF}$	17.07**	0.03
Aug	0.08_a	0.15_b	0.16_b	$0.17_b{}^E$	$0.09_a{}^E$	$0.09_a{}^F$	16.61**	0.03
F-value	2.14ns	1.23ns	1.21ns	12.23**	12.76**	10.05**		
CD	0.01	0.04	0.04	0.02	0.01	0.01		

ns – Non significant; * - Significant at 5% level; ** - Significant at 1% level
Within a row, means having same letter as subscript are homogeneous
Within a column, means having same letter as superscript are homogeneous

Table 7. Monthly phosphorus addition to the soil through litterfall among black pepper standards, kg ha^{-1}

Months	*Casuarina*	*Macaranga*	*Ailanthus*	*Artocarpus*	*Acacia*	*Grevillea*	*F-value*	CD
Sep	0.31_{ab} ^{D}	0.46_{bc} ^{ABC}	0.32_{ab} ^{AB}	0.51_{c} ^{B}	0.24_{a} ^{EF}	0.21_{a} ^{CD}	*3.89***	*0.18*
Oct	0.27_{ab} ^{CD}	0.45_{c} ^{ABC}	0.35_{bc} ^{B}	0.41_{c} ^{AB}	0.22_{a} ^{CDEF}	0.20_{a} ^{BCD}	*6.47***	*0.12*
Nov	0.19_{a} ^{ABCD}	0.69_{b} ^{C}	0.66_{b} ^{C}	0.47_{ab} ^{AB}	0.19_{a} ^{CDEF}	0.29_{a} ^{D}	*3.59**	*0.13*
Dec	0.27_{ab} ^{CD}	1.11_{c} ^{D}	1.07_{c} ^{D}	0.77_{bc} ^{D}	0.23_{a} ^{DEF}	0.47_{ab} ^{E}	*5.57***	*0.52*
Jan	0.16_{ab} ^{ABC}	0.72_{c} ^{C}	0.12_{a} ^{AB}	0.76_{c} ^{CD}	0.14_{ab} ^{ABCD}	0.26_{b} ^{D}	*44.64***	*0.14*
Feb	0.10_{a} ^{AB}	0.63_{b} ^{BC}	0.10_{a} ^{AB}	0.58_{b} ^{BCD}	0.10_{a} ^{AB}	0.12_{a} ^{AB}	*35.61***	*0.13*
Mar	0.16_{a} ^{ABC}	0.59_{b} ^{BC}	0.10_{a} ^{AB}	0.52_{b} ^{BC}	0.10_{a} ^{AB}	0.11_{a} ^{ABC}	*27.50***	*0.14*
Apr	0.17_{a} ^{ABC}	0.42_{b} ^{ABC}	0.04_{a} ^{A}	0.45_{b} ^{AB}	0.09_{a} ^{A}	0.07_{a} ^{A}	*8.79***	*0.19*
May	0.10_{a} ^{AB}	0.47_{b} ^{ABC}	0.07_{a} ^{AB}	0.24_{ab} ^{A}	0.13_{a} ^{ABC}	0.07_{a} ^{A}	*4.40***	*0.24*
Jun	0.27_{a} ^{CD}	0.68_{b} ^{C}	0.11_{a} ^{AB}	0.76_{b} ^{CD}	0.24_{a} ^{EF}	0.09_{a} ^{AB}	*19.28***	*0.20*
Jul	0.11_{ab} ^{A}	0.17_{ab} ^{A}	0.04_{a} ^{AB}	0.45_{c} ^{AB}	0.18_{b} ^{BCDE}	0.13_{ab} ^{ABC}	*11.43***	*0.14*
Aug	0.22_{ab} ^{BCD}	0.26_{b} ^{AB}	0.16_{a} ^{AB}	0.61_{c} ^{BCD}	0.27_{b} ^{F}	0.27_{b} ^{D}	*25.89***	*0.11*
Total	2.32	6.63	3.12	6.53	2.13	2.28		
F-value	*2.98***	*4.59***	*9.60***	*3.83***	*4.30***	*8.95***		
CD	*0.13*	*0.34*	*0.31*	*0.24*	*0.10*	*0.12*		

ns – Non significant; * - Significant at 5% level; ** - Significant at 1% level
Within a row, means having same letter as subscript are homogeneous
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No significant variation in absolute N content was observed for different species during the months from September to December. For the remaining months, absolute addition of N was almost in tune with the litterfall patterns of the different support trees.

4.1.3.2 *Phosphorus*

Litter phosphorus content differed considerably between species during the study period (Table 6 and Fig. 5). Notable seasonal variation in litter P content could be observed only in *Artocarpus*, *Acacia* and *Grevillea*. Data for early months of study (Sep-Dec) showed that *Macaranga* registered highest P content followed by *Ailanthus*. *Casuarina*, *Acacia* and *Grevillea* showed lower P content with closer values. Though litter P content showed marginal increase over the months for *Artocarpus*, *Acacia* and *Grevillea*, the P content remained relatively stable for almost all species during the study period.

The phosphorus content in absolute terms showed significant variation between species for the all the months under study (Table 7).Annual P addition to the soil by way of litterfall (kg ha^{-1} yr^{-1}) was maximum for *Macaranga* (6.63), followed by *Artocarpus* (6.53), *Ailanthus* (3.12), *Casuarina* (2.32) and *Grevillea* (2.28). *Acacia* (2.13) registered the least content. As evident from results the P turnover through litter route was better for *Macaranga* and *Artocarpus*.

4.1.3.3 *Potassium*

The variation in litter potassium content over months has been shown in Table 8 and Fig. 6. During September, maximum potassium content was held by *Macaranga* (0.33%) and the least by *Casuarina* (0.08%). These species registered their highest K content in the litter collected during February. For *Ailanthus*, *Artocarpus* and *Acacia*, K content was maximum for the litter collected during March. But for the fluctuations for *Macaranga* in the early months, litter K content appeared to increase gradually till February to March and declined to initial values for the subsequent months. Table 9 gives the absolute amount of K added to the soil through litter route for different tree species used as black pepper standards.

Table 8. Potassium content in the litter corresponding to various black pepper trees, %

Months	Casuarina	Macaranga	Ailanthus	Artocarpus	Acacia	Grevillea	F-value	CD
Sep	$0.08_a{}^{AB}$	$0.33_d{}^{D}$	$0.12_{bc}{}^{ABCD}$	$0.10_{ab}{}^{ABC}$	$0.09_a{}^{AB}$	$0.14_c{}^{A}$	99.12**	0.03
Oct	$0.06{}^{A}$	$0.20{}^{AB}$	$0.11{}^{ABCD}$	$0.07{}^{A}$	$0.09{}^{AB}$	$0.12{}^{A}$	2.33ns	0.10
Nov	$0.06_a{}^{A}$	$0.31_c{}^{CD}$	$0.15_b{}^{BCDE}$	$0.11_{ab}{}^{ABC}$	$0.12_b{}^{BCD}$	$0.14_b{}^{A}$	28.5**	0.05
Dec	$0.07_a{}^{AB}$	$0.32_c{}^{CD}$	$0.16_b{}^{DEF}$	$0.16_b{}^{DE}$	$0.15_b{}^{DE}$	$0.21_b{}^{AB}$	17.87**	0.06
Jan	$0.09{}^{B}$	$0.22{}^{ABC}$	$0.16{}^{CDE}$	$0.17{}^{DE}$	$0.14{}^{CD}$	$0.19{}^{AB}$	1.47ns	0.11
Feb	$0.09_a{}^{B}$	$0.34_d{}^{D}$	$0.24_{bc}{}^{G}$	$0.20b_c{}^{EF}$	$0.18_b{}^{EF}$	$0.26_c{}^{B}$	13.55**	0.07
Mar	$0.08_a{}^{AB}$	$0.26_c{}^{BCD}$	$0.32_d{}^{H}$	$0.21_{bc}{}^{F}$	$0.21_{bc}{}^{F}$	$0.20_b{}^{F\,AB}$	19.86**	0.05
Apr	$0.06{}^{A}$	$0.15{}^{A}$	$0.20{}^{EFG}$	$0.13{}^{BCD}$	$0.11{}^{ABCD}$	$0.12{}^{A}$	2.01ns	0.10
May	$0.06_a{}^{A}$	$0.16_{abc}{}^{A}$	$0.21_{bc}{}^{FG}$	$0.14_{ab}{}^{CD}$	$0.11_{ab}{}^{ABCD}$	$0.27_c{}^{B}$	3.63*	0.12
Jun	$0.06_a{}^{A}$	$0.14_d{}^{A}$	$0.11_{bc}{}^{ABC}$	$0.11_b{}^{ABC}$	$0.10_b{}^{ABC}$	$0.13_{cd}{}^{A}$	12.25**	0.03
Jul	$0.06_a{}^{A}$	$0.13_d{}^{A}$	$0.10_{ac}{}^{AB}$	$0.09_{bc}{}^{AB}$	$0.08_{ab}{}^{A}$	$0.11_c{}^{A}$	14.92**	0.02
Aug	$0.06_a{}^{A}$	$0.15_d{}^{A}$	$0.08_{ab}{}^{A}$	$0.09_{ab}{}^{A}$	$0.10_{bc}{}^{ABC}$	$0.11_c{}^{A}$	16.03**	0.02
F-value	2.47*	6.00**	14.05**	9.30**	7.20**	2.57**		
CD	0.01	0.10	0.53	0.04	0.05	0.10		

ns – Non significant; * - Significant at 5% level; ** - Significant at 1% level
Within a row, means having same letter as subscript are homogeneous
Within a column, means having same letter as superscript are homogeneous

Table 9. Monthly Potassium addition to the soil through litterfall among black pepper standards, kg ha^{-1}

Months	Casuarina	Macaranga	Ailanthus	Artocarpus	Acacia	Grevillea	F-value	CD
Sep	0.31_{ab} ^{C}	0.79_c ^{ABCD}	0.21_a ^{A}	0.48_b ^{AB}	0.34_{ab}	0.42_{ab} ^{B}	6.05**	0.25
Oct	0.21 ^{BC}	0.55 ^{ABC}	0.26 ^{A}	0.23 ^{A}	0.26	0.34 ^{AB}	1.49ns	0.30
Nov	0.15_a ^{AB}	1.31_c ^{D}	0.72_b ^{A}	0.40_{ab} ^{A}	0.32_{ab}	0.51_{ab} ^{BC}	6.81**	0.50
Dec	0.26_a ^{BC}	2.52_d ^{E}	1.33_c ^{B}	0.97_{abc} ^{D}	0.50_{ab}	1.36_{bc} ^{D}	9.62**	0.80
Jan	0.19_{ab} ^{ABC}	1.16_c ^{CD}	0.14_a ^{A}	0.94_c ^{CD}	0.27_{ab}	0.72_{bc} ^{C}	7.05**	0.51
Feb	0.12_a ^{AB}	1.56_d ^{D}	0.17_a ^{A}	0.76_c ^{CD}	0.25_{ab}	0.45_b ^{AB}	92.89**	0.17
Mar	0.17_a ^{ABC}	1.13_c ^{BCD}	0.23_a ^{A}	0.72_b ^{BC}	0.29_a	0.34_a ^{AB}	27.93**	0.22
Apr	0.14_{ab} ^{AB}	0.45_c ^{AB}	$0.05a$ ^{A}	0.38_{bc} ^{A}	0.13_{ab}	0.11_{ab} ^{A}	3.70*	0.28
May	0.07_a ^{A}	0.52_b ^{AB}	0.10_a ^{A}	0.21_a ^{A}	0.19_a	0.23_a ^{A}	6.61**	0.18
Jun	0.19_b ^{ABC}	0.66_e ^{ABC}	0.08_a ^{A}	0.49_d ^{AB}	0.30_c	0.15_{ab} ^{A}	82.25**	0.08
Jul	0.13_a ^{A}	0.18_b ^{A}	0.45_a ^{A}	0.04_c ^{A}	0.17_{bc}	0.11_b ^{A}	11.05**	0.07
Aug	0.27_b ^{AB}	0.27_c ^{A}	0.61_a ^{A}	0.16_{cd} ^{A}	0.26_{cd}	0.22_d ^{AB}	25.71**	0.06
Total	2.04	11.05	3.39	6.13	3.32	5.10		
F-value	2.29*	8.52**	16.67**	9.42**	3.17*	18.37**		
CD	0.14	0.66	0.27	0.26	0.16	0.22		

ns – Non significant; * - Significant at 5% level; ** - Significant at 1% level
Within a row, means having same letter as subscript are homogeneous
Within a column, means having same letter as superscript are homogeneous

In general, the trends are in tune with the monthly litterfall which is evident in the present study. Monthly variation in K addition for different species is also evident. At the end of the study period, the absolute potassium addition through litterfall on annual basis in kg ha^{-1} is as below; *Macaranga* (11.05) delivered maximum K followed by *Artocarpus* (6.13), *Grevillea* (5.10), *Ailanthus* (3.39), *Acacia* (3.32) and *Casuarina* (2.04). Evidently, *Acacia* litter contributes significantly in K mineralization.

4.1.3.4 *Carbon*

Results of the elemental carbon in the litter of different support trees are shown in the Table 10. Though elemental C exhibited significant variation among the species, the range of variation was found to be very narrow for litter corresponding to different months. Among the species, maximum carbon content was reported for *Macaranga* during the month of December and August (31.3% and 30.15% respectively). In general, *Acacia* and *Grevillea* showed lower C content in their litterfall.

The carbon content for all the species in absolute terms showed significant variation between them except for the initial three months (Sep-Nov) as shown in Table 11. The absolute quantity of elemental C in the litterfall showed significant variation between species till the end of the observation. The annual carbon deposition by the way of litterfall for various species are as follows in kg ha^{-1}; *Casuarina* (829.07), *Macaranga* (1327.66), *Ailanthus* (639.28), *Artocarpus* (1352.99), *Acacia* (787.12) and *Grevillea* (827.57). *Artocarpus* and *Macaranga* were equally good in carbon addition through litterfall.
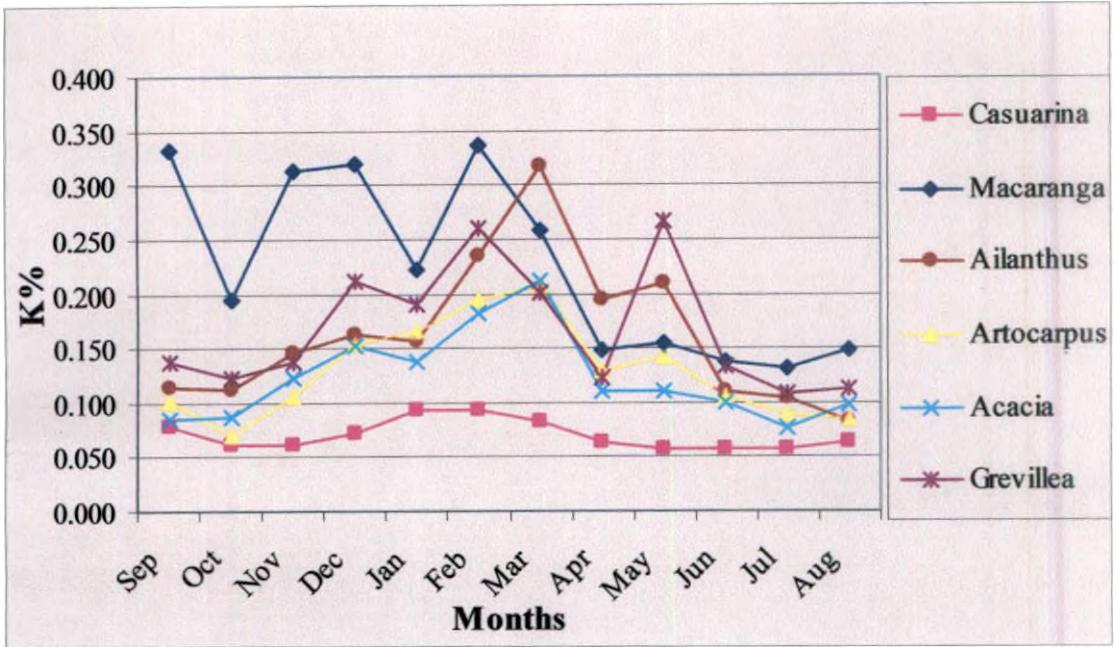
Fig. 6 Changes in the litter K content in the monthly litterfall among black pepper standards
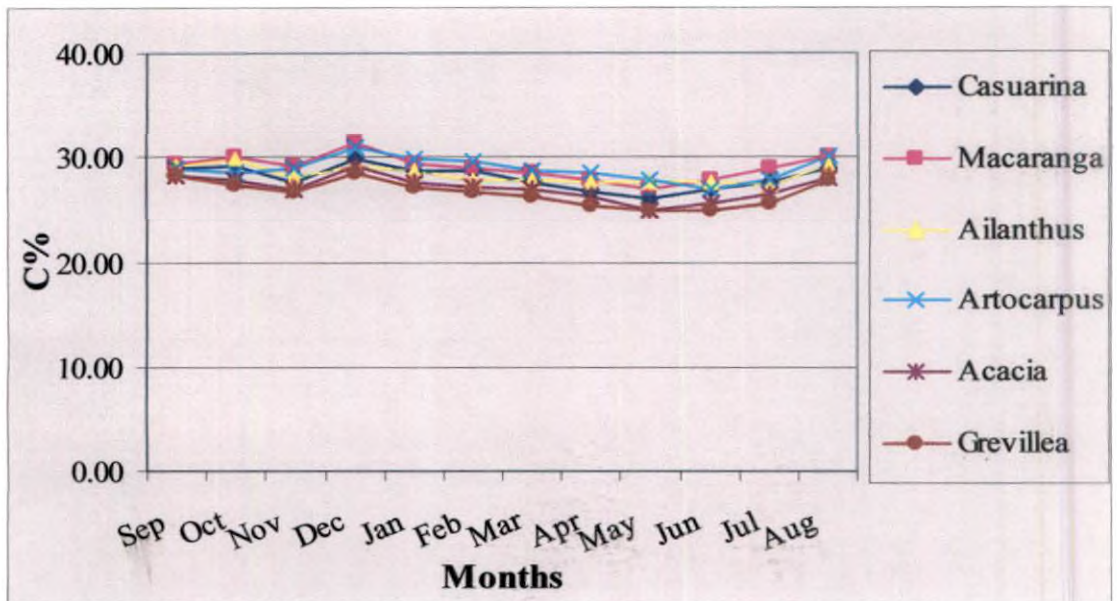
Fig. 7 Changes in the litter C content in the monthly litterfall among black pepper standards

Table 10. Carbon content in the litter corresponding to various black pepper support trees, %

Months	*Casuarina*	*Macaranga*	*Ailanthus*	*Artocarpus*	*Acacia*	*Grevillea*	*F-value*	CD
Sep	28.93^{CD}	29.30^{CD}	29.14	28.87^{BCD}	28.25^{FG}	28.23^{EF}	1.93^{ns}	0.10
Oct	29.12_{bc}^{CD}	30.09_{a}^{DE}	29.77_{ab}	28.42_{bcd}^{ABC}	27.84_{cd}^{EF}	27.39_{d}^{DE}	21.43	0.71
Nov	27.52_{bc}^{B}	29.25_{a}^{CD}	28.16_{ac}	28.93_{ab}^{BCD}	26.87_{c}^{BCDE}	26.75_{c}^{CD}	3.73*	1.67
Dec	29.83_{bc}^{D}	31.31_{a}^{E}	29.19_{cd}	30.86_{ab}^{E}	29.25_{cd}^{G}	28.55_{d}^{F}	9.53*	1.06
Jan	28.80_{ab}^{C}	29.38_{a}^{CD}	28.67_{abc}	29.83_{a}^{CDE}	27.52_{bc}^{DEF}	27.26_{c}^{CDE}	4.78*	1.43
Feb	28.68_{ab}^{C}	28.93_{ab}^{BCD}	27.77_{bc}	29.70_{a}^{CDE}	27.26_{c}^{CDEF}	26.75_{c}^{CD}	8.21*	1.20
Mar	27.52_{ac}^{B}	28.42_{a}^{BC}	27.84_{ab}	28.67_{a}^{BCD}	27.00_{bc}^{CDE}	26.23_{c}^{BC}	4.63*	1.34
Apr	26.68_{bc}^{AB}	27.84_{ab}^{AB}	27.71_{ab}	28.42_{a}^{ABC}	26.23^{BC}	25.40_{c}^{AB}	6.22*	1.41
May	26.10_{bc}^{A}	27.00_{ab}^{A}	27.52_{ab}	27.90_{a}^{AB}	25.01_{c}^{A}	24.88_{c}^{A}	6.09*	1.60
Jun	26.87_{ab}^{AB}	27.77_{a}^{AB}	27.52_{a}	27.00_{ab}^{A}	25.72_{bc}^{AB}	25.01_{c}^{A}	6.09*	1.34
Jul	27.58_{abc}^{B}	28.87_{a}^{BCD}	27.45_{bc}	27.90_{ab}^{AB}	26.55_{cd}^{BCD}	25.65_{d}^{AB}	6.86*	1.31
Aug	28.87_{ac}^{C}	30.15_{a}^{DE}	29.12_{ac}	30.09_{a}^{DE}	27.97_{c}^{EF}	27.77_{c}^{DEF}	3.91*	1.58
F-value	12.94**	6.64**	2.74ns	4.35**	8.23**	11.75**		
CD	0.93	1.34	1.43	1.51	1.18	1.05		

ns – Non significant; * - Significant at 5% level; ** - Significant at 1% level
Within a row, means having same letter as subscript are homogeneous
Within a column, means having same letter as superscript are homogeneous

Table 11. Monthly carbon addition to the soil through litterfall among black pepper standards, kg ha^{-1}

Months	*Casuarina*	*Macaranga*	*Ailanthus*	*Artocarpus*	*Acacia*	*Grevillea*	*F-*	*CD*
Sep	114.54^E	69.83^{AB}	52.66^{AB}	135.82^{CD}	113.43^F	86.39^C	2.89	56.02
Oct	99.70^{CDE}	84.85^{BC}	69.18^B	95.19^{BC}	82.60^{DEF}	74.74^{BC}	0.74	41.58
Nov	64.48^{ABCD}	122.27^{CD}	137.97^C	110.82^{BC}	69.50^{BCDE}	99.71^C	1.88	65.61
Dec	108.19$_b$^{DE}	246.44$_a$^{E}	237.57$_a$^{D}	192.36$_a$^{E}	95.33$_b$^{EF}	183.06$_{ab}$^{C}	3.82	99.87
Jan	57.59$_c$^{ABC}	152.52$_c$^{D}	25.29$_c$^{AB}	170.48$_c$^{DE}	54.37$_c$^{ABCD}	102.87$_b$^{D}	25.7	35.37
Feb	37.40$_b$^{AB}	133.87$_a$^{CD}	19.53$_c$^{A}	115.66$_a$^{BC}	37.76$_b$^{AB}	45.90$_b$^{A}	74.1	16.98
Mar	55.32$_b$^{ABC}	124.18$_a$^{CD}	19.81$_c$^{A}	99.46$_a$^{BC}	36.96$_b$^{AB}	44.06$_b$^{AB}	25.9	25.04
Apr	58.02$_{ab}$^{ABC}	85.25$_a$^{BC}	6.94$_c$^{A}	82.48$_a$^{AB}	30.88$_b$^{A}	23.33$_b$^{A}	7.23	37.27
May	33.40$_b$^{AB}	89.93$_a$^{BC}	12.65$_b$^{A}	41.68$_b$^{A}	43.79$_b$^{ABC}	20.92$_b$^{A}	5.16	37.21
Jun	88.83$_{bc}$^{CDE}	132.91$_a$^{CD}	19.72$_d$^{A}	125.76$_{ab}$^{BC}	76.54$_c$^{CDE}	27.98$_d$^{A}	15.1	38.12
Jul	35.66$_c$^{A}	33.11$_c$^{A}	7.79$_d$^{A}	75.21$_a$^{AB}	58.43$_{ab}$	37.60$_{bc}$^{A}	8.76	25.34
Aug	75.92$_b$^{BCDE}	52.50$_c$^{AB}	30.16$_d$^{AB}	108.08$_a$^{BC}	87.57$_b$^{DEF}	81.01$_b$^{BC}	27.1	16.25
Total	829.07	1327.66	639.28	1352.99	787.14	827.57	9.07	2588.54
F-value	3.39**	9.87**	18.79**	7.10**	4.53**	12.41**		
CD	19.68	21.66	19.71	18.60	14.94	16.64		

*ns – Non significant; * - Significant at 5% level; ** - Significant at 1% level*
Within a row, means having same letter as subscript are homogeneous
Within a column, means having same letter as superscript are homogeneous

4.1.3.5 C: N ratio

C: N ratio of the litter plays significant role in the litter decomposition and subsequent soil fertility improvement. The present study on litterfall of the various support tree species revealed seasonal variation in litter C: N ratio varies between tree species (Table 12 and Fig. 8). *Artocarpus* and *Macaranga* maintained higher C: N ratio almost the entire period of study. Seasonal variation in the C: N ratio indicates feeble relationship between species. However, as evident from the Figure 8, dry months (Jan-May) indicated higher C: N ratios for tree species like *Macaranga*, *Artocarpus* and *Acacia*. The final month of study (August 2003) indicated general drop in C: N ratio and is given below; *Casuarina* (15.40), *Macaranga* (17.01), *Ailanthus* (14.95), *Artocarpus* (17.38), *Acacia* (13.96), and *Grevillea* (16.92). As seen from the data, *Artocarpus* reported highest C: N ratio and *Acacia* the least.

Table 12. Changes in C: N ratio in the monthly litterfall for different support trees

Months	Casuarina	Macaranga	Ailanthus	Artocarpus	Acacia	Grevillea	F-value	CD
Sep	16.03^c	20.58^a	18.22^b	21.41^a	15.30^c	18.94^b	7.44*	1.25
Oct	15.40^d	19.82^b	17.51^c	21.61^a	14.96^d	18.02^c	9.92*	1.14
Nov	13.93^c	18.38^b	16.77^c	21.18^a	15.35^d	15.67^{cd}	8.07*	1.28
Dec	15.33^d	20.69^b	15.32^d	23.42^a	17.80^c	16.03^{cd}	4.85*	2.11
Jan	15.48^d	20.89^b	16.05^{cd}	24.61^a	17.94^c	17.23^{cd}	5.65*	2.05
Feb	15.33	19.71	17.50	21.98	20.21	18.15	ns	-
Mar	15.56	21.29	18.71	22.38	19.07	17.36	ns	-
Apr	16.26	22.75	19.24	20.52	19.63	18.94	ns	-
May	17.18^c	19.73^b	19.20^b	17.50^c	16.49^c	21.18^a	5.55*	1.07
Jun	17.04	17.15	16.32	17.34	14.92	18.00	ns	-
Jul	14.99	16.89	15.05	17.71	14.36	16.77	ns	-
Aug	15.40^b	17.01^a	14.95^b	17.38^a	13.96^c	16.92^a	10.94*	0.58

*ns – Non significant; * - Significant at 5% level; ** - Significant at 1% level*
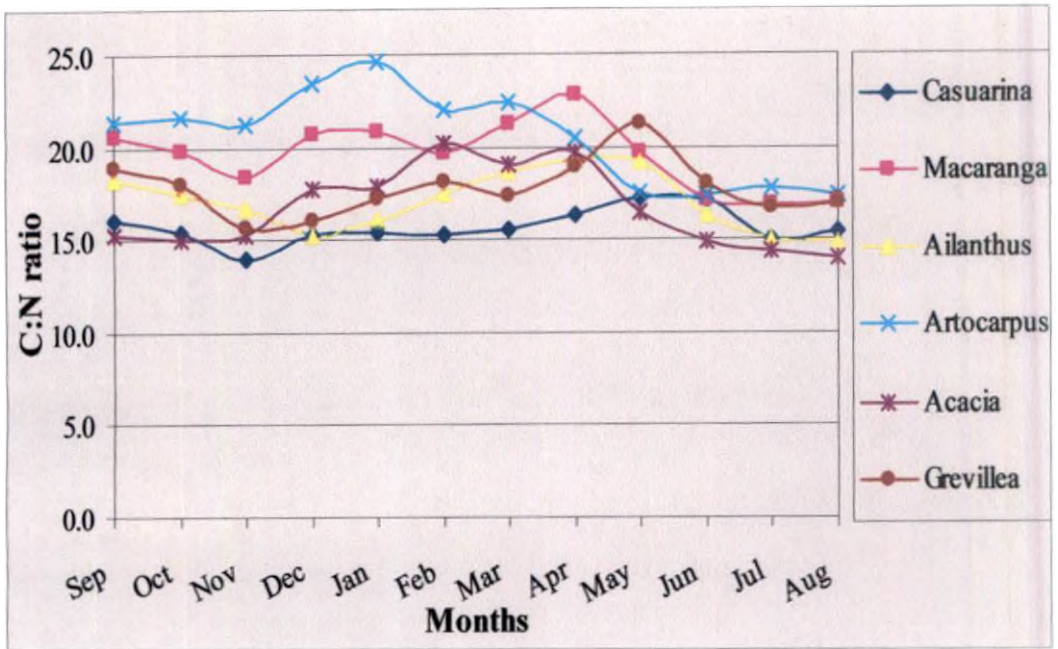
Fig. 8 Variation in C: N ratio in the monthly litterfall for the black pepper
standards
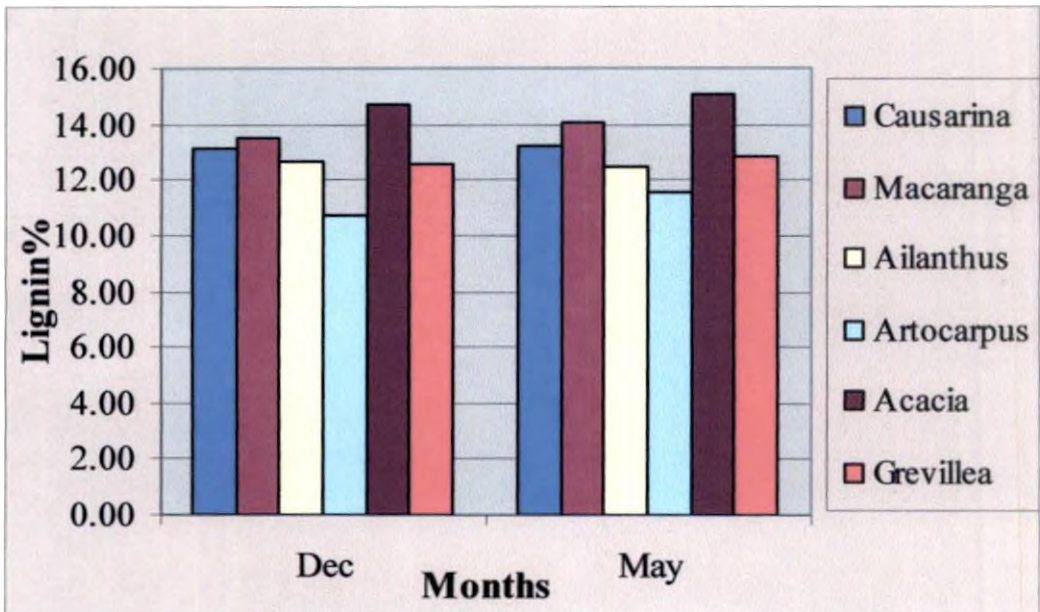
Fig. 9 Changes in litter lignin content (%) of the black pepper standard trees

4.1.3.6 *Lignin content in the litterfall of back pepper standards*

Litter collections were sampled for lignin content during December and May and tabulated (Table 13). During December, which had generally higher rate of litter fall, *Acacia* litter (14.70%) showed the maximum concentration of lignin while *Artocarpus* had the least value (10.70%). Second sampling during the month of May did not showed appreciable variation in the lignin content for support trees, though a marginal increase is evident for all the species. However, *Acacia* and *Artocarpus* showed highest and lowest value respectively as before (Fig. 9).

Table 13. Changes in litter lignin content among the pepper support trees, %

Species	December	May
Casuarina equisetifolia	13.10	13.20
Macaranga peltata	13.50	14.10
Ailanthus triphysa	12.70	12.50
Artocarpus heterophyllus	10.70	11.60
Acacia auriculiformis	14.70	15.10
Grevillea robusta	12.60	12.90

4.1.4 Loppings of black pepper standards

At the final phase of study, pepper standards were lopped as part of stand management during September 2003. Branches and leaves were separated, weighed and analyzed for nutrients viz. N, P and K (Table 14). The biomass yield showed significant difference between species. The branch wood fresh weight was maximum for *Macaranga* (1288.50 kg ha^{-1}) followed by *Acacia* (993.85 kg ha^{-1}) and *Artocarpus* (882.76 kg ha^{-1}) which were on par. Lopping yield in terms of branch wood for *Casuarina* (516.14Kg ha^{-1}), *Ailanthus* (300.42 kg ha^{-1}) and *Grevillea* (234.45 kg ha^{-1}) were moderate. Also, the leaf biomass addition by the way of loppings was maximum for *Artocarpus* (2177.23 kg ha^{-1}) followed by *Acacia* (1684.70 kg ha^{-1}) and *Macaranga* (1557.48Kg ha^{-1}) which were on par. *Grevillea* (376.57 kg ha^{-1}) recorded the lowest foliage output.

Table 15 also gives the nutrient concentration in lopped samples. The nitrogen content in the loppings was maximum for *Ailanthus* (3.78%) and was least for *Macaranga* (2.32%). Phosphorus Content was maximum for the *Acacia* (0.27%) and least for *Macaranga* (0.15%). Potassium content was high in the leaves of *Artocarpus* (0.47%) and minimum for *Casuarina* (0.29%). Carbon content didn't change much between species though it appeared higher in *Ailanthus* (33.17%) and least in *Grevillea* (29.31%).The absolute amount of nitrogen return through loppings was maximum for *Acacia* (60.31 kg ha^{-1}) and least was for *Grevillea* (10.85 kg ha^{-1}). Phosphorus return was maximum for the *Artocarpus* (5.46 kg ha^{-1}) and least for *Grevillea* (0.73 kg ha^{-1}). Higher potassium content was observed in the leaves of *Artocarpus* (10.23 kg ha^{-1}) and minimum for *Grevillea* (1.43 kg ha^{-1}). Carbon return didn't change much between species. However it was found to be higher in *Artocarpus* (697.08 kg ha^{-1}) and least in *Grevillea* (110.40 kg ha^{-1}).

In general, the absolute amount of N, P and K added through loppings was maximum for Artocarpus and Acacia whereas Grevillea turned out to be the poorest supplier for all the nutrients.

Table 14. Lopped biomass yield for different pepper support trees and nutrient content in foliage loppings

Species	Branch wood (Fresh weight in kg ha^{-1})	Foliage (Fresh weight in kg ha^{-1})	N (%)	P (%)	K (%)	C (%)	C:N ratio
Casuarina equisetifolia	516.14^c	529.51^c	2.97	0.25	0.29	31.44	10.59
Macaranga peltata	1288.50^a	1557.48^b	2.32	0.15	0.45	32.21	13.88
Ailanthus triphysa	300.42^{cd}	654.10^c	3.78	0.25	0.38	33.17	8.78
Artocarpus Heterophyllus	882.76^b	2177.23^a	2.58	0.25	0.47	32.02	12.41
Acacia auriculiformis	993.85^b	1684.70^b	3.58	0.27	0.40	32.98	9.21
Grevillea robusta	234.45^d	376.57^c	2.88	0.19	0.38	29.31	10.18
F- value	*8.56**	*8.44**	-	-	-	-	
CD	*260.3*	*463.0*					

ns- Non significant   * - Significant at 5% level

Table 15. Nutrient turnover by way of lopped foliage among the pepper support trees in kg ha^{-1} yr^{-1}

Species	N	P	K	C
Casuarina equisetifolia	15.73	1.31	1.54	166.47
Macaranga peltata	36.13	2.32	7.09	501.66
Ailanthus triphysa	24.72	1.64	2.49	217.00
Artocarpus Heterophyllus	56.17	5.46	10.23	697.08
Acacia auriculiformis	60.31	4.55	6.82	555.65
Grevillea robusta	10.85	0.73	1.43	110.40

4.2 LITTER DECOMPOSITION

Fresh litter representing all the five pepper standards was subjected to decomposition study following litter bag technique for a period of one year.

4.2.1 Rate of biomass decomposition

Table 16 to18 show the monthly litter decomposition rate for the six pepper standards under study. All the species showed faster rates of decomposition during the early months followed by a slow, stable decomposition which lasted for nine months for all species except *Macaranga peltata* and *Ailanthus triphysa* which continued to decompose till 11th month. Significant differences among species in relation to rate of litter decomposition have been observed. The litter remaining in the bags after one month (September) showed considerable variation among the tree species (Table 16 and Fig. 10). The percentage mass remaining (Table 17) was maximum for *Macaranga peltata* (73.62%) followed by *Ailanthus triphysa* (65.99%), *Artocarpus heterophyllus* (44.69%), *Acacia auriculiformis* (20.35%), *Casuarina equisetifolia* (5.04%), and *Grevillea robusta* (3.04%). Heavy mass loss can be observed for both *Casuarina* and *Grevillea*. As compared to other species, *Macaranga* (62.43%) and *Ailanthus* (54.16%) showed moderate rate of decomposition during the second month (October). *Artocarpus* and *Grevillea* showed faster decay rates with only 18.79% and 14.55% of the biomass respectively, left after two months of study. The third month characterized bulk mass loss for most of the species under study which accounted more than 70 % of the initial mass except for the *Macaranga* where the mass loss was 58.20%. *Ailanthus* retained 22.89% of initial mass during this period and for other species, decay rate were on par.

The fourth month characterized the period where all the species except *Macaranga* and *Ailanthus* recorded more than 96% of decomposition of their initial mass. Similar trend in decomposition was observed during the subsequent months with marginal variation in the rates of the decomposition for all species except *Ailanthus* and *Macaranga*.
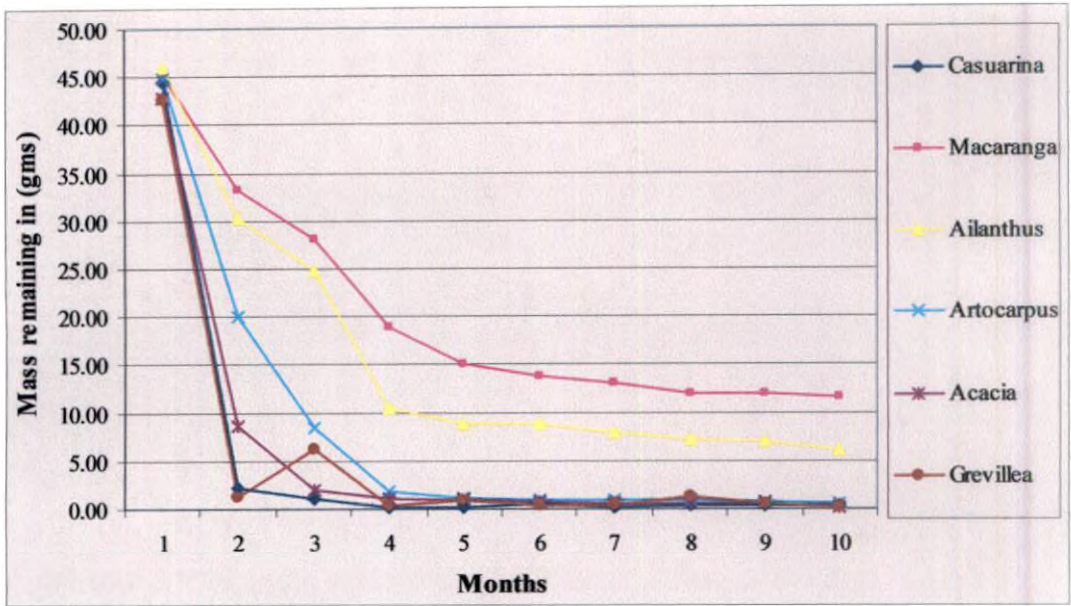
Fig. 10 Monthly variation in the rate of litter decomposition for selected black pepper
standards
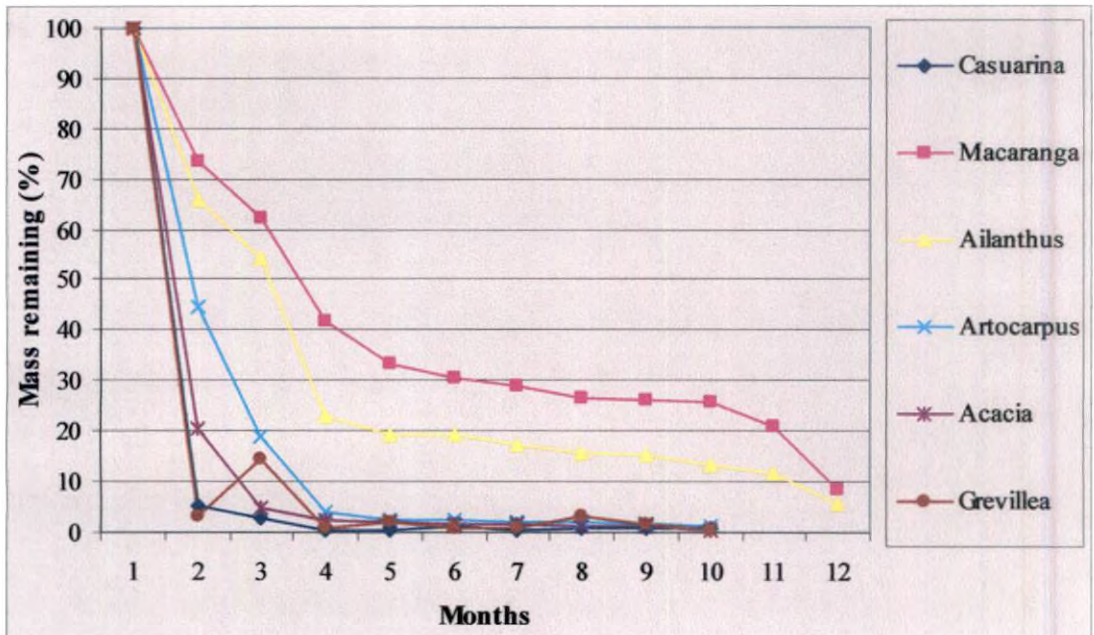
Fig.11 Monthly variation in the rate of litter decomposition for selected black pepper
standards expressed as the percentage of initial mass

Table 16. Litter remaining in the litter bags at monthly intervals for the various support trees (gms)

Species	Aug (0)	Sep (1)	Oct (2)	Nov (3)	Dec (4)	Jan (5)	Feb (6)	Mar (7)	Apr (8)	May (9)	Jun (10)	Jul (11)
Casuarina	44.42	2.24^d	1.17^C	0.25^C	0.20^C	0.53^C	0.23^C	0.34^C	0.34^C	0.29^C	-	-
Macaranga	45.13	33.22^a	28.16^a	18.86^a	15.07^a	13.73^a	13.06^a	11.99^a	11.86^a	11.56^a	9.37	3.86
Ailanthus	45.99	30.35^a	24.90^a	10.53^b	8.89^b	8.85^b	7.99^b	7.20^b	7.00^b	6.15^b	5.30	2.56
Artocarpus	44.87	20.05^b	8.43^b	1.87^C	1.10^C	0.99^C	0.87^C	0.85^C	0.76^C	0.54^C	-	-
Acacia	42.75	8.70^c	2.11^c	1.05^C	0.92^C	0.72^C	0.60^C	0.50^C	0.49^C	0.24^C	-	-
Grevillea	42.59	1.29^d	6.19^b	0.37^C	0.90^C	0.37^C	0.41^C	1.30^C	0.60^C	0.17^C	-	-
F- value	-	*52.36*	*26.81*	*39.88*	*36.00*	*28.76*	*18.42*	*10.18*	*10.94*	*11.18*	*ns*	*ns*
CD	-	*3.05*	*3.51*	*1.90*	*1.61*	*1.68*	*1.986*	*2.58*	*2.68*	*2.23*	-	-

*ns- Non significant   * - Significant at 5% level*

Table 17. Percentage mass remaining in the litterbags for various pepper support trees

Species	Aug (0)	Sep (1)	Oct (2)	Nov (3)	Dec (4)	Jan (5)	Feb (6)	Mar (7)	Apr (8)	May (9)	Jun (10)	Jul (11)
Casuarina	100	5.04	2.63	0.56	0.46	1.20	0.51	0.77	0.76	0.65	-	-
Macaranga	100	73.62	62.43	41.80	33.39	30.43	28.94	26.56	26.28	25.61	20.75	8.54
Ailanthus	100	65.99	54.16	22.89	19.33	19.24	17.37	15.67	15.22	13.37	11.51	5.58
Artocarpus	100	44.69	18.79	4.16	2.46	2.23	1.93	1.89	1.68	1.22	-	-
Acacia	100	20.35	4.93	2.45	2.14	1.68	1.41	1.16	1.16	0.57	-	-
Grevillea	100	3.04	14.55	0.86	2.12	0.87	0.96	3.05	1.41	0.39	-	-

Table 18. Percentage mass loss from decomposing tree litter at monthly intervals

Species	Aug (0)	Sep (1)	Oct (2)	Nov (3)	Dec (4)	Jan (5)	Feb (6)	Mar (7)	Apr (8)	May (9)	Jun (10)	Jul (11)
Casuarina	0	94.96	97.37	99.44	99.54	98.80	99.49	99.23	99.24	99.35	-	-
Macaranga	0	26.38	37.57	58.21	66.61	69.57	71.06	73.45	73.72	74.39	79.25	91.46
Ailanthus	0	34.01	45.84	77.11	80.67	80.76	82.63	84.33	84.78	86.63	88.49	94.42
Artocarpus	0	55.31	81.21	95.84	97.54	97.77	98.07	98.11	98.32	98.78	-	-
Acacia	0	79.65	95.07	97.55	97.86	98.32	98.59	98.84	98.84	99.43	-	-
Grevillea	0	96.96	85.46	99.14	97.88	99.13	99.04	96.95	98.59	99.61	-	-

At the end of the 9th month, all the species except *Ailanthus* and *Macaranga* decomposed completely while former species continued their slower litter decay rate till the end of 11th month. Towards the final phase, the detritus retained by the different species in the descending order of decomposition are Grevillea> Acacia> Casuarina>Artocarpus> Ailanthus> Macaranga

4.2.2 Decay prediction model

Table 19 shows the litter decay coefficient for the various support trees under study. Higher k-values were recorded for *Casuarina* (-0.73) and *Grevillea* (-0.67). Other species had the value viz. *Acacia* (-0.65), *Artocarpus* (-0.60), *Ailanthus* (-0.25), *Macaranga* (-0.19). Regression equations were fitted to predict mass loss pattern over time for the litter of different species, by relating the proportion of the mass remaining in the litter bags with time elapsed in months and the results are graphically represented in Figure (12-17). The exponential equation showed a good fit for all the species with r^2 values ranging from 0.84-0.96. Table 19 also gives the half life values of decomposing litter for various species.

The relative half life value was maximum for *Macaranga* (3.63 months) and least for *Casuarina* (0.95 months). Half life values for the rest of the species were; *Ailanthus* (2.78 months), *Artocarpus* (1.16 months), *Acacia* (1.06 months), and *Grevillea* (1.03 months).

Table 19. Decay rate coefficient and half life period of litters of selected black pepper standards.

Species	K-value	r^2	$t_{(0.5)}$
Casuarina	0.7262	0.861	0.95
Macaranga	0.1910	0.963	3.63
Ailanthus	0.2494	0.952	2.78
Artocarpus	0.5960	0.954	1.16
Acacia	0.6518	0.936	1.06
Grevillea	0.6734	0.843	1.03
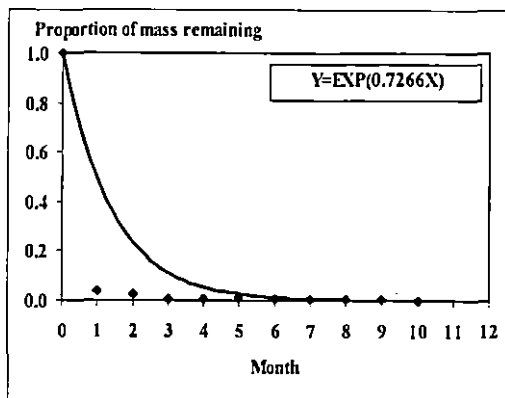
Fig. 12 *Casuarina equisetifolia*
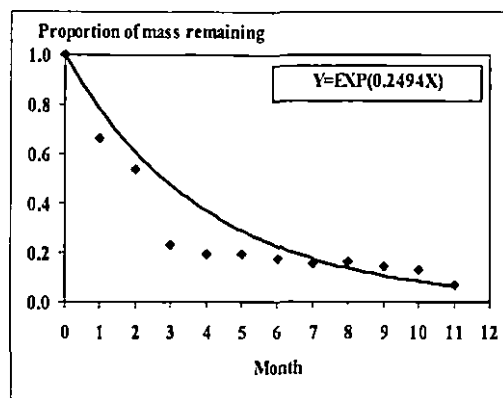
Fig. 14 *Ailanthus triphysa*
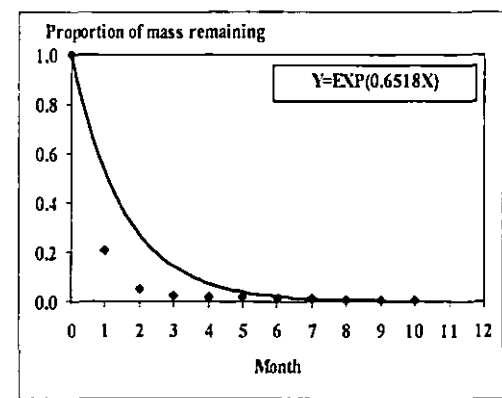
Fig. 16 *Acacia auriculiformis*
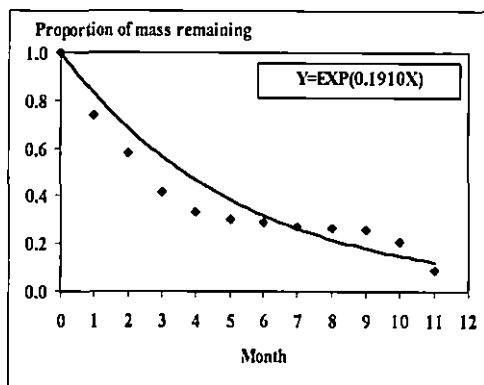
Fig. 13 *Macaranga peltata*
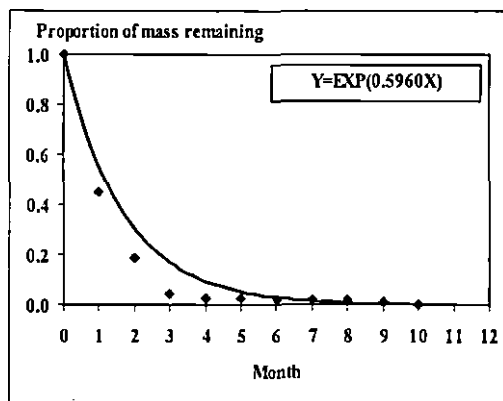
Fig. 15 *Artocarpus heterophyllus*
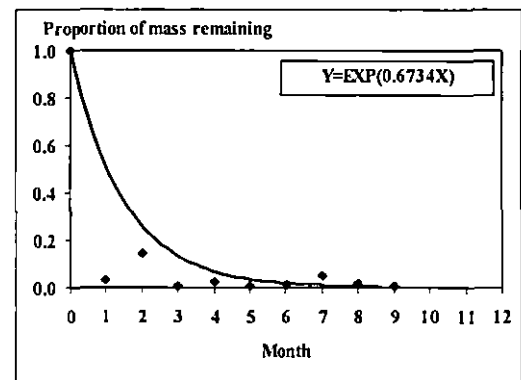
Fig. 17 *Grevillea robusta*

Fig. 12-17 Litter mass loss prediction models for selected black pepper support trees

4.2.3 Nutrient release pattern from decomposing litter

Decomposing litter corresponding to different support tees were subjected to nutrient analysis to characterize the nutrient release pattern for the major nutrients viz. N, P, K and also for C content. Considerable variation in nutrient mineralization has been observed for different support trees.

4.2.3.1 *Nitrogen*

The nitrogen content in the decomposing litter samples showed significant variation between species at the initial five months during the one year of study. Monthly variation in N content was not prominent for trees except the decomposing litter of *Acacia* and *Grevillea* (Table 20). It can be observed that the fresh litter of the *Ailanthus* had the maximum initial nitrogen content (2.74%) and *Grevillea* had the least value (1.99%). Nitrogen concentration in the decaying litter showed an increasing trend during the early phase of the decomposition (1-6 months) for all the tree species (Fig. 18).

However, it didn't follow a predictable pattern thereafter. *Casuarina* represented a marginal increase in the nitrogen content till the fifth month of decomposition. As compared to the initial samples, the nitrogen content at the final stages of sampling showed higher values for *Casuarina* (3.19%). *Macaranga peltata* also followed a similar trend in the nitrogen content with the steady increase in concentration up to third month. In *Ailanthus triphysa*, nitrogen content in the decaying litter corresponding to early three months registered higher values as compared to the initial fresh litter (2.74-3.35%). *Acacia* in general, followed an increase in N content in the decomposing litter through out the period of observation except a dip in the 7th month.

Grevillea robusta represented lowest N concentration in the fresh litter. However, nitrogen concentration steadily increased during the course of litter decomposition. The nitrogen content for the final month for species is as follows; Acacia (3.56%), Artocarpus (3.20%), Casuarina (3.19%), Macaranga and Ailanthus (2.88%) and the least content was held by Grevillea (2.65%).

Table 20. Nitrogen concentration at monthly intervals in the decomposing litters of black pepper standards, %

Months	Casuarina	Macaranga	Ailanthus	Artocarpus	Acacia	Grevillea	F-value	CD
Aug(0)	2.32	2.27	2.74	2.58	2.46	1.99		
Sep(1)	2.59_b	2.80_{bc}	3.02_c	2.64_b	$2.88_{bc}{}^{A}$	$2.17_a{}^{A}$	7.86**	0.33
Oct(2)	2.89_b	2.99_b	3.23_b	2.96_b	$3.14_b{}^{AB}$	$2.30_a{}^{AB}$	5.07**	0.45
Nov(3)	3.11_b	2.68_a	3.35_b	3.05_b	$3.30_b{}^{BC}$	$2.41_a{}^{ABCD}$	9.50**	0.37
Dec(4)	3.17_{bc}	2.94_{ab}	3.10_{bc}	3.17_{bc}	$3.43_c{}^{BC}$	2.54_a	4.52*	0.43
Jan(5)	3.20	3.18	2.93	3.35	$3.60{}^{C}$	$2.76{}^{CDE}$	2.24ns	0.61
Feb(6)	3.00	3.02	3.02	3.10	$3.54{}^{C}$	$2.92{}^{E}$	0.68ns	0.83
Mar(7)	3.00	3.07	2.89	3.20	$3.32{}^{BC}$	$2.80{}^{DE}$	0.47ns	0.87
Apr(8)	3.30_{bc}	2.97_b	3.16_{bc}	3.18_{bc}	$3.63_c{}^{C}$	$2.31_a{}^{ABC}$	4.35*	0.65
May(9)	3.19	2.88	2.88	3.20	$3.56{}^{C}$	$2.65{}^{BCDE}$	2.04ns	0.69
Jun(10)	*-	3.02	1.95	-	-	-		
Jul(11)	-	3.15	2.43	-	-	-		
F-value	0.74ns	0.68ns	0.41ns	1.04ns	3.63*	2.88*		
CD	0.74	0.53	0.75	0.58	0.38	0.46		

ns – Non significant; * - Significant at 5% level; ** - Significant at 1% level
Within a row, means having same letter as subscript are homogeneous
Within a column, means having same letter as superscript are homogeneous
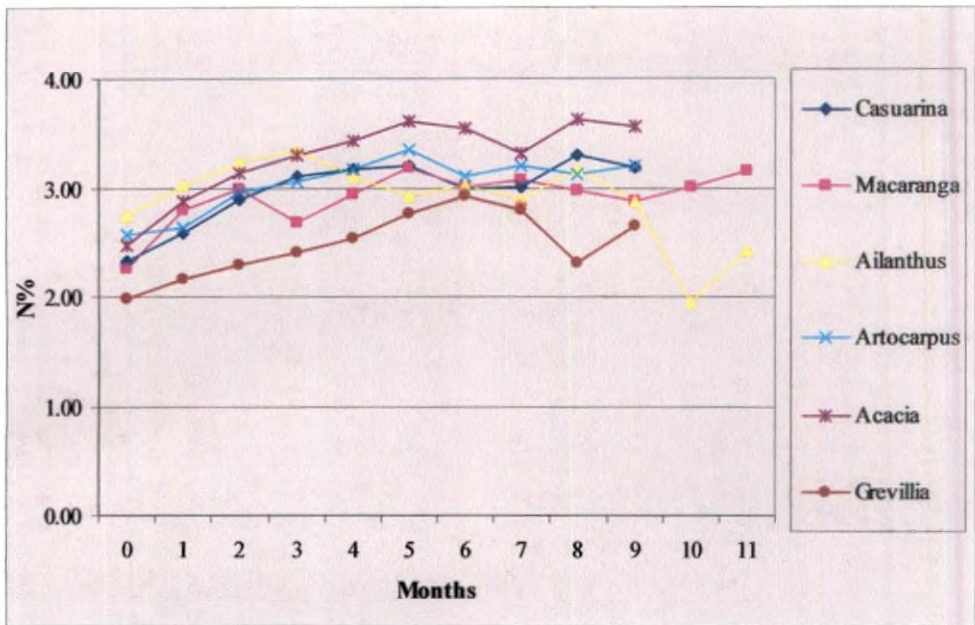
Fig. 18 Changes in the nitrogen concentration of the decomposing litter of
black pepper standards
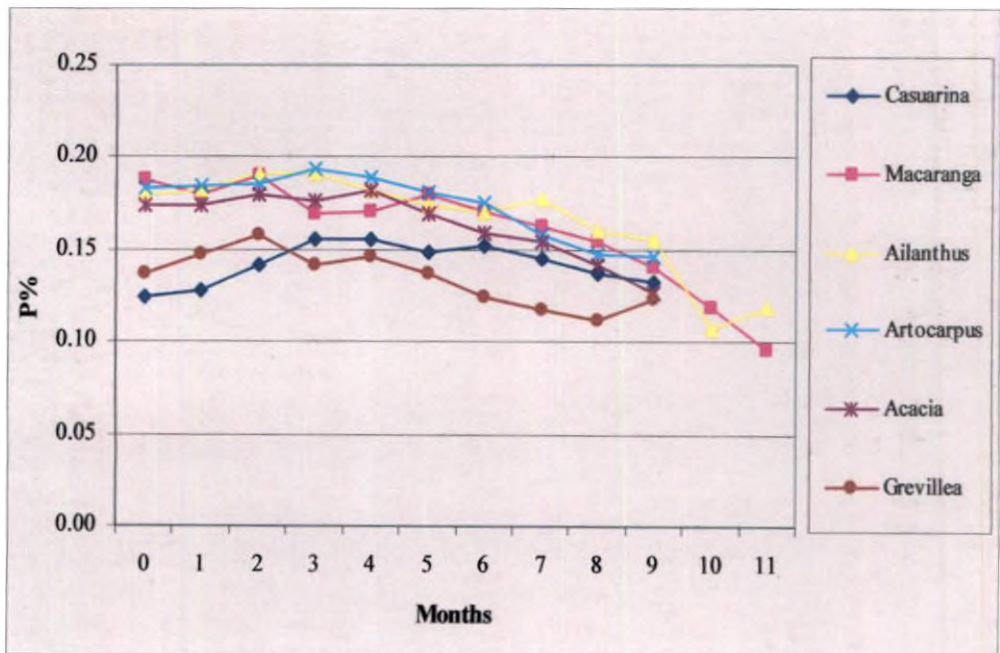
Fig. 19 Changes in the phosphorus concentration in the decomposing litter of
black pepper standards

4.2.3.2 *Phosphorus*

Table 21 and Figure 19 show the variation in the phosphorous content of the decomposing litter of various pepper standards under study. The P content in the fresh litter showed close similarity for all the tree species under study. The initial phosphorus content of the leaf samples was maximum for the *Macaranga* (0.19%) and the least was reported for *Casuarina* (0.12%). The P content in fresh litter corresponding to the *Macaranga, Ailanthus Artocarpus* and *Acacia* showed little variation. Marginal seasonal variation in the P content of the decomposing litter has been observed for various species.

Species such as *Macaranga, Ailanthus* and *Acacia* exhibited marginal decline in P concentration as litter decomposition advanced over months. The phosphorus content remaining in the litter samples at the end of the study was maximum for *Ailanthus* (0.15%) and the minimum was for *Grevillea* (0.12%).

4.2.3.3 *Potassium*

The potassium content of fresh litter was maximum for litters of *Artocarpus* (0.48%) and it was least for *Casuarina* (0.21%). As compared to N and P, characteristic drop in the K content was observed for all the species except *Casuarina* after one month of litter decomposition (Table 22 and Fig. 20). This was more prominent in the case of *Macaranga* and *Artocarpus*. The K content in the decomposing litter showed variation between species except on the 2nd and 5th month of study.
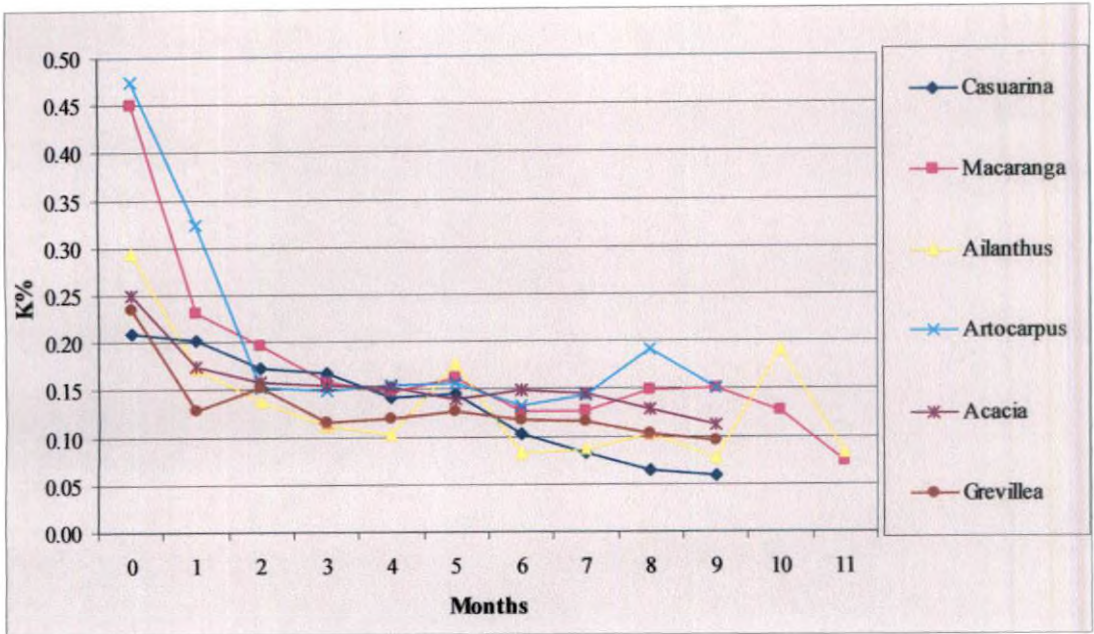
Fig. 20 Changes in the potassium concentration of the decomposing litter of black
pepper standards
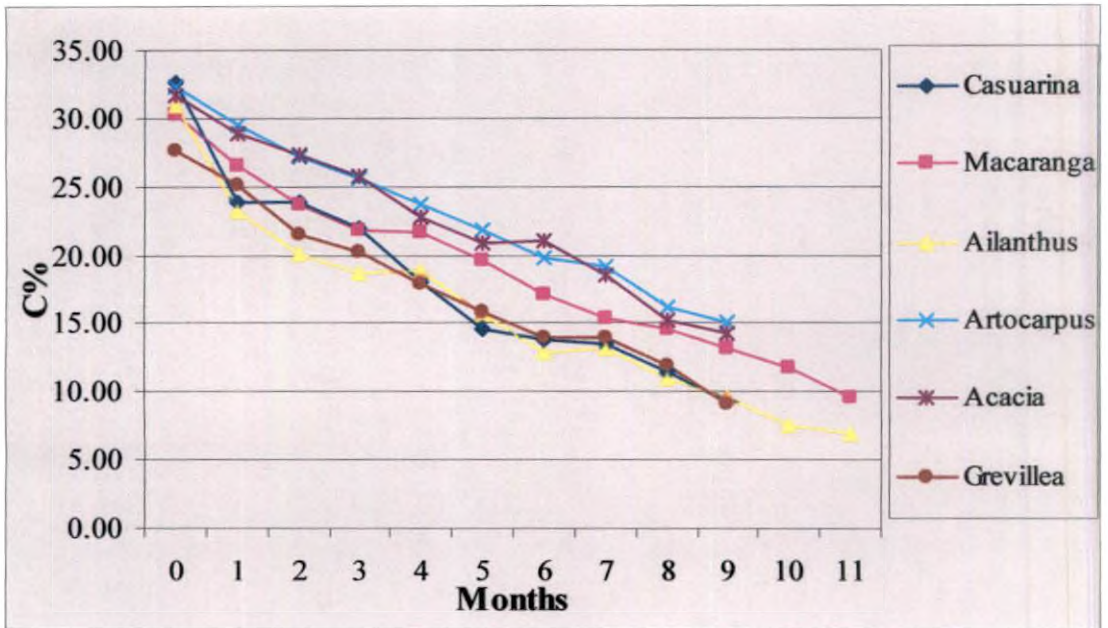
Fig. 21 Changes in the carbon concentration in the decomposing litter of black pepper
standards

Table 21. Phosphorus concentration at monthly intervals in the decomposing litters of black pepper standards, %

Months	Casuarina	Macaranga	Ailanthus	Artocarpus	Acacia	Grevillea	F-value	CD
Aug(0)	0.12	0.19	0.18	0.18	0.17	0.14		
Sep(1)	0.13_a^A	0.18_c^{CD}	0.18_c	0.18_c^{BC}	0.17_c^C	0.15_b^E	29.65**	0.02
Oct(2)	0.14_a^{ABCD}	0.19_b^D	0.19_b	0.19_b^{BC}	0.18_b^C	0.16_a^E	13.53**	0.02
Nov(3)	0.16_{ab}^D	0.17_{bc}^{BC}	0.19_d	0.19_d^C	0.18_{cd}^C	0.14_a^{CDE}	9.46**	0.02
Dec(4)	0.15_{ab}^D	0.17_{bc}^{BC}	0.18_c	0.19_c^C	0.18_c^C	0.15_a^{DE}	5.53**	0.02
Jan(5)	0.15_{ab}^{BCD}	0.18_c^{CD}	0.17_c	0.18_c^{BC}	0.17_{bc}^{BC}	0.14_a^{BCDE}	6.82**	0.02
Feb(6)	0.15_b^{CD}	0.17_{bc}^{BCD}	0.17_{bc}	0.18_c^B	0.16_{bc}^{BC}	0.12_a^{ABCD}	8.95**	0.02
Mar(7)	0.15_{ab}^{ABCD}	0.16_b^{BC}	0.18_b	0.16_b^A	0.15_b^{ABC}	0.12_a^{AB}	3.57*	0.03
Apr(8)	0.16_b^{ABC}	0.15_{bc}^{AB}	0.16_c	0.15_{bc}^A	0.14_b^{AB}	0.11_a^A	8.97**	0.02
May(9)	0.13^{AB}	0.14^A	0.16	0.15^A	0.13^A	0.12^{ABC}	1.39ns	0.03
Jun(10)	-	0.12	0.11	-	-	-		
Jul(11)	-	0.10	0.12	-	-	-		
F-value	2.80*	5.34**	2.09ns	14.40**	3.63*	4.73**		
CD	0.02	0.02	0.03	0.01	0.03	0.02		

ns – Non significant; * - Significant at 5% level; ** - Significant at 1% level
Within a row, means having same letter as subscript are homogeneous
Within a column, means having same letter as superscript are homogeneous

Table 22. Changes in potassium concentration in the decomposing litters of black pepper standards, %

Months	*Casuarina*	*Macaranga*	*Ailanthus*	*Artocarpus*	*Acacia*	*Grevillea*	*F-value*	*CD*
Aug(0)	0.21	0.45	0.30	0.48	0.25	0.24		
Sep(1)	0.20_c ^{E}	0.23_d ^{C}	0.17_b	0.32_e ^{C}	0.18_b ^{D}	0.13_a ^{BC}	*63.96***	*0.03*
Oct(2)	0.17 ^{D}	0.20 ^{BC}	0.14	0.15 ^{AB}	0.16 ^{CD}	0.15 ^{C}	*2.50ns*	*0.04*
Nov(3)	0.17_b ^{CD}	0.16_b ^{AB}	0.11_a	0.15_{ab} ^{AB}	0.16_b	0.12_a ^{AB}	*3.15**	*0.04*
Dec(4)	0.14_{bc} ^{C}	0.15_{bc} ^{AB}	0.10_a	0.16_c ^{AB}	0.15_c	0.12_{ab} ^{AB}	*4.18**	*0.03*
Jan(5)	0.15 ^{C}	0.16 ^{AB}	0.18	0.16 ^{AB}	0.14 ^{BC}	0.13 ^{BC}	*0.32ns*	*0.10*
Feb(6)	0.10_{ab} ^{B}	0.13_{bcd} ^{A}	0.08_a	0.13_{cd} ^{A}	0.15_d	0.12_{bc} ^{AB}	*5.68***	*0.03*
Mar(7)	0.08_a ^{AB}	0.13_b ^{A}	0.09_a	0.14_b ^{A}	0.15_b	0.12_{ab} ^{AB}	*4.47**	*0.04*
Apr(8)	0.07_a ^{A}	0.15_b ^{AB}	0.10_{ab}	0.19_c ^{B}	0.13_b	0.10_{ab} ^{AB}	*6.63***	*0.05*
May(9)	0.06_a ^{A}	0.15_b ^{AB}	0.08_a	0.15_b ^{AB}	0.11_{ab} ^{A}	0.10_{ab} ^{A}	*4.02**	*0.06*
Jun(10)	-	0.13	0.19	-	-	-		
Jul(11)	-	0.07	0.08	-	-	-		
F-value	*35.49***	*3.65**	*1.80ns*	*13.28***	*4.19***	*2.86**		
CD	*0.03*	*0.05*	*0.08*	*0.05*	*0.03*	*0.03*		

ns – Non significant; * - Significant at 5% level; ** - Significant at 1% level
Within a row, means having same letter as subscript are homogeneous
*Within a column, means having same letter as superscript are homogeneous*

Artocarpus and *Macaranga* continued steady decline in the K- content as the decomposition progressed. The rest of the species also followed a general decline in K content with minor fluctuations in between. At the end of the study, the *Artocarpus* and *Macaranga* had highest K content (0.15%) and *Casuarina* reported the least K content (0.06%). In general, the K content showed a steady decline for all the species similar to litter mass loss pattern during the course of litter decomposition (Fig.-20).

4.2.3.4 Carbon

The data regarding the C content of the decomposing litter of the pepper standards over one year showed that significant variation between species for all the months except the last but final month (Table 23).

Seasonal trend indicated that the C content varied significantly between months (Fig. 21) during the period of observation. The initial Carbon content was maximum for *Casuarina* (32.60%) and *Artocarpus* (32.40%) and was least for *Grevillea* (27.58%). Carbon content for all the species registered a steady decrease which is in tune with the decline in biomass over time. After nine months of decomposition the C content in the litter of various species is as follows *Casuarina equisetifolia* (9.19%), *Macaranga peltata* (13.18%), *Ailanthus triphysa* (9.58%), *Artocarpus heterophyllus* (15.04%), *Acacia auriculiformis* (14.33%) and *Grevillea robusta* (9.13%).

4.2.3.5 Lignin%

Lignin content of the decomposing litter for different support trees are shown in Table 24. Lignin content in the fresh litter samples was maximum for *Casuarina* (17.0%), while the least lignin content was reported for *Artocarpus* (10.5%).

Steady increase in lignin content was observed in the decomposing litter during the subsequent stages of sampling (Fig. 22). For instance, *Macaranga peltata* registered increase in the lignin content in the detritus sampled after 9 months of soil incorporation (15.6-24.1%). Similarly, *Ailanthus triphysa* had marked hike in lignin after one month of litter decomposition (14.5-19.7%), culminating at 23.9% after 9 months of decomposition

Table 23. Carbon content in the decomposing litters of black pepper standards, %

Months	Casuarina	Macaranga	Ailanthus	Artocarpus	Acacia	Grevillea	F-value	CD
Aug(0)	32.60	30.28	30.86	32.40	31.63	27.58		
Sep(1)	23.85_a^D	26.55_c^G	23.27_a^E	29.51_d^F	28.93_d^E	25.14_b^G	39.20**	1.28
Oct(2)	23.79_b^D	23.66_b^F	20.06_a^D	27.20_c^{EF}	27.32_c^{DE}	21.54_{ab}^F	12.29**	2.58
Nov(3)	21.92_{ab}^D	21.86_a^{EF}	18.65_a^D	25.65_{bc}^{DE}	25.72_c	20.19_a^{EF}	5.43**	3.79
Dec(4)	18.00_a^C	21.60_b^E	18.77_a^D	23.72_b^{CD}	22.70_b	17.94_a^{DE}	9.005	2.60
Jan(5)	14.53_a^B	19.61_b^D	15.75_a^C	21.80_b^{BC}	20.90_b^{BC}	15.82_a^{CD}	6.57**	3.69
Feb(6)	13.89_a^B	17.17_b^C	12.79_a^B	19.80_{bc}^B	20.96_c^{BC}	13.95_a^{BC}	11.45**	3.11
Mar(7)	13.57_a^B	15.37_{ab}^{BC}	13.12_a^B	19.22_c^B	18.58_{bc}	13.95_a^{BC}	4.93*	3.67
Apr(8)	11.38^{AB}	14.59^{AB}	11.06^{AB}	16.14^A	15.24^A	11.96^B	2.28ns	4.46
May(9)	9.19_a^A	13.18_{bc}^A	9.58_{ab}^A	15.04_c^A	14.34_c^A	9.13_a^A	4.60*	3.95
Jun(10)	-	11.70	7.46	-	-	-		
Jul(11)	-	9.64	6.94	-	-	-		
F-value	21.75**	54.97**	31.98**	24.34**	8.48**	37.225**		
CD	3.47	1.81	2.41	2.97	5.20	2.46		

ns – Non significant; * - Significant at 5% level; ** - Significant at 1% level
Within a row, means having same letter as subscript are homogeneous
Within a column, means having same letter as superscript are homogeneous

process. At the final sampling during the ninth month, *Casuarina* registered highest content of lignin (29.2%) while *Artocarpus* showed the lowest value of 17.3%.

Table 24. Lignin content in the decomposing litter for different support trees, %

Species	August (0)*	September(1)	January (5)	May (9)
Casuarina	17.0	20.7	24.1	29.2
Macaranga	15.6	18.3	21.8	24.1
Ailanthus	14.5	19.7	21.3	23.9
Artocarpus	10.5	13.9	15.7	17.3
Acacia	11.0	12.8	16.7	19.4
Grevillea	15.4	16.2	18.3	20.2

* *Figure in brackets indicate month of sampling after litter incorporation in soil during August*
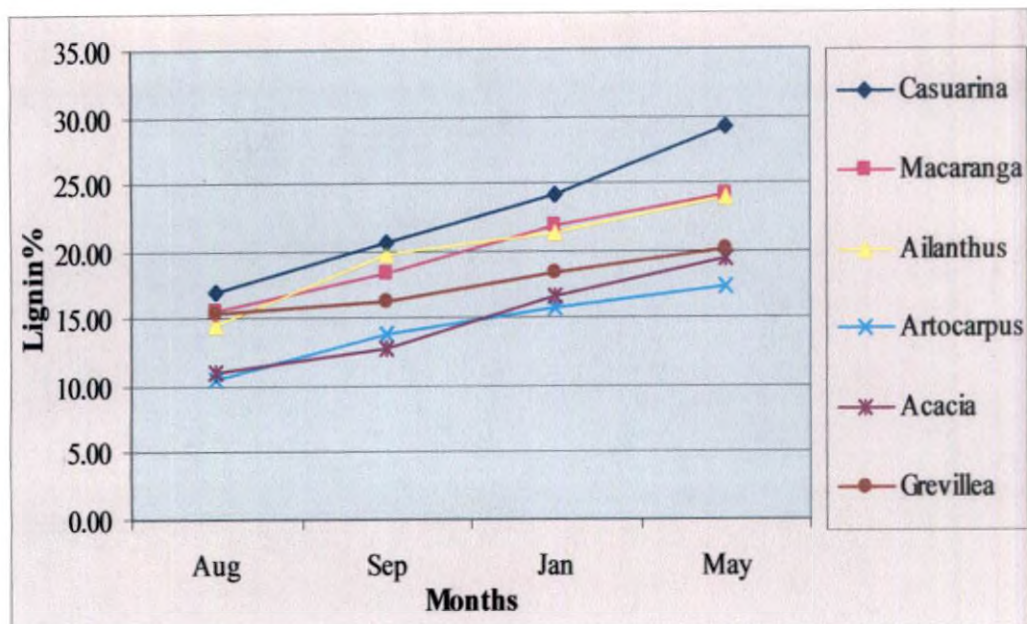
Fig. 22. Changes in the lignin concentration in the decomposing litter of black pepper standards
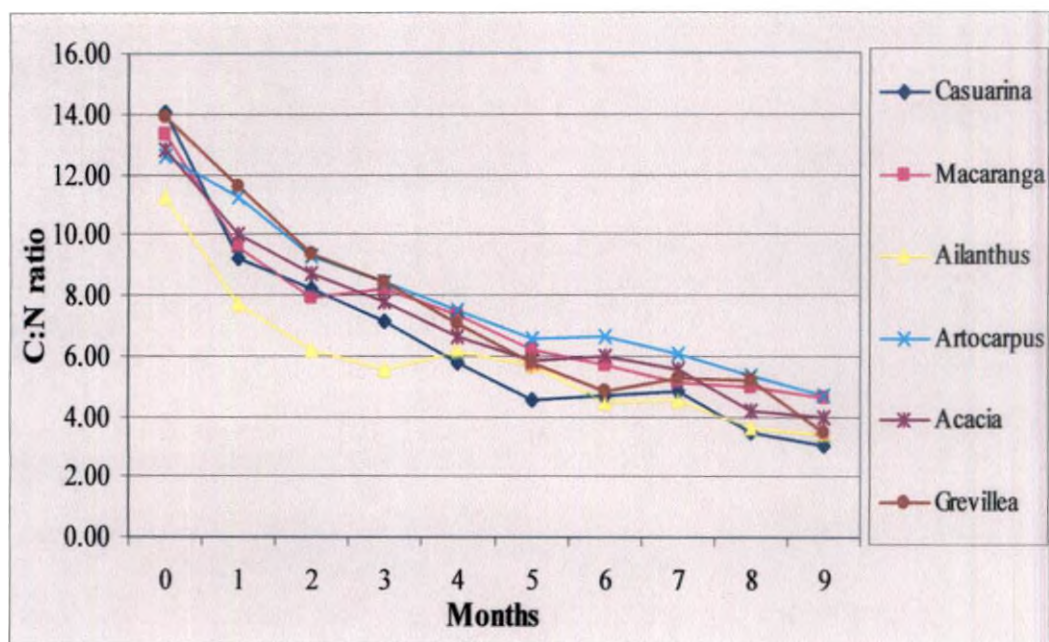
Fig. 23 Changes in the C: N ratio in the decomposing litter of black pepper standards

4.2.3.6 C: N ratio

C: N ratio of fresh litter and that of the decomposing litter samples for the different support trees species are given in Table 25. C: N ratio corresponding to fresh, undecomposed litter was found to be maximum for *Casuarina* (14.0) while it was minimum for *Ailanthus* (11.2). Significant variation in the C: N ratio in the decaying litter has been observed for all the species during the early three months of observation (Sep-Nov). For the rest of the period the ratio was found to be insignificant between species.

Table 25. C: N Ratio in the decomposing litter of black pepper standard trees

Species	Aug (0)	Sep (1)	Oct (2)	Nov (3)	Dec (4)	Jan (5)	Feb (6)	Mar (7)	Apr (8)	May (9)
Casuarina	14.01	9.24[c]	8.25[c]	7.12[b]	5.73	4.54	4.67	4.80	3.48	3.01
Macaranga	13.35	9.55[bc]	7.96[c]	8.21[a]	7.38	6.22	5.72	5.09	4.94	4.61
Ailanthus	11.25	7.69[d]	6.21[d]	5.56[c]	6.11	5.68	4.46	4.57	3.57	3.38
Artocarpus	12.58	11.23[a]	9.28[a]	8.45[a]	7.52	6.53	6.64	6.06	5.30	4.70
Acacia	12.84	10.05[b]	8.75[b]	7.81[ab]	6.64	5.83	5.99	5.56	4.19	3.98
Grevillea	13.87	11.62[a]	9.37[a]	8.40[a]	7.07	5.73	4.80	5.25	5.20	3.48
F-value	-	14.07*	13.59*	4.41*	ns	ns	ns	ns	ns	ns
C D	-	0.60	0.50	0.83	-	-	-	-	-	-

*ns- Non significant   * - Significant at 5% level*

The data revealed a steady decline in C: N ratio over months for all the species (Fig. 23). At the end of study, the C: N ratio for various tree species were as follows; *Casuarina* (3.0), *Macaranga* (4.6), *Ailanthus* (3.4), *Artocarpus* (4.7), *Acacia* (4.0) and *Grevillea* (3.5).

4.2.4 Nutrient return in absolute terms

Table 26-29 represent absolute proportion of the nutrients in the decomposing litter represented as the percentage of their absolute amounts present in the fresh litter.

4.2.4.1 *Nitrogen*

The nitrogen content for most of the species showed a rapid reduction in absolute amounts during the initial three months of decomposition (Table 26 and Fig. 24)

Table 26. Absolute N content in decomposing litter of black pepper standards expressed as percentage of N present in the fresh litter.

Months	Casuarina	Macaranga	Ailanthus	Artocarpus	Acacia	Grevillea
Aug(0)	100.00	100.00	100.00	100.00	100.00	100.00
Sep(1)	5.61	90.89	72.73	45.82	23.81	3.31
Oct(2)	3.28	82.22	63.73	21.59	6.27	16.80
Nov(3)	0.75	49.37	27.95	4.93	3.29	1.04
Dec(4)	0.63	43.29	21.83	3.03	2.98	2.70
Jan(5)	1.65	42.71	20.55	2.90	2.45	1.21
Feb(6)	0.66	38.47	19.15	2.33	2.02	1.40
Mar(7)	1.00	35.96	16.52	2.34	1.57	4.30
Apr(8)	1.08	34.40	17.55	2.04	1.70	1.64
May(9)	0.90	32.57	14.01	1.52	0.82	0.53
Jun(10)	-	27.59	9.30	-	-	-
Jul(11)	-	11.88	5.97	-	-	-

During this period, all the species except *Macaranga* and *Ailanthus*, released more than 90% of the original quantity of the nitrogen. Comparatively, nitrogen mineralization was modest for *Macaranga, Ailanthus*, and *Artocarpus*. After one-month, quantity of the N mineralized was to the tune of 9.11%, 27.27%, and 54.18% of their initial content for *Macaranga, Ailanthus* and *Artocarpus* respectively. *Macaranga* and *Ailanthus* continued to impose control over nitrogen release during the remaining part of the study. However, their absolute nitrogen contents were only 11.88% and 5.97% of the

initial contents when sampled during the 11th month. Heavy N mineralization in tune with litter mass loss pattern has been observed for all the remaining support trees.

Various regression models were suggested to predict the N-mineralization through litter routes in these species. Second order hyperbolic function was found to be good fit for most of the species like *Casuarina, Artocarpus* and *Acacia* with high r^2 value (0.98-0.99). Among the other models attempted to characterize the nitrogen mineralization, modified Hoerl function was found to be suitable for *Macaranga* (r^2=0.96), parabolic function for *Ailanthus* (r^2=0.95) and line and reciprocal model for *Grevillea* (r^2=0.98).

4.2.4.2 *Phosphorus*

Though, the P-concentration showed little variation over time, the absolute amount followed a pattern similar to mass loss for all the species (Table 27 and Fig. 25). Initial month of litter decay characterized rapid P mineralization for all the species. *Macaranga* and *Ailanthus* exhibited better control over P release from decomposing litter. For the rest of the species, more than 90% was released in three months. At the end of one year, for all the species more than 95% of initial phosphorous was released. Regression models depicting P release over time was tried for each species (Appendix-2). Second order hyperbolic function was found to be fitting for species like *Casuarina* (r^2=0.99), *Artocarpus* (r^2=0.99) and *Acacia* (r^2=0.99). Reciprocal straight-line model was best fitting for *Macaranga* (r^2=0.98), Cauchy model for *Ailanthus* (r^2=0.97), and line and reciprocal model for *Grevillea* (r^2=0.98).

Table 27. Absolute P content in decomposing litter of black pepper standards expressed as percentage of P present in the fresh litter.

Months	Casuarina	Macaranga	Ailanthus	Artocarpus	Acacia	Grevillea
Aug(0)	100.00	100.00	100.00	100.00	100.00	100.00
Sep(1)	5.20	70.49	66.72	44.94	20.35	3.26
Oct(2)	3.01	63.09	57.47	19.00	5.10	16.65
Nov(3)	0.70	37.57	24.29	4.38	2.48	0.88
Dec(4)	0.58	30.37	19.55	2.54	2.24	2.24
Jan(5)	1.44	29.13	18.60	2.20	1.63	0.86
Feb(6)	0.63	26.32	16.50	1.85	1.29	0.86
Mar(7)	0.90	22.88	15.41	1.63	1.03	2.59
Apr(8)	0.84	21.53	13.53	1.36	0.94	1.15
May(9)	0.70	19.07	11.51	0.97	0.42	0.35
Jun(10)	-	13.14	7.77	-	-	-
Jul(11)	-	4.36	4.46	-	-	-
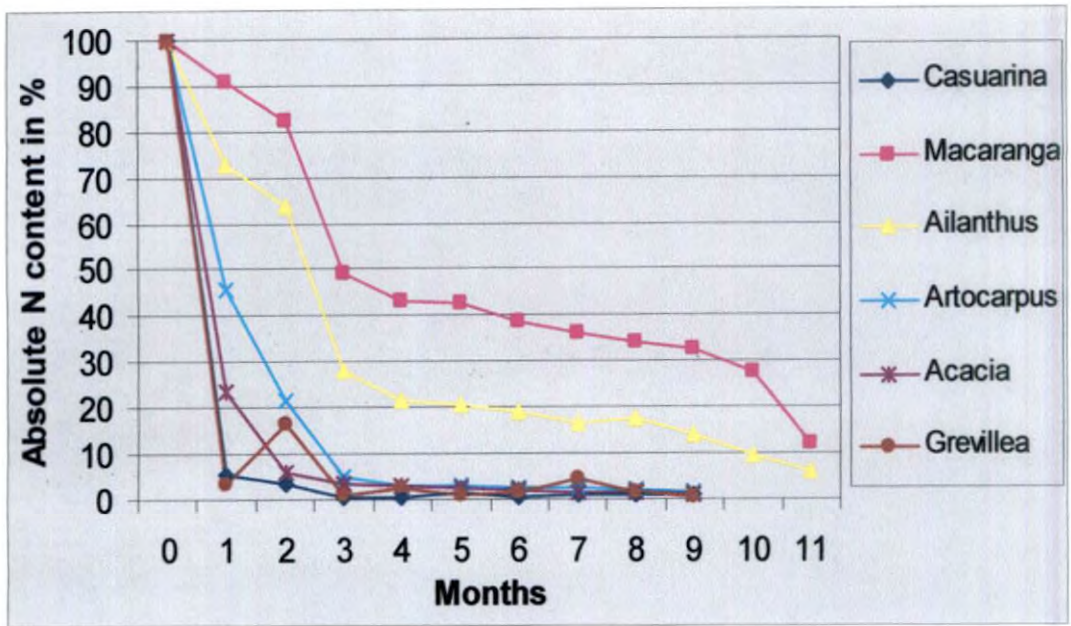
Fig. 24 Monthly changes in absolute amounts of nitrogen of decomposing litter of black pepper standards
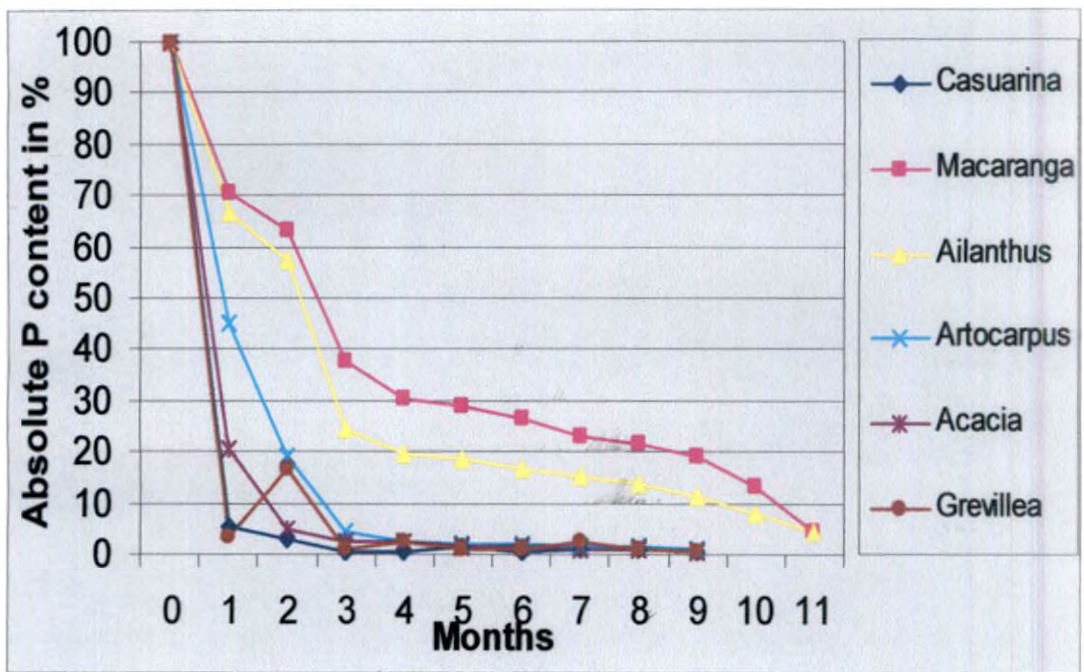
Fig. 25 Monthly changes in absolute amounts of phosphorus in the of decomposing litter of black pepper standards

4.2.4.3 *Potassium*

The potassium showed the fastest rate of release in terms of absolute quantity among all the nutrients under study. For all the species except *Macaranga* and *Ailanthus*, the absolute potassium content declined as low as less than 10% during the first two months of decomposition. At the end of the 4th month all the species released more than 90% of its initial potassium content (Table 28 and Fig. 26).

Table 28. Absolute K content in decomposing litter of black pepper standards expressed as percentage of K present in the fresh litter.

Months	Casuarina	Macaranga	Ailanthus	Artocarpus	Acacia	Grevillea
Aug(0)	100.00	100.00	100.00	100.00	100.00	100.00
Sep(1)	4.85	37.95	38.70	30.39	14.24	1.66
Oct(2)	2.17	27.33	25.15	6.01	3.11	9.47
Nov(3)	0.44	14.68	8.77	1.30	1.52	0.42
Dec(4)	0.31	10.91	6.75	0.80	1.31	1.08
Jan(5)	0.83	10.95	11.55	0.74	0.94	0.47
Feb(6)	0.25	8.17	4.89	0.54	0.83	0.48
Mar(7)	0.31	7.50	4.62	0.57	0.68	1.49
Apr(8)	0.24	8.64	5.32	0.68	0.59	0.62
May(9)	0.18	8.54	3.49	0.39	0.26	0.16
Jun(10)	-	5.86	8.51	-	-	-
Jul(11)	-	1.39	1.90	-	-	-
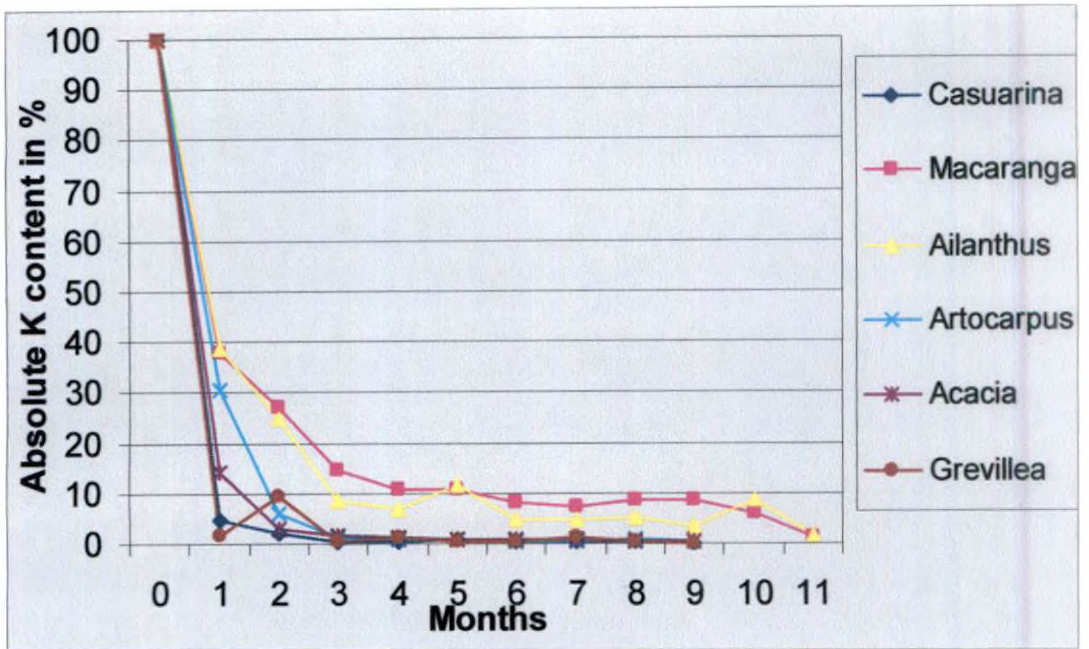
Fig. 26 Variation in the absolute amounts of Potassium in the decomposing litter of black pepper standards
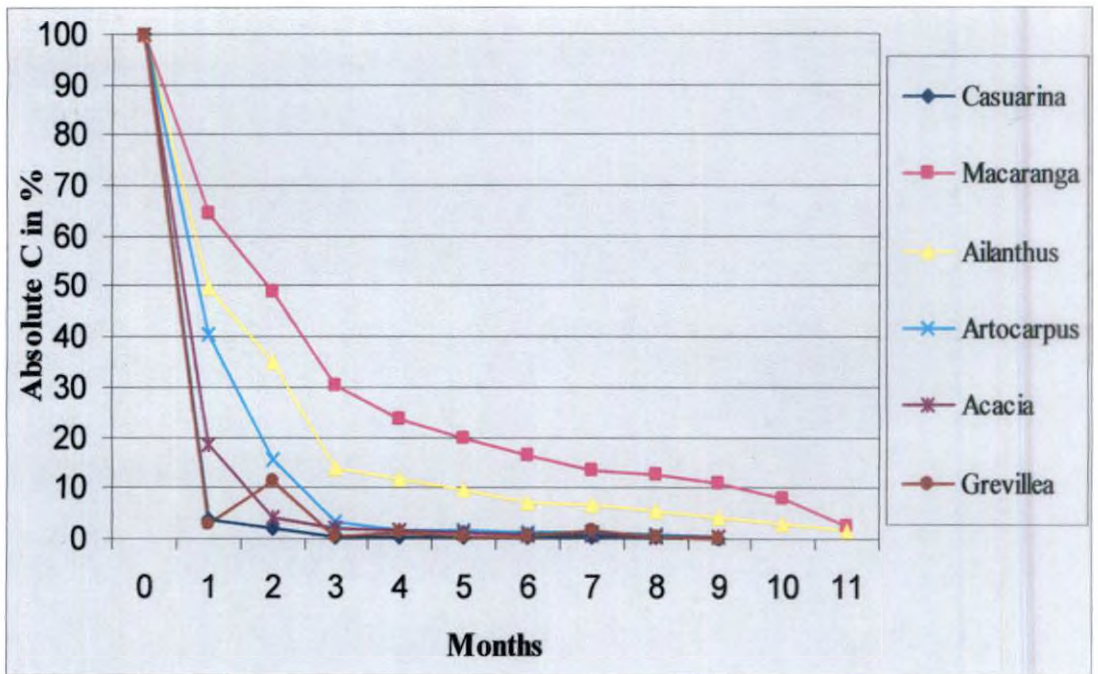
Fig. 27 Variation in absolute amounts of carbon in the decomposing litter of black pepper standards

Second order hyperbolic model was used to explain potassium decomposition in litter samples of all tree species except *Grevillea* with r^2-value of 0.99. *Grevillea* gave comfortable fit with line and reciprocal model (r^2=0.99). Thus potassium exhibited a more homogenous relationship in mineralization irrespective of the species.

4.2.4.4 *Carbon*

Carbon content also followed the general mass loss pattern (Fig. 27 and Table 29). Carbon content declined to less than 10% of the initial content for most of the species except the *Macaranga* and *Ailanthus* during the first three months. *Ailanthus* took 5 months and *Macaranga* 10 months to release 90% of initial carbon content.

Table 29. Absolute C content in decomposing litter of black pepper standards expressed as percentage of C present in the fresh litter.

Months	Casuarina	Macaranga	Ailanthus	Artocarpus	Acacia	Grevillea
Aug(0)	100.00	100.00	100.00	100.00	100.00	100.00
Sep(1)	3.69	64.55	49.77	40.70	18.61	2.77
Oct(2)	1.92	48.77	35.20	15.77	4.26	11.36
Nov(3)	0.38	30.17	13.83	3.29	1.99	0.63
Dec(4)	0.26	23.82	11.76	1.80	1.54	1.38
Jan(5)	0.54	19.70	9.82	1.50	1.11	0.50
Feb(6)	0.22	16.40	7.20	1.18	0.93	0.48
Mar(7)	0.32	13.48	6.66	1.12	0.68	1.54
Apr(8)	0.27	12.67	5.46	0.84	0.56	0.61
May(9)	0.18	11.15	4.15	0.57	0.26	0.13
Jun(10)	-	8.02	3.16	-	-	-
Jul(11)	-	2.72	1.52	-	-	-

The carbon release pattern has been well predicted by second order hyperbolic model, which again was conforming to all the species selected (except *Macaranga* and *Grevillea*) with r^2-value value of 0.99. The other models used to explain the pattern of

carbon decline over time was Normal function for *Macaranga* (r^2=0.99) and line and reciprocal model for *Grevillea* (r^2= 0.99).

4.2.5 Relative mineralization trend

The data furnished in the Table 30 shows the absolute amount of nutrients remaining (percentage of the original content) in the litter bags after a period of three months. Potassium exhibited fastest mineralizing trend among the nutrients under study. Distinct species variation in nitrogen mineralization has been observed in the study. *Macaranga* and *Ailanthus* litter characterized the slow releasers of N as compared to other standards. Same trend followed with P mineralization. However, the P mineralization occurred faster than N for all the species. Potassium exhibited fastest release among the nutrients studied. The general order nutrient mineralization was K>P>N. Species preference in terms of the nutrient release efficiency suggest *Casuarina* and *Grevillea* litter as faster nutrient releasers while *Macaranga* and *Ailanthus* litter exerted more control over nutrient mineralization. Species preference in the order of N and P mineralization is *Casuarina*> *Grevillea*> *Acacia*> *Artocarpus*> *Ailanthus* > *Macaranga*.

4.3 PEPPER YIELD

As evident from the data (Table 31), the yield of pepper trained on each species varied significantly between standards. Berry dry weight was maximum for the vines trailed on *Acacia auriculiformis* (2.56 t ha^{-1}) followed by *Artocarpus heterophyllus* (1.91 t ha^{-1}), *Grevillea robusta* (1.68 t ha^{-1}) and *Casuarina equisetifolia* (1.34 t ha^{-1}). The least value but which were in par was *Ailanthus triphysa* (0.93 t ha^{-1}) and *Macaranga peltata* (0.83 t ha^{-1}). The berry wet weight also revealed the same trend with *Acacia auriculiformis* yielding the highest (7.0 t ha^{-1}) and the *Macaranga peltata* the least (2.30 t ha^{-1}).

Table 30. Relative nutrient mineralization efficiency based on 3 months of litter decomposition

Species	Absolute amount of nutrients remaining (% of original)			Order of mineralization
	Nitrogen	Phosphorus	Potassium	
Casuarina equisetifolia	0.75^c	0.70^c	0.45^b	K>P>N
Macaranga peltata	49.69^a	37.71^a	14.95^a	K>P>N
Ailanthus triphysa	27.96^b	24.19^b	9.26^a	K >P>N
Artocarpus heterophyllus	4.63^c	4.38^c	1.45^b	K >P>N
Acacia auriculiformis	3.22^c	2.46^c	1.54^b	K >P>N
Grevillea robusta	1.06^c	0.91^c	0.41^b	K >P>N
F-value	28.86*	27.47*	10.58*	
CD	11.77	9.347	5.858	

*ns- Non significant   * - Significant at 5% level*

Table 31. Black pepper yield among the standards in terms of berry weight, t ha^{-1}

Species	Wet wt (t ha^{-1})	Dry wt (t ha^{-1})
Casuarina	3.51^{BC}	1.34^{BC}
Macaranga	2.30^C	0.83^C
Ailanthus	2.51^C	0.93^C
Artocarpus	5.27^{AB}	1.91^{AB}
Acacia	7.00^A	2.56^A
Grevillea	4.48^B	1.68^B
F- value	9.51*	9.45*
CD	1.825	0.6684

*ns- Non significant   * - Significant at 5% level*
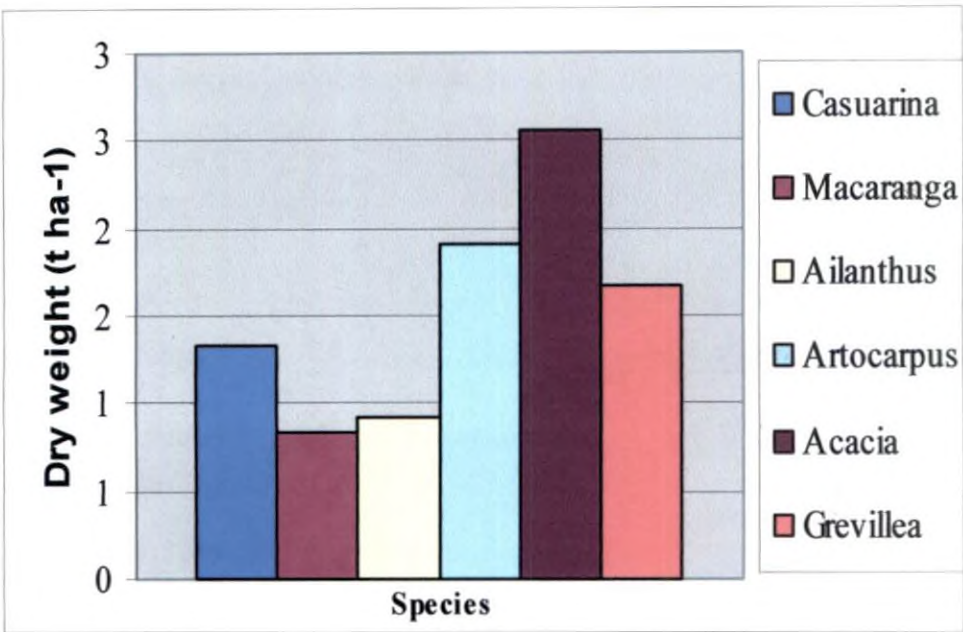
Fig. 28 Species-wise variation in black pepper yield among the support trees

4.3.1 Growth characteristics of black pepper standards

Variation in the growth performance has been observed among support trees. *Acacia* (64.67 cm), *Macaranga* (62.53 cm), and *Artocarpus* (62.40 cm) were found to be the toppers in terms of radial growth and were on par. *Ailanthus*, *Grevillea* and *Casuarina* showed lower values (Table 32).

Table 32. Growth characteristics of the selected black pepper vines and support trees

Species	Girth (cm)	Height (m)	Vine length (m)	Spike length (cm)	Number of berries/ spike
Casuarina	46.53[b]	13.68[a]	6.66	5.6	20[b]
Macaranga	62.53[a]	10.29[c]	5.35	5.2	18[b]
Ailanthus	53.73[b]	8.47[d]	8.98	6.0	28[a]
Artocarpus	62.40[a]	11.00[bc]	6.55	5.9	31[a]
Acacia	64.67[a]	12.47[ab]	7.86	6.1	27[a]
Grevillea	48.93[b]	10.83[c]	6.30	5.1	20[b]
F- value	*9.17**	*13.77**	*ns*	*ns*	*6.21**
CD	*8.09*	*1.53*	-	-	*6.77*

*ns- Non significant   * - Significant at 5% level*

Table 33. Number of pepper vine laterals per unit area (m^2)

Species	Sep	Oct	Nov	Dec	July	Aug
Casuarina	26	17	13	15	6	11
Macaranga	24	18	14	12	4	12
Ailanthus	24	21 .	17	14	7	14
Artocarpus	22	19	18	13	5	10
Acacia	28	20	17	12	5	12
Grevillea	29	19	15	13	7	12
F-value	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*
CD	-	-	-	-	-	-

*ns- Non significant   * - Significant at 5% level*

Height growth of standards trees also differed significantly among species, which was maximum for *Casuarina* (13.68m) followed by *Acacia* (12.47 m) and *Artocarpus* (11.0m). *Grevillea* and *Macaranga* were on par and the lowest height was for *Ailanthus* (8.47m). Variation in spike length among the tree species was not prominent. The number of berries per spike was maximum for *Artocarpus (31)* followed by *Ailanthus* (28) and *Acacia* (27). Least number of berries per spike was reported by *Macaranga*. The number of laterals in unit area was not significantly different for species but there was variation over months.

4.4 SOIL PROPERTIES UNDER PEPPER STANDARDS

4.4.1 Soil moisture content

The moisture content of the soil (Table 34) from plots representing each species showed significant difference during the first sampling (Aug-02). In general, the soils under *Artocarpus* and *Ailanthus* showed higher moisture content during the period.

Table 34. Moisture content of soils collected from support tree plots and treeless open areas, %

Species	August-2002	December-2002	April-2003	August-2003
Casuarina	18.66^{ab}	8.73	14.10	18.38
Macaranga	18.71^{ab}	10.19	14.74	17.19
Ailanthus	20.09^{ab}	10.39	15.03	16.63
Artocarpus	20.41^{a}	11.29	15.23	17.74
Acacia	18.23^{b}	11.47	14.64	18.06
Grevillea	19.37^{ab}	11.02	15.38	17.23
Open area	-	11.53	14.14	16.84
F- value	*10.39**	*ns*	*ns*	*ns*
CD	*1.76*	-	-	-

-: *Data deficient*   *ns- Non significant*   ** - Significant at 5% level*

Soil moisture content in the subsequent sampling revealed no strong difference among species. Also, soil from treeless control plots didn't show appreciable changes in moisture content as compared to that under various support trees. However, soil in

support tree plots, in general retained soil moisture content better than treeless control. No significant correlation was found to be governing the soil moisture and the rate of decomposition of *Ailanthus*, *Artocarpus*, *Acacia* and *Grevillea* litter.

4.4.2 Soil pH

The pH value of the soil samples (Table 35 and Fig. 29) below each species exhibited significant difference, except during the initial sampling (August 2002). No marked variation could be observed during the first sampling. Treeless control plots invariably registered higher pH value during all the sampling.

Table 35. Soil pH of samples collected from various pepper support tree plots

Species	August-2002	December-2002	April-2003	August-2003
Casuarina	4.46	4.57 ^{d}	4.93^{bc}	4.75^{bc}
Macaranga	4.61	4.64^{cd}	4.81^{bc}	4.85^{b}
Ailanthus	4.69	4.83^{b}	4.82^{bc}	4.85^{b}
Artocarpus	4.50	4.78^{bc}	4.92^{bc}	4.70^{bc}
Acacia	4.65	4.74^{bcd}	4.94^{b}	4.74^{bc}
Grevillea	4.55	4.65^{cd}	4.77^{c}	4.62^{c}
Open area	-	5.03^{a}	5.09^{a}	5.10^{a}
F- value	*ns*	*9.16**	*5.03**	*6.12**
CD	-	*0.16*	*0.15*	*0.06*

*ns- Non significant   * - Significant at 5% level*

During the second sampling (December 2002) control plots had a higher pH (5.03). Among the tree plots, *Ailanthus* plots had the highest pH (4.83) closely followed by *Artocarpus* (4.78) and *Acacia* (4.74). *Grevillea* (4.65) and *Macaranga* (4.64) remained on par and *Casuarina* had the least pH value (4.57). In the third sampling during the month of April, *Acacia* had the highest pH (4.94) and *Grevillea* the lowest pH (4.77). The final sampling *Macaranga* and *Ailanthus* plots showed higher pH values while *Grevillea*

continued to record low pH. Soil pH remained highest for open plots at this stage of sampling.

4.4.3 Soil nutrient content

4.4.3.1 *Nitrogen content in the soil*

Soil nitrogen content within the different treatment plots and open areas did not differ significantly during the initial sampling. However, sampling during December suggested that N content in the soil under *Acacia* plots were higher (0.92%) while that of *Macaranga* was lower. The open plot had the least soil nitrogen content (0.76%). In the third phase of soil sampling during April, *Ailanthus* (0.85%) was found to be the topper followed by *Acacia*. The control plot again had the least value (0.68%).

In the final phase sampling (August- 2003) nitrogen content was higher for soils in *Acacia*, *Artocarpus* and *Ailanthus* plots which were on par. Treeless control plots continued lower N content. For all species, the maximum soil nitrogen content was observed during the month of December and it continued to decrease reaching the minimum during April and again continued to increase during August.

Table 36. Nitrogen content in the soil under various black pepper standards, %

Species	August-2002	December-2002	April-2003	August-2003
Casuarina	0.63	0.86^{ab}	0.73^{bc}	0.82^{b}
Macaranga	0.60	0.85^{b}	0.71^{bc}	0.81^{b}
Ailanthus	0.69	0.90^{ab}	0.85^{a}	0.90^{a}
Artocarpus	0.60	0.87^{ab}	0.75^{bc}	0.90^{a}
Acacia	0.68	0.92^{a}	0.79^{ab}	0.95^{a}
Grevillea	0.59	0.87^{ab}	0.70^{c}	0.83^{b}
Open area	-	0.76^{c}	0.68^{c}	0.77^{b}
F- value	*ns*	*4.96**	*0.06**	*3.93**
CD	-	*0.06*	*0.08*	*0.06*

*ns- Non significant   * - Significant at 5% level*
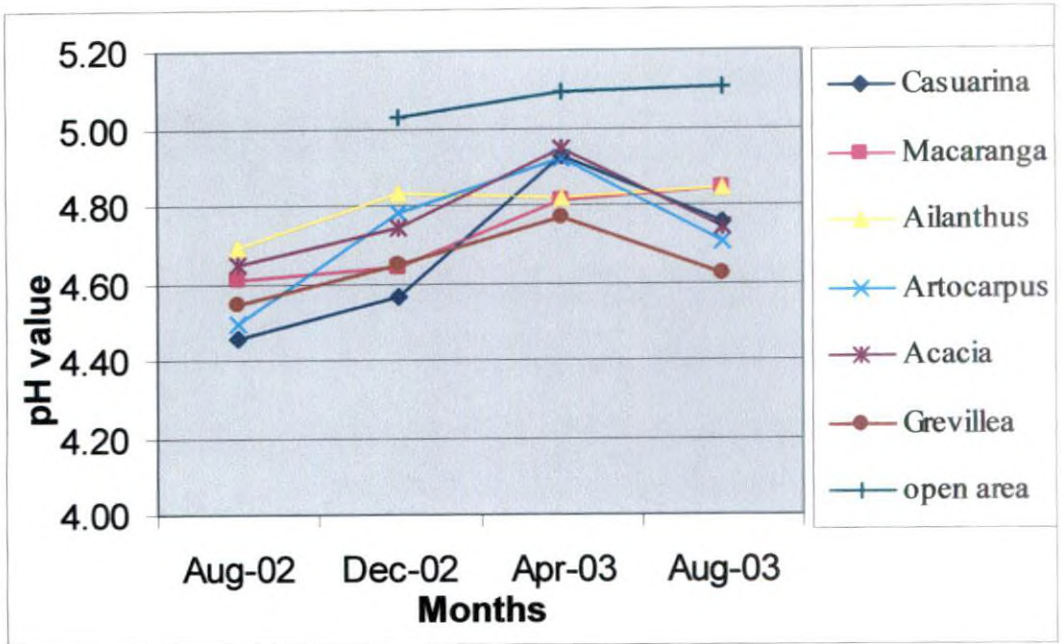
Fig. 29 Changes in soil pH under different black pepper standards
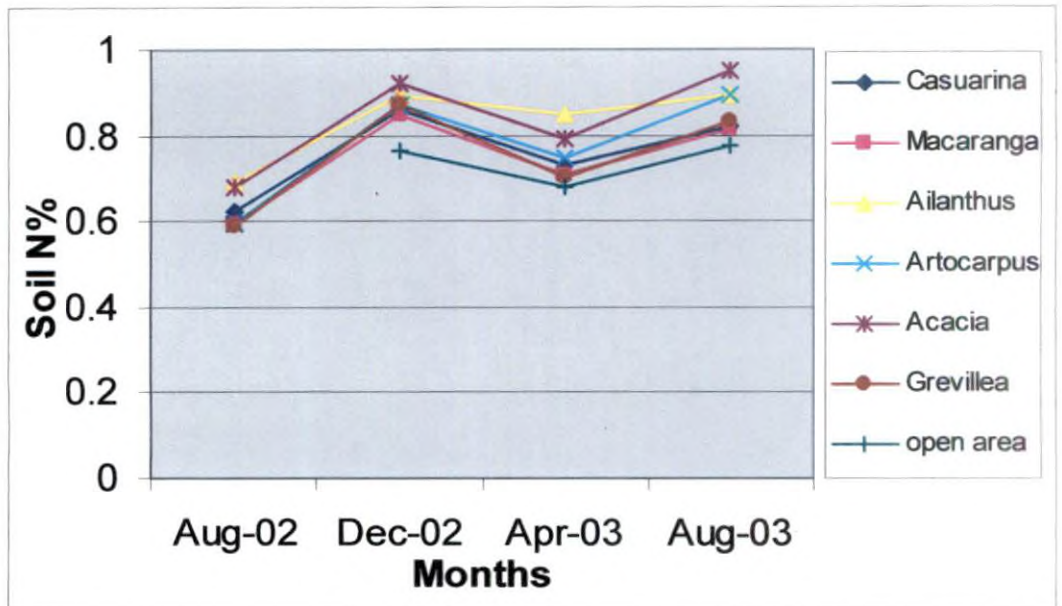
Fig. 30 Changes in soil nitrogen under different black pepper standards over a
year

The control plots always reported the lowest value as compared to other treatment plots showing the effect of trees on the soil nitrogen accretion (Table 36 and Fig. 30). In general, soils under *Ailanthus* plots showed higher nitrogen content as compared to other tree species.

4.4.3.2 *Phosphorus Content in the soil*

Data related to soil P content (Table 37) suggested no appreciable changes under different species except for the first sampling (August 2002).

Table 37. Phosphorous content in the soil under black pepper standards, %

Species	August-2002	December-2002	April-2003	August-2003
Casuarina	0.13^b	0.14	0.15	0.15
Macaranga	0.12^c	0.13	0.14	0.15
Ailanthus	0.14^a	0.14	0.15	0.15
Artocarpus	0.14^a	0.13	0.14	0.15
Acacia	0.13^b	0.14	0.14	0.14
Grevillea	0.13^b	0.14	0.14	0.15
Open area	-	0.13	0.14	0.15
F- value	*4.36**	*ns*	*ns*	*ns*
CD	*0.008*	-	-	-

*ns- Non significant   * - Significant at 5% level*

Soil in the *Ailanthus* (0.14%) and *Artocarpus* (0.14%) plots showed marginal increase in P content. Also striking change in P content of soils in the tree plots and treeless open areas could not be established.

4.4.3.3 *Exchangeable Potassium in the soil*

The exchangeable potassium content in the soil showed significant difference between species (Table 38). *Artocarpus* plots (0.41-0.46%) invariably recorded higher

potassium content than the rest of the species during the four phases of sampling. Also, *Casuarina* (0.31-0.35%) recorded the lowest value among the species. The control plots showed potassium content that was more or less in between that for tree species (0.39-0.41%). The rest of the species was moderate in the potassium content which ranged between (0.35- 0.45%).

Table 38. Exchangeable potassium in the soil under black pepper standards, %

Species	August-2002	December-2002	April-2003	August-2003
Casuarina	0.31^c	0.33^d	0.32^c	0.35^d
Macaranga	0.35^b	0.37^c	0.40^{ab}	0.42^{bc}
Ailanthus	0.37^b	0.41^{ab}	0.42^{ab}	0.45^{ab}
Artocarpus	0.41^a	0.43^a	0.44^a	0.46^a
Acacia	0.35^b	0.38^{bc}	0.40^{ab}	0.44^{abc}
Grevillea	0.35^b	0.37^c	0.39^b	0.41^c
Open area	-	0.39^{bc}	0.41^{ab}	0.42^{bc}
F- value	9.51*	10.40*	12.82*	15.06*
CD	0.04	0.04	0.04	0.03

*ns- Non significant   * - Significant at 5% level*

For both the control plots and the treatment plots, the Potassium content registered a smooth increase till the final phase.

4.4.3.4 *Organic carbon content in the soil*

The organic carbon content in the soil under pepper standards showed considerable difference between species for different sampling periods (Table 39 and Fig. 31). During the initial sampling soil, under *Artocarpus* (6.14%) and *Macaranga* (6.01) were foremost in terms of organic carbon content and the least value was shown by *Grevillea* (4.98%).

During December, organic carbon content in the soil under *Artocarpus* continued to be high. Open control plots invariably showed lower organic carbon content when compared to other treatments at all stages of sampling. Soil organic carbon varied in the similar fashion during December and April sampling. The final phase of sampling during August revealed no strong variation in soil C among species. The soil organic carbon content seemed to increase from August to December and then to decrease during April reaching the minimal value and finally increased during August.

Table 39. Organic carbon content in the soil under black pepper standards, %

Species	August-2002	December-2002	April-2003	August-2003
Casuarina	5.56^b	6.01^{ab}	5.75^c	5.75
Macaranga	6.01^a	6.36^{ab}	5.53^{cd}	6.14
Ailanthus	5.88^{ab}	6.01^{ab}	6.24^{ab}	5.92
Artocarpus	6.14^a	6.53^a	6.62^a	6.82
Acacia	5.46^b	6.14^{ab}	5.85^{bc}	6.20
Grevillea	4.98^c	5.98^b	5.27^d	5.98
Open area	-	4.85^c	4.82^e	5.40
F- value	*10.12 **	*11.55**	*21.25**	-
CD	*0.43*	*0.49*	*0.40*	*ns*

ns- Non significant   * - Significant at 5% level
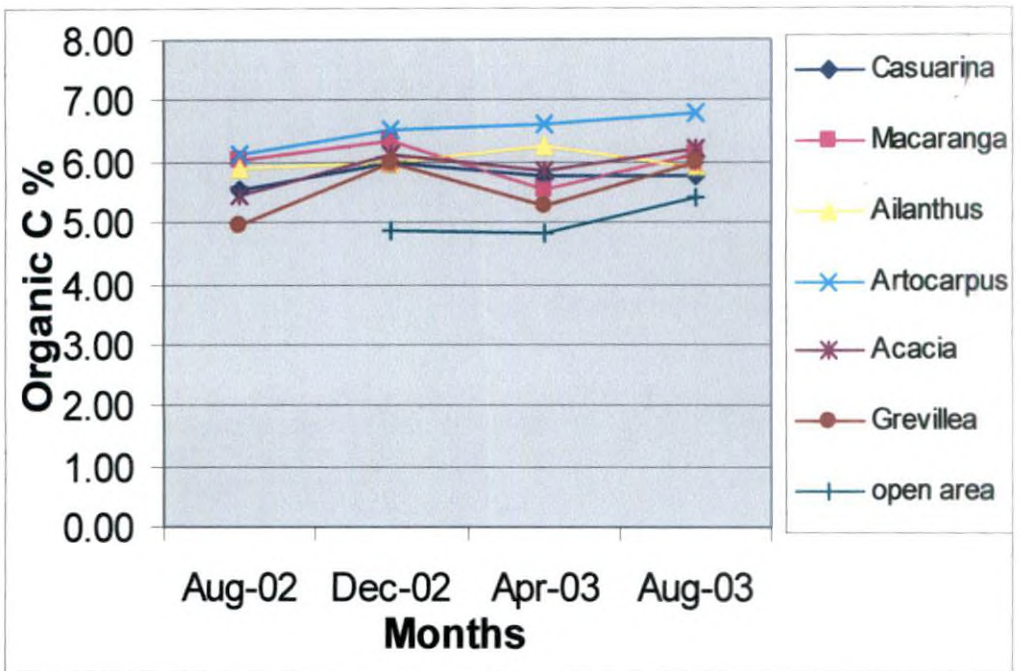
Fig. 31 Changes in soil organic carbon under different black pepper standards

4.4.4 Bulk density of the soil

Attempts were made to monitor soil bulk density under different support trees and also in open areas (Table 40 and 41).

Table 40. Bulk density at 5cm soil depth for various black pepper standards, g cc^{-1}

Species	December-2002	April-2003	August-2003
Casuarina	0.16	0.18	0.21
Macaranga	0.14	0.17	0.22
Ailanthus	0.15	0.16	0.26
Artocarpus	0.18	0.19	0.24
Acacia	0.17	0.18	0.19
Grevillea	0.15	0.18	0.20
Open area	0.23	0.23	0.21
F- value	*ns*	*ns*	*ns*
CD	-	-	-

ns: Nonsignificant

Table 41. Bulk density at 10 cm soil depth for various black pepper standards, g cc^{-1}

Species	December-2002	April-2003	August-2003
Casuarina	0.14	0.16	0.18
Macaranga	0.15	0.16	0.24
Ailanthus	0.14	0.17	0.21
Artocarpus	0.17	0.16	0.20
Acacia	0.15	0.15	0.20
Grevillea	0.16	0.16	0.19
Open area	0.25	0.25	0.21
F- value	*ns*	*ns*	*ns*
CD	-	-	-

ns: Nonsignificant

Observations revealed that very feeble variation in bulk density occur among treatment plots. Nevertheless, it appeared that soil bulk density in the open areas is higher than the support tree plots at 5 cm depth and 10 cm soil depth as well.

4.5 RAINFALL INTERCEPTION BY BLACK PEPPER STANDARDS

The study to compare the throughfall of different pepper standards showed considerable difference between species.

Table 42. Rain water throughfall collected from black pepper support tree plots, mm^3

Species	June	July	August
Casuarina	1680.3^e	4365.7^{de}	4795.8^b
Macaranga	1545.3^f	4311.8^e	5660.4^a
Ailanthus	1889.7^c	4958.3^c	5756.3^a
Artocarpus	982.7^g	2576.7^f	2255.8^c
Acacia	2045.3^b	5175.8^b	5754.6^a
Grevillea	1794.0^d	4542.3^d	4851.3^b
Open area	2164.0^a	5448.7^a	5818.4^a
F- value	33.92*	35.65 *	10.38*
CD	922.7	2173.1	5572.0

*ns- Non significant   * - Significant at 5% level*

Table 43. Rain water through fall collected from black pepper support tree plots, %

Species	June	July	August
Casuarina	77.65	80.12	82.43
Macaranga	71.41	79.14	97.29
Ailanthus	87.32	91.00	98.93
Artocarpus	45.41	47.29	38.77
Acacia	94.52	94.99	98.90
Grevillea	82.90	83.37	83.38
Open area	100.00	100.00	100.00

Throughfall being a function of tree spacing and above ground tree architecture, it varied considerably among different species (Table 42 and 43). The study started at the final month of June due to late monsoon, showed that maximum rainfall interception was attributed to *Artocarpus* followed by *Macaranga, Casuarina, Grevillea, Ailanthus*, and *Acacia*. The same trend was repeated in the month of July also. *Artocarpus* had highest rainfall interception potential *Casuarina* and *Grevillea* were on par and next in sequence. Other species exhibited poor rain interception leading to heavy throughfall.

DISCUSSION

DISCUSSION

Biogeochemical cycle involve continuous, dynamic transfer of nutrients through soil plant continuum. Tree based systems are commonly credited with more efficient nutrient cycling and hence, greater potential to improve the soil productivity. Compared to herbaceous pants, the large quantity of litter production, their return to the soil through the activity of microorganisms and the ability to capture nutrients from the deeper soil layers are some of the key factors that make tree based systems superior. However, the productivity of such systems varies depending on the efficiency with which the tree components contribute to biogeochemical processes. The litter production and its consequent transfer to the soil forms a major part in the litter dynamic pathway (Mudrick *et al.*, 1994).

The ongoing discussions are an attempt to analyze the nutrient input-output processes involved in a fourteen-year-old mature black pepper based production system involving six fast growing multipurpose tree species as standards.

5.1 LITTER PRODUCTION

The present investigation conducted in a fourteen-year-old black pepper stand revealed that litter production of tree species used as pepper standards varied considerably between each other. As the results indicated, the annual litter production was maximum for *Artocarpus* (4653.63 kg ha^{-1} yr^{-1}) where as the minimum value was reported for *Ailanthus* (2221.25 kg ha^{-1} yr^{-1}).

Pronounced variation in litter yield has been noticed for many tropical species. The annual litter production of *Acacia auriculiformis*, *Casuarina equisetifolia* and *Grevillea robusta* in 10 year old mixed stand was 5.10, 3.0, 7.80 t ha^{-1} yr^{-1} respectively (Vajranbhaiah *et al.*, 1996). Kunhamu *et al.*, (1994) in six-year-old plantation found that the litter production of *Acacia auriculiformis* was 12.99 t ha^{-1} yr^{-1}. Jamaludheen and Kumar (1999) in a study at woodlot at Thiruvazhamkunnu found that litter production of *Acacia auriculiformis* was 12.69 t ha^{-1} yr^{-1}. In a seven-year-old *Casuarina equisetifolia* plantation located in the sodic soils, average annual litter production was 6.1 t ha^{-1} yr^{-1} (Rana *et al.*, 2001).

Striking variation in the litter production has been reported in the intensively managed agroforestry systems. The litter production of *Hardwickia binata* under silvopastoral systems at Jhansi was found to be 8.15 t ha^{-1} (Roy *et al.*, 1998). In the case of the plantation crop combinations involving coffee – *Erythrina,* litter production was as high as 20 t ha^{-1} yr^{-1} to as low as 5.8 t ha^{-1} yr^{-1} for *Cacao- Cordia* combination (Nair, 1983). In a silvopastoral study at Thiruvazhamkunnu, Kerala, George (1993) observed the annual litter yield for *Acacia auriculiformis, Casuarina equisetifolia* and *Ailanthus triphysa* as 6.20, 2.30 and 1.92 t ha^{-1} yr^{-1} respectively. It can be seen that the same species under different conditions exhibit varying levels of litter production as in the case of *Acacia auriculiformis* (6.2 -12.99 t ha^{-1} yr^{-1}).

In the present study, annual litter production for *Casuarina equisetifolia* (2.9 t ha^{-1} yr^{-1}) was conforming to the values reported by the earlier studies. *Ailanthus* (2.2 t ha^{-1} yr^{-1}) on the other hand exhibited a much higher value when compared to the value being reported by George (1993) from the same site. *Grevillea* (3.0 t ha^{-1} yr^{-1}) recorded a much lesser litter yield when compared to previous studies.

Physiological responses leading to the litter production vary with species, which is often modified by edapho-climate, crop composition, cropping systems, stand management, stocking levels, stand age etc (Finer, 1996). The general lower litter production in the present study could be attributed to many reasons. The smaller size of the trees and the heavy annual pruning of lateral branches might prolong the time gap needed for full canopy closure, which poses limits to annual litter production. Imposition of such strong control over growth impedes the potential growth of the trees which in turn result in lower biomass accretion and resultant lower litter production. The age of the stand beyond the normal rotation period could be yet another reason for lower litter production exhibited by support trees under study. In the classical study on litterfall patterns, Bray and Gorham (1964) reported such decline in litter production when the stand become older. Here we accounted only the foliage portion which forms 76 to 92% of total litterfall without accounting twigs, barks and other reproductive parts This partly explains the reason for the general lower litter production values of the tree species under study.

It can be seen that the litter production in natural/ manmade forests are by and large higher compared to agroforestry systems, since latter are subjected to more frequent disturbances caused by management practices such as pruning and soil tillage.

5.1.1 Seasonal variation in litterfall

The seasonal trend in the litter production showed variation from fourth month of observation onwards for all the tree species under study. This clearly indicates the influence of tree lopping on litter production rate. Irrespective of the species, peak litter production was observed during December and minimum during May. The high litterfall during December may be due to the strong wind occurring during these seasons, which indirectly elevated the litter production rate for all the species. The present study demonstrated that the peak litter fall was during the dry season for all the species, and the lean period occurred during the end of the summer. Dry period accounted for higher percentage of total litterfall for most of the trees viz. *Ailanthus* (72.24%), *Macaranga* (71.70%), *Grevillea* (62.81%), and *Artocarpus* (59.17%).

Litter production during dry season assumes paramount importance since it accounts for the chunk of the litterfall in almost all the ecosystems. Pascal (1988) working on the wet evergreen forests of Attapady in W. Ghats indicated that the rhythm of the leaf shed was characterized by a heavy litterfall during the dry period. Kumar and Deepu (1992) in the moist deciduous forests of Western Ghats found that the peak litterfall occurred during the period from November to April. Arunachalam *et al.* (1998) during one year study in subtropical humid forest stand reported peak fall during spring and trough during the rainy period. Kunhamu *et al.* (1994), in a study at six-year-old *Acacia* plantation at Thrissur, Kerala showed that litterfall was maximum during the period from September to February and it accounted for 79.8% of the total litterfall. The formation of the abscission layer in leaves due to the moisture stress may be the prime reason behind the peak litter production during dry season (Longman and Jenik, 1974). Higher litter accumulation during dry period serves as effective soil mulch in many tree based systems and prevents evaporation loss.

In the present study, monomodal as well as the bimodal pattern of litterfall were observed. This emphasizes the inherent species variation in litter production. Monomodal pattern of litterfall was reported by Kumar and Deepu (1992) in the moist deciduous forests of Peninsular India. The same trend was reported in sub humid tropical forest of N. India (Aruncahalam *et al.*, 1998) and in the *Acacia auriculiformis* plantations in W. Ghats (Swamy and Proctor, 1997). Jamaludheen and Kumar (1999) found that litterfall followed a unimodal distribution pattern for *Acacia, Ailanthus,*

Pterocarpus and *Casuarina*. Similar monomodal pattern in litter production were exhibited by *Ailanthus, Grevillea* and *Acacia* in the present study while bimodal pattern of litter production was seen in the case of *Casuarina, Macaranga* and *Artocarpus*, with a second peak after May. Such bimodal patterns of litter production have been reported for many species. Increase in the litterfall after summer has been reported by Raizada and Srivastava (1986) due to prolonged water deficit in the area, caused by the poor rainfall. The unprecedented draught, late entry of monsoon in the study area and the consequent extension in draught situation may be the probable reasons for the second peak in litterfall after summer (May) for these species. These species appeared to show a better response to edapho-climatic changes rather than genetic control of seasonality in litter production when compared to the rest of the species.

5.1.2 Litter nutrient content and annual nutrient return

The present study revealed that the N content in the foliage of the pepper support trees varied from 1.18% (*Grevillea*) to 2.01 % (*Acacia*) where as the annual return of N through litterfall was in the range of 39.25 kg ha^{-1}(*Ailanthus*) to 68.13 kg ha^{-1}(*Macaranga*)

Nitrogen content in the litter and its return through litterfall is an important aspect of nutrient cycling. Many reports suggest that nitrogen content in the litter serve as an index of litter quality which varies considerably among species (Anderson and Swift, 1983). Higher nitrogen content in the litter for *Leucaena* (4.33%) and *Gliricidia* (4.21%) has been reported in different agroforestry systems (Nair, 1983). Similarly, considerable variation in N return through litterfall has been observed. Data from different ecosystems reported a wide range of annual N-return. For instance, it was as high as 162 kg ha^{-1} in rainforests to as low as 2.5 kg ha^{-1} in *Erythrina* based alley cropping systems (Nair, 1983). Vidyasagaran *et al.*, (2002) reported N return to the tune of 23.1 kg ha^{-1} yr^{-1} for shola forest where as a study at mining place of Singrauli, India, reported it to be 8.6 kg ha^{-1} yr^{-1} for *Dalbergia sissoo* and 36.5 kg ha^{-1} yr^{-1} for *Shorea robusta*. Nitrogen return through litterfall in a silvopastoral trial at Thiruvazhamkunnu for *Acacia, Casuarina* and *Grevillea* reported values of 68, 34.7 and 15.8 kg ha^{-1} yr^{-1} respectively (George and kumar, 1998). The corresponding

values for the above species in the present study were 49.73, 53.25, and 48.40 kg ha^{-1} yr^{-1}respectively. It can be seen that except *Acacia*, other species reported higher N return than previous studies in the same location. However, the N return through litter route was lower in general, as compared to other systems. This may be attributed to the general reduction in the litterfall which has a direct bearing on the quantity of N return.

The phosphorus content in the litterfall varied from 0.06% (*Acacia*) to 0.19% (*Macaranga*) and the corresponding annual phosphorus return was 2.13 kg ha^{-1}yr^{-1} (*Acacia*) to 6.63 kg ha^{-1} yr^{-1}(*Macaranga*). The litter P content in various agroforestry systems were found to be ranging from 0.16% (*Dactyldenia*) to 0.29 % (*Gliricidia*) where as the P return on annual basis was ranging from 4 kg ha^{-1} yr^{-1} for *Cacao* based mixed shade tree system to 35 kg ha^{-1} yr^{-1} in Coffee/ *Erythrina* system (Nair, 1983). George (1986) observed that the P return in the litterfall of the *Eucalyptus hybrid* was 40.2 kg ha^{-1} yr^{-1}. Lower levels of P return to the tune of 1.9 kg ha^{-1} yr^{-1} have been reported for shola forests (Vidyasagaran *et al.*, 2002). George (1993) observed that in *Acacia, Casuarina* and *Ailanthus,* the corresponding P return values were 2.7, 1.8 and 1.7 kg ha^{-1} yr^{-1} respectively. However, the annual P return for the corresponding species in the present study was on the higher side when compared to the former studies at this location. The immobile nature of P in the plant system characterizes its reasonably stable concentration for different species studied. Again, the lower annual litter yield for different species resulted in a corresponding lower P return through litter as compared to other systems.

The potassium content in the litterfall varied from 0.06% (*Casuarina*) to 0.34 % (*Macaranga*) and the corresponding potential for K return on annual basis ranged from 2.04 kg ha^{-1} yr^{-1} (*Casuarina*) to 11.05 kg ha^{-1} yr^{-1}(*Macaranga*). Litter potassium content and return through litterfall varied considerably for different tree species under different agroforestry systems in the tropics. For instance, the K content in some MPT's under agroforestry was ranging from 0.90% (*Inga*) to 3.43% (*Gliricidia*) (Nair, 1983). Higher K return to the tune of 200 kg ha^{-1} has been reported in intensively managed *Leucaena/ Erythrina* based alley cropping system where annual litter production was 8 to12 t ha^{-1} (Nair, 1983). Similar results have been reported from agroclimatically uniform systems from S. India. For instance, K return in teak plantations of Kerala was of the range 114.86 kg ha^{-1} yr^{-1} (Shanmughavel and Francis, 1999). However, George (1986) observed that the K- return from the litter of

Eucalyptus hybrid was of the order 15 kg ha^{-1} yr^{-1}. Also, George (1993) under silvopastoral system reported the annual K return to be 8.3, 5.0 and 2.4 kg ha^{-1} yr^{-1} for *Acacia, Casuarina* and *Ailanthus* respectively. The above values agree with the general range of K return in the present study. However, K return through litter fall in our study was lower compared to other reports. The general lower values of K return in this system may be attributed to intense pruning and the consequent lower annual litter production.

The carbon content of the litterfall varied from 25.01% (*Acacia*) to 31.31% (*Macaranga*) and the annual carbon return by litterfall was of the order of 639.28 kg ha^{-1} yr^{-1} (*Ailanthus*) to 1352.99 kg ha^{-1} yr^{-1} (*Artocarpus*). The C: N ratio of the litterfall varied from 13.96 (*Acacia*) to 24.61 (*Artocarpus*) and the lignin content in the litterfall varied from 10.70% (*Artocarpus*) to15.10 % (*Acacia*).

The seasonality of the nutrient content varied with species and is to be analyzed on the background of litter production rate (Fig. 4-8). *Casuarina* and *Acacia* maintained higher N content in the litter whereas K content was higher for *Macaranga*. During the dry period representing heavy litterfall, N and K content in the foliage were higher in general, though they showed reduction towards the later part of the summer. However, the seasonality in the P content was not so prominent. Earlier studies by Jamaludheen and Kumar (1999) also showed no distinct seasonal variation was discernable with respect to P concentrations of the litter of multipurpose tree species. This may be due to the immobile nature of phosphorus.

Gradual reduction in the N content with the progression of summer exhibited by *Casuarina* and *Acacia* litter may be attributed to the efficiency of the species to retranslocate nitrogen from the senescing organs before abscission. Nutrient retranslocation in plant system is an effective mechanism to conserve nutrients for new growth as reported by Maggs (1985). Nutrient retranslocation in tree species has been reported by various workers (Negi, 1984; Kushalpa, 1993; Das and Ramakrishnan, 1985). They reported that concentration of different nutrients in the leaf litter was less than that of green leaves due to retranslocation before abscission and the same was evident in the present study also.

Higher C: N ratio was observed for litter corresponding to *Macaranga* (22.75) and *Artocarpus* (24.61) in the present study. Litter C: N ratio is often referred as index of their nutrient mineralization potential. Litter with higher C: N ratio tends to mineralize slowly (Nair, 1983). It was also observed that the C: N ratio of the lopped foliage for

various black pepper standards (8.78 to 13.88) were lower when compared to that of the corresponding litter (13.96 to 24.61). This again suggests the reallocation of higher proportion of leaf N to perennial tissues before leaf fall, thereby making a more efficient use of N (Chapin 1980, Vitousek 1982). Highly nutrient efficient species should have a narrow C: N ratio in their leaf litter, because they are able to deliver higher amount of nitrogen into the site in comparison to the amount of carbon being fixed. The comparatively higher content of potassium in the litterfall during the period of December to May could be due to the profuse flowering and seeds occurring especially in the case of *Acacia*. Similar observation has been reported by Kunhamu *et al.*, (1994).

5.2 LEAF LITTER DECOMPOSITION
5.2.1 Rate of litter decomposition

Black pepper support trees involved in the present study showed considerable variation in their litter decomposition rate. Most of the species exhibited faster rate of litter decomposition during one-year study using litter bags.

In the present study, it was observed that except *Macaranga and Ailanthus* all the species lost more than 90% of their original leaf litter during the initial three months of decomposition. Comparatively, *Macaranga* and *Ailanthus* litter showed slower rates of decomposition, which took almost 11 months for 90% mass loss. However, *Casuarina* and *Grevillea* exhibited heavy mass loss, losing 90% of original biomass during the first month of decomposition. Characteristic needle nature of *Casuarina* litter may have favoured their early fragmentation into smaller units and the consequent physical mass loss from the litter bags. Similar unprecedented mass loss has been observed for *Grevillea* and *Acacia* litter. *Artocarpus* showed moderate pace and took three months for 95% of original mass loss.

Available information on the litter decay rates of many tropical broad-leaved tree species suggest varying trends. Compared to herbaceous vegetation, tree leaf litter showed slower rate of decomposition (Nair, 1983). The faster decomposition rate of the leguminous cover crops when compared to the trees may be due to the low C: N ratio and substances like lignin and polyphenol which are usually higher in tree foliage (Lehmann *et al.*, 1999). However, tree species vary considerably in their litter decay characteristics owing to the litter quality, edapho –climatic factors etc. Kumar

and Deepu (1992) observed faster rate of litter decomposition for tropical deciduous tree species and reported complete mass loss within a period ranging from five to eight months. Observation on shola forest of Nilgiris revealed that 77% of original biomass was lost within the one year period (Vidyasagaran *et al.*, 2002). Kunhamu, 1994 studied the litter decay characteristics of five tree species in a typical home garden and reported that faster rate of decomposition was associated with the *Terminalia paniculata* and *Bridelia retusa* while *Macaranga peltata* registered the lowest decay rate

Comparatively faster rate of litter decay associated with support trees in the present study could be attributed to the congenial edapho-climatic factors existing in the locality which exert a positive influence on the litter decomposition. The study was initiated during the monsoon period (August) which may have favoured the proliferation of soil macro and micro fauna which accelerates the decay rates of litter. This in conjunction with the intrinsic variation of physico-chemical quality of the leaf material could be yet another major reason for the faster rate of biomass decomposition.

5.2.2 Decay rate coefficients

Decay rate coefficient (k) is often cited as the index of decomposability of plant litter. In the present study, *Casuarina* and *Grevillea* litter displayed highest decay rate coefficients (k), 0.73 and 0.67 respectively. The lowest decay rate was recorded by *Macaranga* and *Ailanthus* being 0.19, 0.25 respectively. *Artocarpus* (0.60) displayed moderate k values. Melillo *et al.*, (1982) working on temperate hardwood species reported widely varying annual decay rate coefficient ranging from 0.08-0.47. Das and Ramakrishnan (1985) working on different pine species found that the annual decay rate coefficient varied from 0.31- 0.46. Kumar and Deepu (1992) in the moist deciduous forest of W.Ghats observed that the decay coefficients varied from 0.29 (*Terminalia*) to 0.44 (*Pterocarpus*), which emphasize that the tropical moist deciduous species exhibit higher decay rates when compared to temperate situations. George (1993) in silvopastoral system at Thiruvazhamkunnu, Kerala reported the decay rate coefficient of *Acacia auriculiformis*, *Casuarina equisetifolia* and *Ailanthus triphysa* to be 0.41, 0.66 and 0.14 respectively which mostly conform with our values. Physico-chemical quality of the litter coupled with the conducive edaphic factors may

have prompted faster rate of decomposition which is reflected in higher decay rate coefficients.

In the present study, the half-life value ranged between 3.63 months (*Macaranga*) to 0.95 months (*Casuarina*). George (1993) under silvopastoral system at Thiruvazhamkunnu, Kerala reported the half life period for *Acacia, Casuarina* and *Ailanthus* as 1.6, 1.0 and 4.8 months respectively. It can be seen that the corresponding half-life periods in the present study are in tune with earlier studies.

5.2.3 Patterns of litter decomposition

General decomposition trend for the leaf litter of the tree species under investigation suggest a biphasic decomposition pattern characterized by initial rapid decomposition followed by an extended slower decomposition phase (Fig. 10). Such biphasic mass loss pattern has been reported for many tree species viz. teak, poplar and eucalyptus (Singh *et al.*, 1993). It can be observed that the time gap associated with this initial rapid mass loss phase varied considerably among species. Jamaludeen and Kumar (1999) in woodlot of Kerala observed that decomposition of *Emblica officinalis, Artocarpus heterophyllus and Artocarpus hirsutus* followed a biphasic pattern wherein heavy mass loss was observed for 4-5 months while slower mass loss from 6-12 months. Many workers distinguished two main steps in the litter decomposition process with differential decomposition rates (Palma *et al.*, 1998).

In the present study, all the species except *Macaranga peltata* and *Ailanthus triphysa* decomposed more than 95% of original biomass within the first 3 months. The possible reason for the initial rapid decay could be due to the prevailing congenial environmental conditions. The readily degradable water-soluble compounds in the litter in conjunction with the triggered activity of soil fauna may be a major reason for rapid decomposition. In addition, the high leaching loses of water soluble fractions from the decomposing material during the rainy periods might have added to the heavy mass loss during the initial phase which also was reported by Berg and Staff (1987). The comparatively lower decomposition rate of *Macaranga peltata* and *Ailanthus triphysa* can be due to the lesser bio-degradability of the litter that might hinder the fragmentation stage by soil arthropods. The prolonged slow litter decomposition phase exhibited by all the tree species under study suggests the soil moisture limitation during this period and the consequent lower activity of soil
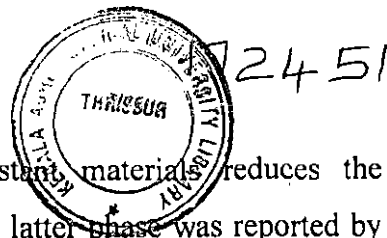
organisms. Also, the prominence of bio-decay resistant materials reduces the decomposition rate. This limitation of decay rate during latter phase was reported by earlier workers (Witkamp, 1963). The diverse factors involved in the leaf litter decomposition have been investigated separately and are discussed here under.

5.2.4 Factors affecting biomass decomposition

Significant variation can be observed in the rate of litter decomposition of all the selected black pepper standards. Diverse factors are responsible for such a wide range of decomposition rate. This is more obvious in the initial rapid decay phase.

5.2.4.1 *Initial nitrogen content in the leaf litter*

In the present study, it was found that all the species retained comparatively higher amount of initial nitrogen. Barring *Casuarina, Grevillea, Acacia*, which followed unprecedented mass loss, *Macaranga* litter exhibited lower N content and showed a corresponding lower decay rate compared to other species. However, the corresponding trend was not seen for *Ailanthus* which incidentally had the highest N content. Divergent reports are available on the influence of the litter N content on the rate of litter decomposition. Under conditions where nitrogen limits the microbial growth, the rate of mass loss is determined both by the nitrogen and lignin concentration (Brendse *et al.*, 1987). Bahuguna *et al.*, (1990) found that the initial higher N content of eucalyptus litter lead to faster decomposition compared to sal that have lesser N content. Pande (1999) in tropical plantations involving sal, teak and eucalyptus found that the initial nitrogen content was positively correlated with the decomposition rate. The general faster decay rate associated with our species could be attributed to their generally higher N content. However, the slower decay rate of *Ailanthus* could be due to the pronounced effect of decay resistant fractions which mask the effect of higher litter N content.

5.2.4.2 *C: N ratio*

The C: N ratio of the decomposing litter showed significant variation between tree species. Many reports highlighted the inverse relationship between C: N

ratio and litter decay rate. Litter with high initial nitrogen content and low C: N ratios are known to decompose rapidly (Singh and Guptha, 1977; Meentemeyer, 1978). A lower initial C: N ratio can enhance the rate of decomposition (Rao *et al.*, 1994). *Artocarpus* with lower C: N ratio had faster decomposition rate as compared to *Macaranga* that had comparatively higher C: N ratio. Over the months, there was a general decline in the C: N ratio for all the species till the end of the study. This decline was more pronounced during the initial three months that witnessed heavy decomposition for all the species. The increased microbial activity and the consequent drain in C source explain the reduction in C: N ratio during this period (Aber and Mellilo, 1980).

5.2.4.3 *Lignin content*

Lignin content of the litter corresponding to the pepper support trees under investigation had strongly influenced the rate of biomass decomposition except *Casuarina equisetifolia*. The slowly decomposing tree species like *Macaranga peltata* exhibited higher lignin content while fast decomposing *Artocarpus heterophyllus* reported lower lignin content. Pande (1999) in tropical plantation observed that lignin as well as lignin: nitrogen ratio indicated a negative correlation with the decomposition rate. The general increase in litter lignin content especially during the later part of the decomposition could be the reason for the corresponding slower decay rate during this period.

5.2.5 Effect of environmental factors on the rate of litter decomposition
5.2.5.1 *Soil and climatic Factors*

Better quality of the litter coupled with ambient soil moisture levels triggers the activity of soil fauna resulting in rapid litter decomposition (Pande, 1999). The present study was started during rainy season and the associated high soil moisture status contributed to the bulk mass loss during this period. However, the tree standards maintained uniform soil moisture content during the period and hence, the pronounced species variation in litter decomposition may be more influenced by bio chemical quality of the litter than soil moisture content, during the early rapid mass

loss phase. Also, the mass remaining in the litter bags was too little to arrive at any strong correlation between rate of mass loss and the soil moisture content in the later slower phase of litter decomposition.

As regards to the soil pH, no strong relationship could be established with the rate of decomposition though marginal variation among species could be observed. However, compared to open areas, soil pH under tree cover was generally lower. Release of organic acids during the process of biomass decomposition could be the probable reason for this. Such instances have already been reported by Cang *et al.,* (1985).

Reports on the effect of the climate on litter decomposition are in plenty (Singh and Guptha, 1977; Agbim, 1987; Woodwele and Dykeman, 1996). Higher precipitation in the initial phase of decomposition has direct influence on the general rapid mass loss for all the species under investigation. However, intrinsic physico-chemical quality of the litter imposes more control over litter decomposition which explains the species variation in decay rate in the early rapid mass loss phase. The slow litter decay phase with minimal residual litter associated with the dry period could not demonstrate any differential change in the rate of decomposition corresponding to the changes in rainfall. In a tropical home garden situation, Gopikumar *et al.,* (2001) observed that rate of decomposition was more rapid during the south-west monsoon period in both the home garden as well as in the open area.

5.3 NUTRIENT RELEASE PATTERNS FROM THE DECOMPOSING LITTER
5.3.1 Nitrogen

The nitrogen concentration in the fresh litter was reasonably higher for all the pepper support trees under investigation. However, chemical analysis of the fresh green leaves carried out as part of the tree lopping study recorded higher N concentration as compared to their corresponding litter. The leaf litters usually contain a lower concentration of nutrients as the major share of which is retranslocated into the plant system before the abscission (Sharma and Pande, 1989). The possibility of the retranslocation cannot be ruled out in this case. Pronounced increase in N content in the decomposing litter was observed for all the tree species especially during the initial months of litter decomposition. Such trends were also reported by other

workers (Kumar and Deepu, 1992). Rapid loss of water-soluble compounds on account of heavy rains during the period better explains the apparent partial increase in N concentration. Further more, intense microbial activity during the early mass loss phase could bring rapid reduction in easily digestible carbon compounds, which cause apparent increase in N content.

The absolute amount of N showed a faster reduction during the initial three months while it was gradual in the subsequent months. Faster mineralization of N in tune with the litter mass loss during the period could be due to the prevailing congenial edaphic conditions. *Acacia, Casuarina* and *Grevillea* recorded fast mineralization of nitrogen seen from the lower absolute values at the end of the study. George (1993) also noted a similar steady reduction in the absolute amount of N in the leaf litter of *Acacia, Ailanthus* and *Casuarina*. As the leaf litter decay, the absolute amount of N was found to decrease as the rate of mass loss was far greater than the concentration increase in nitrogen (Coldwell and Delong, 1980).

5.3.2 Phosphorus

Litter P content in the present study exhibited marginal variation between species. Also, changes in the P content were not prominent during the process of decomposition. The reasonably stable P content in the leaf litter can be due to its immobile nature in the soil atmosphere (Upadhyah, 1987; Sposito, 1989). In general, the phosphorus content recorded a lower status for all the species under study. Relatively better P content was seen for *Macaranga, Ailanthus* and *Artocarpus*.

The absolute amount of P in the litters of black pepper standards showed a steady decline over the one year of decomposition period closely in tune with the litter mass loss patterns. Better control over P release was exhibited by *Macaranga* litter. At the end of one year it can be seen that 95% of P has been released for all the species.

5.3.3 Potassium

As compared to other nutrients, potassium is highly mobile both in plant as well as in the soil system, as it is not structurally bound in the organic compounds (Wild, 1988). In the present study, it can be seen that K concentration exhibited a

characteristic sharp reduction that was much pronounced for species like *Macaranga* and *Artocarpus*. The species difference in K content is also evident in the present study.

The absolute content of K followed a rapid declining trend which is more comparable with the mass loss pattern for all the species under investigation. Heavy rainfall and the associated microbial activities during this period might have caused considerable leaching of K from the litter biomass. The potassium being more mobile element, its transfer may occur by surface runoff that lead to leaching of K from the litter to the soil (Lehmann *et al.,* 1999). Earlier studies have proved that the nutrient input through precipitation was found to be maximum for calcium and potassium (Aggarwal and Lahiri, 1981). This could be the reason for the comparatively higher K status in the decomposing litter especially for the species like *Macaranga* and *Artocarpus* which incidentally recorded high throughfall interception.

5.3.4 Carbon

The carbon content of litter corresponding to different species registered a steady decrease in tune with the decline in biomass over time. The same trends can also be seen in the case of C: N ratio. Enhanced microbial activity during early rapid litter decomposition phase exerts heavy demand on easily fragmentable carbon compounds which explain the decline in the carbon content and consequent reduction in C: N ratio during this period.

The absolute carbon content also displayed a sharp declining trend during the initial 3-4 months and later exhibited a slower but steady declining trend. It can be seen that the decline was much pronounced for species that recorded unprecedented mass loss like *Casuarina* and *Grevillea*. Heavy physical loss from litterbags on account of characteristic fragmentable nature of leaf litter for these species may be the reason for this. During later phase, the slower carbon release may be due to the inability of the decomposers to convert the carbon compounds due to the dominance of bio decay resistant fractions which explains the slow rate at the end.

5.3.5 Relative mineralization efficiency of the nutrients

In the present study, significant difference can be seen between species regarding their rate of mineralization. The nutrient mineralization has been discussed barring those species that recorded unprecedented heavy mass loss viz. *Casuarina, Grevillea* and *Acacia*. In general, potassium appeared to be the fastest mineralized element. Such a trend for potassium is mainly due to the faster rate of leaching of water-soluble fractions from the decomposing residues as emphasized by Staff and Berg (1982). The potassium mineralization was found to be fastest for *Artocarpus*. P and N in the decomposing litter followed faster mineralization for all the species except *Macaranga* and *Ailanthus* where mineralization rate was markedly low for N as compared to P. Also, P showed marginal increase over nitrogen in mineralization rate for the rest of the species. Earlier studies also showed diverse results. In the case of shorea forest at Uttaranchal, the mineralization pattern followed Ca>N>K>Mg>P, which shows the immobile phosphorus as the slowest releaser (Pande, 2001). However, in the present study the pattern followed is K>P>N. A similar nutrient release trend (K>P>N) has been observed from the decomposing litter for *Alnus nepalensis* (Sharma and Ambasth, 1987).

Acacia and *Artocarpus* were found to be the species that promoted fast delivery of nutrients while *Macaranga* and *Ailanthus* exert better control over nutrient release. The variable biochemical quality of the litter could be the reason for this differential nutrient release pattern as noted by many workers (Nair, 1983; George, 1993). Management practices such as lopping and pruning imposes restriction on nutrient intake. It was proved that the pruning considerably reduced the ability of trees like *Acacia* sp. to capture the leached nutrients and lower the uptake of immobile elements like P (Peter and Lehmann, 2000).

5.4 SOIL CHARACTERISTICS UNDER BLACK PEPPER STANDARDS

Physico-chemical attributes of the soil by and large decides the general productivity of any site. This is particularly important in tree based land use systems where the litter dynamics plays a cardinal role in maintaining the site productivity. In the present study, soil physical factors such as soil moisture, bulk density and chemical factors such as pH and soil nutrient status are being discussed.

The soil moisture content during the initial sampling showed significant difference between species, especially for *Ailanthus* and *Artocarpus* and for the rest of the months it was insignificant. Also, marked seasonal variation in soil moisture content has been observed. However, pronounced improvement in soil moisture content on account of tree cover could not be observed in the present study. In general, it can be seen that the soil moisture under trees in this location was lower, which usually in humid tropics vary from 20.5 - 23.5% (Nair, 1983). The annual lopping followed in pepper standards result in the heavy foliage as well as branch loss and much of the time soil remain exposed to sunlight. It takes longer time for canopy closure and this may be the prime reason for the generally low moisture content. However, it can be seen that *Artocarpus* maintained relatively higher soil moisture content as compared to the rest of the species.

The earlier studies at the same location reported soil pH in the tree plots in the range of 6.6-6.8 (Jamaludeen, 1994). In the present study the pH under different pepper standards was lower, showing acidic character and did not show much variation during the initial sampling but displayed difference between species in the subsequent sampling. Soil pH showed an increase during the summer season while lower level was maintained during wet season. Lowering of soil pH during the rainy period could be due to the intense litter decomposition and associated release of organic acids. Towards the dry period, microbial activity in the soil become minimal with the result that pH regains its original higher level. Such observations were also reported by Cang *et al* (1985). Generally, soil pH in the treeless open areas was higher as compared to the soils under tree cover during all stages of sampling. In a study conducted to assess the effect of *Alnus nepalensis* on soil properties, it was found that over five years there, was decrease in the soil pH and K content (Singh, 2000). The influence of the tree litter on soil pH as explained above holds good in this context.
Bulk density is often cited as an important soil property, which is influenced by tree litter dynamics in perennial systems involving trees. In the present study, soil bulk density showed generally lower values as compared to treeless open plots for both the soil depth. Such complementary effect of tree litter in lowering the soil bulk density has been reported for other species. In a study at homegarden at Trivandrum, Isaac and Nair (2002) found that the bulk density of the soil bearing *Artocarpus hirsutus* was significantly lowered as compared to open areas. They also noted an increase in water holding capacity of the soil under study. However, soil bulk density variations

in response to changes in support tree cover are minimal which might take longer period to manifest such differences.

The changes in soil nutrient level were monitored for all support trees and for treeless plots. The N-content in the soil showed a fluctuating trend till the end of the study, though there was an increase towards the end. The addition of leaf litter by litterfall increases the organic carbon content of the soil that facilitates the micro organisms and result in apparent N immobilization in microbial tissues. Subsequently, microbial count diminishes owing to the lack of carbon sources and N eventually released to the soil. The addition of litter is least in the open areas and possibility of N release through litter route is minimum that explains the lower N content of open areas when compared to the tree plots. It can also be seen that the leguminous species rich in nitrogen like *Acacia auriculiformis* maintained higher nitrogen level in the soil. This may be due to the faster transfer of the nitrogen from the *Acacia* litter to the soil. However, the soil nitrogen level in our location 0.59- 0.95% showed marginal increase, when compared to the earlier reported values from the same location 0.15-0.22% (George, 1993).

Marked variation in P content could not be observed either in the tree plots or in the open plots suggesting the strongly immobile nature of P in soil. Earlier studies in the present location indicated the range of P as 11-20 ppm (George, 1993) where as in the present study the range was lower 12- 15 ppm. Phosphorus is generally tightly adsorbed in the highly weathered soil and may be slowly released into the solution with the result that soil solution normally contains very little P compared to the other nutrients (Sposito, 1989; Giles *et al.*, 2002). The low content as well as the consistency in soil P content under different support trees in our study could be the out come of such mechanisms.

The exchangeable potassium content in the soil registered significant difference among tree species and no appreciable change could be noticed in the open areas. Earlier studies in this location have reported K content in the soil within the range of 0.36-0.68% where as in the present study it was lower 0.31-0.46%. It is noteworthy that the soil under *Artocarpus* showed higher K values during all the sampling periods, though its litter had only moderate K content. This may be because *Artocarpus* offered maximum rainfall interception allowing more of potassium to be added through stemflow.

The organic carbon content of the soil was analyzed to monitor the changes on account of tree cover and in general, it was higher. The organic C content in the open areas were lower during all the stages of soil sampling. The general organic carbon content in humid tropics is usually 2% (Young, 1989) and in plantation ecosystems it varies from 3.5 - 4.3% (Sharma and Pande, 1989). The complementary effect of trees in improving the soil organic matter is evident in the study. Litter decomposition and the subsequent release of carbon components improve the soil organic matter in soils under tree cover. The increase in organic-C during the second sampling may be due to the addition of fresh loppings during the period. Interestingly, *Artocarpus* plot maintained higher organic carbon suggesting its superiority in improving soil organic matter status. Production of higher quantity of foliage loppings for *Artocarpus* may explain its ability to improve the soil organic matter. Since there is least addition of litter in open areas they experience the lowest organic C status when compared to tree plots. The general low nutrients status this location may be due to the decline in the soil physical and chemical characteristics induced due to the ageing of the stand.

5. 5 LOPPING OF BLACK PEPPER STANDARDS

Lopping, as an inevitable management practice in black pepper support trees, is another way of biomass addition that favours soil enrichment. In the present study significant variation in the lopped out-turns in terms of branches and foliages can be seen. The addition of biomass by branches was maximum for *Macaranga* (1228.50 kg ha^{-1} yr^{-1}) while for leaves it was maximum for *Artocarpus* (2177.23 kg ha^{-1} yr^{-1}) followed by *Acacia* (1684.7 kg ha^{-1} yr^{-1}). Addition of higher quantity of foliar biomass by the way of lopping for *Artocarpus* may be the reason for higher organic carbon and potassium in its soil. Higher turnover of these elements through lopped foliage for *Artocarpus* validates this observation. In general, it was found that absolute nitrogen supply by way of foliage was maximum for *Acacia*. The nitrogen fixing ability coupled with higher return of lopped foliage explains the high nitrogen supplying ability of *Acacia*. The needled leave species like *Casuarina* recorded the lowest lopping in terms of both foliage and branchwood. The smaller leaves and short nature of these trees may be the reason for their low lopping output. The nutrient

status of the loppings for all the tree species was invariably higher than that of the litterfall. This has been established in earlier studies (Nair, 1983).

5.6 RAINFALL INTERCEPTION STUDIES ON BLACK PEPPER STANDARDS

To characterize the precipitation interception potential, throughfall was monitored for tree cover under different support trees. The species variation on rainfall interception showed that maximum interception potential was associated with trees having more effective canopy cover that depended on the leaf size and branching pattern. The bigger and broader leaves like that of *Macaranga* and *Artocarpus* offered higher control over throughfall. The needle leaves of *Casuarina* and *Grevillea* and smaller leaf size of *Ailanthus* resulted in poor interception of incoming precipitation. Throughfall was found to be an important factor deciding the K cycling and the small scale nutrient input to the soil (Schroth *et al.*, 2001). The better interception by *Artocarpus* may have promoted the stem leachate flow allowing the nutrients like K to be transferred to the soil. This is evident in the *Artocarpus* plots where the soil K content was the highest.

5.7 PEPPER YIELD

The black pepper vines were raised on different living tree species. Significant difference in the pepper yield was observed for each of the tree species tested. The *Acacia* (2.56 t ha^{-1} dry berry) offered maximum quantity of black pepper while *Macaranga* (0.83 t ha^{-1} dry berry) the least, both in the wet as well as dry weight basis. Such variation in pepper yield depending on the type of the standard is evident from earlier studies. Thomas *et al.* (1996) studied the yield and growth characters of pepper in relation to the seven fast growing tree standards at Livestock Research Station Thiruvazhamkunnu. Considerable variation in pepper yield was observed for different support tree species. Pepper growth in terms of vine height, number of leaves, number of nodes, leaf area index, number of spikes and black pepper yield were maximum when vines were trained on *Garuga pinnata* whereas training vines on *Gliricidia sepium* gave the lowest yield. Korikanthimath and Ankegowda (1999) studied the yield of *Piper nigrum*, grown as a mixed crop with robusta coffee, in the eighth year of planting using four shade tree species (*Erythrina lithosperma, Ficus*

glomerata, *Grevillea robusta* and *Terminalia bellerica*). Yield was significantly higher in vines trained on *Terminalia* (37.5 kg vine-green berries) than the other species. In the present study number of berries per spike was maximum for *Artocarpus* while other parameters such as vine length, spike length and number of laterals per unit area were found to be insignificant between species.

Earlier studies have shown that soil factors and the choice of pepper standards as the major factors deciding pepper yield. Near neutral soil pH, high organic matter content and high base saturation with Ca and Mg were found to enhance the productivity of black pepper vines (Mathew *et al.*, 1995). The results of the above study also indicated that soil pH should be maintained around neutral to obtain best yield response for black pepper. In our site, it can be seen that soil pH was acidic in nature and the litter dynamics over the years seemingly enhanced soil acidity. Soil bulk density, though showed marginal improvement in support tree plots compared to open soils, generally remained unchanged among the support tree plots. The general nutrient level also was lower, showing reduced availability to the trees.

Comparison of the pepper yield in our experimental plots over the past five years suggests that there exist a reduction in pepper yield from 1997 onwards. The *Acacia* always reported the highest pepper yield but the reduction in yield over years is very clear. It was 3.64 t ha^{-1} (97-98), 2.84 t ha^{-1} (98-99), 3.89 t ha^{-1} (2000-2001) and 2.56 t ha^{-1} (2002-2003). For *Artocarpus* and *Macaranga* also this yield reduction was evident (AICRPAF reports; 1998, 1999, 2001). The reduction in the pepper yield during the recent years for all the species suggests the general decline in the productivity of the system. Critical analysis shows that physico- chemical attributes of the soil such as soil pH, bulk density and soil moisture content couldn't inflict an overwhelming impact on the pepper production. Nutrient return through litter dynamics was suboptimal which couldn't bring substantial improvement in soil physico- chemical properties. The MPT's under observation have surpassed rotation age (14 years) and the chunk of the soil nutrients are locked in the tree trunk rendering unavailable for efficient nutrient cycling. There are also reports of such decline in the *productivity of intercropped systems induced by the stand age* (Bray and Gorham, 1964). Caliman *et al.*, (1987) attributed decline in the multistrata system due to irrational management practises and use of heavy machinery. The intensive pruning and the exposure of the site for longer periods may have temporarily disturbed the nutrient cycling process in our site. This may facilitate nutrient leaching from the soil

during heavy rainfall period. Nutrient leaching is also a major cause for the reduction in availability of soil nutrients resulting in nitrate accumulations (Schroth *et al.*, 2000). Pepper standards exhibited varying throughfall interception, which was maximum for *Artocarpus* showing the effect of stem leachate flow and the consequent transfer of mobile elements. However, the nutrient loss via this mode has not been estimated.

Among the pepper support trees tested, it can be seen that both *Artocarpus* and *Acacia* could be the best candidates for serving as black pepper standards. Both these species had high lopping out turn and nutrient turnover potential, which helped in better maintenance of organic matter status and soil nutrients. The high pepper yield associated with *Acacia* is attributed to many factors. Physical suitability as support for trailing pepper vines appears to be a cardinal factor for the pepper yield. Also, amenability of Acacia for heavy lopping favoured better vine height. Furthermore, the complementary role of *Acacia* in improving the site productivity by way of nitrogen transfer into the soil is evident in the present study. Higher litter production and decay rates coupled with better rain water interception, associated with *Artocarpus* may have contributed to the better maintenance of good soil organic matter status and site productivity which boosted its pepper yield. *Grevillea* and *Casuarina*, recorded moderate pepper yield, may be because of their lower litter yield and nutrient content. *Macaranga* and *Ailanthus* had the lowest pepper yield. In spite of the better litter yield, lopped out turn and rainfall interception of *Macaranga*, the poor nutrient content and slower litter decay rates offered little scope for soil improvement. Moreover, the poor physical suitability of *Macaranga* added to its low pepper yield. *Ailanthus* had the lowest litter fall and lower lopping out turn. The biochemical quality of the *Ailanthus* litter also offered lower decay of litter that resulted in lower mineralization and the consequent lower black pepper yield.

SUMMARY

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SUMMARY

Land-use systems based on tree crops, such as multistrata agroforestry systems, have clear advantages over annual cropping systems in the maintenance of soil fertility in the humid tropics. These include long-term soil protection, soil biogeochemical processes which favour litter decomposition and soil structural improvement, and more efficient nutrient cycling. The role of MPT's in promoting the sustainability of the system is of great concern and is relevant as the future criteria for the selection of suitable species. However, soil productivity decline under such systems has repeatedly been observed. Well-designed, medium to long-term soil fertility studies are necessary to enable us to define more clearly the conditions for the sustainability and productivity of tree crop based land-use systems in the humid tropics.

The present study that has been conducted at Live Stock Research Station, Thiruvazhamkunnu, Kerala pertains to the litter dynamics and soil fertility changes associated with some of the selected fast growing tree species that has been used as the standards for trailing the black pepper. The species used are *Casuarina equisetifolia* J.R. & G. Forst, *Macaranga peltata* (Roxb) M.-A, *Ailanthus triphysa* (Dennst.) Alston, *Artocarpus heterophyllus* (Linn), *Acacia auriculiformis* (A. Cunn.) ex Benth, *Grevillea robusta* (A. Cunn.) ex R. Br.

The salient outcome of this study are briefed below:

1. Moderate levels of annual litter production have been shown by different pepper support trees under investigation as compared to other systems involving woody perennials. *Artocarpus* (4653.63 kg ha^{-1}) and *Macaranga* (4550.88 kg ha^{-1}), yielded maximum litter while *Ailanthus* (2221.25 kg ha^{-1}) yielded minimum. *Grevillea* (3036.04 kg ha^{-1}), *Casuarina* (2934.96 kg ha^{-1}) and *Acacia* (2879.21 kg ha^{-1}) showed moderate litter production. In general, annual litter production by pepper support trees was moderate as compared to other similar ecosystems involving tree species. Intensive loppings of support trees as stand management practice in pepper standards were found to exert heavy control over annual litter production.

2. Monthly litter production among the tree species varied significantly except for the initial four months. For *Casuarina, Macaranga* and *Artocarpus* bimodal pattern of litter production was observed while *Ailanthus, Acacia* and *Grevillea* exhibited monomodal pattern. Seasonal variation of litterfall shows that the maximum litter production for most of the species occurred during December while lean period for litter production was confined to April-May. The litterfall turnout was maximum during the dry period for the entire tree species studied with the litterfall ranging between 50.22% (*Casuarina*) to 72.24% (*Ailanthus*). The period characterized by relatively high rainfall contributed lowest litterfall ranging between 27.76% (*Ailanthus*) to 49.78% (*Casuarina*).

3. Nitrogen content in the litter fall showed marked seasonal variation. Generally, higher N content were registered by litter corresponding to November- December and July – August, while April- May were lean periods. Nitrogen content in the litterfall was found to be maximum for those trees that fix nitrogen viz. *Acacia* and *Casuarina*. *Macaranga* (68.13 Kg ha^{-1}) and *Artocarpus* (65.75 Kg ha^{-1}) were found to be the species delivering maximum absolute amount of nitrogen in to the soil on an annual basis by way of litter while *Ailanthus* (35.92 Kg ha^{-1}) supplied the minimum.

4. Phosphorus concentration remained stable in the monthly litterfall for different tree species. Implicit in it is the relatively immobile nature of P in the plant system. The study on annual deposition of phosphorus by pepper standards showed that *Macaranga* (6.63 Kg ha^{-1}) and *Artocarpus* (6.53 Kg ha^{-1}) were in forefront in delivering the phosphorous to the soil while *Acacia* (2.13 Kg ha^{-1}) was the least contributor.

5. Litter potassium content varied significantly among the trees from 0.06% (*Casuarina*) to 0.34% (*Macaranga*). Seasonal variation in K content indicates a general increase with a peak during February- March. At the end of the study period, the annual potassium accretion rate was maximum for *Macaranga* (11.05 Kg ha^{-1}) and was least for *Casuarina* (2.04 Kg ha^{-1}).

6. *Artocarpus* (17.38) and *Acacia* (13.96) maintained higher litter C: N ratio among the support trees studied. Dry months (January- May) indicated generally higher C: N ratios for *Macaranga, Artocarpus* and *Acacia.*

7. As a stand management practice tree lopping yielded sizeable biomass for soil amendment which varied among the tree species. The lopped branch wood weight was maximum for *Macaranga* (1228.50 Kg ha^{-1}) and minimal for *Grevillea* (234.45 Kg ha^{-1}). Also the leaf biomass addition, by the way of loppings was maximum for *Artocarpus* (2177.23 Kg ha^{-1}) and lowest for *Grevillea* (376.57 Kg ha^{-1}). The nitrogen returned to soil in the foliage loppings was maximum for *Acacia* (60.31 Kg ha^{-1}) and least was for *Casuarina* (10.85 Kg ha^{-1}). Phosphorus return was maximum for the *Artocarpus* (5.46 Kg ha^{-1}) and least for *Grevillea* (0.73 Kg ha^{-1}). Potassium return showed highest value in *Artocarpus* (10.23 Kg ha^{-1}) and minimum for *Grevillea* (1.43 Kg ha^{-1}). Higher nutrient content and C: N ratio associated with fresh loppings as compared to litter suggests possibility of nutrient translocation from senescing organs.

8. The rate of leaf biomass decomposition was generally faster for all the species studied. During the one-year period, all the species lost more than 91% of their initial biomass. Heavy unconventional mass loss was observed for *Casuarina, Grevillea* and *Acacia* most likely due to the easily fragmentable foliage characteristics and consequent physical loss from litterbags. Barring these species, *Artocarpus* showed relatively faster rate of litter decomposition. Among the species, *Macaranga* and *Ailanthus* showed lower rate of decomposition. All the selected tree species showed a characteristic biphasic pattern of biomass decomposition, with the initial phase of heavy mass loss (3-4 months), followed by a gradual mass loss phase that extended for 6-8 months. Decay coefficients ranged from 0.73 (*Casuarina*) to 0.19 (*Macaranga*). The exponential equation showed a good fit for all the species.

9. Diverse factors are responsible for the variation in litter decay exhibited by different species. It was found that the initial nitrogen or C: N ratio could not establish strong relationship with rate of decomposition. However, there was a general reduction in the C: N ratio as the decomposition advanced. The lignin

content of the leaf biomass was found to influence the rate of litter decomposition. *Artocarpus* registered lower level of lignin, which in turn was reflected in its faster rate of decomposition. *Macaranga* and *Ailanthus* with higher level of lignin showed lower rate of decomposition. In general, lignin control over litter decomposition was prominent for all the species during the slow decomposition phase as indicated by its higher concentration during the period.

10. Higher nitrogen concentration in the decomposing litter has been recorded by all species compared to that of fresh litter. This relative increase in N content could be attribute of the leaching of water-soluble carbon compounds during the early fast decomposition phase. Among the species, *Acacia* and *Ailanthus* showed higher N content in the decomposing litter. In general, the nitrogen concentration showed an initial increasing trend, during the early months of decomposition. The phosphorous content in the decomposing litter showed only marginal variation between species suggesting its stable content in the plant system. The maximum content were observed for *Macaranga* and *Artocarpus* while the least content was observed for *Casuarina*. The potassium content showed a sharp declining trend for all the species for the initial three months followed by a gradual decrease till the end of the study. The initial potassium content was maximum for *Artocarpus* and was found to be least for *Casuarina*.

11. Despite the fluctuations in the nutrient concentration, all the tree species exhibited a steady declining trend with regard to the absolute mass of nutrients which in turn followed their respective litter mass loss pattern. But for *Casuarina, Grevillea* and *Acacia* that exhibited unconventional mass loss during the initial months, *Artocarpus* registered faster rate of nutrient accretion. The slow litter decomposing species like *Macaranga* and *Ailanthus* recorded lower rate of mineralization with regard to most of the nutrients. The general order of nutrient in terms of their respective releasing capacity was K>P>N.

12. The higher soil moisture on account of monsoon rains invariably increased the decay rates for all the tree species. However, interspecific variation in soil moisture content was not observable in the study. Complementary effect of trees in improving soil bulk density is evident inspite of their limited variation due to

different tree cover. Soil pH generally was lower in soil under pepper standards compared to open treeless areas, most likely on account of release of organic acids through litter decomposition.

13. Characteristic increase in soil nitrogen content on account of tree litter addition could not be observed in the present study. Leguminous species like *Acacia* were found to improve the soil N content. Soil P content remained reasonably stable for soils under various pepper support trees. Soil K content also failed to establish characteristic variation on account of different tree covers. However, soils under *Artocarpus* reported maximum K content while *Casuarina* recorded the minimum. The organic carbon content in the soil under each species showed considerable difference among the trees. The soil under *Artocarpus* and *Macaranga* showed maximum carbon content.

14. Overall trends indicate marginal decline in soil productivity in the tree based pepper production system under study, as characterised by the lower litter production and nutrient turn over. Efficiency of trees as potential source of nutrient cycling and soil productivity improvement has been affected by tree age and management practices such as tree pruning.

15. The study to compare the rainfall interception by pepper standards showed considerable difference between species. Maximum rainfall interception was attributed to *Artocarpus* followed by *Macaranga* that may have contributed to stem leachate flow. Tree cover in general, contributed higher rainwater interception as compared to treeless open areas.

16. Significant variation in the growth performance has been observed among the various support trees. *Acacia* (64.67 cm) excelled other species in terms of radial growth. Height growth was maximum for *Casuarina* (13.68 m) while it was found lowest for *Ailanthus* (8.47m). The black pepper vine length and spike length did not exhibit appreciable variation among the species. The number of berries per spike was found to be maximum for *Artocarpus* (31) while the least value was represented by *Macaranga* (18). The pepper yield in terms of the number of laterals in unit area was not found to vary between species.

17. The yield of pepper varied significantly between pepper standards trees. *Acacia* (2.56 t ha^{-1}) and *Artocarpus* (1.91 t ha^{-1}) were foremost in terms of dry berry yield. *Macaranga* (0.83 t ha^{-1}) and *Ailanthus* (0.93 t ha^{-1}) were the lowest in terms of pepper yield. Among the pepper support trees tested, Artocarpus served as better standard for black pepper. It had good physical suitability, high lopped out turn and nutrient turnover potential which helped in better maintenance of organic matter status and soil nutrients. The higher berry yield in the case of *Acacia* could be on account of its better physical suitability for pepper anchorage and amenability to heavy lopping. However, the general reduction in yield of black pepper for each standard over years hints to a declining trend in the productivity of this system, probably induced by the ageing of the stand.

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*** Originals not seen***

APPENDICES

Appendix-1

Weather parameters for the experimental period (August-2002 to August -2003).

Month	Mean Maximum Temperature (^{o}C)	Mean Minimum Temperature (^{o}C)	Rainfall (in mm)
August - 2002	29.4	22.4	481.4
September - 2002	32.9	22.4	49.2
October - 2002	32.1	22.5	821.4
November - 2002	33.2	22.3	63.0
December - 2002	34.1	17.5	-
January - 2003	35.3	18.7	-
February - 2003	36.3	21.0	164.6
March - 2003	35.7	22.3	41.4
April - 2003	35.4	23.6	128.8
May - 2003	34.7	24.3	134.4
June - 2003	31.1	22.9	433.2
July - 2003	30.0	22.3	575.4
August - 2003	30.9	22.4	230.9
		Total rainfall	3123.7

Source: Meteorological observatory Live Stock Research station, Thiruvazhamkunnu.

Appendix-2

Relationships between time elapsed and absolute nutrient content of residual decomposing litter of various tree species

Species	Nutrient	Nutrient Equation	Coef. A	Coef. B	Coef. C	R^2
1. *Casurina equisetifolia*	N	Y = A+B/X+C/X*X	0.00084	0.05134	-0.0000051	0.9997
		Y = A+B*X+C/X	0.03611	-0.003832	0.00009639	0.9988
		Y = A+ B/X	0.01695	0.0000983		0.9977
	P	Y = A+B/X+C/X*X	-0.0009425	0.05189	-0.000005179	0.9998
		Y = A+B*X+C/X	0.03513	-0.003958	0.00009649	0.9989
		Y = A+ B/X	0.01534	0.00009847		0.9978
	K	Y = A+B/X+C/X*X	-0.006291	0.05536	-0.00005526	0.9999
		Y = A+B*X+C/X	0.03286	-0.004357	0.00009671	0.9989
		Y = A+ B/X	0.01108	0.00009889		0.9976
	C	Y = A+B/X+C/X*X	-0.0039801	0.03995	-0.000003985	0.9999
		Y = A+B*X+C/X	0.02425	-0.003140	0.00009758	0.9994
		Y = A+ B/X	0.008546	0.00009915		0.9988
2. *Macaranga peltata*	N	Y = A*B^(1/X)*X^C	0.9552	0.9995	-0.5062	0.9617
		Y = 1(A*(X+B)^2+C)	-0.01557	-12.55	3.283	0.9612
		Y = A*e^((lnX-B)^2/C)	2.395	-4.710	-23.22	0.9588
	P	Y = 1/(A+B*X)	0.9918	0.4859		0.9771
		Y = A*e^((X-B)/C)	0.1973	9.384	54.02	0.9799
		Y = 1(A*(X+B)^2+C)	-0.01039	-27.88	8.95	0.9799
	K	Y = A+B/X+C/X*X	0.03423	0.3642	-0.00003641	0.9940
		Y = A*e^((X-B)/C)	0.07426	7.016	20.04	0.9823
		Y = A+B*lnX	0.2634	-0.08244		0.9686
	C	Y = A*e^((X-B)/C)	0.1124	9.879	44.63	0.9959
		Y = A*e^((lnX-B)^2/C)	3.799	-4.869	-14.11	0.9921
		Y = 1/(A+B*X)	0.6030	0.9300		0.9870

Species	Nutrient	Nutrient Equation	Coef. A	Coef. B	Coef. C	R^2
3. *Ailanthus*	N	Y = A+B*X+C*X*X	0.9745	-0.2449	-0.01782	0.9535
triphysa		Y = A*B^(1/X)*X^C	0.7669	0.9993	-0.7470	0.9461
		Y = A*e^((X-B)/C)	0.1654	8.099	38.09	0.9472
	P	Y = 1(A*(X+B)^2+C)	-0.02723	-19.65	11.17	0.9687
		Y = 1/(A+B*X)	0.9853	0.8249		0.9620
		Y = A*e^((X-B)/C)	0.1306	8.38	33.79	0.9625
	K	Y = A+B/X+C/X*X	-0.0005139	0.3991	-0.00000399	0.9906
		Y = A+B*lnX	0.2430	-0.08503		0.9565
		Y = A+B*X+C/X	0.2983	-0.03468	0.00007017	0.9514
	C	Y = A+B/X+C/X*X	-0.009997	0.5384	-0.00005383	0.9874
		Y = A*e^((lnX-B)^2/C)	5.524	-4.96	-10.57	0.9849
		Y = A*B^(1/X)*X^C	0.5785	0.999	-1.153	0.9825
4. *Artocarpus*	N	Y = A+B/X+C/X*X	-0.06001	0.5075	-0.00005073	0.9890
heterophyllus		Y = A+B*lnX	0.2213	-0.08844		0.9128
		Y = A+B*X+C/X	0.2890	-0.03790	0.00007111	0.8995
	P	Y = A+B/X+C/X*X	-0.06747	0.5006	-0.00005005	0.9925
		Y = A+B*lnX	0.2129	-0.08925		0.9215
		Y = A*e^((X-B)/C)	0.01493	7.290	12.43	0.9293
	K	Y = A+B/X+C/X*X	-0.05466	0.3289	-0.00003288	0.9918
		Y = A+B*lnX	0.1763	-0.09034		0.9686
		Y = A+B*X+C/X	0.1612	-0.0225	0.00008389	0.9470
	C	Y = A+B/X+C/X*X	-0.06762	0.4580	-0.00004579	0.9938
		Y = A*B^(1/X)*X^C	0.3552	0.9985	-1.776	0.9378
		Y = A*e^((X-B)/C)	0.009577	7.507	11.98	0.9373

Species	Nutrient	Nutrient Equation	Coef. A	Coef. B	Coef. C	R^2
5. *Acacia auriculiformis*	N	Y = A+B/X+C/X*X	-0.01113	0.2235	-0.00002234	0.9875
		Y = A+B*lnX	0.1848	-0.08791		0.9745
		Y = A+B*X+C/X	0.1301	-0.01421	0.00008699	0.9632
	P	Y = A+B/X+C/X*X	-.01797	0.2008	-0:00002007	0.9943
		Y = A+B*lnX	0.1726	-0.08894		0.9835
		Y = A+B*X+C/X	0.1129	-0.01355	0.00008871	0.9764
	K	Y = A+B/X+C/X*X	-0.01465	0.1424	-0.00001423	0.9969
		Y = A+B*X+C/X	0.07684	-0.009353	0.00009232	0.9877
		Y = A+B*lnX	0.1592	-0.08951		0.9836
	C	Y = A+B/X+C/X*X	-0.02606	0.1941	-0.0000194	0.9975
		Y = A+B*lnX	0.1637	-0.08983		0.9880
		Y = A+B*X+C/X	0.1039	-0.01379	0.00008961	0.9824
6. *Grevillea robusta*	N	Y = A+B*X+C/X	0.07858	-0.008292	0.00009214	0.9814
		Y = A+ B/X	0.03711	0.00009629		0.9766
		Y = A+B/X+C/X*X	0.01974	0.05538	-0.000005529	0.9789
	P	Y = A+B*X+C/X	-0.08037	-0.009582	0.00009196	0.9805
		Y = A+B/X+C/X*X	0.1151	0.06674	-0.000006664	0.9775
		Y = A+ B/X	0.03246	0.00009675		0.9742
	K	Y = A+B*X+C/X	0.04608	-0.005517	0.000095391	0.9927
		Y = A+ B/X	0.01849	0.00009815		0.9906
		Y = A+B/X+C/X*X	0.006869	0.03708	-0.000003698	0.9916
	C	Y = A+B*X+C/X	0.05475	-0.006785	0.00009452	0.9926
		Y = A+B/X+C/X*X	0.004818	0.05102	-0.000005093	0.9914
		Y = A+ B/X	0.002082	0.00009792		0.9894

Appendix-3

Statistical models used to represent the absolute content of the nutrients in the residual mass of various tree species

Sl. No.	Equation	Explanation
1.	$Y=A+B*X$	Straight line model
2.	$Y=B*X$	Line through origin
3.	$Y=1/(A+B*X)$	Reciprocal straight line model
4.	$Y=A+B*X+C/X$	Line and reciprocal model
5.	$Y=A+B/X$	Hyperbolic function
6.	$Y=X/(A*X+B)$	Reciprocal hyperbolic function
7.	$Y=A+B/X+C/X*X$	Second order hyperbolic function
8.	$Y=A+B*X+C*X*X$	Parabolic function
9.	$Y=A*X+B*X*X$	Par at origin function
10.	$Y=A*X^B$	Power function
11.	$Y=A*B^X$	Modified power function
12.	$Y+B^{(1/X)}$	Root function
13.	$Y+A*X^{(B*X)}$	Super geometric function
14.	$Y+A*X^{(B/X)}$	Modified geometric function
15.	$Y=A*e^{(B*X)}$	Exponential function
16.	$Y=A*e^{(B/X)}$	Modified exponential function
17.	$Y=A+B*\ln(X)$	Logarithmic function
18.	$Y=1/(A+B*\ln(X))$	Reciprocal log function
19.	$Y=A*B^X*X^C$	Hoerl function
20.	$Y=A*B^{(1/X)}*X^C$	Modified Hoerl function
21.	$Y=A*e^{((X-B)/2)}$	Normal function
22.	$Y=A*e^{((\ln(X)-B)^2/C)}$	Log normal function
23.	$Y=A*X^B*(1-X)^C$	Beta function
24.	$Y=A*(X/B)^C*e^{(X/B)}$	Gamma function
25.	$Y=1(A*(X+B)^2+C)$	Cauchy function

Abstracts of ANOVA tables

Abstracts of ANOVA tables for litterfall of the six tree species

Source	d.f	Mean square
Between species	5	54182.272*
Within species	2	5190.635
Error	10	9393.800

Abstracts of ANOVA tables for the nutrient concentrations in the litterfall of six tree species

Nitrogen

Source	d.f	Mean square
Between species	5	2.912*
Within species	2	0.491
Error	10	0.142

Phosphorus

Source	d.f	Mean square
Between species	5	0.010*
Within species	2	0.001
Error	10	0.0001

Potassium

Source	d.f	Mean square
Between species	5	0.027*
Within species	2	0.001
Error	10	0.0001

Carbon

Source	d.f	Mean square
Between species	5	0.605*
Within species	2	0.372
Error	10	0.302

C: N ratio

Source	d.f	Mean square
Between species	5	17.585*
Within species	2	1.118
Error	10	1.025

Abstracts of ANOVA tables for the lopping done on six tree species

Weight of branch wood

Source	d.f	Mean square
Between species	5	525738.707*
Within species	2	17029.499
Error	10	61414.779

Weight of leaves

Source	d.f	Mean square
Between species	5	1641129.594*
Within species	2	100001.918
Error	10	194341.362

Abstracts of ANOVA tables for the leaf biomass decomposition of six tree species

Source	d.f	Mean square
Between species	5	153.765*
Within species	2	2.036
Error	10	5.635

Abstracts of nutrient concentration in decomposing litter

Nitrogen

Source	d.f	Mean square
Between species	5	0.270*
Within species	2	0.015
Error	10	0.038

Phosphorus

Source	d.f	Mean square
Between species	5	0.002*
Within species	2	0.0001
Error	10	0.00002

Potassium

Source	d.f	Mean square
Between species	5	0.014*
Within species	2	0.0001
Error	10	0.0001

Carbon

Source	d.f	Mean square
Between species	5	20.245*
Within species	2	0.585
Error	10	0.503

C: N ratio

Source	d.f	Mean square
Between species	5	
Within species	2	
Error	10	

Relative mineralization efficiency

Nitrogen

Source	d.f	Mean square
Between species	5	1208.299*
Within species	2	6.158
Error	10	41.873

Phosphorus

Source	d.f	Mean square
Between species	5	725.176*
Within species	2	4.402
Error	10	26.396

Potassium

Source	d.f	Mean square
Between species	5	109.692*
Within species	2	0.399
Error	10	10.370

Pepper yield

Wet weight of berries

Source	d.f	Mean square
Between species	5	9.575*
Within species	2	0.264
Error	10	1.006

Dry weight of berries

Source	d.f	Mean square
Between species	5	1.275*
Within species	2	0.033
Error	10	0.135

Girth

Source	d.f	Mean square
Between species	5	181.285*
Within species	2	4.047
Error	10	19.780

Height

Source	d.f	Mean square
Between species	5	9.732*
Within species	2	1.597
Error	10	0.707

Vine-length

Source	d.f	Mean square
Between species	5	4.897
Within species	2	9.468
Error	10	5.699

Spike length

Source	d.f	Mean square
Between species	5	0.570
Within species	2	0.500
Error	10	0.215

Number of berries

Source	d.f	Mean square
Between species	5	85.867*
Within species	2	3.167
Error	10	13.833

Number of laterals

Source	d.f	Mean square
Between species	5	2.597
Within species	2	0.493
Error	10	0.817

Abstracts of ANOVA tables for the soil properties under six tree species

Soil moisture

Source	d.f	Mean square
Between species	6	1.807
Within species	2	4.221
Error	12	1.325

Soil pH

Source	d.f	Mean square
Between species	6	0.051*
Within species	2	0.026
Error	12	0.012

Soil bulk density (5cm)

Source	d.f	Mean square
Between species	6	0.001
Within species	2	0.003
Error	12	0.001

Soil bulk density (10cm)

Source	d.f	Mean square
Between species	6	0.001
Within species	2	0.002
Error	12	0.0001

Soil N content

Source	d.f	Mean square
Between species	6	0.009*
Within species	2	0.005
Error	12	0.002

Soil P content

Source	d.f	Mean square
Between species	6	0.002*
Within species	2	0.0001
Error	12	0.001

Soil K content

Source	d.f	Mean square
Between species	6	0.003*
Within species	2	0.001
Error	12	0.0001

Soil C content

Source	d.f	Mean square
Between species	6	0.765*
Within species	2	0.289
Error	12	0.100

Rainfall

Throughfall interception by trees

Source	d.f	Mean square
Between species	6	3134.202*
Within species	2	27357.08
Error	12	1928.338

Significant @ 5% level

ABSTRACT

A field trial was conducted at Livestock Research Station, Thiruvazhamkunnu, Kerala during August 2002 - August 2003 to characterize the litter dynamics and nutrient flux associated with seven MPTS used as support for black pepper. The study covered quantification of litter production, litter decomposition, nutrient release pattern through litter route and the changes in soil properties and site productivity in terms of pepper yield. The pepper support tree species under study included, *Casuarina equisetifolia* J.R. & G. Forst, *Macaranga peltata* (Roxb) M.-A, *Ailanthus triphysa* (Dennst.) Alston, *Artocarpus heterophyllus* (Linn), *Acacia auriculiformis* (A. Cunn.) ex Benth, *Grevillea robusta* (A. Cunn.) ex R. Br. The experiment was superimposed on a pre-existing, fourteen- year- old pepper stand in a Randomized Block Design with three replications.

Generally, moderate levels of litter production has been shown by different pepper support trees under investigation. Annual litter yield was maximum for *Artocarpus* (4653.63 kg ha^{-1}) and *Macaranga* (4550.88 kg ha^{-1}), while *Ailanthus* (2221.25 kg ha^{-1}) yielded minimum. Nutrient level in litterfall varied between species. Maximum N content was associated with nitrogen fixing trees such as *Acacia* and *Casuarina*.

The leaf litter decomposition rate was generally faster for all the species with almost 90 per cent mass loss within three months. *Artocarpus* showed faster rate of litter decomposition while *Macaranga* and *Ailanthus* were relatively slow decomposers. Unprecedented heavy mass loss was registered by *Casuarina, Grevillea* and *Acacia* from their litterbags owing to physical nature of the litter. All the selected tree species showed a characteristic biphasic pattern of litter decomposition. Decay coefficients ranged from 0.73 (*Casuarina*) to 0.19 (*Macaranga*). The exponential equations relating mass loss over time were worked out for all the species. The lignin content of the leaf litter was found to excerpt negative influence on the rate of litter decomposition. The general order of nutrient in terms of their releasing capacity from the decomposing litter was K>P>N. *Acacia* and *Artocarpus* registered faster rate of nutrient accretion. Changes in soil properties such as moisture content, pH and bulk density was marginal on account of the

presence of tree species. Leguminous species like *Acacia* was found to improve the soil N content.

Maximum rainfall interception was attributed to *Artocarpus* followed by *Macaranga*. The yield of pepper in terms of dry berry weight was maximum for *Acacia* (2.56 t ha^{-1}) and *Artocarpus* (1.91 t ha^{-1}). Better physical suitability, high lopped out turn and nutrient turnover potential suggest these species as ideal candidates for trailing pepper. However, the general reduction in soil physical and chemical properties and reduction in the yield of black pepper for each standard over years suggest a declining trend in the productivity of this system, probably induced by the ageing of the stand as well as the heavy management practice followed.

Plate 1 A close-up view of black pepper plot

Plate 2 A panoramic view of black pepper plot

Plate 3 Litter trap along with the litter bags tied to pegs and rainwater measuring
   bottles

Plate 4 A view of litter traps placed among the plots