FOLIAR NUTRIENT CONTENT AND DECOMPOSITION OF GREEN MANURE SPECIES VIZ. *Gmelina arborea* Roxb. AND *Mallotus philippensis* (Lam.) Muell. Arg.

By

VINU JACOB

2011-17-109

THESIS

Submitted in partial fulfillment of the requirement for the degree of

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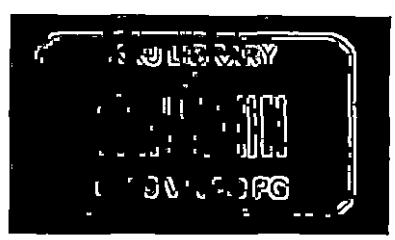

DEPARTMENT OF FOREST MANAGEMENT AND UTILIZATION

COLLEGE OF FORESTRY

VELLANIKKARA, THRISSUR – 680 656

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2014

DECLARATION

I hereby declare that this thesis entitled **"Foliar nutrient content and decomposition of green manure species viz. *Gmelina arborea* Roxb. and *Mallotus philippensis* (Lam.) Muell. Arg."** is a bonafide record of research done by me and that this thesis has not previously formed the basis for the award of any degree, diploma, fellowship or other similar title, of any other University or Society.

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Dedicated to my
Teachers and Parents

Introduction

1. INTRODUCTION

Tropical soils are reported to have low content of soil organic matter when compared to temperate soils. The tree biomass retains a considerable amount of nutrients in tropical forests. In agroforestry systems where trees and annual crops grow in close association, trees absorb nutrients from the deep soil horizons, with the help of their extensive and deep root system; which are not accessible to annual crops with roots concentrated in top soil. Decomposition of these tree litters can make the nutrients available to the annual crops.

The rate at which litter gets decomposed and finally gets converted into CO_2 and mineral elements depend on the substrate or litter quality and activity of soil fauna involved in the decomposition process. Recycling of nutrients from the litter is an important aspect and the rate and timing of its release plays an integral role in the ecosystem functioning. The dynamics of litter production and decomposition are the processes that replenish the soil nutrient pools, maintain soil life and thus endow sustainability to these agroforests (Isaac and Nair, 2006).

Kerala is a land blessed with homegardens. Tropical homegardens are one of the oldest forms of managed land-use systems and are considered to be an epitome of sustainability (Kumar and Nair, 2004). Moreover, the homegarden represents a typical agroforestry system which integrates trees with field crops, livestock, poultry and/or fish, having the basic objective of ensuring sustainable production of multiple products such as food, vegetables, fruits, fodder, fuel, timber, medicines and/or ornamentals, besides generating employment and cash income. However, the increasing pressure and the unscientific, unmanaged and intensive land use systems involving heavy use of chemical fertilizers and plant protection chemicals, lack of soil and water conservation measures, unsustainable harvesting methods, etc. consequently degrade the soil, its structure, physico-

chemical properties and even its productivity. Integrated nutrient management, which has come into limelight, can be considered as an important measure to tackle this problem.

Green manuring is a form of organic farming. These crops provide an effective way to enrich soil nutrients (Pieters, 2004). They are generally fast decomposers. The use of organic manure, especially leaf biomass is a traditional practice. They provide numerous benefits like supply of organic matter into the soil, addition of nitrogen, nutrient and soil conservation, high biochemical activity and finally higher crop productivity. Green manure crops have been used to help maintain soil organic matter and improve soil fertility (Biederbeck *et al.*, 1995). Apart from sustaining soil productivity by improving physical and biological soil conditions and preventing degradation of the soil (Milkha *et al.*, 2001), they also serve as soil amendments and nutrient sources for subsequent crops upon mineralization (Cherr *et al.*, 2006). However, its scientific use calls for the knowledge on the rate of decomposition and nutrient release pattern.

Many tree species are used as green manure sources. Among these, *Gmelina arborea* and *Mallotus philippensis* are very suitable in tropical conditions. They are commonly seen in the homesteads of Kerala. The presence of profuse leaves and coppicing behaviour makes them desirable as green manures. Although they are extensively used by the people, no scientific studies have been undertaken in the rate of leaf biomass decomposition and the use of foliage of these two species as manure. Understanding the decomposition and nutrient release pattern of leaf biomass is important in manipulating its incorporation into cropping systems to improve nutrient synchronization (Partey *et al.*, 2011). Moreover, a sound knowledge of rate and nutrient release through leaf biomass decomposition will help to adopt proper manurial packages for various systems.

The present series of studies were undertaken to compare *Gmelina arborea* and *Mallotus phillippensis* with regard to their foliar nutrient content and

decomposition under various field conditions during different seasons. The study is expected to throw some light on the feasibility of using their leaf biomass as green leaf manure in homegardens, which will thus help in developing a package of practice for the farmers in Kerala.

Review of Literature

2. REVIEW OF LITERATURE

In forestry, the term litter refers to the dead plant material (leaves, branches and other plant parts) spread over the forest floor. Litterfall is the major pathway for the return of organic matter and nutrients from aerial parts of the plant community to the soil surface, thus improving the soil fertility (Prasad *et al.*, 2000). Decomposition is an intricate process regulated by chemical characteristics of detritus (Sariyildiz and Anderson, 2003) and by external factors (Corstanje *et al.*, 2006). Litter production and decomposition rates have great importance in maintaining the fertility of soil. Nutrient recycling through litterfall forms an important aspect and the rate and time of its release plays a vital role in ecosystem functioning (Odiwe and Muoghalu, 2003). A substantial portion of nutrients accumulated by plants is returned to the soil as litterfall followed by its decomposition, i.e. the integrity of an ecosystem is maintained by these transfers of matter and nutrients (Hanagata, 2002; Kaushal *et al.*, 2006). In total, the decomposition process influences the build up of soil organic matter, release of nutrient for plant growth and flux of CO_2 from the soil (Freschet *et al.*, 2013).

Decomposition of plant litter includes leaching, break up by soil fauna, transformation of organic matter by micro-organisms and transfer of organic and mineral compounds to the soil. This process is mostly biological but it is influenced by abiotic factors through their effects on soil fauna. Microbes are the primary agents responsible for litter degradation, and consequently, abiotic factors that affect microbial activity, such as temperature, soil type and moisture content also influence decomposition (Dalias *et al.*, 2001). Apart from this, plant species composition is also considered as one of the most important factors affecting litter degradation. In recent years, researchers have studied the interaction of different litter species during the decomposition process (Smith and Bradford, 2003; Gartner and Cardons, 2004).

Mixing litters from different species can increase microbial activity and/or abundance and, consequently, increases litter decomposition (Hansel and Coleman, 1998). However, in some climatic regions, and in the tropics in particular, litter quality parameters seems to be the best predictors of decomposition rates, whereas environmental conditions such as soil characteristics and microclimate tend to be less important (Songwe *et al.*, 1995; Sinha, 1997; Aerts and Caluwe, 1997; Lavalle *et al.*, 1998). However, many studies have concluded that the combination of climate and litter quality is the primary factors controlling litter decomposition (Gholz *et al.*, 2000; Silver and Miya, 2001). Sariyildiz and Anderson (2003) also found a significant correlation between the rates of litter decomposition and the abiotic environment in which decomposition takes place. Altogether, climate, soil characteristics, quality of decomposing organic matter and soil organisms are the most important factors regulating litter decomposition (Wieder *et al.*, 2009).

The simultaneous effects of trees on decomposition both through their litter quality and by modifying the environmental conditions cause positive litter-environment interactions and further increase decomposition (Austin and Vivanco, 2006). Recent studies on decomposition reveal that tree species can also alter decomposition rates, indirectly through effects on environmental conditions (Mitchell *et al.*, 2007).

2.1 LEAF BIOMASS DECOMPOSITION

Litter production and decomposition rates have great importance in maintaining the fertility of the soil. A substantial portion of nutrients accumulated by plants is returned to the soil as litterfall followed by its decomposition, i.e. the integrity of an ecosystem is maintained by these transfers of matter and nutrients. The leaf biomass of the tropical broad leaved trees are reported to retain the major part of the nutrient capital (Gosz *et al.*, 1973; Whitmore, 1984 and Vogt *et al.*, 1986). In tropical ecosystems, maintenance of soil organic pool is achieved by the

high and rapid circulation of nutrients through the fall and decomposition of litter. Standing crop of litter (total forest-floor material) acts as an input–output system of nutrients and the rates at which forest litter falls, and subsequently decays, regulate energy flow, primary productivity and nutrient cycling in forest ecosystems.

2.1.1 Leaf biomass as green manure

The land's nitrogen and other nutrient status get depleted after years of cropping cereals and vegetables with no addition of adequate quantity of manures. The cost of N fertilizers is also increasing continuously. The quality of soils under monoculture cropping system is also deteriorating. Under these circumstances, green manuring is the best method to save our good farmland (Milkha *et al.*, 2001).

Green manuring is the soil incorporation of any green manure crops while they are green or soon after they start flowering. Green manures are forage or leguminous crops that are grown for their leafy materials needed for soil nutrient conservation. The value of 'green manuring' lies in their capability of incorporating organic matter into the soil. Soil nitrogen is associated with the organic matter and the decay of this organic matter influences the availability of the soil nutrients (Pieters, 2004).

Planting of tree species with high biomass production and which are rich in foliar and branch nutrient content can play a major role in maintaining the levels of soil organic matter in alley cropping systems (Young, 1997). A comprehensive knowledge of the organic matter decomposition and nutrient release patterns from leaf litter maximizes soil sustainability and crop productivity (Clark *et al.*, 1998; Mugendi *et al.*, 1999). In this context comes the importance of leaf biomass decomposition.

The wide scale use of leaf biomass by small scale farmers in developing countries has not only increased food crop yields many times by increasing soil fertility, but simultaneously improved the physico-chemical properties of the soil. In low input agroforestry system, leaf litter incorporation offers a strong base for low cost sustainable agriculture production (Budelman, 1989).

The literature emphasizing some of the important factors about the decomposition of leaf biomass of various tree species are reviewed and arranged under the following heads.

2.1.2 Decomposition studies in forest ecosystems

Litter decomposition plays a crucial role in the nutrient budget of forest ecosystems where vegetation depends mainly on the recycling of nutrients contained in the plant detritus. During this process, plant nutrients are recycled within the ecosystem. The litter on the forest floor acts as an input-output system for nutrients (White *et al.*, 1988). In recent years, there has been an increase in the number of studies conducted on litter dynamics. Litter dynamics is the principal renewal mechanism involved in any ecosystem. It is well known that plant litter acts as a temporary sink for nutrients and functions as a 'slow - release' nutrient source (Cuevas and Medina, 1998), thereby guaranteeing a permanent contribution of nutrients to the soil (Freschet *et al.*, 2013).

Shandagi and Nath (2006) reported forest litter decomposition to be controlled by climatic conditions. However, Gladys *et al.* (2002) did not find any significant correlation between litter decomposition and climatic conditions. They reported litter quality to be the main determinant of litter decomposition in forest ecosystems.

In tropical ecosystems, litter dynamics appear to be closely related to seasonal and interannual cycles of rainfall and temperature. Compared to temperate ecosystems, decomposition dynamics are rapid in the tropics because of

high temperature and rainfall eventually increasing microbial action (Kumar *et al.*, 2012). Apart from the abiotic factors, Ibrahima and Ntonga (2010) observed litter decomposition in tropics to be highly influenced by the litter chemistry and specific nutrient composition; whereas McGlynn and Poirson (2012) found litter-dwelling ants to be responsible for accelerating litter decomposition in lowland tropical rain forests.

In temperate forests, mixing of litters of different species and the snow cover on the forest floor directly decreases the mass loss and increases decomposition rate (Aponte *et al.*, 2012; Wu *et al.*, 2013); whereas Parsons *et al.* (2012) found significant contribution of endophytic fungi on the decomposition process. In sub-tropical forests, litter chemistry along with the UV-B radiation is reported to increase the decomposition process (Song *et al.*, 2013). Studies have also shown that mixing litter of temperate tree species with a deciduous tree species can accelerate the decomposition process (Polyakova and Billor, 2007). Jiang *et al.* (2013) ended up with a conclusion that in any forest type, along with the abiotic factors; the successional stage has a profound effect on the decomposition process, i.e. litter of species in the climax stage tended to decompose faster than the pioneer stage.

Mangrove forest dynamics have been cited to significantly contribute to the nutrient metabolism of sub-tropical coastal ecosystems (Ramos *et al.*, 2007). The species composition and the initial nutrient concentration in mangrove leaves are considered to be the key factor influencing litter decomposition (Mfilinge *et al.*, 2002). However, Silva *et al.* (2009) found the combined action of litter quality, tidal submergence, meteorology and soil phosphorus dynamics as the major pathways for litter decay in mangrove forests.

2.1.3 Rate of decomposition

Leaf biomass decomposition rates have been well studied and determined for a wide variety of species throughout the world. It is clear that litter of different species does not decompose at the same rate even under similar environmental conditions (Alexander, 1977).

2.1.3.1 Effect of ecological variations on decay rates

The rate of decomposition of leaf biomass varies with the plant material and the prevailing environmental conditions. The soil type has an important role on the decay process. Goya *et al.* (2008) reported that the annual rate of decay of dry matter was faster in clay soil (0.44) than that in both sandy soils(0.30). However, Pucheta *et al.* (2006) did not find any significant relationship between soil type and litter decomposition in the field. Low rate of decomposition implies a slow rate of nutrient turnover (Bala *et al.*, 2010). The decomposition rates are reported to be higher, ranging from 0.45 to 1.5 per cent per day for tropical forests (Olson, 1963 and Cornforth, 1970). In temperate forests litter decompose at a slower rate. The lowest rates of decomposition have been reported for Californian pine forests, ranging from one to three per cent per annum (Olson, 1963). Tropics are characterized by rapid turnover of nutrients (Lin *et al.*, 2010).

Decay rates are strongly influenced by microenvironment quality, i.e. forest production systems. In a study conducted to determine the influence of stand type on the decomposition rate, leaf litter decay rates of *Peltogyne angustiflora* and *Macrolobium latifolium* were significantly higher in the mixed stand than in the pure stand of the same species, unlike observed for *Arapateilla psilophylla* (Gama *et al.*, 2003). Secondary forest types, which are related to land use intensities prior to abandonment also have an important influence on litter decomposition (Gurvich *et al.*, 2003).

To study the impact of different sites along an altitudinal gradient on the litter decomposition, a study was undertaken by Majila *et al.* (2005). They observed that rates of decomposition highly varied with the sites. Another study by Manoj and Govind (2005) on decay studies using *Quercus leucotrichophora* and *Q. floribunda* found that after a period of thirteen months, total litter decomposed was 75.1 and 66.6 per cent respectively, indicating the fact that sub-tropical tree leaves decompose slowly even in the tropical condition owing to their inherent resistance to microbial activity.

Swarnalatha and Reddy (2011) compared the decomposition rates of natural forest and plantations. Natural forests were reported to have faster decomposition rates. This observation is in contrast with the findings of Cuevas and Lugo (1998) who observed faster decomposition rates in plantations in comparison with natural forests.

2.1.3.2 Effect of species variation on decay rates

Usman (2013) investigated the decomposition patterns of *Quercus leucotrichophora* and *Pinus roxburghii* under glass house conditions. The *Q. leucotrichophora* leaf litter decomposed completely after eleven months; however, 65 per cent weight loss was recorded in *P. roxburghii* leaf litter after twelve months of study.

Leaf litter decomposition of ten contrasting tree species, i.e. *Entandràphragma utile, Guibourtia tessmannii, Klainedoxa gabonensis, Musanga cecropioides, Panda oleosa, Plagiostyles Africana, Pterocarpus soyauxii, Strombosia scheffleri, Vitex grandifolia* and *Xylopia aethiopica* in a tropical forest Ebom, Southwest Cameroon, was studied by Ibrahima and Ntonga (2010). Mass loss of the litter samples varied from 24.08 per cent in *E. utile* to 92.35per cent in *V. grandifolia*. Decomposition rate constants (k) ranged from 0.014 in *M. cecropioides* to 0.165 week in *V. grandifolia*.

Decomposition rates of leaf litter of *Quercus serrata, Q. variabilis* and *Q. mongolica* was studied in a temperate broad-leaved forest ecosystem by Kim (2007). The observed study indicated that mass loss of litters varied significantly among species and responded differently with the lapse of time. The decomposition constant (k) was 0.398 for *Q. variabils*, 0.340 for *Q. mongolica* and 0.297 for *Q. serrata*. The half-life of litter was 1.7 years, 2.0 years and 2.3 years respectively, and the time required for decomposition of 99 per cent of the decay was 7.5 years, 8.8 years and 10.1 years.

In order to determine the interspecific variation in leaf decomposition rates, a study was done by Xu and Hirata (2005) in a sub-tropical forest of China. Dry mass loss at the end of study varied in the order: *Distylium racemosum* < *Quercus miyagii* < *Rapanea neriifolia* < *Symplocos confusa* < *Castanopsis sieboldii* < *Schima wallichii* < *Daphniphyllum glaucescens*.

2.1.3.3 Effect of stand age on decay rates

An experiment was conducted by Wang *et al.* (2012) to study the decomposition rates of leaf litter in *Larix principis* plantations of different ages. Results showed that the mass loss of litter in the plantations of different ages ranged from 48.47 per cent to 61.72 per cent, and a significant difference was observed between different age groups. The decomposition rate of leaf litter in the mature forest was the highest, followed by near-mature forest, middle-aged forest, and young forest.

Ogunyebi *et al.* (2012) investigated the rate of decomposition of *Gmelina arborea* leaf litter in an age series of *G. arborea* plantations in a Nigerian rainforest. All the plantations studied, recorded a faster decomposition rate. Attempts were also made to study the litter dynamics of high density Poplar (*Populus deltioides*) plantations of one to four years old, growing in the Terai belt in Central Himalaya (Lodhiyal *et al.*, 2002). Decomposition increased with

increase in plantation age. In another study undertaken by Jonczak (2009) in poplar 'Hybrid 275' [*Populus (maximowiczii* × *trichocarpa*) cv. Hybrid 275], direct relationship between stand age and decomposition rate was reported. The process of foliar decomposition was fastest in the 54 years old stand, slightly slower in the 28 years old stand and slowest in the 17 years old stand.

Afrira (2013) observed significant differences in the decomposition rates of *Acacia mangium* litter of different stand ages (seven and nine years). While most of the studies have mentioned positive correlation with decay rate and age, Borders *et al.* (2006) and Jha (2010) found no significant relationship with decay rate and stand age.

In a study conducted by Arunachalam and Singh (2002) on the leaf litter decomposition of *Dillenia indica* (evergreen) and *D. pentagyna* (deciduous) in a humid tropical forest of Arunachal Pradesh, India; the decomposition pattern showed different temporal trends. Hundred per cent decomposition was observed after 150 days for *D. indica* and 120 days for *D. pentagyna* .

2.1.3.4 Effect of field conditions and seasons

Field conditions are highly correlated with the decomposition patterns of different species. The lowest residual litter mass recorded from open canopy, was significantly less than the remains of *Jatropha curcas* under closed canopy (Aburge *et al.*, 2011). However, another study by Isaac and Nair (2004) reported substantially greater decomposition in the sub-canopy than in the open, implying a favourable effect of the sub-canopy conditions. Contradictory to this, no significant difference in decomposition (*Acacia mangium, Acacia aulacocarpa* and *Acacia crassicarpa*) was observed between the open area and plantation (Shuhyb, 2004). Oladoye *et al.* (2008) observed faster decomposition of *Leuceana leucocephala* during the wet season. Similar observations were also made by

Aburge *et al.* (2011) who observed that the litter decayed faster during the wet period than the dry period.

Hegde (1995) observed no significant influence of the field conditions, but a slightly faster decomposition rate was recorded in the open condition compared to homegarden. But, he noticed a significant seasonal effect on the decomposition pattern. The decomposition was faster in north-east monsoon particularly during the initial months. But, during the latter part, the rate of decomposition was more rapid in the south- west monsoon season.

2.1.4 Decomposition studies in agro ecosystems

Land use options that increase livelihood security, but reduce vulnerability to climate and environmental changes are necessary. Tree component in any agroforestry system is also very important in the production of biomass. Properly designed agro-silvicultural systems are those in which organic matter loss under the agricultural crop component is compensated by a gain under tree component. The dynamics of litter production and decomposition are processes that replenish the soil nutrient pools, maintain soil life and thus ensure sustainability to agroforestry systems (Isaac and Nair, 2006). The rates at which litter fall and subsequently decay is thus important in understanding the productivity and nutrient budgeting of these agroforestry systems (Isaac and Nair, 2004).

Leaf litter decomposition and nutrient release patterns from five common multipurpose tree species, viz. *Artocarpus heterophyllus, Mangifera indica, Areca catechu, Citrus* spp. and *Tamarindus indica*, found in homegardens of Mizoram, were studied by Upadhyay *et al.* (2012). *Citrus* spp. and *T. indicia* was found to be the most labile species with a comparatively much higher decay constant and faster nutrient release. The initial slow release and immobilization of N in *A. heterophyllus* and *M. indica* leaf litter reflects their potential as a source of nitrogen storage and effective mulching material. While litter from *T. indica* and

Citrus sp. can provide the short-term nutrient need, the foliage of the other three species may supply the long-term nutrient requirement for the understory crops in such agroforestry systems.

In Karnataka, litter decomposition study was conducted by Dhanya *et al.* (2013) to understand the decomposition and nutrient dynamics of *Ficus benghalensis* in a traditional agroforestry system, using surface and subsurface methods of application. Results revealed a marginally higher rate of decay in subsurface placement (22.5 % of initial litter mass remaining after one year of decomposition) compared to surface treatment (28.3 % of initial litter mass remaining). Litter quality and climatic and soil conditions of the study site (monthly rainfall and soil moisture) were found to influence the rate of decomposition.

Leaf litter decomposition and nutrient dynamics of four important agroforestry tree species viz. Bhimal (*Grewia optiva*), Sehtoot (*Morus alba*), Tun (*Toona ciliata*) and Poplar (*Populus deltoides*) were studied by Kaushal *et al.* (2012) by placing the leaf litter in surface and plough/sub-surface layer for one year. Decomposition rate was highest in *M. alba,* followed by *G. optiva*, *T. ciliata* and *P. deltoids* for both the placements. Sub-surface placed litter showed a faster rate of decomposition than surface placed leaf litter.

A study was conducted to analyze production, mass loss and decomposition rates of leaf litter in agroforestry plots with traditional coffee system (TCS), rustic coffee system (RCS) and medium tropical forest (MTF), in Mexico by Villavicencio, (2012). The decomposition rate (k) was highest for *Piper hispidum.* The lowest k values were obtained in *Robinsonella mirandae, Coffea arabica* and *Mastichodendron capirii.*

In order to compare the suitability of oak, pine and lantana litter for soil fertility management in rainfed fields, decomposition experiment was done by

Kandpal and Negi (2003). Litter of lantana released nutrients when agricultural crops required them. Agronomic yield was higher in lantana mulched plots (110 kg/ha) as compared with those mulched with oak (950 kg/ha) and pine (990 kg/ha).

Decomposition studies in a tropical agroforestry system revealed that during 274 day exposure of litter bags in the field, the mass loss in *Leucaena* spp., *Populus deltoides*, *Eucalyptus* spp. and *Prosopis juliflora* was 86.3, 75.6, 60.5 and 69.0 per cent respectively (Bhardwaj *et al.*, 1992). Kumar *et al.* (2008) assessed the effect of multi-purpose trees, i.e. *Prosopis cineraria, Tecomella undulata, Acacia albida* and *Azadirachta indica* on the productivity of *Hordeum vulgare* (barley) in the arid regions of Haryana. The result was found to be positive. *P. cineraria* enhanced grain yield by 86 per cent, *T. undulata* by 48.8 per cent, *A. albida* by 57.9 per cent and *A. indica* by 16.8 per cent over the control. Biological yield was also higher under trees than that in the open area. Soils under different tree canopies were rich in organic carbon content, moisture availability and nutrient status.

2.1.5 Factors affecting biomass decomposition

The decomposition of organic materials and the release of mineral nutrients from the decaying leaf biomass are mainly due to the result of complex interactions between activities of microbial population, which in turn, are affected by many of the following factors.

2.1.5.1 Substrate quality

Leaves of different plant species are well known to lose mass at different rates (Webster and Benfield, 1986). Litter decomposition is affected by the litter chemistry and specific nutrient composition (Ibrahima and Ntonga, 2010; Fernandes *et al.*, 2012). Litter quality influences the decomposition processes as it determines the decomposability of organic material and the nutrient availability to the decomposer community (Keiblinger *et al.*, 2012). In addition, phenolic

compounds, particularly tannins (Ramio *et al.*, 2013) and variation in leaf physiological traits are also important (Santiago and Mulkey, 2005). Zhou *et al.* (2008) reported that for *Populus tremuloides,* decomposition rates were negatively correlated with initial concentrations of condensed tannins and phenolics. However, Ormeno *et al.* (2006) observed a positive correlation between total phenolic compound concentrations and the decomposing litter. Also, the content of water soluble organic material varies greatly with the species. The content of water soluble materials in the leaves of *Fraxinus excelsior* was 32 per cent while, in *Quercus petraea,* it was only 8 per cent (Gilbert and Bocock, 1960). In a study by Loranger *et al.* (2002) on the leaf decomposition in two semi-evergreen tropical forests, litter quality was the main determinant of litter decomposition in the forests.

2.1.5.1.1 Carbon and nitrogen content

Chemical characteristics of the litter material, such as initial nitrogen content and C: N ratio affects decomposition. Loss of litter mass is positively related to the concentration of nitrogen (Usman, 2013 and Watanabe *et al.*, 2013). C: N ratio is accepted as a general index of quality (Seneviratne, 2000). The C: N ratio of pine leaves is conspicuously higher than that of oak due to which pine leaves decompose at slower rates as compared to oak leaves (Ralhan and Singh, 1987). Low C: N ratio leads to immobilization of available N from soil causing poor nutrient availability (Upadhyay and Singh, 1987). Litter with higher initial N concentrations usually shows higher mass loss and respiration rates than those with lower N concentration, but the importance of initial N concentration decreased with time. Vestgarden (2001) and Ross *et al.* (2002) concluded that the relationships between litter decomposition and their C: N ratios appear to be complex and species dependent and might not be an appropriate general indicator for changes in decomposition rates.

In a study conducted by Upadhyay *et al.* (2012) on the decomposition and nutrient release patterns of *Phyllostachys bambusoides* and *Arundinaria racemosa,* weight loss of both leaf and sheath litter was strongly positively correlated with N and N: P ratio, and significantly negatively correlated with C: N ratio. Another study by Wang *et al.* (2008) on the leaf litter decomposition of *Cunninghamia lanceolata* and *Michelia macclurei*, reported that the mass loss of leaf litter was positively correlated with initial N concentration and negatively correlated with C: N ratio.

In an experiment conducted by Zhou *et al.* (2008) on the factors influencing leaf litter decomposition, the initial C: N ratio was demonstrated to be an important factor in regulating litter decomposition rate. Barbhuiya *et al.* (2008) studied the rates of weight loss in the leaf litter of the dominant tree species (*Ailanthus grandis, Altingia excelsa, Castanopsis indica, Duabanga sonneriatioides, Dysoxylum binectariferum, Mesua ferrea, Shorea assamica, Taluma hodgsonii, Terminalia myriocarpa and Vatica lancefolia*) of a tropical wet evergreen forest of northeast India. Species *like D. sonneriatoides, D. binectariferum*, and *T. hodgsonii* with lower C: N ratio exhibited relatively faster decomposition rates than the other species.

Bahuguna *et al.* (1990) conducted a study using *Eucalyptus* spp. and *Shorea robusta. Eucalyptus* spp. showed a higher initial N (1.12 %) content and consequent faster mineralization while *Shorea robusta* had a lower N content (0.57 %). Kunhamu and Gopikumar (1996) studied the litter decomposition of five selected woody tree species, but, C: N ratio was not found to be directly related with decay rate. However, there was a general reduction in the C: N ratio as decomposing advanced. Studies by Jamaludheen and Kumar (1999) using nine fast growing tree species in Kerala revealed that initial nitrogen content exerted a positive influence on decay rate coefficients.

A Study conducted on leaf litter decomposition and nutrient release patterns of *Acacia mangium* revealed that the rate of decomposition was faster in the litter having high initial N content and low C: N ratio (Gopikumar *et al.*, 2001). Dynamics of nutrients in decomposing leaves was studied in a sub-tropical mangrove dominated by *Bruguiera gymnorrhiza* and *Kandelia candel* by Mfilinge *et al.* (2002). Results showed that *K. candel* leaves with higher initial N concentrations and low C: N ratio decayed faster than *B. gymnorrhiza*; decay constants were 0.062 and 0.022 per day.

2.1.5.1.2 Lignin and cellulose contents

The association of lignin with cellulose fibres results in masking of a large fraction of carbohydrate, which otherwise would be accessible to microbes (Gessner and Chauvet, 1994). In a litter decomposition study conducted by Bontti *et al.* (2009), percentage lignin was found to be the best predictor of leaf and root decomposition. Liginin: nitrogen ratio is considered to be the best indicator of organic matter decomposition and N release (Trap *et al.*, 2013).

A study conducted at Vellanikkara to find out the nutrient content and patterns of leaf litter decomposition of *Acacia mangium* in two different field conditions during south-west monsoon and north-east monsoon periods revealed a strong negative influence of lignin on the rate of decomposition. The low lignin: nitrogen ratio of the litter during the second season favoured faster decay rate, particularly in the initial months (Gopikumar *et al.*, 2001). As lignin is resistant to the enzyme degradation, under higher content of it in the leaves, lower is the relative amount of more readily available carbon compounds.

Chemical characteristics and decomposition patterns of six multipurpose tree species, viz. *Alnus nepalensis, Albizzia lebbeck, Boehmeria rugulosa, Dalbergia sissoo, Ficus glomerata* and *F. roxburghii* [*F. auriculata*] were analyzed in a mixed plantation by Semwal *et al.* (2003). The results revealed that

annual decomposition constants of mass and N were negatively correlated with lignin: N and lignin+polyphenol/N ratios of fresh litter. Arunachalam *et al.* (2005) found significant positive relationships with lignin and N concentrations and L: N ratios. However, another study by Castanho and Oliveira (2008) found no significant correlation between decomposition rates and lignin concentration and L: N ratio.

Barbhuiya *et al.* (2008) studied the rates of weight loss and nutrient release patterns in the leaf litter of the dominant tree species (*Ailanthus grandis, Altingia excelsa, Castanopsis indica, Duabanga sonneriatioides, Dysoxylum binectariferum, Mesua ferrea, Shorea assamica, Taluma hodgsonii, Terminalia myriocarpa* and *Vatica lancefolia*) of a tropical wet evergreen forest of northeast India. Lignin content and L: N showed significant negative correlations with decay rates.

2.1.5.1.3 Polyphenol

Plants contain a variety of polyhydroxyl phenols constituting five to fifteen per cent of their dry weight. De Moral and Muller (1969) noticed the high content of polyphenols in Eucalyptus leaves which hindered their decomposition rate. Nitrogen release from the residue with low C: N ratio but high concentration of polyphenol, could be slow in the initial stages because polyphenols form complexes with protein, making them inaccessible to the micro-organisms (Seneviratne, 2000). There are strong evidences regarding the influences of these substances on controlling the rate of decomposition (Edward and Heath, 1963). An inverse relationship between polyphenol concentration and the rate of decomposition due to feeding activities of soil animals have been well established by Collison *et al.* (2013).

2.1.5.2 Soil micro and macro faunal activity

Microbes are the primary agents responsible for litter degradation, and consequently, abiotic factors that affect microbial activity, such as temperature, soil type, bulk density and moisture content also influence foliar decomposition. In a tropical environment, the climatic seasonality characterized by alternating wet and dry periods plays a vital role in regulating the rates of litter decomposition (Tripathi and Singh, 1992) by changing the population of microbial community on decomposing organic matter (Arunachalam *et al.*, 1997). The litter decomposition process is ultimately driven by specific controlling factors related to the requirement of the decomposer community and whose availability is partly determined by tree species (Aponte *et al.*, 2012).

Studies have shown that soil invertebrates are more numerous and diverse on perennial crop systems compared to the annuals (Lavalle and Pashanasi, 1989; Dangerfield, 1990; Senapati *et al.*, 1995). As soil fauna regulate soil microbial population and activity, their proper management could enhance their contribution of trees to nutrient conservation and cycling such that overall productivity and sustainability is improved (Lavalle *et al.*, 1998; Senapati *et al.*, 1999).

A study conducted on *Eucalyptus hybrid* and mixed pine species planted in the midst of natural forest of sal (*Shorea robusta*) revealed that rate of decomposition was highest in litter of sal (0.0105 g/gday) than eucalyptus (0.0102 g/gday) and pines (0.0090 g/gday). The fast disappearance rate of litter during the rainy season was due to accelerated growth of microbial population and their activities to decompose the material in optimum conditions, while it was very low in the summer season. Similar observations were also reported by Shandagi and Nath (2006).

A study was undertaken by Slade and Riutta (2012) to examine the influence of soil macrofauna and litter environment on the decomposition of six

deciduous tree species (*Fraxinus excelsior* L., *Acer pseudoplatanus* L., *A. campestre* L., *Corylus avellana L., Quercus robur* L., *Fagus sylvatica* L.) in a temperate forest. All species had faster rates of decomposition when macro fauna were present, with 22-41 per cent of the total mass loss attributed to macro fauna. Macro fauna were most important for easily decomposable species as soon as the leaves were placed on the ground, but were most important for recalcitrant species after nine months in the field.

Arthur *et al.* (2012) examined the relationships among microbial community composition, litter chemistry, and decomposition rates in a common garden experiment of the decomposition of the leaf litters of ten plant species. The results suggested that initial litter chemistry determines the rate of decomposition and microbial community composition early in decomposition while the composition of the microbial community plays a more important role in determining the decomposition rate later in decomposition.

Macro fauna invertebrates of forest floors provide important functions in the decomposition process of soil organic matter, which is affected by the nutrient stoichiometry of the leaf litter (Ott *et al.*, 2012). Microorganisms are responsible for the decomposition of plant litter due to their enhanced enzyme capabilities. Among extracellular enzymes, those involved in lignin decomposition are especially relevant in leaf degradation (Ramio *et al.*, 2013). Millipedes are the dominant macro fauna and consume a substantial proportion of annual leaf litterfall, most of which are egested as faecal pellets (Suzuki *et al.*, 2013). Jiang *et al.* (2013) also reported that soil fauna have an important influence on litter decomposition.

2.1.5.3 Environmental parameters

Moisture and temperature are reported to be the two most important abiotic factors controlling the rate of biomass decomposition under natural conditions

(Moore, 1986; Vander, 1963). Many authors have reported higher loss of litter mass during the rainy season compared to the dry season (Facelli and Pickett, 1991; Vucetich *et al.*, 2000). Microbial activity increases exponentially with increasing temperatures which, results in rapid decomposition (Waring and Schlesinger, 1985). However, Prescott *et al.* (1993) and Soundarapandian and Swathy (1999) suggested that summer moisture might be more critical for decomposition. Slow decomposition rates during summer are also possible on account of the aboveground positioning of an abscised decomposing litter, which alters the litter moisture content (Russel and Vitousek, 1997). Jamaludheen and Kumar (1999) found that sampling period has a significant effect on decay rates. Sunanda and Binoy (2009) found that the rate of decomposition was positively correlated with moisture content and temperature. Moreover, soil macro faunal activity is greater in high moisture conditions as compared to low moisture conditions (Collison *et al.*, 2013).

2.1.5.3.1 Moisture

Litter decomposition is an important ecosystem process regulated by both biotic factors (e.g., decomposers and litter types) and abiotic factors (e.g., temperature and moisture). Among the microclimatic and soil factors, forest floor moisture content is the best predictor (Sariyildiz, 2008). But, Greenberg *et al.* (2012) reported that moisture plays only a minor role in the decomposition process. However, Salinas *et al.* (2011) found no direct relationship between litter decomposition and moisture or rainfall.

The positive influence of moisture on the activities of microbes, particularly, arthropods was established by Madge (1965). A correlation coefficient was also calculated between fungal population numbers, bacterial population numbers and moisture content (Kayang, 2001). A faster rate of litter decay in tropical wet evergreen species is mainly accounted due to the high moisture content and temperature (Vituosek and Sanfiord, 1986; Santiago and Mulkey, 2005). Studies

on an altitudinal transit in the Himalayas showed that decomposition increased with increasing litter moisture and temperature (Upadhyay and Singh, 1987). Leaf decay rates were found to be a linear function of water potential and approached maximum at nearly 40°C (Sharma and Ambasht, 1987). Lisanework and Michelsen (1994) established linear relationship between decomposition constant and mean annual rainfall of 600-1800 mm per year. Weight loss was found to be correlated with intensity and distribution of rainfall.

The effect of seasonal moisture on the rate of decomposition of eucalyptus leaf litter collected from two climatically different regions was studied by Orsborne and Macauley (1988). Dry weight losses were found to be positively correlated with soil moisture content. Of the two regions, the one with 31 to 40 per cent moisture content characterized a maximum weight loss when compared to the dry region with low soil moisture status of 18.5 to 20 per cent. Significant and positive correlation was observed between the decomposition rate of *Populus deltoides* litter and rainfall (Kaushal *et al.*, 2006).

A study conducted by Devi and Yadava (2007) on decomposition of *Dipterocarpus tuberculatus* showed a significant correlation between monthly weight loss, soil moisture and rainfall. Climatic factors control the decomposition rate, in which mean annual temperature and annual actual evapotranspiration are dominant and mean annual precipitation is subordinate (Zhou *et al.*, 2008). Prescott *et al.* (2005) observed that moisture is more limiting than temperature for litter decomposition.

2.1.5.3.2 Temperature

The mesophylic bacteria, actinomycetes and fungi require a temperature range of 45°C for their optimum activities while the thermophilic bacteria require a temperature range of 45°C to 60°C (Alexander, 1977). Mehar (2001) reported that 86 per cent of variation in microbial biomass in *Acacia nilotica* based

agroforestry systems in arid regions of Rajasthan was explained by variation in soil moisture and temperature. Climate affects litter decomposition directly through temperature, determining the ecosystem potential decomposition, and indirectly through its effect on plant community composition and litter quality, determining litter potential decomposition (Pandey and Singh, 2010). However, many studies have reported a peak in microbial biomass during summer and attributed this to a higher degree of tolerance to water stress in microbes and improved availability of nutrients to microbes due to lack or poor absorption of nutrients by vegetation at this time of the year (Srivasthava and Singh, 1995). Yasin and Mary (2011) reported temperature to be the major factor influencing decomposition. Salinas *et al.* (2011) concluded his experiments reporting that the warming of approx. 0.9°C experienced in the tropical forests of Peru has increased the decomposition and nutrient mineralization rates by 10 per cent.

The rate of decomposition increased as the days increased, but it was attributed to different seasons, temperature, quality and quantity of fauna (Jain and Surve, 2011). Leaf litter decomposition pattern in *Dipterocarpus tuberculatus* and *Dipterocarpus retusus* forests of north east India was studied by Kumar *et al.* (2012). The study revealed that climatic factors such as rainfall, temperature and seasonal variations directly influence the occurrence and abundance of microbes that results in the variation of rate of leaf litter decomposition.

Marked influence of temperature on biomass decomposition is primarily because of its effect on microbial populations (Yang *et al.*, 2012). Song *et al.* (2012) showed that litter decomposition at different successional stages are directly related to climatic variables such as mean annual precipitation and mean annual temperature. Zhu *et al.* (2013) studied the temporal dynamics of abiotic and biotic factors on leaf litter of three plant species in relation to decomposition rate along a sub-alpine elevation gradient. Results showed that the decomposition rate positively correlated with soil mean temperature during the plant growing season, and with the number of soil freeze-thaw cycles during the winter.

2.1.5.3.3 UV light

Aboveground litter decomposition is controlled mainly by substrate quality and climate factors across terrestrial ecosystems, but photodegradation from exposure to high-intensity ultraviolet-B (UVB) radiation may also be important in arid and semi-arid environments (Uselman *et al.*, 2011). Recent studies have focused on the influence of UV radiation on the decomposition of litter. Exposure to elevated ultraviolet B radiation during plant growth may influence the plant tissue chemistry and subsequent decomposition (Song *et al.*, 2013). However, Messenger *et al.* (2012) reported negative effects of higher UV-B radiation on litter decomposition.

2.1.6 Patterns of biomass decomposition

The general kinetics of biomass decomposition follows a biphasic process (Berg and Staff, 1980). This involves a period of rapid catabolic stage followed by a period of slow CO_2 evolution. The rapid catabolic process involves the metabolism of readily digestible water soluble components such as amino acids, proteins, simple sugars and polysaccharides (Alexander, 1977).

Evolution of some amount of CO_2 during the slow decay period is the result of the catabolism of microbial polymers synthesized during their initial decomposition (Bocock, 1964). During the later period, more biodegradation resistant compounds were found to be metabolized (Brady, 1984). However, some readily metabolized substances may not be catabolised during the initial rapid decomposition phase because of their physical protection from contact with decomposer community.

A monophasic pattern of decomposition was also observed by Nelida *et al.* (2009). In a study conducted by Nath and Das (2011) on the litter decomposition of *Bambusa cacharensis, B. vulgaris* and *B. balcooa* in a homegarden of Assam, the pattern of decomposition was biphasic. Ray and Ranabijoy (2011) observed

biphasic pattern of pattern in teak litter. However, most of the studies have shown a biphasic pattern of decomposition (Shuhyb, 2004; Kaushal *et al.*, 2012; Dhanya *et al.*, 2013).

2.2 NUTRIENT RELEASE PATTERNS

Different nutrients in decomposing litter have different patterns of release over time and that nutrients are retained with different strength in litter structures (Girisha *et al.*, 2003). The greatest release of nutrients was that of K (100 %), and the least was that of N (40 %). P was reported to be the most limiting nutrient.

The results of the litter bag study conducted in nine fast growing tree species in Kerala Agricultural University revealed that residual litter mass declined exponentially with time for *Ailanthus triphysa, Pterocarpus marsupium, Casuarina equisetifolia* and *Leuceana leucocephala. Paraserianthes* spp. showed a linear trend, while Emblica and *Ailanthus* spp. exhibited a biphasic pattern of mass loss. Nutrient release from the decomposing litter followed either a tri-phasic pattern characterized by an initial accumulation, followed by a rapid release and a final slower release phase, or a biphasic pattern that is devoid of initial accumulation phase (Jamaludheen and Kumar, 1999).

Nutrient release patterns of leaf litters of *Acacia mangium* were studied in homegarden and in an open area during south-west monsoon and north-east monsoon under Vellanikkara condition (Gopikumar *et al.*, 2001). Litter collected during the second season registered more content of most of the elements like nitrogen, phosphorus, potassium, calcium and sulphur at the time of incorporation into soil. Generally, K mineralized faster in most of the cases.

A detailed study on litter dynamics in the selected shola forests of Nilgiri hills of Western Ghats was conducted by Vidyasagaran *et al.* (2002). Nutrient concentration in litter indicated that among components, highest concentration of N was found in the leaves while P and K was found maximum in reproductive

parts and fruits respectively. Among different nutrients, N returned maximum while P the least. Leaves returned the maximum amount of all the nutrients compared to other plant parts. Decomposition study also indicated that 77 per cent of original leaf biomass was lost within one year period. Slow initial mineralization of N and rapid mineralization of P and K was also evident from the study.

The release of nutrients from the leaf litter of *Ochlandra travancorica* was studied in Vazhachal, Kerala. It varied with the type of element, and nutrient mobility from decomposing reed litter was in the order K > N > Mg > Ca > P (Sujatha *et al.*, 2003). The nutrient release pattern recorded by Shuhyb (2004) for *Acacia mangium, Acacia aulacocarpa* and *Acacia crassicarpa,* indicated that all the species returned maximum quantity of all nutrients. The three species returned maximum amount of nitrogen when compared to potassium and phosphorus.

Decomposition rates and nutrient dynamics of *Populus deltoides* litter was investigated in Himachal Pradesh (Kaushal *et al.*, 2006). N, P, K, Ca and Mg dynamics in decomposing litter revealed that concentration of N, P and Ca did not follow any specific trend during the decomposition process. Potassium and Mg concentration, however, revealed a decreasing trend throughout the study period. Changes in absolute amount, on the other hand, followed a decreasing pattern through the study period for N, K and Mg. Phosphorus and Ca, however, depicted a three-phase pattern, i.e. leaching, immobilization and release during the entire course of the investigation (Kumar *et al.*, 2008). Decomposition characteristics and dynamics of nutrient element (N, P and K) content of leaf litter of *Schima superba* were analyzed by Zheng (2009). Nutrient release was in the order: K (81.3 %) > C (54.8 %) > N (35.7 %) > P (28.6 %).

Investigations were undertaken by Shailendra *et al.* (2013) find out the rate of decomposition of leaf litter of seven multi-purpose tree species, viz. *Tectona grandis, Eucalyptus tereticornis, Dendrocalamus strictus, Terminalia bellirica,*

Cassia fistula, Casuarina equisetifolia and *Terminalia arjuna*. Significantly the highest amount of nitrogen release per cent was recorded in *Eucalyptus tereticornis* which was followed by *Dendrocalamus strictus*. Among different multipurpose tree species the maximum amount of phosphorus release was recorded in *Cassia fistula* and maximum amount of potassium release percentage was in *Eucalyptus tereticornis* which was at par with *Terminalia bellirica*.

An elaborate study on the decomposition dynamics of *Azadirachta indica*, *Dalbergia sissoo*, and *Melia azedarach* was conducted by Hasanuzzaman and Hossain (2014). All three species showed a similar pattern of nutrient release (K > N > P) during the decomposition process of leaf litter. *D. sissoo* was best in terms of N and P return and *A. indica* was best in terms of K return.

Materials and Methods

3. MATERIALS AND METHODS

3.1 LOCATION

The present series of studies were conducted at College of Forestry, Kerala Agricultural University, during the period 2011-2013. The experimental area selected was a mixed dense homegarden located at Madakatharra, and an open area adjacent to the nursery of College of Forestry, Vellanikkara, Thrissur district, Kerala, lying between $10^0 31^{'}$ N latitude and $76^0 10^{'}$ E longitude at an elevation of 22.0 m above MSL.

3.1.1 Climate

The area enjoys a warm, humid tropical climate and received a total mean annual rainfall of 2903 mm, the bulk of which was during the south-west monsoon. The wettest months were June, July and August. The mean maximum temperature recorded at the nearby agro-meteorological laboratory varied from 29.6^0C (July) to 35.5^0C (March). The mean minimum temperature varied from 22.3^0C (January) to 24.8^0C (April).

3.1.2 Field description

The experiment was laid out in an open field and a well managed homegarden. The open field was selected in the nursery of the college of forestry, Vellanikkkara, Thrissur. The area was devoid of any vegetation. The homegarden selected was from the Madakatharra panchayath, where different varieties of horticultural crops were planted and maintained in a very intensive and scientific manner. The area was predominantly occupied by coconut and areca nut trees. Some other major crops were mango, nutmeg, banana, papaya etc. The tree species grown were mainly *Tectona grandis, Artocarous hirsutus* and *Artocarpus heterophyllus*. All the components were well arranged in a way that there was

minimum competition. A proper and timely sequence of cultural practices like weeding, soil working and fertilization was carried out in the homegarden. Two weedings were carried out in the year; one at the onset of south-west monsoon during May-June and the other in the month of October. Soil working was done during November. Soil fertility was maintained mainly by the addition of farm yard manure and compost.

3.2 FIELD EXPERIMENT

The study involves estimation of the foliar nutrient content and decomposition rate and mineralization pattern of green manure trees viz. *Gmelina arborea* and *Mallotus philippensis*, as influenced by season and site conditions. The study was conducted in an open area and a homegarden during both wet (from June) and dry seasons (from December). The descriptions about these species along with photographs are given below.

(i) *Gmelina arborea* Roxb. (Family: Lamiaceae)

Common name: Gamhar

Gmelina arborea is a fast growing deciduous tree, occurring naturally throughout the greater part of India at altitudes upto 1,500 meters. It grows on different localities and prefers moist, fertile valleys with 750–4500 mm rainfall. *Gmelina arborea* is indigenous to India. The species occurs in a variety of forest habitats, including tropical semi-evergreen, sub-montane, very moist teak forests, deciduous, sal and dry teak forests. In India, *Gmelina arborea* occurs extensively from sub Himalayan tracts, common throughout Assam and adjoining areas of northern West Bengal, also in southern Bihar and Odisha, sporadically found in western and southern India and planted elsewhere on a large scale. In Kerala, it is found throughout the moist and semi-evergreen forests.

Gmelina arborea timber is reasonably strong for its weight. It is used in constructions, furniture, carriages, sports, musical instruments and artificial limbs.

Gmelina arborea

Mallotus philippensis

Plate 1. Green manure tree species selected for the study

This tree is also commonly planted as a garden and an avenue tree; growing in villages along agricultural land and on village community lands and wastelands. It has good capacity to recover from frost injury. *Gmelina arborea* trees coppices very well with vigorous growth. Apart from this, planting this tree along with crops like maize and cassava has been found beneficial in increasing the simultaneous production of wood and food. When intercropped with maize and cassava, it performs better under closely stocked stands of cassava, yams and maize.

(ii) *Mallotus philippensis* (Lam.) Muell. Arg. (Family: Euphorbiaceae)

Common name: Kamala, Red Kamala

Mallotus philippensis is a bush to small or medium sized tree, upto 25 meters tall and a trunk diameter of 40 cm. It is commonly known as the Kamala or 'Red Kamala', due to the fruit covering, which produces a red dye. It is found in the Western Himalayas and Peninsular India, Western and Eastern Ghats. Kamala tree is common in evergreen forest, especially in secondary forest, and sometimes even dominant in the undergrowth. It also occurs in scrubby vegetations and on the open rocky ground. In forests of India, it is dominated by sal tree. It is also common on the slopes by shola borders in forest clearings. It is also found throughout the forests of Kerala.

The wood is suitable for tool handles and building. The granules which cover the ripe fruit are used in India as a dye (Kamala) for dyeing silk and wool. In India, it is also used as a medicine. The evergreen nature and the coppicing power of the tree make it desirable to be used as green manure.

3.2.1 Leaf biomass decomposition

For the decomposition studies, leaf samples were collected by lopping the leaf biomass of fully grown trees already selected from the Peechi forest. Composite samples of the tender and matured leaves were taken for the study.

Plate 2. A view of the selected homegarden

Plate 3. Litter bags used for the study

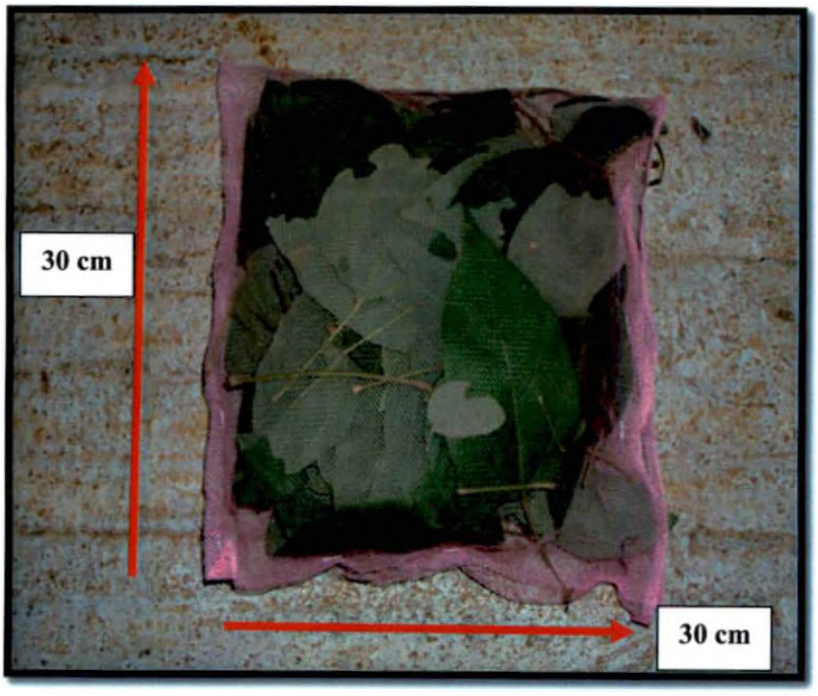
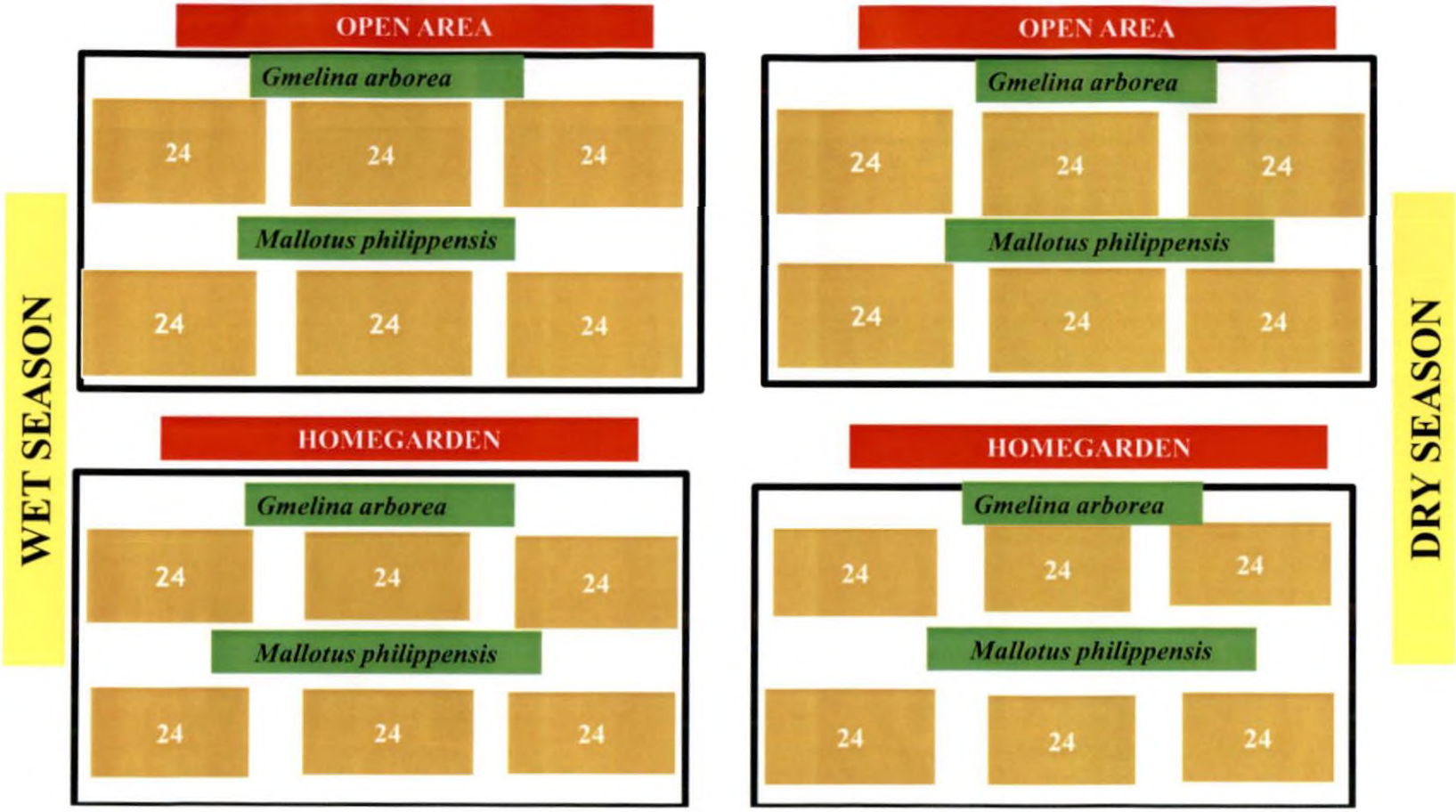


Plate 4. Size of the litter bags used for the study



Total number of litter bags used = 576

Plate 5. Lay out of the fields during both the seasons

Representative sample of each species were drawn for the estimation of dry weight and nutrient analysis before incorporating into the soil. Before the implementation of the experiment, the soil was superficially hoed and raked. Decomposition studies were done using litter bag technique. Each sample containing 100 g of fresh leaves was filled in nylon bags of 30 cm X 30 cm. Subsequently, the bags were sealed on all sides; many holes of 2 mm were made in each bag placed in the soil at a depth of 2 cm for decomposition. Seventy two bags of each species were laid out in three replications in both areas during both the seasons. The total number of bags used for the study was 576.

All the bags were placed randomly in the field on the same day. Samples were taken at fortnightly intervals starting from the first fortnight of June, 2012, during the wet season and January, 2013 during the dry season. Three samples of each species were collected from both areas, i.e. twelve samples in total were retrieved from both the fields in a fortnight by carefully removing the accumulated soil and litter over the bags. Samples were immediately brought to the lab. After removing the extraneous materials like arthropods, fine roots and other soil particles, the samples were carefully washed under running water and finally rinsed with distilled water. The contents of the bags were transferred to paper bags and oven dried at 70^0 C for 48 hrs. The oven dry weight was then recorded using a precision balance. Sampling was continued till the decomposition was almost completed.

3.2.2 Chemical analysis of residues

The fresh leaves and the residues after drying were powdered and analysed for various nutrient elements like organic carbon, nitrogen, phosphorus, potassium and lignin using the following standard procedures.

3.2.2.1 Total carbon

Organic carbon content in the leaf residues was determined using the dry ash method in a muffle furnace (Gaur, 1975). 10 g of the sample was weighed in a

crucible. The crucibles were then placed inside the muffle furnace and heated at 506^{0}C for 6 hours. The crucibles were then taken out and the residual weight was calculated to determine the carbon content.

3.2.2.2 Total nitrogen

Total nitrogen content in leaves was determined in Continuous Flow Analyzer by the Colourimetric method. 0.2 g of the leaf sample was weighed in the digestion tube. 2.5 ml of the digestion mixture was poured into the digestion tube. The tube was then swirled well and allowed to stand for 2 hours or overnight. It was then inserted into the digestion block and heated at 100^{0}C for 2 hours. After cooling, the tubes were removed from the block and 1 ml of 30% H_2O_2 was added. After the reaction ceased, they were again placed in the digestion block and heated at 330^{0}C for 2 hours. When the digest turned colourless, the digestion was assumed to be completed The digest was made upto 75 ml in a standard flask by adding distilled water.. The readings were then taken from the continuous flow analyser directly using the reagents.

3.2.2.3 Phosphorus

One gram of the leaf sample was digested with diacid mixture (HNO_3 and $HClO_4$ in 9: 4 ratios) in a digestion chamber until the solution became colourless. After that the digest was made upto 50 ml by adding distilled water. About 5 ml of the aliquot was used to determine the phosphorus content using the Vanadomolybdophosphoric yellow colour method (Jackson, 1958).

3.2.2.4 Potassium

The potassium content was estimated in a known aliquot of diacid extract using a flame photometer.

3.2.2.5 Lignin

1 g of powdered leaf sample was weighed accurately in a petridish and dried in a hot air oven at 105^0 till constant weight was obtained. The sample was then refluxed with 150 ml of ethanol and benzene solution (1: 2 ratio) for four hours. The solution was then cooled, filtered, and washed with ethanol and dried. The sample was then extracted with 200 ml boiling H_2O for four hours. The extract was again cooled, filtered and dried. The sample was then treated with 25 ml of 72% H_2SO_4 gently stirred and kept at room temperature for two hours. The sample was then diluted with distilled water (580 ml) and refluxed for four hours. The extract was again cooled, filtered and dried. The sample was then washed with distilled water till it became acid free. The filtered acid insoluble sample was then dried in an oven. The weight after drying the sample was then recorded.

Percentage of lignin = (y/x) X 100

Where, y = final weight of sample recorded

x = initial weight of sample recorded

3.2.3 Soil analysis

Representative soil samples were collected from the study area before and after the placement of bags. The samples were taken just below the retrieved litter bags at fortnightly intervals. The standard procedures adopted for the analysis of soils are furnished below.

3.2.3.1 Soil temperature and moisture

Soil temperature was determined using a standard thermometer. The moisture content of the soil samples collected at fortnightly intervals was calculated using the following formula.

Moisture content (%) = (Fresh weight – Dry weight / Dry weight) x 100

3.2.2.2 Organic carbon

Organic carbon content was analysed using Walkley and Black (1934) method at fortnightly intervals and expressed as percent. 1 g of the soil was weighed and taken in a dry conical flask. Exactly 10 ml of potassium dichromate solution (49.04 g $K_2Cr_2O_7$ in distilled water made upto 1000 ml in a standard flask) was added into the conical flask. This was swirled gently to mix the reagent in soil. 20 ml of conc. H_2SO_4 was then added along the walls of the conical flask. The acid was mixed with the soil by rotating the flask gently and was left on asbestos for 30 mts to allow oxidation. 200 ml of distilled water was then added. After that 10 ml of ortho-phosphoric acid along with 1 ml of diphenyl amine indicator was added. The contents in the conical flask was then titrated with ferrous ammonium sulphate solution [140 g of $FeSO_4.(NH_4)2SO_4.6H_2O$]. was taken in about 800 ml distilled water and 100 ml of conc. H_2SO_4 was added. It was then cooled and diluted to 1000 ml in a standard flask. The contents in the conical flask were titrated till the colour changed from blue violet to dull green.

3.2.3.4 Total nitrogen

Total nitrogen was found out using the Colourimetric method in the Continuous Flow Analyzer as mentioned earlier.

3.2.3.5 Available phosphorus

Available phosphorus in the soil was extracted using Brays-I solution and estimated by the blue colour of chlorostannous reduced molybdophosphoric acid in a hydrochloric system.

Air dried soil of 2.5 g was weighed into a 150 ml conical flask and 25 ml of Brays solution was added. The solution was then shaken on a reciprocating shaker for five minutes. After that, it was immediately filtered through Whatmann no. 42 filter paper. About 5 ml of the aliquot of the extract was taken and then

Plate 6. Continuous Flow Analyzer (Colourimetric method for nitrogen estimation)

Plate 7. Spectrophotometer (Phosphorus estimation)

Plate 8. Flame photometer (Potassium estimation)

mixed with 4 ml of reagent B. After 10 mts, the intensity of the blue colour was read on a spectrophotometer at 882 nm. The standard curve was also drawn.

3.2.3.6 Exchangeable potassium

The exchangeable potassium in the soil was estimated using neutral 1 N ammonium acetate extract of the soil, where K^+ ions are replaced by NH_4^+ ions. 5 g of air dried soil was weighed and transferred into a 250 ml conical flask. 25 ml of ammonium acetate solution was added and then shaken for five minutes. The contents were then filtered using whatmann no. 42 filter paper. About 5 ml of soil extract was taken in a 25 ml standard flask and diluted to 25 ml. The diluted soil extract was then fed into the flame photometer and the reading was noted.

3.2.4 Canopy gap analysis

The amount of light falling on the homegarden was studied by measuring the canopy gap area using the LICOR LAI-2000 Plant Canopy Analyzer.

3.4 STATISTICAL ANALYSIS

The observations recorded on leaf biomass decomposition and absolute nutrient content of residual mass were statistically analysed at various periods using the various methods suggested by Panse and Sukhatme (1978) after the $\log_e$ transformation of the data.

The decay constant was worked out for the constant potential weight loss by the following formula suggested by Olson (1963).

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

Where, X = the weight remaining at time 't'

X_0= the original mass

e = base of the natural logarithm

k = decay rate coefficient

t = time

Half-lives ($t_{1/2}$) of decomposing leaf biomass were estimated from the k-values using the equation suggested by Bockheim *et al.*, 1991.

$$t_{1/2} = \ln (0.5)/-k$$

$$= -0.693/-k$$

Nutrient content (absolute content) of the decomposing leaf was derived from the equation suggested by Bockheim *et al.*, 1991.

$$\% \text{ remaining} = (C/C_0) \text{ X } DM/DM_0 \text{ X } 10^2$$

Where,

C = Concentration of element in the leaf mass at the time of sampling

C_0 = Concentration of the element in the initial leaf mass kept for decomposition

DM = Mass of the dry matter at the time of sampling

DM_0 = Mass of the initial dry matter of the sample kept for decomposition.

For the estimation of the mineralization of various nutrients, various regression models were tried.

Results

4. RESULTS

The rate of foliar decomposition in *Gmelina arborea* and *Mallotus philippensis*, the pattern of nutrient release and the subsequent improvement of soil by the addition of nutrients via decomposition were studied in two different locations during two seasons, i.e. wet season and dry season. The oven dry weight of the fresh leaf samples and the residual samples from the litter bags were taken to study the decomposition rate and nutrient content. The salient findings of the study are as follows.

4.1 LEAF BIOMASS DECOMPOSITION

4.1.1 Rate of decomposition as affected by locations and seasons

Gmelina arborea

The oven dry weight data obtained on the residual mass at fortnightly intervals were subjected to statistical analysis (Table 1a). The results showed significant differences in the fortnightly values in all the study situations as the decay advanced.

The relative residual mass remaining at the end of each fortnight under various study situations is demonstrated in Table 1b. Significant differences were observed in the values noted at fortnightly intervals within each location. The interaction effects of both seasons and locations on the fortnightly values were also statistically significant.

The relative mass of the residues collected from the open area during the first fortnights of both wet season and dry season were 70.15 per cent and 82.11

Table 1a. Residual leaf mass (oven dry weight in g) of *Gmelina arborea* remaining at fortnightly intervals

Fortnight	Open area		Homegarden		F Test	SEM±
	Wet season	Dry season	Wet season	Dry season		
0	40.21	50.78	40.21	50.78	-	--
1	$_{a}28.21^{d}$	$_{a}41.70^{a}$	$_{a}30.16^{c}$	$_{a}40.25^{b}$	**	0.389
2	$_{b}20.22^{d}$	$_{b}29.31^{a}$	$_{b}23.76^{c}$	$_{b}27.24^{b}$	**	0.251
3	$_{c}11.21^{d}$	$_{c}1.02^{a}$	$_{c}13.83^{c}$	$_{c}18.39^{b}$	**	0.318
4	$_{d}5.15^{c}$	$_{d}13.18^{a}$	$_{d}9.65^{b}$	$_{d}13.48^{a}$	*	0.692
5	$_{e}3.11^{d}$	$_{e}10.35^{b}$	$_{e}4.92^{c}$	$_{e}10.69^{a}$	**	0.100
6	$_{f}1.55^{c}$	$_{f}8.01^{a}$	$_{f}3.43^{b}$	$_{f}8.23^{a}$	**	0.146
7	$_{fg}0.93^{d}$	$_{g}4.71^{a}$	$_{gh}1.94^{c}$	$_{g}4.17^{b}$	**	0.028
8	$_{g}0.30^{d}$	$_{h}2.37^{a}$	$_{h}0.71^{c}$	$_{h}2.23^{b}$	**	0.027
9	NA	$_{hi}1.85$	NA	$_{hi}1.61$	--	--
10	NA	$_{i}0.89$	NA	$_{hi}1.09$	--	--
11	NA	NA	NA	$_{j}0.54$	--	--
F test	**	**	**	**		
SEM±	0.51	0.645	0.174	0.192		

** Significant at 1%

*Significant at 5%

Figures with the same superscript and subscript do not differ significantly

Superscripts indicate interactions between field and seasons within fortnight

Subscripts indicate interactions between fortnights within a field and season

NA – Not applicable

Table 1b. Relative mass (%) of *Gmelina arborea* remaining at fortnightly intervals

Fortnight	Open area		Homegarden		F Test	SEM±
	Wet season	Dry season	Wet season	Dry season		
0	100.00	100.00	100.00	100.00	--	--
1	$_{a}70.15^{c}$	$_{a}82.11^{a}$	$_{a}75.00^{b}$	$_{a}79.28^{a}$	**	0.914
2	$_{b}50.29^{c}$	$_{b}57.73^{a}$	$_{b}59.10^{a}$	$_{b}53.66^{b}$	**	0.580
3	$_{c}27.88^{c}$	$_{c}41.39^{a}$	$_{c}34.39^{b}$	$_{c}36.22^{b}$	**	0.783
4	$_{d}12.81$	$_{d}25.97$	$_{d}24.58$	$_{d}26.56$	**	1.367
5	$_{e}7.74^{b}$	$_{e}20.40^{a}$	$_{e}12.23^{b}$	$_{e}21.05^{a}$	**	0.202
6	$_{f}3.86^{c}$	$_{f}15.77^{a}$	$_{f}8.53^{b}$	$_{f}16.21^{a}$	**	0.323
7	$_{fg}2.31^{d}$	$_{g}9.25^{a}$	$_{g}4.82^{c}$	$_{g}8.22^{b}$	**	0.065
8	$_{g}0.74^{d}$	$_{h}4.68^{a}$	$_{h}2.95^{c}$	$_{hi}4.39^{b}$	**	0.069
9	NA	$_{ij}3.64$	NA	ij3.15	--	--
10	NA	$_{j}1.75$	NA	$_{jk}2.16$	--	--
11	NA	NA	NA	$_{k}1.06$	--	--
F test	**	**	**	**		
SEM±	2.031	2.502	1.079	0.075		

** Significant at 1%

*Significant at 5%

Figures with the same superscript and subscript do not differ significantly

Superscripts indicate interactions between field and seasons within fortnight

Subscripts indicate interactions between fortnights within a field and season

NA – Not applicable

per cent respectively. Significant differences in the dry weight values were noticed during the initial fortnights of both the seasons. An initial phase of rapid decay followed by a slower phase was observed. The wet season recorded a 90 per cent loss in foliar mass from the beginning of the fifth fortnight, whereas, twenty five per cent foliar mass was remaining in dry season during this period. By the end of the eighth fortnight, the amount of mass remaining during the wet season and dry season was 0.74 per cent and 4.68 per cent respectively. Decomposition in the open area under the influence of wet season was completed in eight fortnights, whereas, it took ten fortnights for decomposition to be completed under the influence of the dry season.

Similarly, in the homegarden also, a faster pace of decomposition was observed in the initial fortnights followed by a phase of slower decomposition. The amount of mass recorded in the first fortnight during the wet and the dry season was 75 per cent and 79.28 per cent respectively. Similarly, at the second period of collection, the amount of mass recorded during the wet season and the dry season was 59.10 per cent and 53.66 per cent respectively. By the end of the eighth fortnight, the residual mass remaining under the influence of wet season and dry season was 2.95 per cent and 4.39 per cent, respectively. Decomposition in the homegarden under the influence of wet season was completed in eight fortnights, whereas, it took eleven fortnights for decomposition to be completed under the influence of the dry season.

In general, significant differences were observed between the seasons of application rather than the fields of application. However, open area registered faster mass loss than homegarden during both the seasons.

Mallotus philippensis

The data obtained on the residual mass at fortnightly intervals were subjected to statistical analysis (Table 2a). The results showed significant

Table 2a. Residual leaf mass (oven dry weight in g) of *Mallotus philippensis* remaining at fortnightly intervals

Fortnight	Open area		Homegarden		F Test	SEM±
	Wet season	Dry season	Wet season	Dry season		
0	44.50	55.32	44.50	55.32	--	--
1	$_{a}31.41^{d}$	$_{a}44.98^{a}$	$_{a}33.18^{c}$	$_{a}42.19^{b}$	**	0.312
2	$_{b}24.21^{d}$	$_{b}39.66^{a}$	$_{b}26.32^{c}$	$_{b}36.94^{b}$	**	0.310
3	$_{c}18.76^{c}$	$_{c}29.01^{a}$	$_{c}20.65^{b}$	$_{c}28.82^{a}$	**	0.325
4	$_{d}12.06^{b}$	$_{d}23.09^{a}$	$_{d}13.39^{b}$	$_{d}22.37^{a}$	**	0.125
5	$_{e}8.93^{c}$	$_{e}20.48^{a}$	$_{e}10.45^{b}$	$_{e}19.83^{a}$	**	0.262
6	$_{f}5.13^{d}$	$_{f}16.21^{a}$	$_{f}9.23^{c}$	$_{f}15.13^{b}$	**	0.058
7	$_{g}2.40^{c}$	$_{g}11.26^{a}$	$_{g}5.14^{b}$	$_{g}11.58^{a}$	**	0.073
8	$_{h}1.30^{c}$	$_{h}10.26^{a}$	$_{g}2.74^{b}$	$_{h}10.62^{a}$	**	0.075
9	$_{ij}0.79^{d}$	$_{i}8.94^{b}$	$_{gh}1.99^{c}$	$_{i}9.31^{a}$	**	0.021
10	$_{j}0.51^{d}$	$_{j}6.31^{b}$	$_{hi}1.31^{c}$	$_{j}7.75^{a}$	**	0.025
11	$_{j}0.11^{d}$	$_{k}4.30^{b}$	$_{ij}1.03^{c}$	$_{k}6.00^{a}$	**	0.007
12	NA	$_{l}2.59$	$_{jk}0.76$	$_{l}4.30$	--	--
13	NA	$_{m}1.92$	$_{k}0.21$	$_{m}3.08$	--	--
14	NA	$_{n}1.11$	NA	$_{mn}2.31$	--	--
15	NA	$_{op}0.68$	NA	$_{no}1.97$	--	--
16	NA	$_{p}0.09$	NA	$_{o}1.01$	--	--
F test	**	**	**	**		
SEM±	0.247	0.201	0.218	0.018		

** Significant at 1%

*Significant at 5%

Figures with the same superscript and subscript do not differ significantly

Superscripts indicate interactions between field and seasons within fortnight

Subscripts indicate interactions between fortnights within a field and season

NA – Not applicable

Table 2b. Relative mass (%) of *Mallotus philippensis* remaining at fortnightly intervals

Fortnight	Open area		Homegarden		F Test	SEM±
	Wet season	Dry season	Wet season	Dry season		
0	100.00	100.00	100.00	100.00	--	--
1	$_{a}70.58^{c}$	$_{a}81.30^{a}$	$_{a}74.57^{b}$	$_{a}76.26^{b}$	**	0.702
2	$_{b}54.40^{d}$	$_{b}71.69^{a}$	$_{b}59.15^{c}$	$_{b}66.78^{b}$	**	0.697
3	$_{c}42.17^{c}$	$_{c}52.43^{a}$	$_{c}46.42^{b}$	$_{c}52.10^{a}$	*	0.732
4	$_{d}27.09^{d}$	$_{d}41.73^{a}$	$_{d}30.09^{c}$	$_{d}40.44^{b}$	**	0.283
5	$_{e}20.06^{c}$	$_{e}37.01^{a}$	$_{e}23.48^{b}$	$_{e}35.85^{a}$	**	0.553
6	$_{f}11.53^{d}$	$_{f}29.30^{a}$	$_{f}20.73^{c}$	$_{f}27.36^{b}$	**	0.128
7	$_{g}5.40^{d}$	$_{g}20.36^{b}$	$_{g}11.55^{c}$	$_{g}20.93^{a}$	**	0.163
8	$_{h}2.92^{d}$	$_{h}18.54^{b}$	$_{h}6.16^{c}$	$_{h}19.17^{a}$	**	0.168
9	$_{hi}1.79^{d}$	$_{i}16.17^{b}$	$_{hi}4.48^{c}$	$_{i}16.82^{a}$	**	0.046
10	$_{i}1.14^{d}$	$_{j}11.41^{b}$	$_{ij}2.94^{c}$	$_{j}14.01^{a}$	**	0.056
11	$_{j}0.24^{d}$	$_{k}7.77^{b}$	$_{jk}2.31^{c}$	$_{k}10.84^{a}$	**	0.013
12	NA	$_{l}4.67$	$_{kl}1.70$	$_{l}7.78$	--	--
13	NA	$_{mn}3.48$	$_{l}0.47$	$_{mn}5.56$	--	--
14	NA	$_{no}2.01$	NA	$_{no}4.17$	--	--
15	NA	$_{o}1.22$	NA	$_{p}3.56$	--	--
16	NA	$_{p}0.16$	NA	$_{q}1.82$	--	--
F test	**	**	**	**		
SEM±	0.972	0.131	1.098	0.60		

** Significant at 1%

*Significant at 5%

Figures with the same superscript and subscript do not differ significantly

Superscripts indicate interactions between field and seasons within fortnight

Subscripts indicate interactions between fortnights within a field and season

NA – Not applicable

differences in the fortnightly values in all the study situations as the decay advanced.

The relative residual mass remaining at the end of each fortnight under various study situations is demonstrated in Table 2b. Significant differences were observed in the values noted at fortnightly intervals within each location. The interaction effects of both seasons and locations on the fortnightly values were also statistically significant.

The samples retrieved from the open area during the first fortnight recorded relative mass of 70.58 per cent during the wet season and 81.30 per cent during the dry season. Significant differences in the relative mass at fortnightly intervals were observed during both wet season and dry season. Also an initial faster decay phase was observed, which was followed by a period of slower decay. In general, the open area witnessed faster mass loss during the wet season rather than the dry season. By the end of the eleventh fortnight, the amount of mass remaining during the wet season and during the dry season in the open area was 0.24 per cent and 7.77 per cent respectively. Decomposition in the open area under the influence of wet season was completed in eleven fortnights, whereas, it took sixteen fortnights for decomposition to be completed under the influence of the dry season.

On the other hand, in the homegarden, the initial fortnight recorded relative mass of 74.57 per cent during the wet season and 76.26 per cent during the dry season. The relative masses recorded at fortnightly intervals showed significant difference. An initial faster decay was followed by a slower phase of decomposition. By the end of the thirteenth fortnight, the amount of mass remaining during the wet season and during the dry season in the homegarden was 0.47 per cent and 5.56 per cent respectively. Decomposition in the homegarden under the influence of wet season was completed in thirteen fortnights, whereas, it

took sixteen fortnights for decomposition to be completed under the influence of the dry season.

The relative mass of the litter bags collected from open area and homegarden during both wet season and dry season showed significant differences in all the fortnights studied. Open area registered faster mass loss than homegarden during both the seasons.

4.1.2 Rate of decomposition as affected by field conditions

Statistical analysis was carried out to understand the main effects of locations on the decomposition of the leaf biomass of *Gmelina arborea* and *Mallotus philippensis* in open area and homegarden.

Gmelina arborea

The change in the relative mass of the residual samples retrieved from the open area as well as from the homegarden at fortnightly intervals is depicted in Fig.1. Statistical analysis didn't show significance in the initial fortnights, but marked significance in the latter fortnights. The initial leaf matter, while its incorporation into the soil, recorded a relative mass of 76.13 per cent in the open area, whereas, a slightly higher relative mass was observed in the homegarden (77.14 %). By the end of the tenth fortnight, the amount of mass remaining in the open area and homegarden was 0.87 per cent and 1.08 per cent respectively.

In general, the rate of decomposition was faster in the open condition, whereas, homegarden witnessed a higher relative mass throughout the study period. The initial sampling intervals showed a drastic reduction in the relative mass followed by a slow reduction of relative mass in the latter phase. Both the locations marked 90 per cent decomposition by the middle of the seventh fortnight.

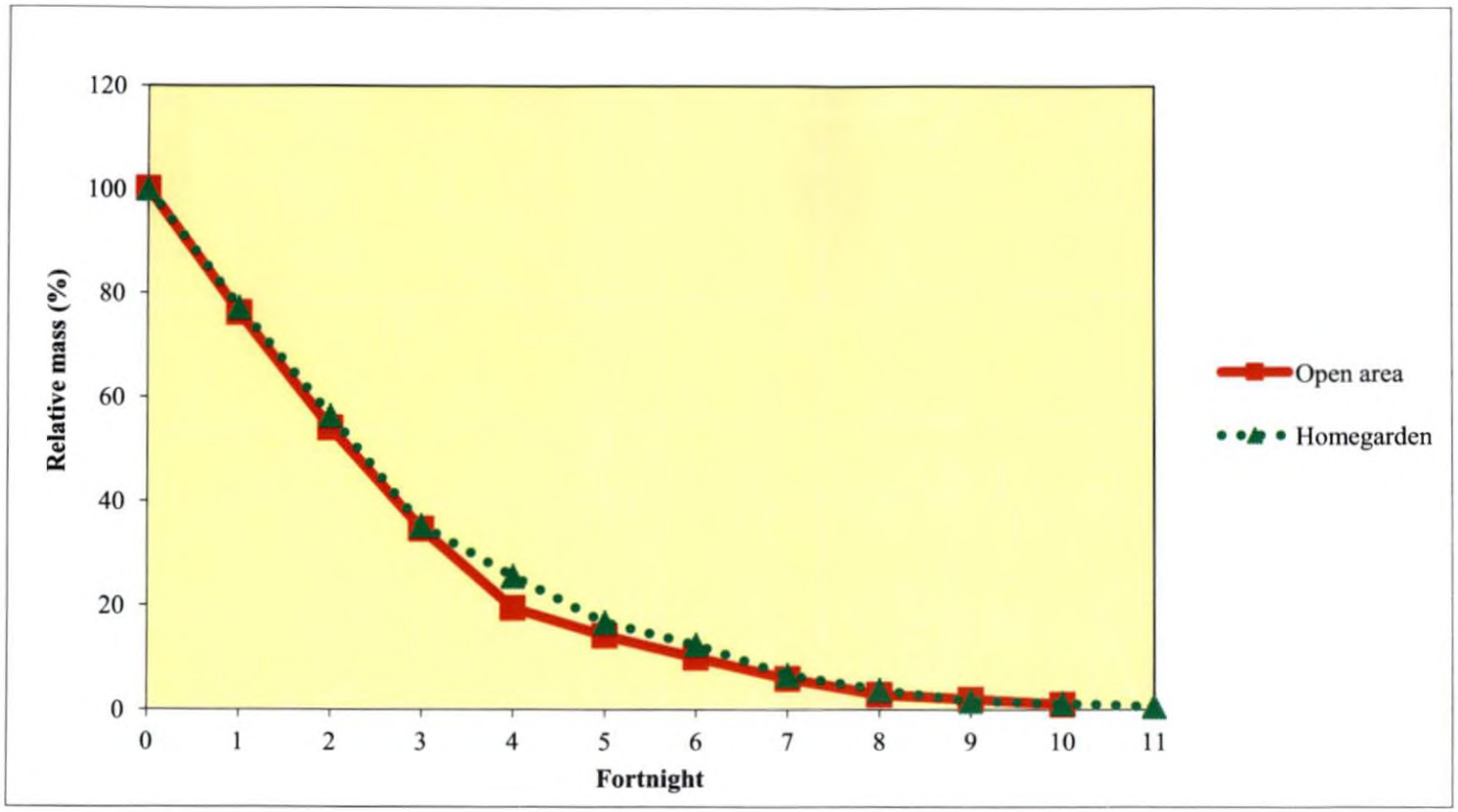


Fig 1. Changes in the relative mass (%) of residues of *Gmelina arborea* as affected by field conditions

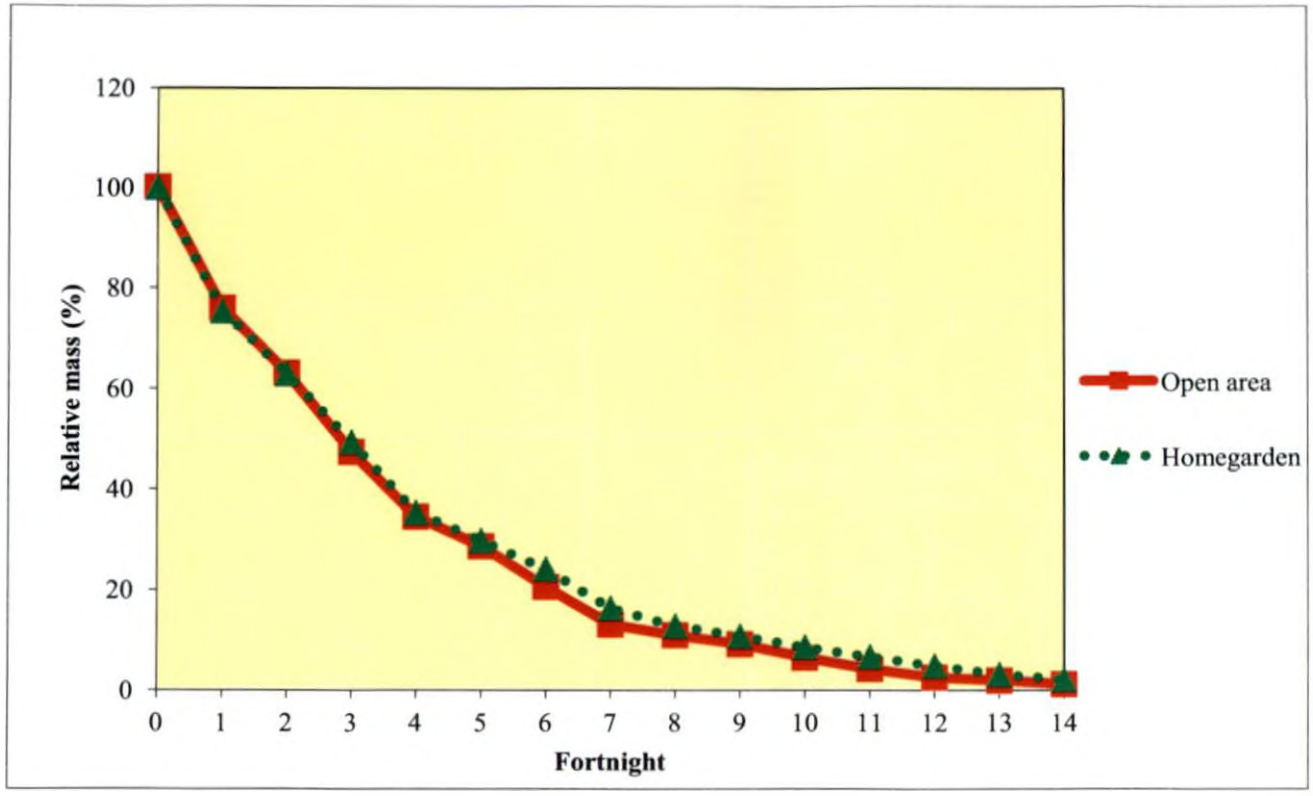


Fig 2. Changes in the relative mass (%) of residues of *Mallotus philippensis* as affected by field conditions

Mallotus philippensis

The relative mass (%) of the residues of *Mallotus philippensis* retrieved from the open area and the homegarden is portrayed in Fig. 2. On subjecting to statistical analysis, no significant influence of the location was observed in the initial fortnights, but significant difference was noticed in the latter fortnights. The relative mass recorded in the first fortnight in the open area and homegarden was 75.94 per cent and 75.42, respectively. Both the locations witnessed 50 per cent mass loss by the third fortnight, whereas, 90 per cent mass loss was noted by the ninth fortnight. By the end of the eleventh fortnight, the relative mass of the residues withdrawn from the litter bags of open area and homegarden recorded a relative mass of 4.01 per cent and 6.58 per cent respectively.

4.1.3 Rate of decomposition as affected by the seasons

In order to find the effect of seasons on the decomposition rate of both the species, statistical analysis was conducted to study the main effect seasons on the foliar decomposition.

Gmelina arborea

The effects of season on the rate of decomposition of *Gmelina arborea* is shown in Fig. 3. After two weeks of incorporation of leaf biomass, the residual mass remaining in the first fortnight was 72.58 per cent in the wet season, whereas a higher relative mass was observed in the homegarden (80.70%). Statistical analysis showed significant influence of seasons on the foliar decomposition during the subsequent fortnights also.

As the decomposition progressed to the fifth fortnight, it was interesting to observe that the amount of residual mass remaining in the litter bags collected during the dry season weighed almost double the mass of those collected from open area. About 95 per cent of the initial leaf biomass decomposed after seven

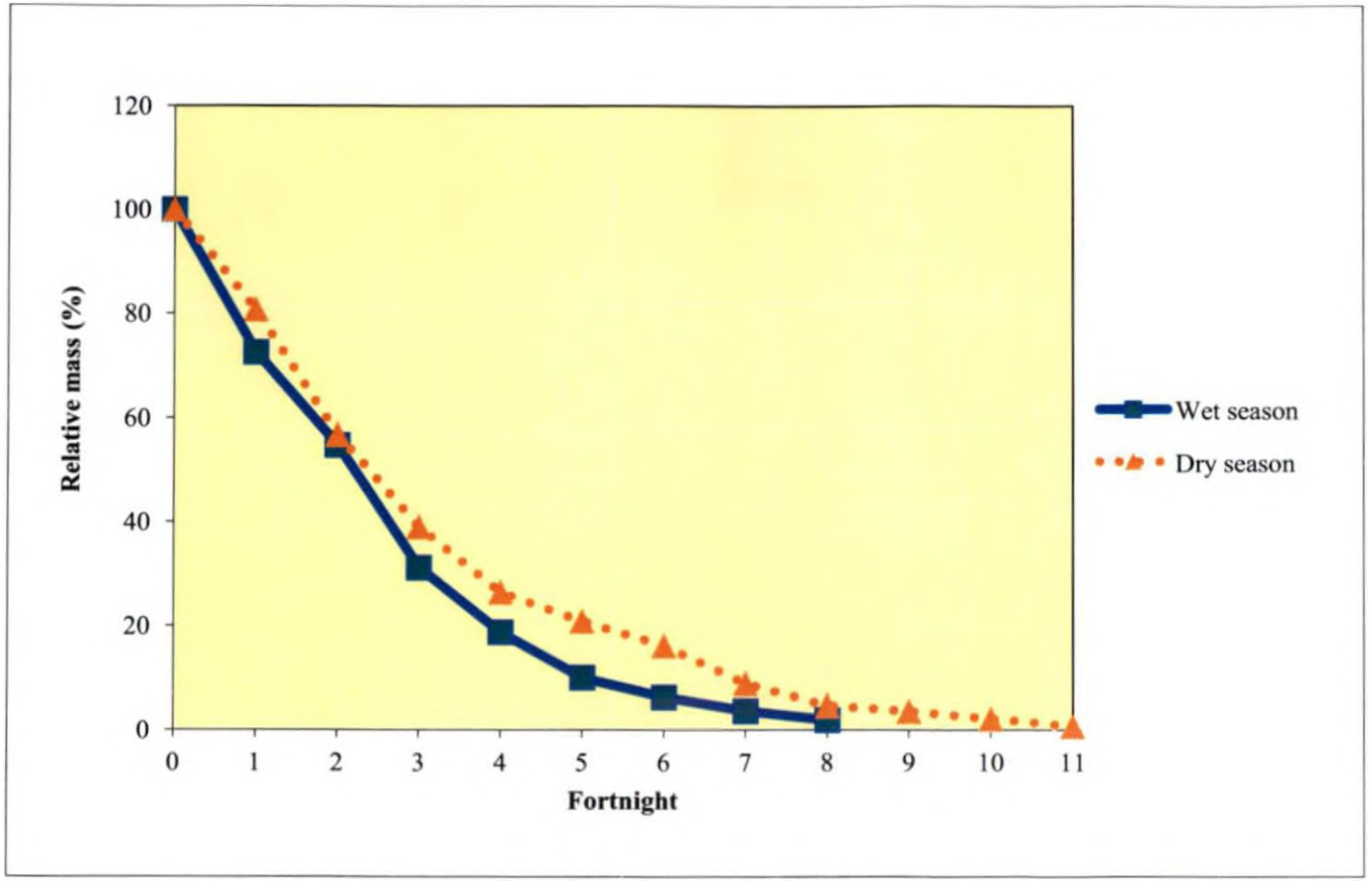


Fig 3. Changes in the relative mass (%) of residues of *Gmelina arborea* as affected by seasons

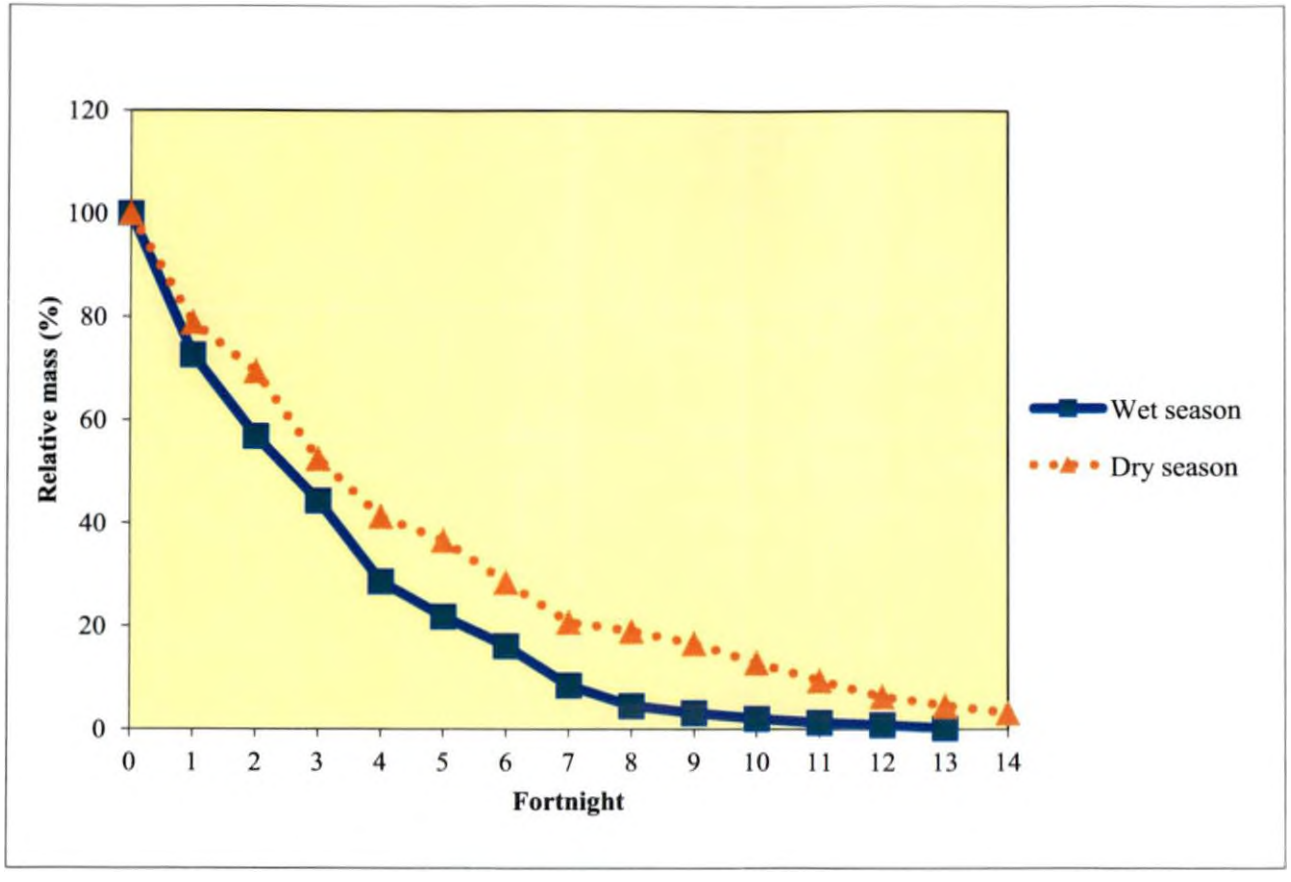


Fig 4. Changes in the relative mass (%) of residues of *Mallotus philippensis* as affected by seasons

fortnights of exposure to decomposition. After eight fortnights, the amount of mass remaining in the litter bag during the wet season and dry season was found to be 1.85 per cent and 4.53 per cent respectively (Fig. 4).

Mallotus philippensis

Attempts were made to study the influence of seasons on the mass loss of the residues of *Mallotus philippensis*. Results obtained showed a significant difference between the relative mass of the foliar mass retrieved at fortnightly intervals (Fig. 4). The wet season marked a faster mass loss than the dry season. The first fortnight recorded a relative mass of 72.58 per cent during the wet season, whereas, homegarden reported a relative mass of 78.79 per cent. It can be clearly seen that wet season witnessed 50 per cent mass loss by the middle of the third sampling period, whereas, dry season showed 50 per cent mass loss by the beginning of the fourth fortnight. By the end of the eleventh fortnight, the relative mass content observed from the litter bags collected from the wet season and dry season were 1.28 per cent and 9.31 per cent respectively, showing a profound influence of the seasons on the foliar mass loss.

The canopy gap area recorded in the homegarden during the wet season and dry season was 188.4 m^2 and 142.25 m^2.

4.1.4 Pattern of decomposition

In general, the decomposition followed a biphasic pattern under all study situations. The decomposition pattern of both *Gmelina arborea* and *Mallotus philippensis* under various study situations are depicted in Fig. 5 and Fig. 6. In all the situations, there was an initial phase of faster decomposition followed by a slower phase.

Leaf biomass of *Gmelina arborea* under both the seasons and field conditions, showed faster decomposition in the initial phase. With respect to the

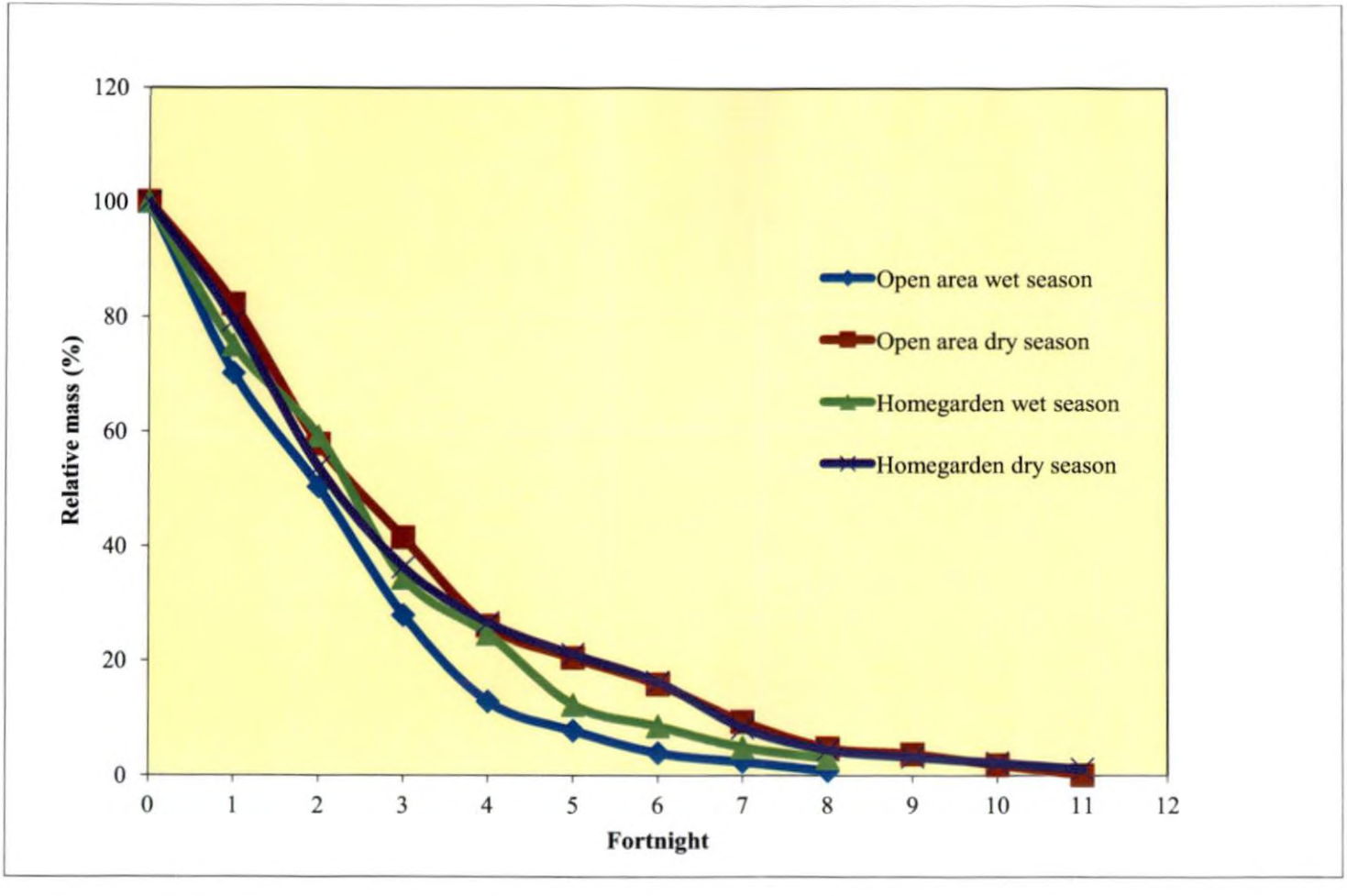


Fig 5. Decomposition pattern of the leaf biomass of *Gmelina arborea* in open area and homegarden

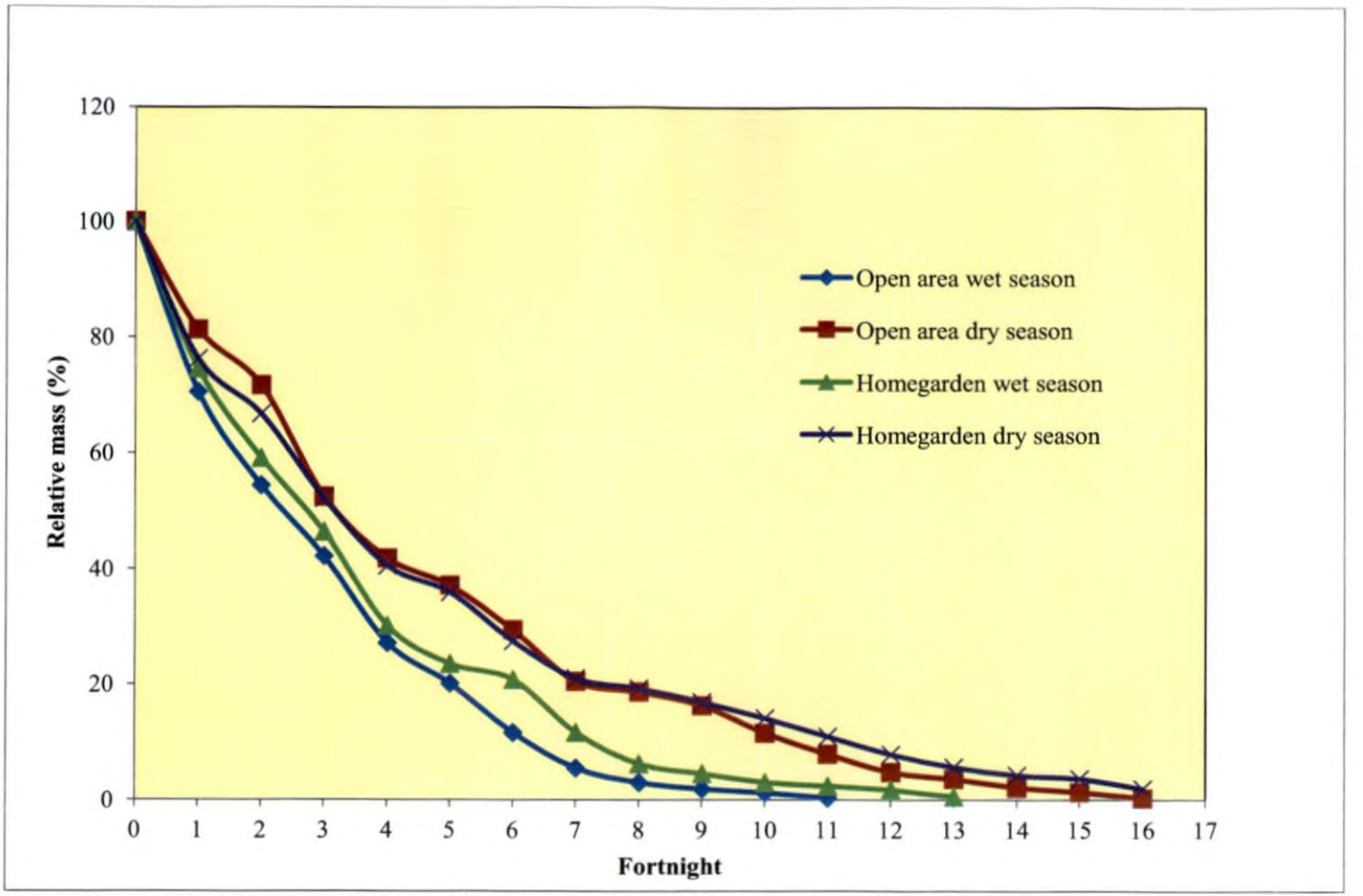


Fig 6. Decomposition pattern of the leaf biomass of *Mallotus philippensis* in open area and homegarden

wet season, the residues collected from the open area marked an initial rapid decline in mass from the commencement of the study till the fifth fortnight, which was followed by a slower phase of mass reduction till the final fortnight. Almost 70 per cent of the leaf mass decomposed within four fortnights during the wet season. Thereafter, they showed a declining trend till the end of the study. Similarly, the residues collected from the homegarden during the wet season also exhibited a similar trend. Faster mass loss was observed till the fifth fortnight followed by a slow decomposition. Seventy per cent mass loss was observed within four fortnights.

The decomposition of the residues of *G. arborea* collected during the dry season also exhibited a biphasic pattern (Fig. 5). Both open area and homegarden recorded faster mass loss within the initial five fortnights. Almost 70 per cent mass loss was observed from the beginning of the fifth fortnight. This was followed by a slower phase of decomposition.

Similarly, leaf biomass of *Mallotus philippensis* during the wet season under open and closed field conditions showed faster decomposition in the initial phase (Fig. 6). A sudden mass loss to 27.09 per cent in the open area and 30.09 per cent in the homegarden was observed from the initial fortnight till the fourth fortnight. This indicates almost 70 per cent of the mass loss within four fortnights during the wet season. Thereafter, they showed a declining trend till the end of the study. On the other hand, the residual samples collected during the dry season from both the open area and homegarden recorded 70 per cent mass loss within six fortnights followed by a phase of gradual decomposition.

4.2 FACTORS AFFECTING LEAF BIOMASS DECOMPOSITION

The various factors affecting the leaf biomass decomposition are discussed here under.

Table 3a. Total carbon content (%) in the residues of *Gmelina arborea* at fortnightly intervals

Fortnight	Open area		Homegarden		F Test	SEM±
	Wet season	Dry season	Wet season	Dry season		
0	71.91	74.01	71.91	74.01	--	--
1	69.21^{a}	71.45^{a}	68.32^{a}	71.16^{a}	NS	--
2	67.26^{ab}	68.83^{b}	65.38^{b}	68.06^{b}	NS	--
3	64.43^{b}	66.49^{c}	62.43^{c}	61.60^{c}	NS	--
4	$_{c}52.61^{e}$	$_{a}61.60^{d}$	$_{ab}60.13^{d}$	$_{b}57.77^{e}$	*	0.043
5	61.20^{c}	59.59^{e}	58.61^{e}	59.04^{d}	NS	--
6	58.46^{d}	57.39^{f}	55.24^{f}	57.72^{e}	NS	--
7	$_{c}51.89^{ef}$	$_{a}54.26^{g}$	$_{ab}53.05^{g}$	$_{d}45.56^{g}$	**	0.083
8	$_{b}49.59^{f}$	$_{a}52.12^{h}$	$_{b}47.07^{h}$	$_{c}44.95^{h}$	*	0.217
9	NA	50.96^{ij}	NA	48.32^{f}	--	--
10	NA	50.19^{j}	NA	48.02^{f}	--	--
F test	**	**	**	**		
SEM±	0.97	1.02	0.84	0.95		

** Significant at 1%

*Significant at 5%

Figures with the same superscript and subscript do not differ significantly

Superscripts indicate interactions between field and seasons within fortnight

Subscripts indicate interactions between fortnights within a field and season

NA – Not applicable

NS – Not significant

Table 3b. Nitrogen content (%) in the residues of *Gmelina arborea* at fortnightly intervals

Fortnight	Open area		Homegarden		F Test	SEM±
	Wet season	Dry season	Wet season	Dry season		
0	3.92	3.21	3.92	3.21	--	--
1	$_{a}b4.03^{a}$	$_{b}3.28^{c}$	$_{a}3.93^{a}$	$_{a}3.57^{b}$	**	0.029
2	$_{a}4.13^{a}$	$_{a}3.48^{c}$	$_{b}3.79^{b}$	$_{a}3.55^{c}$	**	0.026
3	$_{d}3.02^{b}$	$_{d}2.87^{c}$	$_{c}3.05^{b}$	$_{b}3.16^{a}$	**	0.031
4	$_{c}3.21^{a}$	$_{c}2.98^{b}$	$_{ed}3.02^{b}$	$_{b}3.20^{a}$	**	0.028
5	$_{c}3.18^{a}$	$_{e}2.21^{b}$	$_{e}2.95^{b}$	$_{c}2.89^{a}$	**	0.032
6	$_{d}2.99^{a}$	$_{f}2.08^{c}$	$_{f}2.49^{b}$	$_{d}1.92^{d}$	**	0.035
7	$_{e}2.05^{a}$	$_{f}1.99^{a}$	$_{g}2.18^{c}$	$_{e}1.56^{d}$	**	0.019
8	$_{f}1.71^{ab}$	$_{g}1.62^{ab}$	$_{h}1.93^{a}$	$_{f}1.44^{b}$	**	0.035
9	NA	$_{g}1.59$	NA	$_{f}1.40$	--	--
10	NA	$_{h}1.42$	NA	$_{g}1.29$	--	--
F test	**	**	**	**		
SEM±	0.08	0.04	0.07	0.05		

** Significant at 1%

*Significant at 5%

Figures with the same superscript and subscript do not differ significantly

Superscripts indicate interactions between field and seasons within fortnight

Subscripts indicate interactions between fortnights within a field and season

NA – Not applicable

NS – Not significant

Table 3c. C: N ratios of the residues of *Gmelina arborea* at fortnightly intervals

Fortnight	Open area		Homegarden		F Test	SEM±
	Wet season	Dry season	Wet season	Dry season		
0	18.34	23.05	18.34	23.05	--	--
1	$_{e}17.17^{c}$	$_{de}21.69^{a}$	$_{e}17.39^{c}$	$_{e}20.01^{b}$	**	0.127
2	$_{e}16.28^{b}$	$_{e}19.72^{a}$	$_{e}17.24^{b}$	$_{ef}19.20^{a}$	*	0.314
3	$_{c}21.36^{b}$	$_{d}23.30^{a}$	$_{c}20.45^{c}$	$_{e}19.50^{d}$	**	0.250
4	$_{e}16.42^{c}$	$_{de}20.67^{a}$	$_{d}19.91^{a}$	$_{f}18.06^{b}$	**	0.368
5	$_{d}19.29^{b}$	$_{c}26.89^{a}$	$_{d}19.85^{b}$	$_{e}20.42^{b}$	**	0.712
6	$_{d}19.44^{c}$	$_{c}27.66^{a}$	$_{b}22.19^{b}$	$_{d}26.93^{a}$	**	0.734
7	$_{b}25.38^{c}$	$_{c}27.32^{b}$	$_{a}24.34^{c}$	$_{d}29.20^{a}$	**	0.458
8	$_{a}28.93^{a}$	$_{b}32.59^{a}$	$_{a}24.40^{b}$	$_{c}31.21^{a}$	*	0.108
9	NA	$_{b}32.06$	NA	$_{b}34.59$	--	--
10	NA	$_{a}35.47$	NA	$_{a}37.23$	--	--
F test	**	**	**	**		
SEM±	0.981	2.422	0.510	0.526		

** Significant at 1%

*Significant at 5%

Figures with the same superscript and subscript do not differ significantly

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NA – Not applicable

NS – Not significant

4.2.1 Effect of litter quality on the rate of decomposition

The effects of substrate quality on its decomposition under various study situations are detailed below.

4.2.1.1 Nitrogen content and C: N ratio

Gmelina arborea

The total carbon, nitrogen content and C: N ratio of the leaf biomass of *Gmelina arborea* as affected by seasons and locations is shown in Table 3a, 3b and 3c. Attempts were made to relate the influence of seasons on the C: N ratios recorded in the open area and the homegarden. The statistical analysis showed a significant relationship of them on controlling the C: N ratios of the leaf residues. The initial C: N ratio recorded during the wet season and the dry season was 18.34 and 23.05. In general, an increasing trend was observed till the last fortnight in both open area and homegarden under the influence of both the seasons. Higher values were observed in the dry season compared to the wet season. The peak values noted in the open area during the wet season and dry season was 28.93 (eighth fortnight) and 35.47 (tenth fortnight) respectively. Similarly, the maximum C: N ratio noted in the homegarden during the wet season and dry season was 24.40 (eighth fortnight) and 37.23 (tenth fortnight) respectively.

Mallotus philippensis

The effect of wet season and dry season on determining the C: N ratios of the residues retrieved from open area and homegarden was studied separately. The data regarding this are also plotted in Tables 4a, 4b and 4c. The open area and the homegarden during the wet season recorded C: N ratios of 22.20, whereas, in the dry season, it recorded 26.23. A steady increase in the C: N ratio was observed till the decomposition was over. By the end of the eleventh fortnight, the C: N ratios recorded in the open area during the wet season and dry season was 27.22 and

Table 4a. Total carbon content (%) in the residues of *Mallotus philippensis* at fortnightly intervals

Fortnight	Open area		Homegarden		F Test	SEM±
	Wet season	Dry season	Wet season	Dry season		
0	69.26	75.81	69.26	75.81	--	--
1	$_{b}64.23^{a}$	$_{a}70.82^{a}$	$_{b}64.25^{a}$	$_{a}70.01^{a}$	**	0.529
2	$_{c}60.49^{b}$	$_{b}67.96^{b}$	$_{c}60.53^{c}$	$_{a}64.25^{b}$	**	0.089
3	$_{c}57.58^{c}$	$_{a}65.49^{c}$	$_{b}61.44^{bc}$	$_{ab}62.15^{c}$	**	0.512
4	$_{c}54.67^{d}$	$_{a}60.09^{d}$	$_{d}51.61^{de}$	$_{b}58.91^{d}$	**	0.076
5	$_{cd}52.15^{e}$	$_{a}58.95^{de}$	$_{d}51.10^{de}$	$_{b}56.74^{e}$	**	0.059
6	$_{cd}51.05^{ef}$	$_{a}56.47^{ef}$	$_{d}49.80^{e}$	$_{b}54.42^{f}$	**	0.018
7	$_{c}50.11^{ef}$	$_{a}54.57^{fg}$	$_{d}47.35^{f}$	$_{b}50.65^{g}$	**	0.086
8	$_{b}49.29^{fg}$	$_{a}54.14^{fg}$	$_{c}45.10^{g}$	$_{b}48.60^{h}$	**	0.503
9	$_{bc}48.41^{g}$	$_{a}53.99^{gh}$	$_{d}43.57^{h}$	$_{bc}47.71^{hi}$	**	0.068
10	$_{b}45.81^{gh}$	$_{a}51.25^{h}$	$_{c}40.36^{ij}$	$_{b}45.34^{ij}$	**	0.032
11	$_{b}44.61^{h}$	$_{a}48.33^{i}$	$_{c}39.37^{j}$	$_{b}44.59^{jk}$	**	0.064
12	NA	46.99^{ij}	NA	43.23^{kl}	--	--
13	NA	45.58^{j}	NA	42.84^{lm}	--	--
14	NA	44.24^{k}	NA	41.95^{m}	--	--
F test	**	**	**	**		
SEM±	0.89	1.13	0.79	0.96		

** Significant at 1%

*Significant at 5%

Figures with the same superscript and subscript do not differ significantly

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Subscripts indicate interactions between fortnights within a field and season

NA – Not applicable

NS – Not significant

Table 4b. Nitrogen content (%) in the residues of *Mallotus philippensis* at fortnightly intervals

Fortnight	Open area		Homegarden		F Test	SEM±
	Wet season	Dry season	Wet season	Dry season		
0	3.12	2.89	3.12	2.89	--	--
1	$_{a}3.24^{a}$	$_{a}3.01^{c}$	$_{a}3.08^{b}$	$_{a}3.07^{b}$	**	0.028
2	$_{a}3.36^{a}$	$_{b}2.84^{c}$	$_{b}2.95^{c}$	$_{b}3.08^{b}$	**	0.035
3	$_{b}2.46$	$_{b}2.80$	$_{c}2.48$	$_{a}2.95$	NS	--
4	$_{c}2.29$	$_{d}2.51$	$_{d}2.31$	$_{b}2.63$	NS	--
5	$_{b}2.51$	$_{c}2.60$	$_{e}2.19$	$_{b}2.59$	*	0.070
6	$_{bc}2.38^{ab}$	$_{e}2.43^{a}$	$_{f}2.10^{c}$	$_{c}2.34^{b}$	**	0.053
7	$_{c}2.25^{b}$	$_{f}2.32^{a}$	$_{f}2.09^{c}$	$_{d}2.01^{c}$	*	0.021
8	$_{d}2.00^{b}$	$_{g}2.16$	$_{g}1.96^{b}$	$_{e}1.78^{c}$	**	0.025
9	$_{de}1.94^{b}$	$_{h}2.09^{a}$	$_{h}1.68^{c}$	$_{f}1.52^{d}$	**	0.057
10	$_{ef}1.71^{b}$	$_{i}1.91^{a}$	$_{i}1.52^{c}$	$_{g}1.40^{d}$	**	0.019
11	$_{f}1.64$	$_{j}1.76$	$_{j}1.25$	$_{gh}1.35$	NS	--
12	NA	$_{k}1.45$	NA	$_{h}1.52$	--	--
13	NA	$_{l}1.36$	NA	$_{gh}1.40$	--	--
14	NA	$_{m}1.20$	NA	$_{gh}1.31$	--	--
F test	**	**	**	**		
SEM±	0.09	0.03	0.05	0.06		

** Significant at 1%

*Significant at 5%

Figures with the same superscript and subscript do not differ significantly

Superscripts indicate interactions between field and seasons within fortnight

Subscripts indicate interactions between fortnights within a field and season

NA – Not applicable

NS – Not significant

Table 4c. C: N ratios of the residues of *Mallotus philippensis* at fortnightly intervals

Fortnight	Open area		Homegarden		F Test	SEM±
	Wet season	Dry season	Wet season	Dry season		
0	22.20	26.23	22.20	26.23	--	--
1	$_{hi}19.83^{b}$	$_{j}23.51^{a}$	$_{f}20.82^{b}$	$_{de}22.86^{a}$	*	0.328
2	$_{i}17.99^{c}$	$_{j}23.92^{a}$	$_{f}20.51^{b}$	$_{de}20.81^{b}$	**	0.206
3	$_{cde}23.41^{b}$	$_{j}23.37^{b}$	$_{c}24.82^{a}$	$_{def}21.09^{c}$	**	0.342
4	$_{cd}23.84$	$_{j}23.98$	$_{e}22.34$	$_{de}22.43$	NS	--
5	$_{gh}20.95$	$_{k}22.68$	$_{de}22.87$	$_{def}21.86$	NS	--
6	$_{fgh}21.39$	$_{j}23.26$	$_{e}23.71$	$_{d}23.27$	NS	--
7	$_{efg}22.23$	$_{ij}23.52$	$_{de}22.68$	$_{d}25.50$	NS	--
8	$_{bc}24.64^{bc}$	$_{gh}25.03^{b}$	$_{cde}23.01^{c}$	$_{c}27.30^{a}$	**	0.466
9	$_{abc}25.03$	$_{fg}25.80$	$_{b}25.94^{b}$	$_{ab}31.46$	*	0.591
10	$_{ab}26.73^{b}$	$_{ef}26.85^{b}$	$_{b}26.62^{b}$	$_{ab}32.31^{a}$	*	0.512
11	$_{a}27.22^{b}$	$_{d}27.46^{b}$	$_{a}31.68^{ab}$	$_{a}33.03^{a}$	**	0.352
12	NA	$_{c}32.41$	NA	$_{c}28.44$	--	--
13	NA	$_{b}34.01$	NA	$_{b}30.60$	--	--
14	NA	$_{a}36.86$	NA	$_{ab}32.02$	--	--
F test	**	**	**	**		
SEM±	1.685	0.653	0.212	1.080		

** Significant at 1%

*Significant at 5%

Figures with the same superscript and subscript do not differ significantly

Superscripts indicate interactions between field and seasons within fortnight

Subscripts indicate interactions between fortnights within a field and season

NA – Not applicable

NS – Not significant

27.46 respectively. Similarly, homegarden during the wet season and dry season recorded 31.68 and 33.03 respectively.

4.2.1.2 Lignin content and lignin: nitrogen ratio

Gmelina arborea

The results of the chemical analysis of lignin for the fresh leaf biomass and residues of *Gmelina arborea* under different study situations are presented in Table 5a. The fresh leaf samples of the dry season recorded higher lignin content (13.21 %) as compared to the leaf samples of the wet season (10.25 %). Significant differences in values were observed. The analysis of the initial samples and the residues collected during the first and final fortnights of both the seasons showed an increasing lignin content as the decomposition progressed. In general, open field condition reported lower initial lignin content. In the open condition of the wet season, lignin content increased from 10.25 per cent and peaked to 16.32 per cent by the end of the study. During the same season, homegarden registered an increase from 10.21 per cent to 19.28 per cent. Lignin content of the dry season was observed with a steady increase from 13.21 per cent to 25.10 per cent in the open area, whereas, in the homegarden lignin content increased from 13.21 per cent to 26.09 per cent for the wet season and dry season.

The ratio between the lignin and nitrogen of the fresh leaves and the residues also revealed a similar increasing trend from beginning till the end (Table 5a). The initial lignin: nitrogen ratio for the fresh leaves during wet and dry season was 2.61 and 4.11 respectively. The L: N ratio reached its peak value at the end of the study. By the eighth fortnight, the L: N ratio observed in open area during the wet season and dry season was 9.54 and 15.49 respectively. Similarly, the L: N ratio observed in the homegarden during the wet season and dry season was 9.98 and 18.12 respectively.

Table 5a. Lignin: nitrogen ratio of the residues of *Gmelina arborea* as influenced by seasons and location

Fortnight	Wet season						Dry season					
	Open area			Homegarden			Open area			Homegarden		
	Lignin (%)	N (%)	L: N	Lignin (%)	N (%)	L: N	Lignin (%)	N (%)	L: N	Lignin (%)	N (%)	L: N
Initial	10.25	3.92	2.61	10.25	3.92	2.61	13.21	3.21	4.11	13.21	3.21	4.11
First	10.70	4.03	2.65	10.90	3.93	2.77	15.85	3.28	6.35	18.31	3.57	5.12
Final	16.32	1.71	9.54	19.28	1.93	9.98	25.10	1.62	15.49	26.09	1.44	18.12
F test	**	**	**	**	**	**	**	**	**	**	**	**
SEM±	0.67	0.70	0.89	0.31	0.23	0.17	0.12	0.08	0.48	0.39	0.58	0.21

** Significant at 1%

Table 5b. Lignin: nitrogen ratio of the residues of *Mallotus philippensis* as influenced by seasons and locations

Fortnight	Wet season						Dry season					
	Open area			Homegarden			Open area			Homegarden		
	Lignin (%)	N (%)	L: N	Lignin (%)	N (%)	L: N	Lignin (%)	N (%)	L: N	Lignin (%)	N (%)	L: N
Initial	20.09	3.12	6.75	20.09	3.12	6.75	22.80	2.89	7.88	22.80	2.89	7.88
First	23.53	3.24	7.26	24.99	3.08	8.11	24.09	3.01	8.00	26.27	3.07	8.56
Final	33.25	1.64	20.27	35.34	1.25	28.72	37.50	1.76	21.30	44.04	1.35	32.66
F test	**	**	**	**	**	**	**	**	**	**	**	**
SEM±	0.14	0.19	0.06	0.17	0.26	1.79	0.95	1.14	0.22	0.65	0.58	0.35

**Significant at 1%

Mallotus philippensis

The data related to the lignin content in the open area and homegarden as influenced by seasonal variations is shown in Table 5b. The leaf samples of *Mallotus philippensis* also exhibited the similar trend as that of *Gmelina arborea.* Statistical analysis showed significant difference in the values recorded. The fresh leaf samples collected during the dry season recorded higher lignin content (22.80 %) as compared to the leaf samples of the wet season (20.09 %).

Open area during the wet season recorded the lowest lignin content followed by homegarden during dry season. By the end of the eleventh fortnight, lignin content recorded was in the order: open area during the wet season (33.25 %) < homegarden during the wet season (35.34 %) < open area during the dry season (37.50 %) < homegarden during the dry season (44.04 %).

The L: N ratios of the residues with respect to locations and seasons are also presented in Table 5b. The initial value obtained for open area and homegarden during wet season was 6.75 per cent. Similarly, open area and homegarden during the dry season observed L: N ratio of 7.88 per cent. At the end of the eleventh fortnight, the values observed were in the order: open area during the wet season (20.15 %) < homegarden during the wet season (20.07 %) < open area during the dry season (21.30 %) < homegarden during the dry season (29.36 %).

4.2.2 Effect of soil factors on the rate of decomposition

The decomposition of organic matter incorporated into the soil is a function of various edaphic factors. An attempt was made to understand the role of edaphic factors on the rate of decomposition and the salient findings are summarized below.

Table 6a. Soil moisture (%) and soil temperature (^{0}C) at the study area of *Gmelina arborea* at fortnightly intervals

Fortnight	Soil moisture				Soil temperature			
	Wet season		Dry season		Wet season		Dry season	
	Open area (%)	Homegarden (%)	Open area (%)	Homegarden (%)	Open area (^{0}C)	Homegarden (^{0}C)	Open area (^{0}C)	Homegarden (^{0}C)
0	17.87	21.62	8.42	10.42	27.90	26.20	33.10	31.10
1	22.18	24.66	5.27	9.27	27.10	26.60	32.20	29.20
2	30.32	29.62	3.51	6.51	28.80	27.90	33.40	28.40
3	31.37	33.19	5.60	8.60	28.30	28.30	35.00	28.90
4	31.70	29.45	2.08	10.08	28.40	28.30	34.60	28.50
5	20.22	22.72	3.62	11.62	29.10	29.00	27.00	35.00
6	15.78	18.72	4.14	9.14	30.10	28.50	37.00	30.50
7	10.49	19.79	3.23	10.23	28.80	27.80	38.40	30.00
8	17.23	26.30	2.38	11.38	28.60	27.80	39.90	30.10
9	NA	25.83	8.30	12.30	29.40	29.90	40.10	31.50
10	NA	NA	18.85	22.85	31.50	28.30	38.10	32.50
P < 0.05 CD**(5%) = 1.14 SEM± = 0.35					P < 0.05 CD**(5%) = 1.50 SEM± = 0.46			

Table 6b. Soil moisture (%) and soil temperature (^{0}C) at the study area of *Mallotus philippensis* at fortnightly intervals

Fortnight	Soil moisture				Soil temperature			
	Wet season		Dry season		Wet season		Dry season	
	Open area (%)	Homegarden (%)	Open area (%)	Homegarden (%)	Open area (^{0}C)	Homegarden (^{0}C)	Open area (^{0}C)	Homegarden (^{0}C)
0	16.95	24.12	8.39	10.82	27.90	26.20	33.10	31.10
1	22.97	25.32	5.21	9.19	27.10	26.60	32.20	29.20
2	29.42	32.62	3.48	6.70	28.80	27.90	33.40	28.40
3	29.97	33.19	5.59	7.61	28.30	28.30	35.00	28.90
4	31.77	30.45	2.06	9.01	28.40	28.30	34.60	28.50
5	20.76	21.72	3.02	11.62	29.10	29.00	27.00	35.00
6	14.96	18.46	3.94	9.42	30.10	28.50	37.00	30.50
7	10.02	18.77	4.23	10.23	28.80	27.80	38.40	30.00
8	17.92	25.43	3.38	9.88	28.60	27.80	39.90	30.10
9	15.29	25.22	8.23	12.31	29.40	29.90	40.10	31.50
10	13.21	20.11	17.50	21.85	31.50	28.30	38.10	32.50
11	NA	NA	16.99	20.93	NA	29.50	34.40	29.90
12	NA	NA	20.78	22.07	NA	NA	37.70	31.50
13	NA	NA	26.71	30.53	NA	NA	38.1	33.10
14	NA	NA	NA	31.98	NA	NA	38.5	33.80
	$P < 0.05$ CD**(5%) = 2.09 SEM$\pm$ = 0.64				$P < 0.05$ CD**(5%) = 1.50 SEM$\pm$ = 0.46			

4.2.2.1 Soil temperature

The observations recorded on the soil temperature at various fortnightly intervals for both the species during both the seasons are presented in Tables 6a and 6b. The soil temperature observed under *Gmelina arborea* and *Mallotus philippensis* was found to be the same. In both the seasons, maximum soil temperature was recorded during the dry periods. Among the different field conditions, open area registered highest soil temperature.

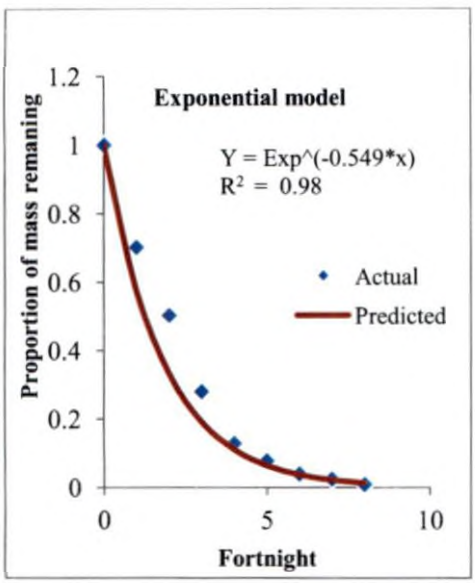
4.2.2.2 Soil moisture

Soil moisture content of the study area was recorded at fortnightly intervals and the relevant data are furnished in Tables 6a and 6b. The soil moisture content for both *Gmelina arborea* and *Mallotus philippensis* was higher during rainy days compared to the non-rainy days. During the dry season, the lowest soil moisture content recorded for *Gmelina arborea* was 2.08 per cent in the open area and 8.60 per cent in the homegarden. Similarly, soil of open area under *Mallotus philippensis* was found to record a very low moisture content of 2.06 per cent, whereas, homegarden reported a low moisture content of 9.01 per cent during the dry season.

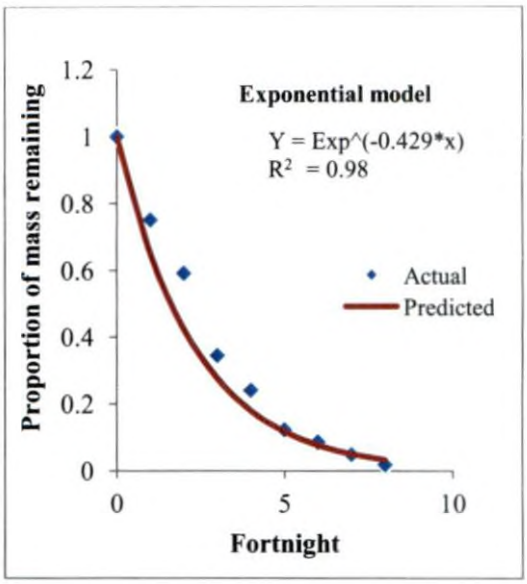
4.2.3 Decomposition model

The quantity of residues present in the litter bags is a function of several factors such as time elapsed, soil moisture content and soil temperature. Mathematical models were developed to assess the effect of these factors on the rate of decomposition (Fig. 7 and 8).

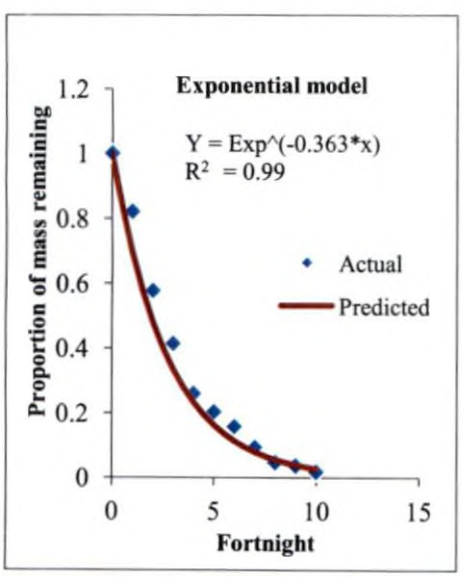
Based on the quantity of residual matter remaining in the litter bags at the end of each fortnight, decay coefficient (k) was estimated for different study situations. For both *Gmelina arborea* and *Mallotus philippensis*, decay coefficient was highest in the open area during the wet season and lowest for the homegarden



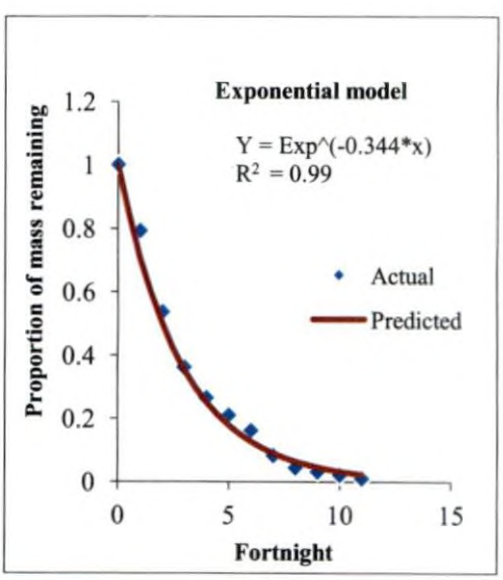
a) Wet season - Open area



b) Wet season - Homegarden

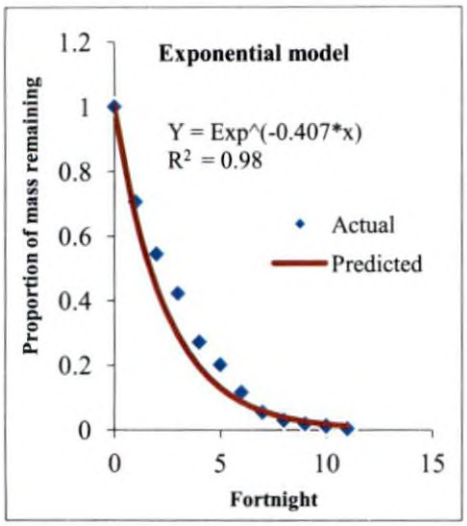


c) Dry season - Open area

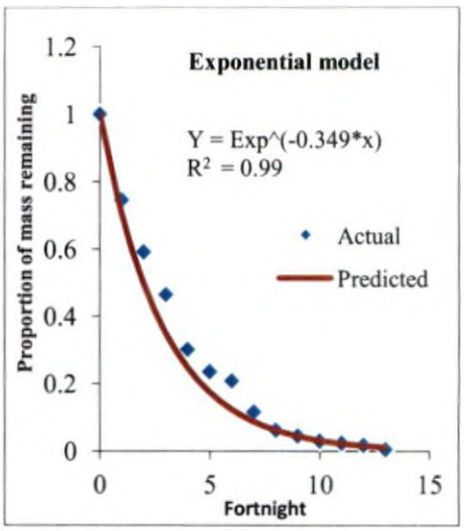


d) Dry season - Homegarden

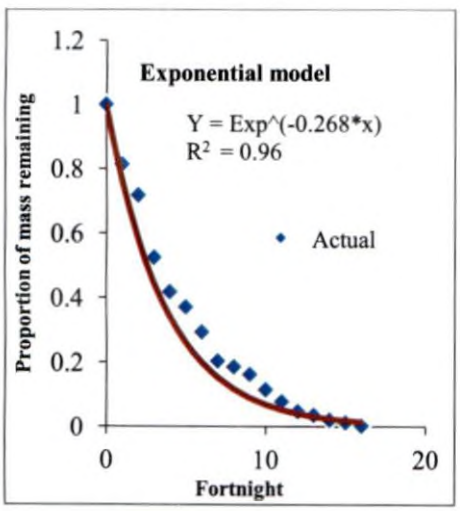
Fig 7. Decay model for *Gmelina arborea* during the wet season and dry season



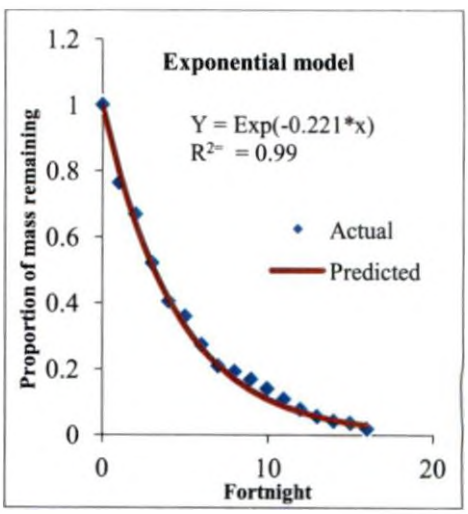
a) Wet season - Open area



b) Wet season - Homegarden



c) Dry season - Open area



d) Dry season - Homegarden

Fig 8. Decay model for *Mallotus philippensis* during wet season and dry season

Table 7. Decay rate coefficients of decomposing leaf biomass of *Gmelina arborea* and *Mallotus philippensis*

Species	Situation	k	R^2	S.E.E	$t_{1/2}$
Gmelina arborea	Open area during wet season	0.549	0.98	0.299	1.26
	Homegarden during wet season	0.429	0.99	0.256	1.61
	Open area during dry season	0.363	0.99	0.221	1.92
	Homegarden during dry season	0.344	0.99	0.182	2.04
Mallotus philippensis	Open area during wet season	0.407	0.98	0.279	1.69
	Homegarden during wet season	0.349	0.99	0.307	1.98
	Open area during dry season	0.268	0.96	0.530	2.57
	Homegarden during dry season	0.221	0.99	0.157	3.30

R^2 – Coefficient of determination

S.E.E – Standard Error of the Estimate

$t_{1/2}$ – Half-life period in fortnights

during the dry season. The decay coefficient recorded for *Gmelina arborea* during the wet season in the open area and homegarden was 0.55 and 0.43 respectively. Similarly, the decay coefficient recorded during the dry season was 0.36 and 0.34 respectively. In the case of *Mallotus philippensis*, the decay coefficient recorded during the wet season in the open area and homegarden was 0.41 and 0.35 respectively. Similarly, the decay coefficient recorded during the dry season was 0.27 and 0.22 respectively (Table 7).

The half- life values recorded for *Gmelina arborea* during the wet season in the open area and homegarden was 1.26 and 1.61 fortnights respectively. Similarly, the half-life values recorded during the dry season was 1.92 and 2.04 fortnights respectively. In the case of *Mallotus philippensis*, the half-life values recorded during the wet season in the open area and homegarden was 1.69 and 1.98 fortnights respectively. Similarly, during the dry season it was 2.57 and 3.30 fortnights respectively.

To determine the pattern of decomposition over a period of time during various situations, regression equations were fitted, by relating the percentage of residues remaining in the litter bags with the time elapsed (Fig. 7 and 8). The exponential equation $X/X^0 = e^{-kt}$ was fitted where R^2 values for *Gmelina arborea* during the dry season in the open area and homegarden was found to be 0.98 and 0.99 respectively, whereas, the same species during the wet season in the open condition and homegarden recorded R^2 value of 0.99 and 0.98 respectively. Similarly, *Mallotus philippensis* during the dry season observed R^2 value of 0.96 and 0.99 respectively, whereas, during the wet season *Mallotus philippensis* recorded R^2 value of 0.99, both in the open area and homegarden.

4.3 NUTRIENT RELEASE PATTERN

The nutrients which are organically bound to leaves are made available to soil through their decomposition. In order to find the suitability of the trees as green manure, scientific knowledge on their nutrient release pattern is essential.

The study was conducted during both the wet season starting from June and dry season starting from December under two different field conditions, i.e. open area and homegarden in *Gmelina arborea* and *Mallotus philippensis*. The initial fresh leaf samples and the residues retrieved from both the fields were subjected to chemical analysis for determining the total carbon, nitrogen, phosphorus, potassium and lignin content.

4.3.1 Changes in nutrient concentrations

The details on the nutrient concentrations in the fresh samples and residual leaf biomass of *Gmelina arborea* and *Mallotus philippensis* collected at fortnightly intervals under various study situations are explained below.

4.3.1.1 Total nitrogen

Gmelina arborea

Efforts were taken to study the influence of seasons on the nitrogen content of the residual samples collected from open area and homegarden. The data related to this is shown in Table 8a. The results obtained after subjecting to statistical analysis showed significant influence of the seasons on the different locations studied at fortnightly intervals. The initial nitrogen content recorded during the wet season and the dry season was 3.92 per cent and 3.21 per cent respectively.

Table 8a. Nitrogen content (%) in the residues of *Gmelina arborea* at fortnightly intervals

Fortnight	Open area		Homegarden		F Test	SEM ±
	Wet season	Dry season	Wet season	Dry season		
0	3.92	3.21	3.92	3.21	--	--
1	4.03^{a}	3.28^{c}	3.93^{a}	3.57^{b}	**	0.029
2	4.13^{a}	3.48^{c}	3.79^{b}	3.55^{c}	**	0.026
3	3.02^{b}	2.87^{c}	3.05^{b}	3.16^{a}	**	0.031
4	3.21^{a}	2.98^{b}	3.02^{b}	3.20^{a}	**	0.028
5	3.18^{a}	2.21^{b}	2.95^{b}	2.89^{a}	**	0.032
6	2.99^{a}	2.08^{c}	2.49^{b}	1.92^{d}	**	0.035
7	2.05^{a}	1.99^{a}	2.18^{c}	1.56^{d}	**	0.019
8	1.71^{ab}	1.62^{ab}	1.93^{a}	1.44^{b}	**	0.035
9	NA	1.59	NA	1.40	--	--
10	NA	1.42	NA	1.29	--	--
F test	**	**	**	**		
SEM±	0.08	0.04	0.07	0.05		

** Significant at 1%

*Significant at 5%

Figures with the same superscript and subscript do not differ significantly

Superscripts indicate interactions between field and seasons within fortnight

Subscripts indicate interactions between fortnights within a field and season

NA – Not applicable

NS – Not significant

With respect to open area, the samples kept for decomposition during both wet season and dry season showed an increase in concentration followed by a gradual decline in the latter fortnights. During the first fortnight of sample collection, the nitrogen content in the wet season increased to 4.03 per cent. Similarly, during the first fortnight the nitrogen content of leaf residues retrieved during the dry season rose to 3.28 per cent. Second fortnights of wet season and dry season registered further increase in nitrogen content of leaf mass retrieved from open area. The third fortnight registered a slight decrease in nitrogen content during both the seasons (wet season – 3.02 % and dry season – 2.87 %). This was followed by a reduction in concentration till the end of the study during both the seasons except during the fourth fortnight. The nitrogen contents during the wet season and the dry season during the final fortnight was 1.71 per cent and 1.42 per cent respectively.

With respect to homegarden, the samples kept for decomposition during both wet season and dry season showed an increase in concentration followed by a gradual decline in the latter fortnights. During the first fortnight of sample collection, the nitrogen content in the wet season increased to 3.93 per cent. Similarly, during the first fortnight the nitrogen content of leaf residues retrieved during the dry season hiked to 3.57 per cent. This was followed by a reduction in concentration till the end of the study during both the seasons. The subsequent fortnights of both the seasons recorded gradual decrease in nitrogen content. The nitrogen contents during the wet season and the dry season during the final fortnight was 1.93 per cent and 1.29 per cent respectively.

The maximum nitrogen content recorded in the open area was in the second fortnight during the wet season (4.13 %), whereas, the least value recorded was in the tenth fortnight during the dry season (1.42 %). Similarly the maximum and minimum nitrogen contents observed in the homegarden was 3.93 per cent (first fortnight) during the wet season and 1.29 per cent (tenth fortnight) during the dry season.

Table 8b. Nitrogen content (%) in the residues *of Mallotus philippensis* at fortnightly intervals

Fortnight	Open area		Homegarden		F Test	SEM±
	Wet season	Dry season	Wet season	Dry season		
0	3.12	2.89	3.12	2.89	--	--
1	3.24^{a}	3.01^{c}	3.08^{b}	3.07^{b}	**	0.021
2	3.36^{a}	2.84^{c}	2.95^{c}	3.08^{b}	**	0.036
3	2.46	2.80	2.48	2.95	NS	--
4	2.29	2.51	2.31	2.63	NS	--
5	2.51	2.60	2.19	2.59	*	0.070
6	2.38^{ab}	2.43^{a}	2.10^{c}	2.34^{b}	**	0.023
7	2.25^{b}	2.32^{a}	2.09^{c}	2.01^{c}	*	0.028
8	2.00^{b}	2.16	1.96^{b}	1.78^{c}	**	0.022
9	1.94^{b}	2.09^{a}	1.68^{c}	1.52^{d}	**	0.017
10	1.71^{b}	1.91^{a}	1.52^{c}	1.40^{d}	**	0.019
11	1.64	1.76	1.25	1.35	NS	--
12	NA	1.45	NA	1.52	--	--
13	NA	1.36	NA	1.40	--	--
14	NA	1.20	NA	1.31	--	--
F test	**	**	**	**		
SEM±	0.09	0.03	0.05	0.06		

** Significant at 1%

*Significant at 5%

Figures with the same superscript and subscript do not differ significantly

Superscripts indicate interactions between field and seasons within fortnight

Subscripts indicate interactions between fortnights within a field and season

NA – Not applicable

NS – Not significant

The nitrogen content recorded in the open area and homegarden at fortnightly intervals during the wet season showed significant differences. Similarly, during the dry season also significant difference in nitrogen concentration was observed in open area and homegarden.

Mallotus philippensis

Similar attempts were also made in *Mallotus philippensis* to study the influence of seasons on the nitrogen content retained by the residues on each location (Table 8b). Statistical analysis emphasized significant differences between the values recorded in the locations at fortnightly intervals. The initial nitrogen contents recorded during wet season was 3.12 per cent and that during the dry season was 2.89 per cent.

With respect to open area, the samples kept for decomposition during both wet season and dry season showed an increase in concentration initially followed by a gradual decline in the latter fortnights. During the first fortnight of sample collection, the nitrogen content in the wet season increased to 3.24 per cent. Similarly, during the first fortnight the nitrogen content of leaf residues retrieved during the dry season hiked to 3.01 per cent. Second fortnights of wet season registered further increase, whereas, dry season recorded a slight decrease in nitrogen content of leaf mass retrieved from open area. The third fortnight marked a gradual decrease in nitrogen content during both the seasons (wet season – 2.46 % and dry season – 2.80 %). The nitrogen contents during the wet season and the dry season during the final fortnight was 1.64 per cent and 1.20 per cent respectively.

With respect to homegarden, the samples kept for decomposition during the wet season showed a continuous but gradual decrease in nitrogen content in the latter fortnights, whereas, the samples kept during the dry season experienced an increase in concentration followed by a gradual decline in the latter fortnights.

During the first fortnight of sample collection, the nitrogen content in the wet season dropped to 3.08 per cent. On the other hand, during the first fortnight the nitrogen content of leaf residues retrieved during the dry season rose to 3.07 per cent. This was followed by a reduction in concentration till the end of the study during both the seasons. The nitrogen contents during the wet season and the dry season during the final fortnight was 1.25 per cent and 1.31 per cent respectively.

The maximum nitrogen content recorded in the open area was in the second fortnight during the wet season (3.36 %), whereas, the least value recorded was in the fourteenth fortnight during the dry season (1.20 %). Similarly the maximum and minimum nitrogen contents observed in the homegarden was 3.12 per cent (initial fortnight) and 1.25 per cent (eleventh fortnight) during the wet season. During the final fortnight, nitrogen content observed in the residues was in the order: open area during the dry season (1.20 %) < homegarden during the wet season (1.25 %) < open area during the dry season (1.31 %) < open area during the wet season (1.64 %).

The nitrogen content recorded in the open area and homegarden at fortnightly intervals during the wet season showed significant differences. Similarly, during the dry season also significant difference in nitrogen concentration was observed in open area and homegarden.

4.3.1.2 Phosphorus

Gmelina arborea

Efforts were taken to study the influence of seasons on the phosphorus content of the residual samples collected from open area and homegarden. The data related to this is shown in Table 9a. The results obtained after subjecting to statistical analysis showed significant influence of the seasons on the different locations studied. The initial phosphorus content recorded during the wet season and the dry season was 0.18 per cent and 0.16 per cent respectively.

Table 9a. Phosphorus content (%) in the residues of *Gmelina arborea* at fortnightly intervals

Fortnight	Open area		Homegarden		F Test	SEM±
	Wet season	Dry season	Wet season	Dry season		
0	0.18	0.16	0.18	0.16	--	--
1	$_{a}0.16$	$_{ab}0.14$	$_{a}0.17$	$_{a}0.17$	NS	--
2	$_{cd}0.13$	$_{a}0.16$	$_{b}0.15$	$_{b}0.15$	NS	--
3	$_{bcd}0.14$	$_{bc}0.12$	$_{ab}0.16$	$_{c}0.13$	NS	--
4	$_{bcd}0.13^{a}$	$_{cd}0.10^{b}$	$_{cd}0.13^{a}$	$_{cd}0.12^{b}$	*	0.051
5	$_{d}0.12^{a}$	$_{d}0.08^{d}$	$_{e}0.10^{b}$	$_{e}0.09^{c}$	*	0.025
6	$_{ac}0.15$	$_{cd}0.10$	$_{bc}0.14$	$_{cd}0.12$	NS	--
7	$_{ac}0.15$	$_{cd}0.11$	$_{bc}0.14$	$_{e}0.09$	NS	--
8	$_{c}0.14$	$_{bc}0.12$	$_{d}0.13$	$_{e}0.10$	NS	--
9	NA	$_{cd}0.10$	NA	$_{cd}0.12$	--	--
10	NA	$_{ab}0.14$	NA	$_{d}0.13$	--	--
F test	**	**	**	**		
SEM±	0.08	0.03	0.05	0.09		

** Significant at 1%

*Significant at 5%

Figures with the same superscript and subscript do not differ significantly

Superscripts indicate interactions between field and seasons within fortnight

Subscripts indicate interactions between fortnights within a field and season

NA – Not applicable

NS – Not significant

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Table 9b. Phosphorus content (%) in the residues of *Mallotus philippensis* at fortnightly intervals

Fortnight	Open area		Homegarden		F Test	SEM±
	Wet season	Dry season	Wet season	Dry season		
0	0.14	0.12	0.14	0.12	--	--
1	0.13	0.12	0.16	0.12	NS	--
2	0.15	0.11	0.14	0.10	NS	--
3	0.11	0.09	0.13	0.09	NS	--
4	0.12	0.09	0.12	0.08	NS	--
5	0.13	0.09	0.12	0.08	NS	--
6	0.09	0.11	0.11	0.09	NS	--
7	0.08	0.07	0.12	0.07	NS	--
8	0.10	0.10	0.11	0.08	NS	--
9	0.09	0.09	0.08	0.08	NS	--
10	0.09	0.10	0.09	0.09	NS	--
11	0.07	0.08	0.09	0.06	NS	--
12	NA	0.09	NA	0.09	--	--
13	NA	0.1	NA	0.08	--	--
14	NA	0.09	NA	0.08	--	--
F test	**	**	**	**		
SEM±	0.032	0.04	0.07	0.05		

** Significant at 1%

*Significant at 5%

Figures with the same superscript and subscript do not differ significantly

Superscripts indicate interactions between field and seasons within fortnight

Subscripts indicate interactions between fortnights within a field and season

NA – Not applicable

NS – Not significant

With respect to open area, the samples kept for decomposition during both wet season and dry season showed a fluctuating trend in phosphorus concentration, i.e. an increase followed by a gradual decline which was further followed by a decrease in value in the latter fortnights. During the first fortnight of sample collection, the phosphorus content in the wet season decreased to 0.16 per cent. Similarly, during the first fortnight the phosphorus content of leaf residues retrieved during the dry season reduced to 0.14 per cent. The final fortnight registered lower phosphorus content. The phosphorus contents during the wet season and the dry season in the final fortnight was 0.14 per cent respectively.

With respect to homegarden, the samples kept for decomposition during both wet season and dry season also showed a fluctuating trend in phosphorus concentration. During the first fortnight of sample collection, the phosphorus content in the wet season decreased to 0.17 per cent. On the other hand, during the first fortnight the phosphorus content of leaf residues retrieved during the dry season rose to 0.17 per cent. Second fortnights of wet season and dry season registered lower phosphorus content of 0.15 per cent respectively. The phosphorus contents during the wet season and the dry season during the final fortnight was 0.13 per cent respectively.

The phosphorus content recorded in the open area and homegarden at fortnightly intervals during the wet season showed no significant differences. Similarly, during the dry season also no significant difference in nitrogen concentration was observed in open area and homegarden.

Mallotus philippensis

Similar attempts were also taken to study the influence of seasons on the phosphorus content of the residual samples of *Mallotus philippensis* collected from open area and homegarden. The data related to this is shown in Table 9b.

The results obtained after subjecting to statistical analysis showed significant influence of the seasons on the different locations studied. The initial phosphorus content recorded during the wet season and the dry season was 0.14 per cent and 0.12 per cent respectively.

With respect to open area, the samples kept for decomposition during both wet season and dry season showed a fluctuating trend in phosphorus concentration, i.e. an increase followed by a gradual decline which was further followed by a decrease in value in the latter fortnights. During the first fortnight of sample collection, the phosphorus content in the wet season decreased to 0.13 per cent. On the other hand, during the first fortnight the phosphorus content of leaf residues retrieved during the dry season did not show any change in phosphorus value (0.12 %). The phosphorus contents observed during the wet season and the dry season in the final fortnight was 0.07 per cent and 0.09 per cent respectively.

With respect to homegarden, the samples kept for decomposition during both wet season and dry season showed a fluctuating trend in phosphorus concentration, i.e. an increase followed by a gradual decline which was further followed by a decrease in value in the latter fortnights. During the first fortnight of sample collection, the phosphorus content in the wet season increased to 0.16 per cent. On the other hand, during the first fortnight the phosphorus content of leaf residues retrieved during the dry season did not show a difference in phosphorus value (0.12 %). The phosphorus contents observed during the wet season and the dry season at the final fortnight was 0.09 per cent and 0.08 per cent respectively.

The phosphorus content recorded in the open area and homegarden at fortnightly intervals during the wet season showed no significant differences. Similarly, during the dry season also no significant difference in nitrogen concentration was observed in open area and homegarden.

Table 10a. Potassium content (%) in the residues of *Gmelina arborea* at fortnightly intervals

Fortnight	Open area		Homegarden		F Test	SEM±
	Wet season	Dry season	Wet season	Dry season		
0	0.93	0.88	0.93	0.88	--	--
1	$_{a}0.43^{c}$	$a0.71^{b}$	$a0.48^{c}$	$_{a}0.78^{a}$	**	0.003
2	$_{b}0.32^{b}$	$_{b}0.64^{a}$	$_{b}0.37^{b}$	$_{b}0.70^{a}$	**	0.007
3	$_{d}0.17$	$_{c}0.54$	$_{c}0.29$	$_{d}0.62$	NS	--
4	$_{e}0.09$	$_{d}0.48$	$_{d}0.19$	$e0.58$	NS	--
5	$_{cd}0.20$	$_{d}0.64$	$_{d}0.19$	$_{c}0.66$	NS	--
6	$_{cd}0.19$	$_{cd}0.51$	$_{d}0.19$	$_{f}0.51$	NS	--
7	$_{c}0.21$	$_{e}0.35$	$_{d}0.21$	$_{g}0.34$	NS	--
8	$_{e}0.12^{c}$	$_{d}0.40^{a}$	$_{e}0.09^{d}$	$_{h}0.27^{d}$	**	0.008
9	NA	$_{f}0.32$	NA	$_{i}0.16$	--	--
10	NA	$_{g}0.11$	NA	$_{j}0.10$	--	--
F test	**	**	**	**		
SEM±	0.018	0.08	0.04	0.06		

** Significant at 1%

*Significant at 5%

Figures with the same superscript and subscript do not differ significantly

Superscripts indicate interactions between field and seasons within fortnight

Subscripts indicate interactions between fortnights within a field and season

NA – Not applicable

NS – Not significant

4.3.1.3 Potassium

Gmelina arborea

The details regarding the interaction of seasons and fields on the potassium content in the residues of *Gmelina arborea* are tabulated in Table 10a. The initial potassium content recorded during the wet season and dry season was 0.93 per cent and 0.88 per cent respectively.

With respect to open area, a drastic reduction in potassium content of the residues was observed during the wet season, whereas, a gradual reduction was observed during the dry season. By the time the decomposition process culminated, the amount of potassium reported in the samples retrieved from the open area during the wet season and dry season was 0.12 per cent and 0.11 per cent respectively. Similar was the observation in the homegarden also. Faster decrease in potassium content was noticed in the samples retrieved during the wet season than those retrieved during the dry season. The final fortnights of both wet season and dry season recorded lower potassium contents of 0.09 per cent and 0.10 per cent respectively.

The potassium content recorded in the open area and homegarden at fortnightly intervals during the wet season showed no significant differences. Similarly, during the dry season also no significant difference in nitrogen concentration was observed in open area and homegarden.

Mallotus philippensis

The details regarding the interaction of seasons and fields on the potassium content in the residues of *Mallotus philippensis* are tabulated in Table 10b. Both the seasons under the influence of both the locations showed a declining trend in potassium content till the end of the study.

Table 10b. Potassium content (%) in the residues of *Mallotus philippensis* at fortnightly intervals

Fortnight	Open area		Homegarden		F Test	SEM±
	Wet season	Dry season	Wet season	Dry season		
0	1.20	0.98	1.20	0.98	--	--
1	$_{a}1.02^{b}$	$_{ab}0.87^{c}$	$_{ab}1.09^{a}$	$_{a}0.84^{c}$	*	0.016
2	$_{b}0.98^{b}$	$_{a}0.91^{b}$	$_{a}1.10^{a}$	$_{b}0.75^{c}$	**	0.025
3	$_{c}0.46$	$_{ab}0.74$	$_{c}0.75$	$_{a}0.88$	NS	--
4	$_{fg}0.17^{d}$	$_{bc}0.65^{c}$	$_{b}0.97^{a}$	$_{b}0.78^{b}$	**	0.013
5	$_{d}0.25^{d}$	$_{cd}0.46^{c}$	$_{d}0.44^{a}$	$_{c}0.66^{b}$	**	0.009
6	$_{de}0.22^{d}$	$_{de}0.33^{c}$	$_{d}0.39^{b}$	$_{d}0.55^{a}$	**	0.012
7	$_{def}0.18^{c}$	$_{def}0.25^{c}$	$_{e}0.27^{b}$	$_{e}0.48^{a}$	**	0.011
8	$_{def}0.18$	$_{defg}0.18$	$_{ef}0.19$	$_{f}0.35$	NS	0.017
9	$_{g}0.12^{b}$	0.09^{b}	$_{f}0.07^{b}$	$_{g}0.24^{a}$	*	0.025
10	$_{g}0.12^{b}$	0.05^{d}	$_{f}0.10^{c}$	$_{h}0.18^{a}$	**	0.022
11	$_{h}0.07^{b}$	0.03^{c}	$_{f}0.09^{a}$	$_{ij}0.08^{ab}$	*	0.015
12	NA	0.02	NA	$_{ij}0.09$	--	--
13	NA	0.02	NA	$_{jk}0.06$	--	--
14	NA	0.01	NA	$_{k}0.04$	--	--
F test	**	**	**	**		
SEM±	0.08	0.02	0.12	0.05		

** Significant at 1%

*Significant at 5%

Figures with the same superscript and subscript do not differ significantly

Superscripts indicate interactions between field and seasons within fortnight

Subscripts indicate interactions between fortnights within a field and season

NA – Not applicable

With respect to open area, a drastic reduction in potassium content of the residues was observed during the wet season, whereas, a gradual reduction was observed during the dry season. By the time the decomposition process culminated, the amount of potassium reported in the samples retrieved from the open area during the wet season and dry season was 0.07 per cent and 0.01 per cent respectively. Similar was the observation in the homegarden also. Faster decrease in potassium content was noticed in the samples retrieved during the wet season than those retrieved during the dry season. The final fortnights of both wet season and dry season recorded lower potassium contents of 0.09 per cent and 0.04 per cent respectively.

The potassium content recorded in the open area and homegarden at fortnightly intervals during the wet season and showed significant differences.

4.3.2 Changes in absolute nutrient content

4.3.2.1 Nitrogen

Gmelina arborea

The interaction of the individual field condition and season on the nitrogen release of *Gmelina arborea* at fortnightly interval was also studied. The data related to this is shown in Table 11a. In other words, an attempt was made to determine the influence of seasons on the variation in nitrogen mineralization pattern in individual field conditions. A significant difference was observed with regards to seasons and locations at fortnightly intervals.

Both open area and homegarden showed a higher nitrogen mineralization in the wet season as compared to the dry season (Fig. 9). Within the wet season and the dry season, open area showed a faster nitrogen mineralization as compared to the homegarden. During the wet season, by the end of the first fortnight, open area recorded absolute nitrogen content of 72.18 per cent, whereas,

Table 11a. Absolute nitrogen content (%) in the residues of *Gmelina arborea* at fortnightly intervals

Fortnight	Open area		Homegarden		F Test	SEM±
	Wet season	Dry season	Wet season	Dry season		
0	100.00	100.00	100.00	100.00	--	--
1	$_{a}72.18^{d}$	$_{a}84.07^{b}$	$_{a}75.17^{c}$	$_{a}88.09^{a}$	**	0.39
2	$_{b}53.00^{c}$	$_{b}62.71^{a}$	$_{b}57.19^{b}$	$_{b}59.28^{b}$	**	0.74
3	$_{c}21.45^{c}$	$_{c}37.05^{a}$	$_{c}26.81^{b}$	$_{c}35.65^{a}$	**	0.73
4	$_{d}10.50^{c}$	$_{d}24.16^{a}$	$_{d}18.49^{b}$	$_{d}26.50^{a}$	NS	--
5	$_{e}6.27^{d}$	$_{e}14.04^{b}$	$_{e}9.22^{c}$	$_{e}18.93^{a}$	**	0.248
6	$_{f}2.95^{c}$	$_{f}10.22^{a}$	$_{f}5.41^{b}$	$_{f}9.71^{a}$	**	0.287
7	$_{fg}1.21^{d}$	$_{g}5.73^{a}$	$_{g}2.68^{c}$	$_{g}4.01^{b}$	**	0.056
8	$_{g}0.32^{d}$	$_{h}2.36^{a}$	$_{h}0.87^{c}$	$_{h}1.96^{b}$	**	0.737
9	NA	$_{h}1.80^{a}$	NA	$_{hi}1.37^{b}$	--	--
10	NA	$_{h}0.77^{b}$	NA	$_{i}0.87^{a}$	--	--
F test	**	**	**	**		
SEM±	1.460	2.438	0.794	0.178		

** Significant at 1%

*Significant at 5%

Figures with the same superscript and subscript do not differ significantly

Superscripts indicate interactions between field and seasons within fortnight

Subscripts indicate interactions between fortnights within a field and season

NA – Not applicable

NS – Not significant

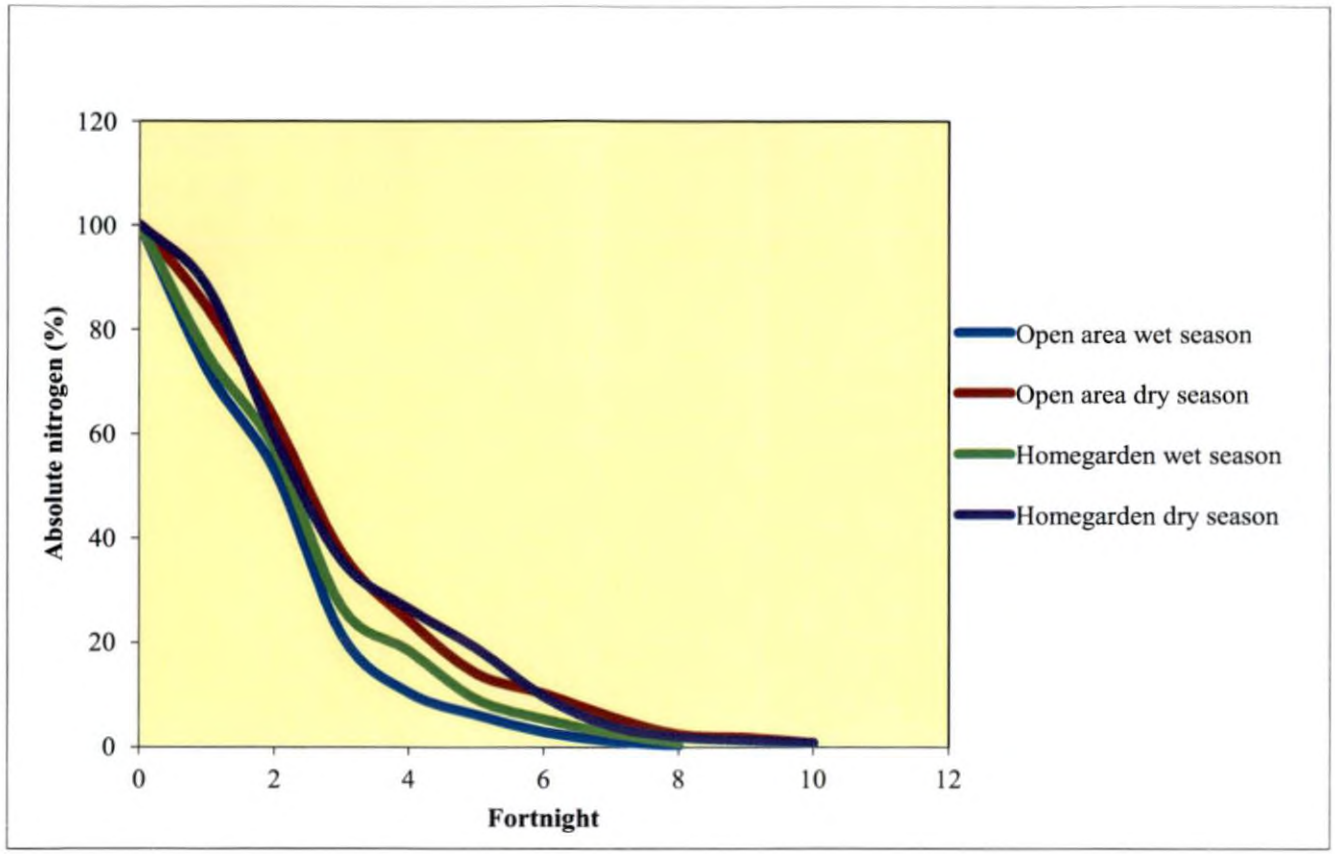

Fig 9. Changes in the absolute nitrogen content (%) of the residues of *Gmelina arborea*

open area in the dry season recorded 84.07 per cent. Also, homegarden during the wet season registered absolute nitrogen content of 75.17 per cent during the same fortnight, whereas, during dry season, 88.09 per cent of nitrogen content was observed. The nitrogen release pattern in both the locations during both the seasons showed an initial faster mineralization till the sixth fortnight followed by a slower release during the latter phase. Maximum nitrogen mineralization was observed during the wet season and the least was observed during dry season. By the end of the eighth fortnight, the absolute nitrogen content observed was in the order: open area during the dry season (2.36 %) > homegarden during the dry season (1.96 %) > homegarden during the wet season (0.87 %) > open area during the wet season (0.32 %).

Among the different models suggested for nitrogen mineralization modified hoerl and hoerl model gave a good fit for *Gmelina arborea* kept in the open area and homegarden during the wet season (Appendix I and II). The R^2 value in the case of the open area was 0.997 and 0.994, whereas, for homegarden was 0.995 and 0.992. On the other hand, for *Gmelina arborea* kept in the open area during the dry season, hoerl model (R^2 = 0.996) and geometric (R^2= 0.994) gave a suitable fitting. Similarly, hoerl (R^2 = 0.995) and exponential model (R^2 = 0.995) was found to be the best fit for the homegarden during dry season.

Mallotus philippensis

Similar efforts were also taken to study the influence of seasons on the nitrogen release in each location. A considerable difference was observed between both the locations due to seasonal variations (Table 11b). The amount of absolute nitrogen content observed in the open area during the wet season and dry season was observed to be 73.29 per cent and 84.77 per cent respectively. Similarly, homegarden during the wet season and dry season registered absolute nitrogen content of 73.77 per cent and 80.92 per cent respectively. Throughout the study period, homegarden during the dry season retained the maximum nitrogen

Table 11b. Absolute nitrogen content (%) in the residues of *Mallotus philippensis* at fortnightly intervals

Fortnight	Open area		Homegarden		F Test	SEM±
	Wet season	Dry season	Wet season	Dry season		
0	100.00	100.00	100.00	100.00	--	--
1	$_{a}73.29$	$_{a}84.77$	$_{a}73.77$	$_{a}80.92$	**	0.891
2	$_{b}58.67$	$_{b}70.54$	$_{b}55.92$	$_{b}71.33$	NS	--
3	$_{c}33.22$	$_{c}50.86$	$_{c}36.85$	$_{c}53.18$	NS	--
4	$_{e}19.91$	$_{d}36.20$	$_{d}22.28$	$_{d}36.89$	NS	--
5	$_{f}16.12$	$_{e}33.30$	$_{e}16.48$	$_{e}32.20$	NS	--
6	$_{g}8.82^{c}$	$_{d}24.60^{a}$	$_{f}13.96^{b}$	$_{f}22.15^{a}$	**	0.256
7	$_{gh}4.02^{d}$	$_{e}16.34^{a}$	$_{g}7.74^{c}$	$_{g}14.53^{b}$	**	0.548
8	$_{i}1.87^{d}$	$_{f}13.88^{a}$	$_{h}3.87^{c}$	$_{h}11.83^{b}$	**	0.166
9	$_{i}1.11^{d}$	$_{g}11.71^{a}$	$_{i}2.41^{c}$	$_{i}8.82^{b}$	**	0.054
10	$_{ij}0.63^{b}$	$_{h}7.54^{a}$	$_{ij}1.43^{b}$	$_{ij}6.80^{a}$	*	0.080
11	$_{j}0.13^{b}$	$_{i}4.74^{a}$	$_{j}0.93^{b}$	$_{jk}5.06^{a}$	*	0.027
12	NA	$_{j}2.34$	NA	$_{kl}4.08$	--	--
13	NA	$_{jk}1.61$	NA	$_{lm}2.69$	--	--
14	NA	$_{l}0.83$	NA	$_{m}1.87$	--	--
F test	**	**	**	**		
SEM±	1.563	1.323	1.711	1.582		

** Significant at 1%

*Significant at 5%

Figures with the same superscript and subscript do not differ significantly

Superscripts indicate interactions between field and seasons within fortnight

Subscripts indicate interactions between fortnights within a field and season

NA – Not applicable

NS – Not significant

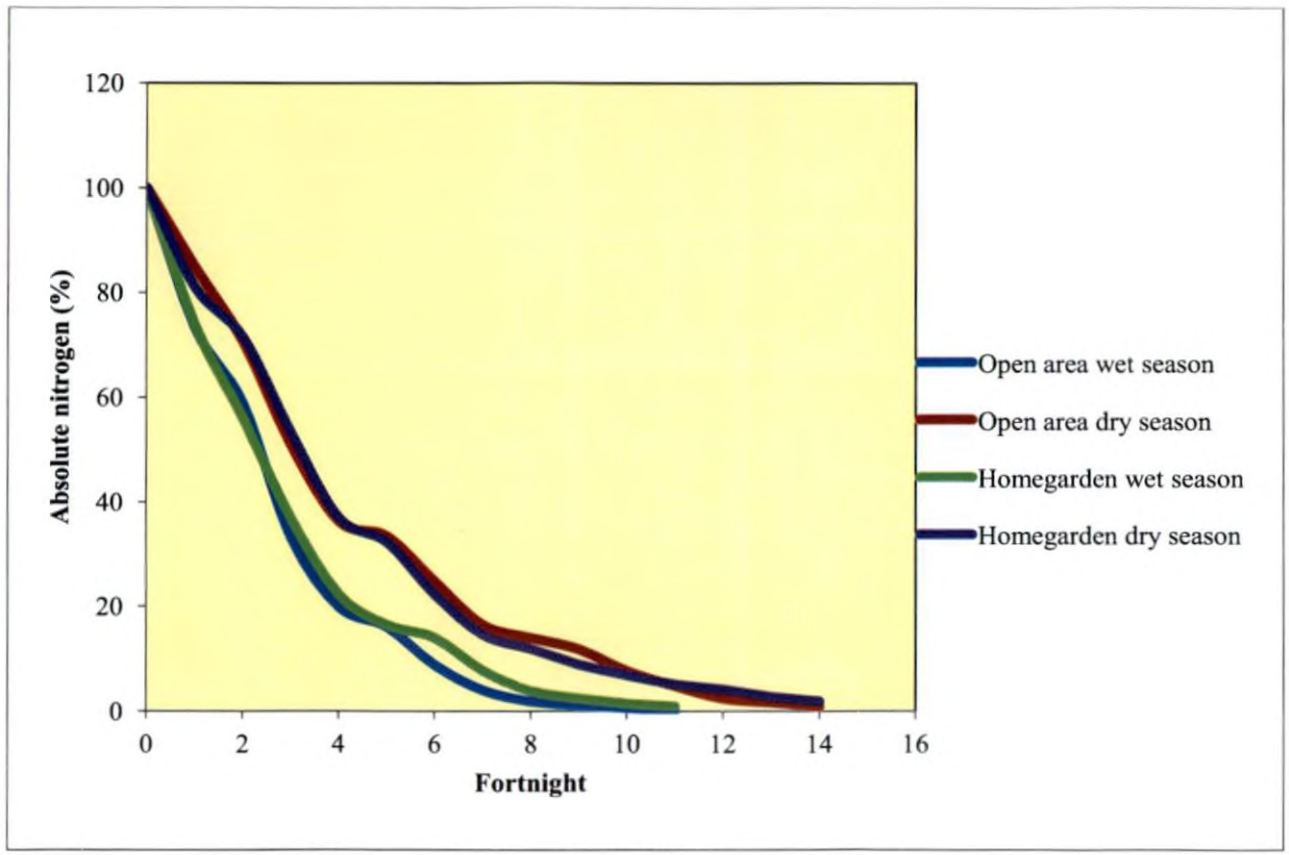

Fig 10. Changes in the absolute nitrogen content (%) of the residues of *Mallotus philippensis*

showing a lower mineralization succeeded by open area during the dry season. In general, with respect to location, open area registered higher nitrogen release and with respect to seasons, wet season recorded maximum nitrogen release. Both the locations recorded a steady decline in absolute nitrogen content as decomposition progressed. The amount of nitrogen retained by the end of the eleventh fortnight in the open area during the wet season and dry season was 0.63 per cent and 7.54 per cent respectively. Similarly, homegarden during the wet season and the dry season registered absolute nitrogen content of 1.43 per cent and 6.80 per cent respectively (Fig. 10).

Among the different models suggested for nitrogen mineralization, hoerl and modified hoerl model gave a good fit for *Mallotus philippensis* kept in the open area during the wet season (R^2 = 0.992). Similarly, hoerl (R^2 = 0.995) and exponential (R^2 =0.992) model was suitable fit for homegarden during wet season. On the other hand, for *Mallotus philippensis* kept in the open area during the dry season, hoerl model (R^2 = 0.994) and exponential (R^2 = 0.993) gave a suitable fitting. On the other hand, for *Mallotus philippensis* kept in the homegarden during the dry season, hoerl model (r^2 = 0.995) and exponential (R^2= 0.992) gave a suitable fitting (Appendix I and II).

4.3.2.2 Phosphorus

Gmelina arborea

Attempts were made to find the influence of seasons on the phosphorus content at different locations and the corresponding phosphorus mineralization at fortnightly intervals. A significant difference was observed on subjecting the values to statistical analysis (Table 12a). Among the locations, open area registered a faster mineralization. Within each location, wet season had a prominent influence on the phosphorus release. In the open area, wet season in the first fortnight reported absolute phosphorus content of 63.61 per cent, whereas,

Table 12a. Absolute phosphorus content (%) in the residues of *Gmelina arborea* at fortnightly intervals

Fortnight	Open area		Homegarden		F Test	SEM±
	Wet season	Dry season	Wet season	Dry season		
0	100.00	100.00	100.00	100.00	--	--
1	$_{a}63.61^{c}$	$_{a}72.53^{b}$	$_{a}70.71^{b}$	$_{a}85.89^{a}$	**	2.098
2	$_{b}35.39^{b}$	$_{b}56.28^{a}$	$_{b}48.18^{b}$	$_{b}51.43^{ab}$	**	2.115
3	$_{c}21.72$	$_{c}31.19$	$_{c}29.95$	$_{c}30.18$	NS	--
4	$_{d}9.49$	$_{d}15.81$	$_{d}17.35$	$_{d}20.64$	NS	--
5	$_{e}5.20^{d}$	$_{e}10.19^{b}$	$_{e}7.10^{c}$	$_{e}11.92^{a}$	**	2.051
6	$_{f}3.23$	$_{e}10.08$	$_{e}6.77$	$_{e}11.82$	NS	--
7	$_{fg}1.92^{c}$	$_{ef}6.34^{a}$	$_{ef}3.87^{b}$	$_{f}4.57^{b}$	**	0.301
8	$_{g}0.60^{d}$	$_{fg}3.11^{a}$	$_{f}1.23^{c}$	$_{fg}2.62^{b}$	**	0.737
9	NA	$_{fg}2.25$	NA	$_{fg}2.42$	--	--
10	NA	$_{g}1.56$	NA	$_{g}1.72$	--	--
F test	**	**	**	**		
SEM±	2.442	5.766	3.879	1.725		

** Significant at 1%

*Significant at 5%

Figures with the same superscript and subscript do not differ significantly

Superscripts indicate interactions between field and seasons within fortnight

Subscripts indicate interactions between fortnights within a field and season

NA – Not applicable

NS – Not significant

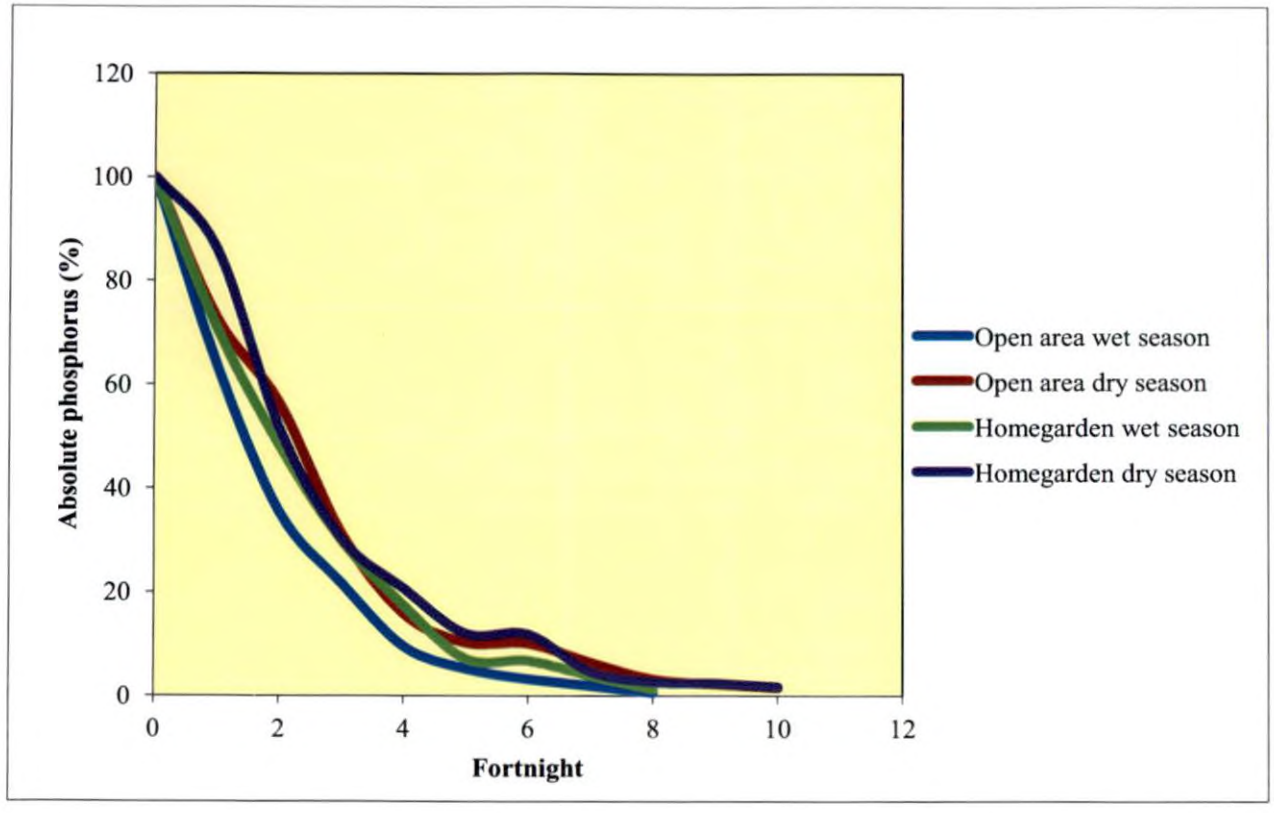

Fig 11. Changes in the absolute phosphorus content (%) of the residues of *Gmelina arborea*

dry season observed absolute phosphorus content of 72.53 per cent. During the wet season, homegarden showed 70.71 per cent of the absolute phosphorus content, whereas, dry season recorded 85.89 per cent absolute phosphorus content. In both the locations under both the seasons, faster mineralization was observed initially followed by a slower phase (Fig. 11).

By the end of the eighth fortnight, the absolute phosphorus content observed during the wet season in open area and homegarden was 0.59 per cent and 1.23 per cent respectively. Similarly, by the end of the tenth fortnight, the amount of absolute phosphorus observed during the dry season in open area and homegarden was 1.56 per cent and 1.72 per cent respectively. By the end of the eighth fortnight, the absolute nitrogen content was retained in the order: open area during the dry season (3.11 %) > homegarden during the dry season (2.62 %) > homegarden during the wet season (1.23 %) >open area during the wet season (0.60 %).

Among the different models suggested for phosphorus mineralization, exponential (r^2 = 0.994) and hoerl model (R^2 = 0.994) gave a good fit for *Gmelina arborea* kept in the open area during the wet season. Similarly, modified hoerl (R^2 = 0.990) and hoerl (R^2= 0.983) model was suitable fit for homegarden during wet season. On the other hand, for *Gmelina arborea* kept in the open area during the dry season, hoerl (R^2 = 0.996) and geometric model (R^2 = 0.994) gave best fitting to open area, whereas, hoerl (R^2= 0.994) and exponential (R^2 = 0.994) model gave a suitable fitting for *Gmelina arborea* kept in homegarden (Appendix I and II).

Mallotus philippensis

The data related to the influence of seasons on the phosphorus mineralization of the residues in the litter bags from both open area and homegarden is enumerated in Table 12b. The results showed a considerable variation in the phosphorus release in both the locations. Maximum mineralization

Table 12b. Absolute phosphorus content (%) in the residues of *Mallotus philippensis* at fortnightly intervals

Fortnight	Open area		Homegarden		F Test	SEM±
	Wet season	Dry season	Wet season	Dry season		
0	100.00	100.00	100.00	100.00	--	--
1	$_{a}63.83^{b}$	$_{a}81.30^{ab}$	$_{a}83.23^{a}$	$_{a}76.26^{ab}$	**	1.430
2	$_{b}58.34$	$_{b}63.37$	$_{b}60.56$	$_{b}53.80$	**	1.640
3	$_{c}33.03$	$_{c}39.33$	$_{c}42.02$	$_{c}39.07$	NS	--
4	$_{d}23.87^{ab}$	$_{d}31.30^{a}$	$_{de}20.40^{b}$	$_{d}26.96^{ab}$	**	0.592
5	$_{e}18.15$	$_{d}28.38$	$_{ef}16.68$	$_{d}23.95$	NS	--
6	$_{f}7.71^{b}$	$_{d}26.04^{a}$	$_{gh}9.87^{b}$	$_{ef}20.52^{a}$	*	0.156
7	$_{gh}3.08^{b}$	$_{ef}11.88^{a}$	$_{i}4.76^{b}$	$_{fg}12.21^{a}$	**	0.142
8	2.07^{b}	$_{e}14.94^{a}$	$_{jk}2.48^{b}$	$_{fg}12.57^{a}$	**	0.233
9	$_{h}1.10$	$_{ef}12.12$	$_{kl}1.97$	$_{gh}10.65$	NS	--
10	$_{hi}0.76^{d}$	$_{efg}9.19^{b}$	$_{m}1.47^{c}$	$_{gh}10.12^{a}$	**	0.117
11	$_{i}0.15^{d}$	$_{fgh}5.18^{b}$	$_{lm}1.56^{c}$	$_{ij}5.72^{a}$	**	0.067
12	NA	$_{gh}3.72$	NA	$_{i}6.01$	--	--
13	NA	$_{ghi}2.84$	NA	$_{jk}3.72$	--	--
14	NA	$_{i}1.61$	NA	$_{k}2.23$	--	--
F test	**	**	**	**		
SEM±	8.871	14.955	24.215	25.271		

** Significant at 1%

*Significant at 5%

Figures with the same superscript and subscript do not differ significantly

Superscripts indicate interactions between field and seasons within fortnight

Subscripts indicate interactions between fortnights within a field and season

NA – Not applicable

NS – Not significant

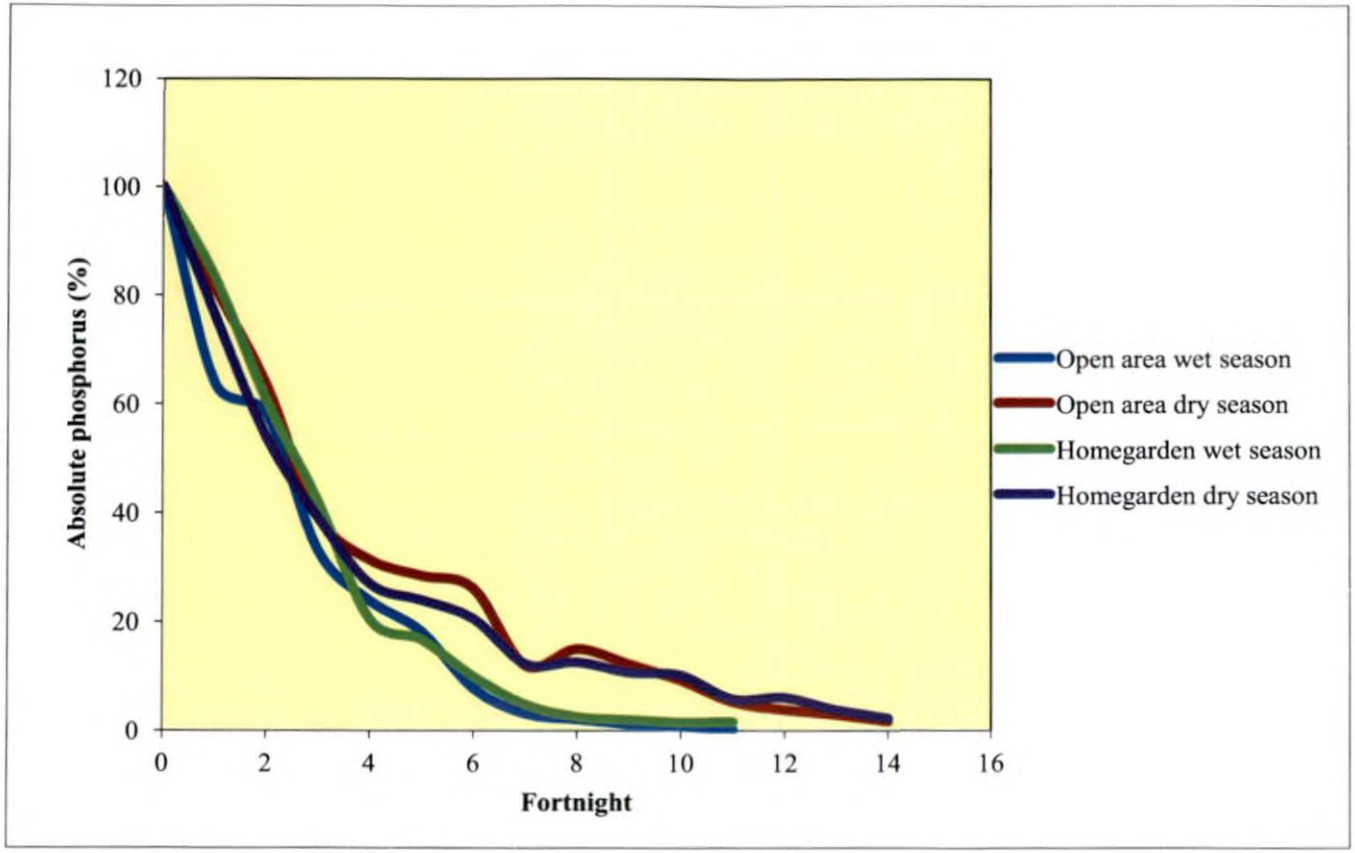

Fig 12. Changes in the absolute phosphorus content (%) of the residues of *Mallotus philippensis*

of phosphorus was observed in the open during the wet season followed by homegarden during the dry season. At the end of the eleventh fortnight, the amount of absolute phosphorus content retained during the wet season in the open area and the homegarden was 0.15 per cent and 1.56 per cent respectively. Similarly, dry season in the open area and homegarden was 5.18 per cent and 5.72 per cent respectively (Fig. 12).

Among the different models suggested for phosphorus mineralization, hoerl (R^2 = 0.978) and modified hoerl model (R^2 = 0.976) gave a good fit for *Mallotus philippensis* kept in the open area during the wet season. Similarly, modified hoerl (R^2 = 0.972) and exponential (R^2 = 0.971) model was suitable fit for homegarden during wet season. On the other hand, for *Mallotus philippensis* kept in the open area during the dry season, hoerl (R^2 = 0.965) and exponential model (R^2 = 0.962) gave best fitting to open area, whereas, hoerl (R^2 = 0.995) and geometric (R^2 = 0.992) model gave a suitable fitting for homegarden (Appendix I and II).

4.3.2.3 Potassium

Gmelina arborea

The influence of both the seasons at different field locations on each location was also studied. The data regarding this is tabulated in the Table 13a. Among the locations, open area recorded lower absolute potassium contents in both the seasons as compared to the homegarden. The wet season showed the maximum potassium release in both the areas as compared to the dry seasons. At the end of the first fortnight, open area during the wet season recorded 32 per cent of potassium content, showing a 60 per cent release. Similar was the case with homegarden in the wet season (38.66 %). On the other hand, the open area during the dry season retained 65.95 per cent of potassium content in the first fortnight, whereas, homegarden retained a higher amount of 69.96 per cent of potassium

Table 13a. Absolute potassium content (%) in the residues of *Gmelina arborea* at fortnightly intervals

Fortnight	Open area		Homegarden		F Test	SEM±
	Wet season	Dry season	Wet season	Dry season		
0	100.00	100.00	100.00	100.00	--	--
1	$_{a}32.00^{d}$	$_{a}65.95^{b}$	$_{a}38.66^{c}$	$_{a}69.96^{a}$	**	0.390
2	$_{b}17.57^{c}$	$_{b}41.76^{a}$	$_{b}23.64^{b}$	$_{b}42.64^{a}$	*	0.321
3	$_{c}5.03^{d}$	$_{c}25.24^{a}$	$_{c}10.74^{c}$	$_{c}25.38^{a}$	**	0.387
4	$_{d}1.28$	$_{d}14.02$	$_{d}4.91$	$_{d}17.38$	NS	--
5	$_{d}1.63$	$_{d}14.83$	$_{ef}2.52$	$_{de}15.58$	NS	--
6	$_{ef}0.77^{c}$	$_{e}9.09^{a}$	$_{fg}1.71^{b}$	$_{e}9.40^{a}$	*	0.364
7	$_{fg}0.52^{c}$	$_{f}3.70^{a}$	$_{fg}1.08^{b}$	$_{f}3.13^{a}$	*	0.297
8	$_{g}0.09^{c}$	$_{gh}2.14^{a}$	$_{h}0.18^{c}$	$_{fg}1.32^{b}$	**	0.302
9	NA	$_{hi}0.69$	NA	$_{gh}0.97$	--	--
10	NA	$_{i}0.14$	NA	$_{h}0.23$	--	--
F test	**	**	**	**		
SEM±	1.051	5.524	7.576	1.079		

** Significant at 1%

*Significant at 5%

Figures with the same superscript and subscript do not differ significantly

Superscripts indicate interactions between field and seasons within fortnight

Subscripts indicate interactions between fortnights within a field and season

NA – Not applicable

NS – Not significant

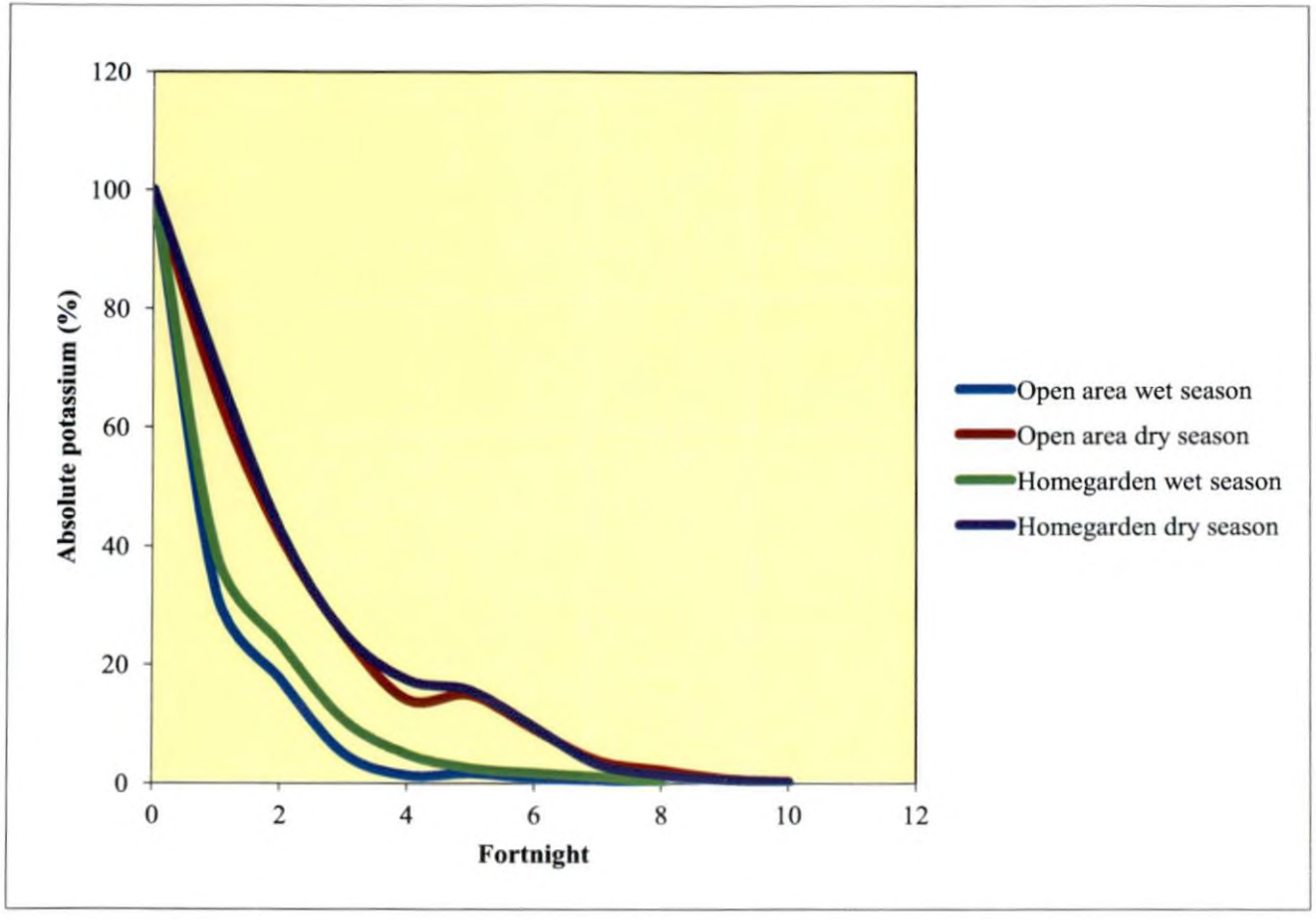

Fig 13. Changes in the absolute potassium content (%) of the residues of *Gmelina arborea*

content. By the end of the eighth fortnight, the absolute potassium content observed during the wet season in the open area and homegarden was 0.09 per cent and 0.18 per cent respectively. On the other hand, during the dry season, the absolute potassium content recorded in open area was 2.14 per cent and 1.32 per cent in the homegarden by the end of the tenth fortnight (Fig. 13).

Among the different models suggested for phosphorus mineralization, modified hoerl (R^2 = 0.994) and hoerl model (R^2= 0.989) gave a good fit for *Gmelina arborea* kept in the open area during the wet season. Similarly, modified hoerl (R^2 = 0.993) and hoerl (R^2 = 0.992) model was suitable fit for homegarden during wet season. On the other hand, for *Gmelina arborea* kept in the open area during the dry season, hoerl (R^2 = 0.990) and exponential (R^2 = 0.989) gave best fitting to open area, whereas, hoerl (R^2= 0.990) and exponential (R^2 = 0.990) model gave a suitable fitting for *Gmelina arborea* kept in homegarden (Appendix I and II).

Mallotus philippensis

Attempts were made to study the influence of the different seasons on the mineralization of potassium from the leaf residues collected from the open area and homegarden at fortnightly intervals. The data pertaining to this (Table 13b) showed significant differences in potassium content between the seasons studied on the locations. The potassium content recorded in the first fortnight in the open area during the wet season and dry season was 60.20 per cent and 72.18 per cent respectively. Similarly, homegarden during the wet season and dry season recorded absolute potassium content of 67.74 per cent and 65.52 per cent respectively. The absolute potassium content in the residues retrieved was found to drop as the decomposition progressed (Fig. 14).

By the end of the eleventh fortnight, the amount of absolute potassium retained in the open area during the wet season and dry season was recorded to be

Table 13b. Absolute potassium content (%) in the residues of *Mallotus philippensis* at fortnightly intervals

Fortnight	Open area		Homegarden		F Test	SEM±
	Wet season	Dry season	Wet season	Dry season		
0	100.00	100.00	100.00	100.00	--	--
1	$_{a}60.20^{c}$	$_{a}72.18^{a}$	$_{a}67.74^{ab}$	$_{a}65.62^{b}$	**	1.43
2	$_{b}44.37^{c}$	$_{b}66.58^{a}$	$_{b}54.38^{b}$	$_{b}50.88^{b}$	**	1.64
3	$_{c}16.30$	$_{c}39.72$	$_{c}28.81$	$_{c}46.60$	NS	--
4	$_{de}3.76^{d}$	$_{d}27.82^{b}$	$_{c}24.42^{c}$	$_{d}32.05^{a}$	**	0.592
5	$_{d}4.12$	$_{e}17.50$	$_{d}8.63$	$_{e}24.14$	**	0.015
6	$_{e}2.11$	$_{f}9.12$	$_{e}6.68$	$_{f}15.26$	NS	--
7	$_{fg}0.82^{d}$	$_{g}5.19^{b}$	$_{f}2.57^{c}$	$_{g}10.25^{a}$	**	0.142
8	$_{gh}0.44^{c}$	$_{h}3.41^{b}$	$_{fg}0.99^{c}$	$_{hi}6.91^{a}$	**	0.233
9	$_{hi}0.18$	$_{g}6.45$	$_{gh}0.27$	$_{ij}4.06$	NS	--
10	$_{hi}0.10^{c}$	$_{hi}0.74^{b}$	$_{gh}0.23^{c}$	$_{jk}2.57^{a}$	**	0.117
11	$_{i}0.01^{c}$	$_{hi}0.63^{b}$	$_{i}0.15^{c}$	$_{k}1.32^{a}$	**	0.068
12	NA	$_{j}0.08$	NA	$_{lm}0.39$	--	--
13	NA	$_{i}0.17$	NA	$_{mn}0.26$	--	--
14	NA	$_{j}0.06$	NA	$_{n}0.13$	--	--
F test	**	**	**	**		
SEM±	1.529	1.608	1.663	0.352		

** Significant at 1%

*Significant at 5%

Figures with the same superscript and subscript do not differ significantly

Superscripts indicate interactions between field and seasons within fortnight

Subscripts indicate interactions between fortnights within a field and season

NA – Not applicable

NS – Not significant

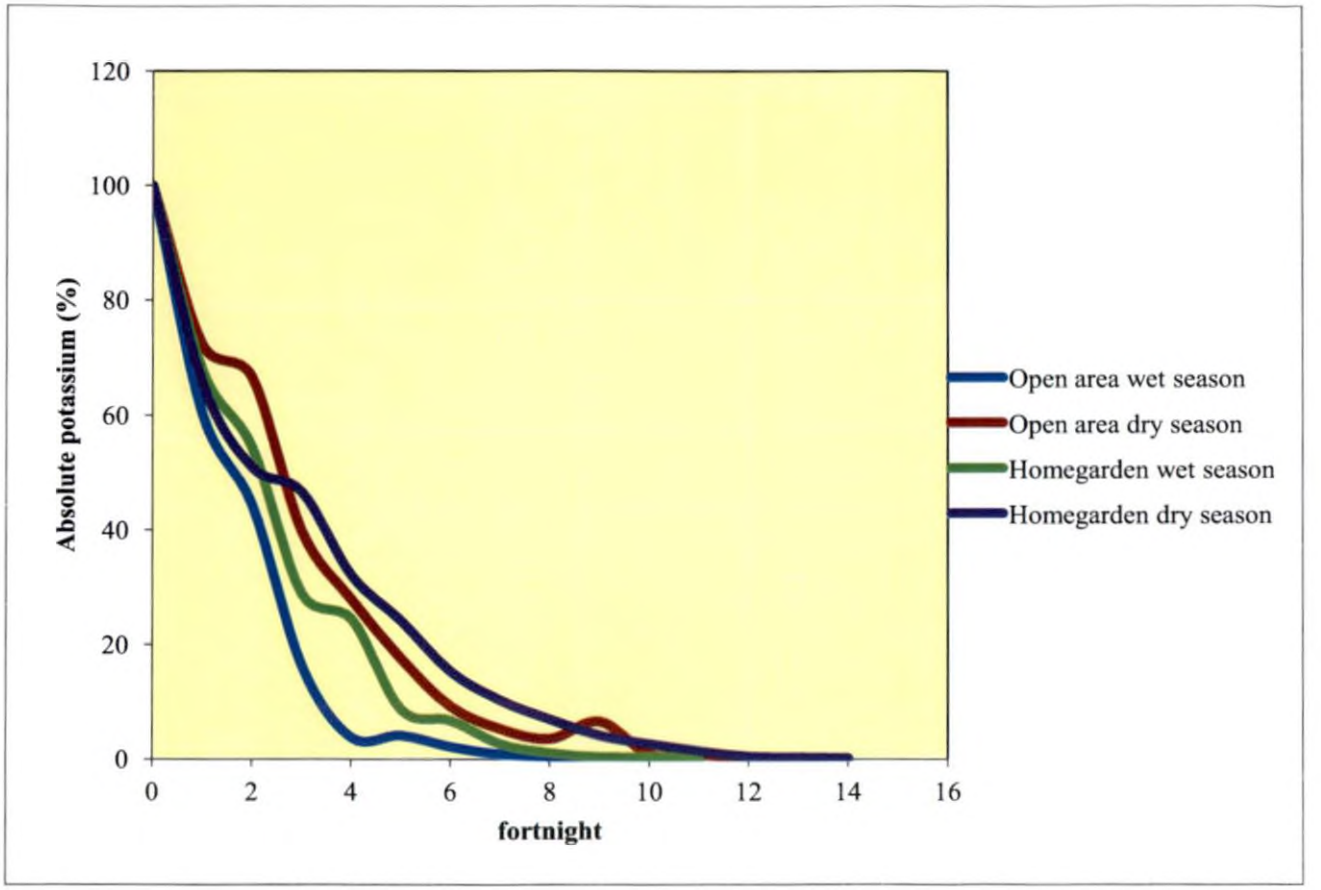

Fig 14. Changes in the absolute potassium content (%) of the residues of *Mallotus philippensis*

0.01 per cent and 0.63 per cent respectively. Similarly, the absolute potassium content remaining in the homegarden during the wet season and dry season was 0.15 per cent and 1.32 per cent respectively. The least amount of absolute potassium content was found in the order: open area during the wet season (0.01 %) < homegarden during the wet season (0.15 %) < open area during the dry season (0.63 %) < homegarden during the dry season (1.32 %).

Among the different models suggested for potassium mineralization, modified hoerl (R^2= 0.992) and hoerl model (R^2 = 0.991) gave a good fit for *Mallotus philippensis* kept in the open area during the wet season. Similarly, hoerl (R^2= 0.986) and geometric (R^2 = 0.979) model was suitable fit for homegarden during wet season. On the other hand, for *Mallotus philippensis* kept in the open area during the dry season, modified hoerl (R^2 = 0.986) and her model (R^2 = 0.984) gave best fitting to open area, whereas, geometric (r^2 = 0.990) and hoerl (R^2= 0.988) model gave a suitable fitting for *Mallotus philippensis* kept in homegarden (Appendix I and II).

4.3.3 Relative changes in nutrient content

4.3.3.1 Nitrogen

Gmelina arborea

The data regarding the relative changes in nutrient content of leaf biomass of *Gmelina arborea* under different study situations are furnished in Tables 14a and 14b.

The relative nitrogen concentration recorded during the wet season under both the study situations increased initially followed by a decrease in value. The homegarden registered a continuous decrease in nitrogen content till the decomposition culminated. The subsequent sampling periods in open area also depicted a decrease in relative nitrogen concentration except for the fourth

Table 14a. Changes in the relative nutrient content (%) of the residues of *Gmelina arborea* during wet season

Fortnight	Open area				Homegarden			
	Relative nutrient concentration (%)				Relative nutrient concentration (%)			
	Residual mass (g)	N	P	K	Residual mass (g)	N	P	K
0	40.21	100.00	100.00	100.00	40.21	100.00	100.00	100.00
1	28.21	102.81^{b}	88.89^{a}	46.24^{a}	30.16	100.26^{a}	94.45^{a}	51.61^{a}
2	20.22	105.36^{a}	72.22^{cd}	34.41^{b}	23.76	96.68^{a}	83.20^{b}	39.78^{b}
3	11.21	77.04^{d}	77.78^{bcd}	18.28^{d}	13.83	77.81^{b}	88.89^{ab}	31.18^{c}
4	5.15	81.89^{c}	77.22^{bcd}	9.68^{e}	9.65	77.04^{b}	72.22^{cd}	20.43^{d}
5	3.11	81.12^{e}	67.79^{d}	21.51^{cd}	4.92	75.26^{c}	55.56^{e}	20.43^{d}
6	1.55	76.28^{d}	83.34^{ab}	20.43^{cd}	3.43	63.52^{d}	78.02^{bc}	20.43^{d}
7	0.93	52.30^{e}	83.34^{ab}	22.58^{c}	1.94	55.61^{e}	78.02^{bc}	22.58^{d}
8	0.30	43.62^{f}	77.68^{bcd}	12.90^{e}	0.71	49.23^{f}	72.22^{bc}	9.68^{e}
F Test	-	**	**	**	-	**	**	**
SEM±	-	0.21	0.07	0.13	-	0.14	0.14	0.34

** Significant at 1%

Figures with the same superscript do not differ significantly

Superscripts indicate interactions between fortnights between field and season between fortnights

Table 14b. Changes in the relative nutrient content (%) of the residues of *Gmelina arborea* during dry season

Fortnight	Open area				Homegarden			
	Relative nutrient concentration (%)				Relative nutrient concentration (%)			
	Residual mass (g)	N	P	K	Residual mass (g)	N	P	K
0	50.78	100.00	100.00	100.00	50.78	100.00	100.00	100.00
1	41.70	102.18^{b}	97.50^{a}	80.68^{a}	40.25	111.21^{a}	106.25^{a}	88.64^{a}
2	29.31	108.41^{a}	100.01^{a}	72.73^{b}	27.24	110.59^{a}	93.75^{b}	79.55^{b}
3	21.02	89.41^{c}	75.00^{d}	61.36^{c}	18.39	98.44^{b}	81.25^{c}	70.45^{d}
4	13.18	92.83^{bc}	60.50^{f}	54.55^{d}	13.48	99.69^{b}	75.00^{d}	65.91^{e}
5	10.35	68.85^{d}	50.01^{g}	72.73^{b}	10.69	90.03^{c}	56.25^{f}	75.01^{c}
6	8.01	64.80^{e}	62.50^{ef}	57.95^{cd}	8.23	59.81^{d}	75.00^{d}	57.95^{f}
7	4.71	61.99^{e}	68.75^{e}	39.77^{f}	4.17	48.60^{e}	56.25^{f}	38.64^{g}
8	2.37	50.47^{f}	75.00^{d}	45.57^{e}	2.23	44.86^{f}	62.50^{ef}	30.68^{h}
9	1.85	49.53^{f}	62.50^{ef}	36.43^{f}	1.61	43.61^{f}	75.00^{d}	18.20^{i}
10	0.89	44.23^{g}	87.50^{c}	12.50^{g}	1.09	40.19^{g}	81.25^{c}	11.36^{j}
F Test	-	**	**	**	-	**	**	**
SEM±	-	0.07	0.15	0.67	-	0.12	0.25	0.05

** Significant at 1% Superscripts indicate interactions between fortnights between field and season between fortnights

fortnight (81.89 %) which witnessed an increase in relative nitrogen content. By the end of the eighth fortnight, the relative nitrogen content recorded during the wet season in the open area and the homegarden was 43.62 per cent and 49.23 per cent respectively.

During the dry season, open area recorded an increase in relative nitrogen content in the first and the second fortnight followed by a decrease till the end of the study, whereas, homegarden witnessed a drop in relative nitrogen content till the end of the study except for the third fortnight (100.01 %) which recorded an increase in value. By the end of the eighth fortnight, the relative nitrogen concentration recorded in open area and homegarden was 50.47 per cent and 44.86 per cent respectively.

Mallotus philippensis

The data regarding the relative changes in nutrient content of leaf biomass of *Mallotus philippensis* under different study situations are furnished in Tables 15a and 15b.

The open area during the wet season recorded higher relative nitrogen content in the first (103.85 %) and the second fortnight (107.80 %) followed by a gradual decline till the end of the study except for the sixth fortnight, which recorded an increase in relative nitrogen content. However, continuous decline in relative nitrogen content was observed in the residues retrieved from the homegarden during the wet season. At the end of the eleventh fortnight, the relative nitrogen content recorded in the open area and homegarden was 52.56 per cent and 40.06 per cent respectively.

During the dry season, open area registered higher relative nitrogen content in the first fortnight (104.15 %) followed by a phase of decline in relative nitrogen content. On the other hand, homegarden observed higher nitrogen concentration till the third fortnight (106.57 %) followed by a decrease in nitrogen

Table 15a. Changes in the relative nutrient content (%) of the residues of *Mallotus philippensis* during wet season

Fortnight	Open area				Homegarden			
	Relative nutrient concentration (%)				Relative nutrient concentration (%)			
	Residual mass (g)	N	P	K	Residual mass (g)	N	P	K
0	44.50	100.00	100.00	100.00	44.50	100.00	100.00	100.00
1	31.41	103.85^{a}	92.86^{b}	85.00^{a}	33.18	98.72^{a}	114.29^{a}	90.83^{ab}
2	24.21	107.80^{a}	107.14^{a}	81.67^{a}	26.32	94.55^{b}	100.02^{ab}	91.67^{a}
3	18.76	78.85^{b}	78.57^{bc}	38.32^{b}	20.65	79.38^{c}	92.86^{abc}	62.50^{c}
4	12.06	73.50^{d}	85.71^{b}	14.17^{de}	13.39	74.04^{d}	85.71^{abcd}	80.83^{b}
5	8.93	80.45^{b}	92.86^{b}	20.83^{c}	10.45	70.19^{e}	85.71^{abcd}	36.67^{c}
6	5.13	76.28^{cd}	64.29^{cd}	18.34^{cd}	9.23	67.31^{f}	78.57^{bcd}	32.50^{c}
7	2.40	72.12^{d}	57.14^{e}	15.12^{cde}	5.14	66.99^{e}	85.71^{abcd}	22.51^{d}
8	1.30	64.10^{e}	71.43^{cd}	15.12^{cde}	2.74	62.82^{f}	78.57^{bcd}	15.83^{de}
9	0.79	62.18^{e}	64.29^{cd}	10.01^{ef}	1.99	53.85^{g}	57.14^{d}	5.94^{e}
10	0.51	54.81^{f}	64.29^{cd}	10.01^{ef}	1.31	48.72^{h}	64.29^{cd}	8.21^{e}
11	0.11	52.56^{f}	50.01^{e}	5.83^{g}	1.03	40.06^{i}	64.29^{cd}	7.50^{e}
F Test	-	**	**	**	-	**	**	**
SEM±	-	0.08	0.12	0.14	-	0.42	0.09	0.31

** Significant at 1% Figures with the same superscript do not differ significantly

Superscripts indicate interactions between fortnights between field and season between fortnights

Table 15b. Changes in the relative nutrient content (%) of the residues of *Mallotus philippensis* during dry season

Fortnight	Open area				Homegarden			
	Relative nutrient concentration (%)				Relative nutrient concentration (%)			
	Residual mass (g)	N	P	K	Residual mass (g)	N	P	K
0	55.32	100.00	100.00	100.00	55.32	100.00	100.00	100.00
1	44.98	104.15^{a}	100.00^{a}	88.78^{a}	42.19	106.23^{a}	100.00^{a}	85.71^{a}
2	39.66	98.27^{b}	91.67^{ab}	92.86^{a}	36.94	106.57^{a}	83.32^{b}	76.53^{b}
3	29.01	96.89^{b}	75.00^{bcd}	75.51^{a}	28.82	102.08^{a}	75.00^{bc}	89.81^{a}
4	23.09	86.85^{d}	75.00^{bcd}	66.34^{ab}	22.37	91.01^{b}	66.67^{bcd}	79.58^{b}
5	20.48	89.97^{c}	75.00^{bcd}	46.94^{bc}	19.83	89.62^{b}	66.67^{bcd}	67.34^{c}
6	16.21	84.08^{e}	91.67^{ab}	33.67^{cde}	15.13	80.97^{c}	75.00^{bc}	56.12^{d}
7	11.26	80.28^{f}	58.33^{d}	25.51^{def}	11.58	69.45^{d}	58.94^{cd}	48.98^{e}
8	10.26	74.73^{g}	84.32^{abc}	18.37^{fgh}	10.62	61.59^{e}	66.67^{bcd}	35.71^{f}
9	8.94	72.32^{h}	75.00^{bcd}	9.18^{gh}	9.31	52.60^{f}	66.67^{bcd}	24.49^{g}
10	6.31	66.09^{i}	84.32^{abc}	5.10^{h}	7.75	48.44^{f}	75.00^{vc}	18.36^{h}
11	4.30	60.90^{j}	66.67^{ab}	3.06^{h}	6.00	46.71^{fg}	50.00^{d}	8.45^{i}
12	2.59	50.17^{k}	75.00^{cd}	2.04^{h}	4.30	52.60^{fg}	75.00^{bc}	9.18^{ij}
13	1.92	47.06^{l}	84.32^{abc}	2.04^{h}	3.08	48.44^{fg}	66.67^{bcd}	6.12^{jk}
14	1.11	41.52^{m}	75.00^{bcd}	1.02^{h}	2.31	45.33^{h}	66.67^{bcd}	4.08^{k}
F Test	-	**	**	**	-	**	**	**
SEM±	-	0.08	0.12	0.14	-	1.79	0.95	1.14

** Significant at 1% Superscripts indicate interactions between fortnights between field and season between fortnights

content. By the end of the fourteenth fortnight, relative nitrogen content recorded during the dry season in open area and dry season was 41.52 per cent and 45.33 per cent respectively.

4.3.3.2 Phosphorus

Gmelina arborea

The changes in the relative content of phosphorus in the residual mass retrieved at fortnightly intervals from the open area and the homegarden during the wet and the dry season have been enumerated in Tables 14a and 14b. The leaf residues retrieved from the open area during the wet season recorded decrease in relative phosphorus content till the fifth fortnight (67.79 %) followed by an alternate rise and fall in phosphorus content till the end of the study. On the other hand, residues withdrawn from the homegarden recorded a sharp decline in phosphorus content in the subsequent fortnights (78.02 %). By the end of the eighth fortnight, the relative phosphorus content of *Gmelina arborea* residues retrieved from the open area and homegarden was 77.68 per cent and 72.22 per cent respectively.

The residues collected from the open area recorded a gradual decline in relative phosphorus till the last fortnight, whereas, those retrieved from homegarden witnessed a gradual decline till the eighth fortnight (59.79 %) followed by a steady increase. The culmination of decomposition observed relative phosphorus contents of 68.54 per cent in the open area and 79.79 per cent in the homegarden respectively.

Mallotus philippensis

The changes in the relative content of phosphorus in the residual mass retrieved at fortnightly intervals from the open area and the homegarden during the wet and the dry season have been arranged in Tables 15a and 15b. The leaf

residues collected from the open area during the dry season exhibited a general decrease in relative phosphorus content till the end of the study except for the second fortnight (107.14 %) which experienced an increase in phosphorus content. Similarly, residues collected from the homegarden during the wet season witnessed an increase in relative phosphorus content in the first fortnight (114.29 %) and second fortnight (100.02 %) followed by a gradual decrease in relative phosphorus content throughout the study period. By the end of the eleventh fortnight, relative phosphorus contents recorded in the open area and homegarden were 50.01 per cent and 64.29 per cent respectively.

The relative phosphorus content in the open area and homegarden during the dry season showed a fluctuating pattern till the end of the study. The relative phosphorus content observed in the open area and homegarden by the end of the fourteenth fortnight was 75 per cent and 66.67 per cent respectively.

4.3.3.3 Potassium

Gmelina arborea

The changes in the relative content of potassium in the residual mass retrieved at fortnightly intervals from the open area and the homegarden during the wet and the dry season have been tabulated in Tables 14a and 14b. The residual samples retrieved from the open area during the wet season recorded a rapid decline in relative potassium content in the first fortnight (46.24 %) followed by a gradual decline till the eighth fortnight except for the seventh fortnight (22.58 %) which experienced an increase in potassium content. Similarly, the homegarden also exhibited a steady decline in relative potassium content. As the decomposition terminated, the relative potassium content recorded during the eighth fortnight in the open area and homegarden during the wet season was 12.90 per cent and 9.68 per cent respectively.

Similarly, both the open area and the homegarden during the dry season also witnessed a steady decline in potassium content throughout the study period. The open area, however, recorded higher relative potassium content in the fifth fortnight (72.73 %). The end of the tenth fortnight marked relative potassium content of 12.50 per cent in the open area and 11.36 per cent in the homegarden.

Mallotus philippensis

The changes in the relative content of phosphorus in the residual mass retrieved at fortnightly intervals from the open area and the homegarden during the wet and the dry season have been arranged in Tables 15a and 15b. Both the open area and the homegarden during the wet season witnessed a fast and steady reduction in the relative potassium content during the wet season till the end of the study. By the end of the eleventh fortnight, the relative potassium content recorded in the open area and homegarden during the wet season was 5.83 per cent and 7.50 per cent respectively.

Similar trends in results were obtained in the open area and homegarden during the dry season. A fast reduction in the relative potassium content was observed. By the end of the fourteenth fortnight, the relative potassium content observed in the open area and homegarden during the dry season was 6.00 per cent and 8.45 per cent respectively.

4.3.4 Relative mineralization of nutrients under various study situations

Attempts were made to study the mineralization pattern of N, P and K from the decaying leaf biomass. The observations furnished in Table 16 indicate the absolute amount of nutrients present in the residual mass of *Gmelina arborea* and *Mallotus philippensis* after a period of four months under different study situations. In general, faster mineralization was observed for potassium in both *Gmelina arborea* and *Mallotus philippensis* under all the study conditions.

Table 16. Relative mineralization of the leaf biomass of *Gmelina arborea* and *Mallotus philippensis* after four months of incorporation

Sl. No.	Species	Study situation	Field condition	Absolute amount of nutrients remaining (%)			Order of mineralization
				N	P	k	
1	*Gmelina arborea*	a) Wet season	i) Open area	0.32	0.60	0.09	K > N > P
			ii) Homegarden	0.87	1.23	0.18	K > N > P
		b) Dry season	i) Open area	2.36	3.11	2.14	K > N > P
			ii) Homegarden	1.96	2.62	1.32	K > N > P
2	*Mallotus philippensis*	a) Wet season	i) Open area	1.87	2.07	0.44	K > N > P
			ii) Homegarden	3.87	2.48	0.99	K > N > P
		b) Dry season	i) Open area	13.88	14.94	3.41	K > N > P
			ii) Homegarden	11.83	12.57	6.91	K > N > P

Gmelina arborea

The absolute amount of potassium remaining in the residues of *Gmelina arborea* after eight fortnights were in the order: open area during the wet season (0.09 %) < homegarden during the wet season (0.18 %) < homegarden during the dry season (1.32 %) < open area during the dry season (2.14 %). Next to potassium, nitrogen showed faster mineralization. The absolute amount of nitrogen remaining in the residues of *Gmelina arborea* after eight fortnights were in the order: open area during the wet season (0.32 %) < homegarden during the wet season (0.87 %) < homegarden during the dry season (1.96 %) < open area during the dry season (2.36 %). Among all the nutrients studied, phosphorus showed the lowest mineralization. The absolute amount of phosphorus remaining in the residues of *Gmelina arborea* after eight fortnights were in the order: open area during the wet season (0.60 %) < homegarden during the wet season (1.23 %) < homegarden during the dry season (2.62 %) < open area during the dry season (3.11 %).

Mallotus philippensis

The absolute amount of potassium remaining in the residues of *Gmelina arborea* after eight fortnights were in the order: open area during the wet season (0.44 %) < homegarden during the wet season (0.99 %) < open area during the dry season (3.41 %) < homegarden during the dry season (6.91 %). Next to potassium, nitrogen showed faster mineralization. The absolute amount of nitrogen remaining in the residues of *Mallotus philippensis* after eight fortnights were in the order: open area during the wet season (1.87 %) < homegarden during the wet season (3.87 %) < homegarden during the dry season (11.83 %) < open area during the dry season (13.88 %). Among all the nutrients studied, phosphorus showed the lowest mineralization. The absolute amount of phosphorus remaining in the residues of *Mallotus philippensis* after eight fortnights were in the order: open area during the wet season (2.07 %) < homegarden during the wet season (2.48 %)

< homegarden during the dry season (12.57 %) < open area during the dry season (14.94 %).

4.4 CHANGES IN THE SOIL NUTRIENT STATUS DUE TO LEAF BIOMASS DECOMPOSITION

The present study was also envisaged to find out the effect of the foliar decomposition on changes in soil nutrient content. The soil samples of the open area and homegarden were collected before the incorporation of litter bags. The sample was then subjected to analysis. After the incorporation of the bags also, at fortnightly intervals, soil samples underneath the bags were collected along with the litter bags for nutrient analysis.

4.4.1 Total carbon

Gmelina arborea

The results after statistical analysis showed significant difference of the influence of both season and location on the soil carbon content (Table 17a). The initial carbon content of the soil samples was in the order, homegarden during wet season (1.01 %) followed by open area during the wet season (0.82 %), homegarden during the dry season (0.98 %) and open area during the dry season (0.63 %). Both the locations under the influence of both the seasons recorded an increasing trend in the soil carbon content till the end of the study. However, the soil collected during the wet season recorded higher carbon content than those collected during the dry season. By the end of the eighth fortnight, the organic carbon content in the open area during the wet season and dry season were 1.80 per cent and 1.54 per cent respectively. Similarly, the carbon contents noted in homegarden were 1.92 per cent and 1.96 per cent in the wet and the dry season respectively.

Table 17a. Organic carbon content (%) of soil under the residues of *Gmelina arborea* at fortnightly intervals

Fortnight	Open area		Homegarden		F test	SEM±
	Wet season	Dry season	Wet season	Dry season		
0	0.82	0.63	1.01	0.98	--	--
1	0.99^{b}	0.83^{b}	1.19^{a}	1.02^{ab}	*	0.524
2	1.06	1.01	1.32	1.14	NS	--
3	1.25	1.15	1.48	1.34	NS	--
4	1.38	1.21	1.56	1.47	NS	--
5	1.48	1.25	1.67	1.59	NS	--
6	1.61	1.31	1.72	1.63	NS	--
7	1.72	1.46	1.84	1.75	NS	--
8	1.80	1.54	1.92	1.79	NS	--
9	NA	1.68	NA	1.86	--	--
10	NA	1.84	NA	1.92	--	--
F test	NS	NS	NS	NS		
SEM±	--	--	--	--		

** Significant at 1%

*Significant at 5%

Figures with the same superscript and subscript do not differ significantly

Superscripts indicate interactions between field and seasons within fortnight

Subscripts indicate interactions between fortnights within a field and season

NA – Not applicable

NS – Not significant

Table 17b. Organic carbon content (%) of soil under the residues of *Mallotus philippensis* at fortnightly intervals

Fortnight	Open area		Homegarden		F test	SEM±
	Wet season	Dry season	Wet season	Dry season		
0	0.82	0.63	1.01	0.98	--	--
1	0.95	0.71	1.08	1.03	NS	--
2	1.02	0.81	1.26	1.09	NS	--
3	1.19	0.87	1.32	1.18	NS	--
4	1.28^{b}	0.90^{c}	1.45^{a}	1.27^{b}	*	0.089
5	1.36	1.01	1.51	1.32^{b}	NS	--
6	1.44	1.08	1.61	1.45	NS	--
7	1.56	1.12	1.72	1.51	NS	--
8	1.62	1.29	1.80	1.61	NS	--
9	1.72	1.36	1.86	1.67	NS	--
10	1.76	1.54	1.88	1.68	NS	--
11	1.91	1.61	1.92	1.72	NS	--
12	NA	1.69	NA	1.81	--	--
13	NA	1.86	NA	1.89	--	--
14	NA	1.92	NA	1.94	--	--
F test	NS	NS	NS	NS		
SEM±	--	--	--	--		

** Significant at 1%

*Significant at 5%

Figures with the same superscript and subscript do not differ significantly

Superscripts indicate interactions between field and seasons within fortnight

Subscripts indicate interactions between fortnights within a field and season

NA – Not applicable

NS – Not significant

Mallotus philippensis

Attempts were made to study the influence of seasons on the increase in carbon content of the locations. The data corresponding to the study is presented in Table 17b. Both open area and homegarden showed an increase in carbon content throughout the study. The initial carbon content recorded in the open area during the wet season and dry season was 0.82 per cent and 0.63 per cent. Similarly, homegarden during the wet season and the dry season recorded an initial carbon content of 1.01 per cent and 0.98 per cent respectively. Soil samples collected from the open area reported higher carbon content during both the seasons. The peak carbon content in both the locations was witnessed at the final fortnight. In addition to this, wet season added more carbon to the soil than the dry season.

4.4.2 Total nitrogen

Gmelina arborea

The data pertaining to the nitrogen content in the soil samples as the decomposition of foliar mass progressed is represented in the Table 18a. Significant differences in values were observed under all the study situations.

The initial nitrogen contents recorded from the open area during the wet and dry season were 0.08 per cent and 0.06 per cent respectively. Similarly, the nitrogen content in the homegarden during the wet and dry season was 0.12 per cent and 0.09 per cent respectively. Both the locations under the influence of both the seasons showed a gradual rise in soil nitrogen till the end of the study. At the end of the eighth fortnight, the nitrogen content observed during the wet season in the open area and homegarden was 0.13 per cent and 0.17 per cent respectively. Similarly, the nitrogen content recorded in open area and homegarden in the tenth fortnight during the dry season was 0.12 per cent and 0.15 per cent respectively.

Table 18a. Total nitrogen content (%) of soil under the residues of *Gmelina arborea* at fortnightly intervals

Fortnight	Open area		Homegarden		F test	SEM±
	Wet season	Dry season	Wet season	Dry season		
0	0.08	0.06	0.12	0.09	--	--
1	0.09	0.07	0.13	0.09	NS	--
2	0.09	0.07	0.14	0.11	NS	--
3	0.09	0.08	0.15	0.11	NS	--
4	0.10	0.09	0.15	0.12	NS	--
5	0.11	0.09	0.16	0.12	NS	--
6	0.12	0.09	0.16	0.13	NS	--
7	0.13	0.10	0.16	0.14	NS	--
8	0.13	0.10	0.17	0.14	NS	--
9	NA	0.11	NA	0.15	--	--
10	NA	0.12	NA	0.15	--	--
F test	NS	NS	NS	NS		
SEM±	--	--	--	--		

** Significant at 1%

*Significant at 5%

Figures with the same superscript and subscript do not differ significantly

Superscripts indicate interactions between field and seasons within fortnight

Subscripts indicate interactions between fortnights within a field and season

NA – Not applicable

NS – Not significant

Table 18b. Total nitrogen content (%) of soil under the residues of *Mallotus philippensis* at fortnightly intervals

Fortnight	Open area		Homegarden		F test	SEM±
	Wet season	Dry season	Wet season	Dry season		
0	0.08	0.06	0.12	0.09	--	--
1	0.09	0.07	0.13	0.09	NS	--
2	0.08	0.07	0.13	0.1	NS	--
3	0.09	0.07	0.14	0.1	NS	--
4	0.09	0.08	0.14	0.11	NS	--
5	0.1	0.08	0.15	0.12	NS	--
6	0.11	0.09	0.16	0.12	NS	--
7	0.12	0.09	0.16	0.13	NS	--
8	0.12	0.1	0.16	0.14	NS	--
9	0.13	0.11	0.17	0.14	NS	--
10	0.13	0.12	0.17	0.14	NS	--
11	0.14	0.13	0.17	0.15	NS	--
12	NA	0.13	NA	0.16	--	--
13	NA	0.14	NA	0.16	--	--
14	NA	0.14	NA	0.16	--	--
F test	NS	NS	NS	NS		
SEM±	--	--	--	--		

** Significant at 1%

*Significant at 5%

Figures with the same superscript and subscript do not differ significantly

Superscripts indicate interactions between field and seasons within fortnight

Subscripts indicate interactions between fortnights within a field and season

NA – Not applicable

NS – Not significant

Mallotus philippensis

The statistical results of the data correlating the influence of seasons on the improvement of nitrogen content in the open area and the homegarden is tabulated in Table 18b. The initial nitrogen content observed in the open area during the wet season and dry season was 0.08 per cent and 0.06 per cent respectively. Similarly, homegarden also registered higher initial nitrogen content during the wet season (0.12 %) than the dry season (0.09 %). A slow increase in the soil nitrogen content was observed till the study culminated. Peak nitrogen contents were observed during the final fortnight.

4.4.3 Soil carbon: nitrogen ratio

Gmelina arborea

The C: N ratio of the soil samples collected underneath the *Gmelina arborea* residues at fortnightly intervals after statistical analysis is presented in Table 19a.

The initial samples recorded C: N ratio of 10.25 in the open area during the wet season and 10.50 during the dry season. Similarly, the C: N ratios recorded in the homegarden during the wet season and dry season was 8.42 and 10.89 respectively. Both the fields during both the seasons recorded a rise in soil C: N ratio.

Mallotus philippensis

The data pertaining to the influence of the different seasons on the pattern of soil C: N ratios of each location are also tabulated in Table 19b. The initial samples recorded C: N ratio of 10.25 in the open area during the wet season and 10.50 during the dry season. Similarly, the C: N ratios recorded in the homegarden during the wet season and dry season was 8.42 and 10.89

Table 19a. C: N ratios of soil under the residues of *Gmelina arborea* at fortnightly intervals

Fortnight	Open area		Homegarden		F test	SEM±
	Wet season	Dry season	Wet season	Dry season		
0	10.25	10.50	8.42	10.89	--	--
1	11.05	11.85	9.15	11.30	**	0.009
2	11.78^{b}	14.42^{a}	9.42^{c}	10.36^{d}	**	0.016
3	13.83^{ab}	14.37^{a}	9.86^{s}	12.18^{b}	**	0.048
4	13.89^{a}	13.44^{a}	10.47^{c}	12.25^{b}	**	0.012
5	13.45	13.89	10.43	13.25	NS	--
6	13.41^{ab}	14.52^{a}	10.75^{c}	12.53^{b}	**	0.109
7	13.27^{ab}	14.60^{a}	11.58^{c}	12.50^{bc}	**	0.007
8	13.84^{bc}	15.41^{a}	11.29^{d}	12.78^{cd}	**	0.061
9	NA	15.27	NA	12.41	--	--
10	NA	15.34	NA	12.87	--	--
F test	NS	NS	NS	NS		
SEM±	--	--	--	--		

** Significant at 1%

*Significant at 5%

Figures with the same superscript and subscript do not differ significantly

Superscripts indicate interactions between field and seasons within fortnight

Subscripts indicate interactions between fortnights within a field and season

NA – Not applicable

NS – Not significant

Table 19b . C: N ratios of soil under the residues of *Mallotus philippensis* at fortnightly intervals

Fortnight	Open area		Homegarden		F test	SEM±
	Wet season	Dry season	Wet season	Dry season		
0	10.25	10.50	8.42	10.89	--	--
1	10.56^{b}	10.14^{b}	8.31^{c}	11.44^{a}	*	0.061
2	12.75^{a}	11.57^{ab}	9.69^{c}	10.90^{bc}	**	0.004
3	13.22^{a}	12.43^{ab}	9.43^{c}	11.80^{b}	**	0.065
4	14.22^{a}	11.25^{bc}	10.36^{c}	11.55^{bc}	**	0.003
5	13.60^{a}	12.63^{ab}	10.07^{c}	11.00^{bc}	**	0.065
6	13.09^{a}	12.00^{b}	10.06^{c}	12.08^{b}	**	0.109
7	13.00^{a}	12.44^{ab}	10.75^{c}	11.62^{b}	**	0.007
8	13.50^{a}	12.90^{bc}	11.25^{c}	11.50^{bc}	*	0.119
9	13.23^{a}	12.36^{abc}	10.94^{d}	11.93^{bcd}	*	0.045
10	13.54^{a}	12.83^{bc}	11.06^{c}	12.00^{bc}	*	0.031
11	13.64^{a}	12.38^{bc}	11.29^{c}	11.47^{c}	*	0.067
12	NA	13.00	NA	11.31	--	--
13	NA	13.29	NA	11.81	--	--
14	NA	13.71	NA	12.13	--	--
F test	NS	NS	NS	NS		
SEM±	--	--	--	--		

** Significant at 1%

*Significant at 5%

Figures with the same superscript and subscript do not differ significantly

Superscripts indicate interactions between field and seasons within fortnight

Subscripts indicate interactions between fortnights within a field and season

NA – Not applicable

NS – Not significant

Table 20a. Available phosphorus content (kg/ha) of soil under the residues of *Gmelina arborea* at fortnightly intervals

Fortnight	Open area		Homegarden		F test	SEM±
	Wet season	Dry season	Wet season	Dry season		
0	21.64	18.58	24.98	21.39	--	--
1	$_{f}23.56^{b}$	$_{h}21.39^{bc}$	$_{g}25.87^{a}$	$_{g}20.24^{c}$	**	0.120
2	$_{e}24.47^{b}$	$_{gh}22.60^{c}$	$_{f}27.48^{a}$	$_{f}22.35^{c}$	**	0.628
3	$_{de}27.20^{a}$	$_{fg}23.47^{c}$	$_{f}27.88^{a}$	$_{e}25.19^{b}$	**	0.509
4	$_{d}28.05^{a}$	$_{fg}23.98^{c}$	$_{ef}28.71^{a}$	$_{de}26.09^{b}$	**	0.318
5	$_{d}28.82^{b}$	$_{e}26.36^{c}$	$_{d}30.25^{a}$	$_{de}26.57^{bc}$	**	0.098
6	$_{c}32.54^{a}$	$_{d}28.61^{b}$	$_{c}32.31^{a}$	$_{de}26.72^{c}$	**	0.105
7	$_{bc}34.88^{ab}$	$_{c}30.88^{b}$	$_{b}35.80^{a}$	$_{c}29.76^{c}$	**	0.007
8	$_{a}38.99^{a}$	$_{ab}34.71^{b}$	$_{a}38.67^{a}$	$_{b}31.17^{c}$	**	0.092
9	NA	$_{b}35.88$	NA	$_{ab}33.19$	--	--
10	NA	$_{a}35.94$	NA	$_{a}35.60$	--	--
F test	**	**	**	**		
SEM±	1.059	1.241	0.918	1.032		

** Significant at 1%

*Significant at 5%

Figures with the same superscript and subscript do not differ significantly

Superscripts indicate interactions between field and seasons within fortnight

Subscripts indicate interactions between fortnights within a field and season

NA – Not applicable

NS – Not significant

Table 20b. Available phosphorus content (kg/ha) of soil under the residues of *Mallotus philippensis* at fortnightly intervals

Fortnight	Open area		Homegarden		F test	SEM±
	Wet season	Dry season	Wet season	Dry season		
0	21.64	18.58	24.98	21.39	--	--
1	$_{i}22.81^{b}$	$_{i}19.32^{d}$	$_{h}25.01^{a}$	$_{g}20.15^{c}$	**	0.710
2	$_{hi}23.32^{b}$	$_{hi}21.69^{c}$	$_{gh}26.83^{a}$	$_{fg}21.68^{c}$	**	0.581
3	$_{g}25.12^{b}$	$_{hi}21.74^{c}$	$_{gh}26.99^{a}$	$_{e}23.92^{bc}$	**	0.309
4	$_{fg}26.08^{b}$	$_{g}23.91^{c}$	$_{f}28.26^{a}$	$_{e}23.46^{c}$	**	0.114
5	$_{fg}26.94^{b}$	$_{fg}24.84^{c}$	$_{ef}29.13^{a}$	$_{d}25.89^{bc}$	**	0.713
6	$_{e}28.36^{e}$	$_{e}26.01^{c}$	$_{d}32.15^{a}$	$_{d}25.99^{c}$	**	0.954
7	$_{e}28.84^{b}$	$_{de}26.79^{bc}$	$_{d}32.79^{a}$	$_{cd}26.01^{c}$	**	0.010
8	$_{de}29.71^{bc}$	$_{de}28.91^{bc}$	$_{c}34.87^{a}$	$_{cd}26.83^{c}$	*	0.235
9	$_{c}34.73^{a}$	$_{de}28.98^{b}$	$_{bc}35.22^{a}$	$_{bc}28.79^{b}$	*	0.014
10	$_{b}36.56^{b}$	$_{c}30.02^{b}$	$_{bc}35.11^{a}$	$_{bc}28.54^{c}$	**	0.003
11	$_{a}40.26^{a}$	$_{b}32.36^{b}$	$_{a}39.31^{a}$	$_{b}29.62^{c}$	**	0.346
12	NA	$_{b}32.91$	NA	$_{ab}30.18$	--	--
13	NA	$_{a}34.56$	NA	$_{ab}30.52$	--	--
14	NA	$_{a}34.99$	NA	$_{ab}30.99$	--	--
F test	**	**	**	**		
SEM±	2.091	1.362	0.867	1.045		

** Significant at 1%

*Significant at 5%

Figures with the same superscript and subscript do not differ significantly

Superscripts indicate interactions between field and seasons within fortnight

Subscripts indicate interactions between fortnights within a field and season

NA – Not applicable

NS – Not significant

respectively. Both the fields during both the seasons recorded a rise in soil C: N ratio.

4.4.4 Available phosphorus

Gmelina arborea

Attempts were made to determine the influence of seasons on the addition of phosphorus content into the soil samples collected from the open area and homegarden at fortnightly intervals. The results are shown in Table 20a. The initial phosphorus content observed in the open area during the wet season and dry season was 21.64 kg/ha and 18.58 kg/ha. Similarly, the initial phosphorus content recorded in the soil samples collected from homegarden during the wet season and dry season was 24.98 kg/ha and 24.39 kg/ha respectively. The entire study period registered an increase in phosphorus content. The maximum phosphorus contents in both the locations were observed in the final fortnight. As the decomposition terminated (eighth fortnight), the soil phosphorus contents recorded were as follows: open area during the wet season (38.99 kg/ha) > homegarden during the wet season (38.67 kg/ha) > open area during the dry season (34.71 kg/ha) > homegarden during the dry season (31.17 kg/ha). A considerable increase in the soil phosphorus content was observed as the decomposition progressed.

Mallotus philippensis

Studies were conducted to understand the influence of seasons on improving the soil phosphorus content of each location. Table 20b depicts the results of the statistical analysis of the data. The initial phosphorus content recorded in the open area during the wet season and the dry season was 21.64 kg/ha and 18.58 kg/ha respectively. The impending fortnights recorded an increase in phosphorus content till the decomposition culminated. By the end of the eleventh fortnight, considerable improvement in the soil phosphorus content

Table 21a. Exchangeable potassium content (kg/ha) of soil under the residues of *Gmelina arborea* at fortnightly intervals

Fortnight	Open area		Homegarden		F test	SEM±
	Wet season	Dry season	Wet season	Dry season		
0	546.06	438.94	695.37	629.57	--	--
1	$_{c}582.01^{h}$	$_{d}467.01^{j}$	$_{a}740.25^{h}$	$_{b}652.48^{j}$	**	0.528
2	$_{c}620.16^{g}$	$_{d}492.49^{i}$	$_{a}762.34^{g}$	$_{b}674.59^{i}$	**	0.364
3	$_{c}644.66^{f}$	$_{d}515.18^{h}$	$_{a}798.45^{f}$	$_{b}692.92^{h}$	**	0.069
4	$_{c}684.39^{e}$	$_{d}532.40^{g}$	$_{a}827.39^{e}$	$_{b}707.28^{g}$	**	0.093
5	$_{c}702.31^{d}$	$_{d}540.24^{f}$	$_{a}852.42^{d}$	$_{b}724.69^{f}$	**	0.212
6	$_{c}713.31^{c}$	$_{d}546.47^{e}$	$_{a}879.11^{c}$	$_{b}773.62^{e}$	**	0.017
7	$_{c}733.19^{b}$	$_{d}553.91^{d}$	$_{a}890.34^{b}$	$_{b}803.56^{d}$	**	0.024
8	$_{c}775.60^{a}$	$_{d}574.46^{c}$	$_{a}916.57^{a}$	$_{b}850.46^{c}$	**	0.152
9	NA	589.00^{b}	NA	902.45^{b}	--	--
10	NA	612.00^{a}	NA	936.72^{a}	--	--
F test	**	**	**	**		
SEM±	1.04	0.30	0.95	0.84		

** Significant at 1%

*Significant at 5%

Figures with the same superscript and subscript do not differ significantly

Superscripts indicate interactions between field and seasons within fortnight

Subscripts indicate interactions between fortnights within a field and season

NA – Not applicable

NS – Not significant

Table 21b. Exchangable potassium content (kg/ha) of soil under the residues of *Mallotus philippensis* at fortnightly intervals

Fortnight	Open area		Homegarden		F test	SEM±
	Wet season	Dry season	Wet season	Dry season		
0	546.06	438.94	695.37	629.57	--	--
1	$_{c}576.26^{k}$	451.74^{n}	$_{a}722.43^{k}$	$_{b}648.09^{n}$	**	0.759
2	$_{c}616.52^{j}$	$_{d}472.49^{m}$	$_{a}748.29^{j}$	$_{b}662.23^{m}$	**	0.348
3	$_{c}634.86^{i}$	$_{d}489.00^{l}$	$_{a}756.29^{i}$	$_{b}690.12^{l}$	**	0.140
4	$_{c}671.33^{h}$	$_{d}511.33^{k}$	$_{a}783.21^{h}$	$_{b}712.29^{k}$	**	0.739
5	$_{c}692.31^{g}$	$_{d}520.00^{j}$	$_{a}812.54^{g}$	$_{b}722.34^{j}$	**	0.530
6	$_{c}714.00^{f}$	$_{d}534.00^{i}$	$_{a}837.36^{f}$	$_{b}758.94^{i}$	**	0.791
7	$_{c}725.32^{e}$	$_{d}549.00^{h}$	$_{a}859.03^{e}$	$_{b}785.21^{h}$	**	0.102
8	$_{c}748.70^{d}$	$_{d}553.91^{g}$	$_{a}867.24^{d}$	$_{b}821.02^{g}$	**	0.094
9	$_{c}773.70^{c}$	$_{d}574.46^{f}$	$_{a}882.69^{c}$	$_{b}849.00^{f}$	**	0.068
10	$_{c}799.10^{b}$	$_{d}588.67^{e}$	$_{a}900.63^{b}$	$_{b}878.24^{e}$	**	0.174
11	$_{c}820.54^{a}$	$_{d}604.00^{d}$	$_{a}918.18^{a}$	$_{b}894.02^{d}$	**	0.090
12	NA	614.67^{c}	NA	902.81^{c}	--	--
13	NA	638.00^{b}	NA	928.50^{b}	--	--
14	NA	657.00^{a}	NA	946.10^{a}	--	--
F test	**	**	**	**		
SEM±	0.95	0.47	0.62	0.59		

** Significant at 1%

*Significant at 5%

Figures with the same superscript and subscript do not differ significantly

Superscripts indicate interactions between field and seasons within fortnight

Subscripts indicate interactions between fortnights within a field and season

NA – Not applicable

NS – Not significant

was noted. By the end of the eleventh fortnight, the total phosphorus content recorded were in the order: open area during the wet season (36.56 kg/ha) > homegarden during the wet season (35.11 kg/ha) > open area during the dry season (30.02 kg/ha) > homegarden during the dry season (28.54 kg/ha).

4.4.5 Exchangeable potassium

Gmelina arborea

Attempts were made to study the changes in soil potassium content in the open area and homegarden affected by different seasons after the addition of the leaf biomass of *Gmelina arborea*. The data regarding this are enumerated in Table 21a. The soil potassium content observed in the open area and homegarden during the wet season was 545.06 kg/ha and 695.37 kg/ha respectively, whereas, during the dry season was 438.94 kg/ha and 629.57 kg/ha respectively. Under all the situations studied, an increasing trend in potassium content was observed.

Mallotus philippensis

Attempts were made to study the changes in soil potassium content in the open area and homegarden affected by different seasons after the addition of the leaf biomass of *Mallotus philippensis* (Table 21b). The soil potassium content observed in the open area and homegarden during the wet season was 545.06 kg/ha and 695.37 kg/ha respectively, whereas, during the dry season was 438.94 kg/ha and 629.57 kg/ha respectively. Under all the situations studied, an increasing trend in potassium content was observed.

4.5 COMPARISON BETWEEN *Gmelina arborea* AND *Mallotus philippensis*

Apart from the above mentioned aspects, attempts were also taken to compare *Gmelina arborea* and *Mallotus philippensis* at fortnightly intervals with

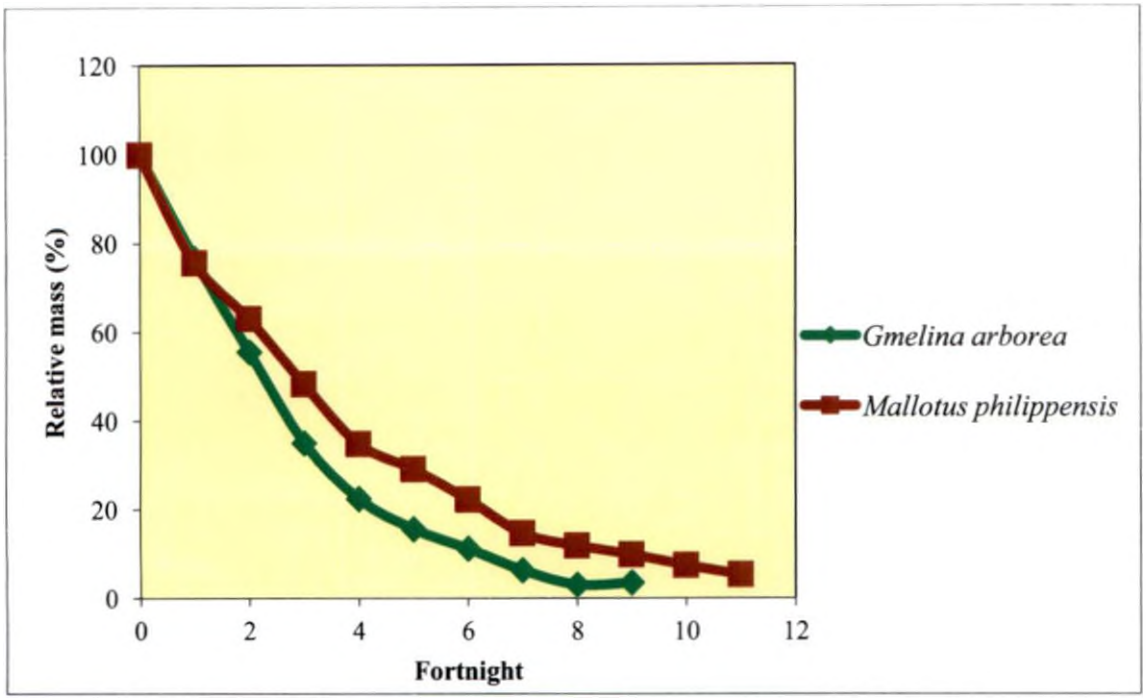

Fig 15. Changes in the relative mass (%) of residues of *Gmelina arborea* and *Mallotus philippensis*

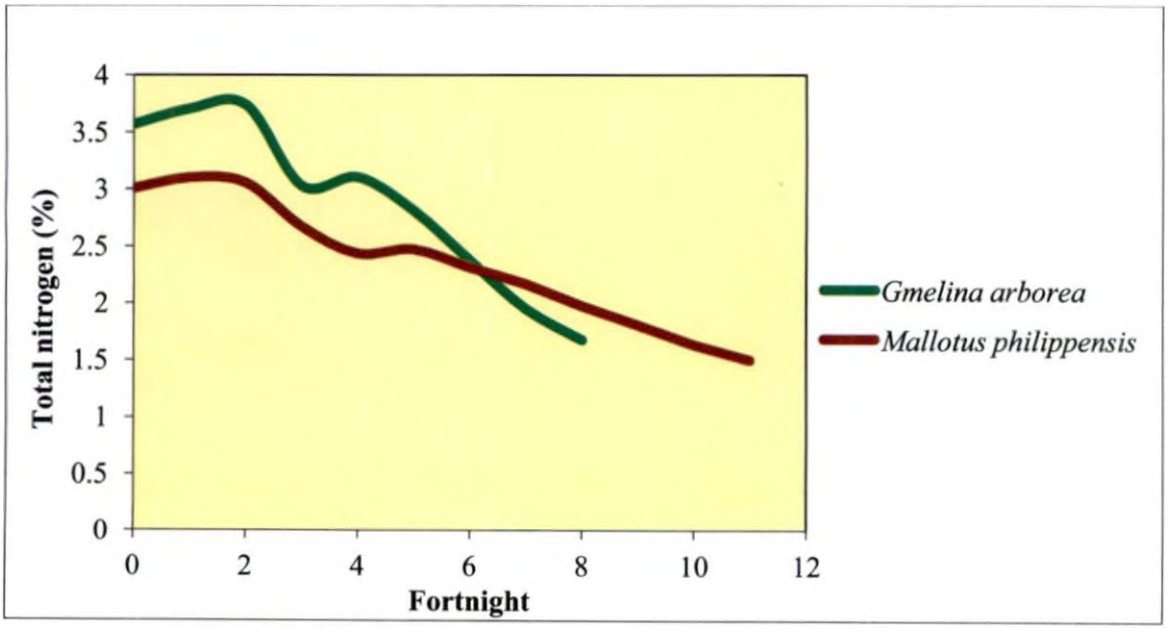

Fig 16 . Changes in the total nitrogen content (%) of residues of *Gmelina arborea* and *Mallotus philippensis*

respect to the changes in their relative mass, nutrient release pattern and the consequent improvement of the soil nutrient status by their incorporation into soil.

4.5.1 Relative mass

The data relating to the relative mass content of the fresh samples and residues of *Gmelina arborea* and *Mallotus philippensis* at fortnightly intervals when subjected to decomposition is illustrated in Fig.15. The results obtained through the statistical analysis conveyed a significant difference between the relative mass content at fortnightly intervals. Throughout the study, the leaf residues of *Gmelina arborea* registered faster mass loss than the residues of *Mallotus philippensis*. The beginning of the first fortnight recorded a relative mass of 76.62 per cent in *Gmelina arborea* followed by *Mallotus philippensis* (75.67 %). Both the species witnessed an initial rapid reduction in mass followed by a phase of gradual reduction in mass. The residues of *Gmelina arborea* experienced a 90 per cent mass loss from the beginning of the sixth fortnight, whereas, *Mallotus philippensis* reported a 90 per cent mass loss by the ninth fortnight. The total mass loss was observed in *Gmelina arborea* in eleven fortnights, whereas, decomposition of *Mallotus philippensis* was completed in sixteen fortnights.

4.5.2 Changes in nitrogen content and C: N ratio

4.5.2.1 Total nitrogen

The changes in the nitrogen content of the fresh samples collected and residues of *Gmelina arborea* and *Mallotus philippensis* retrieved at fortnightly intervals is plotted in Fig. 16. Significant differences were observed in the nitrogen content of leaf residues of *Gmelina arborea* and *Mallotus philippensis* retrieved at fortnightly intervals. The initial nitrogen content of the fresh samples of *Gmelina arborea* and *Mallotus philippensis* recorded was 3.56 per cent and 3.01 per cent respectively. The residues of *Gmelina arborea* recorded higher nitrogen contents in the initial phase than the residues of *Mallotus philippensis*.

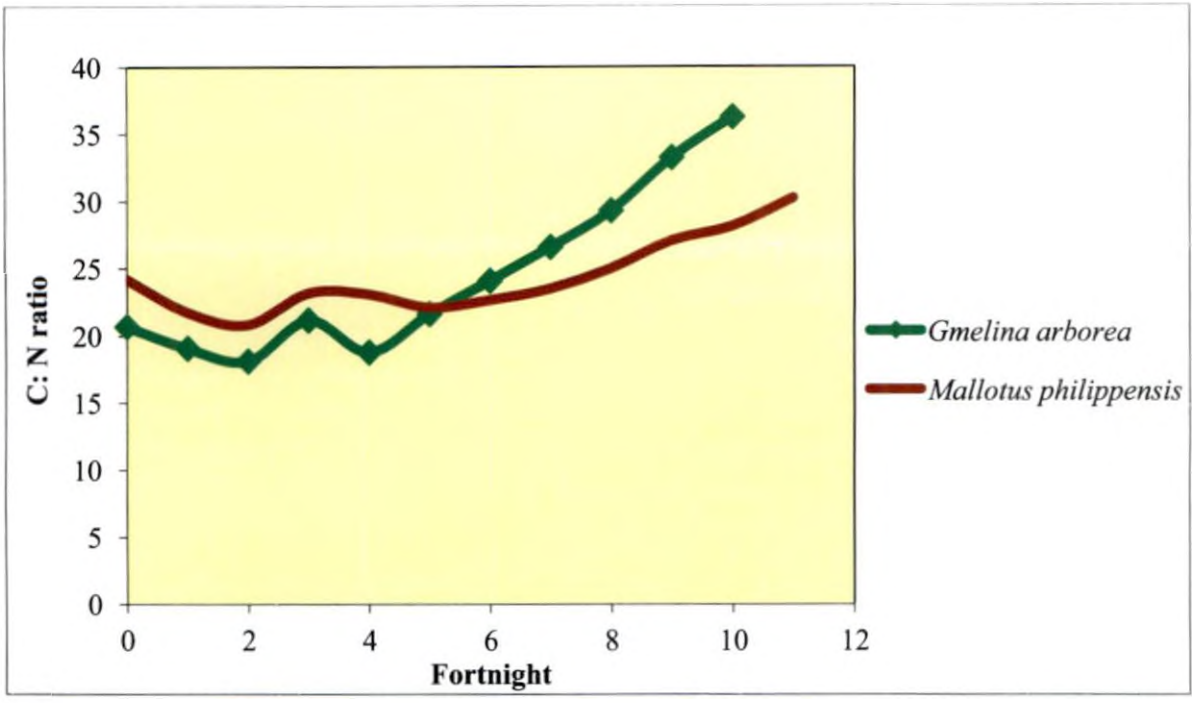

Fig 17. Changes in the C: N ratios of residues of *Gmelina arborea* and *Mallotus philippensis*

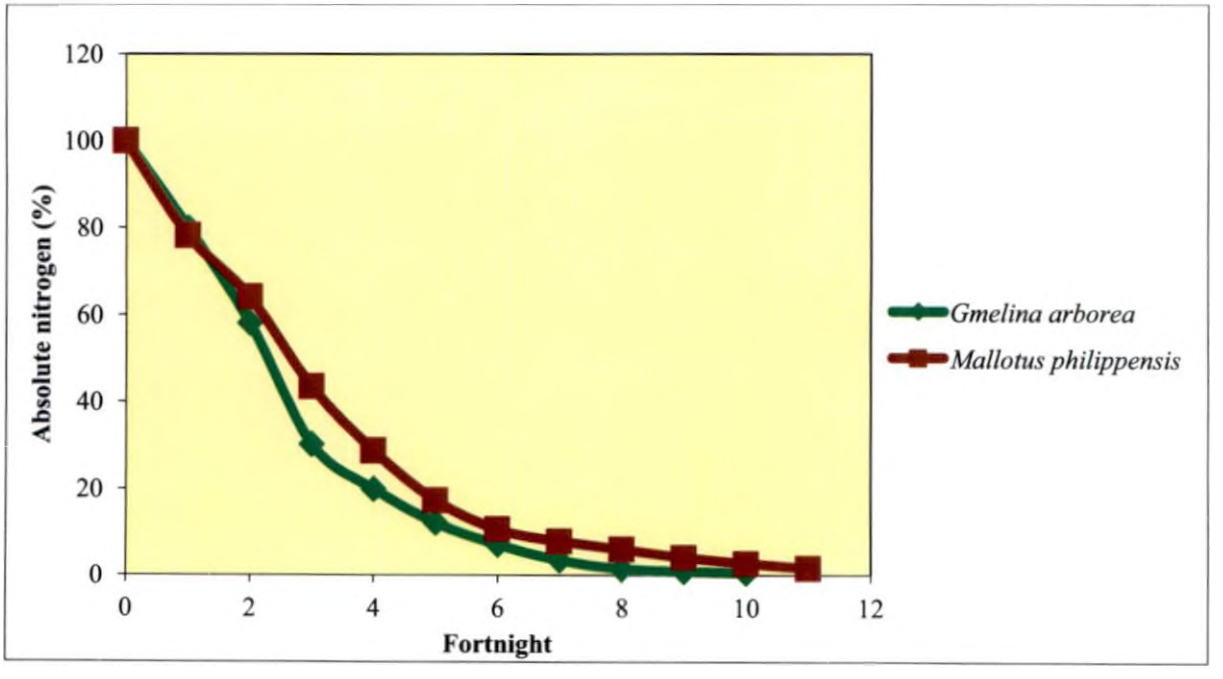

Fig 18. Changes in the absolute nitrogen content (%) of residues of *Gmelina arborea* and *Mallotus philippensis*

The subsequent fortnights recorded a gradual reduction in the amount of nitrogen content in both the species.

4.5.2.2 C: N ratio

Similar attempts were also made to study the C: N ratios of the leaf residues of *Gmelina arborea* and *Mallotus philippensis* retrieved at fortnightly intervals and it is shown in Fig. 17. Statistical analysis showed significant differences among different fortnights. The initial samples collected showed a lower C: N ratio (20.69) in *Gmelina arborea*, whereas, *Mallotus philippensis* recorded higher C: N ratio (24.21). The C: N ratios of both the tree species followed a fluctuating trend till the fifth fortnight. Thereafter a gradual increase in C: N ratios were observed in both *Gmelina arborea* and *Mallotus philippensis* till the decomposition terminated. By the end of the tenth fortnight, the C: N ratios noted in *Gmelina arborea* and *Mallotus philippensis* were 36.25 and 28.13 respectively. Throughout the study, *Gmelina arborea* witnessed higher C: N ratios than the residues of *Mallotus philippensis*.

4.5.3 Changes in the absolute nutrient content

4.5.3.1 Absolute nitrogen

The changes in the absolute nitrogen content of the residues of *Gmelina arborea* and *Mallotus philippensis* retrieved at fortnightly intervals is presented in Fig. 18. The initial fortnight recorded no significant difference but significant differences in the forthcoming fortnights. The first fortnight experienced *Gmelina arborea* (79.87 %) retaining the higher amount of absolute nitrogen content than that in *Mallotus philippensis* (78.18 %). A declining trend in absolute nitrogen content was observed in both the species till the decomposition was completed. Almost 90 per cent release of nitrogen was observed in *Gmelina arborea* and *Mallotus philippensis* by the beginning of sixth fortnight and seventh fortnight respectively. By the end of the tenth fortnight, the amount of absolute nitrogen

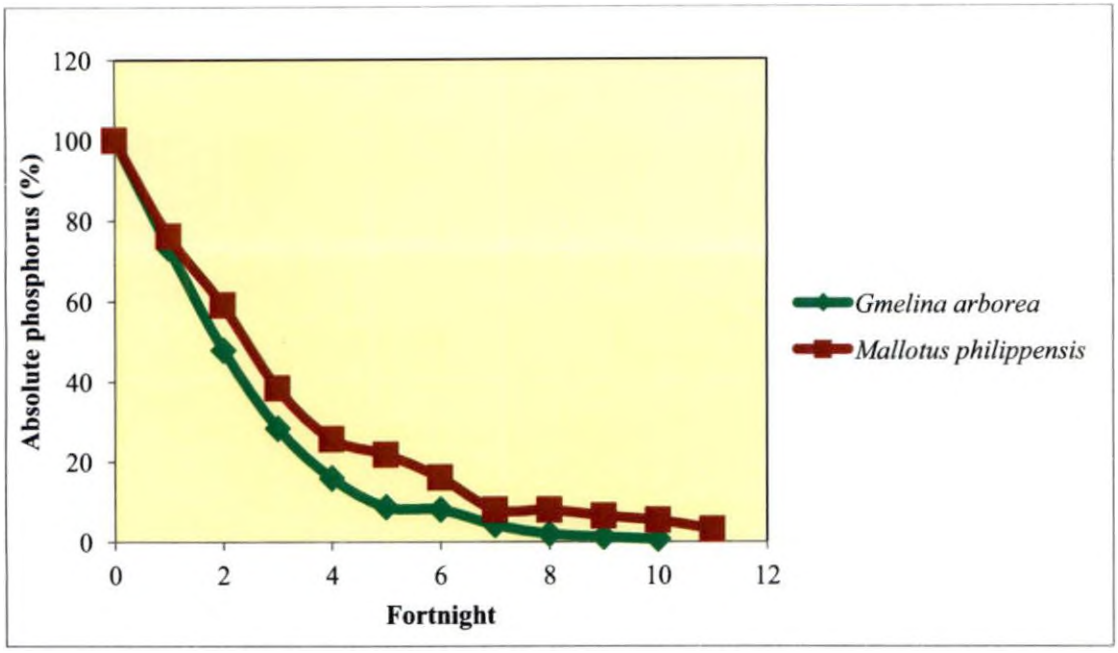

Fig 19. Changes in the absolute phosphorus content (%) of residues of *Gmelina arborea* and *Mallotus philippensis*

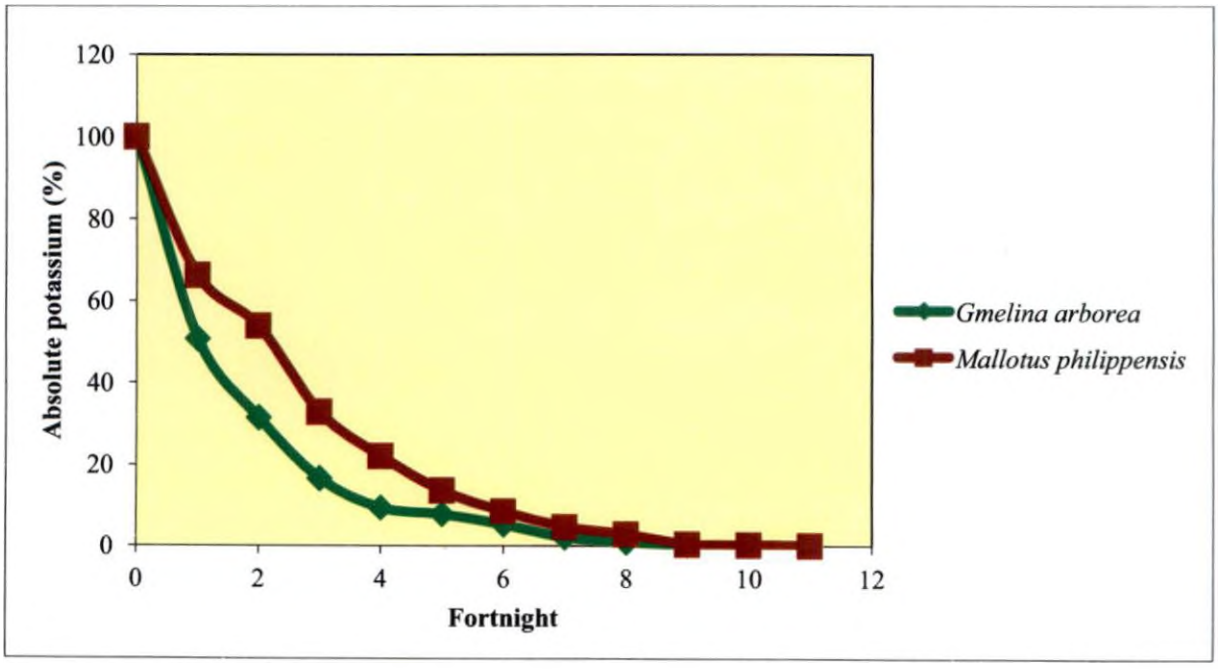

Fig 20. Changes in the absolute potassium content (%) of residues of *Gmelina arborea* and *Mallotus philippensis*

content registered in the residues of *Gmelina arborea* (0.49 %) was much lesser than the residues of *Mallotus philippensis* (2.72 %).

4.5.3.2 Absolute phosphorous

The data corresponding to the absolute amount of phosphorus found in the residues of *Gmelina arborea* and *Mallotus philippensis* is summarized in Fig. 19. Statistical analysis recorded significant differences between the values obtained. A sharp drop in the absolute phosphorus content was observed in both the tree species till the decomposition culminated. The residues retained from the litter bags of *Gmelina arborea* registered 90 per cent mineralization of phosphorus by the end of the fifth fortnight, whereas , *Mallotus philippensis* observed 90 per cent phosphorus release by the end of seventh fortnight. The pattern of phosphorus release was very fast in the initial fortnights followed by a comparatively slower mineralization in the successive sampling periods.

4.5.3.3 Absolute potassium

The changes in the absolute potassium contents of *Gmelina arborea* and *Mallotus philippensis* are illustrated in Fig. 20. Significant differences in the absolute potassium content of the leaf residues of both the tree species is evident from the table. A very rapid mineralization of potassium content was observed till the end of the study as 90 per cent potassium release was observed in *Gmelina arborea* by the middle of fourth fortnight, whereas, *Mallotus philippensis* reported 90 per cent potassium mineralization by the end of sixth fortnight. The amount of potassium content retained in *Gmelina arborea* and *Mallotus philippensis* by the end of the tenth fortnight was 0.14 per cent and 0.30 per cent respectively.

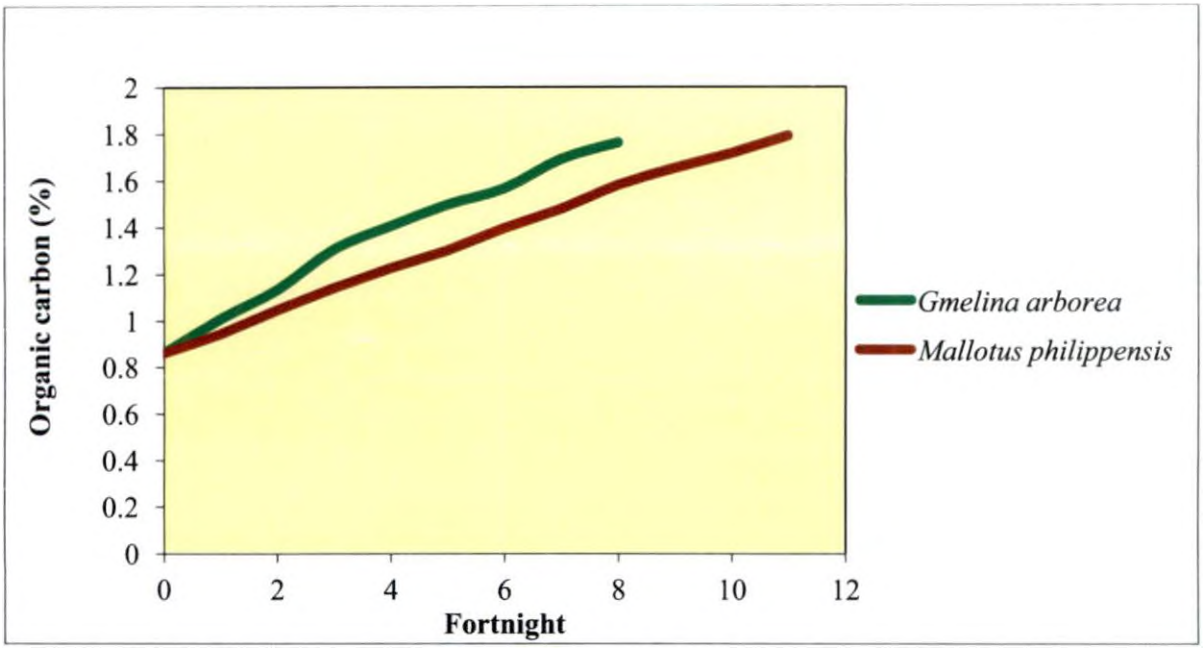

Fig 21. Changes in the organic carbon content (%) of soil under *Gmelina arborea* and *Mallotus philippensis* residues

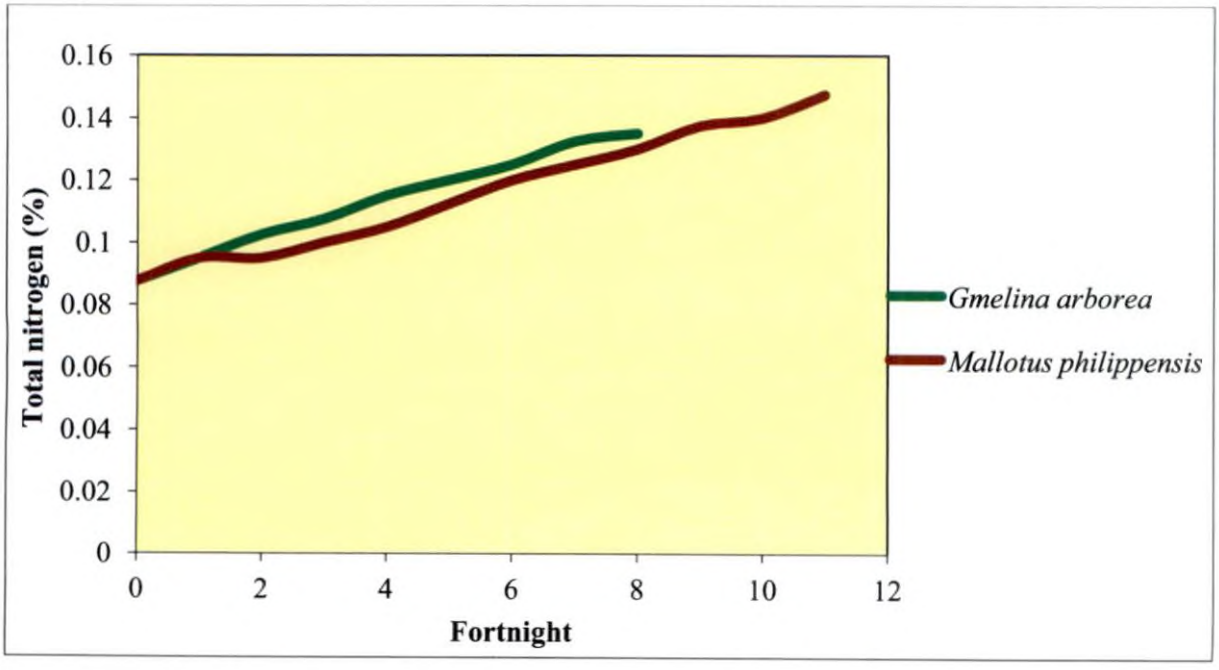

Fig 22. Changes in the total nitrogen content (%) of soil under *Gmelina arborea* and *Mallotus philippensis* residues

4.6 CHANGES IN THE NUTRIENT STATUS OF SOIL

4.6.1 Total carbon

The data pertaining to the improvement of soil carbon by the addition of *Gmelina arborea* and *Mallotus philippensis* leaf biomass is illustrated in Fig. 21. Statistical analysis revealed a considerable difference in the carbon content of the soil collected from underneath the litter bags of both the tree species. The initial carbon content of the soil before incorporating the residues was 0.86 per cent. A considerable increase in soil organic carbon was observed till the decomposition was completed.

4.6.2 Total nitrogen

The changes in the soil nitrogen status by the addition of *Gmelina arborea* and *Mallotus philippensis* residues is illustrated in Fig. 22. The soil samples collected before the incorporation of *Gmelina arborea* and *Mallotus philippensis* leaf biomass was recorded as 0.08 per cent. Throughout the study, no significant difference in soil nitrogen content was observed in the soil samples collected from beneath the litter bags of *Gmelina arborea* and *Mallotus philippensis*. However, a gradual increase in the nitrogen content of the soil was noticed.

4.6.3 C: N ratio

Attempts were made to study the C: N ratios of the soil samples incorporated with the leaf residues of *Gmelina arborea* and *Mallotus philippensis*, and the influence of their decomposition on determining the C: N ratios of the soil (Fig. 23). C: N ratios of the initial samples before adding leaf residues were found to be 10.02. Along with the progression of decomposition, soil C: N ratio was also found to increase gradually.

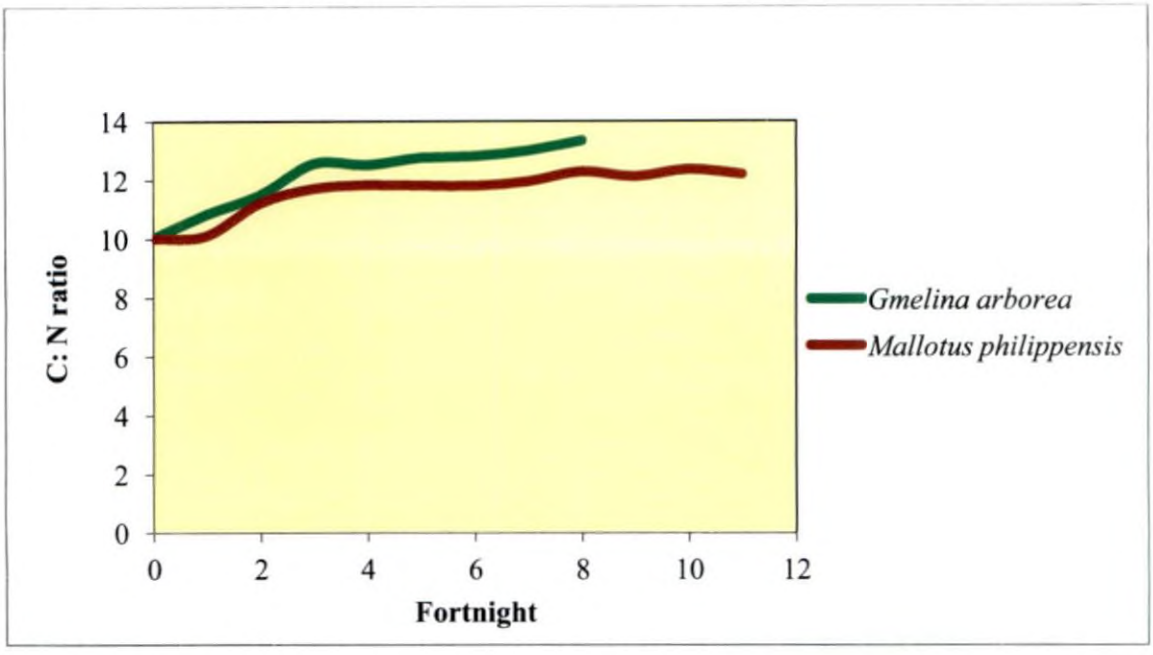

Fig 23. Changes in the C: N ratios of soil under *Gmelina arborea* and *Mallotus philippensis* residues

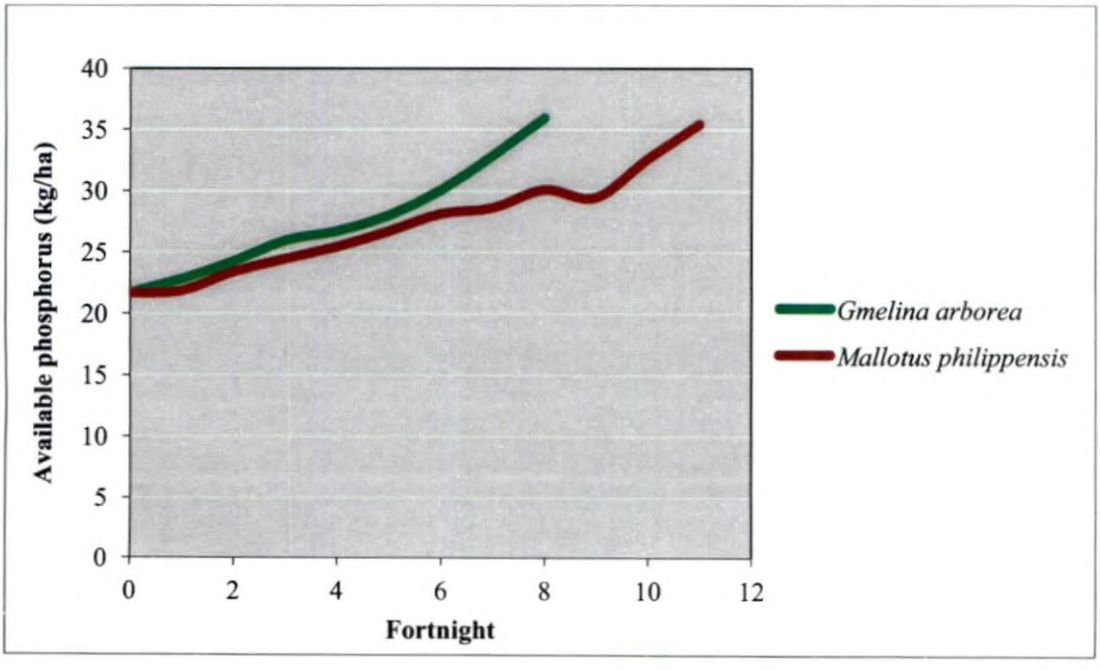

Fig 24. Changes in the available phosphorus content (kg/ha) of soil under *Gmelina arborea* and *Mallotus philippensis* residues

4.6.4 Available phosphorous

The data pertaining to the soil phosphorus content during the decomposition of *Gmelina arborea* and *Mallotus philippensis* is plotted in Fig. 24. The initial phosphorus content in the soil before the incorporation of leaf residues was 21.65 kg/ha. A considerable increase in soil phosphorus content was observed till the end of the study. Significant differences were noted in the phosphorus content of soils collected, however, the soil beneath the residues of *Gmelina arborea* recorded higher phosphorus content than that of *Mallotus philippensis* throughout the study. By the end of the eighth fortnight, soil samples beneath *Gmelina arborea* and *Mallotus philippensis* registered phosphorus content of 35.89 kg/ha and 31.93 kg/ha respectively.

4.6.5 Exchangeable potassium

The data comparing the soil potassium content during the decomposition of *Gmelina arborea* and *Mallotus philippensis* is illustrated in Fig. 25. Significant difference was noted in the values obtained after statistical analysis. The initial potassium content in the soil before the incorporation of leaf residues was 577.49 kg/ha. The soil samples collected from beneath the litter bags of *Gmelina arborea* recorded higher potassium content than that of *Mallotus philippensis* till the decomposition ceased. A considerable increase in soil potassium content was observed till the end of the study.

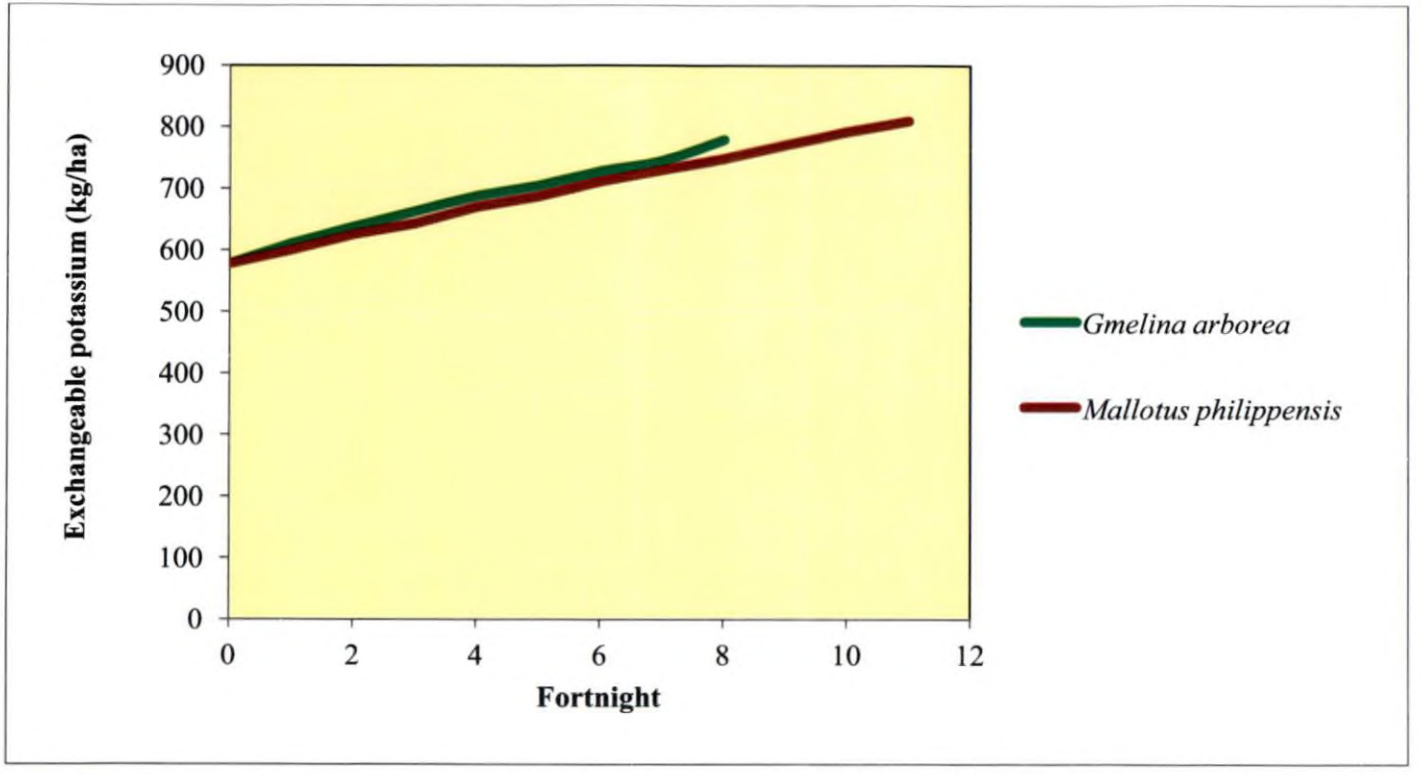

Fig 25. Changes in the exchangeable potassium content (kg/ha) of soil under *Gmelina arborea* and *Mallotus philippensis* residues

Discussion

5. DISCUSSION

It is a well established fact that leaf biomass of tropical trees retain considerable amount of nutrients. Moreover, much of the energy originating from primary production is released during decomposition. Litter production and their decomposition are the primary mechanisms through which the nutrient pool in the natural ecosystem is maintained. Also, litter decomposition is the key process controlling the rate at which nutrients of plant biomass are returned and incorporated into the forest soil (Ragu, 2000; Lodhiyal *et al.*, 2002). During this release, plant nutrients become available for recycling within the ecosystem. Thus, litter when incorporated into soil, contributes to soil fertility through the regeneration of plant nutrients and the maintenance of soil organic matter. Many researchers have attempted to quantify the rate of litterfall and decomposition as an important pathway for the transfer of litter mass and minerals to the soil surface in forest ecosystems (Polyakova and Billor, 2007).

Decomposition and nutrient release processes are particularly important in tropical ecosystems, where soils can be naturally low in fertility and nutrient status. Also, litter contains a considerable amount of the nutrients necessary for plant growth. In order to release these nutrients, the litter must be fragmented and decomposed. Litter breakdown and mineralization are mediated by the decomposer community of soil and forest floor microorganisms and fauna (Voriskova and Baldrian, 2013). Decomposition rates are regulated by interactions among the decomposer community, the physio-chemical environment, and litter quality. Litter quality refers to intrinsic chemical and structural characteristics that govern the activity of decomposer organisms, which partly determines the rate of organic matter decay. Litter resource quality is determined largely by the species contributing to the forest floor mass (Strickland *et al.*, 2009).

In agroforestry systems, the addition of nutrients to the soil is the paramount role of trees. The nutrients are absorbed from deeper layers and are deposited in the upper layer through the process of nutrient cycling. In this context, green manuring can play a pivotal role. "Green manuring" is the soil incorporation of any green manure crops, while they are green or soon after they start flowering. They are mostly forage or leguminous crops that are grown for their leafy materials needed for soil nutrient conservation (Pieters, 2004). Moreover, the value of 'green manuring' lies in their capability of incorporating organic matter into the soil. Along with the litter, fresh leaves of green manure trees also supplement the nutrient flux in the soil. In modern agriculture and agroforestry systems, a sound knowledge of the rates of decomposition and nutrient release patterns from the decaying leaf biomass is quintessential for the proper nutrient budgeting of the crops (Milkha *et al.*, 2001).

The present study demonstrated the role of leaf biomass of *Gmelina arborea* and *Mallotus philippensis*, in improving the soil properties and nutrient pool, thus, facilitating sustainable agricultural production. This study was carried out in the College of Forestry, Vellanikkara to estimate the decomposition rate and mineralization pattern of leaf material collected from two green manure tree species viz. *Gmelina arborea* and *Mallotus philippensis*. The salient features are discussed here under.

5.1 LEAF BIOMASS DECOMPOSITION

5.1.1 Decomposition as affected by seasonal variations on different fields

In the case of *Gmelina arborea*, the leaf samples kept for decomposition in the open area during the wet season exhibited complete decomposition within eight fortnights, whereas during the dry season it took ten fortnights (Table 1b). On the other hand, the litter bags kept for decomposition in the homegarden manifested complete decomposition within eight and eleven fortnights. Similarly,

leaf biomass of *Mallotus philippensis* kept in the open area took eleven and sixteen fortnights for decomposition, whereas, those kept in the homegarden took thirteen and sixteen fortnights (Table 2b).

Kunhamu (1994) reported complete decomposition of the leaf biomass of *Pongamia pinnata* and *Macaranga peltata* in a time period of twelve months. Isaac and Nair (2006) observed complete decomposition of *Artocarpus heterophyllus* leaf biomass after twelve fortnights of application. Jinsy (2007) reported that the foliar mass of *Gliricida sepium* decomposed in eight fortnights in homegarden. Similarly, the foliar mass of *Leauceana leucocephala* decomposed in eight fortnights (Oladoye *et al.*, 2008). In a study conducted by Aburge *et al.* (2011), it was observed that the leaf biomass of *Jatropha curcas* decomposed in ten fortnights.

During the entire course of study, open area reported faster decomposition rate than homegarden for both the species (Fig. 1 and 2). This observation suggests that solar radiation might have exerted a significant effect on the decomposition processes in open areas. Solar radiation on bare soil dehydrated plant material faster, facilitating its mechanical destruction. This confirms that physical factors such as temperature influences decomposition (Yasin and Mary, 2011). Also, more exposure of soil to rainfall, temperature, sunlight and microbial activity would have triggered faster decomposition in open area compared to homegarden where the floor is densely covered by canopies of trees and shrubs (Girisha *et al.*, 2003).

Laura and Yolanda (2007) in an experiment on spatial variability in decomposition rates in a desert scrub of North-western Mexico, found that leaf litter exposed to radiation decomposed faster compared to those under the canopy of nursed trees. Sarjubala and Yadava (2007) also found similar results in their study. Aburge *et al.* (2011) on the leaf decomposition of *Jatropha curcas* biomass reported faster decomposition in the open area than the homegarden. Another

reason for the rapid mass loss in open area might be the abundant termite population which actively promoted leaf decomposition. Similar finding was also reported by Uma *et al.* (2014) in the litter of *Casuarina equisetifolia*, where termites were exceedingly abundant resulting in faster decomposition of the litter.

Both *Gmelina arborea* and *Mallotus philippensis* registered faster mass loss during the wet season (Fig. 3 and 4). During the wet season, presence of favourable soil temperature, soil moisture, soil fauna and other micro-organisms coupled with physico-chemical qualities of the leaf matter would have attributed to the rapid rate of decomposition. Oladoye *et al.* (2008) also recorded higher rates of decomposition of *Leauceana leucocephala* leaf biomass during July – August than the dry season. Ray and Ranabijoy (2011) also found higher decomposition rates of teak litter during the wet season. Also, Kaushal *et al.* (2012) reported faster decomposition of the leaf litter of *Grewia optiva*, *Morus alba*, *Toona ciliata* and *Populus deltoides* during the wet period when the rainfall is high. Uma *et al.* (2014) also reported faster decomposition of *Casuarina equisetifolia* litter during the rainy season. The study showed maximum weight loss during May 2005 to November 2005, may be due to the reason that this time of the year characterized by heavy rainfall, high relative humidity and temperature facilitate the growth of decomposers.

But it was interesting to note that during the initial months of the dry season (December and January) decomposition trends of both *Gmelina arborea* and *Mallotus philippensis* was slow under open canopy compared to those kept under closed canopy (Table 1b and 2b). This means that water is also a physical factor that plays a key role in decomposition rates. The more water present, faster the material will be broken down, to a certain point (Hasanuzzaman and Hossain, 2014). But, when the amount of water becomes too much, decomposition rate becomes slower, as was experienced by the leaf biomass remaining under the canopy of trees during the wet period, hindering its decomposition rate. The amount of water present, therefore greatly influences the rate of decomposition.

However, during the dry season, decreased soil moisture and low temperature (Table 6a and 6b) were responsible for the slow rate of litter decomposition as a result of retarded activity of soil microorganisms (Kaushal *et al.*, 2006).

Generally, leaf biomass of *Gmelina arborea* and *Mallotus philippensis* showed a faster rate of decomposition. Among the species, *Gmelina arborea* decomposed faster than *Mallotus philippensis*.

5.1.2 Pattern of decomposition

Generally, a biphasic pattern of decomposition was observed in all the study situations. In the present study, the leaf biomass of *Gmelina arborea* witnessed 90 per cent mass loss within four months in all the study situations (Fig. 5), whereas the leaf biomass of *Mallotus philippensis* reported a 90 per cent mass loss within four months during the wet season and within five months during the dry season (Fig. 6). The results also compare favourably with the work of Sreekala *et al.* (2001) who studied decomposition and dynamics of cocoa litter under humid tropical conditions. Similarly, Shuhyb (2004), observed seventy five per cent mass loss of the litter of *Acacia* spp. in the initial three months.

Gopikumar *et al.* (2001) reported a biphasic model of decomposition with a rapid initial phase followed by a slower phase was noticed in the decomposition of selected agroforestry tree species (*Artocarpus heterophyllus, Erythrina indica, Albizia falcataria* and *Artocarpus hirsuta*). Similarly, Kaushal *et al.* (2012) also observed a biphasic pattern of decomposition in *Grewia optiva, Morus alba, Toona ciliata* and *Populus deltoides* in north-western mountain region of Indian Himalaya. Dhanya *et al.* (2013) also noted a biphasic pattern of decomposition of *Ficus benghalensis* in a traditional agroforestry system of Karnataka.

The initial rapid decay could be due to the prevailing congenial environmental condition associated with the presence of readily digestible water soluble compounds in the leaf matter. This might have triggered the activity of

soil fauna and soil microbes which are mainly responsible for decomposition. In addition, the high leaching losses of water soluble fractions from the decomposing material during the wet season might have resulted in a heavy mass loss during the initial phase. The latter slower phase could be due to absence of congenial condition such as high rainfall and also due to increased content of bio-decay resistant compounds like lignin and phenols. This is in accordance with the findings of Hegde (1995), Barbhuiya *et al.* (2008) and Kaushal *et al.* (2012) who opined that the slower decomposition phase was due to the labile carbon and refractory fractions.

5.1.3 Factors affecting leaf biomass decomposition

5.1.3.1 Effect of substrate quality on the rate of decomposition

Initial nitrogen and C: N ratio

At a regional scale with similar climatic conditions, litter decomposition rates are primarily controlled by the substrate quality of litter (Berg, 2000; Ribeiro *et al.*, 2002 and Tateno *et al.*, 2007). Studies have suggested that nitrogen exerts great influence in the early stage of decomposition because it affects the physiological adaptation of decomposition organisms (Salamanca *et al.*, 1995; Hobbie, 1996; Temel, 2003; Gusewell and Gessner, 2009). In addition to this, C: N ratio is accepted as a general index of quality (Seneviratne, 2000). Crop plant litters and crop residues with high quality (characterized by higher N concentration and lower C: N ratio) can decompose faster in comparison with low quality litter (Seneviratne *et al.*, 1998; Sanchez, 2001; Su *et al.*, 2004).

It was interesting to note that the fresh leaves of *Gmelina arborea* and *Mallotus philippensis* collected during the wet season recorded higher initial nitrogen content (Table 3a and 3b) and lower C: N ratio (Table 3c and 4c) than the leaves of the respective species collected during the dry season. *Gmelina arborea* during the wet season and dry season recorded C: N ratios of 18.34 per cent and

22.20 per cent respectively. Similarly, the fresh leaves of *Mallotus philippensis* during the wet season and dry season recorded C: N ratios of 22.20 per cent and 26.23 per cent respectively. Consequently, both *Gmelina arborea* and *Mallotus philippensis* exhibited faster decomposition in the wet season than the dry season. Kunhamu (1994) reported initial nitrogen content of 3.67 per cent in the leaf biomass of *Macaranga peltata.* Also, *Artocarpus heterophyllus* was reported to have an initial nitrogen content of 1.10 per cent by Isaac and Nair (2004). The initial nitrogen content recorded in leaf biomass of *Lagerstroemia speciosa* and *Cassia siamea* during the wet season was 2.19 per cent and 3.06 per cent respectively (Jinsy, 2007). Besides this, *Jatropha curcas* recorded initial nitrogen content of 2.53 per cent (Aburge *et al.*, 2011).

Javier and Enriquez (1996) also reported higher nitrogen content in the leaf litter collected during the rainy season. Similarly, Tekalay and Malmer (2004) found higher nitrogen content in the leaf biomass of *Albizia gumifera* collected during the wet season than the leaf biomass collected during the dry season. The higher initial nitrogen content during the wet season would have aided the microbial activity.

Semwal *et al.* (2003) showed a positive correlation with the initial nitrogen content and decomposition rates of six multipurpose tree species (*Alnus nepalensis, Albizia lebbeck, Boehmeria rugulosa, Dalbergia sissoo, Ficus glomerata* and *F. roxburghii*) in the central Himalaya, India. *A. lebbeck, A. nepalensis* and *D. sissoo* which showed higher N content (2.2–2.6 %) but lower polyphenol concentrations (3.2–4.7 %) than *B. rugulosa, F. glomerata* and *F. roxburghii*, marked faster decomposition. Huang *et al.* (2007) also confirmed the significant influence of initial nitrogen content on litter decomposition in an evergreen broad-leaved forest in eastern China. Kaushal *et al.* (2012) also reported faster decomposition of *Grewia optiva* and *Morus alba* due to high N concentration in leaf litter compared to *Toona ciliata* and *Populus deltoides* as high initial nitrogen promotes decomposition.

The initial samples of *Gmelina arborea* and *Mallotus philippensis* collected showed a lower C: N ratio (20.69) in *Gmelina arborea*, whereas *Mallotus philippensis* recorded relatively higher C: N ratio (24.21). The C: N ratios of *Gmelina arborea* and *Mallotus philippensis* during the wet season was 18.34 and 22.20 respectively. Tripathi *et al.* (1999) reported higher C: N ratios in *Azadirachta indica* (42.1), *Dalbergia sissoo* (36.7), *Pongamia pinnata* (36.1) and *Shorea robusta* (60.9).

5.1.3.1.2 Lignin and lignin: nitrogen ratio

The influence of lignin content on the rate of decomposition is also quite evident from the data presented earlier. Lignin tends to dominate the shape of the long term decay curve (Minderman, 1968) in the last stage of decomposition. It provides little or no energy to the decomposers until the last stage of decomposition. Thus, species having more lignin content decomposes more slowly, which results in the biphasic pattern of decomposition (Jamma and Nair, 1996; Mugendi *et al.*, 1999 and Arunanchalam *et al.*, 1998).

Berg *et al.* (2000) proposed a two phase decay model with an early decomposition stage, when the rapid decay of soluble and non-lignified carbohydrates are regulated by N content, a late decomposition stage, when decay is regulated by the degradation of lignin. This can be further supported by the findings of Sariyildiz (2008) who revealed an initial lignin concentration as most strongly correlated with the decay rates. Kaushal *et al.* (2012) also attributed low decomposition rate in *Populus deltoides* to its higher lignin content. Leaf litter of jack tree (*Artocarpus heterophyllus*), a prominent homegarden component, had a lignin concentration of 15.18 per cent which resulted in the reduced decomposition rate of the leaf litter (Isaac and Nair, 2004).

The present study during the wet season recorded initial lignin content of 10.25 per cent in *Gmelina arborea* and 13.21 per cent in *Mallotus philippensis.*

The initial lignin content recorded in the leaf biomass of *Azadirachta indica*, *Dalbergia sissoo*, *Pongamia pinnata* and *Shorea robusta* was 18.26, 23.48, 26.30 and 30.38 (Tripathi *et al.*, 1999).

Lignin content and lignin: nitrogen ratio is negatively correlated with decomposition indicating a faster decomposition of *Gmelina arborea*. The fresh leaf samples of *Gmelina arborea* collected during the dry season recorded higher lignin content (13.21 %) as compared to the leaf samples of the wet season (10.25 %). Similarly, Tekalay and Malmer (2004) who found lower lignin content in the leaf biomass of *Albizia gummifera* collected during the wet season than the dry season highlighting its pivotal role in enhanced decomposition in wet seasons than the dry season. In a litter decomposition study conducted by Bontti *et al.* (2009), percentage lignin was found to be the best predictor of leaf decomposition. Bala *et al.* (2010) also found lignin content as the major factor slowing the decomposition rate of *Eucalyptus camaldulensis.*

Similarly, the initial lignin: nitrogen ratio for the fresh leaves of *Gmelina arborea* during wet season and dry season was 2.61 and 4.11 respectively (Table 5a). Similar observations were also made by Afrira (2013) in the leaf litter of *Acaia mangium.* The L: N ratios of *Mallotus philippensis* were 6.75 and 7.88 during the wet season and dry season (Table 5b). The lower the lignin: N ratio, faster is the decomposition rate (Aponte *et al.*, 2012). Thus, the low lignin content coupled with the low L: N ratio might have enhanced the decomposition rate of *Gmelina arborea.*

Ragu (2000) also reported that the lignin content of leaf biomass strongly influenced the rate of decomposition of *Artocarpus heterophyllus, Erythrina indica, Albizia falcataria* and *Artocarpus hirsutus*. Arunachalam *et al.* (2005) found significant positive relationships with lignin and N concentrations and lignin: N ratios. Similar finding was reported by Barbhuiya *et al.* (2008). He observed faster decomposition rates in species like *Duabanga sonneriatoides*

(6.78), *Dysoxylum binectariferum* (8.47), and *Taluma hodgsonii* (16.0) with lower lignin: N ratio than the other species. He also reported the L: N ratios in *Ailanthus grandis, Mesua ferrea* and *Terminalia myriocarpa* as 16.2, 43.6 and 12.4. Similar findings were also reported by Ray and Ranabijoy (2011) in the litter of *Tectona grandis*. The analysis of the initial chemistry of litter recognized that both C: N ratio (43.06) and L: N ratio (42.28) was high which indicate a low rate of decomposability.

In the current study, lignin content of both *Gmelina arborea* and *Mallotus philippensis* was found to increase as the time elapsed which clearly indicates its pronounced influence on the rate of decomposition during the latter stages. The initial lignin content recorded in *Gmelina arborea* and *Mallotus philippensis* was 11.73 per cent and 21.45 per cent respectively. Among the two species studied, *Gmelina arborea* with a lower lignin content recorded faster decomposition rate. Sarjubala and Yadava (2007) also reported an increasing trend in lignin content as decomposition proceeded. This finding is also in agreement with the results obtained by Goma and Bernhard (2006), which showed that the amount of lignin content in the leaf litter of *Terminalia superba* increased as the decomposition progressed. These observations were in confirmation with the findings of the present study. Bontti *et al.* (2009) stated that the slow rate of decomposition in the latter phase is lignin controlled, whereas the initial rapid mass loss is attributed by the nitrogen present in the soluble carbon compounds.

5.1.3.2 Effect of soil factors on the rate of decomposition

5.1.3.2.1 Soil moisture and soil temperature

The influence of favourable conditions of soil moisture and temperature on decomposition has already been established by Gopikumar *et al.* (2001). Table 8a and 8b, furnished earlier points a noticeable difference between the soil temperature and soil moisture conditions under different study situations, thus

influencing the rate of decomposition in a particular manner. Increased rate of leaf biomass decomposition of both *Gmelina arborea* and *Mallotus philippensis* was observed during the wet season i.e. July. This period with abundant rainfall, high soil moisture content and relative humidity, might have enhanced the microbial proliferation and subsequent rapid mass loss. Low moisture limits the metabolic activity of the microbes, and as the soil moisture level rises, metabolic activity increases until an optimum level is reached (Couteaux *et al.*, 1998).

Panda *et al.* (2010) also found a significant influence of soil moisture and temperature on the litter decomposition of cashew nut plantation in Orissa. The influence of soil temperature on the rate of decomposition has also been observed by Yasin and Mary (2011) on the decomposition of *Pinus patula* litter. Salinas *et al.* (2011) found the soil temperature to be detrimental in the litter decomposition. Dhanya *et al.* (2013) also reported significant influence of soil moisture and soil temperature on the decomposition of leaf biomass of *Ficus benghalensis.* Hanna *et al.* (2014) also reported significant influence of both soil moisture and soil temperature on the rate of litter decomposition.

5.1.4 Decay rate coefficients

In the present study, the decay rates of both *Gmelina arborea* and *Mallotus philippensis* for various study situations were found to be different (Table 7). The k value observed for the decay of leaf biomass of *Gmelina arborea* in the open area during the wet season and dry season was 0.55 and 0.36 respectively. Similarly, the k values in the homegarden were 0.43 and 0.34 respectively. On the other hand, the k values noted for *Mallotus philippensis* in the open area for both wet season and dry season was 0.41 and 0.27 respectively. Similarly, the k values for homegarden were 0.35 and 0.22 respectively. The higher the k value, the faster is the rate of decomposition. Thus, *Gmelina arborea* with higher decay coefficient recorded faster mass loss than *Mallotus philippensis* for the same time period.

Dutta and Agrawal (2001) also reported higher decomposition rate in *Acacia auriculiformis, Cassia siamea, Casuarina equisetifolia, Eucalyptus hybrid* and *Gravelia pteridifloia* during the wet season than the dry season. Similarly, Oladoye *et al.* (2008) found higher decomposition rate during the wet season. Mugendi *et al.* (1999) reported the decay rates in *Calliandra calothyrsus* and *Leucaena leucocephala* as 0.12 and 0.23 respectively. Similarly, Jamaludheen and Kumar (1999) in his study also reported decay coefficient of 0.31 in the litter of *Ailanthus triphysa* and 0.17 in *Casuarina equisetifolia*. Shuhyb (2004) noted higher decay coefficients for the litter of *Acacia aulococarpa* and *Acacia mangium* kept in the open field. The k values recorded for *Acacia aulococarpa* in the open area and plantation, were 0.60 and 0.51 respectively. Similarly, the k values recorded for *Acacia mangium* in the open area and plantation were 0.59 and 0.51.

5.2 NUTRIENT RELEASE PATTERN

Litterfall is a fundamental process in nutrient cycling and it is the main means of transfer of organic matter and mineral elements from vegetation to the soil surface (Russel and Vitousek, 1997; Regina *et al.*, 1999). The analysis of litter quality and its rate of decomposition is highly important for the understanding of energy flow, primary productivity and nutrient cycling in forest ecosystems. Leaf biomass decomposition is the primary mechanism by which the organically bound nutrients are mineralized to soil for subsequent absorptions by plants. Tropical tree leaves are found to contain higher levels of nutrients and their incorporation into the soil enriches the soil nutrient pool. Chemical composition is an intrinsic property of the leaf litter which determines the rate of turnover of organically bound nutrients (Meentemeyer, 1978).

Different species exhibit different nutrient release pattern during the process of decomposition (Aponte *et al.*, 2012). Also, different nutrients in decomposing litter have different patterns of release over time and that nutrients

are retained with different strength in litter structures (Girisha *et al.*, 2003). A comprehensive knowledge of the organic matter decomposition and nutrient release patterns from leaf litter maximizes soil sustainability and crop productivity (Mugendi *et al.*, 1999). Planting tree species with high biomass production and which are rich in foliar and branch nutrient content can therefore play a major role in maintaining levels of soil organic matter in agroforestry systems (Cardelus, 2010).

5.2.1 Nitrogen

Wet season recorded higher initial nitrogen content than dry season. The values recorded in *Gmelina arborea* and *Mallotus philippensis* during wet season was 3.92 per cent and 3.12 per cent (Table 10a and 10b). Similarly, dry season recorded initial nitrogen content of 3.21 per cent and 2.89 per cent respectively (Table 8a and 8b). Oladoye *et al.* (2008) also recorded higher nitrogen content during the rainy season than the dry season.

The present study recorded initial nitrogen content of 3.92 per cent in *Gmelina arborea* and 3.12 per cent in *Mallotus philippensis* during wet season. Nitrogen concentration in the fresh leaf sample of *Gmelina arborea* and *Mallotus philippensis* was found to be much higher than that reported for the leaf samples of many other tropical tree species. The initial nitrogen content reported by Shailendra *et al.* (2013) in the leaf litter of *Terminalia arjuna, Terminalia bellerica, Tectona grandis* and *Cassia fistula* was 0.50 per cent, 0.23 per cent, 0.30 per cent and 0.24 per cent respectively.

A close observation of the data shows that nitrogen concentration of both the species in all the study situations increased during the initial two fortnights except for the leaf biomass of leaf biomass incorporated in the homegarden during the second season. The increase in N concentration in all species is a common observation in decomposing litter (Moro and Domingo, 2000; Huang *et al.*, 2007).

Such increase could be attributed to the addition of N from exogenous sources into microbial biomass (Sinsabauhg and Findlay, 1995). Also, the conversion of carbon into CO_2 due to faster oxidation and leaching of soluble carbon compounds and the subsequent weight loss resulted in increased N concentration (Cherr, 2006 and Afrira, 2013). The succeeding mass loss of N is biologically mediated by decomposer organisms (Panda, 2012). This increase in nitrogen content was followed by a gradual decline in nitrogen content in the leaf residues till the end of the study.

Early immobilization of N and subsequent decrease in concentration following mass loss has been found in other studies (Kim, 2007; Shailendra *et al.*, 2013). The lower nitrogen content of the leaf biomass of *Mallotus philippensis* during the initial phase of decomposition in the homegarden during the wet season could be attributed to the higher demand for nitrogen for the intense microbial activity. Moreover, the leaching of water soluble nitrogenous substances might have accounted for its decrease (Dutta and Agrawal, 2001).

A high degree of variation in nitrogen concentration was observed under both the study situations. Presence of various microbial types, their population and the prevailing soil conditions might have resulted in an apparent fluctuation in the concentration of nitrogen under various study situations. As decay advances, mineralization results in the decline of nitrogen content in residual litter and this accounted for its release (Kandpal and Negi, 2005).

Despite the variation in the nitrogen concentration, the absolute amount of nitrogen decreased gradually with the progress in decomposition in all the seasons and field conditions (Fig. 9 and 10). However, the absolute amount of nitrogen differed significantly in different seasons. Since the decay coefficient was different for different seasons, the corresponding absolute amount was also found to be different. Goya *et al.* (2008) observed an increase in nitrogen concentration, but decrease in absolute amount of nitrogen in leaf litters of casuarinas, acacia,

ailanthus and leucaena. It was also seen that homegarden retained more nitrogen content than open area, thus indicating the higher mineralization efficiency for the leaf biomass kept in open area than homegarden. Similar finding was also noted by Li-hua *et al.* (2014). Also, the nutrient release from litter was significantly slower in the canopy than on the forest floor, which was similar to the findings of Cardelus (2010).

5.2.2 Phosphorus

In the current study, the initial phosphorus content recorded in the leaf biomass of *Gmelina arborea* during the wet and the dry season was 0.18 per cent and 0.16 per cent respectively. Similarly, *Mallotus philippensis* during the wet and the dry season recorded initial phosphorus content of 0.14 per cent and 0.12 per cent respectively (Table 9a and 9b).

The initial phosphorus content recorded in the present study was much higher than that reported in *Leucaena leucocephala* and *Cassia siamea* (Jamma and Nair, 1996) and that in *Ficus benghalensis* (Dhanya *et al.,* 2013). The phosphorus content of the species studied was also higher than that observed in *Ailanthus triphysa* and *Leuceana leucocephala* (Jamaludheen and Kumar, 1999) and *Dipterocarpus tuberculatus* (Devi and Yadava, 2009).

Phosphorus content in the fresh leaf biomass of *Gmelina arborea* was higher than that of *Mallotus philippensis* under all the study situations. Also the leaf biomass collected during the wet season was richer in phosphorus content than dry season for both the tree species. Klinge and Rodrigues (1968) also recorded a high concentration of phosphorus content during the wet season. Similar results were also noticed by Tekalay and Malmer (2004) in the leaf biomass of *Albizia gummifera, Milletia ferruginea, Cordia Africana* and *Croton macrostachyus.*

In the case of *Gmelina arborea*, no specific trend in phosphorus content was observed in all the study situations (Table 9a). Phosphorus concentration in decomposing leaf biomass was irregular in both open canopy and closed canopy. Similar finding was also observed in *Jatropha curcas* leaves by Aburge *et al.* (2011).

During the wet season, in both the open area and homegarden, a general decline in phosphorus content was noted in the initial fortnights followed by a gradual increase. However, at the end of the study, the phosphorus content in the residues retrieved from both the locations was lower than those recorded from the initial sample. The general decline in phosphorus content during the initial fortnight might be due to the leaching associated with the rapid loss of phosphorus along with the decaying leaf biomass in the early rapid mass loss phase of decomposition. However, in the latter phase, increase in P content in the decomposing leaf biomass suggests an immobilization phase, i.e. better retention of P as compared to other leachable compounds. This clearly supports the immobile nature of phosphorus (Gladys *et al.*, 2002). The increase of P content observed in between also suggests that phosphorus is limiting for microbial growth and consequently is immobilized by microorganisms (Xu and Hirata, 2005). A Similar pattern was also recorded from litters of *Ailanthus triphysa* and *Swietenia macrophylla* (Isaac and Nair, 2006). Niranjana (2006) and Goya *et al.* (2008) also observed similar pattern.

During the dry season, the residues of *Gmelina arborea* showed an initial decline (leaching), followed by a phase of immobilization and a phase of release. However, at the end of the final fortnight, a slight increase in phosphorus content was also evident. This is in agreement with the observations made by Kaushal *et al.* (2006) on the nutrient dynamics of the decomposing leaf litter mineralization of *Populus deltoides*, where he observed a tri-phasic pattern of phosphorus, i.e. leaching, immobilization and release during the entire course of the investigation.

In the case of *Mallotus philippensis* during the wet season, in both open area and homegarden, the initial fortnight showed a general decline in phosphorus content (Table 9b). This might be because of the leaching of the phosphorus compounds due to rain. This was followed by a phase of accumulation or immobilization of phosphorus in the leaf matter, which was succeeded by a phase of release of phosphorus from the decaying leaf biomass (Gusewell and Gessner, 2009). Nutrient release from the decomposing litter followed either a tri-phasic pattern characterized by an initial accumulation, followed by a rapid release and a final slower release phase, or a biphasic pattern that is devoid of initial accumulation phase (Kaushal *et al.*, 2012)

During the dry season, in both the study situations, an initial slow reduction in phosphorus content was noted, followed by a phase of immobilization which was further followed by a phase of release in phosphorus content. The initial slow decline in phosphorus content might be due to the loss of phosphorus compounds along with the loss of leaf biomass. The increase of P content observed in between suggests that phosphorus is limiting for microbial growth and consequently is immobilized by microorganisms (Xu and Hirata, 2005). The final phase of release of phosphorus might be due to the onset of summer showers followed by south-west monsoon and the subsequent loss of phosphorus compounds. Vidyasagaran *et al.* (2002) also reported a fluctuating trend in phosphorus content in *Casuarina equisetifolia* in the shola forests of western ghats.

Despite the variation in the phosphorus concentration, the absolute amount of phosphorus decreased gradually with the progress in decomposition in all the seasons and field conditions (Fig. 11 and 12). However, the absolute amount of phosphorus differed significantly within different seasons. Similar finding was also noted in *Grewia optiva* and *Morus alba* (Kaushal *et al.*, 2012) and in *Ficus benghalensis* (Dhanya *et al.*, 2013). Hasanuzzaman and Hossain (2014) also observed an increase in phosphorus concentration, but decrease in absolute

amount of phosphorus. It was also seen that homegarden retained more phosphorus content than open area. Also, higher initial phosphorus content was observed in the fresh leaves of *Gmelina arborea* than *Mallotus philippensis.* With respect to season, the leaves of both the species collected during the wet season showed higher phosphorus content than those collected during the dry season.

In the current study, mineralization of phosphorus was faster in *Gmelina arborea* than *Mallotus philippensis*. The rate of mineralization of phosphorus in *Gmelina arborea* and *Mallotus philippensis* was much faster than that in *Acacia* spp. (Mehar, 2001) and *Ficus benghalensis* (Dhanya *et al.*, 2013).

5.2.3 Potassium

The initial potassium content recorded in the leaf biomass of *Gmelina arborea* during the wet and the dry season was 0.93 per cent and 0.88 per cent respectively. Similarly, *Mallotus philippensis* during the wet and the dry season recorded initial potassium content of 1.20 per cent and 0.98 per cent respectively (Table 10a and 10b).

Potassium content in the fresh leaf sample of *Gmelina arborea* (0.93 %) and *Mallotus philippensis* (1.20 %) during wet season was found to be much higher than that reported for the leaf samples of many other tropical tree species. Kunhamu (1994) reported initial potassium content of 0.90 per cent (*Macaranga peltata),* 0.80 per cent (*Terminalia paniculata*), 0.88 per cent (*Bridelia retusa*) and 0.44 per cent (*Pongamia pinnata*). The initial potassium content recorded in *Acacia mangium, A. aulacocarpa* and *A. crassicarpa* was 0.79 per cent, 0.74 per cent and 0.67 per cent respectively (Shuhyb, 2004). The observed value was also higher than the value reported by Kumar *et al.* (2012) in *Dipterocarpus tuberculatus* and *Dipterocarpus retusus*.

Among both the species studied, *Gmelina arborea* reported higher potassium content than *Mallotus philippensis* during both the seasons. With

respect to season, higher potassium content in the fresh leaves was observed during the wet season for both the species. Klinge and Rodrigues (1968) also recorded a high concentration of K in litter collected during the wet season. Javier and Enriquez (1996) also found higher potassium content in the leaf litter collected during the wet season. Potassium (K) release in both open area and closed canopy was fast.

In the case of *Gmelina arborea*, a drastic reduction in potassium content was observed in all the study situations at various sampling periods (Table 10a). Rapid mineralization of K is also evident from the study conducted in selected shola forests (Vidyasagaran *et al.*, 2002). A similar observation was also made by Jha (2010) in the litter of *Tectona grandis.* Similar finding was also observed in *Jatropha curcas* leaves by Aburge *et al.* (2011). Afrira (2013) also reported drastic loss of potassium in the litter decomposition of *Acacia mangium.*

During the wet season, in both the open area and homegarden, a general decline in potassium content was noted. Also, at the end of the study, the potassium content in the residues retrieved from both the locations was lower than those recorded from the initial sample. The general decline in potassium content during the initial fortnight might be due to leaching due to the rainfall and the rapid loss of potassium along with the decaying leaf biomass in the early rapid phase of decomposition. Potassium in plants occurs mainly in the soluble ionic form (Tukey, 1970). Potassium being a monovalent ion is weakly bound to adsorption sites, and is highly water soluble (Bocock, 1964 and Attiwill, 1968). Potassium can therefore be easily leached from litter and losses may be accelerated by high rainfall. The release pattern agrees with the review of potassium dynamics of decaying litter given by Turkey and Singh (1993). During the dry season, the residues of *Gmelina arborea* showed a gradual reduction in the potassium content (Fig. 13). This is in agreement with the observations made by Kaushal *et al.* (2006) on the nutrient dynamics of the decomposing leaf litter mineralization of *Populus deltoides*.

In the case of *Mallotus philippensis,* during the wet season, rapid decline in potassium content was observed in both open area and homegarden (Table 10b). This might be because of the leaching of the potassium compounds due to rain. During the dry season, in both the study situations, slow reduction in potassium content was noted, followed by a phase of immobilization which was further followed by a phase of release in potassium content. Kumar *et al.* (2008) also reported the same in the litter of *Acacia mangium.* Devi and Yadava (2009) also reported the similar trend during the litter decomposition of *Dipterocarpus tuberculatus.*

The absolute amount of potassium also followed a declining trend till the end of the study (Fig. 13 and 14). Nutrient dynamics of decomposing leaf litter showed nutrient contents of some elements in the residual litter to decline relative to the weight of the litter (Goya *et al.*, 2008). Heavy rainfall and associated microbial activity might have caused considerable leaching of potassium from litter bags. Similar finding was also reported by Barbhuiya *et al.* (2008) in species like *Duabanga sonneriatoides, Dysoxylum binectariferum* and *Taluma hodgsonii.*

Although the nutrient mineralization of both the species studied was faster, more rapid release of potassium was noted in *Gmelina arborea* than *Mallotus philippensis*. Also, when compared to the other trees, the mineralization was quite faster. The mineralization pattern observed in the present study was also faster than that recorded in *Bauhinia purpurea* (Jinsy, 2007). In addition to this, the rate of mineralization of potassium in *Gmelina arborea* and *Mallotus philippensis* was much faster than that reported by Florez *et al.* (2013) in *Azadirachta indica.* This indicates the potential of *Gmelina arborea* and *Mallotus philippensis* to be used as green manure.

5.2.4 Relative mineralization efficiency of nutrients

Relative mineralization efficiency of nitrogen, phosphorus and potassium varied with species, season and location (Table 16). The residues of *Gmelina arborea* retrieved from the open area during the wet season marked faster nutrient mineralization than those retrieved during the dry season.

In general, faster rate of mineralization was observed for potassium. Both *Gmelina arborea* and *Mallotus philippensis* exhibited faster mineralization of nitrogen. The observation of faster mineralization of nitrogen in the present study is in agreement with the reports made by Kaushal *et al.* (2006) in *Populus deltoides* and Kumar *et al.* (2012) in *Dipterocarpus tuberculatus* and *D. retusus*. The slow release of nitrogen as compared to potassium might be because of rapid immobilization of mineralized nitrogen (Recous *et al.*, 1996) or accumulation of mineral nitrogen in the form of immobile microbial mass (Kristensen *et al.*, 2000).

Zheng (2009) observed that potassium mineralized faster from the leaves followed by nitrogen and phosphorus. Hasanuzzaman and Hossain (2014) also observed the similar pattern in mineralization of *Azadirachta indica*, *Dalbergia sissoo* and *Melia azedarach*.

In both the species, under all the study situations, phosphorus showed lower rates of mineralization, which may perhaps be due to their lower mobility and structural complexity. In general, absolute mineralization of nitrogen and phosphorus was found to be faster for *Gmelina arborea* whereas that of potassium content was faster in *Mallotus philippensis*. Open area showed faster mineralization than homegarden. Similarly, wet season experienced faster mineralization of absolute nutrients than the dry season. This is in agreement with the observations made by Hegde (1995) and Oladoye *et al.* (2008).

5.3 SOIL NUTRIENT STATUS

5.3.1 Total carbon

The organic carbon content of the soil determines the mobilization of nitrogen and thereby influences its availability for the plant growth. The addition of leaf biomass enriches the organic matter content, which on decomposition accretes organic carbon portion of the soil. It is believed that the maximum mobilization and availability of nitrogen in the soil are governed by its organic carbon content (Panda *et al.*, 2010).

In the present study, soil showed an increasing carbon content of soil towards the end of the study with respect to both the species under all the study situations (Table 17a and 17b). The maximum amount of organic carbon was added to the soil by the leaf biomass of *Gmelina arborea*. With respect to seasons, wet season exhibited maximum organic carbon addition to soil. Similarly, open area showed faster addition of organic carbon content than the homegarden. The shade of tree canopies also has the effect of reducing soil temperatures and hence the rate of organic matter decomposition (Wang *et al.*, 2010). On the other hand, soil outside the influence of tree canopies is exposed to direct solar radiation that enhances soil organic matter decomposition on account of elevated soil temperatures. The increase in organic carbon content due to the addition of decomposing leaf biomass, is also reported by Pandey and Singh (2010). It is known that litter production and the rate of litter decomposition are the most important factors by which tree species regulate the size and distribution of soil C and N pools.

The amount of organic carbon added to the soil through the addition of the leaf biomass of *Gmelina arborea* and *Mallotus philippensis* was comparatively more than that added by the leaves of other trees like *Bauhinia purpurea*,

Peltophorum pterocarpum, Lagerstroemia speciosa and *Cassia fistula* (Jinsy, 2007).

5.3.2 Nitrogen

Contribution of trees through fallow, hedge row and shade to N economy of tropical systems has been well established (Giller, 2001; Nygren and Leblanc, 2009). In the present study, both the species followed an increasing trend in the addition of nitrogen content to soil (Table 18a and 18b). No significant difference in nitrogen content was observed. Also, no significant difference in nitrogen content of the soil was noted with respect to field condition; however wet season showed maximum addition of nitrogen into soil than the dry season. This might be due to the faster rate of decomposition and mineralization during the wet season (Ragu, 2000). The insistent demand of nitrogen by microbes to build their tissues could have immobilized this nutrient element (Florez *et al.*, 2013). This condition persists until the activities of the decomposers gradually decrease due to lack of easily oxidizable carbon. Also, it is reported that amount of inorganic nitrogen in the soil beneath the litter bag is unrelated to decomposition rate (Hunt *et al.*, 1988). This could be one of the probable reasons for increase in mineral nitrogen content in the latter part of the study.

The leaf biomass of *Gmelina arborea* resulted in more addition of nitrogen into the soil than *Mallotus philippensis.* The amount of total nitrogen added to the soil through the addition of the leaf litter *Duabanga sonneriatoides, Dysoxylum binectariferum,* and *Taluma hodgsonii* (Barbhuiya *et al.*, 2008).

5.3.3 C: N ratio

A close perusal of data also shows an increase in C: N ratio towards the end of the study period (Table 19a and 19b). A higher C: N ratio was noted in *Gmelina arborea.* High C: N ratio of 10 or above indicates that there is N mineralization occurring in the soil (Agbenin and Goladi, 1997). With respect to

season and field conditions, wet season and open area showed higher C: N ratio. A similar result was also obtained by Ron *et al.* (1998) in a study conducted in *Acacia nilotica* and *Prosopis cineraria.* in which acacia litter mineralized at a faster rate compared to *Prosopis cineraria* because of a higher C: N ratio. Nsabimana *et al.* (2008) found the C: N range under *Eucalyptus* spp. (C: N ratio of 15.17), which was higher than that of *Calliandra calothysus* (13.4), *Casualina equisetifolia* (13.1) and *Leucaena leucocephala* (12.2) and which enhanced the decomposition process.

5.3.4 Phosphorus

Gmelina arborea resulted in faster addition of phosphorus content into soil than *Mallotus philippensis*. For both the species, no significant difference was noted with respect to the phosphorus content in different fields. However, wet season recorded higher phosphorus content than dry season as the decomposition completed (Table 20a and 20b). The phosphorus content added to soil was found to increase during the entire course of the study. Thomas (1995) reported that the addition of green manures increased the availability of phosphorus even up to three times compared to control. Hegde (1995) also reported an increase in soil phosphorus content by the addition of *Acacia mangium* leaf litter. The organic acid synthesized during the process of decomposition could have been responsible for the increased availability of phosphorus (Ray and Ranabijoy, 2011).

The amount of phosphorus added to the soil through the addition of the leaf biomass of *Gmelina arborea* and *Mallotus philippensis* was comparatively more than that added by the leaves of other trees like *Bauhinia purpurea, Peltophorum pterocarpum, Gliricidia sepium, Lagerstroemia speciosa* and *Cassia fistula* (Jinsy, 2007).

5.3.5 Potassium

The leaf biomass of *Mallotus philippensis* showed faster addition of soil potassium than *Gmelina arborea*. For both the species, no significant difference was noted with respect to the phosphorus content in different fields, however, open area recorded higher potassium content than homegarden (Table 21a and 21b). The data furnished earlier reveals an increase in potassium content of the soil throughout the study. The rapid mass loss coupled with heavy leaching losses from the decomposing leaf biomass could be the possible reasons for increased availability of K (Sivakumar, 1992; Sarjubala and Yadava, 2007).

The amount of potassium added to the soil through the addition of the leaf biomass of *Gmelina arborea* and *Mallotus philippensis* was comparatively more than that added by the leaves of other commonly used green manure tree species like *Azadirachta indica* (Florez *et al.*, 2013), *Bauhinia purpurea*, *Gliricidia sepium*, *Cassia fistula* (Jinsy, 2007), *Duabanga sonneriatoides*, *Dysoxylum binectariferum*, and *Taluma hodgsonii* (Barbhuiya *et al.*, 2008).

In nutshell, the current study throws light to the prospects and potential scope of using the leaf biomass of *Gmelina arborea* and *Mallotus philippensis* as green manure on a scientific basis. Although *Gmelina arborea* proved to be better than *Mallotus philippensis* in the present study, the results observed for both the species studied showed faster decomposition rate, higher decay constant, higher nitrogen content, lower C: N ratio, lower lignin content, lower L: N ratio, faster mineralization of nutrients and net improvement of soil nutrient status than most of the other tropical tree species. Wet season and open area showed faster decomposition than dry season and homegarden.

Summary

6. SUMMARY

Incorporation of tree leaf biomass into the soil supply large quantities of organic matter through the process of decomposition. The decomposition of leaf biomass and the release of nutrients into the soil nutrient pool in various agroforestry systems have been well studied. This is one of the most probable reasons in maintaining the aggregate stability and inherent fertility of the forest soil. The rate of decomposition and nutrient release are strongly dependent on the substrate quality, field conditions and other prevailing environmental factors.

The present series of investigations were undertaken in the College of Forestry, Vellanikkara to find out the nutrient content and pattern of leaf biomass decomposition of *Gmelina arborea* and *Mallotus philippensis* under two different field conditions during the wet season and the dry season. The salient findings of the study are summarized hereunder.

1. The leaf biomass of *Gmelina arborea* decomposed faster than *Mallotus philippensis* under all the study situations. At the end of eleven fortnights, *Gmelina arborea* witnessed highest decomposition rate, retaining 1.06 per cent of leaf biomass, whereas *Mallotus philippensis* retained 5.29 per cent of the leaf biomass.

2. For both *Gmelina arborea* and *Mallotus philippensis*, the rate of leaf biomass decomposition was generally faster in the open area than the homegarden during both the wet season and the dry season. In case of *Gmelina arborea*, the time required for completion of decomposition in the open area was ten fortnights, whereas for homegarden it took eleven fortnights. Similarly, in case of *Mallotus philippensis*, although the time

required for decomposition in the open area and homegarden was sixteen fortnights, higher decomposition rate was noticed in open area.

3. Significant differences in the rate of decomposition were noticed with regards to the season of application. For both *Gmelina arborea* and *Mallotus philippensis*, the decomposition of leaf biomass was faster during the wet season, particularly during the initial months of decomposition than the dry season. With respect to *Gmelina arborea,* after eight fortnights of incorporation of leaf biomass into the soil, the amount of mass remaining in the litter bag during the wet season and dry season was found to be 1.85 per cent and 4.53 per cent respectively. On the other hand, by the end of the eleventh fortnight, the relative mass content of *Mallotus philippensis* observed from the litter bags collected from the wet season and dry season were 1.28 per cent and 9.31 per cent respectively.

4. A characteristic biphasic pattern of biomass decomposition was observed in all the study situations with a rapid initial phase for a period of four months followed by a slower latter phase. Nearly 90 per cent of the total leaf biomass kept for the study was decomposed in the initial rapid phase which lasted for four months and this rapid phase was followed by a slow phase.

5. Among *Gmelina arborea* and *Mallotus philippensis, Gmelina arborea* showed high initial nitrogen content and low C: N ratio which accelerated the rate of decomposition.

6. With respect to seasons, both *Gmelina arborea* and *Mallotus philippensis,* recorded higher nitrogen content and lower C: N ratio during the wet season and this consequently resulted in faster decomposition during the wet season than the dry season.

7. The lignin content of the leaf biomass influenced the rate of decomposition. The lower the lignin content and lignin: nitrogen ratio, faster the decomposition. *Gmelina arborea* registered lower lignin content and lignin: nitrogen ratio than *Mallotus philippensis* during both the seasons enabling faster decomposition of leaf biomass of the respective species.

8. The strong negative influence of lignin on the rate of decomposition was evident in all the study situations. With respect to season of collection, the low lignin: nitrogen ratio of the leaf biomass *Gmelina arborea* and *Mallotus philippensis* collected during the wet season favoured faster decay rate in the wet season than the dry season.

9. Generally, leaf biomass collected during the wet season registered more content of nutrients like N, P and K. With respect to species, leaf biomass of *Gmelina arborea* recorded higher nitrogen and phosphorus content, whereas higher potassium content was observed in the leaf biomass of *Mallotus philippensis.*

10. Mineralization of leaf biomass of *Gmelina arborea* kept for decomposition in two field conditions showed a declining trend. By the end of the eighth fortnight, the phosphorus content observed in open area and homegarden was 0.13 per cent and 0.12 per cent respectively. Similarly, leaf biomass of *Mallotus philippensis* also showed a declining trend in phosphorus content under both the locations studied.

11. The leaf biomass of *Gmelina arborea* kept for decomposition during the wet season and dry season showed a declining trend, however wet season, reportedly showed an increase in phosphorus content from the middle of the eighth fortnight. On the other hand, leaf biomass of *Mallotus philippensis* showed a fluctuating trend in phosphorus content during the wet and dry seasons.

12. The potassium content of the leaf biomass of both *Gmelina arborea* and *Mallotus philippensis* showed a drastic reduction in all the fortnights under all the study situations.

13. Despite the fluctuations in the nutrient concentration, the absolute amount of nutrients of both *Gmelina arborea* and *Mallotus philippensis* in both the field conditions and seasons gradually declined as the decomposition advanced.

14. The relative nutrient content of the leaf biomass of both *Gmelina arborea* and *Mallotus philippensis* showed fluctuations in values till the end of the study under all the study situations.

15. In general, for both *Gmelina arborea* and *Mallotus philippensis,* potassium mineralized faster in all the study situations. This was followed by nitrogen and phosphorus.

16. The addition of leaf biomass showed considerable improvement in soil carbon, nitrogen, phosphorus and potassium content under all the study situations.

17. The leaf biomass of *Gmelina arborea* added more carbon content into the soil than the leaf biomass of *Mallotus philippensis.*

18. No significant differences were observed among the species with regards to the addition of nitrogen into the soil.

19. Higher phosphorus content was added into the soil by the decomposing leaf biomass of *Gmelina arborea.*

20. *Gmelina arborea* improved the potassium content of the soil in a larger quantity than *Mallotus philippensis.*

21. Higher soil C: N ratio was observed in the soil sample collected beneath the litter bags of *Gmelina arborea* thus showing an important role in accelerating the leaf biomass decomposition.

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Appendices

Appendix I. Statistical models used to represent the absolute content of nutrients

Sl. No.	Equation	Explanation
1	Y= A + B*X	Linear model
2	Y = B*X	Line through origin
3	Y = A*X^B	Power function
4	Y = A*B^X	Modified power function
5	Y = B^(1/X)	Root function
6	Y = A*X^(B*X)	Geometric function
7	Y = A*X^(B*X)	Modified geometric function
8	Y = A*e^(B*X)	Exponential model
9	Y = A*e^(B/X)	Modified exponential model
10	Y = A+B*ln(X)	Logarithmic model
11	Y = A*B^X*X^C	Hoerl function
12	Y = A*B^(1/X)*X^C	Modified hoerl function
13	Y = A*e^((X-B)/2)	Normal function
14	Y = A*e^((ln(X) - B)^2/C)	Log normal function

Appendix II. Mathematical relationship between time elapsed and absolute nutrient content of the residual mass of various species under different study situations

Species	Study situation	Nutrient	Equation	Coeff. Of A	Coeff. Of B	Coeff. Of C	R^2
1	2	3	4	5	6	7	8
Gmelina arborea	Open area wet season	N	Y = A*B^(1/X)*X^C	15149.345	0.004	-4.309	0.997
			Y = A*B^X*X^C	273.823	0.264	1.430	0.994
			Y = A*X^(B*X)	74.328	-0.326	0.000	0.987
		P	Y = A*e^(B*X)	114.824	-0.587	0.000	0.994
			Y = A*B^X*X^C	122.586	0.518	0.137	0.994
			Y = A*B^(1/X)*X^C	114.824	0.555	0.000	0.994
		K	Y = A*B^(1/X)*X^C	28669.01	0.001	-5.77	0.989
			Y = A*B^X*X^C	234.658	0.136	1.99	0.987
			Y = A*X^(B*X)	32.37	-0.490	0.000	0.984

Contd.

1	2	3	4	5	6	7	8
Gmelina arborea	Homegarden wet season	N	Y = A*B^(1/X)*X^C	4471.980	0.016	-3.35	0.995
			Y = A*B^X*X^C	179.856	0.420	0.781	0.992
			Y = A*X^(B*X)	76.50	-0.260	0.000	0.990
		P	Y = A*B^X*X^C	138.046	0.510	0.41	0.993
			Y = A*X^(B*X)	70.08	-0.250	0.000	0.992
			Y = A*B^(1/X)*X^C	1724.82	0.040	-2.809	0.989
		K	Y = A*B^(1/X)*X^C	2684.060	0.014	-3.760	0.993
			Y = A*B^X*X^C	106.330	0.722	0.000	0.992
			Y = A*X^(B*X)	38.716	-0.368	0.000	0.991
Gmelina arborea	Open area dry season	N	Y = A*B^X*X^C	154.510	0.546	0.404	0.996
			Y = A*X^(B*X)	83.73	-0.22	0.000	0.994
			Y = A*B^(1/X)*X^C	2122.04	0.039	-2.72	0.990
		P	Y = A*B^(1/X)*X^C	2549.73	0.028	-2.93	0.990
			Y = A*B^X*X^C	146.98	0.498	0.55	0.983
			Y = A*X^(B*X)	73.420	-0.23	0.000	0.980
		K	Y = A*B^X*X^C	98.850	0.668	0.110	0.990
			Y = A*e^(B*X)	108.05	-0.452	0.000	0.989
			Y = A*B^(X)	103.05	0.636	0.000	0.989

Contd.

1	2	3	4	5	6	7	8
Gmelina arborea	Homegarden dry season	N	Y = A*B^X*X^C	142.15	0.618	0.116	0.995
			Y = A*e^(B*X)	136.42	-0.429	0.000	0.995
			Y = A*B^(X)	136.42	0.650	0.000	0.989
		P	Y = A*B^X*X^C	126.92	0.670	-0.203	0.995
			Y = A*e^(B*X)	137.71	-0.483	0.000	0.994
			Y = A*B^(X)	137.72	0.610	0.000	0.994
		K	Y = A*B^X*X^C	102.49	0.680	-0.162	0.991
			Y = A*e^(B*X)	108.77	-0.450	0.000	0.990
			Y = A*B^(X)	108.77	0.630	0.000	0.990
Mallotus phillipensis	Open area wet season	N	Y = A*B^X*X^C	143.57	0.514	0.563	0.992
			Y = A*B^(1/X)*X^C	2668.96	0.027	-2.89	0.992
			Y = A*X^(B*X)	74.28	1.130	0.000	0.991
		P	Y = A*B^X*X^C	130.13	0.495	0.795	0.978
			Y = A*B^(1/X)*X^C	3082.12	0.020	-2.909	0.976
			Y = A*X^(B*X)	67.104	-0.185	0.000	0.973
		K	Y = A*B^(1/X)*X^C	56277.4000	0001	-5.37	0.992
			Y = A*B^X*X^C	408.725	0.147	2.314	0.991
			Y = A*X^(B*X)	62.77	-0.363	0.000	0.976

Contd.

1	2	3	4	5	6	7	8
Mallotus phillipensis	Homegardenwet season	N	Y = A*B^X*X^C	118.510	0.625	0.231	0.995
			Y = A*e^(B*X)	110.220	-0.373	0.000	0.992
			Y = A*B^(X)	110.229	0.680	0.000	0.992
		P	Y = A*B^X*X^C	125.38	0.664	0.116	0.972
			Y = A*e^(B*X)	121.20	-0.36	0.000	0.971
			Y = A*B^(X)	121.20	0.696	0.000	0.971
		K	Y = A*B^X*X^C	143.73	0.472	0.713	0.986
			Y = A*X^(B*X)	69.197	-0.220	0.000	0.979
			Y = A*B^(1/X)*X^C	3170.030	0.020	-3.060	0.976
Mallotus phillipensis	Open area dry season	N	Y = A*B^X*X^C	115.300	0.739	0.109	0.994
			Y = A*e^(B*X)	113.520	-0.260	0.000	0.993
			Y = A*X^(B*X)	113.527	0.766	0.000	0.993
		P	Y = A*B^X*X^C	102.007	0.805	-0.160	0.965
			Y = A*e^(B*X)	104.488	-0.270	0.000	0.962
			Y = A*X^(B*X)	104.480	0.762	0.000	0.962
		K	Y = A*B^(1/X)*X^C	3121.240	0.023	-2.81	0.986
			Y = A*B^X*X^C	145.212	0.502	0.788	0.984
			Y = A*X^(B*X)	76.05	-0.179	0.000	0.978

Contd.

1	2	3	4	5	6	7	8
Mallotus phillipensis	Homegarden dry season	N	Y = A*B^X*X^C	227.070	0.698	0.700	0.995
			Y = A*X^(B*X)	80.910	-0.120	0.000	0.992
			Y = A*e^(B*X)	112.04	-0.266	0.000	0.988
		P	Y = A*B^X*X^C	91.470	0.838	-0.296	0.956
			Y = A*B^(1/X)*X^C	328.240	0.231	-1.511	0.954
			Y = A*e^(B*X)	95.926	-0.276	0.000	0.947
		K	Y = A*X^(B*X)	65.229	-0.129	0.000	0.990
			Y = A*B^X*X^C	98.180	0.654	0.402	0.988
			Y = A*e^(B*X)	91.328	-0.282	0.000	0.974

FOLIAR NUTRIENT CONTENT AND DECOMPOSITION OF GREEN MANURE SPECIES VIZ. *Gmelina arborea* Roxb. AND *Mallotus philippensis* (Lam.) Muell. Arg.

By

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ABSTRACT

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8. ABSTRACT

A detailed work was undertaken in the College of Forestry, Kerala Agricultural University, Vellanikkara, Thrissur, Kerala during 2011 - 2014 to study the foliar nutrient content and the decomposition rate of the leaf biomass of two green manure tree species, i.e. *Gmelina arborea* and *Mallotus philippensis,* as affected by seasons and field conditions. The experiment was conducted in an open and homegarden during the wet season and the dry season.

The rate of decomposition was generally faster for both the species studied under all the study situations. However, *Gmelina arborea* showed faster rates of leaf biomass decomposition than *Mallotus philippensis.* With respect to seasons, wet season reported faster decomposition for both the tree species. Although no significant influence of field conditions on the decomposition rate was observed, open area registered faster decomposition than homegarden. Decay coefficient recorded was maximum for *Gmelina arborea.* Generally, both the species under all the conditions followed a biphasic pattern of biomass decomposition. The initial nitrogen content, C: N ratio, lignin content and lignin: nitrogen ratio of the leaf biomass influenced the decomposition rate. The decomposition rate was also found to be a function of soil moisture content and soil temperature.

Leaf biomass of *Gmelina arborea* showed rapid release of nutrients than *Mallotus philippensis.* Among the nutrients, potassium registered faster mineralization followed by nitrogen for both the species under all the study situations. The lowest mineralization tendency was seen for phosphorus in both the species under all the conditions. Also, significant improvement in the soil nutrient status of the soil was observed by the incorporation of leaf biomass of *Gmelina arborea* and *Mallotus philippensis* into the soil. However, no significant differences were observed with regards to the species on increasing the soil carbon and nitrogen content. The leaf biomass of *Gmelina arborea* showed maximum improvement of soil phosphorus content and exchangeable potassium.