ORGANIC RECYCLING THROUGH COCOA LITTER

BY

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THESIS

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DEPARTMENT OF AGRONOMY
COLLEGE OF HORTICULTURE
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DECLARATION

I hereby declare that this thesis entitled **"Organic recycling through cocoa litter"** is a bonafide record of research work done by me during the course of research and that this thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title of any other University or Society.

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N.V. SREEKALA

Dedicated to
my parents

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Introduction

INTRODUCTION

Cocoa (*Theobroma cacao* L.) is a major agricultural commodity which is mainly produced by the developing countries in the tropics. It is believed to have originated in the upper Amazon region of Latin America. Commercial cultivation of cocoa in India was started in the early 1960's, but area expansion gained momentum only from 1970. In India it is grown in an area of 15,287 ha. with a production of 8,329 tonnes (Rethinam, 1995). Kerala stands first in area and production followed by Karnataka and Tamil Nadu.

In Kerala cocoa is mainly grown in homesteads and also as a component crop in coconut and arecanut gardens. Such two tier cropping of perennials and heavy foliage of cocoa creates an ecosystem similar to forest where the leaf litter acts as a store house of nutrients.

In properly designed agro-ecosystem, the loss of organic matter through one component crop is compensated by a gain through the other. The addition of nutrients through the process of litter fall and subsequent decomposition is an important factor to be considered in the nutrient budgeting of crops. Cocoa has dense foliage and considerable litter fall throughout the year. The organic matter enrichment and subsequent nutrient availability in cocoa fields assume great importance while considering the fact that only small quantities of nutrients are removed through harvested pods.

In this context a study was undertaken at the College of Horticulture, Vellanikkara, with the following objectives:

1. To estimate the time required for natural senescence of cocoa leaves
2. To estimate the quantity of litter produced in a cocoa plantation in an year
3. To estimate the quantity of nutrients returned through cocoa litter and
4. To estimate the rate of decomposition of cocoa litter

Review of Literature

REVIEW OF LITERATURE

Litter decomposition plays an important role in maintaining soil nutrient and organic matter content in plantation crops. Several researches have indicated that there is substantial recycling of nutrients in cocoa fields through leaf fall. Considering the fact that only small quantities of nutrients are removed through harvested pods of the crop, litter fall in cocoa fields assumes greater importance. The rate at which crop residues decay in soil also influences the nutrients returned to the soil during a particular season. Studies on litter fall and dynamics of decomposition in cocoa plantations as well as in similar agro ecosystems are reviewed.

2.1 Leaf senescence

The periodic defoliation of perennial plants is a complex phenomenon involving the development of features bringing about the separation of the leaf from the stem, without injury to the newly exposed surface from desiccation and invasion by microorganisms (Esau, 1965). The cause of leaf senescence is thought to be mobilisation and redistribution of mineral and organic nutrients to more competitive sinks such as young leaves, fruits etc. (Gardner *et al.*, 1985).

According to Fahn (1990), leaves of gymnosperms and woody dicotyledons are usually shed as a result of changes that take place in the tissues of the leaf base prior to leaf fall.

2.1.1 Leaf senescence in cocoa

In cocoa, flushing and leaf fall are closely related phenomena. Intensive leaf fall invariably occurs simultaneously with, or just before or after an intensive flush or shoot growth.

Alvim *et al.* (1969) proposed two hypothesis to explain the correlation between leaf fall and leaf flushing in cocoa (a) the concentration of an inhibitor responsible for bud dormancy and originating in the leaf is reduced as a consequence of leaf abscission, thus triggering bud expansion, (b) flushing imposes a strain for nutrients and/or hormones, which accelerates senescence and abscission of old leaves.

According to Boyer (1974), in cocoa, maximum leaf fall as a rule took place soon after the intensive flushing during September-October. However Varghese *et al.* (1978) reported that under Kasaragod conditions the main flushes in cocoa occurred in April-May and August-September and maximum leaf fall was observed during April-May, synchronizing with the intense flushing time.

Alvim (1977) has pointed out that severe defoliation occurred in cocoa seedlings kept in an open area, during the first two months, presumably due to absence of overhead shade.

2.1.2 Period for natural senescence of cocoa leaves

A longer life span for the leaves in a cocoa plantation which was frequently watered was observed by sale (1970) when compared to drought affected ones.

Vasudeva (1967) reported that the life span of coffee leaves ranged from a few months to more than a year under field conditions. In a subsequent study Vasudeva and Gopal (1975) reported that life span of coffee leaves ranged from 40 to 510 days. Maximum defoliation occurred between 3 to 9 months after the leaves were formed on the plant.

2.2 Litter fall

Intensive studies on litter production in several agro and forest ecosystem had been carried out in many parts of the world (Bray and Gorham, 1964; Hopkins, 1966; Ewel, 1976; Cooper, 1982; Prasad and Mishra, 1985; Eklahya and Ambasht, 1987; Sharma and Pande, 1989).

George (1982) emphasized the quantitative aspects of litter production as most important due to its role in both energy and nutrient transfer in forest ecosystems. Soil productivity of an ecosystem is partially maintained by transfer of energy and matter through litter fall. The litter on the soil surface acted as an input-output system of nutrients (Das and Ramakrishnan, 1985).

2.2.1 Quantity of litter fall

Litter fall in forest ecosystem and cocoa plantation was comparable. However it varied with certain trees in similar environment. Litter fall in shaded and open cocoa monoculture was also different. Litter fall and hence the quantity of leaf residue was found to be more in warm tropical regions with declining trend towards warm temperate and cool temperate regions (Bray and Gorham, 1964).

In one of the preliminary works on litter fall in cocoa ecosystem, Boyer (1973) reported litter fall of 8.5 t ha^{-1} yr^{-1} for a moderately shaded cocoa plantation in Cameroon. Aranguren *et al.* (1982a) observed an annual litter fall of 20.8 t ha^{-1} in a shaded cocoa plantation, of which 50% was identified as shade tree leaves.

Santana and Cabala (1983) reported about 8.0 t ha^{-1} of litter fall annually in a cocoa plantation. According to Ling (1986), a cocoa plantation on an average was found to produce 4.5 to 6.5 tonnes of dry litter per hectare per year. Santana *et al.* (1987) observed more litter fall in open fields of cocoa monoculture than cocoa fields where shade trees were present.

Beer (1988) observed that the shade trees in cocoa ecosystem contributed 5 to 10 t of organic material per hectare per year. Beer *et al.* (1990) reported that the litter fall of cocoa alone, shaded with *Cordia alliodora* amounted to 4.4 t ha^{-1} yr^{-1} whereas that for cocoa shaded with *Erythrina poeppigiana* it was 3.93 t ha^{-1} yr^{-1}.

Venkataramanan *et al.* (1983) monitored the extent of litter fall in *Eucalyptus globulus* (blue gum) and *Acacia mearnsii* (black wattle) plantations in Nilgiris. For blue gum the annual amount of dry weight of litter was 1.94 t ha^{-1} and for black wattle it was 0.96 t ha^{-1}. Litter production investigation in tropical moist deciduous forests revealed that the annual litter fall ranged from 12.18 to 14.43 t ha^{-1} (Kumar and Deepu, 1992).

Singh *et al.* (1993) reported the annual leaf litter production for sal, teak, eucalyptus and poplar as 6.86, 7.70, 6.51 and 5.29 t ha^{-1}, respectively, on oven dry basis.

2.2.2 Factors affecting litter fall

Litter fall is related to many biologically important factors. According to Jensen (1974), species composition, stand density, age of trees, climate, soil fertility status etc are some of the factors which are capable of bringing in variation in litter fall.

Zavitkovski and Newton (1971) suggested that the amount of litter fall increased with increasing age until the canopy becomes closed and then the litter fall remained constant over a long period of time.

Egunjobi (1974) found that in a monoculture of teak (*Tectona grandis*) a considerable amount of annual litter fell between December and March. Devineau (1976) reported that heavy drying of soil initiated early leaf fall and maximum litter fall occurred during summer season. In a shaded cocoa plantain, Aranguren *et al.* (1982) observed the maximum litter fall in March. Many scientists have reported that maximum litter fall in tree species occurred during winter starting from October and extended up to February (Rajvanshi and Gupta, 1985; Gill *et al.*, 1987; Sharma *et al.*, 1988; Sugur, 1989). Studies on leaf shedding behaviour in the tree species *Populus deltoides* have revealed that 90 per cent of leaves were shed from October to December (Pokhriyal *et al.*, 1989; Singh *et al.*, 1993).

In general tree density decisively affected the litter production (Prasad and Mishra, 1985; Palmer, 1988; Sharma and Pande, 1989). According to Reiner and Lang (1987) climate, including effects of altitude and exposure seemed to be the most important factor determining the annual litter production.

2.3 Nutrient contribution through litter fall

The nutrient content of foliage of different tree species has been reported by many workers (Puri and Gupta, 1954; Singh, 1984; Lalman and Mishra, 1985; Pande and Sharma, 1993; Montagnini and Sancho, 1994). Mason and Whitefield (1960) reported that changes in the nutrient concentration of leaves might be a function of nutrient transfer from older parts of the plant to the actively growing regions. The concentration of nitrogen, phosphorus, potassium and certain other nutrients was found to decrease during or just prior to senescence, these elements being translocated away from the dying leaf (Onland, 1963; Small, 1972).

According to Waughman and Bellamy (1981) movement of cations into dying leaves would facilitate their removal during leaf abscission. Removal of nutrients in the extracted biomass and return of nutrients in the form of litter fall, addition of post harvest debris and root decay have significant impact on forest soil (Perala and Alaban, 1982). Beer (1988) suggested that litter fall had potential importance for the cycling of N, P, K, Ca and Mg in cocoa and coffee plantations since the litter inputs frequently exceeded nutrient inputs from inorganic fertilizers.

It had been reported that a harvest of 1000 kg of dry cocoa beans removed 38.3, 5.7 and 76.9 kilograms of N, P and K respectively (Omotoso, 1975). Young (1989) reported that the annual nutrient contribution by the litter from coffee/cocoa and the shade trees combined was in the range of 150 to 300 kg N, 10 to 20 kg P, 75 to 150 kg K and 100 to 300 kg Ca per hectare.

2.3.1 Nitrogen

Eernstman (1968) reported that about 50 kg N was returned to the soil every year through leaf fall of cocoa under double hedge system of mixed cropping. According to Boyer (1973) the litter fall from a cocoa ecosystem accounted for a nitrogen flux of 50 kg ha^{-1} yr^{-1}. Aranguren *et al.* (1982b) reported that the highest N concentration in cocoa leaf litter occurred in August (1.58 per cent) and the lowest in the month of February (0.94 per cent). The litter from the cocoa and shade trees combined was found to return 320 kg N ha^{-1} yr^{-1}.

The concentration of nitrogen in coffee litter was also recorded by Aranguren *et al.* (1982a). It varied from 1.97 per cent in April to 0.42 per cent in October. The coffee litter was found to return 27.9 and the shade tree litter 78.5 kg N ha^{-1} yr^{-1}.

Santana and Cabala (1982) reported a nitrogen concentration of 0.91 per cent for cocoa leaf litter and 1.85 per cent for shade tree leaf litter. Santana and Cabala (1983) observed that the annual litter fall in a cocoa agro-system was equivalent to 140 kg N ha^{-1} representing 6 to 8 times the N content in 1000 kg of dry cocoa beans.

According to Ling (1986) cocoa litter fall was estimated to return about 75 to 94 kg N ha^{-1} yr^{-1}. Opakunle (1989) observed that a total of 175.6 kg N ha^{-1} was returned to the soil annually through litter fall in a cocoa agrosystem. According to Fassbender *et al.* (1991), natural litter fall in a cocoa plantation shaded with *Cordia alliodora* returned 129 kg N per hectare per year.

Sivanadyan *et al.* (1995) reported that rubber leaf litter returned 60 kg N per hectare annually to the soil.

2.3.2 Phosphorus

Eernstman (1968) observed that, under double hedge system of mixed cropping of cocoa, the leaf fall returned 11 kg phosphorus per hectare annually to the soil.

In a study on nutrient transport in cocoa, Wessel (1970) observed that phosphorus is mobilised from older cocoa leaves to developing adjacent leaves. In general, the concentration of phosphorus in the litter was found to be lower than nitrogen, potassium, calcium and magnesium (Pande and Sharma, 1983; Osman *et al.*, 1992).

Ling (1986) and Opakunle (1989) reported that in an year cocoa litter fall returned 4 to 5 kg and 7.7 kg of phosphorus per hectare, respectively, to the soil.

The annual litter fall in a mature rubber plantation was found to contribute 3.2 to 7.2 kg phosphorus per hectare to the soil. The litter of leguminous cover crops in a rubber plantation was found to return 11 kg phosphorus per hectare annually to the soil (Sivanadyan *et al.*, 1995).

2.3.3 Potassium

Eernstman (1968) observed that about 35 kg of potassium was returned to the soil annually through leaf fall of cocoa under double hedge system of mixed cropping. An annual addition of 98 kg ha^{-1} of potassium through natural litter fall in cocoa was reported by Opakunle (1989).

Ling (1986) reported that 84 to 100 kg of potassium was given back through cocoa litter fall per hectare in an year. Fassbender *et al.* (1991) observed that a 10 year old cocoa plantation shaded with

Cordia alliodora returned 37.7 kg ha^{-1} yr^{-1} of potassium through natural leaf fall.

Rubber leaf litter contributed 10 kg ha^{-1} annually towards the ecosystem nutrient bank for potassium (Sivanadyan *et al.*, 1995).

2.3.4 Calcium

The concentration of calcium in the senile leaves was reported to be higher than in the live leaves (Onland, 1963; Small, 1972; Waughman and Bellamy, 1981). Wessel (1970) studied the intake and export of cations in cocoa leaves and found that export of leaf potassium increased the intake of calcium by approximately 72 per cent. Gosz *et al.* (1973), reported that calcium being the structural element had no possibility of back translocation.

According to Ling (1986), cocoa litter fall was estimated to return 58 to 75 kg calcium per hectare per year to the soil. Santana *et al.* (1987) found that the concentration of calcium was higher in the litter of cocoa than in the shade trees. Opakunle (1989) reported that the quantity of calcium added annually through litter fall in a cocoa plantation was 179.5 kg ha^{-1} and was the highest among all other nutrients.

The concentration of calcium in teak litter was reported to be varying from 1.4 to 1.6 per cent and it was found to return 115 kg calcium ha^{-1} yr^{-1}, to the soil (Singh *et al.*, 1993).

2.3.5 Magnesium

Wessel (1970) reported that in cocoa, magnesium content of the third flush leaves increased with time. Within one month the magnesium concentration of the leaves was changed from 0.43 to 0.61 per cent.

Ling (1986) found that 28 to 34 kg Mg was returned to the soil per hectare annually through cocoa litter fall. Raizada and Srivastava (1986) observed that leaf litter concentration of magnesium was positively correlated with the magnitude of leaf fall. Magnesium was showing very less mobility suggesting very less translocation into the tissues prior to leaf fall. Opakunle (1989) reported an addition of 48.2 kg Mg per hectare annually to the soil through litter fall in cocoa agro-system.

Singh *et al.* (1992) studied the nutrient release in sal, eucalyptus and poplar plantations. The highest quantity of magnesium was returned by eucalyptus, which added 20.5 kg Mg ha^{-1} yr^{-1}. According to Sivanadyan *et al.* (1995), the annual litter fall from a hectare of mature rubber plantation was found to return 9 to 18 kg magnesium to the soil.

2.4 Litter decomposition

Aber and Melillo (1980) opined that the litter in the forest floor acted as an input-output system for nutrients. Litter decomposition is the primary mechanism by which organic matter and nutrients are returned to the soil for reabsorption by plants.

The kinetics of biomass decomposition followed a biphasic process. This involved a period of rapid catabolic stage followed by a period of slow Co_2 evolution (Berg and Staaf, 1981; Singh *et al.*, 1993). During the latter period more biodegradable resistant compounds were found to be metabolized (Brady, 1984). The tropical broad leaved trees are reported to retain a considerable portion of the nutrient capital incorporated in the leaf biomass (Vogt *et al.*, 1986). Litter dynamics studies were reported to be very important in the nutrition budgeting of tropical ecosystems where vegetation depended on the recycling of nutrients in the leaf detritus (Prichett and Fisher, 1987).

2.4.1 Factors affecting litter decomposition and its effect on soil properties

Daubenmire and Prusso (1963) reported that the rate of decay of plant litter is governed by three factors; the physio-chemical properties of the substrate, the environment under which decomposition takes place and the species active under the particular substratal and environmental conditions. Most of the energy fixed autotrophically of the ecosystem found its way in the form of dead organic matter releasing different nutrients back to the soil by the action of biological and physical agencies (Swift *et al.*, 1979).

2.4.1.1 Physical factors

Many scientists have reported moisture and temperature to be the most important abiotic factors governing the rate of biomass decomposition (Jenney *et al.*, 1949; Olson, 1963; Madge, 1965; Moore, 1986).

Hutson and Veitch (1985) found that weight loss of litter was correlated with intensity and distribution of rainfall. Sankaran *et al.* (1993) reported that the decomposition of *Acacia* leaf litter was maximum in September to November during north-east monsoon period in Kerala, India.

A high rate of litter decomposition during rainy season in tropical condition has been observed by many workers (Gupta and Singh, 1988; Singh *et al.*, 1980; Luizao and Schubart, 1987; Sankaran, 1993).

Hoyle (1973) reported that organic matter reduced bulk density of soil, increased the water holding capacity and served as a reserve store of plant nutrients. According to Alexander (1977), marked influence of temperature on biomass decomposition was primarily due to its effect on microbial populations.

A lower range of soil temperature fluctuation due to the mulch provided by the periodic shedding of leaves was reported by Varghese *et al.* (1978). According to Mathur *et al.* (1982), due to low bulk density of soil under forest cover, it has enormous infiltration capacity and excellent percolating rates as well as nutrient concentration in soil.

2.4.1.2 Chemical factors

Several authors have reported that biochemical quality of litter exerted a marked influence on the decay rate (Singh and Gupta, 1977; Melillo *et al.*, 1982; Harmon *et al.*, 1990).

The high rate of litter decomposition was attributed to the higher leaf litter nitrogen content (Cisternas and Yates, 1982; Taylor *et al.*, 1989). Rates of litter decomposition in N fertilized plots had been reported to be similar (Will *et al.*, 1984; Theodore and Bowen, 1990) or slower (Titus and Malcom, 1987; Nohrstedt *et al.*, 1989) or faster (Hunt *et al.*, 1988; Prescott *et al.*, 1992) than no N fertilized plots.

Kumar and Deepu (1992) reported that off the structural chemistry attributes nitrogen content of the detritus appeared to be a better predictor of decay rate constant.

Dalton *et al.* (1952), pointed out that organic matter derived from decomposition of plant debris was effective in increasing the availability of soil phosphates. Birch (1961) opined that during plant decomposition microbial organic phosphorus was rapidly formed from plant inorganic phosphorus. Subsequently with young plant material much of the organic phosphorus was dephosphorylated and recovered as inorganic phosphorus.

Nelliat *et al.* (1979) reported that in a coconut-cocoa mixed cropping system, there was an improvement in soil fertility attributed to the addition of organic matter by the periodic shedding of cocoa leaves and the consequent intense microbial activity in the rhizosphere region of the crop mix.

Young (1989) has stated that trees would affect the soil chemical condition through addition of bases in tree litter. Soil humus also exerted a buffering action against humidity. Prasad *et al.* (1991) reported that incubation of tree leaves increased the available P, K and exchangeable Ca and Na significantly.

2.4.1.3 Biological factors

The action of soil fauna might have a significant influence on the decomposition of litter entering in to the soil ecosystem. Bocock (1964) found that litter decomposition by earth worms and millipedes was more rapid during the initial few months of decomposition. Seastedt and Crossley (1983) reported that the soil fauna was not only stimulating the litter decomposition rate but their activity also resulted in the increased nutrient concentration of the decomposing litter.

Tate (1987) pointed out that the action of soil fauna might be the physical mixing and disintegration of organic matter, inoculation of the plant litter with decomposer populations or adjustment of soil physical properties to levels more conducive for organic matter decomposition.

Rangaswamy and Bagyaraj (1993) had suggested that animal groups such as earthworms, insects and snails brought about mechanical reduction by biting and eating the organic matter and thus pulverized the material. In the early stages of decomposition heterotrophic bacteria were found to be highly active. Later, the other bacteria, actionomycetes and fungi which were capable of attacking intermediate products became active and they utilised CO_2 to synthesize various carbon compounds. Sankaran (1993) reported that the main decomposers in the litter of teak, albizia and eucalyptus were belonging to the group of fungi, bacteria and actinomycetes.

According to Lohins (1926), consequent upon the decomposition of any organic matter added to soil, the native soil organic matter also began to decompose and in this process more quantities of nutrients were liberated for use by the plant, through "priming action".

2.4.2 Rate of litter decomposition

Leaf biomass decomposition rates have been well studied and determined for a wide variety of species, through out the world.

In tropical forests the decomposition rates were reported to be higher ranging from K values of 0.45 to 1.50 per day (Olson, 1963). Hopkins (1966) compared the rates of leaf decomposition under varying environmental conditions. The litter was decomposed completely within 1.6 years in subtropical forests (Jenney *et al.*, 1949) while it took only 0.1 to 0.6 years in moist semideciduous and moist evergreen forests in tropical environment, and more or less one year in temperate deciduous forests (Ovington, 1962). Singh (1969) reported that generally 3 to 5 months were required for almost complete decomposition of leaf litter of some important tree species in tropical deciduous forests.

Aranguren *et al.* (1982b) in a study on decomposition of cocoa litter found that nearly 95 per cent of the litter was decomposed within the first four months in a shaded cocoa plantation. Santana and Cabala (1983) reported that 50 per cent of fallen cocoa residue decomposed within 6 to 9 months. According to Ling (1986) the rate of decomposition of cocoa litter was rapid, 75 per cent loss in dry weight occurred within 12 months.

In a study conducted to assess the leaf litter decay rates of six tree species, Kumar and Deepu (1992) reported that the mass remaining in the litter bags which was considered as a measure for judging the rate of decomposition, was decreased linearly with time for all the species. The rate of decomposition of different species of plants was found to show significant variation (Sankaran, 1993; Kunhamu, 1994; Mwiinga *et al.*, 1994).

Kunhamu *et al.* (1994) reported that 90 per cent of the litter of *Acacia auriculiformis* disappeared within six months and the residual mass was remaining up to 16 months.

Material and Methods

MATERIALS AND METHODS

An experiment was conducted at the College of Horticulture, Vellanikkara to study the organic recycling through litter fall in a cocoa plantation for one year from July, 1995. The details of materials and methods used are presented.

3.1 Details of field experiments

3.1.1 Site, climate and soil

The experiment was conducted at cocoa plantations of Cadbury - KAU Co-operative Cocoa Research Project (CCRP), Vellanikkara, Thrissur. The site was located at 10° 31' N latitude and 76° 3' E longitude. The experimental field lies at an altitude of 22.5 m above MSL. The area enjoys a typical humid tropical climate. The meteorological data for the period of investigation are given in Fig.1 and Appendix I.

The soil of the experimental field was sandy clay loam in texture. The physical and chemical properties of the soil are presented in Table 1.

3.1.2 History of the field and crop

Two cocoa fields, one in open and the other in shaded condition were selected.

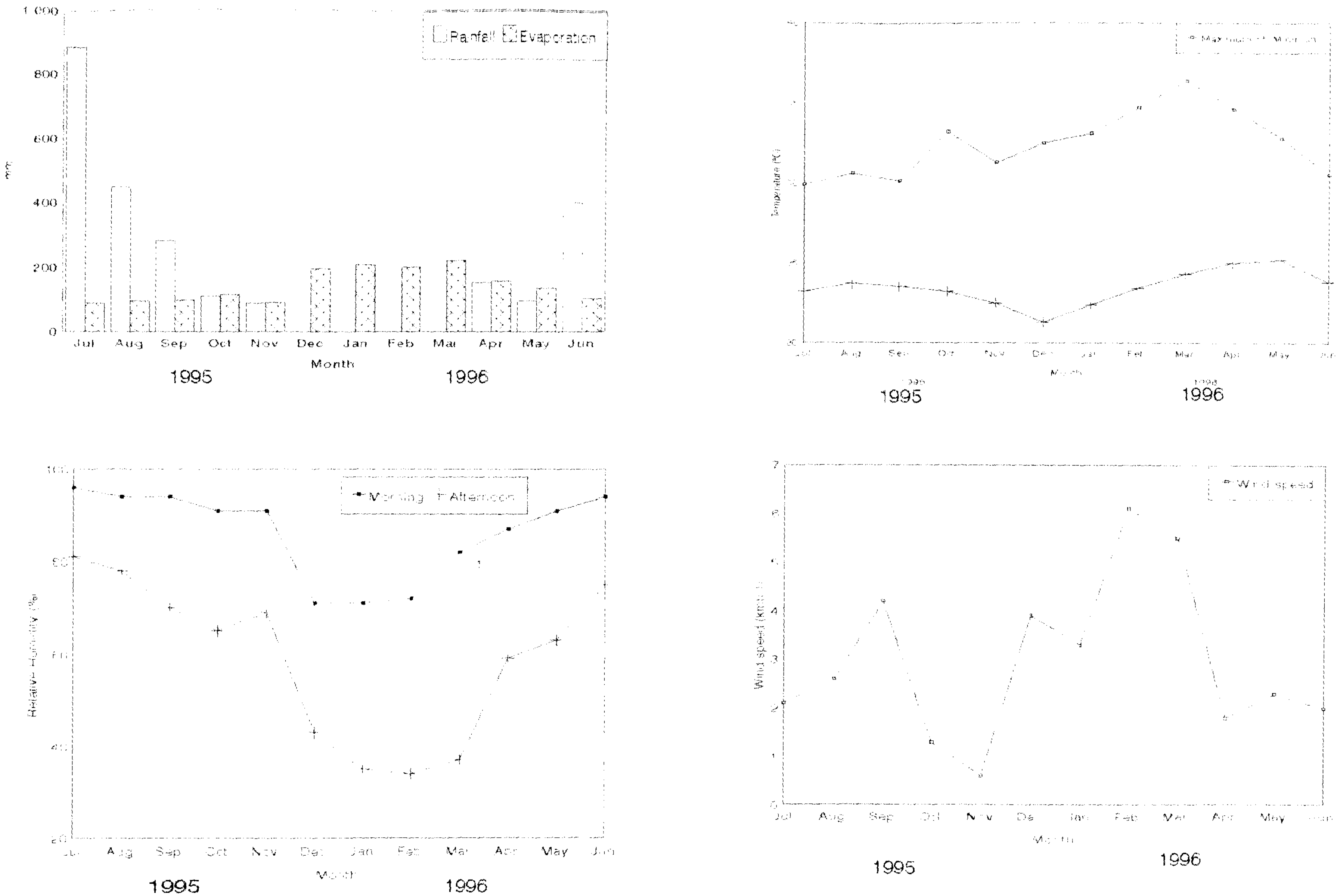

Fig.1 Weather during the experimental period

Table 1 Soil characteristics of the experimental site

Sl. No.	Fraction	Per cent composition	Procedure adopted	Reference
1.	Mechanical composition			
	Coarse sand	26.70	Robinson's International Pipette method	Piper, 1942
	Fine sand	27.10		
	Silt	10.00		
	Clay	36.20		
	Textural class	Sandy clay loam		ISSS system

2. Chemical properties

Chemical property	Field condition		Procedure adopted	Reference
	Shaded	Open		
pH	4.25	5.25	Soil water suspension of 1:2.5	Jackson, 1958
Organic carbon (%)	1.43	1.36	Walkley and Black rapid titration method	Piper, 1942
Available nitrogen (kg ha^{-1})	451.58	426.49	Alkaline permanganate method	Sankaran, 1966
Available phosphorus (kg ha^{-1})	14.52	11.20	Ascorbic acid blue colour method (Bray-I extraction)	Watanabe and Olsen, 1965
Available potassium (kg ha^{-1})	443.00	430.08	Flame photometry (Neutral normal ammonium acetate extraction)	Jackson, 1958
Exchangeable calcium (kg ha^{-1})	688.00	1147.60	Estimated in Atomic Absorption Spectrophotometer using neutral normal ammonium acetate extractant	Jackson, 1958
Exchangeable magnesium (kg ha^{-1})	304.00	648.00	- do -	Jackson, 1958

In the shaded condition a seven year old cocoa plantation was selected. The cocoa seedlings were planted at a spacing of 3m x 3m in an existing rubber plantation which was selectively thinned to give adequate shade for the cocoa plants. The fertilizers were applied as recommended in the Package of Practices (KAU, 1993).

In the open condition a 15 year old pure cocoa field was selected. The cocoa trees were planted at a spacing of 3m x 3m. Fertilizer application was done at the dozes and periods as recommended (KAU, 1993).

3.2 Technical programme

Four separate experiments were conducted to meet the specific objectives of the study.

3.2.1 Estimation of time required for natural senescence of cocoa leaves

For determining the time required for natural senescence of coca leaves, fresh hardened leaves were tagged and observed for natural senescence. It took at an average, ten days for the newly opened copper coloured leaves to reach the fresh hardened stage. Six trees in shaded field and two trees in the open were randomly selected. Seventy five leaves from the six trees in the shaded condition and 25 leaves from two trees in the open were randomly selected and tagged. The number of tagged leaves fallen on each date was recorded. The data were analysed using F test (Cochran and Cox, 1957) and Student's 't' test (Panse and Sukhatme, 1985).

3.2.2 Estimation of quantity of cocoa litter

The quantity of cocoa litter produced under shaded and open condition was found out. Litter collection was done using litter traps (Plate 1) made of wooden trays of 1m x 1m size, with wire mesh bottom which was elevated 30 cm from the ground so as to avoid contact with the soil.

Central points of four trees in rows and columns were serially numbered. Ten such points were randomly selected and the litter traps were placed on 3rd July, 1995 (Fig.2&3). Litter was collected from the trap once in a fortnight for one year ie., till July, 1996. In the shaded cocoa field the litter from the shade tree (rubber) which was seen admixture with the cocoa litter was carefully removed. The collected litter from both the shaded and open fields were oven dried for 48 hours at 80°C and the weight was recorded. The dry weight of litter was expressed on unit area basis to quantify the litter fall. The data were subjected to two way factorial analysis of variance.

3.2.3 Estimation of quantity of nutrients returned through cocoa litter

The oven dried samples were mixed thoroughly and ground to fine powder. These samples were used for the estimation of nitrogen, phosphorus, potassium, calcium and magnesium. The procedure used for the estimation is given in Table 2.

Plate 1 Litter trap used for the study

Plate 2 Litter bag used for the study

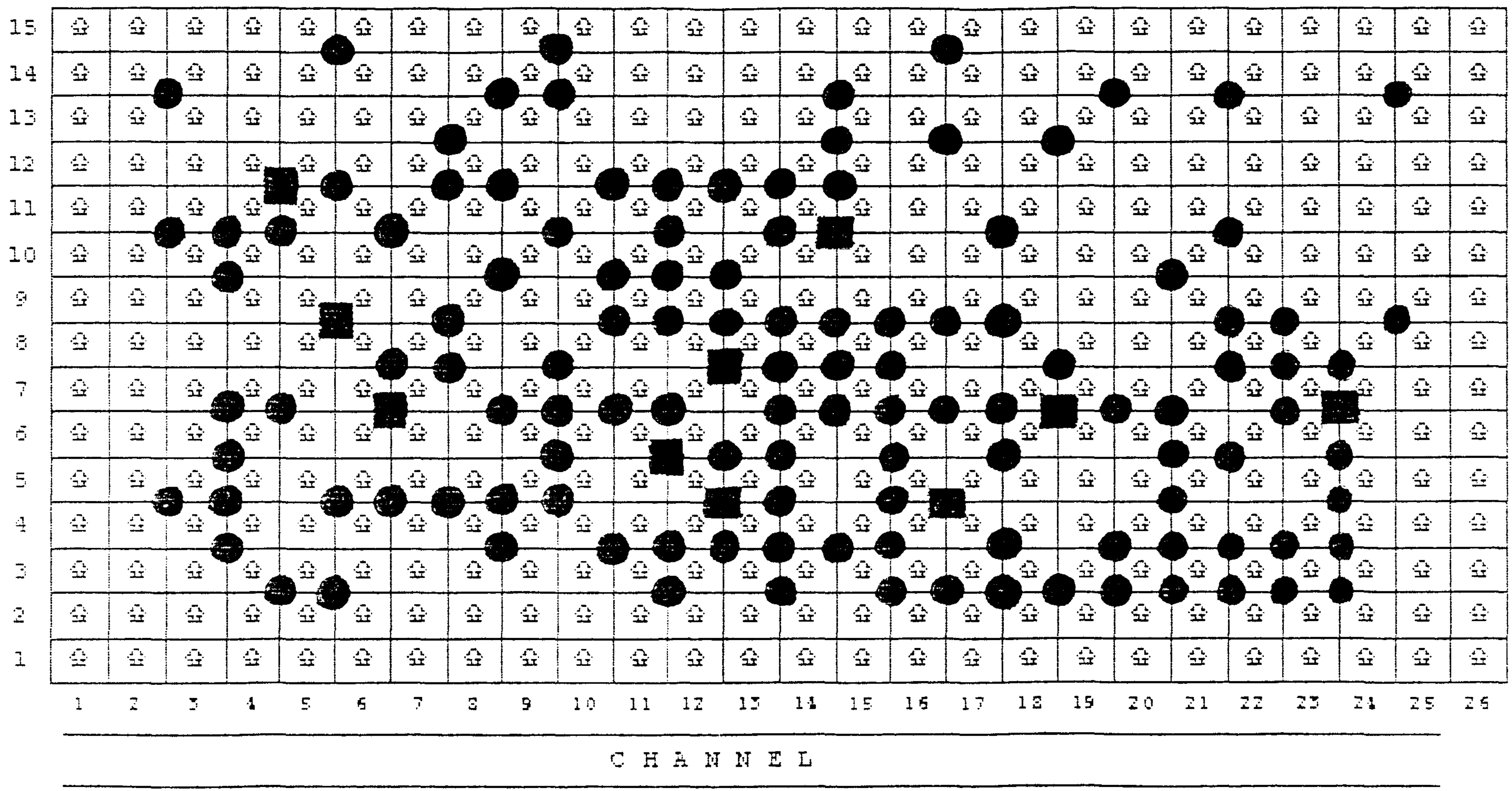

Fig. 2 Layout of the shaded cocoa field showing the placement of litter traps and liter bags

■ Litter trap
● Litter bag
⌂ Cocoa trees

Number of litter traps - 10
Number of litter bags - 120

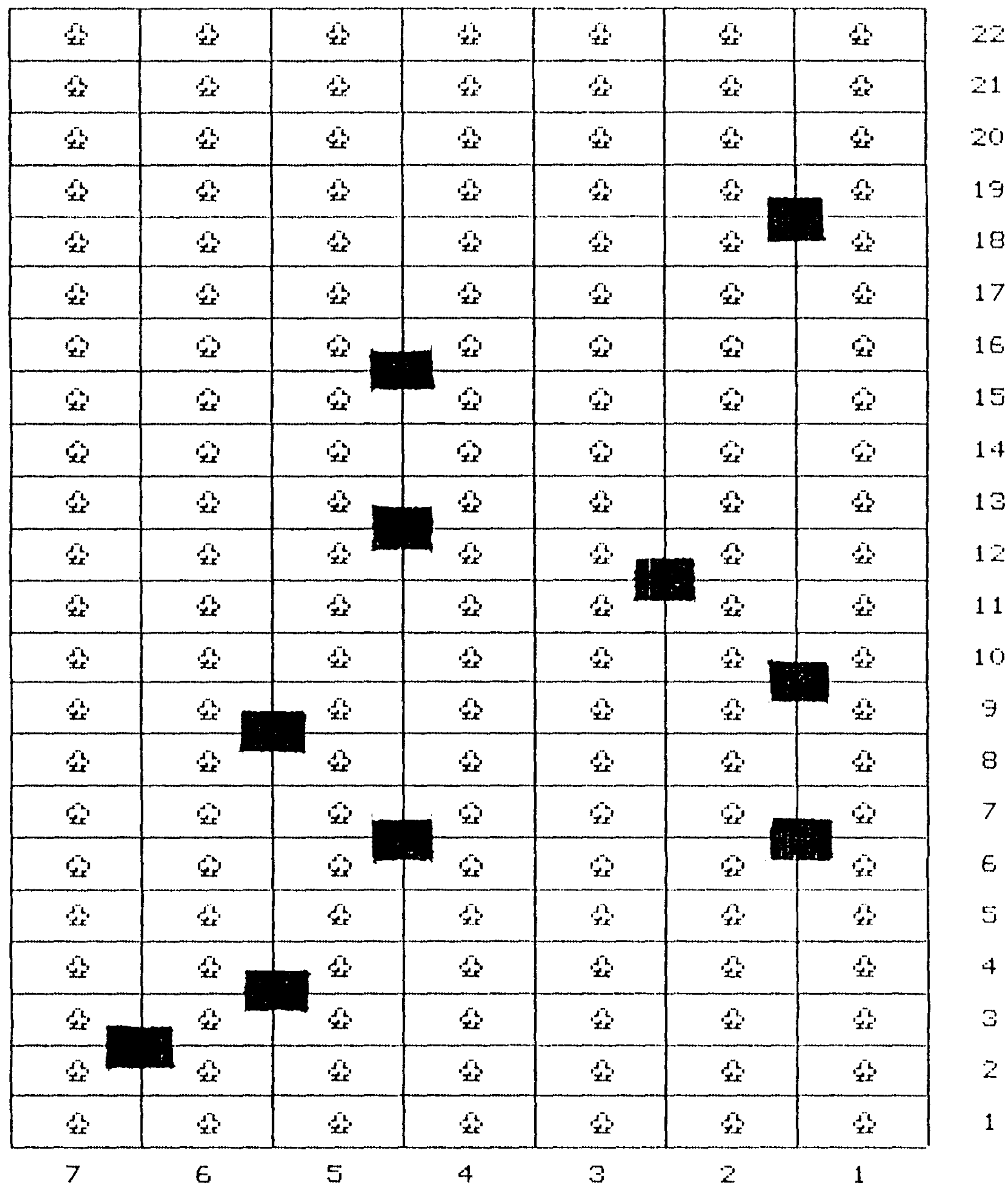

Fig.3 Layout of the open cocoa field showing the placement of litter traps

Cocoa trees

Litter traps

Number of litter traps - 10

Table 2 Procedure used for the estimation of nutrient elements in cocoa litter

Nutrient element	Method	Reference
Nitrogen	Micro Kjeldahl method	Jackson, 1958
Phosphorus	Vanadomolybdo phosphoric yellow colour method	Jackson, 1958
Potassium	Flame photometry	Jackson, 1958
Calcium	EDTA method	Hesse, 1971
Magnesium	EDTA method	Hesse, 1971

The percentage nutrient contents were worked out. The quantity of nutrients (kg ha^{-1}) returned through cocoa litter was found out by multiplying the contents with the litter production (kg ha^{-1}). The data were analysed statistically using two way factorial analysis of variance.

3.2.4 Estimation of rate of decomposition of cocoa litter

The litter decomposition was studied only in the shaded field. A total of 120 central points between rows and columns of cocoa trees were randomly selected as described in Section 3.2.2 in order to place the litter bags.

The study was conducted using the standard litter bag technique (Bocock and Gilbert, 1957). Litter bags of size 35 x 35 cm size were made with 2 mm mesh nylon net (Plate 2). Quadrats of size 1 m^2 were placed at 15 central points of cocoa in rows and columns to quantify the litter fall. From this the amount of fresh litter occurring naturally in a shaded cocoa field in 35 cm^2 area was found out. This was found to be 38 g on an average (the corresponding dry weight being 26.57 g). This much quantity of fresh cocoa litter was filled in each litter bag, the sides of which were stapled. These bags were kept in the surface in 120 places selected as mentioned earlier, on 7th July, 1995 (Fig.2).

At bimonthly intervals, 20 bags each were withdrawn at random. The bags were washed to remove adhering soil particles. Extraneous materials like roots were removed and the dry weight of residue remaining in each bag was recorded. The weight loss was worked out in percentage.

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

$$\frac{X}{X^0} = e^{-kt} \qquad \text{(Model 1)}$$

where,

X = the weight remaining at time t (g)

X^0 = original weight (g)

e = base of natural logarithm

k = decay rate coefficient

t = time

Results and Discussion

RESULTS AND DISCUSSION

The results of an investigation carried out to study the leaf fall, litter decomposition and related characteristics in a cocoa field for a period of one year are presented and discussed under the following heads.

1. Estimation of time required for natural senescence of cocoa leaves
2. Estimation of quantity of cocoa litter produced in a cocoa plantation in an year
3. Estimation of quantity of nutrients returned through cocoa litter and
4. Estimation of rate of decomposition of cocoa litter

4.1 Estimation of time required for natural senescence of cocoa leaves

The life span of cocoa leaves in shaded and open field conditions were studied and are presented in Table 3. Fresh hardened leaves were tagged on 19th August, 1995. The Cochran and Cox approximate test and Student's 't' test showed that the time taken for natural senescence of leaves of cocoa plants in shaded and open fields differed significantly.

In the shaded situation, the life span was found to be ranging from 94 to 193 days whereas in the open condition it was from 108 to 159 days after tagging. It showed that in the open condition the leaf retention in the plant was only for a maximum of 159 days whereas it

Table 3 Time taken for natural senescence of cocoa leaves tagged on 19.08.1995 in shaded and open fields

Date of leaf fall	No. of leaves fallen		Days after tagging	Percentage of leaves shed		Cumulative percentage of leaves shed	
	Shade	Open		Shade	Open	Shade	Open
21-11-95	1	-	94	1.33	-	1.33	-
27-11-95	2	-	100	2.66	-	4.00	-
05-12-95	10	1	108	13.33	4	17.33	4
07-12-95	-	2	110	-	8	-	12
08-12-93	-	1	111	-	4	-	16
13-12-95	13	4	116	17.33	16	34.66	32
16-12-95	10	1	119	13.33	4	48.00	36
18-12-95	4	1	121	5.33	4	53.33	40
22-12-95	4	1	125	5.33	4	58.66	44
26-12-95	4	2	129	5.33	8	64.00	52
30-12-95	-	3	133	-	12	-	64
02-01-96	1	-	136	1.33	-	65.33	-
16-01-96	3	3	150	4.00	12	69.33	76
18-01-96	1	-	152	1.33	-	70.66	-
22-01-96	1	3	156	1.33	12	72.00	88
23-01-96	-	2	157	-	8	-	96
25-01-96	1	1	159	1.33	4	73.33	100
29-01-96	1	-	163	1.33	-	74.66	-
30-01-96	2	-	164	2.66	-	77.33	-
07-02-96	1	-	172	1.33	-	78.66	-
09-02-96	4	-	174	5.33	-	84.00	-
15-02-96	5	-	180	6.66	-	90.66	-
16-02-96	1	-	181	1.33	-	92.00	-
20-02-96	4	-	185	5.33	-	97.33	-
22-02-96	1	-	187	1.33	-	98.66	-
28-02-96	1	-	193	1.33	-	100.00	-
Total	75	25		100.00	100.00		
F (0.01)			Sig				
t (0.01)			Sig				

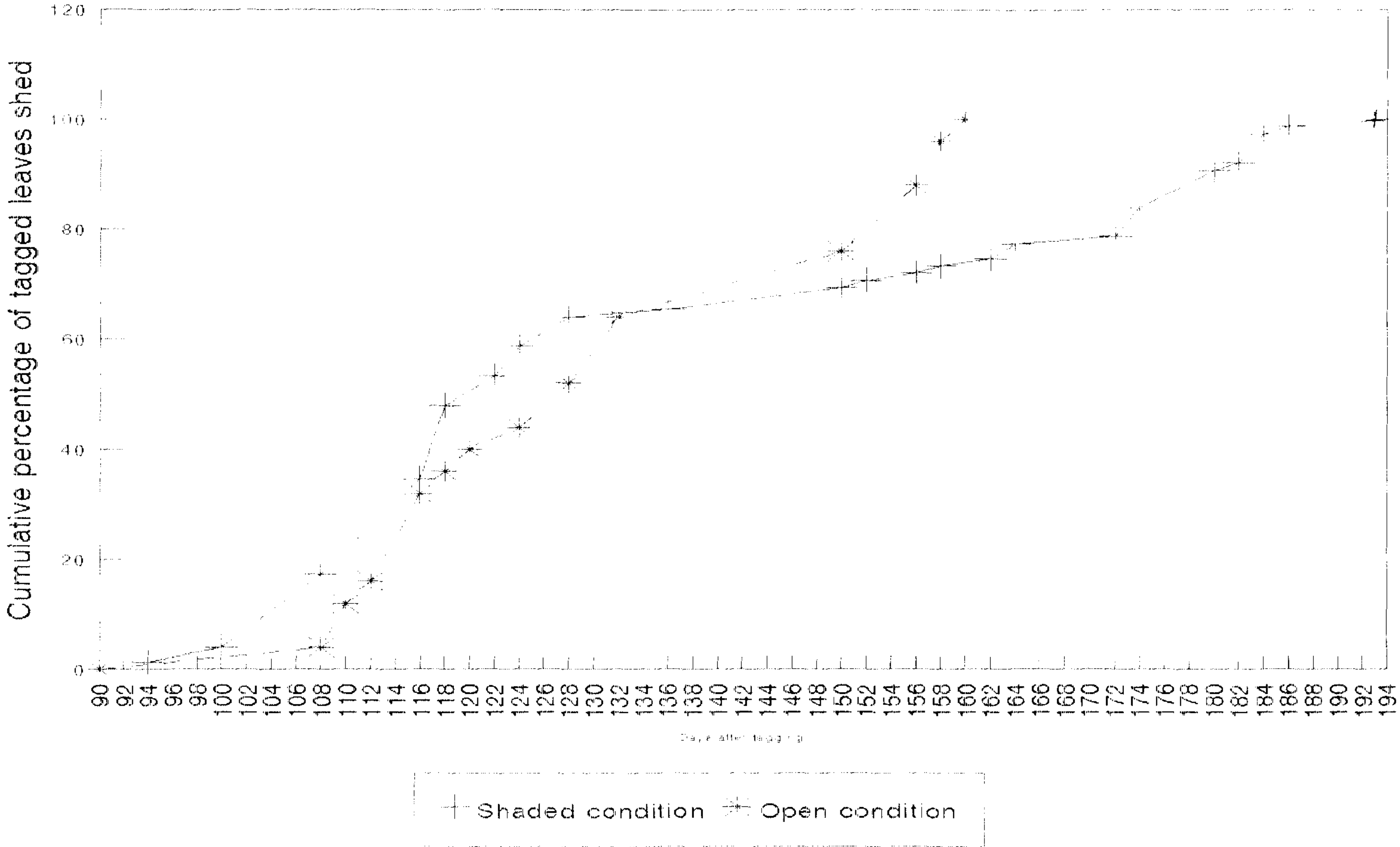

Fig.4 Time taken for natural senescence of cocoa leaves under shaded and open condition

extended to 193 days in shaded situation. A wide range of life span for the leaves had been reported by Vasudeva and Gopal (1975) in the coffee plants.

More than 60 per cent of the leaves were defoliated by the end of December within four and a half months after hardening of the leaves in both the situations. By the end of January all the tagged leaves were shed off in the open field (within 159 days after tagging) whereas it continued till the end of February in the shaded condition (193 days after tagging). Hardy (1958) had also reported that cocoa leaves developed under full sunlight were shed early.

Under open condition it took only 51 days to complete the shedding of all the tagged leaves after the falling of first leaf, whereas under shaded condition it took double the period of about 99 days to complete the falling of all the tagged leaves.

The cumulative percentage of tagged leaves shed under open and shaded condition is given in Fig. 4. Though the leaf fall started earlier under shaded condition, it progressed almost linearly in both the conditions and reached a similar cumulative percentage of 64 on 133rd day after tagging. Afterwards it took a reverse turn of completing the leaf fall earlier under open condition.

In the shaded situation the leaf fall started early ie. from 21st of November and extended to the end of February. A sudden rate of increase in leaf fall was observed in December - January, in general. By the time all the leaves were shed in the open condition only 73 per cent was fallen in shaded condition ie. by 25th January (159 days after tagging). In the open fields all the 25 leaves were fallen between four to five months. In both the situations maximum percentage of tagged leaves fell in December followed by January in the open condition and February in the shaded condition.

Dry winds and water stress might have induced synthesis of abscissic acid causing leaf abscission as reported by Moore (1980) and Kumar and Deepu (1992) during this period. It is generally observed that after leaf fall flushing starts in cocoa during January - February. Another flushing also occur in August.

Leaf senescence normally occurs after the stoppage of leaf function mainly the photosynthesis which inturn depends on availability of nutrients, water and sunlight. Nutrient mobility both in soil and plant is very much related to availability of water. Under shaded condition, the relatively low water stress and low sunlight availability might have prolonged the photosynthetic period and hence a longer life span for leaves was observed.

4.2 Estimation of quantity of cocoa litter produced in a cocoa plantation in an year

The total litter fall in the shaded and open cocoa fields for a period of one year at fortnightly intervals is presented in Table 4.

Table 4 Dry weight of cocoa litter in shaded and open cocoa fields at fortnightly intervals

Month	Fortnight	Dry weight of cocoa litter (kg ha^{-1})		Mean
		Shaded field	Open field	
July 1995	1	129	99	114
	2	162	178	170
August 1995	3	64	229	146
	4	98	333	215
September 1995	5	197	488	343
	6	161	256	209
October 1995	7	100	216	158
	8	268	374	321
November 1995	9	120	338	229
	10	254	164	209
December 1995	11	254	319	287
	12	468	985	726
January 1996	13	670	1139	905
	14	377	425	401
February 1996	15	490	430	460
	16	258	434	346
March 1996	17	354	425	390
	18	256	441	349
April 1996	19	67	140	104
	20	92	98	95
May 1996	21	100	270	185
	22	218	240	229
June 1996	23	86	129	107
	24	80	80	80
Total		5323	8230	6678
Mean		222	343	282

	Fortnight	Condition	Interaction
SEm±	36.5	10.5	51.6
CD (0.05)	101.5	29.2	143.5

Statistical analysis of the data revealed that the litter fall was significantly influenced by the season and condition of the field (shaded or open). Their interaction effect was also significant.

The litter fall was very much influenced by season in both the conditions. The highest litter production of 905 kg ha^{-1} was observed to be during the first fortnight of January followed by the second fortnight of December where 726 kg ha^{-1} of litter fall was occurred. The lowest quantity 80 kg ha^{-1} of litter was produced in the second fortnight of June.

The monthly litter fall under shaded and open conditions are graphically represented in Fig. 5. From December to March there was significantly high litter production compared to other months. Nearly 59 per cent of total litter in the shaded field and 56 per cent of litter in the open field fell during these months. This is in agreement with the findings that maximum litter fall in tree species in tropical condition occurred during winter starting from October extending up to February (Gill *et al.*, 1987; Sharma *et al.*, 1988). One of the reasons for the high rate of litter production in December and January could be the dry wind which prevailed during that time. The wind speed from the second week of December up to the first week of January ranged from 7.9 to 8.6 km hr^{-1} which happened to be the highest range of wind speed recorded for the year (Appendix-I). The high defoliation due to strong wind was in accordance with the observation of Wood and Lass(1985). Tree water stress is a cardinal aspect

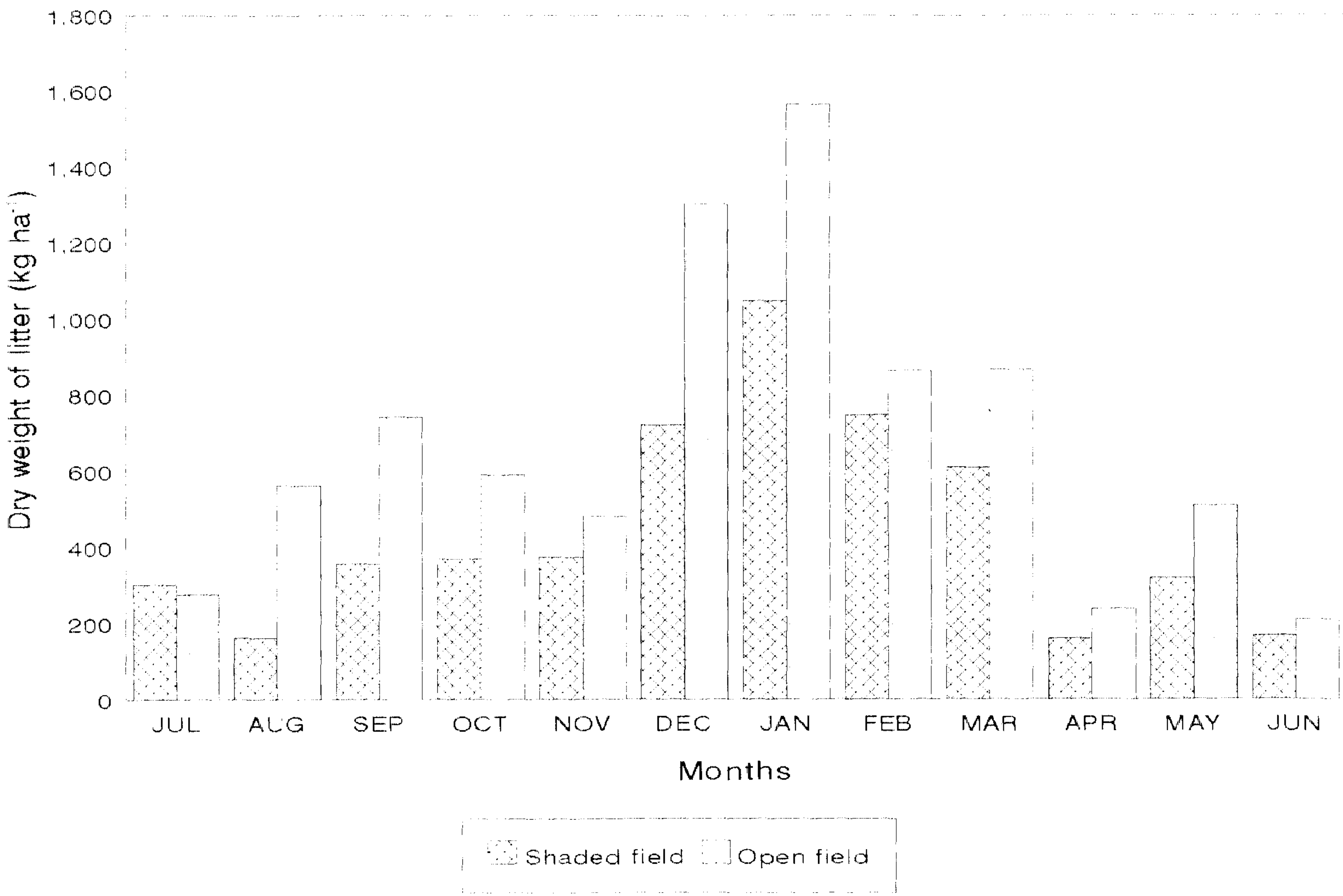

Fig.5 Monthly litterfall in a cocoa field (dry weight kg ha^{-1})

influencing leaf senescence. The rainfall was practically nil during this period at Vellanikkara. This coupled with the strong desiccating wind might have caused water stress in plants. Evaporation was also higher during December to January. Kumar and Deepu (1992) have also reported high litter fall due to water stress. Moore (1980) had reported that water stress triggers the synthesis of abscissic acid in foliage of plants which inturn stimulate senescence of leaves and other parts. Hence changes in the endogenous hormonal balance could be a possible explanation for the high leaf fall that occurred during the relatively dry periods, ie. from December to March. Since most of the leaves were fallen by the end of March, thereafter the litter fall exhibited decreasing trend. Moreover, the wind speed and consequently the evaporation was also lower from April.

The effect of shaded and open conditions on leaf fall was also found to be significant. The total annual litter fall in the shaded field was 5.32 t ha^{-1} while it was 8.23 t ha^{-1} in the open field, which was 55 per cent more than in the shaded field. The average litter fall at fortnightly interval was 222 kg ha^{-1} in shaded condition and 343 kg ha^{-1} in open condition.

The high rate of litter fall observed in the open field is in confirmity with the findings of Santana *et al.* (1987) who had reported litter fall of 8.5 t ha^{-1} yr^{-1} under monoculture of cocoa which was higher than that in the shaded situation. The reason for the high litter production in the open field could also be attributed to the high rate of leaf production owing to vigorous and intensive flushing observed in unshaded cocoa (Alvim, 1977; Owusu *et al.*, 1978).

The interaction effect of season and the shaded/open condition on litter fall was also significant as mentioned earlier. It could be seen that in the first fortnight of January, the leaf fall was highest in the shaded and open conditions, but there was significant difference between them. Leaf fall was 670 kg ha^{-1} in the shaded situation and 1139 kg ha^{-1} in the open situation. The lowest quantity of litter fall occurred in the second fortnight of August in the shaded field (64 kg ha^{-1}) whereas in the open field the lowest quantity of litter fell in the second fortnight of June (80 kg ha^{-1}).

As a general observation, leaf fall was lower during wetter months of the year, and when the rainy season was over it was higher. Hot summer season is from March to May in Kerala and before that most of the mature leaves were shed. The maximum leaf fall was in December-January when strong desiccating wind prevailed in the area.

4.3 Estimation of quantity of nutrients returned through cocoa litter

Nutrient return through leaf litter is a function of litter dry matter, nutrient concentration in leaf and litter decomposition process. The concentration of nutrients in cocoa litter produced at fortnightly intervals were estimated. The maximum possible quantity of nutrients returned was worked out based on the quantity of litter produced and its nutrient concentration.

4.3.1 Nitrogen

4.3.1.1 Nitrogen concentration in litter

The concentration of N in the cocoa litter at fortnightly intervals in the shaded and open cocoa fields is presented in Table 5.

The effect of season and the shaded/open condition on N concentration of litter was found to be significant.

The seasonal influence on N concentration in leaf litter was prominent, it increased to an extent of 100 per cent during the second fortnight of January with 1.68 per cent N from 0.85 per cent during first fortnight of June. In general a lower but statistically similar N content of leaf litter was observed from second fortnight of May to first fortnight of July; a higher but statistically similar ones were observed from first fortnight of September to first fortnight of February.

The N concentration as low as 0.85 per cent in dry leaf might be due to several factors influencing the leaf growth, N accumulation and N dynamics in leaf. The fallen leaves during May to July where low N concentration occurred have initiated and developed during a period of water stress, when N uptake from soil and further synthesis might have been seriously affected. It could also be due to the retranslocation of N from older parts to the newly formed flushes (Mason and Whitefield, 1960) that occurred during January to February. Raizada and Srivastava (1991) had also reported about the leaching loss

Table 5 Nitrogen content of cocoa litter in shaded and open cocoa fields at fortnightly intervals

Month	Fortnight	Nitrogen content (%)		Mean
		Shaded field	Open field	
July 1995	1	0.95	0.95	0.95
	2	1.04	1.08	1.06
August 1995	3	0.93	1.15	1.04
	4	1.25	1.16	1.20
September 1995	5	1.56	1.66	1.61
	6	1.20	1.46	1.33
October 1995	7	1.30	1.37	1.34
	8	1.10	1.23	1.16
November 1995	9	1.29	1.37	1.33
	10	1.25	1.21	1.23
December 1995	11	1.18	1.23	1.20
	12	1.25	1.33	1.29
January 1996	13	1.43	1.55	1.49
	14	1.64	1.73	1.68
February 1996	15	1.28	1.45	1.37
	16	1.18	1.14	1.16
March 1996	17	1.13	1.20	1.17
	18	1.22	1.27	1.25
April 1996	19	1.20	1.20	1.20
	20	1.12	1.25	1.18
May 1996	21	1.23	1.34	1.29
	22	0.97	0.91	0.94
June 1996	23	0.83	0.86	0.85
	24	1.01	0.87	0.94
Mean		1.19	1.25	1.22

	Fortnight	Condition	Interaction
SEm±	0.041	0.012	0.058
CD (0.05)	0.113	0.032	NS

of N from leaves due to canopy washing, which could also have accounted for lowering N concentration in leaves.

The effect of shaded/open condition on the N concentration of litter was also found to be significant. In the shaded field N concentration was 1.19 per cent and in the open field it was 1.25 per cent. Many authors have reported that under light limited environment, leaf nitrogen concentration was generally low (Field and Mooney, 1983; Hirose, 1988). Under shaded condition mobilization of photosynthates from older leaves to new meristematic regions was reported to be greater than plants in open conditions and consequently a lower N content was expected.

A similar effect of season on N concentration in leaves of plants under shaded or unshaded condition is evident from the lack of interaction between season and growing conditions.

4.3.1.2 Nitrogen return through cocoa litter

N contribution followed the same trend as that of N concentration but here the interaction effect was also significant (Table 6).

Considering the effect of season, the highest quantity of N was returned through cocoa litter in the first fortnight of January (13.61 kg ha^{-1}), followed by the second fortnight of December (9.39 kg ha^{-1}). The lowest N return was in the second fortnight of June (0.75 kg ha^{-1})

Table 6 Nitrogen return through cocoa litter in shaded and open cocoa fields at fortnightly intervals

Month	Fortnight	N return (kg ha^{-1})		Mean
		Shaded field	Open field	
July 1995	1	1.34	0.96	1.15
	2	1.76	1.93	1.84
August 1995	3	0.66	2.57	1.62
	4	1.22	3.95	2.59
September 1995	5	3.18	7.95	5.56
	6	2.14	3.70	2.92
October 1995	7	1.28	2.92	2.10
	8	2.92	4.59	3.75
November 1995	9	1.58	4.61	3.09
	10	3.26	2.05	2.66
December 1995	11	3.04	3.98	3.51
	12	5.78	13.08	9.39
January 1996	13	9.67	17.55	13.61
	14	6.12	7.39	6.57
February 1996	15	6.22	6.32	6.27
	16	2.99	4.97	3.98
March 1996	17	3.95	5.24	4.60
	18	3.16	5.53	4.34
April 1996	19	0.79	1.68	1.24
	20	1.03	1.21	1.12
May 1996	21	1.20	3.58	2.39
	22	2.11	2.23	2.17
June 1996	23	0.72	1.04	0.88
	24	0.80	0.70	0.75
Total		66.92	109.73	88.10
Mean		2.78	4.57	3.67

	Fortnight	Condition	Interaction
SEm±	0.512	0.148	0.725
CD (0.05)	1.424	0.410	2.014

and it was on par with the first half of June, whole of July, first fortnights of August and October. It also showed that the N return was lowest in the rainy months. It could be due to the fact that the litter fall was low in these months coupled with a low N content.

The N return through litter fall in the open field was significantly higher than that in the shaded field, obviously due to higher litter fall and higher N content of leaves. The total annual N return was 66.92 kg ha^{-1} in the shaded field, whereas in the open field it was 109.73 kg ha^{-1} (62 per cent higher). Comparable values have been obtained by many workers (Aranguren *et al.*, 1982b; Santana and Cabala, 1983).

The interaction effect of season and shaded/open condition was also found to be significant. In both the shaded and open conditions, the highest quantity of N was returned in the first fortnight of January (9.67 and 17.55 kg ha^{-1} respectively) but there was significant difference between them.

4.3.2 Phosphorus

4.3.2.1 Phosphorus concentration in cocoa litter

The phosphorus concentration of cocoa litter was found to be affected significantly by the season and also by its interaction with shaded/open condition (Table 7) whereas the shaded/open condition alone could not make significant difference.

Table 7 Phosphorus content of cocoa litter in shaded and open cocoa fields at fortnightly intervals

Month	Fortnight	Phosphorus content (%)		Mean
		Shaded field	Open field	
July 1995	1	0.12	0.12	0.12
	2	0.15	0.15	0.15
August 1995	3	0.14	0.14	0.14
	4	0.14	0.14	0.14
September 1995	5	0.14	0.16	0.15
	6	0.12	0.12	0.12
October 1995	7	0.08	0.11	0.10
	8	0.10	0.13	0.11
November 1995	9	0.12	0.13	0.12
	10	0.13	0.11	0.12
December 1995	11	0.11	0.11	0.11
	12	0.12	0.05	0.08
January 1996	13	0.07	0.07	0.07
	14	0.07	0.08	0.07
February 1996	15	0.06	0.05	0.05
	16	0.04	0.05	0.04
March 1996	17	0.05	0.05	0.05
	18	0.03	0.04	0.04
April 1996	19	0.06	0.08	0.07
	20	0.09	0.05	0.07
May 1996	21	0.05	0.04	0.04
	22	0.04	0.03	0.03
June 1996	23	0.05	0.05	0.05
	24	0.14	0.09	0.11
Mean		0.09	0.09	0.09

	Fortnight	Condition	Interaction
SEm±	0.006	0.002	0.009
CD (0.05)	0.197	NS	0.028

The highest concentration of phosphorus in cocoa litter was observed from the second fortnight of July (0.15 per cent) to September. There was a gradual decline afterwards reaching the minimum (0.03 per cent) during May. From June onwards the P content started increasing reaching the maximum towards the second half of July and persisting till September. However, the lowest P concentration was observed during the month of May, where the N concentration was also the lowest.

The markedly high P concentration in litter during wetter months could be possibly explained on the basis of P uptake from soil. Most of the soil phosphorus moves to the roots by diffusion (Tisdale *et al.*, 1995). During rainy season soil moisture content increased, thereby rate of diffusion also increased. This led to an increased uptake of phosphorus during rainy season and it was reflected in the P concentration in litter.

The effect of shaded/open condition on P concentration was not significant and it was 0.09 per cent in both the conditions. Wessel (1971) had reported P concentration of 0.08 per cent in the older leaves in a healthy cocoa tree.

However the interaction between season and shaded/open condition was significant. In the shaded field, the highest P concentration (0.15 per cent) was observed in the litter from the second fortnight of July and it was comparable with second half of June to December end. But the highest P concentration of litter in the open field was observed in the first fortnight of September (0.16 per cent) and it was statistically on par with that in July to first half of November.

4.3.2.2 Phosphorus return through cocoa litter

The contribution of P through cocoa litter in the shaded and open fields is given in Table 8. The influence of season, shaded/open conditions and the interaction between these two were significant. The highest quantity of P return was observed in the first fortnight of January followed by second half of December obviously due to the high leaf fall during that period. However, it was statistically on par with that in the first fortnight of September.

The lowest quantity of P return was in the first fortnight of June (0.05 kg ha^{-1}) and it was on par with the P return from April to June. It indicated that throughout the summer months the P return was low. The litter fall during this period was also very low.

The P return through leaf fall from the open field was significantly higher by 53 per cent than that of shaded field with absolute values of 4.97 and 6.83 kg ha^{-1}, respectively. This difference was obviously due to the higher litter fall in the open field, the P concentration being the same under both the situations. Similar observations were reported by various workers like Ling (1986), Opakunle (1989) and Sivanadyan *et al.* (1995).

Table 8 Phosphorus return through cocoa litter in shaded and open cocoa fields at fortnightly intervals

Month	Fortnight	Phosphorus return (kg ha^{-1})		Mean
		Shaded field	Open field	
July 1995	1	0.18	0.13	0.16
	2	0.24	0.25	0.25
August 1995	3	0.09	0.31	0.20
	4	0.13	0.47	0.30
September 1995	5	0.34	0.75	0.54
	6	0.21	0.31	0.26
October 1995	7	0.08	0.24	0.16
	8	0.47	0.49	0.48
November 1995	9	0.14	0.42	0.28
	10	0.36	0.19	0.27
December 1995	11	0.26	0.34	0.30
	12	0.53	0.50	0.52
January 1996	13	0.45	0.88	0.66
	14	0.26	0.36	0.31
February 1996	15	0.27	0.21	0.24
	16	0.26	0.21	0.24
March 1996	17	0.18	0.17	0.18
	18	0.09	0.16	0.13
April 1996	19	0.05	0.10	0.07
	20	0.09	0.04	0.06
May 1996	21	0.05	0.10	0.07
	22	0.09	0.08	0.08
June 1996	23	0.04	0.06	0.05
	24	0.11	0.06	0.08
Total		4.97	6.83	5.90
Mean		0.21	0.28	0.25

	Fortnight	Condition	Interaction
SEm±	0.046	0.013	0.065
CD (0.05)	0.127	0.037	0.180

In the shaded field, the highest P return was observed in the second fortnight of December (0.53 kg ha^{-1}). In the open field, the highest P return was in the first fortnight of January (0.88 kg ha^{-1}) and it was on par with the P return during first fortnight of September. The P content was highest in September eventhough the litter fall was less and it had resulted in comparable P return with that of January.

4.3.3 Potassium

4.3.3.1 Potassium concentration in litter

There was significant difference in the K concentration of litter due to the period of growth, condition of the field (shaded/open) and its cumulative influence. The K content varied from 0.39 to 1.81 per cent (Table 9).

Considering the seasonal effect, the highest K concentration in the litter was observed in the second fortnight of February (1.55 per cent) followed by first half of March (1.48 per cent). It could also be seen that the litter contained more K during the non-rainy season compared to the rainy season. This could be due to the leaching loss of K because of canopy washing by rainfall. Tukey (1969) observed heavy leaching of K from cocoa foliage. During the wetter months the atmospheric temperature was low, which also decreased the rate of K uptake of plant.

The K concentration in the cocoa litter from the open field was significantly higher (1.19 per cent) than that from the shaded

Table 9 Potassium content of cocoa litter in shaded and open cocoa fields at fortnightly intervals

Month	Fortnight	Potassium content (%)		Mean
		Shaded field	Open field	
July 1995	1	0.51	0.74	0.63
	2	1.01	0.89	0.95
August 1995	3	0.39	0.59	0.49
	4	0.61	0.72	0.67
September 1995	5	0.83	1.00	0.91
	6	0.62	0.98	0.80
October 1995	7	1.09	1.45	1.27
	8	1.15	1.77	1.46
November 1995	9	0.98	1.07	1.03
	10	1.08	1.22	1.15
December 1995	11	1.19	1.17	1.18
	12	1.02	1.27	1.29
January 1996	13	1.46	1.47	1.47
	14	1.34	1.60	1.47
February 1996	15	1.09	1.52	1.31
	16	1.30	1.81	1.55
March 1996	17	1.41	1.55	1.48
	18	1.01	1.62	1.32
April 1996	19	1.22	1.37	1.30
	20	1.00	0.96	0.98
May 1996	21	0.87	0.81	0.84
	22	0.92	0.99	0.96
June 1996	23	1.30	0.88	1.09
	24	0.67	1.08	0.87
Mean		1.02	1.19	1.11

	Fortnight	Condition	Interaction
SEm±	0.062	0.018	0.088
CD (0.05)	0.174	0.050	0.246

field (1.02 per cent). Similar results were also reported by Wessel (1971). The absorption of K was depressed by shade and as a result foliar K levels were less in shaded condition compared to unshaded condition (Gopinathan, 1981 and Leite, 1985).

The interaction effect of season and shaded/open condition was also significant on K concentration of litter. In the second fortnight of February, the mean K concentration of litter was 1.81 per cent in the open field and 1.30 per cent in the shaded field and they were significantly different. In the shaded field the maximum K content was observed in first fortnight of March (1.41 per cent) which was significantly lower than the highest K concentration in an open situation. Almost throughout the year the litter K content was higher in the open field.

4.3.3.2 K return through cocoa litter

The K return through cocoa litter was also significantly influenced by season, shaded/open condition and their interaction (Table 10).

The highest quantity of K return through litter fall occurred in the first fortnight of January (13.19 kg ha^{-1}) which was significantly higher than the other periods and it was followed by the second fortnight of December (9.25 kg ha^{-1}). The lowest quantity of K return was observed in the first fortnight of July (0.7 kg ha^{-1}). The high rate of K return in January and December could be attributed to the high litter fall and high K content observed during that period.

Table 10 Potassium return through cocoa litter in shaded and open cocoa fields at fortnightly intervals

Month	Fortnight	Potassium return (kg ha^{-1})		Mean
		Shaded field	Open field	
July 1995	1	0.70	0.70	0.70
	2	1.24	1.58	1.41
August 1995	3	0.26	1.37	0.82
	4	0.61	2.33	1.47
September 1995	5	0.69	4.71	3.20
	6	1.11	2.38	1.74
October 1995	7	1.24	3.12	2.17
	8	2.96	6.55	4.75
November 1995	9	1.18	3.61	2.40
	10	3.30	1.97	2.63
December 1995	11	3.13	3.74	3.43
	12	6.00	12.49	9.25
January 1996	13	9.75	16.64	13.19
	14	4.88	6.81	5.85
February 1996	15	5.30	6.51	5.91
	16	3.39	6.72	5.05
March 1996	17	4.94	6.56	5.75
	18	2.81	7.08	4.95
April 1996	19	0.70	1.89	1.29
	20	0.98	0.93	0.95
May 1996	21	0.82	2.03	1.43
	22	2.01	2.41	2.21
June 1996	23	1.18	1.17	1.17
	24	0.54	0.87	0.71
Total		59.72	104.17	81.95
Mean		2.49	4.34	3.41

	Fortnight	Condition	Interaction
SEm±	0.505	0.146	0.715
CD (0.05)	1.405	0.404	1.986

The total K return was 59.72 kg ha^{-1} yr^{-1} in the shaded field and 104.17 kg ha^{-1} yr^{-1} in the open field, which was significantly higher. Similar results were reported by Ling (1986) and Opakunle (1989). The interaction effect of season and shaded/open condition was also significant on K contribution through litter fall. In the first fortnight of January the K addition was maximum in the shaded and open fields (9.75 and 16.64 kg ha^{-1}, respectively) but they were significantly different.

• The results of N, P and K returns through litter fall showed that they were at the maximum rates during the first fortnight of January, the quantities being 13.61, 0.66 and 13.19 kg ha^{-1}, respectively. There was variation between shaded and open fields at fortnightly intervals. In the shaded field the highest N, P and K return was in the tune of 9.67, 0.53 and 9.75 kg ha^{-1} whereas in open fields it was 17.55, 0.88 and 16.64 kg ha^{-1}, respectively. The total return of N, P and K per hectare in the whole year under study was 66.92, 4.97 and 59.72 kg, respectively in the shaded field whereas it was 107.93, 6.83 and 104.17 kg, respectively in the open field.

4.3.4 Calcium

4.3.4.1 Calcium concentration in cocoa litter

Calcium concentration in cocoa litter was significantly influenced by season, shade/open environment and their interaction (Table 11).

Table 11 Calcium content of cocoa litter in shaded and open cocoa fields at fortnightly intervals

Month	Fortnight	Calcium content (%)		Mean
		Shaded field	Open field	
July 1995	1	1.91	1.70	1.80
	2	1.78	1.32	1.55
August 1995	3	1.74	1.00	1.37
	4	1.48	1.22	1.35
September 1995	5	1.36	1.38	1.37
	6	1.29	1.60	1.44
October 1995	7	1.79	1.38	1.58
	8	1.76	1.42	1.59
November 1995	9	1.92	1.46	1.69
	10	1.66	1.01	1.34
December 1995	11	1.42	1.60	1.51
	12	1.62	1.39	1.51
January 1996	13	1.51	1.05	1.28
	14	1.45	1.13	1.29
February 1996	15	1.70	1.27	1.49
	16	1.22	1.01	1.11
March 1996	17	1.48	1.24	1.36
	18	1.45	1.12	1.29
April 1996	19	1.55	1.41	1.48
	20	1.71	1.14	1.42
May 1996	21	1.58	1.26	1.42
	22	1.52	1.35	1.44
June 1996	23	1.66	1.55	1.60
	24	1.44	1.42	1.43
Mean		1.58	1.31	1.45

	Fortnight	Condition	Interaction
SEm±	0.076	0.022	0.107
CD (0.05)	0.210	0.060	0.297

There was seasonal variation in the Ca concentration of litter. The highest concentration of Ca was observed in the first fortnight of July (1.80 per cent) and it was statistically on par with that in the first fortnight of June and November. It might be due to higher absorbtion of calcium during wetter periods. The lowest concentration of Ca (1.11 per cent) was observed in the second fortnight of February. The dry period from January to March showed lesser calcium content in the litter. The concentration of Ca was higher than all other nutrients analysed in the litter.

Gosz *et al.* (1973) reported that Ca being a structural element had no possibility of retranslocation prior to leaf fall. Many scientists have reported that the concentration of calcium increased in the senescing leaves (Onland, 1963; Small, 1972). Wessel (1971) reported that in a cocoa tree, the Ca concentration was 1.03, 1.69 and 2.33 per cent respectively in the young, medium old and old senescing leaves. This probably could explain the lower calcium content in dry periods because the leaves were retained in plants for a shorter period in summer months.

The effect of shaded/open environment was significant on Ca concentration of litter. Unlike N and K, the Ca content of litter was more in shaded than open condition. In the shaded field the Ca concentration of litter was 1.58 per cent which was significantly higher than that in the open field (1.31 per cent). According to Murray (1967) cocoa plants showed higher levels of Ca in their leaves under heavy shade as compared to trees growing under less or no shade.

The interaction effect of season and shaded/open environment was also significant on the Ca concentration of litter. The highest concentration of Ca in litter occurred in the first fortnight of July both in the shaded and open fields (1.91 and 1.70 per cent, respectively) but they were significantly different.

4.3.4.2 Calcium return through cocoa litter

There was significant seasonal effect on Ca return through cocoa litter fall (Table 12). The highest quantity of calcium was returned in the first fortnight of January (10.94 kg ha^{-1}) and it was statistically on par with the Ca return in the second fortnight of December, ie. the preceding fortnight. Though the Ca concentration in litter was highest in July, owing to high magnitude of litter fall in January, the Ca return was higher in January.

The total annual Ca return was significantly higher in the open field (103.68 kg ha^{-1}) compared to that from shaded field (84.94 kg ha^{-1}). It is confirmity with the report of Young (1989). Report of a higher level of Ca return (179 kg ha^{-1} yr^{-1}) was made earlier (Opakunle, 1989) under shaded condition.

The interaction effect was also significant. In the first fortnight of January, when Ca return was highest, in the shaded field it was 10.15 kg ha^{-1} and in the open field it was 11.72 kg ha^{-1}.

Table 12 Calcium return through cocoa litter in shaded and open cocoa fields at fortnightly intervals

Month	Fortnight	Calcium return (kg ha^{-1})		Mean
		Shaded field	Open field	
July 1995	1	2.83	1.66	2.25
	2	3.21	2.42	2.81
August 1995	3	1.17	2.20	1.68
	4	1.41	3.94	2.67
September 1995	5	2.58	6.55	4.56
	6	2.22	4.13	3.18
October 1995	7	1.77	3.02	2.40
	8	4.73	5.31	5.02
November 1995	9	2.42	4.92	3.67
	10	4.41	1.58	3.00
December 1995	11	3.66	5.17	4.41
	12	7.38	12.99	10.19
January 1996	13	10.15	11.72	10.94
	14	5.66	4.73	5.19
February 1996	15	8.19	5.66	6.92
	16	4.19	4.45	4.32
March 1996	17	5.10	5.41	5.25
	18	3.58	4.82	4.20
April 1996	19	1.13	2.00	1.57
	20	1.57	1.15	1.36
May 1996	21	1.59	3.41	2.50
	22	3.42	3.37	3.39
June 1996	23	1.43	1.93	1.68
	24	1.14	1.09	1.12
Total		84.94	103.68	94.31
Mean		3.54	4.32	3.93

	Fortnight	Condition	Interaction
SEm±	0.513	0.148	0.726
CD (0.05)	1.427	0.411	2.018

4.3.5 Magnesium

4.3.5.1 Magnesium concentration in litter

The effect of season and shaded/open environment was significant on Mg concentration of litter (Table 13).

Considering seasonal effect, the highest Mg concentration of 0.82 per cent in litter was observed in the first fortnight of January. Wessel (1970) had reported that within one month of leaf growth the concentration of Mg in cocoa foliage changed from 0.43 to 0.61 per cent. Wessel (1971) again reported Mg concentration of medium old and old senescing cocoa leaves to be 0.62 and 0.59 per cent, respectively.

The mean Mg concentration was 0.72 per cent in the litter from shaded field and 0.69 per cent in the litter from unshaded field. This could be explained on the basis of K-Mg antagonism (Anilkumar, 1987; Jegannathan, 1990). The K level in litter was higher in the unshaded field which tended to depress the level of Mg under such condition.

The interaction effect was however not significant on the Mg concentration of litter.

4.3.5.2 Magnesium return through cocoa litter

The Mg contribution through cocoa litter was significantly influenced by the season (Table 14). The highest Mg return of 7.11 kg ha^{-1} through litter fall was in the first fortnight of January followed by the preceding fortnight with 4.97 kg ha^{-1}.

Table 13 Magnesium content of cocoa litter in shaded and open cocoa fields at fortnightly intervals

Month	Fortnight	Magnesium content (%)		Mean
		Shaded field	Open field	
July 1995	1	0.53	0.57	0.55
	2	0.69	0.66	0.67
August 1995	3	0.64	0.72	0.68
	4	0.79	0.62	0.71
September 1995	5	0.67	0.66	0.67
	6	0.67	0.51	0.59
October 1995	7	0.52	0.50	0.51
	8	0.68	0.74	0.71
November 1995	9	0.90	0.72	0.81
	10	0.83	0.69	0.76
December 1995	11	0.75	0.74	0.74
	12	0.75	0.72	0.73
January 1996	13	0.76	0.89	0.82
	14	0.84	0.76	0.80
February 1996	15	0.70	0.65	0.68
	16	0.79	0.82	0.80
March 1996	17	0.76	0.68	0.72
	18	0.75	0.69	0.72
April 1996	19	0.80	0.75	0.78
	20	0.63	0.63	0.63
May 1996	21	0.75	0.75	0.75
	22	0.71	0.61	0.66
June 1996	23	0.77	0.75	0.76
	24	0.56	0.64	0.60
Mean		0.72	0.69	0.71

	Fortnight	Condition	Interaction
SEm±	0.042	0.012	0.06
CD (0.05)	0.117	0.034	NS

Table 14 Magnesium return through cocoa litter in shaded and open cocoa fields at fortnightly intervals

Month	Fortnight	Magnesium return (kg ha^{-1})		Mean
		Shaded field	Open field	
July 1995	1	0.78	0.56	0.67
	2	1.16	1.18	1.17
August 1995	3	0.46	1.70	1.08
	4	0.86	2.23	1.54
September 1995	5	1.40	3.21	2.31
	6	1.05	1.27	1.16
October 1995	7	0.53	1.08	0.81
	8	1.80	2.76	2.28
November 1995	9	1.08	2.41	1.75
	10	2.18	1.15	1.67
December 1995	11	1.84	2.53	2.18
	12	3.37	6.57	4.97
January 1996	13	5.86	8.36	7.11
	14	3.09	3.10	3.10
February 1996	15	3.42	2.85	3.13
	16	2.11	3.70	2.91
March 1996	17	2.66	2.79	2.73
	18	1.93	3.04	2.49
April 1996	19	0.64	1.02	0.83
	20	0.55	0.61	0.58
May 1996	21	0.79	2.18	1.48
	22	1.56	1.53	1.55
June 1996	23	0.67	1.07	0.87
	24	0.48	0.53	0.49
Total		40.27	57.43	48.85
Mean		1.68	2.39	2.04

	Fortnight	Condition	Interaction
SEm±	0.321	0.093	0.454
CD (0.05)	0.891	0.257	1.261

The effect of shaded/open environment on magnesium return was also significant. The total return of Mg was 40.27 kg ha^{-1} in the shaded field and 57.43 kg ha^{-1} in the open field. Though the concentration of Mg was lower in the open field, owing to a high litter production, the Mg return was higher here. The value of total Mg addition through cocoa litter fall comes within the range of value reported by Opakunle (1989).

The interaction between the season and growing environment was also significant. In the first fortnight of January, the Mg return through litterfall was highest in both the shaded (5.86 kg ha^{-1}) and open (8.36 kg ha^{-1}) field conditions, but they were significantly different.

Owing to the intensive litter production, the nutrient return through litter fall was also higher in the open field. The total annual litter fall was 5.3 t ha^{-1} in the shaded field and 8.2 t ha^{-1} in the open field. This difference could be due to the intensive leaf production in the open situation which has been) reported by many workers (Hurd and Cunningham, 1961; Asomaning *et al.*, 1971; Boyer, 1974).

The return of N, P, K, Ca and Mg from the shaded field was 66.72, 4.97, 59.72, 84.94 and 40.27 kg ha^{-1} yr^{-1}, respectively and from the open field it was 107.93, 6.83, 104.17, 103.68 and 57.43 kg ha^{-1} yr^{-1} (Fig. 6). The ratio of nutrient return in the shaded and open field was 1:1.7, 1:1.5, 1:1.7, 1:1.3 and 1:1.3 respectively, for N, P, K, Ca

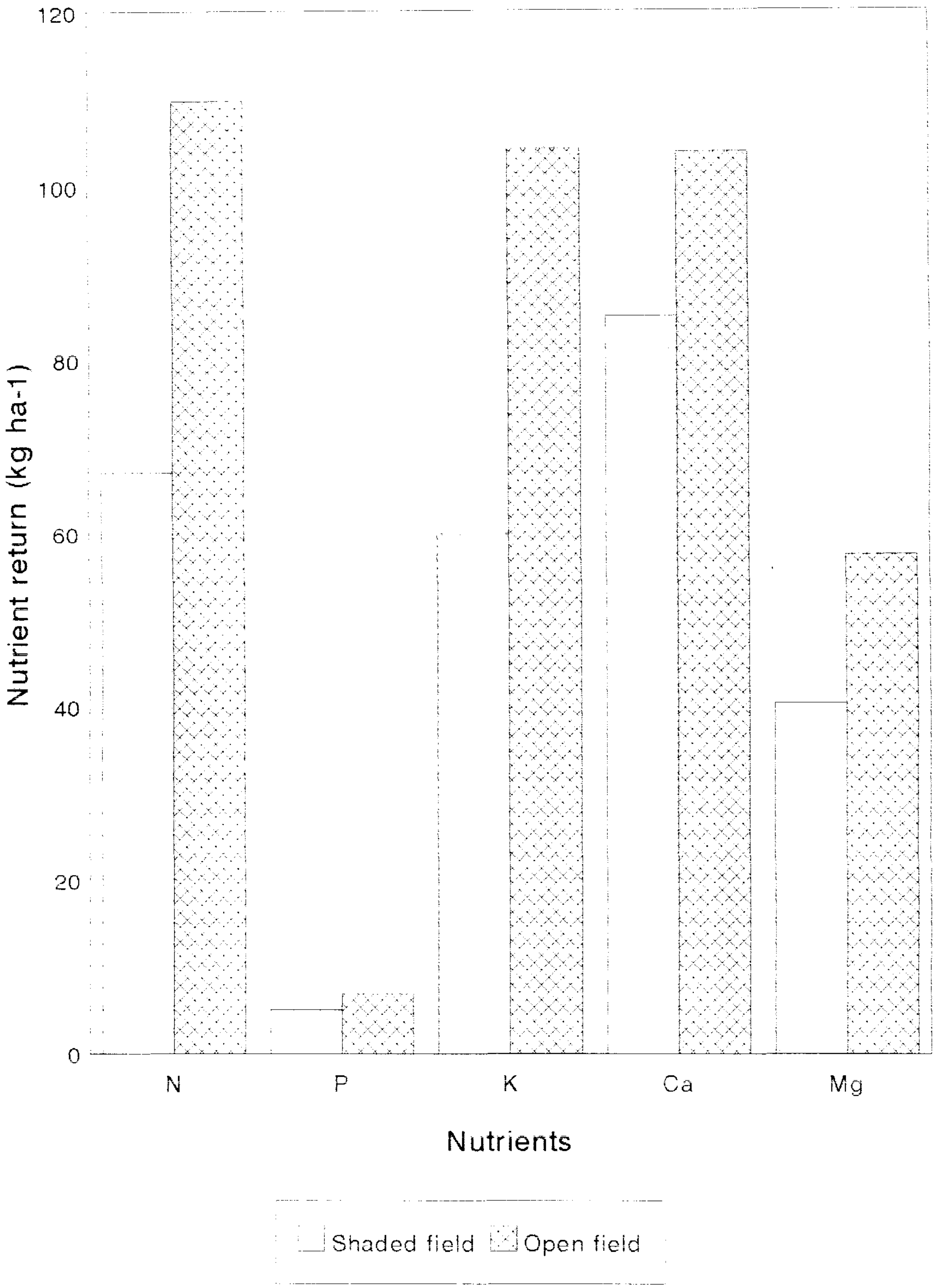

Fig.6 The annual return of nutrients through cocoa litter in shaded and open cocoa fields

and Mg. From the results obtained in the present study it could be seen that litter fall maintained the nutrient balance in the cocoa ecosystem by recycling the nutrients that were taken up from the soil for leaf growth.

4.4 Estimation of rate of decomposition of cocoa litter

The rate of decomposition of cocoa litter for one year is shown in Table 15. The litter bags were kept for decomposition in the month of July. Within two months, 40.53 percent of the original material was decomposed. More than 95 per cent of the litter was decomposed within the first four months. A fast rate of decomposition had been reported for the litter of tropical tree species by many workers (Kumar and Deepu, 1992; Kunhamu, 1994 and Hegde, 1995). Favourable moisture and temperature regimes during this season (July-November) must have contributed towards the faster rate of decomposition. An enhanced activity of soil fauna usually observed in such soil and climate also might have contributed towards a faster rate of decomposition. A very high population of millipedes and termites were seen in the field during the rainy season.

After the fourth month, the rate of decomposition increased gradually and reached a maximum of 98.83 percent by the end of the year. This implied that even after one year of exposure 1.17 per cent of the original material was not decomposed. Thus the decomposition pattern was bimodal with an initial rapid phase followed by a latter slower phase (Fig.7).

Table 15 Decomposition per cent of cocoa litter during one year

Duration	Time (t) (months)	Initial weight X^0 (g)	Wt. (x) after 't' (g)	Decomposition per cent
July-September 1995	2	26.57	15.80	40.53
September-November 1995	4	26.57	1.175	95.56
November-January 1996	6	26.57	1.165	95.62
January-March 1996	8	26.57	0.675	97.46
March-May 1996	10	26.57	0.557	97.90
May-July 1996	12	26.57	0.310	98.83

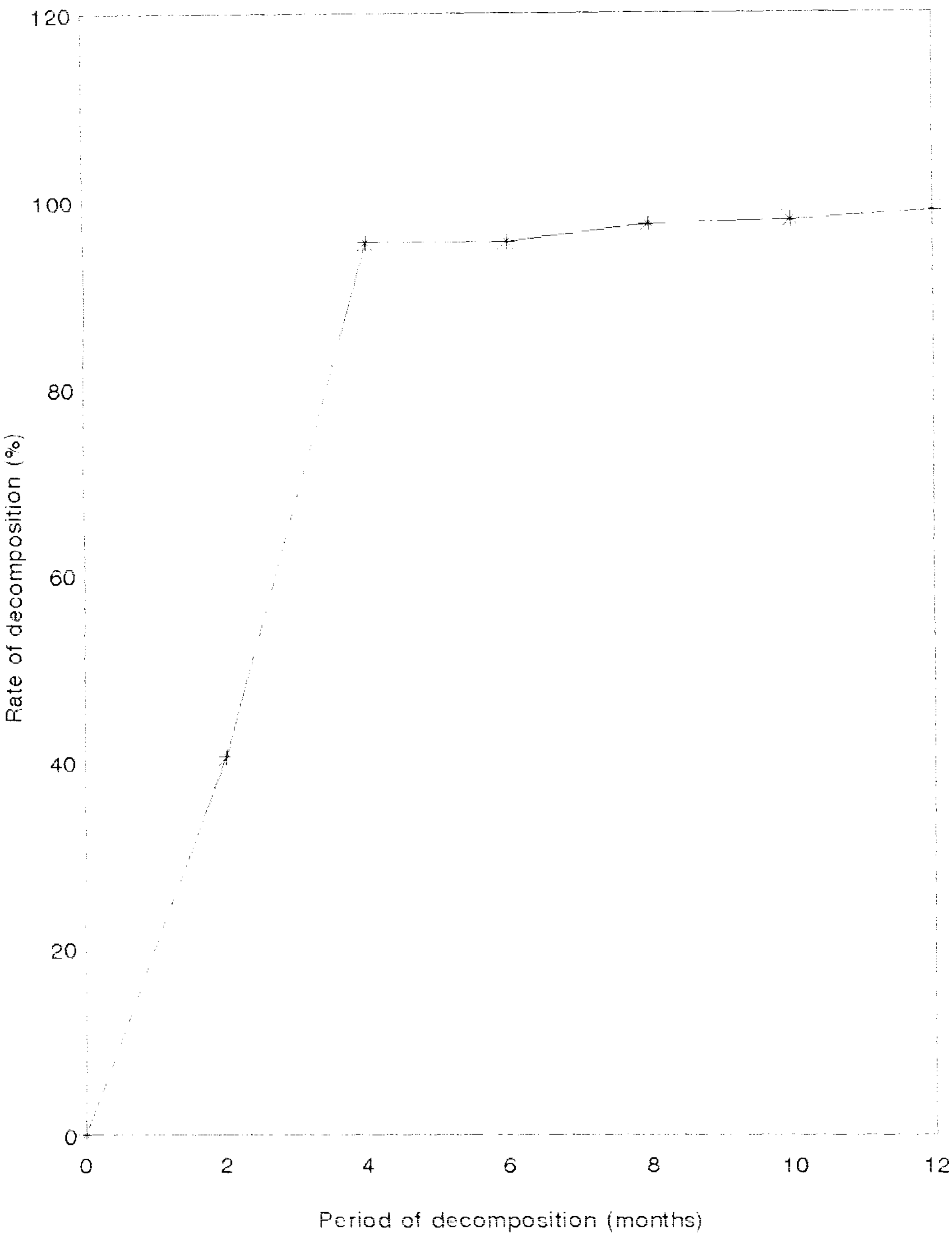

Fig.7 Rate of decomposition of cocoa litter during one year

The initial rapid phase could be due to congenial environmental conditions associated with the presence of readily digestible water soluble compounds in the litter. This might have triggered the activity of soil fauna and soil microbes which are responsible for decomposition. In addition, the high leaching losses of water soluble fractions from the decomposing materials during the rainy periods might have resulted in a heavy mass loss during the initial phase (Hegde, 1995).

The latter slower phase could be due to absence of congenial condition such as high rainfall and also due to the increased content of bio-decay resistant compounds (Berg and Staaf, 1981).

The rate of decomposition of cocoa residue was a function of time of exposure. The decay rate coefficient, K, to study the constant potential weight loss was worked out by an exponential model (3.2.4). Model (1) was estimated by least square technique after logarithmic transformation. Values of X_0 and K in model (1) was estimated to be 16.56 and 0.3679 respectively. The value of K indicates the relative rate of decomposition in a month. Comparable K values had been reported for litter of tropical tree species by Hegde (1995).

The coefficient of determination (R^2) was 0.853 indicating a fairly good fit of the model to the observed data. The observed weight of cocoa litter along with the expected weights based on the estimated model is given in Table 16, for examination of the fit.

Table 16 Observed and expected weights of cocoa litter after one year of exposure to decomposition

Period of exposure (months)	Observed weight (g)	Expected weight (g)
0	26.570	16.560
2	15.800	7.932
4	1.175	3.792
6	1.165	1.820
8	0.675	0.873
10	0.557	0.417
12	0.310	0.199

Future line of work

The present study could bring out only the decomposition pattern of litter fallen during a particular month. Since litter fall is a continuous process, it is worthwhile to study the decomposition pattern of freshly fallen litter during every month/season of the year. The activity of soil fauna responsible for decomposition may change with season. The population and related aspects of soil fauna and their influence on rate of decomposition also should be examined in detail.

Summary

SUMMARY

An investigation was carried out at the College of Horticulture in the cocoa fields of Cadbury-KAU Co-operative Cocoa Research Project during 1995-'96 to study the organic recycling through cocoa litter. The objectives of the study included finding out the time required for natural senescence of cocoa leaves, the quantity of litter produced in a cocoa field in an year, the nutrient contribution through litter fall and also the rate of decomposition of cocoa litter.

The studies were undertaken both in the shaded and unshaded conditions. The litter decomposition study was carried out only in the shaded condition since cocoa is usually grown as an intercrop in farmer's field.

The salient findings of the study are summarised below:

There was significant difference in the lifespan of cocoa leaves between the shaded and open fields. The fresh hardened leaves took 94 to 193 days in the shaded situation and 109 to 159 days in the open situation for shedding. In the open field, all the leaves selected for study were shed within five and a half months whereas in the shaded condition it was only around 75 per cent, which indicated that the leaves were retained for a longer period in the shaded situation.

The quantity of total litter produced was significantly influenced by the season, shaded/open condition and their interaction. The total annual litter fall on dry weight basis was 5.3 t ha^{-1} in the shaded field and 8.2 t ha^{-1} in the open field. Peak litter fall was observed in the first fortnight of January, irrespective of the shaded/open condition. A higher rate of litter fall in both the situations occurred during December to March. During this period, nearly 70 per cent of the annual litter fall occurred in the shaded and open fields. There was very little litter fall during the wetter months of the year.

The nutrient contribution through litter fall was also higher in the open field. The addition of N, P, K, Ca and Mg through litter fall was significantly influenced by the season, shaded/open condition and their interaction.

The addition of N through litter fall was 66.9 kg ha^{-1} yr^{-1} in the shaded field and 109.7 kg ha^{-1} yr^{-1} in the open field.

Phosphorus return was 5.0 and 6.8 kg ha^{-1} yr^{-1} in the shaded and open fields, respectively.

Potassium addition through litter fall was 59.7 and 104.2 kg ha^{-1} yr^{-1} respectively, in the shaded and open fields.

Return of calcium through cocoa litter was 84.9 kg ha^{-1} yr^{-1} in the shaded field while it was 103.7 kg ha^{-1} yr^{-1} in the open field.

The addition of magnesium amounted to 40.3 and 57.4 kg ha^{-1} yr^{-1} in the shaded and open fields respectively.

The decomposition of cocoa litter followed a biphasic pattern. There was an initial rapid phase followed by a slower phase. Nearly 95 per cent of litter was decomposed within the first four months. Thereafter, the decomposition proceeded gradually and reached 98.9 per cent by the end of one year. The decay rate coefficient, K, value was worked out to be 0.3679.

Considering the substantially high quantity of litter produced and nutrients recycled it can be concluded that litter fall has an important role in maintaining nutrient balance in cocoa ecosystem.

References

REFERENCES

Aber, J.D. and Melillo, J.M. 1980. Litter decomposition: Measuring relative contribtions of organic matter and nitrogen to forest soils. *Can. J. Bot.* **60**: 2263-69

Alexander, M. 1977. *Introduction to Soil Microbiology.* 2nd ed., Wiley Eastern Ltd, New Delhi, p. 467

Alvim, P. de T. 1977. Cacao. Alvim, P. de T and Kozlowski, T.T. (eds.) *Ecophysiology of Tropical Crops.* Academic Press, London, p. 502

*Alvim, P.de T., Machado, A.D. and Grangler, A. Jr. 1969. Alguns estudos sobre as relacoes de agua solo e cresci men to do caca ueiro. *Mem. Conf. Int. Pesquis cacau* p. 316-326

Anilkumar, K.S. 1987. Chemistry of coconut rhizosphere. M.Sc. (Ag.) thesis, Kerala Agricultural University, Thrissur, Kerala

Aranguren, J., Escalente, G. and Herrera, R. 1982a. Nitrogen cycle of tropical perennial crops under shade trees. I. Coffee. *Pl. Soil* **67**: 247-258

Aranguren, J., Esscalente, G. and Herrera, R. 1982b. Nitrogen cycle of tropical perennial crops under shade trees. II Cacao. *Pl. Soil* **67**: 259-269

Ashton, D.H. 1975. Studies of litter in *Eucalyptus regnans* forest. *Aus. J. Bot.,* **23**: 413-433

Asomaning, E.J.A., Kwakwa, R.S. and Hutscheon, W.V. 1971. Physiological studies on an Amazon shade and fertiliser trial at the Cocoa Research Institute of Ghana. *Ghana J. agri. Sci.* **4**: 47-64

Bahuguna, V.K., Negi, J.D.S., Joshi, S.R. aand Naithani, K.C. 1990. Leaf litter decomposition and nutrient release in *Shorea robusta* and *Eucalyptus camaldulensis* plantations. *Indian For.* **116**: 103-114

Beer, J.W. 1988. Litter production and nutrient cycling in coffee (*Coffea arabica*) or cacao (*Theobroma cacao*) plantations with shade trees. *Agrofor.* 7(2): 103-114

Beer, J., Bonnemann, A., Chavez, W., Fassbender, H.W., Imbach, A.C. and Martel, I. 1990. Modelling agro-forestry systems of cacao *(Theobroma cacao)*with *Cordia alliodora* and *Erythrina poeppigiana* in Costa Rica. V. Productivity indices, organic matter models and sustainability over ten years. *Agrofor. Syst.* **12**: 229-249

*Berg, B. and Staaf, H. 1981. Leaching, accumulation and release of nitrogen in decomposing forest litter. Clark, F.E. and Rosswall, T. (ed.). *Terrestrial Nitrogen Cycles: Processes, Ecosystem Strategies and Management Impacts.* Ecological Bulletins, Stockholus, p. 163-178

Birch, H.F. 1961. Phosphorus transformations during plant decomposition. *Pl. Soil* **15**: 347-365

Bocock, K.L. 1964. Changes in the amount of dry matter, nitrogen, carbon and energy in decomposing woodland leaf litter in relation to activities of the soil fauna. *J. Ecol.* **52**: 273-284

Bocock, K.L. and Gilbert, O.J.W. 1957. The disappearance of litter under different wood land conditions. *Pl. Soil* **9**: 179-185

*Boyer, J. 1973. Cicles de la ma tiere organiqie et des elements mineraux dans une cacaoyere camerounaise. *Cafe. Cacao The* **17**: 3-24

*Boyer, J. 1974. Etude ecophysiologique de development de cacaoyers cultivesau Cameroun. *Cafe cacao The.* **18**: 3-30

Brady, N.C. 1984. *The Nature and Properties of Soils.* Eurasia Publishing House, New Delhi, p. 737

Bray, J.R. and Gorham, E. 1964. Litter production in the forests of the world. *Adv. Ecol. Res.* **2**: 101-157

Cisternas, R.E. and Yates, L.R. 1982. Nitrogen in litter fall and precipitation and its release during litter decomposition in the chilean piedmont matorral. *Pl. Soil* **67**: 359-365

Cochran, W.G. and Cox, G.M. 1957. *Experimental Designs*. 2nd ed., Wiley, New York

Cooper, A. 1982. Litter fall and decomposition in tropical xeromorphic wood land and shrub. *Trop. Ecol.* **23**(2): 193-207

Dalton, J.D., Russel, C.G. and Sieling, D.H. 1952. Effect of organic matter on phosphate availability. *Soil Sci.* **73**: 173-181

Das, A.K. and Ramakrishnan, P.S. 1985. Litter dynamics in khasipine of North East India. *For. Ecol. Manage.* **10**: 135-153

Daubenmire, R. and Prusso, D.C. 1963. Studies of the decomposition rates of tree litter. *Ecology* **44**(3): 589-592

Devineau, J.L. 1976. Preliminary data on the litter and leaf fall in some semi-deciduous forest of Central Ivory Coast. *Oecol. Pl.* **11**(4): 375-395

Egunjobi, J.K. 1974. Litter fall and mineralization in a teak (*Tectona grandis*) stand. *Oikos* **25**:(2): 222-226

Eklahya, S. and Ambasht, R.S. 1987. Litterfall decomposition and nutrient release in an age sequence of *Alnus repalensis* plantations stand in the eastern Himalaya. *J. Ecol.* **77**: 997-1010

*Eernstman, T. 1968. Chemical analysis of leaves and other organs of *Theobroma cacao* L. as a means of diagnosing fertilizer requirements. Pub. No.54, PUDOC Wageningen, p. 55

Esau, K. 1965. *Plant Anatomy.* 2nd ed., Wiley Eastern Ltd, New Delhi, p. 767

Ewel, J.J. 1976. Litter fall and leaf decomposition in tropical forests succession in eastern Guatemala. *J. Ecol.* **64**: 293-308

Fahn, A. 1990. *Plant Anatomy.* 4th ed., Pergamon Press, New York, p. 588

Fassbender, H.W., Beer, J., Heuveldop, J., Imbach, A., Enriquez, G. and Bonnemann, A. 1991. Ten year balances of organic matter and nutrients in agroforestry systems at CATIE, Costa Rica. *For. Ecol. Manage.* **45**: 173-183

Field, C. and Mooney, H.A. 1983. Leaf age and seasonal effects on light, water and nitrogen use efficiency in California shrub. *Oecologia* **56**: 348-355

Gardner, F.P., Pearce, R.B. and Mitchell, R.L. 1985. *Physiology of Crop Plants.* Scientific Publishers, Jodhpur, p. 327

George, M. 1982. Litter production and nutrient return in *Eucalyptus hybrid* plantations. *Indian For.* **108**: 253-259

Gill, H.S., Abrol, I.P. and Samra, J.S. 1987. Nutrient recycling through litter production in young plantations of *Acacia nilotica* and *Eucalyptus tereticornis* in a highly alkaline soil. *For. Ecol. Manage.* **22**(1-2): 57-69

Gopinathan, R. 1981. Effect of shade and moisture regimes on the growth of cocoa (*Theobroma cacao* L.) M.Sc. (Ag.) thesis, Kerala Agricultural University, Thrissur, Kerala

Gosz, J.R., Likens, G.E. and Bormann, F.H. 1973. Nutrient release from decomposing leaf and branch litter in the Hubbard Brook forest, New Hempshire. *Ecol. Monogr.* **43**: 173-191

*Gupta, S.R. and Singh, J.S. 1977. Decomposition of litter in a tropical grassland. *Pedobiologia* **17**: 330-333

*Hardy, F. 1958. The light relation of cocoa. *Cocoa Manual.,* Inter. Amer. Inst Agric. Sci. Turrialla, Costa Rica. p. 85-91

Harmon, M.E., Baker, G.A., Spycher, G. and Greene, S.E. 1990. Leaf litter decomposition in Picea/Tsuga forests of Olympic National Park, Washington, USA. *For. Ecol. Manage.* **31**: 55-66

Hegde, R. 1995. Nutrient content and decomposition of leaf litter of *Acacia mangium* Willd as affected by season and field conditions. M.Sc. thesis, Kerala Agricultural University, Vellanikkara

Hesse, P.R. 1971. *A Text Book of Soil Chemical Analysis.* John Murray Publishers, Ltd., London, p. 520

Hirose, T. 1988. Modelling the relative growth rate as a function of plant nitrogen concentration. *Physiol. Plant.* **72**: 185-189

Hopkins, B. 1966. Vegetation of the Olokemiji Reserve, Nigeria. IV. The litter and soil with special reference to their seasonal changes. *J. Ecol.* **54**: 687-703

*Hoyle, M.C. 1973. Nature and properties of some forest soils in the white mountains of New Hampshire. USDA Forest Service Research Paper. NE **260**: 18

Hunt, H.W., Ingham, E.R., Coleman, D.C., Elliot, E.T. and Reid, C.P.P. 1988. Nitrogen limitation of production and decomposition in prairie, mountain meadow and pine forest. *Ecology* **69**: 1009-1016

Hurd, R.G. and Cunningham, R.K. 1961. A cocoa shade and manurial experiment at the West African Cocoa Research Institute III. Physiological results. *J. hort. Sci.* **36**: 126-137

Hutson, B.R. and Veitch, L.G. 1985. Relationships between litter fall rate, litter mass and decomposition rate in Eucalyptus forests in Australia. *Aus. J. Ecol.* **10**: 443-450

Jackson, M.L. 1958. *Soil Chemical Analysis.* Prentice Hall Inc. Engle Wood Cliffs, N.J., USA, reprint (1973) by Prentice Hall of India (Pvt.) Ltd., New Delhi

Jenney, H., Gessel, S.P. and Bingham, F.T. 1949. Comparative study of decomposition rates of organic matter in temperate and tropical regions. *Soil Sci.* **68**: 419-432

Jensen, V. 1974. Decomposition of angiosperm tree leaf litter. Dickinson, C.H. and Pugh, G.J.F. (eds.) *Biology of Plant Litter Decomposition Vol.I.* Academic Press, London, p.75-84

Jegannathan, M. 1990. Studies on potassium magnesium interaction in coconut (*Cocos nucifera*) *Cocos* **8**: 1-7

KAU, 1993. *Package of Practices Recommendations 'Crops'.* Directorate of Extension, Kerala Agricultural University, Vellanikkar, p. 149-159

Kumar, B.M. and Deepu, J.K. 1992. Litter production and decomposition dynamics in moist deciduous forests of the Western Ghats in Peninsular, India. *For. Ecol. Manage.* **50**: 181-201

Kunhamu, T.K. 1994. Nutrient content and decomposition of leaf biomass of selected woody tree species. M.Sc. thesis, Kerala Agricultural University, Vellanikkara, Thrissur

Kunhamu, T.K., Kumar, B.M., Assif, P.K. and Jayadevan, C.N. 1994. Litter yield and decomposition under *Acacia auriculiformis.* NFTRR **12**: 29-32

Lalman, A. and Mishra, A. 1985. Nutrients utilization in some tropical forest seedlings. *Indian For.* **111**: 368-384

*Lata, K. and Bisht, N.S. 1993. Foliar nutrients during growth phases of *Q. leucotrichophora* growing at different aspects in Garhwal, Himalaya. *Indian J. For.* **16**(1): 62-66

*Leite, O.J. 1985. Relacaoentre O fosforo, O potassio e O calcio contidos em quatro components de ecossistema cacau na Bahia *Rev. Bras. Ci. do solo* **9**: 95-101

*Ling, A.H. 1986. Litter production and nutrient cycling in a mature cocoa plantation on inland soils of Peninsulaar Malaysia. International Conference on Cocoa and Coconuts: Progress and Outlook p. 451-467

Lohins, F. 1926. Nitrogen availability of green manures. *Soil Sci.* **22**: 253-290

Lugo, A.E., Cuevas, E. and Sanchez, M.J. 1990. Nutrients and mass in litter and top soil of ten tropical tree plantations. *Pl. Soil* **125**: 263-280

*Luizao, F.J. and Schubart, H.O.R. 1987. Litter production and decomposition in a terra - firme forest of Central Amazonia. *Experientia* **43**: 259-265

*Madge, D.S. 1965. Litter fall and litter disappearance in a tropical forest. *Pedobiologia* **5**: 273-288

Mason, A.C. and White field, A.B. 1960. Seasonal changes in uptake and distribution of mineral elements in apple trees. *J. hort. Sci.* **35**: 34-55

Mathur, H.N., Singh, R.D. and Gupta, M.K. 1982. Comparative study of infiltration in soils under forest cover and agriculture in temperate climate *Indian For.* **108**: 648-652

Melillo, J.M., Aber, J.D. and Muratore, J.F. 1982. Nitrogen and lignin control of hardwood leaf litter decomposition dynamics. *Ecology* **63**: 621-626

Montagnini, F. and Sancho, F. 1994. Above ground biomass and nutrients in young plantations of indegenous trees on infertile soils in Costa Rica: Implications for site nutrient conservation. *J. Sustainable Forestry* **1**(4): 115-139

Moore, A.M. 1986. Temperature and moisture dependence of decomposition rates of hardwood and coniferous leaf litter. *Soil Biol. Biochem.* **18**: 427-435

Moore, T.C. 1980. *Biochemistry and Physiology of Plant Hormones.* Narosa Publishing House and Springer Verlag, New Delhi, p. 274

Murray, D.B. 1967. Leaf analysis applied to cocoa. *Cocoa Growers Bull.* **9**: 25-31

Mwiinga, D.R., Kwesiga, F.R. and Kamara, C.S. 1994. Decomposition of leaves of six multipurpose tree species in chipata, Zambia. *For. Ecol. Manage.* **64**: 209-216

Nelliat, E.V., Gopalasundaram, P., Thomas Varghese, P. and Sivaraman, K. 1979. Mixed cropping in coconut, In *Multiple Cropping in Coconut and Arecanut Gardens,* CPCRI, p. 28-33

Nohrstedt, H.O., Arnebrant, K., Baath, E. and Soderstrom, B. 1989. Changes in carbon content, respiration rate, ATP content and mircrobial biomass in nitrogen-fertilized pine forest soils in Sweden. *Can. J. For. Res.* **19**: 323-328

O'connell, A.M. 1994. Decomposition and nutrient content of litter in a fertilized eucalypt forest. *Biol. Fertil. Soils* **17**: 159-166

Olson, J.S. 1963. Energy storage and balance of producers and decomposers in ecological systems. *Ecology.* **44**: 322-331

Omotoso, T.I. 1975. Amounts of nutrients removed from the soil in harvested Amelonado and F_3 Amazon cacao during a year. *Turrialba.* **25**: 425-428

Onland, K. 1963. Changes in the content of dry matter and major nutrient elements of apple foliage during senescence and abscission. *Physiologia Pl.* 16: 687-94

Opakunle, J.S. 1989. Nutrient distribution and cycling in a *Theobroma cacao* L. agroecosystem in South Western Nigeria. *Acta Oecologica* **10**(4): 347-357

Osman, K.T., Haque, S.M.S. and Mia, F. 1992. Above ground biomass and nutrient distribution in *Acacia auriculiformis, Dipterocarpus turbinalis* and *Pinus caribaea* plantations at Chittagong University hills. *Indian J. For.* **15**: 193-197

Ovington, J.D. 1962. Quantitative ecology and woodland ecosystem concept. *Adv. Ecol. Res.* **1**: 103-192

Owusu, J.K., Adomako, D. and Hutcheon, W.V. 1978. Seasonal changes in total free sugar content of cocoa plants *Physiol. Plant.* **44**: 43-47

Palmer, J.W. 1988. Annual drymatter production and partitioning over the first 5 years of 2 bed system of erispin/m-27 apple tree at four spacings. *J. appl. Ecol.* **25**: 569-578

Pande, P.K. and Sharma, S.C. 1993. Biochemical cycling and nutrient conservation strategy in some plantations. *Indian For.* **119**: 299-305

Panse, V.G. and Sukhatme, P.V. 1985. *Statistical Methods for Agricultural Workers.* 4th ed., ICAR, New Delhi, p.347

Perala, D.A. and Alaban, D.H. 1982. Biomass, nutrient distribution and litter fall in *Populus, Pinus* and *Picea* stands on two different soils in Minnesota. *Pl. Soil* **64**: 177-192

Piper, C.S. 1942. *Soil and Plant Analysis.* Academic Press, New York, Asian Reprint, 1966, Hans Publishers, Bombay, p. 368

Pochriyal, T.C., Pant, S.P. and Joshy, S.R. 1989. Leaf emergence and shedding behaviour of *Populus deltoides. Indian For.* **115**: 48-51

Prasad, N.G.A., Totey, N.G., Khari, P.K. and Bhowmik, A.K. 1991. Effect of added tree leaves on the composition of humus and availablity of nutrients in soil *J. Indian Soc. Soil Sci.* **39**: 429-434

Prasad, R. and Mishra, G.P. 1985. Litter productions of dry deciduous teak forest stands of Sagar, Madhya Pradesh. *Indian For.* **111**: 359-367

Prescott, C.E., Corbin, J.P. and Parkinson, D. 1992. Immobilization and availability of N and P in the forest floors of fertilized Rocky Mountain coniferous forests. *Pl. Soil* **143**: 1-10

Prichett, W.L. and Fisher, F.F. 1987. *Properties and Management of Forest Soils.* 2nd (ed.), John Wiley, New York, p. 494

Puri, G.S. and Gupta, A.C. 1954. Seasonal variation in foliage composition of some Indian forest trees. *J. Indian Bot. Soc.* **33**: 382-393

Raizada, A. and Srivastava, M.M. 1986. Litter production in *Populus deltoides* marsh plantation. *For. Ecol. Manage.* **15**: 215-218

Raizada, A. and Srivastava, M.M. 1991. Nutrient accumulation in standing crop and returns through litter fall in a *Populus deltoides* marsh. Plantation. *Van vigyan* **29**(4): 192-199

Rajvanshi, R. and Gupta, S.R. 1985. Biomass, productivity and litter fall in a tropical *Dalbergia sisoo* Roxb. forest. *J. Tree Sci.* **4**(2): 73-78

Rangaswamy, G. and Bagyaraj, 1993. *Agricultural Microbiology.* 2nd ed., Prentice Hall of India. Pvt Ltd, New Delhi, p. 211-217

Reiner, W.A. and Lang, G.E. 1987. Change in litter fall along a gradient in altitude. *J. Ecol* **75**: 629-638

Rethinam, P. 1995. Cocoa - New hope for farmers. *Survey of Indian Agriculture.* The Hindu, Kasthuri and Sons (Ltd.), Madras, p.107

Sale, P.J.M. 1970. Growth, flowering and fruiting of cacao under controlled soil moisture conditions *J. hort. Sci.* **45**: 99-118

Sankaran, A. 1966. *A Laboratory Manual for Agricultural Chemistry.* Asia Publishing House

Sankaran, K.V. 1993. Decomposition of leaf litter of albizzia (*Paraserianthus falcataria*), eucalypt (*Eucalyptus tereticornis* and teak *(Tectona grandis)* in Kerala, India. *For. Ecol. Manage.* **56**(1-4): 225-242

Sankaran, K.V., Balasundaran, M., Thomas, P.T. and Swatha, M.P. 1993. *Leaf Litter Dynamics, Microbial Associations and Soil Studies in Acacia auriculliformis Plantations in Kerala.* Kerala Forest Research Institute, Peechi, Kerala, p. 55

Santana, M.B.M. and Cabala, R.P. 1982. Dynamics of nitrogen in a shaded cocoa planation. *Pl. Soil* **67**: 271-281

*Santana, M.B.M. and Cabala, R.P. 1983. Nitrogen requirements in a cocoa agrosystem. *Revista Theobroma* **13**(3): 211-221

*Santana, M.B.M., Cabala, R.P. and Serodio, M.H. 1987. Nutrient recycling in cocoa agrosystems. *Proceedings of the Tenth International Cocoa Research Conference, Santo Dominigo, Dominican Republic.* Cocoa Producers Alliance, Lagos, Nigeria, p. 233-237

Seastedt, T.R. and Crossley, Jr. D.A. 1983. Nutrients in forest litter treated naphthalene and simulated through fall: A field microsom study. *Soil Biol. Biochem.* **15**: 159-165

Sharma, D.C., Taulja, R.C. and Bisht, A.P.S. 1988. Biomass productivity and nutrient cycling in a *Dalbergia sissoo* plantation. *Indian For.* **114**: 261-267

Sharma, S.C. and Pande, P.K. 1989. Patterns of litter nutrient concentration in some plantation ecosystem. *For. Ecol. Manage.* **29**: 151-163

*Singh, A.K., Ambasht, R.S. and Mishra, C.N. 1980. Litter production and turn over of organic matter in a tropical *Zizyphus jujuba* shrub community. *Jap. J. Ecol.* **30**: 203-209

Singh, J.S. and Gupta, S.R. 1977. Plant decomposition and soil respiration in terrestrial ecosystems. *Botanical Review* **43**: 449-528

Singh, K.P. 1969. Nutrient concentration in leaf litter of ten important tree species of deciduous forests at Varanasi. *Trop. Ecol.* **10**: 83-95

Singh, O., Sharma, D.C. and Rawat, J.K. 1992. Biomass and nutrient release in natural sal, Eucalyptus and Poplar plantations of Uttar Pradesh. *Van vigyan.* **30**(3-4): 134-140

Singh, O., Sharma, D.C. and Rawat, J.K. 1993. Production and decomposition of leaf litter in sal, teak, eucalyptus and poplar forests in Uttar Pradesh. *Indian For.* **119**: 112-120

Singh, R.P. 1984. Nutrient cycle in *E. tereticornis* plantation. *Indian For.* **110**: 76-85

Sivanadyan, K., Ghandimathi, H. and Haridas, G. 1995. *Rubber, A Unique crop: The Mature Hevea Stand as a Nutritionally Self-sustaining Ecosystem in Relation to Latex Yield.* Rubber Research Institute of Malaysia, p. 52

Small, E. 1972. Ecological significance of four critical elements in plants of raised sphagnum peat bogs. *Ecology* **53**: 498-503

Sugur, G.V. 1989. Litter production and nutrient cycling of different species under plantation conditions. *My Forest* **25**(1): 43-49

Swift, M.J., Heal, O.W. and Anderson, J.M., 1979. *Decomposition in Terrestrial Ecosystems.* Black Well, Oxford, p. 372

Tate, R.L. 1987. *Soil Organic Matter, Biological and Ecological Effects.* John Wiley and Sons, Singapore, p. 291

Taylor, B.R., Parkinson, D. and Parsons, W.F.J. 1989. Nitrogen and lignin content as predictors of litter decay rates: a microsom test. *Ecology*. **70**: 97-104

Theodore, C. and Bowen, G.D. 1990. Effects of fertilizers on litter fall and N and P release from decomposing litter on a *Pinus radiata* plantation. *For. Ecol. Manage.* **32**: 87-102

Tisdale, S.L., Nelson, W.L., Beaton, J.D. and Havlin, J.L. 1995. *Soil Fertility and Fertilizers.* 5th ed., Prentice Hall of INdia Pvt. Ltd, New Delhi, p. 634

Titus, B.D. and Malcolm, D.C. 1987. The effect of fertilization on litter decomposition in clearfelled spruce stands. *Pl. Soil* **100**: 297-322

Tukey, H.B. 1969. Leaching of substances from plants. *An. Rev. Pl. Physiol.* **21**: 305-324

Varghese, P.T., Nelliat, E.V. and Balakrishnan, T.K. 1978. Beneficial interactions of coconut-cocoa crop combination. *Proc. PLACROSYM I., CPCRI,* Kasaragod, India, p. 383-392

Vasudeva, N. 1967. Preliminary studies on the growth of coffee leaves. *Indian Coffee.* **31**(8): 5-6

Vasudeva, N. and Gopal, N.H. 1975. Studies on leaf growth V. The life span of coffee leaves in South India. *Indian Coffee* **39**(6): 171-174

Venkataramanan, C., Haldorai, B., Samraj, P., Nalatwadmath, S.K. and Henry, C. 1983. Return of nutrients by the leaf litter of blue gum and black wattle plantations of Nilgiri. *Indian For.* **109**: 370-378

Vogt, K.A., Grier, C.G. and Vogt, D.J. 1986. Production turnover and nutrient dynamics of above and below grounds detritus of world forests. *Adv. Ecol. Res.* **15**: 303-377

Watanabe, F.S. and Olsen, S.R. 1965. Test of an ascorbic acid method for determining phosphorus in water and $NaHCO_3$ extracts from soil. *Proc. Soil Sci. Soc. Am.* **29:** 677-678

Waughman, G.J. and Bellamy, D.J. 1981. Movement of cations in some plant species prior to leaf senescence. *Ann. Bot.* **47**: 141-145

Wessel, M. 1970. Intake and export of nutrients in cacao leaves. *Trop. agric. Trin.* **47**(2): 167-170

*Wessel, M. 1971. Fertiliser requirements of cacao (*Theobroma cacao* L.) in South Western Nigeria. Communication 61., Dept. of Agric. Res., Royal Trop. Inst. Amsterdam

*Will, G.M., Hodgkiss, P.D. and Madgwick, H.A.I. 1984. Nutrient losses from litter bags containing *Pinus radiata* litter: Influences of thinning, clear-felling and urea fertilizer. *New Zealand J. For. Sci.* **13**: 291-304

Wood, G.A.R. and Lass, R.A. 1985. *Cocoa*. 4th ed., Longman, New York, p. 620

Young, A. 1989. *Agroforestry for Soil Conservation.* CAB International and ICRAF, Walling Ford, UK p. 276

Zavitkovski, J. and Newton, M. 1971. Forest biomass studies. *Pl. Soil* **35**: 257-268

* Originals not seen

Appendices

APPENDIX I

Meteorological data (weekly average) for the experimental period
(from 03-07-1995 to 30-06-1996)

Standard week No.	Month and date	Total rainfall (mm)	Temperature		Relative humidity		Sunshine hours	Wind speed (km h^{-1})	Evapo-ration mm/day
			max.°C	Min.°C	FN (%)	AN (%)			
27	Jul 2-8	122.6	30.7	23.4	94	78	3.4	2.1	3.2
28	Jul 9-15	160.3	28.9	23.0	96	86	1.2	2.0	2.6
29	Jul 16-22	227.8	30.0	23.2	97	81	1.8	2.2	2.6
30	Jul 23-29	209.0	29.8	23.1	96	79	2.3	2.1	3.1
31	Jul 30-Aug 5	169.9	30.2	23.3	95	76	3.6	2.0	2.6
32	Aug 6-12	40.8	31.3	24.1	93	73	4.6	2.5	3.5
33	Aug 13-19	113.7	31.3	23.6	94	74	5.2	2.6	3.3
34	Aug 20-26	107.8	31.0	24.2	94	80	3.7	2.0	2.8
35	Aug 27-Sep 2	194.4	28.5	23.3	95	87	0.2	2.5	2.9
36	Sep 3-9	89.6	30.0	23.9	94	78	3.7	2.6	3.1
37	Sep 10-16	25.2	32.0	23.5	92	66	8.5	1.4	3.5
38	Sep 17-23	121.3	31.0	23.3	94	72	4.7	1.5	2.5
39	Sep 24-30	109.0	32.4	23.1	94	63	9.4	1.7	3.5
40	Oct 1-7	3.8	33.0	23.2	93	68	8.0	1.4	3.0
41	Oct 8-14	12.4	32.0	22.9	92	67	7.0	1.9	3.3

Contd....2

Appendix 1 contd...

Standard week No.	Month and date	Total rainfall (mm)	Temperature		Relative humidity		Sunshine hours	Wind speed (km h^{-1})	Evapo-ration mm/day
			max.°C	Min.°C	FN (%)	AN (%)			
42	Oct 15-21	7.4	33.1	23.2	95	62	9.1	1.3	4.0
43	Oct 22-28	15.0	34.3	23.5	84	58	9.1	2.7	4.4
44	Oct 29-Nov 4	144.5	33.5	22.8	94	73	6.5	1.1	3.7
45	Nov 5-11	15.1	30.2	22.7	94	76	2.2	0.5	2.1
46	Nov 12-18	0.6	30.9	22.3	90	73	8.2	1.0	2.8
47	Nov 19-25	0.0	31.6	22.8	95	63	7.6	0.8	3.1
48	Nov 26-Dec 2	0.0	32.3	21.9	80	51	10.2	1.8	3.9
49	Dec 3-9	0.0	32.9	20.6	75	48	10.7	4.7	4.9
50	Dec 10-16	0.0	32.6	20.9	67	43	10.0	5.4	5.5
51	Dec 17-23	0.0	31.9	21.7	67	44	10.5	8.1	8.5
52	Dec 24-31	0.0	32.3	22.3	73	41	10.0	8.6	6.7
1	Jan 1-7	0.0	32.4	22.6	76	41	9.4	8.3	6.1
2	Jan 8-14	0.0	32.9	22.4	71	35	9.9	7.9	7.1
3	Jan 15-21	0.0	33.6	22.9	77	38	8.1	3.9	5.3
4	Jan 22-28	0.0	33.3	21.7	62	28	9.9	7.5	7.9

Contd.....3

Appendix 1 contd.....

Standard week No.	Month and date	Total rainfall (mm)	Temperature		Relative humidity		Sunshine hours	Wind speed (km h⁻¹)	Evapo-ration mm/day
			max.°C	Min.°C	FN (%)	AN (%)			
5	Jan 29-Feb 4	0.0	33.6	22.0	67	32	10.2	8.5	8.3
6	Feb 5-11	0.0	34.1	23.1	68	34	10.1	7.2	6.8
7	Feb 12-18	0.0	34.8	23.3	71	30	9.6	5.5	6.6
8	Feb 19-25	0.0	35.2	24.2	77	38	9.7	4.5	7.0
9	Feb 26-Mar 4	0.0	35.9	23.5	71	28	10.4	5.6	7.5
10	Mar 5-11	0.0	37.1	22.9	70	19	10.4	4.3	8.0
11	Mar 12-18	0.0	37.4	24.8	90	36	7.9	2.9	6.8
12	Mar 19-25	0.0	36.5	25.6	86	47	9.0	3.2	6.7
13	Mar 26-Apr 1	0.0	35.0	25.0	87	57	6.6	3.1	5.5
14	Apr 2-8	9.0	36.1	25.4	83	59	8.0	2.8	5.8
15	Apr 9-15	8.6	34.6	24.6	84	56	7.8	3.1	5.5
16	Apr 16-22	119.2	33.6	24.4	91	58	8.1	3.0	4.7
17	Apr 23-29	15.2	34.1	25.5	90	61	9.6	2.6	5.0
18	Apr 30-May 6	68.2	32.0	25.4	92	69	6.3	2.6	3.9
19	May 7-13	0.0	32.5	25.3	90	61	7.5	2.2	4.0

Contd.....4

Appendix 1 contd....

Standard week No.	Month and date	Total rainfall (mm)	Temperature		Relative humidity		Sunshine hours	Wind speed (km h^{-1})	Evapo-ration mm/day
			max.°C	Min.°C	FN (%)	AN (%)			
20	May 14-20	16.2	33.3	24.9	90	60	9.6	3.2	4.9
21	May 21-27	6.0	33.6	25.6	91	60	7.9	2.2	4.6
22	May 28-Jun 3	5.2	33.5	25.3	92	63	6.7	2.3	4.4
23	Jun 4-10	42.6	32.2	24.0	91	69	6.2	2.5	3.7
24	Jun 11-17	216.1	28.2	22.9	94	86	1.6	3.6	2.4
25	Jun 18-24	141.2	28.4	23.3	95	82	2.5	3.5	3.0
26	Jun 25-Jul 1	0.4	31.4	24.3	94	66	7.5	2.5	4.0

ORGANIC RECYCLING THROUGH COCOA LITTER

BY

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ABSTRACT OF A THESIS

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ABSTRACT

A field experiment was conducted in the cocoa fields of Cadbury-KAU Co-operative Cocoa Research Project, College of Horticulture, Vellanikkara, to study the organic recycling through cocoa litter. The objectives of the study were to find out the time required for natural senescence of cocoa leaves, to estimate the quantity of litter produced in a cocoa field in an year, to quantify the nutrient return through litter fall and to find out the rate of decomposition of cocoa litter. The studies were carried out both in shaded and unshaded cocoa fields, except the litter decomposition study which was carried out in the shaded field only.

The lifespan of cocoa leaves was found to be significantly different in the shaded and open fields, ranging from 94 to 193 days in the open condition and from 108 to 159 days in the shaded condition.

The quantity of litter produced was significantly influenced by the season, shaded/open condition and their interaction. The total annual litter fall was 5.3 t ha^{-1} in the shaded field and 8.2 t ha^{-1} in the open field. In both the fields, litter fall was maximum during December to March with the peak occurring in the first fortnight of January. Litter fall was lower during the wetter months of the year.

The nutrient return through litter fall was higher in the unshaded field.

In the shaded field, the nutrient return through litter fall from a hectare for an year was 66.9, 5.0, 59.7, 84.9 and 40.3 kilograms of N, P, K, Ca and Mg, respectively.

In the open field, the annual nutrient addition through litter fall from a hectare was 109.7, 6.8, 104.2, 103.7 and 57.4 kilograms of N, P, K, Ca and Mg, respectively.

Litter decomposition followed a biphasic pattern with an initial rapid phase and a subsequent slower phase. About 95 per cent of dry weight of litter was decomposed during the rapid phase of first four months and it took eight more months for decomposition of 98.9 per cent of the original weight.